Congressional Research Service
Informing the legislative debate since 1914

Forecasting Tropical Cyclones: Overview and Issues for Congress

June 16, 2020

Congressional Research Service
https://crsreports.congress.gov
R46416

CRS REPORT
Prepared for Members and
Committees of Congress

Congressional Research Service
Informing the legislative debate since 1914

SUMMARY

R46416

June 16, 2020

Eva Lipiec
Analyst in Natural Resources Policy

Forecasting Tropical Cyclones: Overview and Issues for Congress

Timely tropical cyclone forecasts can provide early and accurate warnings to parts of the U.S. coastline vulnerable to tropical cyclone impacts. The National Oceanic and Atmospheric Administration (NOAA) is the federal agency responsible for tropical cyclone forecasts, including track, intensity, storm surge, and rainfall forecasts. NOAA defines *tropical cyclones* as tropical depressions, tropical storms, hurricanes, and major hurricanes, and the agency makes tropical cyclone forecasts using data from multiple observational tools—satellites, reconnaissance aircraft, ships, radar, and buoys, among others.

Each year, NOAA releases outlooks for three ocean regions—Atlantic, eastern Pacific, and central Pacific. Although the outlooks typically cover all types of tropical cyclones, the agency uses the term "hurricane" in the outlook title. The north Atlantic and eastern Pacific outlooks include the predicted number of named storms (typically tropical storm strength or stronger), hurricanes, and major hurricanes. The central Pacific outlook forecasts the total number of tropical cyclones expected.

NOAA released its 2020 hurricane season outlooks for the Atlantic, eastern Pacific, and central Pacific regions in May 2020. NOAA predicts an above-normal season in the Atlantic, with 13 to 19 named storms, 6 to 10 hurricanes, and 3 to 6 major hurricanes. (Some nonfederal entities have predicted a near-normal to above-normal Atlantic hurricane season.) In addition, the agency anticipates that the eastern and central Pacific regions will most likely experience a near-normal season. The forecast includes 11 to 18 named storms, 5 to 10 hurricanes, and 1 to 5 major hurricanes in the eastern Pacific and between 2 and 6 tropical cyclones in the central Pacific. Recent hurricane seasons have included several major hurricanes—such as hurricanes Dorian in 2019 and Florence, Lane, Michael, and Olivia in 2018—which resulted in multiple deaths and billions of dollars of damage in the southeastern United States and Hawaii, among other places.

In 2017, Congress enacted the Weather Research and Forecasting Act (P.L. 115-25), which included provisions regarding hurricane forecasting and warnings. Members of Congress continue to be interested in the potential impacts of climate change on tropical cyclones and the challenges in accurately forecasting certain aspects—such as intensity, storm surge, and precipitation—of tropical cyclones. Some Members also may consider potential impacts on tropical cyclone forecasting due to shifts in the NOAA's and private sector's roles in the weather enterprise. Some stakeholders advocate for retaining the current distribution of responsibilities; other stakeholders believe changes in responsibility are already occurring and should, in some cases, continue or expand. Members also may continue to consider the potential for interference from fifth-generation telecommunications (5G) technology on NOAA and other federal satellite sensors. For instance, some stakeholders have argued that interference could impact the quality of data used for hurricane forecasting, among other activities. Others have rejected interference claims altogether, among other views.

Contents

Forecasting Tropical Cyclones 1
Collecting Data 2
Analyzing the Data 3
Forecasts and Warnings 4
NOAA's Seasonal Hurricane Outlooks 6
2020 Hurricane Season Outlooks 7
Issues for Congress 9
Impacts of Climate Change on Tropical Cyclones 9
Forecasting Certain Aspects of Tropical Cyclones 10
NOAA Interactions with the Private Sector Weather Enterprise 14
Potential 5G Technology Interference with Satellite Sensors 17
NOAA's Use of the 23.8 Gigahertz Frequency 17
Federal Frequency Management 18
NOAA and Other Stakeholder Concerns—Selected Timeline 18

Figures

Figure 1. 96 Hour Track Error vs. Consistency 4
Figure 2. Storm Surge and Storm Tide 6
Figure 3. NHC Official Average Track Errors Comparison 11
Figure 4. NHC Official Average Intensity Errors Comparison 12

Figure A-1. Hurricane Dorian's Track 26
Figure A-2. Hurricane Humberto's Track 28
Figure A-3. Hurricane Lorenzo's Track 30
Figure B-1. Hurricane Florence's Track 34
Figure B-2. Hurricane Michael's Track 37
Figure B-3. Hurricane Lane's Track 41
Figure B-4. Hurricane Olivia's Track 43

Tables

Table 1. Seasonal Means and Ranges for Atlantic Named Storms 7
Table 2. Seasonal Means for Eastern Pacific Named Storms 7
Table 3. 2020 Atlantic Hurricane Season Seasonal Outlook 8
Table 4. 2020 Eastern Pacific Hurricane Season Seasonal Outlook 9

Table A-1. 2019 Atlantic Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms 23

Table A-2. NHC Official Track Forecast Errors for Hurricane Dorian Compared with the 2014-2018 Average 26
Table A-3. NHC Official Intensity Forecast Errors for Hurricane Dorian Compared with the 2014-2018 Average 27
Table A-4. NHC Official Track Forecast Errors for Hurricane Humberto Compared with the 2014-2018 Average 29
Table A-5. NHC Official Intensity Forecast Errors for Hurricane Humberto Compared with the 2014-2018 Average 29
Table A-6. NHC Official Track Forecast Errors for Hurricane Lorenzo Compared with the 2014-2018 Average 31
Table A-7. NHC Official Intensity Forecast Errors for Hurricane Lorenzo Compared with the 2014-2018 Average 31
Table A-8. 2019 Eastern Pacific Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms 32
Table B-1. 2018 Atlantic Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms 33
Table B-2. NHC Official Track Forecast Errors for Hurricane Florence Compared with the 2013-2017 Average 35
Table B-3. NHC Official Intensity Forecast Errors for Hurricane Florence Compared with the 2013-2017 Average 35
Table B-4. NHC Official Track Forecast Errors for Hurricane Michael Compared with the 2013-2017 Average 38
Table B-5. NHC Official Intensity Forecast Errors for Hurricane Michael Compared with the 2013-2017 Average 38
Table B-6. 2018 Eastern Pacific Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms 39
Table B-7. NHC Official Track Forecast Errors for Hurricane Lane Compared with the 2013-2017 Average 41
Table B-8. NHC Official Intensity Forecast Errors for Hurricane Lane Compared with the 2013-2017 Average 42
Table B-9. NHC Official Track Forecast Errors for Hurricane Olivia Compared with the 2013-2017 Average 44
Table B-10. NHC Official Intensity Forecast Errors for Hurricane Olivia Compared with the 2013-2017 Average 44
Table B-11. 2018 Central Pacific Tropical Cyclone Season: Comparison Between Seasonal Outlook and Actual Storms 45

Appendixes

Appendix A. 2019 Hurricane Season Outlooks and Overviews 23
Appendix B. 2018 Hurricane Season Outlooks and Overviews 33

Contacts

Author Information 45

The potential for widespread destruction to parts of the U.S. coastline underscores the value of timely hurricane—or more broadly, tropical cyclone—forecasts as a means for providing early and accurate warnings to affected communities. The National Oceanic and Atmospheric Administration (NOAA) is the federal agency responsible for tropical cyclone forecasting, including track, intensity, storm surge, and rainfall forecasts. The agency reports on how accurate the forecasts are compared with the actual events, calculates damages, and more.

A variety of terms can be used to describe these types of storms (see text box below). This report uses the terms *storm* and *tropical cyclone* and provides a description of how NOAA's National Hurricane Center (NHC) forecasts tropical cyclone tracks, intensities, and effects. The report also discusses potential issues for Congress, including challenges with tracking and forecasting tropical cyclones and the potential impacts of climate change on tropical cyclones. The report then provides an overview of forecasts for the 2020 hurricane season. The report includes two appendices (**Appendix A** and **Appendix B**) with information about the 2019 and 2018 hurricane seasons.

Tropical Cyclones, Storms, and Hurricanes

The National Oceanic and Atmospheric Administration (NOAA) defines a *tropical cyclone* as a "rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation." Cyclones rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Tropical cyclones that form between 5° and 30° North latitude typically move westward. According to NOAA, tropical cyclones include the following:

- Tropical Depression—a tropical cyclone with maximum sustained winds of 38 miles per hour (mph) or less.
- Tropical Storm—a tropical cyclone with maximum sustained winds of 39 to 73 mph.
- Hurricane—a tropical cyclone with maximum sustained winds of 74 mph or higher. Hurricanes are called *typhoons* in the western North Pacific Ocean and *cyclones* in the Indian Ocean and South Pacific Ocean.
- Major Hurricane—a tropical cyclone with maximum sustained winds of 111 mph or higher, corresponding to a category 3, 4, or 5 on the Saffir-Simpson Hurricane Wind Scale.

Source: National Hurricane Center, "Tropical Cyclone Climatology," at https://www.nhc.noaa.gov/climo/.

Forecasting Tropical Cyclones

NHC, part of NOAA's National Weather Service (NWS), is responsible for forecasting tropical cyclones, including hurricanes in the Atlantic and Pacific Oceans.[1] NHC provides estimates of the path or track, intensity or wind speed, size, and structure of the storm, as well as predictions of storm surge, precipitation, and tornadoes associated with these storms.[2] NOAA may use this information to issue a hurricane watch or a hurricane warning and public advisories.[3]

[1] National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center (NHC), "About the National Hurricane Center," at https://www.nhc.noaa.gov/aboutintro.shtml.

[2] University of Rhode Island Graduate School of Oceanography (URI GSO), "National Hurricane Center Forecast Process," at http://www.hurricanescience.org/science/forecast/forecasting/forecastprocess/. Hereafter URI GSO, "National Hurricane Center Forecast Process."

[3] A *hurricane watch* is an announcement that hurricane conditions—sustained winds 74 miles per hour (mph) or greater—are possible within a specified coastal area, usually issued 48 hours in advance of the onset of tropical storm force winds. A *hurricane warning* is issued when hurricane conditions are expected somewhere within the specified coastal area. URI GSO, "National Hurricane Center Forecast Process."

Collecting Data

Storm forecasts involve many components and use a broad array of resources and capabilities within NOAA and NWS, all of which are coordinated and interpreted by NHC.[4] The process begins with observations; satellites, aircraft, ships, buoys, radar, and other sources provide data used to create storm-track and intensity predictions. Most Atlantic hurricanes, for example, begin to form west of Africa over the ocean.[5] NOAA weather satellites, including two Geostationary Operational Environmental Satellites (GOES; known as GOES-East and GOES-West) and polar-orbiting weather satellites, provide remote-sensing observations in the Atlantic and Pacific basins.[6]

NOAA and U.S. Air Force aircraft, known as "Hurricane Hunters," fly directly into and above the storm to collect real-time data if a tropical cyclone is judged to pose a threat to the U.S. coastline.[7] The Chief, Aerial Reconnaissance Coordination, All Hurricanes (CARCAH) unit coordinates all tropical cyclone operation reconnaissance in accordance with the National Hurricane Operations Plan.[8] Data collected from the Hurricane Hunters and other aircraft (e.g., the National Aeronautics and Space Administration [NASA] *Global Hawk*) are checked at the CARCAH and provided to NHC forecasters.[9] Land-based radars begin to provide NHC with precipitation and wind-velocity data once the storm is approximately 280 miles from the coast. Automated Surface Observation Systems instruments provide additional ground-based measurements when the storm is close to shore or makes landfall.[10] Information from other systems, such as ships and buoys, is also included in forecasts.

---

[4] Although the entire federal hurricane forecast effort is broader than NOAA, this report focuses on NHC's. The National Hurricane Operations Plan outlines various agency responsibilities across the federal government. See Office of the Federal Coordinator for Meteorology (OFCM), *National Hurricane Plan*, at https://www.ofcm.gov/publications/nhop/nhop2.htm. Hereafter OFCM, *National Hurricane Operations Plan.*

[5] For more information about why hurricanes may threaten the U.S. East Coast and not the U.S. West Coast, see "Why Do Hurricanes Hit the East Coast of the U.S. but Never the West Coast?," *Scientific American*, October 21, 1999, at https://www.scientificamerican.com/article/why-do-hurricanes-hit-the-east-coast-of-the-u-s-but-never-the-west-coast/.

[6] URI GSO, "National Hurricane Center Forecast Process." Generally, Geostationary Operational Environmental Satellite-West (GOES-West) covers the east and central Pacific Ocean and GOES-East covers most of the Atlantic Ocean. The Japanese Himawari 8 satellite covers the west and central Pacific Ocean, and the Japan Meteorological Agency shares the satellite's images with NOAA and the public. URI GSO, "Geostationary Satellites," at http://www.hurricanescience.org/science/observation/satellites/geostationary/; email correspondence with NOAA Office of Legislative Affairs, January 24, 2020; and NOAA, "Full Disk: Himawari-8," at https://www.goes.noaa.gov/f_himawari-8.html.

[7] NOAA *Hurricane Hunters* are specially equipped aircraft that collect data during hurricanes. The NOAA fleet includes two Lockheed *WP-3D Orion* four-engine turboprop aircraft and one Gulfstream *IV-SP* jet aircraft. The *WP-3D* aircraft fly directly into hurricanes during the storms and collect in-situ data on winds and atmospheric pressures, among other measurements. The *IV-SP* jet flies at higher altitudes and collects critical information on the "steering" winds that affect the hurricane track, among other data. NOAA, Office of Marine and Aviation Operations, "NOAA Hurricane Hunters," at https://www.omao.noaa.gov/learn/aircraft-operations/about/hurricane-hunters. The 53rd Weather Reconnaissance Squadron, a component of the 403rd Wing of the U.S. Air Force located at Keesler Air Force Base in Biloxi, MS, flies 10 *WC-130J* Hercules aircraft into hurricanes during weather reconnaissance missions. 403rd Wing, "53rd Weather Reconnaissance Squadron 'Hurricane Hunters,'" at http://www.403wg.afrc.af.mil/About/Fact-Sheets/Display/Article/192529/53rd-weather-reconnaissance-squadron-hurricane-hunters/.

[8] The Chief, Aerial Reconnaissance Coordination, All Hurricanes (CARCAH) is a subunit of the 53rd Weather Reconnaissance Squadron, U.S. Air Force. OFCM, *National Hurricane Operations Plan.*

[9] National Aeronautics and Space Administration (NASA), Armstrong Flight Research Center, "Global Hawk," at https://www.nasa.gov/centers/armstrong/aircraft/GlobalHawk/index.html.

[10] URI GSO, "Automated Surface Observation Systems (ASOS)," at http://www.hurricanescience.org/science/observation/landbased/automatedsurfaceobssystems/.

Analyzing the Data

NHC gathers observational data as a tropical cyclone approaches the U.S. coastline and uses the data to generate a series of forecast computer model simulations.[11] Tropical cyclone forecast model simulations typically predict the *track* (the path) and *intensity* (the wind speeds) over a period of three to five days.[12] Available observational data provide a baseline for the model, which then uses mathematical equations to produce forecasts.

Tropical cyclone forecast models vary. They may differ in how they process information, such as when observations are fed into the model, which equations they use, how they make forecasts from the solutions to the equations, and other factors. These differences explain why NHC forecasts may differ from those of other countries or institutions (e.g., the European Center for Medium-Range Forecasts produces Atlantic forecasts, as do some research institutions within the United States, such as the National Center for Atmospheric Research).[13]

NHC forecasters analyze the model results and use their experience and expertise to adjust model forecasts. NHC measures forecast *skill* by comparing the adjusted forecasts, model-only forecasts, and a baseline forecast.[14] For example, NHC-adjusted forecasts of Atlantic tropical cyclone tracks at the 96-hour mark have been more accurate than specific model-only forecasts for the last three years (**Figure 1**).[15] NHC-adjusted forecasts have also been more consistent than model-only forecasts in the last three years, meaning the NHC forecast "holds steady more than the models" between predictions made every 12 hours, avoiding large track shifts or storm speed changes (**Figure 1**).[16]

[11] URI GSO, "Hurricane Forecast Models," at http://www.hurricanescience.org/science/forecast/models/. Hereafter URI GSO, "Hurricane Forecast Models."

[12] Hurricane intensity generally is measured as highest sustained wind speeds. However, that measurement does not take into consideration the storm-surge or precipitation-caused flooding, both of which may be among the most dangerous elements of a hurricane.

[13] The European Centre for Medium-Range Weather Forecasts (ECMWF) is an independent, intergovernmental organization supported by 34 countries. It produces global numerical weather forecasts using weather models. ECMWF, "Advancing Global NWP Through International Collaboration," at https://www.ecmwf.int/; and URI GSO, "Hurricane Forecast Models."

[14] According to NOAA, the baseline model "makes forecasts based on a combination of what past storms with similar characteristics—like location, intensity, forward speed, and the time of year—have done ... and a continuation of what the current storm has been doing.... This model contains no information about the current state of the atmosphere and represents a 'no-skill' level of accuracy." NOAA, "Skill or Luck? How NHC's Hurricane Track Forecasts Beat the Models," April 9, 2020, at https://noaanhc.wordpress.com/2020/04/09/skill-or-luck-how-nhcs-hurricane-track-forecasts-beat-the-models/. Hereafter NOAA, "Skill or Luck?"

[15] NOAA, "Skill or Luck?"

[16] NOAA, "Skill or Luck?"

Figure 1. 96 Hour Track Error vs. Consistency

2017-2019 in the Atlantic basin

Source: National Oceanic and Atmospheric Administration (NOAA), "Skill or Luck? How NHC's Hurricane Track Forecasts Beat the Models," April 9, 2020, at https://noaanhc.wordpress.com/2020/04/09/skill-or-luck-how-nhcs-hurricane-track-forecasts-beat-the-models/.

Notes: n mi = nautical miles; ECMWF = European Centre for Medium Range Weather Forecasts, GFS = U.S. Global Forecast System, NHC = National Hurricane Center, UKMET = United Kingdom Meteorological Office model.

According to NOAA, these three models are "the three best individual track models."

