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IN FOCUS

Updated August 10, 2022

Forecasting Tropical Cyclones: NOAA's Role

Timely and accurate forecasts of tropical cyclones, including tropical depressions, tropical storms, and hurricanes (hereinafter TCs or storms), can provide life-and property-saving warnings to parts of the U.S. coastline vulnerable to a storm's impacts. The National Hurricane Center and Central Pacific Hurricane Center (NHC), part of the National Weather Service (NWS) within the National Oceanic and Atmospheric Administration (NOAA), is responsible for forecasting TCs in the Northern Atlantic Ocean and the Central and Eastern Pacific Ocean. (Other entities are responsible for these storms in other parts of the world.)

Tropical Cyclone Designations

Tropical cyclones are categorized based on their wind speeds. Designations include

- Tropical depressions—maximum sustained winds of ≤ 38 miles per hour (mph).
- Tropical storms—maximum sustained winds of 39-73 mph. NOAA typically names a storm once it reaches this strength.
- Hurricanes—maximum sustained winds of 74-95 mph (category 1 on the Saffir-Simpson Hurricane Wind Scale) and 96-110 mph (category 2). Hurricanes also may be called typhoons or cyclones.
- Major hurricanes—maximum sustained winds of ≥111 mph, corresponding to a category 3, 4, or 5 hurricane.

A tropical cyclone forecast uses a broad array of resources and capabilities within NOAA, which must be coordinated and interpreted by NHC. NHC estimates a tropical cyclone's track (i.e., the storm's path) and intensity (i.e., its wind speed), as well as the size and structure of the storm. NHC works with other parts of NOAA, such as the National Environmental Satellite, Data, and Information Service (NESDIS), National Ocean Service (NOS), and Office of Marine and Aviation Operations, on these estimates and on predictions of associated storm surge, rainfall, and tornadoes.

This In Focus describes NHC TC-related activities, from storm formation through forecasts and warnings. It also sets out ongoing TC forecasting challenges that Congress may consider via oversight or legislative actions.

Storm Observations

The forecasting process begins with observations: satellites, aircraft, ships, buoys, radar, and other sources provide data used to create storm-track and intensity predictions. NOAA weather satellites primarily provide the remote-sensing observations during the early stages of storm development. Several satellites, including NESDIS's Geostationary Operational Environmental Satellites and Joint Polar Satellite System, provide data as TCs form and intensify during their journey across ocean regions.

If a storm is judged to pose a threat to U.S. interests, NOAA and U.S. Air Force aircraft (often referred to as *Hurricane Hunters*) may fly into the storm to collect real-time data. Moored and drifting buoys may collect additional meteorological and oceanographic information. If the storm gets close enough to the coast, land-based radars provide NHC with precipitation and wind-speed data. Additional measurements are provided by NWS's ground-based Automated Surface Observation Systems and NOS's National Water Level Observing Network instruments when the storm is close to shore or makes landfall.

Analyzing the Data

NHC gathers all the observational data to generate numerical weather prediction models. The models use the data to determine the state of the atmosphere and the ocean and then use mathematical equations to produce TC track and intensity forecasts. Not all numerical weather prediction models are the same; they may differ in how they process information, such as when observations are fed into the model, which equations are used, how the solutions to the equations are used to make forecasts, and other factors. These differences explain why NHC forecasts may differ from those of other countries or institutions that also produce forecasts (e.g., the European Center for Medium-Range Forecasts produces Atlantic TC forecasts).

Forecasts, Watches, and Warnings

Using model outputs and their understanding of the meteorological and oceanographic data, NHC forecasters produce tropical weather text and graphical products for emergency managers and the public. These include outlooks covering the next 120 hours (5 days), watches and warnings, discussions, and updates. These products note storm location, motion, pressure, and wind speeds; contain information about hazards to land (i.e., storm surge, surf, wind, rainfall, tornadoes, and inland hazards); and indicate the next expected advisory. NHC updates the products on a set schedule throughout the storm's lifetime, and more frequently as appropriate.

Tropical Cyclone-Related Watches and Warnings

NWS may issue tropical cyclone-related watches and warnings depending on a tropical cyclone's characteristics.

- Watches for storm surge and hurricane or tropical storm-force winds. For example, a *hurricane watch* is an announcement that hurricane conditions (sustained wind speeds of 74 mph or higher) are possible within a specified area, issued 48 hours in advance of the onset of tropical storm-force winds.

- Warnings for storm surge, hurricane or tropical storm-form winds, and extreme wind. For example, a *hurricane warning* is issued when hurricane conditions are expected somewhere within the specified area, issued 36 hours in advance of tropical storm-force winds.

