Reanalysis of the 1954–63 Atlantic Hurricane Seasons

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ABSTRACT

The National Hurricane Center (NHC) ''best track'' hurricane database (HURDAT2) is the main historical archive of all tropical storms, subtropical storms, and hurricanes from 1851 to the present in the North Atlantic basin, which includes the Caribbean Sea and Gulf of Mexico. The Atlantic Hurricane Reanalysis Project is an ongoing effort to maintain HURDAT2 and to provide the most accurate database possible based upon on all available data. The work reported here covers hurricane seasons from 1954 to 1963, during the early years of aircraft reconnaissance, but before satellite imagery became available routinely. All available original observations were analyzed from aircraft reconnaissance, ships, land stations, land-based radars, and satellite images. The track and intensity of each existing tropical cyclone have been reassessed, and previously unrecognized tropical cyclones have been discovered, analyzed, and recommended to the Best Track Change Committee for inclusion into HURDAT2. Changes were recommended for every storm analyzed in this 10-yr period.

1. Introduction

The goal for this project is to reanalyze the National Hurricane Center (NHC) ''best-track'' North Atlantic hurricane database (HURDAT2; Landsea and Franklin 2013) for the period 1954–63. Since the database was initially developed in the 1960s, HURDAT2 has been utilized for such purposes as ''setting appropriate building codes for coastal zones, risk assessment for emergency managers, analysis of potential losses for insurance and business interests, development of intensity forecasting techniques, verification of official and model projections of track and intensity, seasonal forecasting, and climatic change studies'' (Landsea and Franklin 2013, p. 3576; see also Landsea et al. 2008). The challenge is that HURDAT2 was not developed with these purposes in mind. Thus, the focus of the Atlantic Hurricane Reanalysis Project is to improve the accuracy and completeness of HURDAT2 through the correction of random errors and biases, by revisions where necessary, to the time of genesis or dissipation, positions, intensities,[1] central pressures, and status[2] (Office of the Federal

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[1] The highest 1-min average wind (at an elevation on 10 m with an unobstructed exposure) at a particular point in time.

[2] Status in this era is restricted to the following categories: tropical cyclone, extratropical cyclone, and tropical disturbance. A tropical cyclone is a warm-core nonfrontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. A tropical disturbance is a discrete tropical weather system of apparently organized convection, generally 100 to 300 mi in diameter, originating in the tropics or subtropics, having a nonfrontal migratory character, and maintaining its identity for 24 h or more. It may or may not be associated with a detectable perturbation of the wind field. An extratropical cyclone is a cyclone (of any intensity) for which the primary energy source is baroclinic (i.e., results from the temperature contrast between warm and cold air masses).

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Coordinator for Meteorology 2015). Some of the random errors include positions resulting from insufficient observations near the storm. Sparse observations also introduce biases in estimated intensity. For example, the intensity of hurricanes may have been significantly underestimated without ships passing close to or through the center and also without reconnaissance aircraft observations (Landsea et al. 2004). Also, in the early 1960s, the first satellite images produced by TIROS showed cloud masses that the forecasters were able to identify as tropical cyclones (United States Weather Bureau Topics 1960). However, without a technique to estimate intensity, the forecasters still had to wait for reconnaissance aircraft or ship observations to begin advisories operationally and to assess the intensity in post analysis.[3]

New data sources, such as ship reports, land-based surface weather observations, and satellite and radar images, that were not available either operationally or during a postseason assessment (''best track'' analysis) have become available. The new data allow for a better assessment of the track and intensity. One objective is the correction of U.S. hurricane landfall characteristics, because many landfall intensities are inaccurate and inconsistencies often exist between the last intensity record before landfall and the assigned Saffir–Simpson category (Landsea et al. 2008). Moreover, some tropical cyclones that existed were not included in the original HURDAT2 because of the lack of data over the open Atlantic or because they were considered to have been extratropical. Also, advancements in the understanding of tropical cyclones, such as the Brown et al. (2006) pressure–wind relationship, and better analysis techniques, such as the Franklin et al. (2003) flight level to surface wind methodology, support more accurate interpretations.

Systematic biases in the original HURDAT2 database are typically easier to detect and quantify than are random errors. For example, when the original HURDAT2 was developed, the position and intensity of the tropical cyclones was estimated only once daily and then interpolated to 6-hourly intervals (Landsea et al. 2008). This caused many errors, including a systematic but artificial apparent weakening before landfall. Another problem was that many tropical cyclones showed unrealistic accelerations or decelerations at the beginnings or the ends of their tracks when the original hand-drawn track maps were digitized in the 1960s. For example, the position in the track of tropical cyclones was assumed to be the point in the arrow at the end of the track and not the center position of the arrow, leading to unrealistic acceleration at the last point. In other cases, the analysis did not follow storms until dissipation after extratropical transition (such as Carla in 1958, Anna in 1961, and Debbie in 1961).

2. Data sources and methodology

The primary objective is the reassessment of previous tracks, intensities, and classifications of tropical cyclones as well as finding previously unknown tropical cyclones. Many of the data sources used in this paper are similar to those used in previous HURDAT2 reanalyses, as described in Hagen et al. (2012). They include historical weather maps, microfilm of original hand-plotted surface weather maps used by hurricane forecasters at the Miami Weather Bureau Office (lead hurricane forecasting agency for the United States in the 1950s and early 1960s), the Comprehensive Ocean–Atmosphere Dataset (COADS; Woodruff et al. 1987), *Monthly Weather Review*, Connor (1956), *Annual Tropical Storm Reports* of the Navy Hurricane Hunter aircraft reconnaissance missions by the U.S. Fleet Weather Facility (1954–63), climatological data reports, and synoptic observations from stations in the United States, Caribbean islands, Mexico, Bermuda, and Canada available from NOAA's Environmental Document Access and Display System, version 2 (EV2) website (https://www.ncdc.noaa.gov/EdadsV2/).