Forecasts and Warnings

The NWS, as delegated by the Secretary of Commerce, has statutory authority for weather forecasting and for issuing storm warnings.[17] Using the results from hurricane forecast models, different components inside and outside of NHC contribute to the hurricane forecast process. These components include the Hurricane Specialist Unit (HSU), the Tropical Analysis and Forecast Branch (TAFB), and the Hurricane Liaison Team (HLT).[18] Of these, the HSU produces

[17] 15 U.S.C. §313.

[18] The Tropical Analysis and Forecast Branch (TAFB) and Hurricane Specialist Unit (HSU) are within NHC; the Hurricane Liaison Team (HLT) is within the Federal Emergency Management Agency (FEMA). HLT is comprised of federal, state, and local emergency managers, FEMA personnel, and National Weather Service (NWS) forecasters and hydrologists. On or before the beginning of hurricane season, the NHC director is to request that FEMA activate HLT, which remains active throughout the hurricane season. If a tropical cyclone in the Atlantic or eastern Pacific basin

the final, official public forecast products, issued every six hours after a storm forms and more frequently if a hurricane watch or hurricane warning is issued.[19] The HSU also provides briefings on tropical storms to emergency managers and to the public, and it cooperates with meteorological services in other countries (e.g., Mexico). The TAFB supports the HSU by providing tropical cyclone position and intensity estimates, conducting media interviews, and assisting in tropical cyclone operations.[20]

Forecasts and warnings generally are coordinated between the NWS national centers and the local forecast offices. When NHC issues its forecast, local NWS Weather Forecast Offices use the information for their own forecasts, which take into consideration local conditions, and help disseminate the forecast through established local networks.

Other forecast models are designed specifically to forecast storm surge. The NHC Storm Surge Unit models and predicts storm-surge vulnerability over the U.S. Atlantic and Gulf Coasts, Hawaii, Puerto Rico, the U.S. Virgin Islands, and the Bahamas.[21] *Storm surge* is defined as an abnormal rise in sea level generated by a storm, above the predicted astronomical tide.[22] It generally refers to the difference between the measured level of the sea surface during the storm compared with what the sea level would have been without a storm (**Figure 2**). Storm surge can combine with other factors to create significant flood conditions, such as when it combines with extreme precipitation or the astronomical high tide (also known as a *storm tide*, **Figure 2**).[23] For example, Superstorm Sandy's landfall coincided with an astronomical high tide, which produced a storm tide that inundated the coastline of New Jersey and New York.[24]

threatens the United States or its territories, NHC can request that NWS meteorologists or hydrologists be assigned to HLT until the storm threat has passed. One of HLT's main functions is to communicate the threat level to federal, state, and local officials. Neither HLT nor NHC assumes responsibility for issuing evacuations; state or local officials are responsible for those decisions. NOAA NHC, "About the National Hurricane Center," at https://www.nhc.noaa.gov/aboutintro.shtml; and NOAA NWS, *National Weather Service Instruction 10-603*, September 21, 2016, at http://www.nws.noaa.gov/directives/sym/pd01006003curr.pdf.

[19] For more on hurricane watches and hurricane warnings, see footnote 3.

[20] URI GSO, "National Hurricane Center Forecast Process."

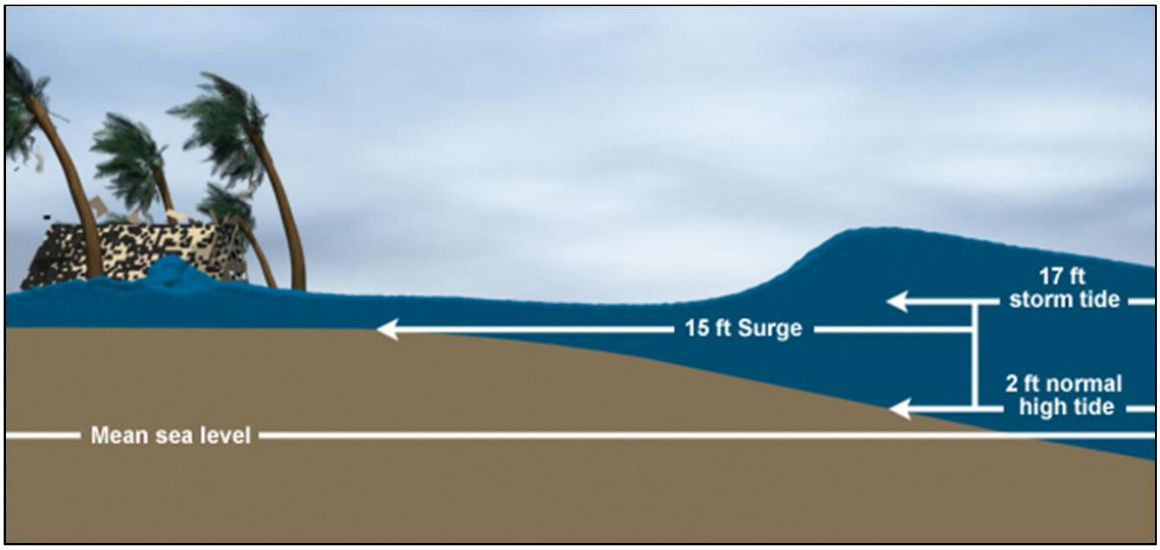
[21] NOAA NHC, "Storm Surge Unit," at https://www.nhc.noaa.gov/surge/ssu.php.

[22] NOAA NHC, "Storm Surge Overview," at https://www.nhc.noaa.gov/surge/. Hereafter NOAA, "Store Surge Overview."

[23] NOAA, "Store Surge Overview."

[24] Eric S. Blake et al., *National Hurricane Center Tropical Cyclone Report – Hurricane Sandy*, February 12, 2013, at https://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf.

Figure 2. Storm Surge and Storm Tide



Source: National Hurricane Center, "Storm Surge Overview," at https://www.nhc.noaa.gov/surge/. (Modified by CRS.)

Note: The 17-foot storm tide (top arrow) indicates the sum of the 2-foot normal astronomical high tide and the 15-foot storm surge.

NOAA's Seasonal Hurricane Outlooks[25]

NOAA releases its seasonal outlooks for the Atlantic, eastern Pacific, and central Pacific prior to the start of each respective hurricane season.[26] The Atlantic and central Pacific hurricane seasons each run from June 1 to November 30, and the eastern Pacific hurricane season runs from May 15 through November 30; however, tropical cyclones may form outside of these time frames.[27] NOAA typically provides an update to the Atlantic outlook in August of each year but does not do so for the Pacific regions. NOAA includes several disclaimers when issuing its seasonal hurricane outlook. For example, NOAA does not make a seasonal hurricane *landfall* forecast, and it does not predict levels of hurricane activity for any particular area.[28]

NOAA provides information about seasonal means and ranges for Atlantic named storms (**Table 1**) and seasonal means for eastern Pacific named storms (**Table 2**).[29] For the central Pacific Ocean, a shorter observational record of hurricanes and major hurricanes limits the statistical

[25] NOAA's outlooks typically cover all types of tropical cyclones, but the agency uses the term "hurricane" in outlook titles.

[26] NOAA, NWS Climate Prediction Center (CPC), "Expert Assessments," at https://www.cpc.ncep.noaa.gov/products/expert_assessment/. The Eastern Pacific hurricane region covers the eastern Pacific Ocean east of 140°W north of the equator, and the Central Pacific hurricane region covers the areas between 140°W and 180°.

[27] According to NOAA, "When the Weather Bureau organized its new hurricane warning network in 1935 it scheduled a special telegraph line to connect the various centers to run from June 15th through November 15th. Those remained the start and end dates of the 'official' season until 1965, when it was decided to start at the beginning of the month of June and run until the end of November." NOAA Atlantic Oceanographic and Meteorological Laboratory

[28] NOAA, NWS CPC, "NOAA 2020 Atlantic Hurricane Season Outlook," press release, May 21, 2020, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml. Hereafter NOAA 2020 Atlantic Hurricane Season Outlook, May 2020

[29] NOAA typically names a storm once it reaches tropical storm strength (e.g., sustained winds of 39 or more mph).

information available. NOAA uses available information to predict that four to five tropical cyclones, on average, develop or move across the central Pacific region each year.[30]

Table 1. Seasonal Means and Ranges for Atlantic Named Storms

1981-2010

Season Type	Mean Number of Named Storms	Range of Named Storms	Mean Number of Hurricanes	Range of Hurricanes	Mean Number of Major Hurricanes	Range of Major Hurricanes
Above Normal	16.5	12-28	9.7	7-15	4.8	3-7
Near Normal	12.3	10-15	6.3	4-9	2.3	1-4
Below Normal	6.7	4-9	3.3	2-4	1.0	0-2
All Seasons	12.1	4-28	6.4	2-15	2.7	0-7

Sources: National Oceanic and Atmospheric Administration (NOAA), National Weather Service, Climate Prediction Center, "Background Information: North Atlantic Hurricane Season," at https://www.cpc.ncep.noaa.gov/products/outlooks/archives/hurricane2017/August/NorATL_Background.shtml; and email correspondence with NOAA Office of Legislative and Intergovernmental Affairs, May 14, 2020.

Notes: According to NOAA, climatological averages for weather data are typically computed over a 30-year time period (currently 1981-2010). The 30-year averages are updated every 10 years. The next update is expected to occur after the 2020 season.

NOAA typically names a storm once it reaches tropical storm strength (e.g., sustained winds of 39 or more miles per hour).

Table 2. Seasonal Means for Eastern Pacific Named Storms

1981-2010

Season Type	Mean Number of Named Storms	Mean Number of Hurricanes	Mean Number of Major Hurricanes
All Seasons	15	8	4

Source: Email correspondence with NOAA, Office of Legislative Affairs, May 14, 2020.

Notes: According to NOAA, climatological averages for weather data are typically computed over a 30-year time period (currently 1981-2010). The 30-year averages are updated every 10 years. The next update is expected to occur after the 2020 season.

2020 Hurricane Season Outlooks

NOAA issued its 2020 Atlantic hurricane season outlook in May 2020 (**Table 3**) and indicated that an above-normal season had the highest chance (60%) of occurring.[31]

[30] E-mail correspondence with NOAA Office of Legislative Affairs, January 24, 2020.

[31] NOAA 2020 Atlantic Hurricane Season Outlook, May 2020.

Table 3. 2020 Atlantic Hurricane Season Seasonal Outlook

NOAA Seasonal Outlook (May 2020)
Named Storms: 13-19
Hurricanes: 6-10
Major Hurricanes: 3-6

Source: NOAA, "Busy Atlantic hurricane season predicted for 2020," May 21, 2020, at https://www.noaa.gov/media-release/busy-atlantic-hurricane-season-predicted-for-2020.

For comparison, the 1981 to 2010 seasonal averages include 12 named storms, 6 hurricanes, and 3 major hurricanes.[32] For the sixth year in a row, a tropical cyclone formed before the June 1 start of the hurricane season—Tropical Storm Arthur formed on May 16, 2020, and Tropical Storm Bertha formed on May 27, 2020.[33]

Several nonfederal entities also have published their outlooks for the season. For example, the private weather forecasting company AccuWeather published its 2020 Atlantic hurricane outlook in March 2020, predicting 14 to 18 named storms, 7 to 9 hurricanes, and 2 to 4 major hurricanes.[34] The Department of Atmospheric Science at Colorado State University (CSU) issued its forecast in early April 2020. CSU predicted above-normal activity, with 16 named storms, 8 hurricanes, and 4 major hurricanes in the Atlantic.[35] In late April 2020, the Penn State Earth System Science Center released its 2020 forecast, predicting 15 to 24 named storms.[36] All three forecasts rely, in part, on information collected and shared by NOAA.

NOAA also released its 2020 outlooks for the eastern and central Pacific hurricane seasons in May 2020.[37] NOAA anticipates that both basins would most likely experience a near-normal (40% chance of occurring) to a below-normal (35%) season, with an above-normal season less likely to occur (25%).[38] See **Table 4** for the eastern Pacific outlook. NOAA predicts the central Pacific will experience two to six tropical cyclones. On average, the eastern Pacific basin experiences 15 named storms, 8 hurricanes, and 4 major hurricanes each year, and the central Pacific averages 4 to 5 tropical cyclones each year.

[32] According to NOAA, climatological averages for weather data are typically computed over a 30-year time period (currently 1981 to 2010). The 30-year averages are updated every 10 years, with the next update expected to occur after the 2020 season. Email correspondence with NOAA Office of Legislative and Intergovernmental Affairs, May 14, 2020.

[33] NHC, "Arthur Graphics Archive," at https://www.nhc.noaa.gov/archive/2020/ARTHUR_graphics.php; and NHC, "Bertha Graphics Archive," at https://www.nhc.noaa.gov/archive/2020/BERTHA_graphics.php.

[34] Jillian MacMath, "AccuWeather's 2020 Atlantic hurricane season forecast is out," AccuWeather, March 25, 2020, at https://www.accuweather.com/en/hurricane/accuweathers-2020-atlantic-hurricane-season-forecast/705233. AccuWeather's forecast also estimated two to four "high-impact storms affecting the United States."

[35] Phil Klotzbach et al., "Extended range forecast of Atlantic seasonal hurricane activity and landfall strike probability for 2020," April 2, 2020, at https://tropical.colostate.edu/media/sites/111/2020/04/2020-04.pdf. Unlike the NOAA hurricane forecasts, Klotzbach, et al.'s outlook includes an estimate of landfall probability—for 2020 the researchers predict an above-average probability for major hurricanes to make landfall along the conterminous United States and the Caribbean.

[36] Penn State Earth System Science Center, "The 2020 North Atlantic Hurricane Season: Penn State ESSC Forecast," April 2020, at http://www.essc.psu.edu/essc_web/research/Hurricane2020.html.

[37] NOAA, "NOAA's 2020 Hurricane Season Outlooks," at https://www.cpc.ncep.noaa.gov/products/Epac_hurr/Slide1.JPG. Hereafter NOAA's 2020 Hurricane Outlooks, Slide 1.

[38] NOAA's 2020 Hurricane Outlooks, Slide 1.

Table 4. 2020 Eastern Pacific Hurricane Season Seasonal Outlook

NOAA Seasonal Outlook (May 2020)
Named Storms: 11-18
Hurricanes: 5-10
Major Hurricanes: 1-5

Source: NOAA, "NOAA's 2020 Hurricane Season Outlooks," at https://www.cpc.ncep.noaa.gov/products/Epac_hurr/Slide1.JPG.

Issues for Congress

Congress has considered and may continue to consider issues around federal activities related to tropical cyclone forecasting and impacts. Some issues, including the effects of climate change on tropical cyclones and forecasting certain aspects of these storms, are directly linked to federal tropical cyclone activities. Other issues, such as federal government interactions with the private sector weather enterprise and potential fifth-generation (5G) interference with satellite sensors, may affect the existing weather data structure, potentially leading to indirect impacts on federal tropical cyclone activities.

Impacts of Climate Change on Tropical Cyclones

As of February 2020, NOAA has identified several potential changes related to tropical cyclones, including that

- all else equal, coastal inundation levels associated with tropical cyclones should increase with sea level rise;[39]
- tropical cyclone rainfall rates will *likely* increase in the future;
- tropical cyclone intensities (wind speeds) globally will *likely* increase on average; and
- the global proportion of tropical cyclones that reach very intense (category 4 and 5) levels will *likely* increase.[40]

NOAA continues to support research into the effects of climate change on tropical cyclones under its current authorities. Members of Congress may consider whether additional federal resources should be allocated to study the potential impacts of climate change on certain aspects of tropical cyclones, such as storm surge and precipitation. At the House Science, Space, and Technology Committee hearing entitled "Weathering the Storm: Improving Resiliency through Research" in Houston, TX, on July 22, 2019, several participants spoke of work being done at federal and

[39] NOAA Geophysical Fluid Dynamics Laboratory (GFDL), "Global Warming and Hurricanes," last revised February 5, 2020, at https://www.gfdl.noaa.gov/global-warming-and-hurricanes/. Hereafter NOAA GFDL, "Global Warming and Hurricanes," 2020. According to the report, the average rate of global sea level rise over the 21st century will very likely exceed that observed during 1971-2010 for a range of future emission scenarios. NOAA's terminology for its likelihood statements (for the assessed likelihood of an outcome or result) generally follows the conventions used by the Intergovernmental Panel on Climate Change. In this case, *very likely* denotes a greater than 90% probability of occurring and *likely* denotes a greater than 66% probability of occurring.

[40] NOAA GFDL, "Global Warming and Hurricanes," 2020.

nonfederal organizations and the need to better understand how storm surge and precipitation may change with climate change.[41]

For example, NOAA's Assistant Administrator for Weather Services and Director of NWS Dr. Louis Uccellini stated that NWS has been accommodating "that background, the changing background state, into storm surge and potential impacts of intense storms," and the agency needs "to account for [the changing background state] with respect to [NWS] watches and warnings."[42] Representative Sheila Jackson Lee noted that "we need to focus our time understanding how impactful climate change is." University of Houston Director of the Hurricane Resilience Research Institute Dr. Hanadi Rifai, noted that "much more effort" is needed to further develop storm surge models into "robust predictive platforms" that incorporate climate change, among other factors.[43]

Forecasting Certain Aspects of Tropical Cyclones

The ability to forecast the potential path a storm may take, also known as its track, has improved steadily since the 1960s (**Figure 3**). For example, track errors in the current decade are less than half of what they were in the 1990s.[44] According to NOAA, the 2019 five-day track forecast was better than the 1970s 36-hour forecast.[45] Accuracy over an extended forecast time frame has improved. In the 1990s, forecasts were available only on a three-day time frame; today forecasts typically extend out to five days.[46] Some stakeholders argue that after years of significant advances, improvements in track forecasting may be slowing.[47] The slowdown, these researchers contend, may be due to the limit of predicting how the most minor meteorological factors may change over the course of a forecast.[48]

[41] U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Environment, *Field Hearing: Weathering the Storm: Improving Hurricane Resiliency through Research*, 116th Cong., 1st sess., July 22, 2019 (Washington, DC: GPO, 2019), pp. 85-86, 94. Hereafter House Committee hearing, *Improving Hurricane Resiliency through Research*, 2019.