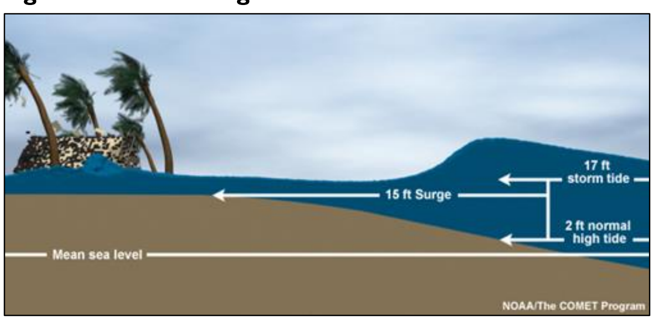
NWS may release other storm-related warnings and watches for hazards such as flooding and tornadoes.

NHC forecasts, watches, and warnings are coordinated with local NWS Weather Forecast Offices that may be affected by the storm. These offices use the information for their own forecasts, which consider local conditions.

Storm Surge

Forecasts also provide information about potential storm surge in coastal areas. *Storm surge* is defined as an abnormal rise in sea level accompanying a TC or other intense storm, above the predicted astronomical tide (**Figure 1**). Storm surge is primarily caused by storm winds pushing waters toward the shore. The amount of surge is determined by the storm's intensity; size; the storm's forward speed and angle of approach to the coast; the shape of the coastline; the slope of the ocean bottom; and the incidence of local features, such as bays and rivers. NHC issues storm surge watches or warnings along the U.S. Atlantic and Caribbean coasts.

Figure 1. Storm Surge



Source: National Hurricane Center at http://www.nhc.noaa.gov/surge/ssu.php.

Rainfall

The Weather Prediction Center provides rainfall forecasts to NHC when TC wind warnings are in effect and as appropriate. These forecasts note geographic areas at greatest risk, including inland areas, and expected area-average amounts. Storm surge, especially when combined with large amounts of rainfall from a TC, can create dangerous flood conditions for coastal communities.

Working with Other Stakeholders

NWS participates in the Hurricane Liaison Team, led by the Federal Emergency Management Agency (FEMA). The term coordinates federal, state, and local emergency managers; FEMA personnel; and NHC and Weather Prediction Center forecasters and hydrologists. FEMA typically activates the team for the duration of the *hurricane season*, which runs May 15 or June 1, depending on the ocean region, through November 30.

In addition to working with local, state, and federal stakeholders, NWS provides briefings on storms to the public and cooperates with meteorological services in other countries (e.g., Mexico and other Central American and Caribbean countries). Neither the Hurricane Liaison Team nor NWS issues evacuations; those decisions are left to state or local officials.

Challenges

NOAA has identified several ongoing challenges in forecasting TC intensity and storm-associated rainfall and in sharing that information with the public, among other forecasting concerns. Congress addressed these topics in a broad weather forecasting law, the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25). Congress may consider conducting further oversight on NOAA's implementation of the act or directing NOAA to address these issues in additional ways.

Intensity

While storm track forecasts have improved steadily since the 1960s, improvements to intensity forecasts have not kept pace. Additionally, understanding how and why a storm may experience rapid intensification, where its wind speed increases at least 35 mph in 24 hours (e.g., Hurricanes Dorian in 2019 and Laura in 2020), remains a challenge. Storms that undergo rapid intensification close to shore may be especially dangerous and destructive if forecasts do not predict the possibility of increased storm intensity in time for coastal residents to prepare. According to NOAA, forecast models currently are limited by computing capability, which cannot accurately simulate the inner core of a TC, a key part of a storm's intensity. NOAA continues to work with other stakeholders, such as the Naval Research Laboratory, to improve wind models.

Rainfall

Forecasting storm precipitation continues to be a challenge. According to NOAA, flooding resulting from extreme precipitation during TCs is responsible for a significant portion of fatalities caused by a storm. The amount of rainfall produced by a storm, however, may not necessarily be related to the intensity of the storm. Rainfall location and amounts appear to be more closely tied to a storm's track and the underlying geographic terrain than to storm intensity. Improving track forecasts, and using models at varying time and space scales, may help mitigate flood impacts, according to NOAA.

Communication

Storm-related fatalities continue to occur in the United States even as storm forecasts improve, in part, because of how forecasts, watches, and warnings are communicated to the public. For example, a storm's Saffir-Simpson scale rating (e.g., Category 1) does not reflect the full suite of potential hazards, such as expected storm surge or precipitation-caused flooding. Incorporating social and behavioral science research may improve how storm risks are communicated and acted upon, according to NOAA.

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IF10719

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