Moreover, new data sources became available during the period of 1954–63. The *Mariners Weather Log* (*MWL*), put out by the United States Weather Bureau, began publication in 1957. The *MWL* catalogs ship reports of winds at least 35 kt (1 kt = 0.51 m s^{-1}) during each month, and also includes summaries of the tropical cyclones and other low pressure systems and their tracks. Data in the *MWL* sometimes reveal important observations that were not available from other sources, including satellite images in the publications starting in 1961. These data complement the information available from the other sources.

Figure 1 provides an example of the revolutionary advance for the reanalysis project provided by weather satellites beginning in the early 1960s, starting with the TIROS program. For the first time, it became possible to

[3] Hurricane Esther in 1961 is an excellent example of this. The satellite images showed a well-organized system over the eastern Atlantic, resembling a tropical storm, but it was not until reconnaissance aircraft investigated the cyclone a couple days later that advisories started being issued. Without the data from ships or reconnaissance aircrafts, there was not a method to estimate the organization state of disturbances and the intensities, or to know their location in some cases, especially before satellite images. By the 1970s (outside of the scope of this paper), the methodology had changed. Interpretation of satellite images allowed for estimate of the position, intensity, and forward speed of tropical cyclones.

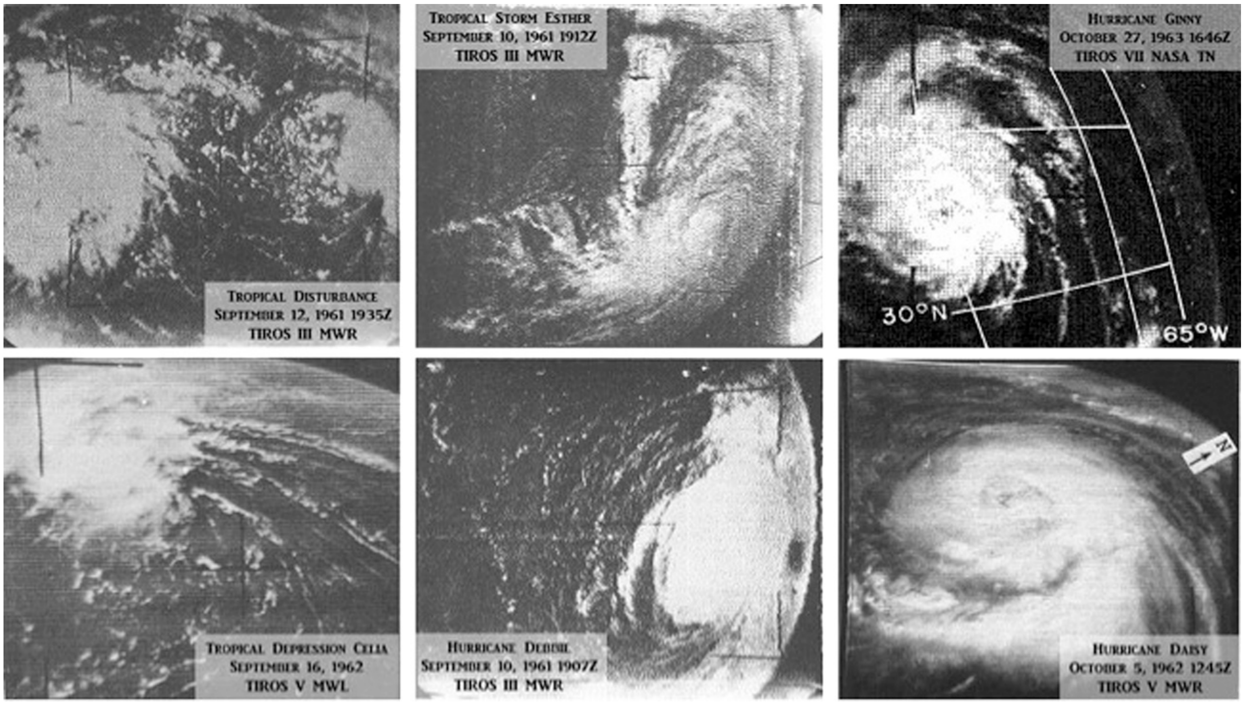

FIG. 1. Satellite images captured by NASA's Television Infrared Observation Satellite Program (TIROS) between 1961 and 1963 showing many tropical systems at different stages of development and organization. The availability of the satellite images was once per day and the quality was generally poor compared with today's standards.

visually assess the convective organizational state of the tropical cyclones. Visible satellite images captured all types of tropical cyclones, from tropical disturbances to hurricanes. Images can show that vertical shear is affecting a storm or that a well-defined eye has developed. Unfortunately, unlike today, with geostationary satellite images available as often as 1–2 min, the polar-orbiting satellites in the early 1960s typically provided images about once per day. Furthermore, the quality of the visible images were generally too poor to allow for Dvorak intensity estimates (Velden et al. 2006). The latitudes and longitudes added manually to the satellite images were not accurate enough to justify changing cyclone positions.