[42] House Committee hearing, *Improving Hurricane Resiliency through Research*, 2019, p. 85.

[43] House Committee hearing, *Improving Hurricane Resiliency through Research*, 2019, pp. 29-30, 94.

[44] Forecast errors indicate the difference between the forecast track and the actual track in nautical miles (n mi). The forecast period is shown in hours (h).

[45] Written testimony of Assistant Administrator for Weather Services and Director of the NWS, Dr. Louis Uccellini in U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Environment, *Field Hearing: Weathering the Storm: Improving Hurricane Resiliency through Research*, 116th Cong., 1st sess., July 22, 2019. Hereafter, Uccellini, written testimony, 2019.

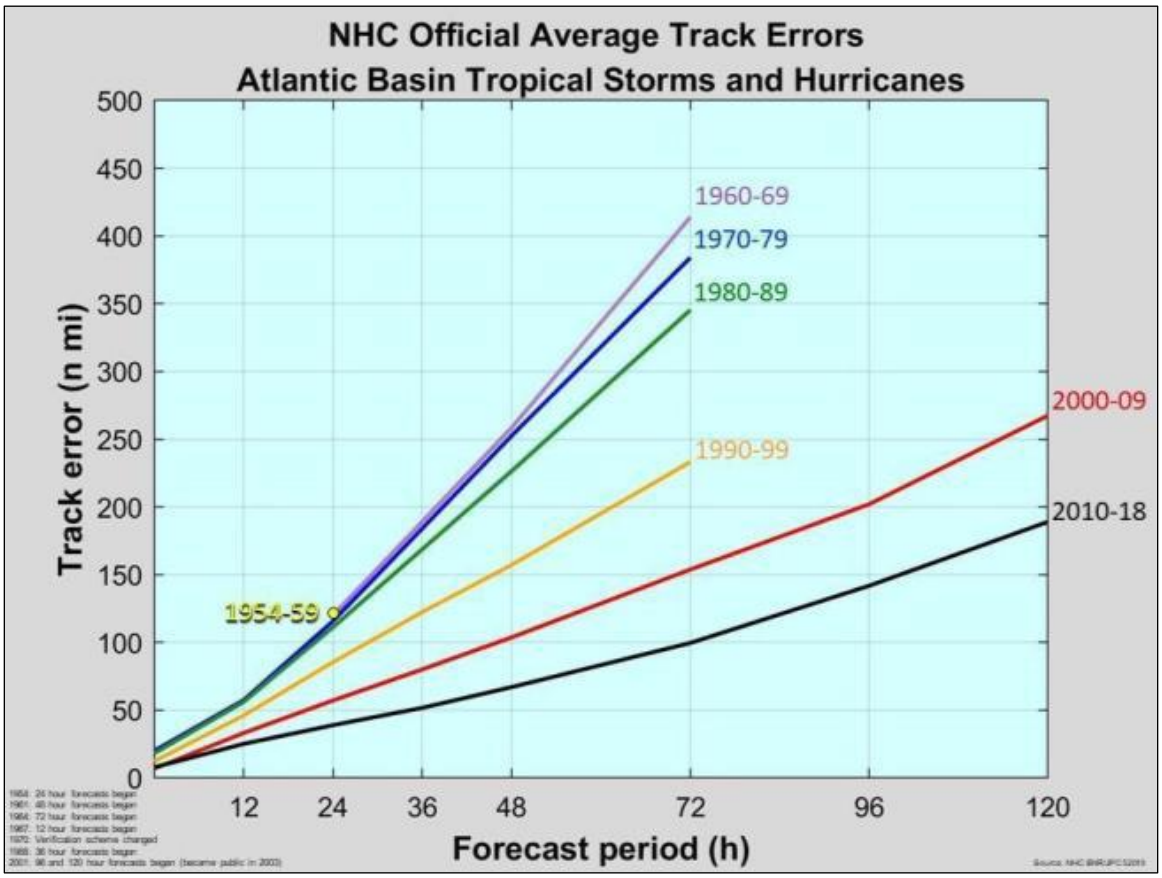
[46] In other words, five-day forecasts today are as good as three-day forecasts were 25 years ago.

[47] Christopher W. Landsea and John P. Cangialosi, "Have we reached the limits of predictability for tropical cyclone track forecasting?," *Bulletin of the American Meteorological Society*, vol. 99, no. 11 (November 2018), pp. 2237-2243. Hereafter Landsea and Cangialosi, "Limits of Predictability," 2018.

[48] Landsea and Cangialosi, "Limits of Predictability," 2018.

Figure 3. NHC Official Average Track Errors Comparison

by decade for Atlantic basin tropical storms and hurricanes



Source: Written testimony of Assistant Administrator for Weather Services and Director of the National Weather Service Dr. Louis Uccellini, in U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Environment, *Field Hearing: Weathering the Storm: Improving Hurricane Resiliency through Research*, 116th Cong., 1st sess., July 22, 2019.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles (n mi); forecast period shown in hours (h). The National Hurricane Center (NHC) issues official forecasts every 6 h; each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 h after the forecast's initial time.

Forecasting a storm's wind speeds, also known as its intensity, is considered to be more difficult than forecasting its track. The last decade brought advances in intensity forecasting (**Figure 4**). The largest incremental improvements since the 1970s occurred between 2010 and 2018, especially at the three-day and longer forecasts.[49] Some researchers identify the need for improved models, enhanced observations, and better understanding of a storm's inner core to further improve the accuracy of intensity forecasts.[50] The increased accuracy and extended time

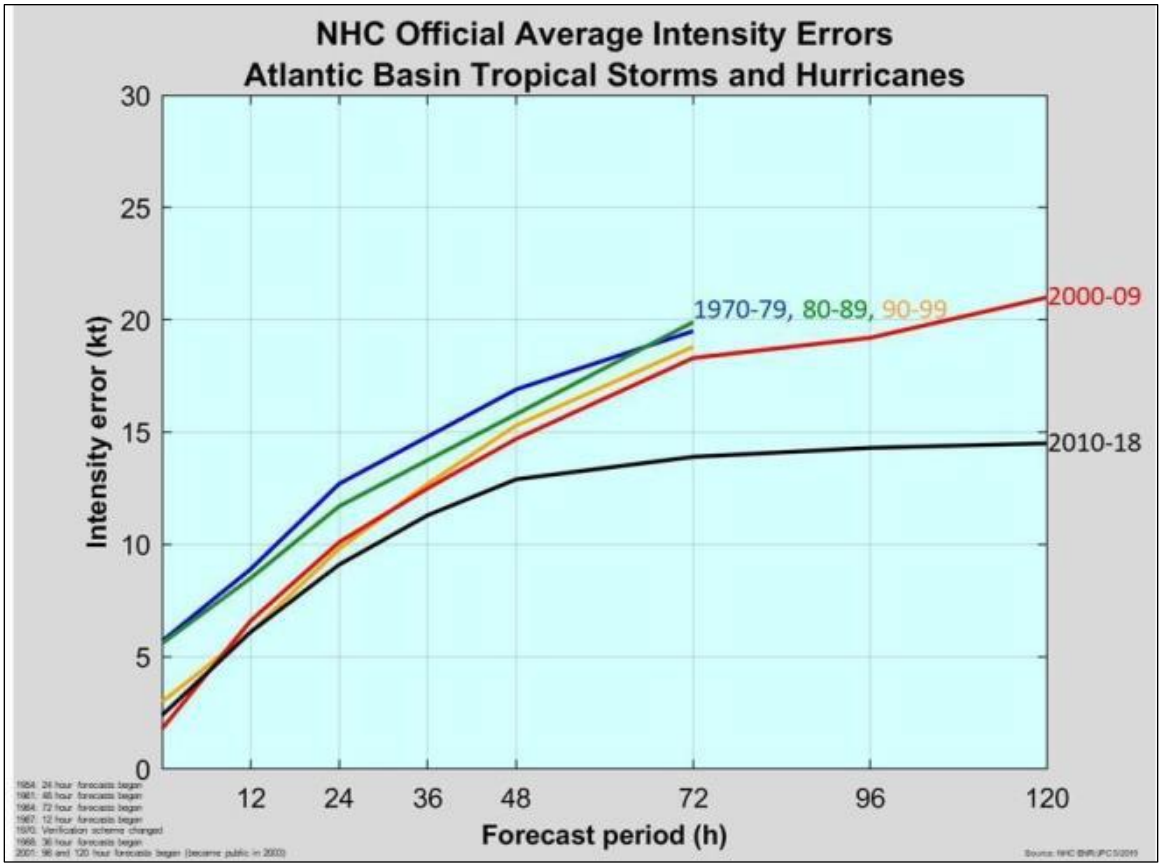
[49] The 2010 to 2018 average intensity error for Atlantic basin tropical storms and hurricanes was close to 15 knots, which corresponds roughly to a difference of one hurricane category on the Saffir-Simpson Hurricane Wind Scale. NOAA encourages communities that may be affected by these storms to prepare for a storm one category stronger than what is forecasted to account for the expected average intensity error. NOAA NHC, "The State of Hurricane Forecasting," March 9, 2018, at https://noaanhc.wordpress.com/2018/03/09/the-state-of-hurricane-forecasting/.

[50] Mark DeMaria, "Tropical Cyclone Intensity Analysis and Forecasting," paper presented at the WMO RA-IV Workshop on Hurricane Forecasting and Warning, Miami, FL, March 7, 2017, at https://severeweather.wmo.int/TCFW/RAIV_Workshop2017/19c_TC_Intensity_Forecasting_MarkDeMaria.pdf.

frame provide useful information to local, state, and federal emergency managers faced with decisions about evacuating coastlines and staging emergency equipment and supplies.

Figure 4. NHC Official Average Intensity Errors Comparison

by decade for Atlantic basin tropical storms and hurricanes



Source: Written testimony of Assistant Administrator for Weather Services and Director of the National Weather Service Dr. Louis Uccellini, in U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Environment, *Field Hearing: Weathering the Storm: Improving Hurricane Resiliency through Research*, 116th Cong., 1st sess., July 22, 2019.

Notes: Intensity errors expressed as wind speed measured in knots (kts). Forecast period shown in hours (h). The National Hurricane Center (NHC) issues official forecasts every 6 h, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 h after the forecast's initial time.

Track and intensity forecasts do not consider storm surge or precipitation-caused flooding, both of which may be among the most dangerous elements of a storm. The amount of rainfall produced by a storm may not necessarily be related to the intensity of the hurricane.[51] For example, record levels of precipitation and subsequent flooding during Hurricane Harvey continued even after the storm made landfall and was downgraded from a hurricane to a tropical storm.[52] Improving the

[51] NOAA NHC, "Hurricane Preparedness-Hazards," at https://www.nhc.noaa.gov/prepare/hazards.php.

[52] Tom Di Liberto, "Reviewing Hurricane Harvey's catastrophic rain and flooding," NOAA, September 18, 2017, at https://www.climate.gov/news-features/event-tracker/reviewing-hurricane-harveys-catastrophic-rain-and-flooding.

ability to accurately forecast the timing, amount, and location of high rainfall periods could advance the value of tropical cyclone forecasting. Research in both areas is ongoing.[53]

Congress has directed or supported agency efforts in tropical cyclone-related research and applications. Most recently, Congress enacted the Weather Research and Forecasting Innovation Act of 2017 (WRFIA; P.L. 115-25, 15 U.S.C. 8514), which aimed to improve weather forecasting and prediction, among other activities.[54] WRFIA Section 104 required the Under Secretary of Commerce for Oceans and Atmosphere to maintain a project to improve hurricane forecasting with a goal to

> "develop and extend accurate hurricane forecasts and warnings in order to reduce loss of life, injury, and damage to the economy," with a focus on
>
> (1) improving the prediction of rapid intensification and track of hurricanes;
>
> (2) improving the forecast and communication of storm surges from hurricanes; and
>
> (3) incorporating risk communication research to create more effective watch and warning products.[55]

Section 104 also required the development of a project plan to reach the congressional goals. NOAA released the project plan in 2019.[56] The plan lists several strategies the agency plans to use to achieve the goals, including the following:

- advance an operational Hurricane Analysis and Forecast System (a multiscale model and data package capable of providing analyses and forecasts of the inner core structure of tropical cyclones out to seven days);
- improve probabilistic guidance that quantifies uncertainty for all tropical cyclone hazards, such as wind and storm surge;
- enhance communication of risk and uncertainty with "iterative, collaborated physical, social, and behavioral science research";
- support dedicated high performance computing allocation to eliminate competition with other high-priority computing needs across NOAA's programs;
- enhance research to operations including the acceleration of research and new observing systems and platforms to operations; and
- broaden expertise and expand interaction with the nonfederal community through the Scientific Review Committee, a grants and contracts program, and outreach and education.

[53] For example, researchers discuss recent research studies and forecast challenges related to tropical cyclones in Kevin Cheung et al., "Recent Advances in Research and Forecasting of Tropical Storm Rainfall," *Tropical Cyclone Research and Review*, vol. 7, no. 2 (May 2018).

[54] For example, §107 requires the Assistant Administrator for Oceanic and Atmospheric Research to undertake Observing System Simulation Experiments, or such other assessments as the Assistant Administrator considers appropriate, to quantitatively assess the relative value and benefits of observing capabilities and systems over a variety of topics (e.g., the impact of observing capabilities on hurricane track and intensity forecasting) and §413 of the act requires the Under Secretary of Commerce for Oceans and Atmosphere to acquire backup capabilities for *Hurricane Hunter* aircraft.

[55] 15 U.S.C. §8514.

[56] NOAA, *Report to Congress: Hurricane Forecast Improvement Program*, 2019, at https://repository.library.noaa.gov/view/noaa/22034.

The plan includes objectives for each strategy. It is unclear how NOAA has specifically implemented each of the strategies and objectives and how much progress has been made in reaching the goals established in P.L. 115-25. For example, the agency has continued to develop and release a variety of tropical cyclone-related storm surge products for the public.[57] NOAA plans to release additional products in 2020, including storm surge watch/warning graphics for Puerto Rico and the U.S. Virgin Islands and experimental peak storm surge forecast graphics for the U.S. East and Gulf Coasts, Puerto Rico and the U.S. Virgin Islands.[58] In another instance, NOAA indicated in an annual report required under WRFIA that the U.S. Weather Research Program currently supports several tropical cyclone projects, primarily focused on storm development and intensity.[59] In both cases, it is unclear if these new products or projects are in response to congressional direction in WRFIA or were planned or in development before WRFIA's enactment.

Congress continues to consider tropical cyclone forecasting in the 116th Congress. For example, the House Science, Space, and Technology Committee held a hearing on July 22, 2019 (see the section entitled "Impacts of Climate Change on Tropical Cyclones"). Several participants noted potential areas of storm forecasting improvement, including short- and long-term forecasting and predicting storm surge and rainfall flooding.[60] In S.Rept. 116-127, the appropriations committee "encourage[d] NWS to reduce errors in tracking and intensity forecasts of hurricanes by identifying technology and methods available to significantly improve hurricane forecasting."[61]

NOAA Interactions with the Private Sector Weather Enterprise

NOAA recognizes that the "nation's environmental information enterprise," including the weather enterprise, is conducted by many parties (i.e., the government, private sector entities, and the academic and research community), and the agency has the "responsibility" to foster growth of the enterprise to serve the public interest and the nation's economy.[62] Under statute, the Secretary of Commerce is responsible for

> forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, ... the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.[63]

[57] For example, NOAA has released experimental storm surge watch/warning graphics for the U.S. Atlantic and Gulf Coasts since 2017. NHC, "Prototype Storm Surge Watch/Warning Graphic," at https://www.nhc.noaa.gov/experimental/surgewarning/.

[58] Michael Brennan, "National Hurricane Center Product Changes for 2020," online video presentation, April 29, 2020, at https://www.youtube.com/watch?v=oWfh_iJcfv0&feature=youtu.be.

[59] NOAA, *Report to Congress: United States Weather Research Program Annual Project Report, 2020,* at https://repository.library.noaa.gov/view/noaa/23647.

[60] House Committee hearing, *Improving Hurricane Resiliency through Research,* 2019, pp. 10 and 92.

[61] U.S. Congress, Senate Committee on Appropriations, *Departments of Commerce and Justice, Science, and Related Agencies Appropriations Bill, 2020*, report to accompany S. 2584, 116th Cong., 1st sess., S.Rept. 116-127, September 26, 2019 (Washington, DC: GPO, 2019), p. 54.

[62] NOAA, "Policy on Partnerships in the Provision of Environmental Information," NAO 216-112, last reviewed January 31, 2019, at https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-112.html. Hereafter NOAA, NAO 216-112.

[63] 15 U.S.C. §313.

To complete these activities, the federal government invests in physical infrastructure, shares information with other federal agencies and nonfederal groups, and contracts services and data from the private sector, among other sectors.[64] According to NOAA, the private sector uses agency information; develops and maintains an infrastructure of observation, communication, and prediction systems; and provides a "critical private sector role" in working with the agency to communicate forecasts and warnings that may affect public safety.[65]

In 2016 and 2017, NWS "conducted a study to better understand the current and future landscape of the broader weather enterprise in the United States."[66] NWS's findings stated the following:

> The NWS has an important role as the impartial and authoritative voice on public safety and is a trusted partner to emergency managers, but could seek to collaborate more with the private industry in this role by looking for opportunities to harness commercial capabilities, engaging with companies to address risks, and identifying areas where private industry services can complement core NWS services.
>
> The NWS plays a key role in enabling the weather enterprise by providing weather, water, and climate data at the forefront of science, and by partnering with the private industry and academia to drive innovation – especially to operationalize emerging technologies and foster community model development.
>
> While many in the private industry have built upon the NWS's infrastructure, products and services thus far, there is potential for this paradigm to shift as private industry capabilities increase and businesses become more dependent on weather, water, and climate information.[67]

Congress has considered and may continue to consider whether federal government and private sector roles in the weather enterprise should change.[68] For example, in 2016, Congress directed that NOAA

> shall, through an open competitive process, seek to enter into at least one pilot contract to assess the potential viability of commercial weather data in its weather modeling and forecasting. This funding shall be used to purchase, evaluate, and calibrate available data,

[64] NWS, *National Weather Service Enterprise Analysis Report: Findings on changes to the private weather industry*, June 8, 2017, p. 5, at https://www.weather.gov/media/about/Final_NWS%20Enterprise%20Analysis%20Report_June%202017.pdf. (hereafter NWS, *Enterprise Analysis Report*); and NOAA, *Acquisition of Space-based Scientific Data from Commercial Sources to Supplement NOAA's Weather and Climate Observation Requirements: Report to Congress*, 2010, at https://www.space.commerce.gov/wp-content/uploads/2010-03-commercial-observations.pdf. Congress has limited the private sector's role in the federal weather enterprise in at least one aspect. Under statute, neither the President nor any other government official can "lease, sell or transfer to the private sector, or commercialize" any weather satellite systems operated by the Department of Commerce. See P.L. 111-314 §60161.

