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Disaster Series: Appendix 1: Hurricane Meteorology

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The Hurricane Environment

For those who do not live where hurricanes are common, we offer a short glossary of terms to better appreciate the events and threats during a hurricane.

Monsoons are seasonal periods of a dramatic increase in precipitation and prevailing winds with a wet summer and dry winter. The summer heating of land greater than the ocean drives monsoonal weather. The reversal of surface winds is associated with heavy precipitation, often thunderstorms. Though seemingly regional, monsoons are part of the large-scale global weather circulation.

Tornadoes are part of a severe convective storm (thunderstorm) that can occur worldwide except in Antarctica. A 'supercell,' a tall, rotating thunderstorm with a well-developed anvil, creates the most destructive tornadoes. Supercell thunderstorms can form on the margins of a hurricane. In spring, tornado conditions often exist over the continental US when a cold front approaches warm, humid air in the south and east.

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Hurricanes, generically 'tropical cyclones,' are symmetrical, rotating low-pressure weather systems that gain energy from warm tropical or subtropical ocean waters. Thunderstorms organize from the hurricane's rotation rather than asymmetrical weather fronts between warm and cold air masses, which hurricanes do not contain. Hurricanes, typhoons, and cyclones are regional names for the same type of storm:

- Hurricanes – North Atlantic; central and eastern North Pacific
- Typhoons – western North Pacific
- Cyclones – South Pacific and the Indian Ocean

The maximum sustained windspeed classifies tropical cyclones. A tropical cyclone can change between classifications and categories within classifications because of the variability and nature of windspeeds and release of energy.

- Tropical Depression, 38 mph (33 knots) or less
- Tropical Storm, 39 to 73 mph (34 to 63 knots)
- Hurricane, 74 mph (64 knots)
- Major hurricane, 111 mph (96 knots) or higher

Energy and Encountering the Cold

Condensation distinguishes *tropical cyclones* from weather phenomena driven by temperature and pressure gradients. Warm tropical ocean water evaporates, transferring latent heat to the upper atmosphere where it condenses to form heavy rains. High winds and lower atmospheric pressure accelerate this heat transfer, creating a positive feedback loop (1, 2). There is a large vertical temperature gradient *within* the hurricane, creating a *warm core*, a characteristic of tropical cyclones. The energy gained from warm tropical ocean water evaporation and its condensation at altitude is converted to kinetic and potential energy, driving the hurricane.

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As these patterns move toward the earth's poles, hurricanes encounter cold air masses, cooler sea surfaces, greater air temperature differences, and stronger environmental winds. The resulting instability causes the hurricane to dissipate, particularly as it travels overland (2).

But if the hurricane encounters a large cold front, rather than dissipating, the strong horizontal temperature and pressure gradients (frontogenesis) generate energy to drive the hurricane. The change in energy source also changes the characteristics of the hurricane, the symmetrical *tropical cyclone* transitions to an asymmetrical *extratropical cyclone.* Closer to the poles, temperature differences increase instability and decrease the predictability of extratropical cyclones (3). The winds can be as weak as a tropical depression or the strength of a hurricane.

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Extratropical Cyclones

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During this 'extratropical transition,' residual vertical temperature gradients in the 'warm-core' tropical cyclone continue to generate energy while new horizontal pressure and temperature gradients from 'cold-core' storms begin to generate energy.

This combination produces dangerous, poorly understood, poorly forecast hurricanes (1, 2), often with larger wind fields and the heaviest rain, hail, or snow concentrated away from the central storm. In tropical cyclones, the heaviest rainfall occurs within the hurricane (3). Hurricane Sandy transitioned into an extratropical hurricane as it neared landfall in New Jersey.

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These changes also affect the characteristics and shape of the hurricane. Windspeed due to the warm-core character does not change with altitude, which stabilizes the hurricane, while the wind peed due to the cold-core structure does increase with altitude, which destabilizes the hurricane (1). The energy distribution between the warm-core hurricane and cold-core front further distorts the storm into the asymmetric shape of the extratropical cyclone (2). The symmetrical concentration of wind and rain changes to an asymmetrical distribution over a far greater area with less predictability (2). The result is a fast-moving extratropical cyclone producing intense rainfall, huge waves, hurricane-force winds, and the potential to intensify, impairing accurate forecasts (1).

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An Asymmetric Extratropical Cyclone – Hurricane Sandy (4)

Hurricane Sandy's type of transition to become an extratropical cyclone is rare in the western North Atlantic. Hurricane Sandy changed in intensity and characteristics as it moved north, encountering a cold air mass. Its symmetric warm-core surrounded cooler air, developing into an asymmetric, less predictable extratropical cyclone. Sandy's core changed from warm to cold as an extratropical cyclone, and the strongest winds began to spread over a much larger area during its expansion.

- October 26. Sandy moved slowly north as a tropical cyclone, encountering strong wind shear, causing slightly decreasing intensity.
- October 27. Sandy briefly weakened to a tropical storm, traveling northeast, then merged with a cold front from the eastern US to re-intensify as a minimal hurricane while over the Gulf Stream's warm water (81° F).
- October 28. While continuing in a northeast direction, wind shear decreased, and, drawing energy from the cold front, Sandy began robust intensification as a Category 1 tropical cyclone, developing an eyewall.
- October 29. Turning to the northwest and New Jersey, Sandy encountered a cold front on its western periphery, with a warm front over the Canadian Atlantic on its eastern edge. Its warm-core remained intact as the surrounding environment became cold. Energy from the storms on either side intensified Sandy's energy, beginning the transition to an extratropical cyclone having a larger-scale cyclonic circulation. By 0630 EDT, cold continental air began wrapping around its warm core. By 1600 EDT, the warm core was entirely encircled by cooler continental air, and sea level pressure decreased. 1930 EDT, Sandy reached landfall along the New Jersey shoreline.
- October 30. Hurricane Sandy continued west.

Hurricane Damage

Storm damage. From the speed and intensity of the hurricane and the rising water level. For coastal margins, the major threat is wind, waves, and storm surge causing flooding while away from the flood zones the major threat is wind.

Speed and intensity. As a tropical cyclone moves to higher latitudes, the intensity of the hurricane, defined by central mean sea-level atmospheric pressure and maximum surface windspeed, will decrease. However, upon encountering a cold front, a tropical cyclone can become an extratropical cyclone and re-intensify (1).

Water, rain, flooding. Water, not wind, is the biggest threat. Total Water Level = Storm Surge + Astronomical Tides (natural or lunar tides) + Waves + Freshwater Input.

Storm surge is the water level rise above the predicted astronomical tide level. Storm surge is caused by strong storm winds pushing water toward shore. The low pressure of the storm has minimal contribution to storm surge.

Storm tide is the water level rise due to the storm surge *and* the astronomical tide. While storm surge has no reference level, the astronomical tide does, as the height above mean sea level.

Waves generated by slower-moving tropical cyclones quickly advance of the storm as decaying swells. An extratropical hurricane produces large surface waves from constant high windspeeds and the speed of the faster-moving storm. The waves and the extratropical hurricane can arrive simultaneously with little or no warning.

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Rainfall increases in a hurricane when the greater moisture of warm air condenses as the air cools at altitude. High rainfall can occur farther inland with an extratropical hurricane, causing dangerous flooding.

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