Another advancement during this decade was the development of the coastal weather radar network (Fig. 2), allowing for better tracking of tropical cyclones as they approached the U.S. coast. The first high-powered radar station of the United States Weather Bureau was installed on Cape Hatteras, North Carolina, on 1 August 1955 (United States Weather Bureau Topics 1955). This radar allowed for the detection to ranges of 250 nautical miles (n mi; 1 n mi = 1.852 km). The first hurricane to be tracked with this radar was Connie in August 1955. The radar was also instrumental in tracking Hurricanes Diane and Ione, which also hit North Carolina in 1955. Photos taken at Hatteras were sent in near–real time via radio facsimile to the forecast center at Washington. The next Weather Bureau radar was installed at San Juan, Puerto Rico, in July 1956. This radar tracked Hurricane Betsy as it hit the island in August 1956 (United States Weather Bureau 1956).

In 1961, radar data were instrumental for adding into HURDAT2 for the first time an unnamed tropical storm after the hurricane season (Fay 1962). The September disturbance was becoming organized ahead of a frontal boundary as the cyclone made landfall in North Carolina. Radar images indicated that it was a tropical storm and the Weather Bureau assigned that status after the season.

Starting in 1957, research flights associated with the National Hurricane Research Project (Gray and Shea 1976) increased the aircraft missions penetrating to the centers of tropical cyclones. The research flights were typically limited to hurricanes, but they provided data on the central pressure, location to the nearest degree latitude/longitude, radius of maximum winds, and estimates of the surface and flight-level winds. Navy and Air Force reconnaissance aircraft performed day and night center penetrations of tropical cyclones, even in major hurricanes. This resulted in a great increase in data from the cores of tropical cyclones, since in the 1940s and early 1950s flights had been limited to daylight missions in systems weaker than a major hurricane (Hagen et al.

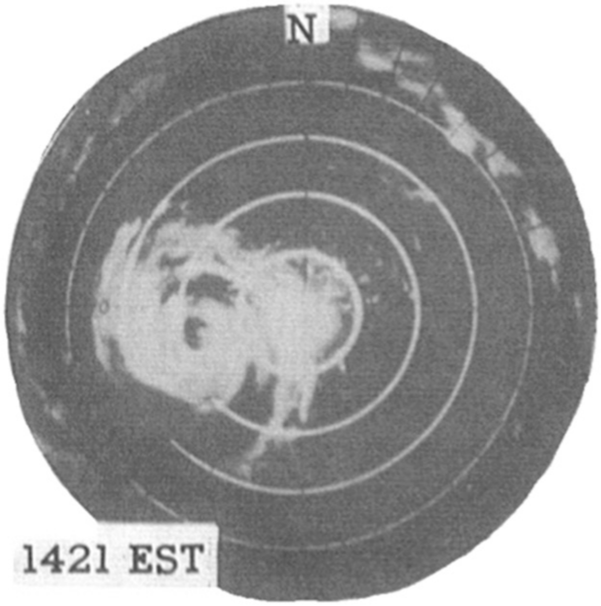

FIG. 2. Radar image of Hurricane Connie, 1955, west-southwest of Cape Hatteras, NC. The rings are 50 n mi. (United States Weather Bureau Topics 1955).

2012). However, the standard operating procedure for the Navy remained not to penetrate hurricanes with eyes less than around 10 to 20 n mi in diameter (J. Pavone 2014, personal communication), since these hurricanes were typically extremely intense, category 4 or 5 on the Saffir–Simpson Hurricane Wind Scale. The resulting lack of in situ winds and pressures suggests that the intensity of these extreme hurricanes will, like those during the 1940s and early 1950s, remain significantly underestimated (Hagen and Landsea 2012).

Reconnaissance aircraft started being used to investigate disturbances in 1954 (United States Fleet Weather Facility 1954). Exploratory missions were flown over the tropical Atlantic between Africa and the Lesser Antilles, the Caribbean Sea, and the Gulf of Mexico, when there was the suspicion that a tropical cyclone might be developing, generally based on ship or commercial airliner reports (Fig. 3; United States Fleet Weather Facility 1960). The additional data during this decade allowed for a more complete assessment of the intensities and center positions of tropical cyclones. Note that these routine missions, however, did not cover the central subtropical North Atlantic or eastern tropical North Atlantic. Thus tropical cyclones even up to major hurricane intensity in these regions could have been underanalyzed in intensity or even missed completely.

Many maximum wind observations obtained by the reconnaissance aircraft in this era were overestimates (Hagen et al. 2012). In the 1950s and 1960s, reconnaissance aircraft were not able to measure surface winds directly. The flight aerologists made visual estimates of the surface winds based upon the appearance of the sea state, which were mostly uncalibrated beyond about 70 kt of wind. They were, however, able to measure the minimum sea level pressure by extrapolation or dropsonde. Modern pressure–wind relationships using quantitative, physically based methods allow us to improve estimates of the maximum surface winds. Sometimes the central pressures yield maximum wind speeds of 20 to even 50 kt less [according to the Brown et al. (2006) pressure–wind relationships] than the estimated maximum wind speed provided by the flight aerologist. The use of pressure–wind relationships in the reanalysis also takes into account factors such as size, latitude, translational velocity, and environmental pressure that affect the simple relationship between central pressure and maximum wind. Pressure–wind relationships increase in uncertainty in circumstances when there is an eyewall replacement cycle underway (Kossin 2015). [The semiquantatitively measured flight-level winds of the era were not accurate in areas of heavy precipitation and thus were not of use in the reanalysis. See Hagen et al. (2012) for more details.]

Another advancement in the mid-1950s and early 1960s was the development of pressure–wind relationships. Fletcher (1955) and later Kraft (1961) developed similar pressure–wind relationships based on the estimated intensity and measured central pressure of well-known tropical cyclones in the Atlantic and the northwest Pacific. This was a step forward in tackling the problem of the large uncertainty and general overestimation of the maximum surface winds of tropical cyclones during reconnaissance missions, which often ended up in the best-track intensities of hurricanes in the 1940s, 1950s, and 1960s (Landsea 1993).