[65] NOAA, NAO 216-112.

[66] NWS, *Enterprise Analysis Report*, p. 2.

[67] NWS, *Enterprise Analysis Report*, p. 3.

[68] NOAA and other stakeholders have considered the appropriate roles for the federal government and private sector in other NOAA activities. For example, NOAA released a request for information on the private sector's role, among other sectors, in mapping, exploring, and characterizing the U.S. exclusive economic zone (EEZ), and NOAA's FY2021 budget proposal notes that the agency "will continue its mapping of the U.S. EEZ utilizing Federal, academic, philanthropic, and private research vessels." NOAA, "Strategy for Mapping, Exploring, and Characterizing the U.S. Exclusive Economic Zone," 85 *Federal Register* 7734, February 11, 2020; and NOAA, *Budget Estimates Fiscal Year 2021*, p. 530, at https://www.commerce.gov/sites/default/files/2020-02/fy2021_noaa_congressional_budget_justification.pdf.

> which meets the standards and specifications set by NOAA in its Commercial Data Policy.[69]

In its post-pilot report, required under WRFIA Section 302, NOAA stated that the "commercial sector was not able to provide the quality and quantity of [radio occultation (RO)] data that NOAA requires for use in operational weather forecasting" in the initial round.[70] However, NOAA further asserted that "commercial RO systems show potential and, if progress continues, could serve in the future as complementary sources to existing and future government systems," warranting further pilot project purchases for a more thorough evaluation.[71]

Congress and the Trump Administration have indicated their support for increased agency procurement and utilization of data and services from the private sector. In S.Rept. 116-127, accompanying FY2020 appropriations legislation, Congress stated that FY2020 appropriations would "support the assessment and potential use of commercial data in NOAA's weather modeling and forecasting through pilot purchases of commercial data."[72] NOAA's FY2021 budget proposal states that "NOAA will engage private and academic institutions ... ultimately leveraging their expertise and innovative cultures to reclaim and maintain international leadership in the area of numerical weather prediction."[73]

The private sector has also expanded its role in the weather enterprise. For example, AccuWeather, a private company that develops and publishes its own hurricane forecasts, began using a new scale for conveying the severity of hurricanes, rather than the historically used Saffir-Simpson scale.[74] Some stakeholders have expressed that the creation and use of a new scale could potentially cause public confusion during an emergency; others believe the new scale provides more comprehensive information about a storm.[75]

Some stakeholders believe the current distribution of roles and responsibilities between and the government and the private sector should be maintained.[76] Others note that the private sector's role will continue to shift as private companies launch their own observational systems and run their own forecasting models.[77] Still others have suggested that government and private sector roles may change. For example, some have advocated for private and public entities to "continue to promote adoption of open data policies and common alerting protocols while also encouraging

---

[69] P.L. 114-113.

[70] NOAA, *Report to Congress: Commercial Weather Data Pilot Program*, 2018, p. 6, at https://repository.library.noaa.gov/view/noaa/23645. Hereafter NOAA, *CWDPP*, 2018.

[71] NOAA, *CWDPP*, 2018, p. 6.

[72] S.Rept. 116-127, p. 62.

[73] NOAA, *Budget Estimates Fiscal Year 2021*, p. 488, at https://www.commerce.gov/sites/default/files/2020-02/fy2021_noaa_congressional_budget_justification.pdf.

[74] AccuWeather, "AccuWeather's New RealImpact (TM) Scale for Hurricanes will Revolutionize Damage Predictions for Greater Public Safety," January 9, 2019, at https://www.accuweather.com/en/press/83423274.

[75] Our Daily Planet, "Private Weather Company to Use Different Hurricane Severity Scale," January 15, 2019, at https://www.ourdailyplanet.com/story/private-weather-company-to-use-different-hurricane-severity-scale/; and Angela Fritz, "AccuWeather developed a hurricane category scale, and it worries some meteorologists," *The Washington Post*, January 10, 2019, at https://www.washingtonpost.com/weather/2019/01/11/accuweather-developed-hurricane-category-scale-it-worries-some-meteorologists/.

[76] Jim Foerster, "What's the difference between private weather companies and the National Weather Service?," *Forbes*, January 24, 2020, at https://www.forbes.com/sites/jimfoerster/2020/01/24/whats-the-difference-between-private-weather-companies-and-the-national-weather-service/#5645031c4a29.

[77] Andrew Freedman, "Weather is turning into big business. And that could be trouble for the public," *The Washington Post*, November 25, 2019, https://www.washingtonpost.com/business/2019/11/25/weather-is-big-business-its-veering-toward-collision-with-federal-government/.

the use of new technologies and procurement approaches to help increase the reliability of equipment."[78]

Potential 5G Technology Interference with Satellite Sensors

NOAA's Use of the 23.8 Gigahertz Frequency

NOAA utilizes certain radio frequencies or bands for weather sensing, monitoring, forecasting, and warning. For instance, water vapor emits microwave radiation at the 23.8 gigahertz (GHz) frequency. An instrument known as the Advanced Technology Microwave Sounder (ATMS), which is a part of several existing and planned NOAA satellites, passively measures 23.8 GHz frequency to obtain data on water vapor, clouds, and precipitation.[79] According to NOAA, ATMS collects "essential data for accurate near-term weather predictions needed for farming, commercial and defense aircraft flight path planning, terrestrial extreme weather preparedness and oceanographic inputs for civilian and defense ships."[80]

Passive sensors, such as the ATMS, only receive signals, whereas active sensors (e.g., active radar instruments) both emit and receive signals. Thus, passive sensors rely on the strength or "emissivity" of natural sources. The inherent low-level emissivity of natural sources, such as water vapor, makes the signals "particularly vulnerable" to active sources of signals close to the same frequency as the natural source.[81] Measuring natural sources using alternative frequencies is "usually not feasible," as natural sources of electromagnetic radiation, such as water vapor, emit only in specific frequencies (as a matter of physics).[82]

According to NOAA, the 23.8 GHz frequency is the sole frequency used to measure water vapor for the entire vertical atmospheric profile between the satellite and the Earth's surface; other spectrum bands may complement this data.[83] Measurements taken at the 23.8 GHz frequency are used in numerical weather prediction models and storm forecasting and tracking, among other activities.[84] According to the National Research Council, global water vapor profiles are

[78] Mary Glackin, "Improving the Forecast: Value and Public-Private Collaboration in Data Driven Weather Insights," *World Meteorological Organization Bulletin*, vol 68 (1) (2019), at https://public.wmo.int/en/resources/bulletin/improving-forecast-value-and-public-private-collaboration-data-driven-weather.

[79] Email correspondence with NOAA Office of Legislative Affairs on August 13, 2019. Additional U.S. satellite missions that have used passive sensors to measure at the 23.8 gigahertz (GHz) band include NEMS/SCAMS, AMSU-A, TMI, JASON-1 JMR, AMSR-E, AMSR, Jason-2 AMR, AMSR-2, and GMI. National Research Council (NRC), *Spectrum Management for Science in the 21st Century*, (Washington, DC: National Academies Press, 2010), pp. 56-57 (hereafter NRC, *Spectrum Management*, 2010) and Joint Polar Satellite System (JPSS), "Advanced Technology Microwave Sounder (ATMS)," at https://www.jpss.noaa.gov/atms.html (hereafter JPSS, "ATMS").

[80] JPSS, "ATMS."

[81] Sandra Cruz-Pol et al., "Spectrum Management and the Impact of RFI on Science Sensors," 2018 IEEE 15th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad), p. 53. Hereafter Cruz-Pol et al., 2018.

[82] Cruz-Pol et al., 2018.

[83] Telephone conversation with NOAA Senior Policy Advisor, August 2, 2019 and email correspondence with NOAA Office of Legislative Affairs on August 13, 2019. According to NOAA, water vapor measurements are also calibrated using the 50 GHz spectrum band, another spectrum band being considered by the Federal Communications Commission (FCC) for fifth-generation (5G) use.

[84] NRC, *Spectrum Management*, 2010, pp. 54-55.

"essential" to predicting rainfall and drought.[85] Water vapor data can help forecasters determine how likely a storm is to develop and the locations with the heaviest rainfall.[86]

Federal Frequency Management

In 2018, telecommunications providers began deploying 5G networks to meet growing demands for data from consumer and industrial users. As more people use more mobile devices for more purposes, the segment of the spectrum typically used for mobile communications (i.e., below 6 GHz) has become crowded. Proposed 5G expansion includes use of the 24 GHz band. The Federal Communications Commission (FCC) manages spectrum allocation for nonfederal users in the United States. The agency allocates spectrum for specific users and can assign frequencies to entities or auction rights to use the spectrum.[87] All users who are assigned frequencies must adhere to technical requirements to limit interference to users operating nearby, including limits on *out-of-band emissions*—when high-power signals transmitted in one band disrupt signals in an adjacent band.

Spectrum use is coordinated globally through the International Telecommunications Union (ITU), an agency of the United Nations. The member-nations of the ITU adopt standards and requirements for use, including emission limits to advance the ability to communicate globally.

NOAA and Other Stakeholder Concerns—Selected Timeline

According to NOAA, in 2016, ITU encouraged NOAA to complete studies of the impacts of 5G expansion and emission interference on the 23.8 GHz frequency, among other frequencies.[88] In 2017, NOAA began working with FCC on initial 23.8 GHz studies and models using pre-packaged modeling software and a limited set of input parameters determined by the software specifications. After voicing concerns about the inherent assumptions used by the pre-packaged software, FCC requested NOAA create its own model to allow the agencies to control the programming code and input parameters.[89] NOAA partnered with NASA to do so.[90]

NOAA has expressed concerns over interference in the 23.8 GHz band from use of nearby bands. In a February 28, 2019, letter to FCC, Commerce Secretary Wilbur Ross and NASA Administrator Jim Bridenstine noted that the "current FCC proposal would have a significant negative impact on the transmission of critical science data."[91] NOAA and NASA provided their

[85] NRC, *Spectrum Management*, 2010, p. 29.

[86] NASA, TERRA, "Atlantic's Hurricane Oscar's Water Vapor Measured by NASA's Terra Satellite," October 29, 2018, at https://terra.nasa.gov/news/atlantics-hurricane-oscars-water-vapor-measured-by-nasas-terra-satellite.

[87] For example, FCC may allocate spectrum to public safety use, and license specific frequencies to specific public safety agencies. FCC may also auction rights to use certain bands and frequencies; once the bidding process has concluded, FCC may enter into licensing agreements with winners. For more information about 5G and spectrum allocation, see CRS Report R45485, *Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress*, by Jill C. Gallagher and Michael E. DeVine.

[88] Telephone conversation with NOAA Senior Policy Advisor, August 2, 2019.

[89] U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Environment, *The Future of Forecasting: Building a Stronger U.S. Weather Enterprise*, 116th Cong., 1st sess., May 16, 2019 (Washington, DC: GPO, 2019), at https://plus.cq.com/doc/congressionaltranscripts-5544078?1&searchId=HPjfb3fd (accessed July 29, 2019). Hereafter House Committee hearing, *The Future of Forecasting*, 2019.

[90] House Committee hearing, *The Future of Forecasting*, 2019.

[91] Debra Werner, "5G trumps weather in spectrum debate," *Space* News, March 8, 2019, at https://spacenews.com/5g-trumps-weather-in-spectrum-debate/.

joint study to FCC in March 2019 and advocated for an emission limit near -50 decibel watts (dBW) per 200 megahertz (MHz).[92]

FCC opened the 24 GHz auction to bidders on March 14, 2019, and closed the auction on May 28, 2019.[93] In a March 13, 2019, letter, Chairwoman Eddie Bernice Johnson and ranking member Frank Lucas of the House Committee on Science, Space, and Technology requested that FCC "delay the auction of 5G spectrum until NOAA, NASA, and the [Department of Defense] have been adequately consulted and their concerns have been addressed."[94] FCC Chairman Ajit Pai responded that the agency had established emission limits to protect passive service operations for other nearby bands and had "not been presented with *any* evidence of harmful interference from these existing services nor a validated study suggesting that operations in accordance with these rules would adversely affect use of the 23.6-24 GHz allocation, including for weather forecasting."[95] In a May 13, 2019, letter, ranking member Ron Wyden of the Senate Committee on Finance and ranking member Maria Cantwell of the Senate Committee on Commerce, Science, and Transportation requested FCC Chairman Pai

> not to award any final licenses to winning bidders for the future commercial broadband use in the 24 GHz spectrum until the FCC approves the passive band protection limits that [NASA] and [NOAA] determine are necessary to protect critical satellite-based measurements of atmospheric water vapor needed to forecast the weather.[96]

FCC Chairman Pai's letter in response to the Senators provided information about the interagency coordination process, timeline for of federal agency consideration, and thoughts on existing study claims, including that "adopting the limits suggested by the Department of Commerce would undeniably render the 24 GHz band unusable for 5G."[97]

---

[92] NOAA Acting Under Secretary of Oceans and Atmosphere Neil Jacobs testified that NOAA and NASA had shared the study with FCC in March 2019, but the report is undated. According to FCC Chairman Ajit Pai, NOAA shared the study with FCC on March 11, 2019. A decibel watt (dBW) is a unit of power in decibel scale referenced to 1 watt. The decibel scale is logarithmic, therefore a -50 dBW limit would allow about three orders of magnitude less interference than a -20 dBW limit. A 50 dBW limit would allow about three orders of magnitude more interference than a 20 dBW limit. NOAA and NASA, *Results from NASA/NOAA Sharing Studies on WRC-19 Agenda Item 1.13*, undated, at https://science.house.gov/imo/media/doc/Study%20prepared%20by%20NOAA%20and%20NASA%20-%20Results%20from%20NASANOAA%20Sharing%20Studies%20on%20WRC-19%20Agenda%20Item%201.13.pdf (hereafter NOAA and NASA joint study); House Committee hearing, *The Future of Forecasting*, 2019; and letter correspondence from FCC Chairman Pai to Senate Committee on Commerce, Science, and Transportation ranking member Maria Cantwell, June 11, 2019, at https://docs.fcc.gov/public/attachments/DOC-358166A1.pdf.

[93] FCC, "Public Notice: Upfront Payment Deadline and Instructions and Other Dates for the Auction of 24 GHz Upper Microwave Flexible Use Service Licenses (Auction 102)," January 31, 2019, at https://docs.fcc.gov/public/attachments/DA-19-24A1.pdf and FCC, "Public Notice: Auction of 24 GHz Upper Microwave Flexible Use Service Licenses Closes," June 3, 2019, at https://docs.fcc.gov/public/attachments/DA-19-485A1.pdf

[94] Letter correspondence from House Committee on Science, Space, and Technology Chairwoman Eddie Bernice Johnson and ranking member Frank Lucas to FCC Chairman Pai, March 13, 2019, at https://docs.fcc.gov/public/attachments/DOC-357582A2.pdf.

[95] Letter correspondence from FCC Chairman Pai to House Committee on Science, Space, and Technology Chairwoman Johnson and ranking member Lucas, April 29, 2019, at https://docs.fcc.gov/public/attachments/DOC-357582A1.pdf.

[96] Letter correspondence from Senate Committee on Finance ranking member Ron Wyden and Senate Committee on Commerce, Science, and Transportation ranking member Cantwell to FCC Chairman Pai, May 13, 2019, at https://www.wyden.senate.gov/imo/media/doc/05132019%20FINAL%20Wyden%20Cantwell%20Letter%20to%20FCC%20re%205G%2024%20GHz%20Spectrum.pdf.

[97] Letter correspondence from FCC Chairman Pai to Senate Committee on Commerce, Science, and Transportation ranking member Cantwell, June 11, 2019, at https://docs.fcc.gov/public/attachments/DOC-358166A1.pdf.

In a May 16, 2019, House Science, Space, and Technology committee hearing, NOAA Acting Under Secretary of Oceans and Atmosphere Neil Jacobs stated that the NOAA and NASA joint study found that the emission limit proposed by FCC (-20 dBW per 200 MHz) "would result in roughly a 77 percent data loss from [NOAA] passive microwave sounders."[98] According to Jacobs, the loss would

> degrade the forecast scale by up to 30 percent, so if you look back in time to see when our forecast goes roughly 30 percent less than it was today, it's somewhere around 1980. This would result in the reduction of hurricane track forecast lead time by roughly two to three days.
>
> A good example of this is a data denial study that the European Center did, where they withheld the microwave sounder data during the forecast for Superstorm Sandy and a model, which is the most accurate model in the world right now, kept the storm out to sea.[99]

When asked if other instruments and observations could offset the loss, Jacobs testified that there were currently no existing capabilities to mitigate the loss of information.[100] According to NOAA, data losses of 2% or more due to emission interference would likely force NOAA to issue a stop-work order to contractors working on the next generation of satellites, as the onboard instruments would no longer be able to meet mission requirements.[101]

Jacobs also stated that NOAA had not identified scientific evidence to support FCC's proposed emissions limit, and NOAA had instead advocated for an emissions limit near -50 dBW per 200 MHz, which "would result in roughly zero data loss."[102] According to NOAA, its proposed emission limit relied on the NOAA and NASA joint study, in concurrence with the U.S. Navy and a study by the European Space Agency, which found that a more restrictive emissions limit was needed.[103]

A July 2019 National Academy of Sciences meeting to discuss the "implications of proposed 5G service in 24 GHz bands for remote sensing of atmospheric water vapor" was canceled reportedly due to a reluctance to participate by "many of the 'most knowledgeable about the topic.'"[104] In a July 2019 letter to FCC Chairman Pai, Senator John Kennedy wrote to "commend [FCC] for the

---

[98] House Committee hearing, *The Future of Forecasting*, 2019. The House Committee on Science, Space, and Technology has since released NOAA's report. NOAA and NASA joint study.