A thorough search of all available observations was conducted to determine if there were any tropical cyclones that occurred that were not originally listed in HURDAT2. For inclusion in HURDAT2, these tropical cyclones must have produced winds of tropical-storm force (34 kt) or greater. All potential cyclones (called ''suspects'') are investigated for each season. The search also extends to the months outside the official hurricane season, which runs from June to November. Usually, the suspects were tropical waves/troughs or occluding baroclinic cyclones that never officially became tropical cyclones. However, up to five previously unrecognized systems qualified as tropical cyclones of tropical storm strength each year. Their tracks, positions, and intensities are catalogued every 6 h and presented to the HURDAT2 Best Track Change Committee (BTCC) for potential

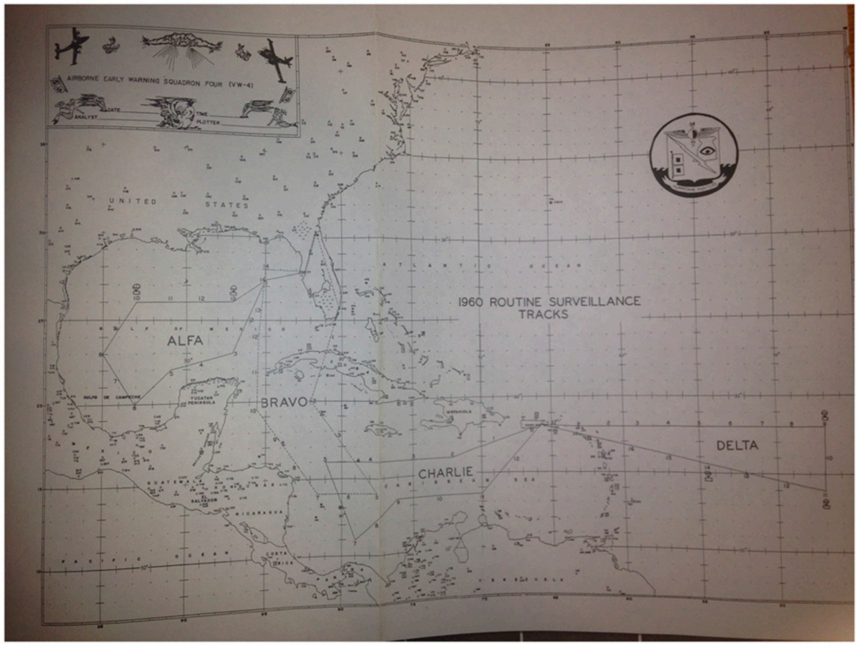

FIG. 3. Routine surveillance tracks of the Navy Reconnaissance Aircraft (United States Fleet Weather Facility 1960).

inclusion to HURDAT. For the suspects in the early 1960s, the first satellite images are only somewhat helpful in identifying potential tropical cyclones and understanding their structure due to the poor quality of the images and limited availability.

A total of 11 tropical cyclones are listed as unnamed tropical storms in the original HURDAT2 between 1954 and 1963. Unnamed tropical cyclones were systems that were not considered tropical storms operationally during the hurricane season but their existence was known by the forecasters. The observations needed for their inclusion to HURDAT2 after the end of the season often arrived well after the storm had dissipated in the form of a ship report, station observations, and/or radar images.

3. Track and intensity uncertainty estimates

The position uncertainty, intensity uncertainty, and intensity bias were subjectively estimated for the decade of 1954–63 (Tables 1–3). These values can be compared against those determined by Landsea et al. (2008, 2012, 2014) for the period of 1851–1943, Hagen et al. (2012) for the decade of 1944–53, and Landsea and Franklin (2013) for the late 1990s to late 2000s. For position estimates (Table 1), the increase in data—particularly radar imagery near the U.S. coast, better aircraft navigation, and more frequent ship observations—during the decade of 1954–63 allowed for a better assessment for U.S. landfalling tropical cyclones and also for storms far from land, even without data from reconnaissance aircraft. During this decade, the number of systems monitored by aircraft reconnaissance increased largely due to the National Hurricane Research Project and in part by increased nighttime missions into the tropical cyclones. However, the uncertainty in intensity (Table 2) and the biases in the intensity (Table 3) likely did not change. It is important to point out that the large intensity bias identified in Landsea (1993) for the early reconnaissance era (1940s to 1960s) HURDAT2 has now been corrected through 1963 when aircraft (or other) central pressures are available (Table 3).

4. Results

a. Overall activity

The reanalysis yield changes to the number of tropical storms, hurricanes, and major hurricanes for each year in the period of 1954–63, as detailed in the online supplemental material. The changes to the number of tropical storms are also shown in Fig. 4, hurricanes in Fig. 5, and major hurricanes in Fig. 6. Twenty tropical cyclones, previously unknown to HURDAT2, were added, increasing the overall total of tropical cyclones in the reanalyzed period from 92 to 112, by 2.0 per year. Out of the additional 20 tropical cyclones, only one (in 1962) was analyzed to have reached hurricane intensity and 11 developed over the northwestern Atlantic. This

TABLE 1. Estimates of the position uncertainty (mean absolute error) in the revised HURDAT2 for the years 1954–63 (in bold) in comparison to other periods. (Hagen et al. 2012; Landsea et al. 2008, 2012, 2014; Landsea and Franklin 2013). Here and in the following tables "N/A" means "not applicable."

Years	U.S. landfalling	Open ocean with aircraft	Open ocean without aircraft (or landfall along unpopulated coastline)
1851–85	60 n mi	N/A	120 n mi
1886–1943	60 n mi	N/A	100 n mi
1944–53	20 n mi	35 n mi	80 n mi
1954–63	**15 n mi**	**30 n mi**	**60 n mi**
Late 1990s–late 2000s	12 n mi	12 n mi	25 n mi

change is due in part to the more frequent ship traffic there compared to the rest of the tropical and subtropical Atlantic Ocean. Many of the 11 new systems in the northwestern Atlantic were likely hybrids,[4] which were not typically "named" as tropical storms during the 1950s and 1960s.[5] Hybrids are systems that develop from nontropical origins, such as frontal boundaries and cold-core lows. Over warm waters, these cyclones acquire some tropical characteristics and may become subtropical cyclones, but they still retain some nontropical characteristics from their extratropical past, such as a wind field larger than average. In the past, without satellite images, it would have been difficult to assess the transition of these systems, and thus many were originally considered extratropical cyclones. Observations over the central and eastern Atlantic remained sparse during this decade, suggesting that some tropical cyclones could have occurred even after this reanalysis but were not observed (Vecchi and Knutson 2008). The number of analyzed hurricanes decreased from 60 to 59, and the number of major hurricane decreased from 31 to 25. Likewise, the accumulated cyclone energy (ACE[6]) dropped from 110 to 101. The primary reason for the decrease in these quantities is that the original HURDAT2 placed too much emphasis on the unreliable visual estimates of surface winds from the reconnaissance aircraft (Landsea 1993; Hagen et al. 2012). The ACE decreased in every year analyzed except for 1956, 1959, and 1962, as shown in Fig. 7. None of the tropical cyclones originally in HURDAT2 for these seasons was removed, although occasionally cyclones have been taken out of HURDAT2 in earlier seasons if they were now judged to have not had tropical cyclone characteristics or had not reached tropical storm intensity. Figure 8a shows the revised track map and Fig. 8b shows the comparison track map for the 1954 hurricane season. The underlying blue tracks in Fig. 8b show the original tracks. Table 4 shows the revisions for the 1954 hurricane season. (Track maps and details of the revisions for the 1955 to 1963 seasons appear in the online supplemental material.)

b. *Continental U.S. tropical storms and hurricanes*

Table 5 lists all hurricanes that either made landfall (center crossed the coast) or bypassing storms that produced hurricane-force winds in the continental United States. A total of 14 hurricanes struck the United States during 1954–63, compared to 16 originally in HURDAT2. In comparison, the average number of hurricane landfalls per decade between 1851 and 2010 was 17.8 (Blake et al. 2011). Of the 14 hurricanes reanalyzed here, 7 were major hurricanes, compared with the long-term average of 6.0. Table 6 lists all tropical storms that made landfall or produced tropical-storm-force winds in the continental United States. The analyzed number of tropical storms that struck the United States between 1954 and 1963 was 29, of which 4 are new tropical cyclones.

Table 7 shows the changes in Saffir–Simpson category for hurricanes that made landfall or produced sustained hurricane-force winds in the United States. In total, 16 systems were originally analyzed in HURDAT2 to have affected the United States between 1954 and 1963 as hurricanes. The reanalysis indicates that both Diane in 1959 and Cindy in 1963 had only tropical-storm-force winds when they made landfall. Furthermore, changes were made to the intensities of many landfalling hurricanes. Of the 14 remaining hurricanes, five had their peak U.S. intensity decreased one category, one had its intensity increased one category, and eight retained their original intensities. The most significant year reanalyzed for hurricane landfalls in the United States was 1954, with originally three major hurricanes on the East Coast: Carol and Edna as category 3 hurricanes and Hazel as a category 4 hurricane. While Carol and Hazel were maintained with their original assessment, Edna was

[4] Cyclones with characteristics of both tropical and extratropical cyclones, sometimes also called "subtropical cyclones."

[5] The status of "subtropical cyclone" for many of these systems would likely be the most appropriate, if such a definition could be used. However, without routine satellite imagery available to confirm an asymmetric structure of the deep convection, among other factors, officially these systems will be considered to be "tropical cyclones." Such ambiguity will be noted though, where appropriate, in the individual system metadata description.

[6] An index that combines the numbers of systems, how long they existed, and how intense they became. It is calculated by squaring the maximum sustained surface wind in the system every six hours that the cyclone is a tropical storm or hurricane and summing it up for the season. It is expressed in 10^4 kt^2.

TABLE 2. Estimates of the intensity uncertainty (mean absolute error) in the revised HURDAT2 for the years 1954–63 (in bold) in comparison to other periods. (Hagen et al. 2012; Landsea et al. 2008, 2012, 2014).

Years	U.S. landfalling	Open ocean with aircraft, central pressures	Open ocean with aircraft, no central pressures	Open ocean without aircraft (or landfall along unpopulated coastline)
1851–85	15 kt	N/A	N/A	25 kt
1886–1943	15 kt	N/A	N/A	20 kt
1944–53	11 kt	13 kt	17 kt	20 kt
1954–63	**11 kt**	**13 kt**	**17 kt**	**20 kt**
Late 1990s	10 kt	12 kt	N/A	15 kt
Late 2000s	9 kt	10 kt	N/A	12 kt

downgraded to a category 2 hurricane at U.S. landfall. 1955 was also very significant for the United States with three hurricane landfalls, two of which (Connie and Ione) were originally analyzed at category 3. In the reanalysis, both were revised downward to category 2 at U.S. landfall. Five hurricanes—Hazel (1954), Audrey (1957), Gracie (1959), Donna (1960), and Carla (1961)—were originally assessed as category 4 at U.S. landfall and no category 5 hurricanes struck during this decade. After revision, four of the five were retained as category 4 hurricanes: Donna and Carla at 125 kt, and Gracie and Hazel at 115 kt. Audrey was instead reanalyzed to be a category 3 at landfall with 110 kt. Further details of these tropical cyclones are described below.