[99] House Committee hearing, *The Future of Forecasting*, 2019.

[100] House Committee hearing, *The Future of Forecasting*, 2019.

[101] House Committee hearing, *The Future of Forecasting*, 2019.

[102] House Committee hearing, *The Future of Forecasting*, 2019. The decibel scale is logarithmic, therefore a -50 dBW limit would allow about three orders of magnitude less interference than the proposed -20 dBW limit. American Institute of Physics, "NOAA Warns 5G Spectrum Interference Presents Major Threat to Weather Forecasts," May 22, 2019, at https://www.aip.org/fyi/2019/noaa-warns-5g-spectrum-interference-presents-major-threat-weather-forecasts.

[103] House Committee hearing, *The Future of Forecasting*, 2019. Senator Wyden released a document from the Navy regarding "operational impacts from potential loss of NOAA/NASA METOC satellite data resulting from the FCC spectrum auction for 5G." Captain Marc Eckardt, *Operational impacts from potential loss of NOAA/NASA METOC satellite data resulting from the FCC spectrum auction for 5G*, Information Brief, March 27, 2019, at https://www.wyden.senate.gov/imo/media/doc/Navy%2024Hz%205G%20Spectrum%20Impacts.pdf.

[104] Hal Bernton, "High-stakes dispute turns nasty, pits 5G technology against weather forecasting," *The Seattle Times*, August 5, 2019, at https://www.seattletimes.com/seattle-news/will-5g-satellite-deployment-undermine-noaa-weather-forecasting/; and workshop cancellation notice at National Academy of Sciences Board on Atmospheric Science and Climate, "Upcoming Workshop," at http://dels.nas.edu/Upcoming-Workshop/Implications-Proposed-Service/AUTO-6-14-56-P?bname=basc.

successful close of the 24 GHz band auction," noting that "no federal party—not the Department of Commerce, NOAA, or NASA—raised any objections or concerns in the public docket."[105]

In September 2019, House Committee on Science, Space, and Technology Chairwoman Johnson sent a letter to FCC Chairman Pai requesting FCC analysis of the out of band emissions limits, including the agency's review of the NOAA and NASA joint study.[106]

In an October 15, 2019, letter, FCC Chairman Pai responded to Senator Kennedy stating that "despite efforts by some to undermine the official position of the US government" the FCC was successful in advocating for a mandatory limit of -28 dBW per 200 MHz at a regional telecommunications meeting.[107] Chairwoman Johnson sent a follow-up letter dated October 23, 2019 to FCC Chairman Pai requesting a response to her September letter.[108] FCC's site with Chairman Pai's responses to congressional letters does not include a response to Chairwoman Johnson's September and October 2019 letters.[109]

In November 2019, national delegations met at ITU's World Radiocommunication Conference to finalize 5G spectrum allocations. The United States proposed an emissions limit of -28 dBW per 200 MHz for the 24 GHz band.[110] The conference participants agreed to an emissions limit of -33 dBW per 200 MHz, with the limit increasing to -39 dBW per 200 MHz in 2027.[111]

In December 2019, Chairwoman Johnson and ranking member Lucas of the House Committee on Science, Space, and Technology requested that the Government Accountability Office conduct an evaluation of "how the Federal government, including the FCC and the National Telecommunications and Information Administration (NTIA), resolves interference issues and ensures that spectrum is available to meet critical needs."[112]

Some stakeholders, such as the University Corporation for Atmospheric Research (UCAR) and the World Meteorological Organization, have expressed their concerns of interference and have advocated for an emissions limit of -42 dBW for the 24 GHz band.[113] Others have argued that

---

[105] Letter correspondence from Senator Kennedy to FCC Chairman Pai, July 18, 2019, at https://docs.fcc.gov/public/attachments/DOC-360437A2.pdf.

[106] Letter correspondence from Chairwoman Johnson to FCC Chairman Pai, September 30, 2019, at https://science.house.gov/imo/media/doc/9.30.19%20Letter%20to%20FCC%20re%20NOAA%20NASA%20Studies%201.pdf.

[107] Letter correspondence from FCC Chairman Pai to Senator John Kennedy, October 15, 2019, at https://docs.fcc.gov/public/attachments/DOC-360437A1.pdf. It is unclear when and how FCC changed its emissions limit proposal from -20 dBW per 200 megahertz (MHz) to -28 dBW per 200 MHz.

[108] Letter correspondence from Chairwoman Johnson to FCC Chairman Pai, October 23, 2019, at https://science.house.gov/imo/media/doc/10.23.19%20Follow-up%20FCC%20Letter%20%20.pdf.

[109] FCC, "Chairman Pai's Letters to Congress," at https://www.fcc.gov/chairman-pais-letters-congress.

[110] Inter-American Telecommunication Commission (CITEL), "Status of CITEL's Preparations for WRC-19," slides presented at the 3rd International Telecommunications Union (ITU) Inter-Regional Workshop on WRC-19 Preparation, Geneva, September 2-6, 2019, p. 9, at https://www.itu.int/dms_pub/itu-r/md/15/3rdwrc19prepwork/c/R15-3RDWRC19PREPWORK-C-0007!!PDF-E.pdf.

[111] ITU, "Key outcomes of the World Radiocommunications Conference 2019," *ITU News Magazine,* no. 6, 2019, p.23, at https://www.itu.int/en/itunews/Documents/2019/2019-06/2019_ITUNews06-en.pdf.

[112] Letter correspondence between Chairwoman Johnson and ranking member Lucas and Government Accountability Office (GAO) Comptroller General of the United States General Dodaro, December 2019, at https://science.house.gov/imo/media/doc/12.10.19%20GAO%20Request%20Letter%2024%20GHz%20_EBJ%20and%20Lucas%20.pdf. As of June 10, 2020, it is unknown if the GAO has begun conducting the requested study.

[113] National Center for Atmospheric Research, University Corporation for Atmospheric Research (UCAR), "UCAR Statement on Opening the 24 GHz Spectrum," June 18, 2019, at https://news.ucar.edu/132669/ucar-statement-opening-24-ghz-spectrum; World Meteorological Organization, "WMO: protect ratio frequencies vital to earth observations,"

NOAA's claims are based on flawed studies, fail to consider new technologies, and were introduced at the last minute.[114] Concerns over emission limits and degradation of satellite data are likely to continue as FCC plans to open up several other spectrum bands for auction in the next few years.

June 14, 2019, at https://public.wmo.int/en/media/news/wmo-protect-radio-frequencies-vital-earth-observations; and Debra Werner, "International weather agencies object to 5G spectrum decision," *Space* News, November 27, 2019, at https://spacenews.com/international-weather-agencies-object-to-5g-spectrum-decision/.

[114] Liam Siguad, "5G won't ruin your weather forecast," *The Hill*, June 18, 2019, at https://thehill.com/opinion/technology/449060-5g-wont-ruin-your-weather-forecast; letter correspondence from members of several organizations to FCC Chairman Pai, December 16, 2019, at https://www.ccagw.org/sites/default/files/L-Band%20Coalition%20letter.pdf; and CTIA, "How 5G will improve weather forecasting & preparedness," July 2, 2019, at https://www.ctia.org/news/how-5g-will-improve-weather-forecasting-preparedness.

Appendix A. **2019 Hurricane Season Outlooks and Overviews**

2019 Atlantic Hurricane Season Outlook and Overview

The National Oceanic and Atmospheric Administration (NOAA) issued its 2019 Atlantic hurricane season outlook in May 2019 and published an updated outlook in August 2019 (**Table A-1**). In the May outlook, NOAA indicated that a near-normal season had the highest chance (40%) of occurring.[115] The August update indicated an increased chance (45%) that the 2019 hurricane season would be above-normal, with a 35% chance of a near-normal season and a 20% chance of a below-normal season.[116] For comparison, the 1981 to 2010 seasonal averages include 12 named storms, 6 hurricanes, and 3 major hurricanes.

Table A-1. 2019 Atlantic Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms

NOAA Seasonal Outlook (May 2019)	NOAA Seasonal Outlook (August 2019)	Actual
Named Storms: 9-15	Named Storms: 10-17	Named Storms: 18
Hurricanes: 4-8	Hurricanes: 5-9	Hurricanes: 6
Major Hurricanes: 2-4	Major Hurricanes: 2-4	Major Hurricanes: 3

Sources: National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) Climate Prediction Center (CPC), "NOAA 2019 Atlantic Hurricane Season Outlook," May 23, 2019, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2019/May/hurricane.shtml; NOAA, NWS CPC, "NOAA 2019 Atlantic Hurricane Season Outlook," August 8, 2019, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2019/August/hurricane.shtml; and NOAA, "Hurricanes and Tropical Storms – November 2019," at https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201911.

In its August update, NOAA provided two reasons for a more active 2019 hurricane season than originally predicted in May 2019:[117]

- El Niño conditions dissipated in July, and El Niño conditions were expected to remain neutral. (El Niño conditions typically suppress factors that may lead to hurricanes, so neutral conditions could favor increased hurricane activity.)[118]
- The conducive conditions associated with the ongoing high-activity era for Atlantic hurricanes that began in 1995 remained in effect.[119]

[115] National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) Climate Prediction Center (CPC), "NOAA 2019 Atlantic Hurricane Season Outlook," May 23, 2019, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2019/May/hurricane.shtml.

[116] NOAA NWS CPC, "NOAA 2019 Atlantic Hurricane Season Outlook," August 8, 2019, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2019/August/hurricane.shtml. Hereafter NOAA, "August 2019 Atlantic Hurricane Outlook."

[117] NOAA, "August 2019 Atlantic Hurricane Outlook."

[118] For more information about El Niño, see NOAA, "El Niño," at https://www.noaa.gov/education/resource-collections/weather-atmosphere-education-resources/el-nino.

[119] For more information about the ongoing high-activity era, see NOAA, "Atlantic high-activity eras: What does it mean for hurricane season?," at https://www.noaa.gov/stories/atlantic-high-activity-eras-what-does-it-mean-for-

In 2019, for the fifth consecutive year, hurricane activity began prior to June 1, with the formation of Subtropical Storm Andrea on May 20, 2019.[120] Eighteen named storms formed in the north Atlantic basin between May 20 and November 30, 2019, three of which reached major hurricane strength (Dorian, Humberto, and Lorenzo).[121] Tropical Storm Imelda produced historic rainfall totals and devastating flooding over parts of eastern Texas, similar to that of Hurricane Harvey in 2017.[122] The 2019 Atlantic hurricane season marks the fourth consecutive above-normal Atlantic hurricane season (1998-2001 is the only other period on record with four consecutive above-normal seasons).[123] Forecasts for each of the three major hurricanes are discussed below.

Hurricane Dorian

Hurricane Dorian was the first major hurricane of the 2019 season (**Figure A-1**). The category 5 storm tied with three other hurricanes as the second strongest hurricane on record in the Atlantic basin in terms of wind speed.[124] The storm caused catastrophic storm surge flooding in the Bahamas and various levels of storm surge flooding along the coast of the southeastern United States.[125] The storm also resulted in high rainfall in parts of the Bahamas, South Carolina, North Carolina, and later in Nova Scotia.[126] It spawned 21 tornadoes, mostly in North Carolina, of assorted intensities.[127] After stalling over the northwestern Bahamas for several days, Hurricane Dorian brushed the southeast U.S. coast and made landfall on the Outer Banks of North Carolina as a category 1 hurricane.[128] Hurricane Dorian was responsible for four indirect deaths in the United States, in addition to multiple deaths reported in the Bahamas.[129] The storm caused estimated damages of $3.4 billion in the Bahamas and $1.6 billion in the United States.[130]

The National Hurricane Center (NHC) track forecast for Hurricane Dorian was better than average, meaning the forecast errors were lower than the average official forecast errors for hurricanes during the previous five-year (2014-2018) period (**Table A-2**). According to NOAA, the reformation of Dorian's center after crossing St. Lucia resulted in a significant shift in track,

hurricane-season.

[120] NOAA, "Active 2019 Atlantic hurricane season comes to an end," at https://www.noaa.gov/media-release/active-2019-atlantic-hurricane-season-comes-to-end. Hereafter NOAA, "Active 2019 Atlantic."

[121]NOAA, "Active 2019 Atlantic."

[122] NOAA, "Hurricanes and Tropical Storms – September 2019," at https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201909 (hereafter NOAA, "Hurricanes and Tropical Storms – September 2019"); and Andy Latto and Robbie Berg, *National Hurricane Center Tropical Cyclone Report: Tropical Storm Imelda*, NOAA, 2019, at https://www.nhc.noaa.gov/data/tcr/AL112019_Imelda.pdf.

[123] NOAA, "Active 2019 Atlantic"; and NOAA, "Hurricanes and Tropical Storms – September 2019."

[124] NOAA, "Hurricanes and Tropical Storms – August 2019," at https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201908. Hereafter NOAA, "Hurricanes and Tropical Storms – August 2019."

[125] Lixion A. Avila et al., *National Hurricane Center Tropical Cyclone Report: Hurricane Dorian*, 2020, pp. 6-8 at https://www.nhc.noaa.gov/data/tcr/AL052019_Dorian.pdf. Hereafter Avila et al., *Hurricane Dorian*, 2020.

[126] Avila et al., *Hurricane Dorian*, 2020, p. 8.

[127] Avila et al., *Hurricane Dorian*, 2020, p. 8.

[128] NOAA, "Hurricanes and Tropical Storms – August 2019."

[129] According to NOAA, "deaths occurring from such factors as heart attacks, house fires, electrocutions from downed power lines, vehicle accidents on wet roads, etc., are considered 'indirect' deaths." Avila et al., *Hurricane Dorian*, 2020, pp. 8-10.

[130] Avila et al., *Hurricane Dorian*, 2020, pp. 8-9.

resulting in a "lack of adequate warning for some of the islands of the northeastern Caribbean Sea" and an intensity forecast that underestimated the storm's expected wind speeds.[131]

The official NHC intensity forecasts for Hurricane Dorian were worse than the previous five-year average in all forecast periods (**Table A-3**). NHC noted that "most of the large errors are related to the fact that Dorian's center did not move over Hispaniola, and the failure in forecasting rapid intensification (RI) when Dorian was near the Bahamas."[132]

NHC issued storm surge watches and warnings at various times along the coasts of the Bahamas and the southeastern United States. NHC forecasted storm surge of peak storm surge of 18 to 23 feet above normal tide level in parts of the Bahamas; according to NHC, "eye witness accounts indicate that at least 20 feet of inundation occurred."[133] Storm surge of at least 3 feet occurred along some parts of the southeastern shore of the United States, however, other portions of the warning area did not "verify," with inundation less than 3 feet above ground level.[134] According to NHC, "although a sizeable portion of the Storm Surge Warning area did not verify, the issuance of the watch and warning was justified given that a slight westward deviation of Dorian's track, or an expansion of its wind field, would have caused significant storm surge flooding to occur along a larger proportion of the coast."[135]

[131] Avila et al., *Hurricane Dorian*, 2020, p. 10.

[132] Avila et al., *Hurricane Dorian*, 2020, p. 11.

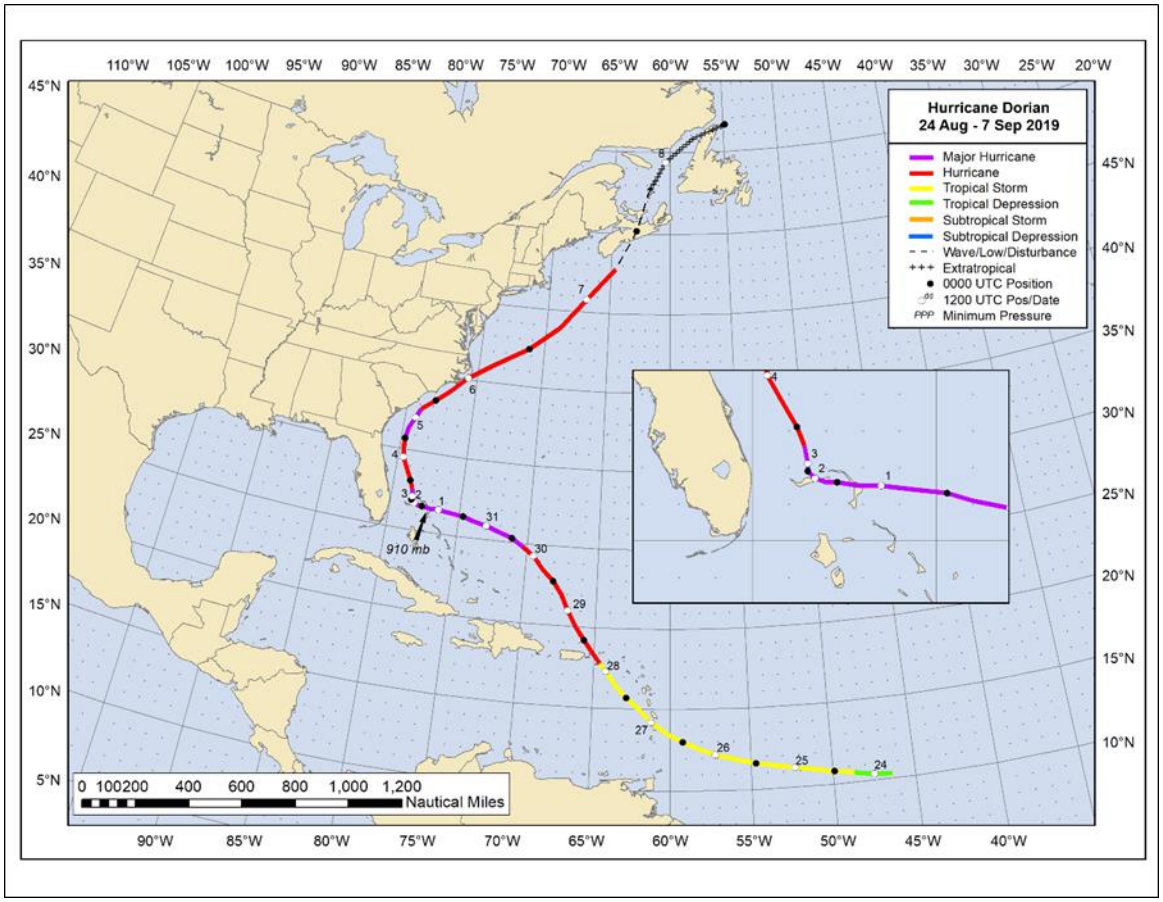
[133] Avila et al., *Hurricane Dorian*, 2020, p. 12.