Hurricane Hazel developed from a tropical wave in early October 1954, just east of the Lesser Antilles. The tropical cyclone gradually intensified on the 12th and made landfall in Haiti as a category 3 hurricane. On the 13th, Hazel crossed the central Bahamas as a category 2 hurricane. The next day it became a major hurricane again and on the 15th reached South Carolina, causing immense damages. A ship reported a central pressure of 938 mb at 1530 UTC on the 15th, around landfall. Wind observations from Myrtle Beach indicate a radius of maximum wind (RMW) about about 20 n mi, while the climatological value is 23 n mi for this central pressure and a landfall latitude of 34°N (Vickery et al. 2009). A central pressure of 938 mb suggests maximum sustained winds of 116 kt from the north of 25°N per the Brown et al. (2006) pressure–wind relationship, which is stratified by latitude. Based on a fast forward speed of about 25 kt and a near-average RMW but low (1008 mb) environmental pressures, the analyzed intensity at landfall is 115 kt, up from 110 kt originally shown in HURDAT2. After landfall, the hurricane lost its tropical characteristics and became a strong extratropical cyclone. On the 16th, Hazel produced extreme rains over eastern Canada, causing over 80 deaths and widespread damages. The system continued northward and dissipated on the 18th.

Hurricane Audrey developed in the Gulf of Mexico in late June 1957. The tropical cyclone rapidly intensified to a hurricane on the 25th while slowly moving northward. Early on the 27th it became a major hurricane and made landfall a few hours later near the Texas–Louisiana border. Audrey was originally analyzed as a category 4 at landfall, but it is now reanalyzed as a category 3. Surface observations at the time of landfall supported a 946-mb central pressure at landfall, which was used to estimate maximum sustained winds of 110 kt (down from 125 kt originally shown in HURDAT2), taking into account the forward speed of the hurricane of about 14 kt, radius of maximum winds of about 15 n mi, and environmental pressure of 1003 mb. After moving over land, Audrey weakened and was absorbed

TABLE 3. Estimated average intensity error bias in the revised best track for the years 1954–63 (in bold) in comparison to other periods. (Hagen et al. 2012, Landsea et al. 2008, 2012, 2014).

Year	U.S. landfalling (populated coastline)	Open ocean with aircraft, central pressures	Open ocean with aircraft, no central pressures (30–60 kt)	Open ocean with aircraft, no central pressures (65–95 kt)	Open ocean with aircraft, no central pressures (100–115 kt)	Open ocean with aircraft, no central pressure (120+ kt)	Open ocean with no aircraft
1851–85	0 kt	N/A	N/A	N/A	N/A	N/A	−15 kt
1886–1943	0 kt	N/A	N/A	N/A	N/A	N/A	−10 kt
1944–53	0 kt	0 kt	+3 kt	+5 kt	0 kt	−10 kt	−10 kt
1954–63	**0 kt**	**0 kt**	**+3 kt**	**+5 kt**	**0 kt**	**−10 kt**	**−10 kt**
Late 1990s–2000s	0 kt	0 kt	N/A	N/A	N/A	N/A	0 kt

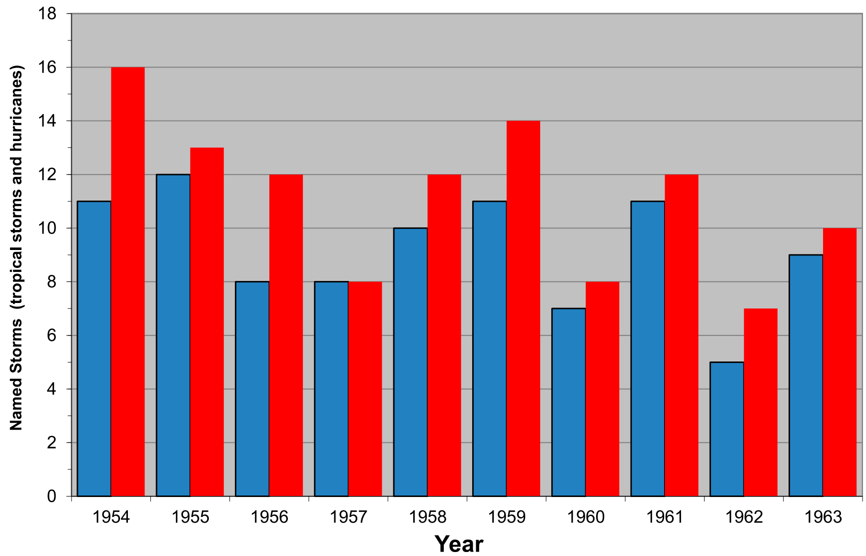

FIG. 4. Comparison between the original (blue) and revised (red) number of named storms (tropical storm and hurricanes) for the 1954–63 hurricane seasons.

by a large extratropical cyclone over the Great Lakes on the 29th.