[134] Avila et al., *Hurricane Dorian*, 2020, p. 12.

[135] Avila et al., *Hurricane Dorian*, 2020, p. 12.

Figure A-1. Hurricane Dorian's Track

August 24, 2019, through September 7, 2019



Source: Lixion A. Avila et al., *National Hurricane Center Tropical Cyclone Report: Hurricane Dorian*, 2020, p. 56, at https://www.nhc.noaa.gov/data/tcr/AL052019_Dorian.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 14 equals September 14, 2019). The small arrow indicates the point where the hurricane reached its lowest recorded pressure (910 millibars).

Table A-2. NHC Official Track Forecast Errors for Hurricane Dorian Compared with the 2014-2018 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	14.3	27.0	38.9	49.5	70.6	109.4	159.7
2014-2018 Averages	23.6	35.5	47.0	61.8	96.0	136.0	179.6

Sources: Lixion A. Avila et al., *National Hurricane Center Tropical Cyclone Report: Hurricane Dorian*, 2020, p. 39, at https://www.nhc.noaa.gov/data/tcr/AL052019_Dorian.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

The National Hurricane Center (NHC) issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Table A-3. NHC Official Intensity Forecast Errors for Hurricane Dorian Compared with the 2014-2018 Average

in nautical miles per hour, or knots

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	6.6	10.7	13.1	14.3	17.8	25.7	38.9
2014-2018 Averages	5.3	7.9	9.9	11.2	13.3	14.4	14.2

Sources: Lixion A. Avila et al., *National Hurricane Center Tropical Cyclone Report: Hurricane Dorian*, 2020, p. 41, at https://www.nhc.noaa.gov/data/tcr/AL052019_Dorian.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Hurricane Humberto

Hurricane Humberto was a category 3 hurricane that passed the eastern portions of the Bahamas, days after Hurricane Dorian's impacts (**Figure A-2**).[136] The storm brought hurricane-force winds to Bermuda and large swells and rip currents to the southeast United States.[137] Hurricane Humberto was responsible for two deaths in the United States and over $25 million in damages in Bermuda.[138] According to NOAA, rainfall amounts associated with the storm were relatively light compared with most tropical cyclones.[139]

[136] Stacy R. Stewart, *National Hurricane Center Tropical Cyclone Report: Hurricane Humberto*, 2019, at https://www.nhc.noaa.gov/data/tcr/AL092019_Humberto.pdf. Hereafter Stewart, *Hurricane Humberto*, 2019.

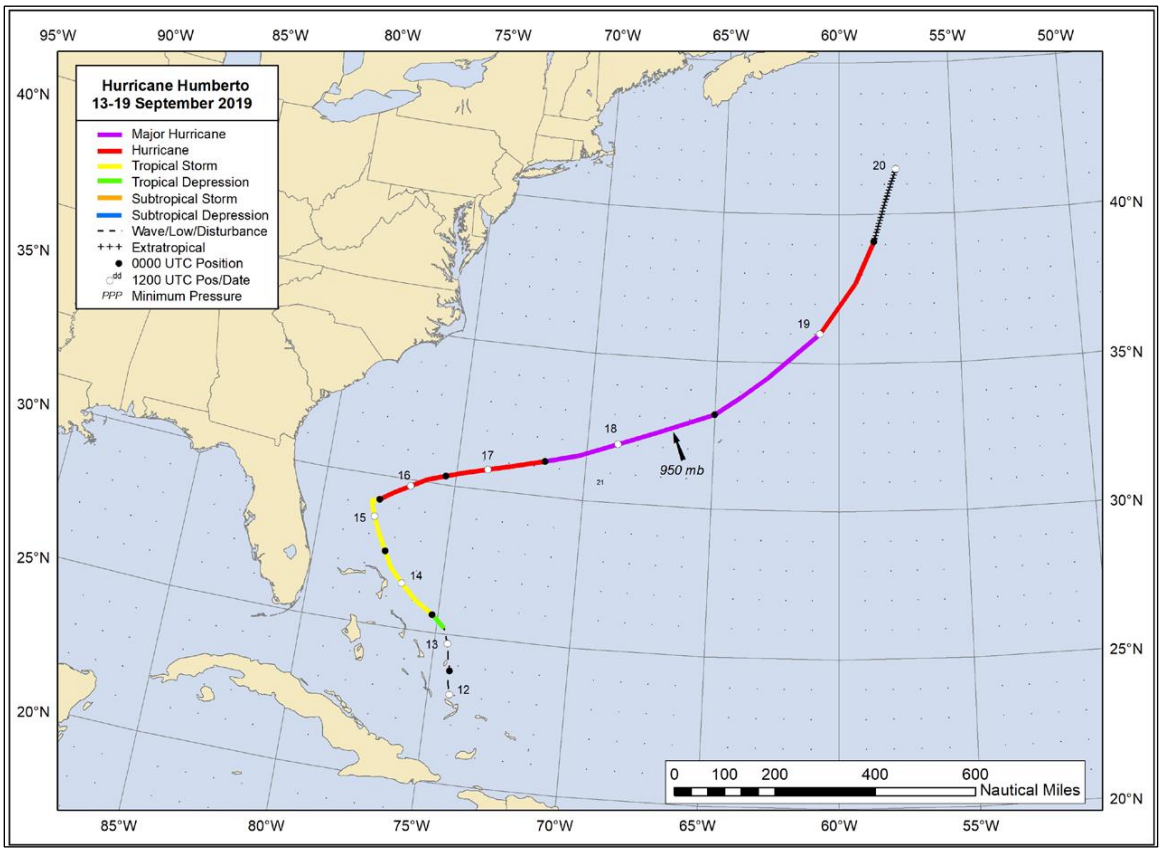
[137] Stewart, *Hurricane Humberto*, 2019.

[138] Stewart, *Hurricane Humberto*, 2019, pp. 6-7.

[139] Stewart, *Hurricane Humberto*, 2019, p. 6.

Figure A-2. Hurricane Humberto's Track

September 13, 2019, through September 19, 2019



Source: Stacy R. Stewart, *National Hurricane Center Tropical Cyclone Report: Hurricane Humberto*, 2019, p. 26, at https://www.nhc.noaa.gov/data/tcr/AL092019_Humberto.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 14 denotes September 14, 2019). The small arrow indicates the point where the hurricane reached its lowest recorded pressure (950 millibars).

The NHC track forecast for Hurricane Humberto was better than average, meaning the forecast errors were lower than the average official forecast errors for hurricanes during the previous five-year (2014-2018) period (**Table A-4**). According to NOAA, once Hurricane Humberto became a tropical cyclone, track forecasts improved "significantly."[140]

The accuracy of the official NHC intensity forecast for Hurricane Humberto was better than the previous five-year average forecasts in the 12 hour to 72 hour periods but worse than the averages in the 96 hour and 120 hour periods (**Table A-5**). NHC noted that forecasts did not anticipate Hurricane Humberto's continued strengthening in high wind shear conditions, which led to the larger than average errors at the 96 hour and 120 hour marks.[141] The forecast also did not capture the storm's rapid weakening. NHC did not issue any storm surge watches or warnings for this storm.

[140] Stewart, *Hurricane Humberto*, 2019, p. 7.

[141] Stewart, *Hurricane Humberto*, 2019, p. 8.

Table A-4. NHC Official Track Forecast Errors for Hurricane Humberto Compared with the 2014-2018 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	17.5	29.2	44.6	58.8	93.2	75.5	122.8
2014-2018 Averages	23.6	35.5	47.0	61.8	96.0	136.0	179.6

Sources: Stacy R. Stewart, *National Hurricane Center Tropical Cyclone Report: Hurricane Humberto*, 2019, p. 26, at https://www.nhc.noaa.gov/data/tcr/AL092019_Humberto.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Table A-5. NHC Official Intensity Forecast Errors for Hurricane Humberto Compared with the 2014-2018 Average

in nautical miles per hour, or knots

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	5.2	6.2	5.3	8.5	10.8	17.2	21.0
2014-2018 Averages	5.3	7.9	9.9	11.2	13.3	14.4	14.2

Source: Stacy R. Stewart, *National Hurricane Center Tropical Cyclone Report: Hurricane Humberto*, 2019, p. 28, at https://www.nhc.noaa.gov/data/tcr/AL092019_Humberto.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Hurricane Lorenzo

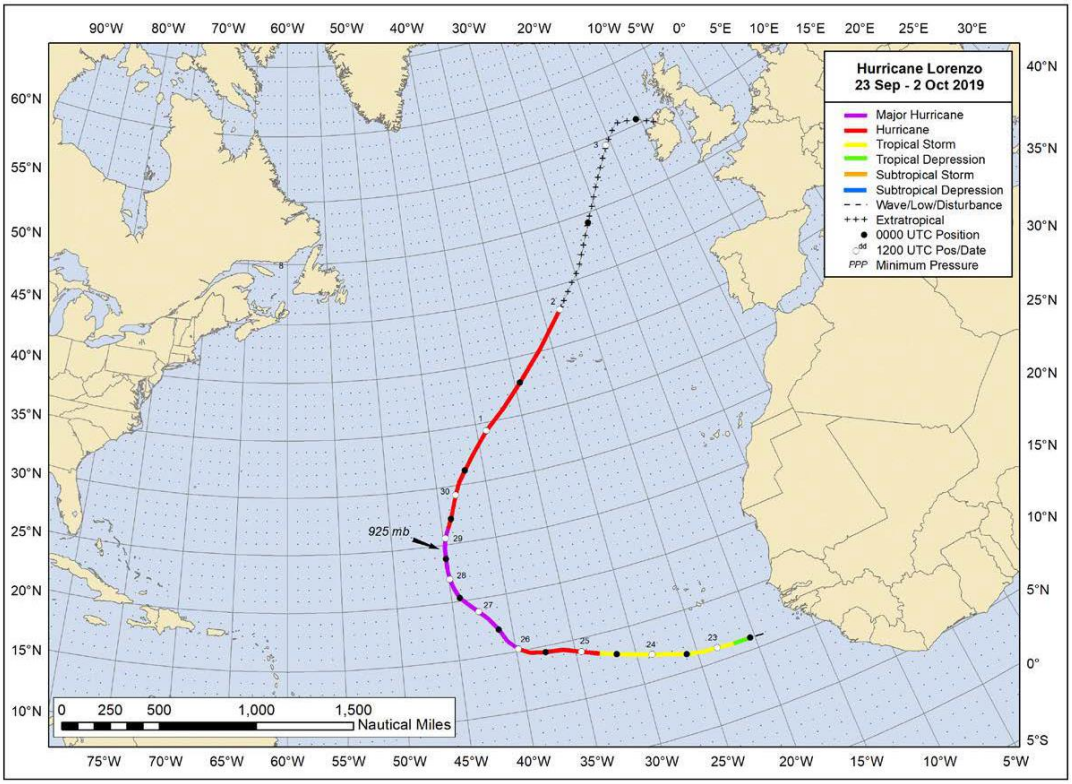
Hurricanes typically become major hurricanes in the western portion of the north Atlantic Ocean; Hurricane Lorenzo was one of the strongest hurricanes on record in the eastern or central Atlantic and the farthest east of any category 5 hurricane in the Atlantic on record (**Figure A-3**).[142] The

[142] David A. Zelinsky, *National Hurricane Center Tropical Cyclone Report: Hurricane Lorenzo*, 2019, at https://www.nhc.noaa.gov/data/tcr/AL132019_Lorenzo.pdf (hereafter Zelinsky, *Hurricane Lorenzo*, 2019); and

storm remained a category 1 hurricane as it passed the Azores Islands.[143] The hurricane generated hazardous surf and marine conditions along the U.S. East Coast and strong winds and powerful waves in the Azores and Ireland.[144] Hurricane Lorenzo was responsible for 19 deaths in total, including 8 people along the U.S. East Coast.[145]

Figure A-3. Hurricane Lorenzo's Track

September 22, 2019, through October 4, 2019



Source: David A. Zelinsky, *National Hurricane Center Tropical Cyclone Report: Hurricane Lorenzo*, 2019, at https://www.nhc.noaa.gov/data/tcr/AL132019_Lorenzo.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 24 denotes September 14, 2019). The small arrow indicates the point where the hurricane reached its lowest recorded pressure (925 millibars).

The NHC track forecast errors for Hurricane Lorenzo were lower than the average official forecast errors during the previous five-year (2014-2018) period (**Table A-6**).[146] The NHC intensity forecast for Hurricane Lorenzo had greater errors in the 12 hour and 24 hour periods than the mean official errors for the previous five-year period but the errors decreased at 36 hours and beyond (**Table A-7**). [147] NHC noted that the relatively high errors in the short-term forecasts

NOAA, "Hurricanes and Tropical Storms – September 2019."

[143] NOAA, "Hurricanes and Tropical Storms – September 2019."

[144] Zelinsky, *Hurricane Lorenzo*, 2019, pp. 4-5.

[145] The other 11 deaths account for the crewmembers of the *Bourbon Rhode*. NHC provided 35 forecasts in support of the U.S. Coast Guard's search and rescue mission. Zelinsky, *Hurricane Lorenzo*, 2019, pp. 4 and 6.

[146] Zelinsky, *Hurricane Lorenzo*, 2019, p. 5.

[147] Zelinsky, *Hurricane Lorenzo*, 2019, p. 6.

were primarily associated with Hurricane Lorenzo's rapid intensification (RI) and weakening at the storm's onset.[148] None of the intensity models reviewed captured the storm's large intensity swings.[149]

Table A-6. NHC Official Track Forecast Errors for Hurricane Lorenzo Compared with the 2014-2018 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	19.0	25.2	34.0	45.2	68.2	90.5	102.0
2014-2018 Averages	23.6	35.5	47.0	61.8	96.0	136.0	179.6

Sources: David A. Zelinsky, *National Hurricane Center Tropical Cyclone Report: Hurricane Lorenzo*, 2019, p. 12, at https://www.nhc.noaa.gov/data/tcr/AL132019_Lorenzo.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Table A-7. NHC Official Intensity Forecast Errors for Hurricane Lorenzo Compared with the 2014-2018 Average

in nautical miles per hour, or knots

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	7.6	10.7	8.6	8.7	12.7	11.6	11.4
2014-2018 Averages	5.3	7.9	9.9	11.2	13.3	14.4	14.2

Sources: David A. Zelinsky, *National Hurricane Center Tropical Cyclone Report: Hurricane Lorenzo*, 2019, p. 14, at https://www.nhc.noaa.gov/data/tcr/AL132019_Lorenzo.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

[148] Zelinsky, *Hurricane Lorenzo*, 2019, p. 6.

[149] Zelinsky, *Hurricane Lorenzo*, 2019, p. 6.

2019 Eastern Pacific Hurricane Season Outlook and Overview

NOAA's May 2019 eastern Pacific hurricane outlook predicted a 70% chance of an above-normal hurricane season, a 20% chance of a near-normal season, and a 10% chance of a below-normal season (**Table A-8**).[150] The 2019 eastern Pacific hurricane season ran from May 15 to November 30.

Table A-8. 2019 Eastern Pacific Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms

NOAA Seasonal Outlook (May 2019)	Actual
Named Storms: 15-22	Named Storms: 17
Hurricanes: 8-13	Hurricanes: 7
Major Hurricanes: 4-8	Major Hurricanes: 4

Sources: NHC, *NOAA 2019 Eastern Pacific Hurricane Season Outlook*, May 23, 2019, at https://www.cpc.ncep.noaa.gov/products/Epac_hurr/; and NOAA, "Hurricanes and Tropical Storms – November 2019," at https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201911.

According to NOAA, the 2019 eastern Pacific hurricane season was in line with the seasonal outlook and had near average activity.[151] Four hurricanes (Barbara, Erick, Juliette, and Kiko) reached major hurricane status in the eastern Pacific region.[152] Several storms impacted Hawaii, including by then-Tropical Storm Barbara and Hurricane Erick, each of which created high surf and heavy rain across parts of the islands.[153]

2019 Central Pacific Hurricane Season Outlook and Overview

NOAA does not identify a specific number of named storms, hurricanes, or major hurricanes in its central Pacific hurricane outlooks.[154] Instead, the agency predicted five to eight tropical cyclones in 2019, with a 70% chance of above-normal tropical cyclone activity.[155] Tropical cyclones include tropical depressions, tropical storms, and hurricanes.[156] An El Niño event was expected to last through the fall, however, cooling commenced early in the summer leading to neutral conditions.[157] As a result, the 2019 central Pacific hurricane season featured four tropical cyclones, several of which originated (Erick and Flossie) in the eastern Pacific area.[158]

[150] NOAA, *NOAA's 2019 Hurricanes Season Outlooks*, at https://cpc.ncep.noaa.gov/products/Epac_hurr/Slide1.JPG. Hereafter NOAA's 2019 Hurricane Outlooks, Slide 1.

[151] NOAA, "Monthly Eastern North Pacific Tropical Weather Summary," at https://www.nhc.noaa.gov/text/MIATWSEP.shtml.

[152] U.S. Department of Commerce, National Weather Service (NWS), "Eastern North Pacific Hurricane Tracking Chart," at https://www.nhc.noaa.gov/tafb_latest/tws_pac_latest.gif.

[153] NWS, "2019 Hurricane Season Summary for the Central Pacific Basin" at https://www.weather.gov/hfo/2019_CentralPacificHurricaneSeasonSummary. Hereafter NWS, "2019 Central Pacific."

[154] NOAA predicts the total number of tropical cyclones, instead of a breakdown of named storms, hurricanes, and major hurricanes, in its central Pacific hurricane outlook due to "low statistical skill provided the typically small sample size of hurricanes and major hurricanes in the Central Pacific." E-mail from NOAA Office of Legislative Affairs, January 24, 2020.

[155] NWS, "2019 Central Pacific."

[156] NOAA's 2019 Hurricane Outlooks, Slide 1.

[157] NWS, "2019 Central Pacific."

[158] NWS, "2019 Central Pacific."

Appendix B. **2018 Hurricane Season Outlooks and Overviews**

2018 Atlantic Hurricane Season Outlook and Overview

NOAA predicted a total of 10-16 named storms in its May 2018 outlook and downgraded the total named storms to 9-13 storms in the August update.[159] The number and strength of actual storms exceeded the upper range of NOAA's seasonal outlook (**Table B-1**).

Table B-1. 2018 Atlantic Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms

NOAA Seasonal Outlook (May 2018)	NOAA Seasonal Outlook (August 2018)	Actual
Named Storms: 10-16	Named Storms: 9-13	Named Storms: 15
Hurricanes: 5-9	Hurricanes: 4-7	Hurricanes: 8
Major Hurricanes: 1-4	Major Hurricanes: 0-2	Major Hurricanes: 2

Sources: NOAA, *NOAA's 2018 Hurricane Season Outlooks*, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2018/May/Slide1.JPG; NOAA, *NOAA's Updated 2018 Atlantic Hurricane Season Outlook*, at https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2018/August/Slide1.JPG; and NOAA, "Destructive 2018 Atlantic Hurricane Season Draws to an End," November 28, 2018, at https://www.noaa.gov/media-release/destructive-2018-atlantic-hurricane-season-draws-to-end.

In 2018, for the fourth consecutive year, hurricane activity began prior to June 1, with Tropical Storm Alberto forming on May 25.[160] The 2018 hurricane season also featured four named storms active at the same time.[161] Two major hurricanes affected the continental United States in 2018, causing severe damage: Hurricane Florence and Hurricane Michael.[162] Forecasts for each of the two major hurricanes are discussed below.

Hurricane Florence

Hurricane Florence was the first major hurricane of the 2018 season, making landfall near Wrightsville Beach, NC, on September 14, 2018 (**Figure B-1**). It achieved category 4 strength before making landfall. The maximum total rainfall of 35.93 inches was reported about 6 nautical miles (n mi) northwest of Elizabethtown, NC.[163] In total, Hurricane Florence is linked to 52 deaths (direct and indirect) and $24 billion in wind and water damage.[164] Hurricane Florence resulted in state rainfall records for both North Carolina and South Carolina, at 35.93 inches and 23.63 inches, respectively. Hurricane Florence also set record peak water levels in the Waccamaw

[159] NOAA, "NOAA 2018 Atlantic Hurricane Season Outlook."

[160] NOAA, "Destructive 2018 Atlantic Hurricane Season Draws to an End," November 28, 2018, at https://www.noaa.gov/media-release/destructive-2018-atlantic-hurricane-season-draws-to-end. Hereafter NOAA, "Destructive 2018," 2018.

[161] NOAA, "Destructive 2018," 2018.

[162] NOAA NHC, "2018 Atlantic Hurricane Season," at https://www.nhc.noaa.gov/data/tcr/index.php?season=2018&basin=atl. Hereafter NHC, "2018 Atlantic Hurricane Season."

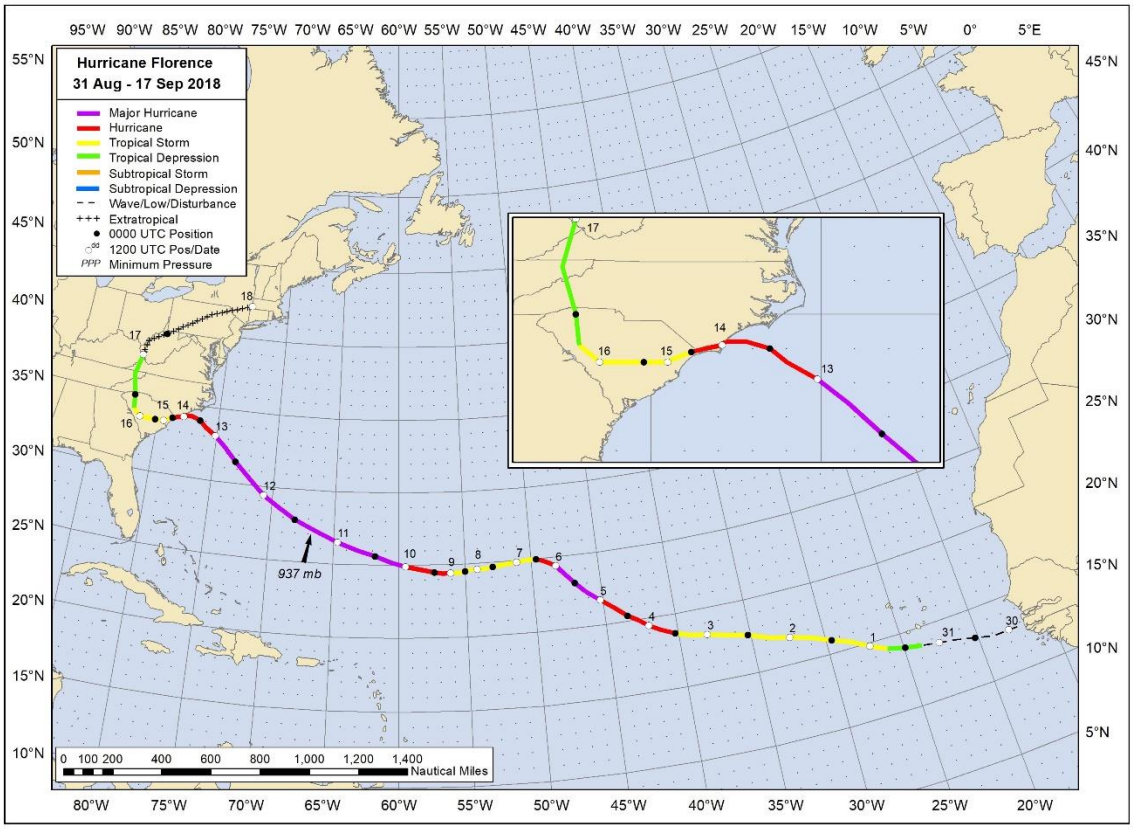
[163] Stewart and Berg, *Hurricane Florence*, 2019.

[164] Stewart and Berg, *Hurricane Florence*, 2019, pp. 8-9.

River in Freeland, NC, and the Little Pee Dee River in Galivants Ferry, SC, with the river reaching peak flood levels a month after Hurricane Florence made landfall.[165]

Figure B-1. Hurricane Florence's Track

August 31, 2018, through September 17, 2018



Source: Stacy R. Stewart and Robbie Berg, *National Hurricane Center Tropical Cyclone Report: Hurricane Florence*, 2019, at https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 14 denotes September 14, 2018). The small arrow indicates the point where the hurricane reached its lowest recorded pressure (937 millibars).

The NHC track forecast for Florence was better than average, meaning the forecast errors were lower than the average official forecast errors for hurricanes during the previous five-year period (2013-2017, **Table B-2**). The accuracy of the official NHC intensity forecast for Hurricane Florence generally had higher forecast errors than the previous five-year average forecasts (**Table B-3**). The previous five-year average intensity forecasts were better than the Hurricane Florence forecasts for all but the 120 hour period.[166] NHC indicated that the errors were due to the storm's unexpected first rapid intensification (RI) and its unanticipated rapid weakening. NHC noted that "the second RI period was anticipated and thus better forecast, albeit the time of peak intensity was about 18h later and 10 kt higher than what occurred."[167]

[165] Stewart and Berg, *Hurricane Florence*, 2019, p. 7, and NOAA, "Destructive 2018," 2018.

[166] A knot (kt) is 1 nautical mile per hour (mph), equivalent to approximately 1.15 mph.

[167] Stewart and Berg, *Hurricane Florence*, 2019, p. 15.

Table B-2. NHC Official Track Forecast Errors for Hurricane Florence Compared with the 2013-2017 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	18.3	30.8	40.8	50.2	71.5	115.7	155.7
2013-2017 Averages	24.1	37.4	50.5	66.6	98.4	137.4	180.7

Sources: Stacy R. Stewart and Robbie Berg, *National Hurricane Center Tropical Cyclone Report: Hurricane Florence*, 2019, p. 74, at https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Table B-3. NHC Official Intensity Forecast Errors for Hurricane Florence Compared with the 2013-2017 Average

in nautical miles per hour, or knots

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	6.3	12.7	16.1	18.1	22.5	17.3	13.3
2013-2017 Averages	5.5	8.0	10.0	11.4	12.7	14.5	15.0

Sources: Stacy R. Stewart and Robbie Berg, *National Hurricane Center Tropical Cyclone Report: Hurricane Florence*, 2019, p. 76, at https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

NHC issued storm surge warnings for parts of North Carolina and South Carolina. According to NHC, it "provided an accurate portrayal of the storm surge inundation risk in the area that received the worst coastal flooding."[168] Furthermore, "the initial Potential Storm Surge Flooding Map's inundation values were slightly high (which is not unexpected), but the map provided an

[168] Stewart and Berg, *Hurricane Florence*, 2019, p. 17.

accurate representation of the ultimate storm surge footprint and a depiction of the areas most at risk of the highest storm surge despite the hurricane's evolving structure and intensity."[169]

Hurricane Michael

Hurricane Michael was the second major hurricane to strike the conterminous U.S. coast in 2018, making landfall near Mexico Beach and Tyndall Air Force Base, FL, at category 5 strength—which was unprecedented for the region—on October 10, 2018 (**Figure B-2**). Hurricane Michael was originally recorded as a high-end category 4 storm, but upon post-storm analysis, it was upgraded to category 5.[170] According to NHC, Hurricane Michael was "the strongest hurricane on record to strike the Florida panhandle, and was the third-most-intense hurricane to make landfall in the continental U.S. in terms of central pressure (919 mb) and the fourth-strongest in terms of maximum sustained winds (155 mph)."[171] In total, 59 deaths (direct and indirect) and $25 billion in wind and water damages were linked to Hurricane Michael.[172] Hurricane Michael's landfall marks the latest date of a category 5 hurricane landfall in the United States.[173] Hurricane Michael produced high storm surge, peaking at about 14 feet near Mexico Beach, FL, in addition to significant wave activity along the shoreline.[174]

[169] Stewart and Berg, *Hurricane Florence*, 2019, p. 17.

[170] NOAA, "Hurricane Michael Upgraded to a Category 5 at time of U.S. Landfall," April 19, 2019, at https://www.noaa.gov/media-release/hurricane-michael-upgraded-to-category-5-at-time-of-us-landfall. Hereafter NOAA, "Hurricane Michael Upgraded," 2019.

[171] NOAA, "Destructive 2018," 2018.

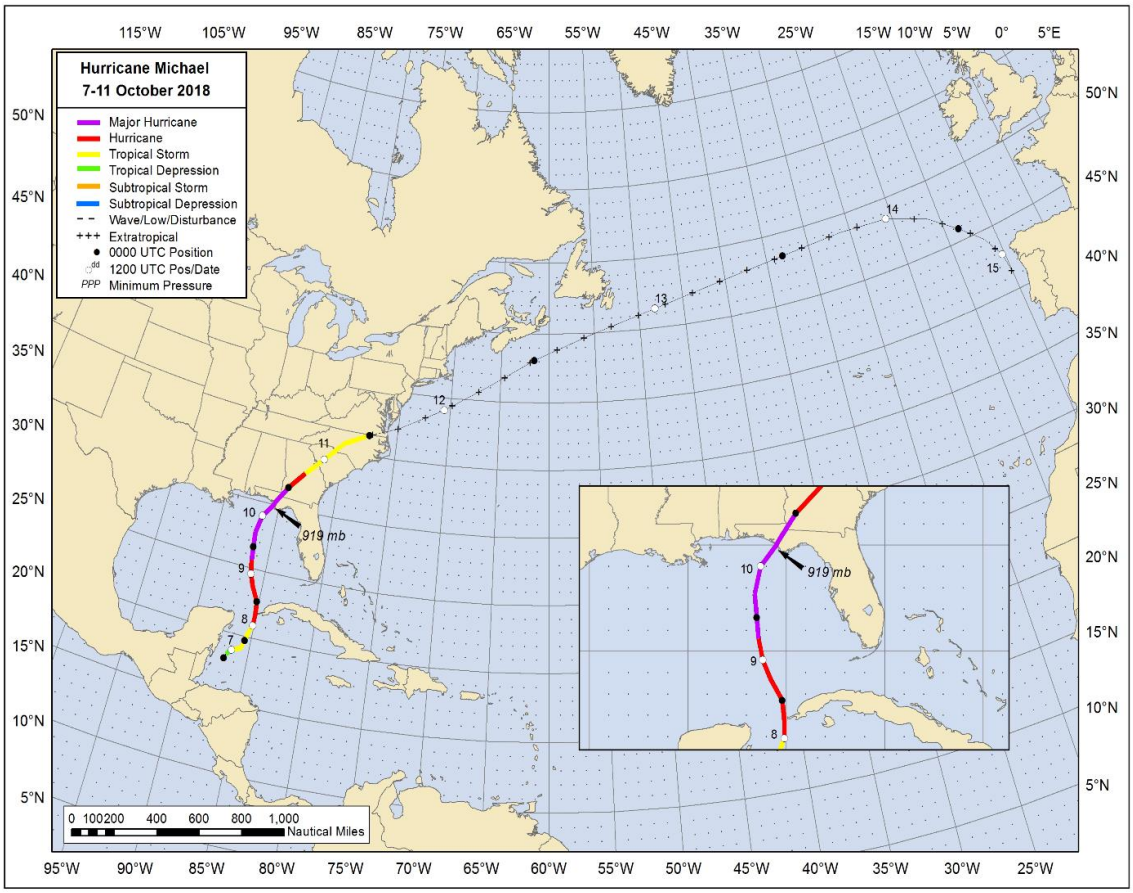
[172] John L. Beven II, Robbie Berg, and Andrew Hagan, *National Hurricane Center Tropical Cyclone Report: Hurricane Michael*, NOAA, 2019, p. 11, at https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf. Hereafter Beven, Berg, and Hagan, Hurricane Michael, 2019.

[173] Beven, Berg, and Hagan, *Hurricane Michael*, 2019, p. 6.

[174] Beven, Berg, and Hagan, *Hurricane Michael*, 2019, p. 8.

Figure B-2. Hurricane Michael's Track

October 7, 2018, through October 11, 2018



Source: John L. Beven II, Robbie Berg, and Andrew Hagan, *National Hurricane Center Tropical Cyclone Report: Hurricane Michael*, 2019, at https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 10 denotes October 10, 2018).

The NHC track forecast for Hurricane Michael had smaller forecast errors than the previous five-year period (**Table B-4**). According to NHC, the forecasts were "less skillful during two periods": (1) during its initial movement from the Caribbean Sea into the Gulf of Mexico, and (2) when tracking the storm through South Carolina and North Carolina.[175]

[175] Beven, Berg, and Hagan, *Hurricane Michael*, 2019, pp. 12.

Table B-4. NHC Official Track Forecast Errors for Hurricane Michael Compared with the 2013-2017 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	20.0	34.5	47.1	45.9	64.4	85.2	N/A
2013-2017 Averages	24.1	37.4	50.5	66.6	98.4	137.4	N/A

Sources: John L. Beven II, Robbie Berg, and Andrew Hagan, *National Hurricane Center Tropical Cyclone Report: Hurricane Michael*, 2019, p. 66, at https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

The intensity forecast errors for Hurricane Michael were greater than the five-year period averages in all cases except the 96-hour period (**Table B-5**). NHC acknowledged that Hurricane Michael intensified more quickly than anticipated, despite a moderate-to-strong wind shear, which may have undermined later predictions, as the forecasted intensity was greater than the actual storm intensity.[176]

Table B-5. NHC Official Intensity Forecast Errors for Hurricane Michael Compared with the 2013-2017 Average

in nautical miles per hour, or knots

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	12 Hours
NHC Official	6.8	12.3	14.6	19.1	24.3	3.3	N/A
2013-2017 Averages	5.5	8.0	10.1	11.4	12.7	14.5	N/A

Sources: John L. Beven II, Robbie Berg, and Andrew Hagan, *National Hurricane Center Tropical Cyclone Report: Hurricane Michael*, 2019, p. 68, at https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

[176] Beven, Berg, and Hagan, *Hurricane Michael*, 2019, p. 13. Wind shear refers to how wind changes speed and direction with height. NWS, "Severe Weather Topics," at https://www.weather.gov/ilx/swop-springtopics.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

NHC issued several storm surge watches and warnings along the coasts of North Carolina and Florida related to Hurricane Michael. NHC did not comment on the accuracy of its storm surge warnings in its post-hurricane report.[177]

2018 Eastern Pacific Hurricane Season Overview

NOAA predicted 14-20 named storms for the 2018 eastern Pacific hurricane season (**Table B-6**). The actual total was 22 named storms.

Table B-6. 2018 Eastern Pacific Hurricane Season: Comparison Between Seasonal Outlook and Actual Storms

NOAA Seasonal Outlook (May 2018)	Actual
Named Storms: 14-20	Named Storms: 22
Hurricanes: 7-12	Hurricanes: 12
Major Hurricanes: 3-7	Major Hurricanes: 9

Sources: NOAA, "Forecasters predict a near- or above-normal 2018 Atlantic hurricane season," at https://www.noaa.gov/media-release/forecasters-predict-near-or-above-normal-2018-atlantic-hurricane-season; and NOAA, "2018 Monthly Tropical Cyclone Summary," at https://www.nhc.noaa.gov/archive/tws/?yyyy=2018&bb=EP&mm=11.

Notes: Other NOAA sources include an additional storm, Hurricane Walaka, in their total actual numbers for 2018. Hurricane Walaka formed in the central Pacific and passed over Johnson Atoll and several northwestern Hawaiian Islands. Hurricane Walaka is neither included in the counts above nor described in the rest of the report. NOAA National Centers for Environmental Information, "Hurricanes and Tropical Storms – Annual 2018," at https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201813#pac.