Hurricane Gracie, also a late-season tropical cyclone in 1959, developed over the Bahamas. Early in its life, it encountered weak steering currents and meandered just north of the islands. On 27 October, a ridge of high pressure intensified to the north and forced Gracie to take a northwestward track toward the United States. The system intensified under conducive conditions and a reconnaissance aircraft measured a central pressure of 951 mb just before landfall in South Carolina on the 29th. A central pressure of 951 mb suggests maximum sustained winds of 109 kt from the intensifying subset of the north of 25°N pressure–wind relationship. Based on an RMW of about 10 n mi, which is substantially smaller than the climatological value of 23 n mi (Kimball and Mulekar 2004), a forward speed of about 13 kt, and near-average environmental pressure of 1013 mb, an intensity of 115 kt is analyzed at landfall at 1700 UTC on the 29th, down from 120 kt originally in HURDAT2.

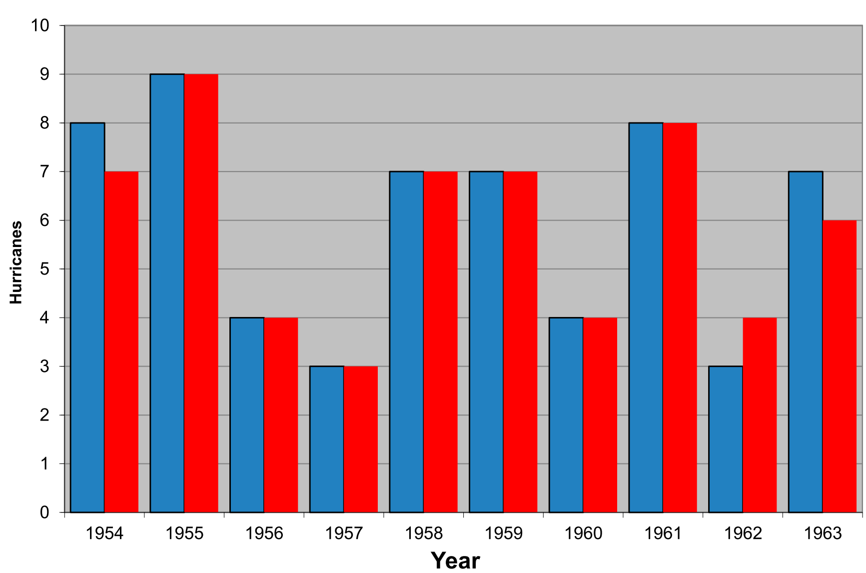

FIG. 5. Comparison between the original (blue) and revised (red) number of hurricanes for the 1954–63 hurricane seasons.

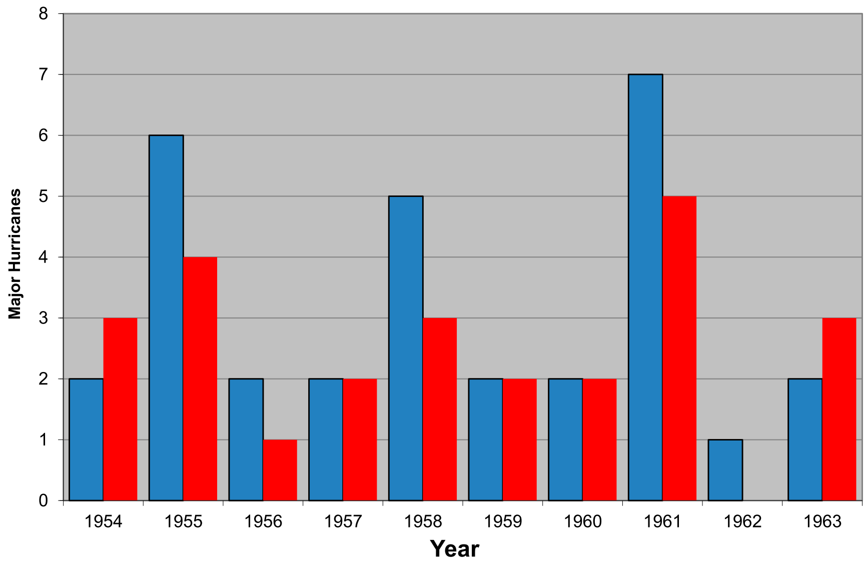

FIG. 6. Comparison between the original (blue) and revised (red) number of major hurricanes for the 1954–63 hurricane seasons.

After landfall, the hurricane steadily weakened over the eastern United States.

Hurricane Donna was a long-lived Cape Verde hurricane that developed in late August 1960. The tropical cyclone reached hurricane intensity on 2 September and became a major hurricane a few days later. On 4 and 5 September, it passed over the Leeward Islands and just a few miles to the north of Puerto Rico. Later, from the 6th to the 9th, it moved across the Bahamas, remaining a major hurricane. On the 10th, as the hurricane approached the Florida Keys, it intensified. A central pressure of 930 mb is estimated at landfall based upon observed of 933 mb at Conch Key, Florida. A central pressure of 930 mb suggests maximum sustained winds of 132 kt from the intensifying subset of the south of 25°N pressure–wind relationship and 129 kt from the intensifying subset of the north of 25°N pressure–wind relationship (as the system was straddling the 25°N latitude). At this time, the RMW was about 20 n mi according to reconnaissance aircraft and radar data, and