According to NOAA, the 2018 eastern Pacific hurricane season was very active, with the number of named storms, hurricanes, and major hurricanes higher than the May 2018 seasonal outlook and 1981 to 2010 averages.[178] The year 2018 ties with the years 1982 and 1985, as years with the second highest number of named storms in a season for the eastern Pacific.[179] No major hurricanes made landfall in Hawaii in 2018, although several damaging tropical cyclones (Lane and Olivia, described below) passed near or over the islands.[180] Both of the storms originated in the eastern Pacific and moved westward into the central Pacific. According to NOAA, the 2018 eastern Pacific hurricane season had the highest recorded *accumulated cyclone energy (ACE) index*, a wind energy index calculated from maximum sustained surface wind speed measurements taken every six hours for all named storms while they are at least tropical storm

[177] Beven, Berg, and Hagan, *Hurricane Michael*, 2019.

[178] NOAA, "Forecasters predict a near- or above-normal 2018 Atlantic hurricane season," at https://www.noaa.gov/media-release/forecasters-predict-near-or-above-normal-2018-atlantic-hurricane-season; and NOAA National Centers for Environmental Information, "Hurricanes and Tropical Storms – Annual 2018," at https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201813#pac. Hereafter NOAA, "Annual 2018."

[179] NOAA, "Annual 2018."

[180] NOAA, "Annual 2018." Four major Pacific Ocean hurricanes did make landfall in Mexico in 2018.

intensity.[181] The ACE index for the eastern Pacific basin during 2018 was 316, almost three times the 1981 to 2010 average of 132.

Hurricane Lane

Hurricane Lane was the first major storm of the 2018 eastern Pacific hurricane season to affect the United States.[182] Hurricane Lane passed close to Hawaii from August 23 to August 26 as a category 4 storm (**Figure B-3**). According to NOAA, Hurricane Lane set the state of Hawaii record for tropical cyclone total rainfall, with one location on the Big Island measuring 58 inches of total rainfall from the storm.[183] As the storm moved across the islands, it produced freshwater flooding and gusty winds, causing at least $20 million in damage to public infrastructure on the Big Island, another $2 million in damage on Maui, and over $1.5 million in damage to Kauai.[184] In addition to the rains, strong winds preceding the storm helped spread wildfires on Maui that resulted in over $4 million in damage.[185]

[181] NOAA, "Annual 2018."

[182] John L. Beven II, *National Hurricane Center Tropical Cyclone Report - Hurricane Lane*, NOAA, April 2, 2019, at https://www.nhc.noaa.gov/data/tcr/EP142018_Lane.pdf. Hereafter Beven, *Hurricane Lane*, 2019.

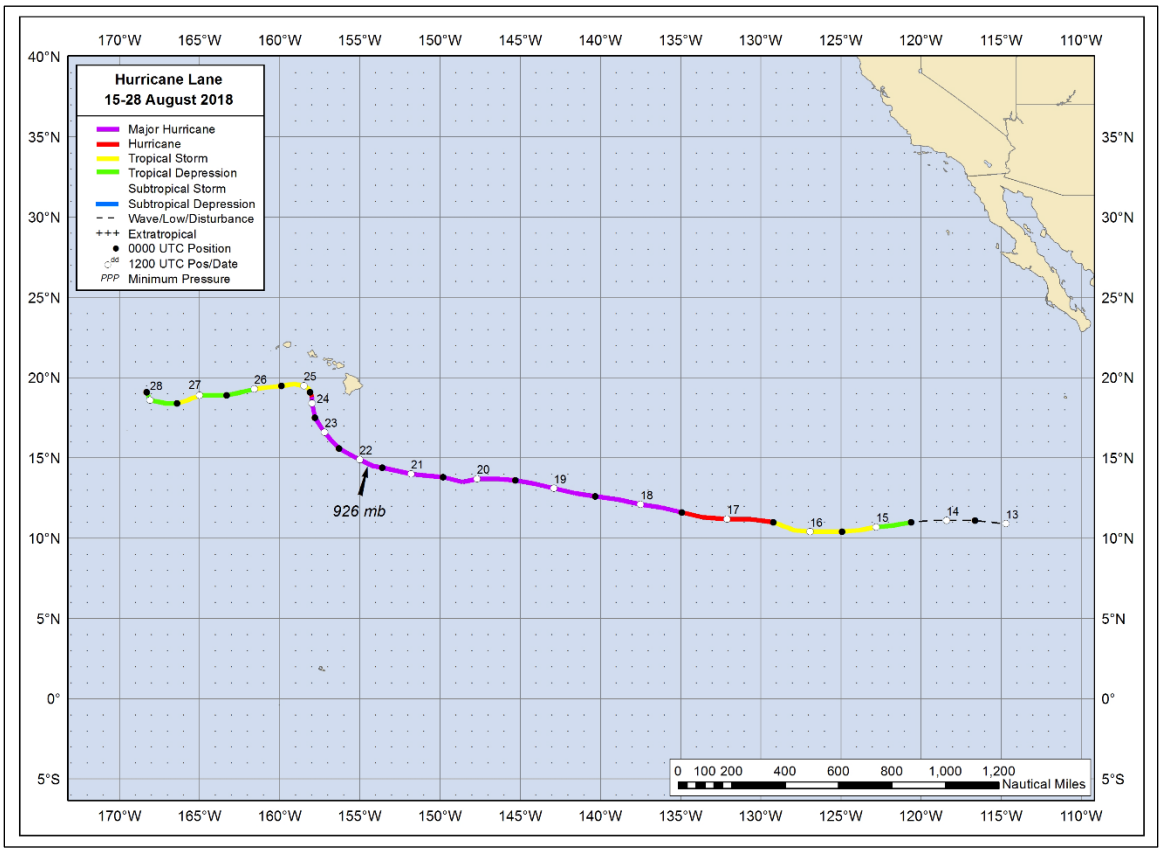
[183] NOAA, "2018 Summary for the Central Pacific Basin."

[184] NOAA, "2018 Summary for the Central Pacific Basin."

[185] NOAA, "2018 Summary for the Central Pacific Basin."

Figure B-3. Hurricane Lane's Track

August 15, 2018 - August 28, 2018



Source: John L. Beven II, *National Hurricane Center Tropical Cyclone Report - Hurricane Lane*, April 2, 2019, at https://www.nhc.noaa.gov/data/tcr/EP142018_Lane.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 23 denotes August 23, 2018). The small arrow indicating 926 milllibars indicates the lowest pressure recorded for the storm along this track.

The NHC track forecast was more accurate than the previous five-year period. NHC does not offer an explanation for the results (**Table B-7**).[186] According to NOAA, the NHC track forecasts performed better than most other models, with several exceptions.[187]

Table B-7. NHC Official Track Forecast Errors for Hurricane Lane Compared with the 2013-2017 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	18.9	25.9	28.4	30.3	50.2	71.7	82.1
2013-2017 Averages	21.8	33.2	43.0	53.9	80.7	111.1	150.5

[186] Beven, *Hurricane Lane*, 2019, pp. 3-4.

[187] Beven, *Hurricane Lane*, 2019, p. 4.

Sources: John L. Beven II, *National Hurricane Center Tropical Cyclone Report - Hurricane Lane*, NOAA, April 2, 2019, p. 14, at https://www.nhc.noaa.gov/data/tcr/EP142018_Lane.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

The NHC intensity forecasts for Hurricane Lane were more accurate than the previous five-year period for the first 48 hours, and they were less accurate than the previous five-year period between 72 and 120 hours out (**Table B-8**). According to NHC, the forecasts anticipated Hurricane Lane's rapid intensification into a major hurricane in the eastern Pacific (with subsequent weakening) but did not expect the hurricane's reintensification in the central Pacific.[188]

Table B-8. NHC Official Intensity Forecast Errors for Hurricane Lane Compared with the 2013-2017 Average

in nautical miles per hour, or knots

	Forecast			Forecast Period			
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	3.2	6.9	7.8	7.5	15.9	26.9	35.9
2013-2017 Averages	5.8	9.6	11.8	13.2	15.1	15.1	14.6

Sources: John L. Beven II, *National Hurricane Center Tropical Cyclone Report - Hurricane Lane*, NOAA, April 2, 2019, p. 16, at https://www.nhc.noaa.gov/data/tcr/EP142018_Lane.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Hurricane Olivia

Hurricane Olivia reached a category 4 at its peak in the eastern Pacific Ocean (**Figure B-4**).[189] It weakened as it crossed into the central Pacific Ocean and moved across Hawaii as a tropical storm. Tropical Storm Olivia made landfall on September 12, 2018, twice: (1) 10 nm northwest of Kahului, Maui, and (2) 6 nm north-northwest of Lanai City, Lanai.[190] Tropical Storm Olivia resulted in an extended period of heavy rainfall and flash flooding across the state, including 11 to

[188] Beven, *Hurricane Lane*, 2019, p. 4.

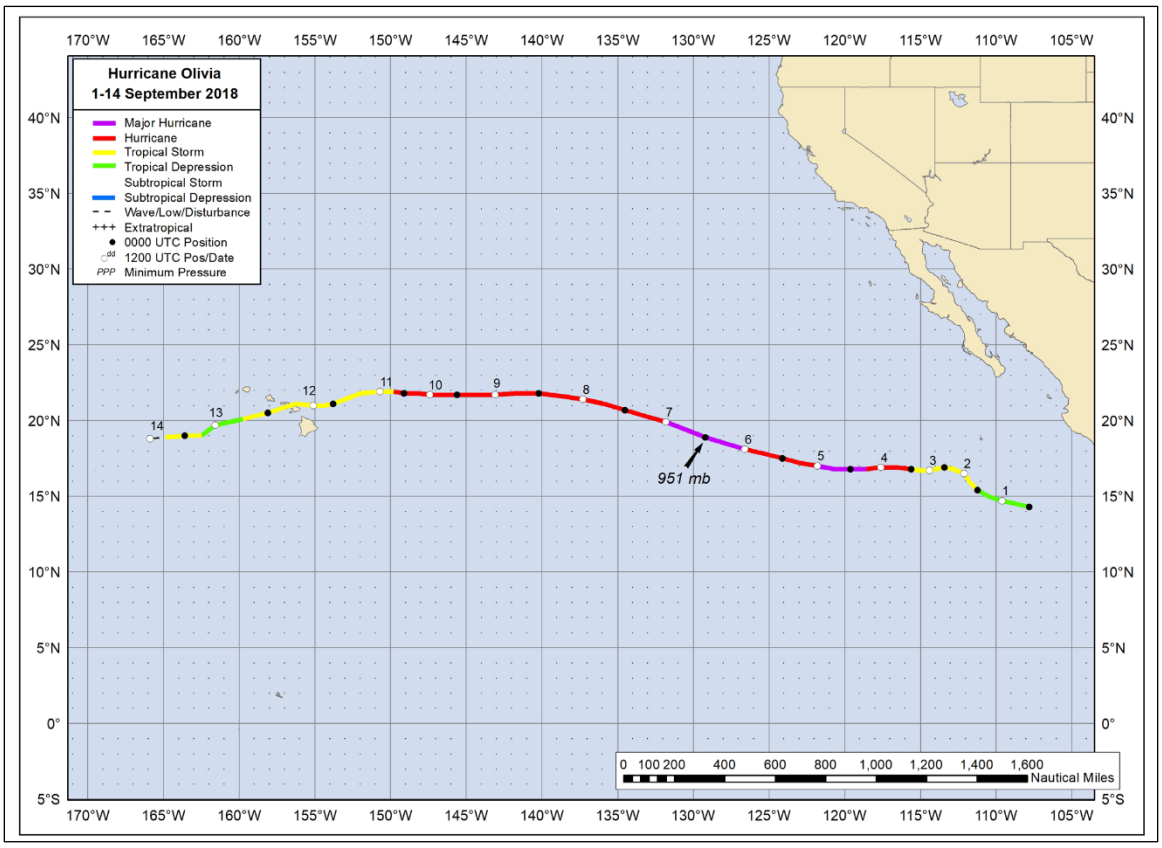
[189] John P. Cangialosi and Jon Jelsema, *National Hurricane Center Tropical Cyclone Report – Hurricane Olivia*, NOAA, July 25, 2019, at https://www.nhc.noaa.gov/data/tcr/EP172018_Olivia.pdf, p. 6. Hereafter Cangialosi and Jelsema, *Hurricane Olivia*, 2019

[190] Cangialosi and Jelsema, *Hurricane Olivia*, 2019, p. 6.

13 inches of rain over 48 hours in parts of Molokai, Maui, and Oahu.[191] According to NOAA, no casualties were reported in association with Olivia, and no official estimates of damages are available.[192]

Figure B-4. Hurricane Olivia's Track

September 1, 2018 - September 14, 2018



Source: John P. Cangialosi and Jon Jelsema, *National Hurricane Center Tropical Cyclone Report – Hurricane Olivia*, NOAA, July 25, 2019, at https://www.nhc.noaa.gov/data/tcr/EP172018_Olivia.pdf.

Notes: Numbers along the hurricane track indicate dates (e.g., 10 denotes October 10, 2018).

The official NHC track forecast was more accurate than the previous five-year averages for all forecast times (**Table B-9**).[193] The 120-hour error for Hurricane Olivia was the lowest track forecast error on record in the eastern Pacific region for tropical cyclones with 20 or more forecasts at the time of the report.[194]

[191] Cangialosi and Jelsema, *Hurricane Olivia*, 2019, p. 6.

[192] Cangialosi and Jelsema, *Hurricane Olivia*, 2019, p. 7.

[193] Cangialosi and Jelsema, *Hurricane Olivia*, 2019, p. 7.

[194] Cangialosi and Jelsema, *Hurricane Olivia*, 2019, pp. 7-8.

Table B-9. NHC Official Track Forecast Errors for Hurricane Olivia Compared with the 2013-2017 Average

in nautical miles

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours
NHC Official	17.5	26.7	32.3	38.1	49.4	57.0	61.3
2013-2017 Averages	21.8	33.2	43.0	53.9	80.7	111.1	150.5

Sources: John P. Cangialosi and Jon Jelsema, *National Hurricane Center Tropical Cyclone Report – Hurricane Olivia*, NOAA, July 25, 2019, p. 16, at https://www.nhc.noaa.gov/data/tcr/EP172018_Olivia.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast track and the actual track in nautical miles.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

The intensity forecasts for Hurricane Olivia were more accurate than the five-year period for the 36-hour and 72-hour periods but less accurate for all other forecast periods (**Table B-10**). According to NHC, the largest contributor to the forecast errors were low biases during the two intensification phases.[195]

Table B-10. NHC Official Intensity Forecast Errors for Hurricane Olivia Compared with the 2013-2017 Average

in nautical miles per hour, or knots

Forecast	Forecast Period						
	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	12 Hours
NHC Official	8.0	10.6	11.7	13.8	15.0	16.2	16.2
2013-2017 Averages	5.8	9.6	11.8	13.2	15.1	15.1	14.6

Sources: John P. Cangialosi and Jon Jelsema, *National Hurricane Center Tropical Cyclone Report – Hurricane Olivia*, NOAA, July 25, 2019, p. 18, at https://www.nhc.noaa.gov/data/tcr/EP172018_Olivia.pdf; and email correspondence with NOAA Office of Legislative Affairs, May 14, 2020.

Notes: Forecast errors indicate the difference between the forecast intensity and the actual intensity in nautical miles per hour, or knots.

NHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

[195] Cangialosi and Jelsema, *Hurricane Olivia*, 2019, p. 8.

2018 Central Pacific Hurricane Season Overview

In 2018, NOAA predicted the formation of three to six tropical cyclones, including tropical depressions, named storms, and hurricanes for the central Pacific region, in near- to above-normal conditions (**Table B-11**). A near-normal season in the central Pacific has three to five tropical cyclones, and an above-normal season has six or more tropical cyclones.[196]

A total of six tropical cyclones formed or impacted the central Pacific region in 2018.[197] Of the six tropical cyclones, two storms—Lane and Olivia, described in the sections entitled "Hurricane Lane" and "Hurricane OliviaNHC issues official forecasts every 6 hours, and each forecast has projections valid 12, 24, 36, 48, 72, 96, and 120 hours after the forecast's initial time.

According to NOAA, forecast errors are compared with a five-year period of average errors, as the five-year period is 1) recent with respect to the state of the science and 2) includes a large number of tropical cyclones to allow for robust statistical analysis.

Hurricane Olivia"—originated in the eastern Pacific, moved west, and had impacts on Hawaii.

Table B-11. 2018 Central Pacific Tropical Cyclone Season: Comparison Between Seasonal Outlook and Actual Storms

NOAA Seasonal Outlook (May 2018)	Actual
Tropical Cyclones: 3-6	Tropical Cyclones: 6

Sources: NOAA, "NOAA Predicts a near- or above-normal 2018 hurricane season in the Central Pacific," May 23, 2018, at https://www.noaa.gov/media-release/noaa-predicts-near-or-above-normal-2018-hurricane-season-in-central-pacific; and NHC, "Tropical Cyclone Climatology: Central Pacific Climatology," at https://www.nhc.noaa.gov/climo/#cpac.

Author Information

Eva Lipiec
Analyst in Natural Resources Policy

[196] NOAA, "NOAA Predicts a near- or above-normal 2018 hurricane season in the Central Pacific," May 23, 2018, at https://www.noaa.gov/media-release/noaa-predicts-near-or-above-normal-2018-hurricane-season-in-central-pacific.

[197] NHC, "Tropical Cyclone Climatology: Central Pacific Climatology," at https://www.nhc.noaa.gov/climo/#cpac.

Disclaimer

This document was prepared by the Congressional Research Service (CRS). CRS serves as nonpartisan shared staff to congressional committees and Members of Congress. It operates solely at the behest of and under the direction of Congress. Information in a CRS Report should not be relied upon for purposes other than public understanding of information that has been provided by CRS to Members of Congress in connection with CRS's institutional role. CRS Reports, as a work of the United States Government, are not subject to copyright protection in the United States. Any CRS Report may be reproduced and distributed in its entirety without permission from CRS. However, as a CRS Report may include copyrighted images or material from a third party, you may need to obtain the permission of the copyright holder if you wish to copy or otherwise use copyrighted material.