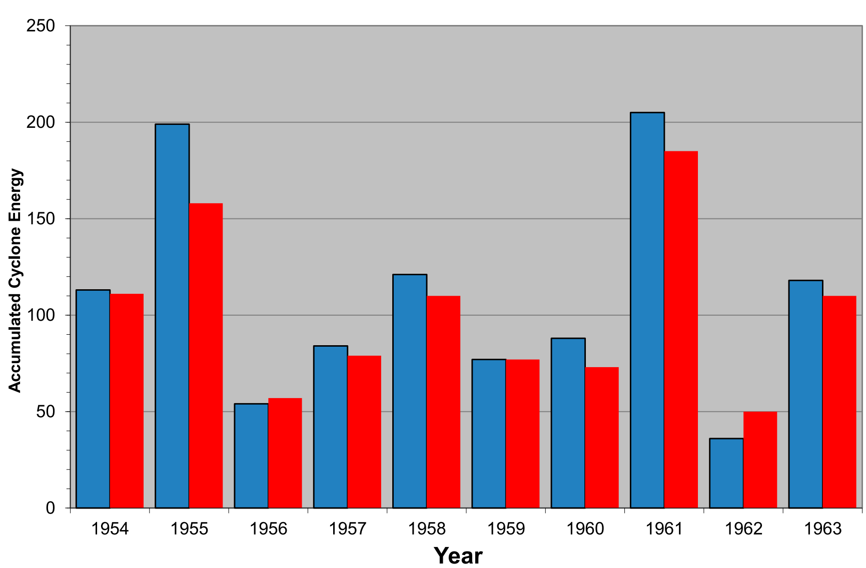

FIG. 7. Comparison between the original (blue) and revised (red) ACE values for the 1954–63 hurricane seasons.

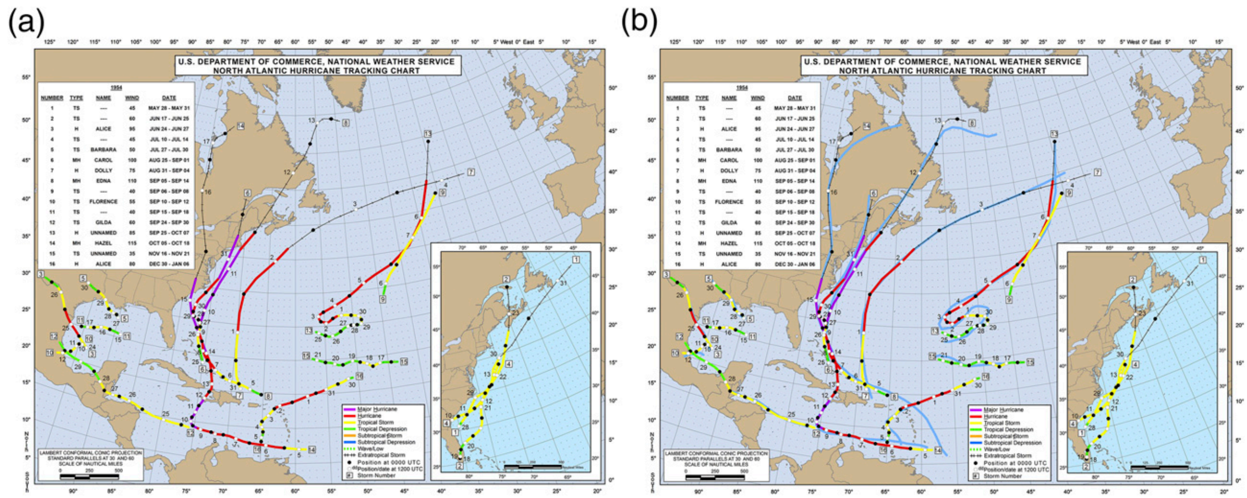

FIG. 8. (a) 1954 revised and (b) comparison track maps. Faded blue lines correspond to the original HURDAT2 tracks. Storms number 1, 2, 4, 9, and 11 are newly added to HURDAT2.

the climatological value was 15 n mi. The forward speed had decreased to about 9 kt and the environmental pressures were low (1009-mb outer closed isobar), both of which suggest a lower intensity than the standard pressure–wind relationship. Thus, the analyzed intensity at landfall in the Florida Keys is 125 kt, higher than the 115 kt originally in HURDAT2. Donna weakened as it turned to the northwest making a landfall in southwest Florida at 1600 UTC on the 10th with maximum sustained winds of 105 kt. During the next few days, the hurricane accelerated to the northeast, making landfall in North Carolina on the 12th with maximum sustained winds of 90 kt. Later on that day, Donna made landfall again, this time in Long Island, New York, with maximum sustained winds of 85 kt. The hurricane became extratropical on the 13th and was absorbed by a stronger extratropical cyclone on the 14th near Greenland.

Hurricane Carla developed from a tropical wave in the central Caribbean Sea in early September 1961. The tropical cyclone moved northwestward and became a

TABLE 4. Revisions for the 1954 hurricane season. Major track changes are defined by latitude/longitude changes of greater than 1.0° and major intensity changes of 15 kt or more from the original HURDAT2 values.

Name	Date	Original peak intensity (kt)	Revised peak intensity (kt)	Track change	Intensity change	Genesis/decay change
Unnamed (new)	28–31 May	—	45	—	—	—
Unnamed (new)	17–25 Jun	—	60	—	—	—
Alice	24–27 Jun	70	95	Minor	Major	Decay 12 h later
Unnamed (new)	10–14 Jul	—	45	—	—	—
Barbara	27–30 Jul	40	50	Minor	Major	Genesis 6 h later, decay 6 h earlier
Carol	25 Aug–1 Sep	85	100	Minor	Major	No change
Dolly	31 Aug–4 Sep	85	75	Minor	Major	Genesis 6 h later, decay 6 h later
Edna	5–14 Sep	105	110	Major	Major	Genesis 66 h later, decay 24 h earlier
Unnamed (new)	6–8 Sep	—	40	—	—	—
Florence	10–12 Sep	65	45	Minor	Major	Genesis 12 h earlier
Unnamed (new)	15–18 Sep	—	40	—	—	—
Gilda	24–30 Sep	60	60	Minor	Minor	Decay 60 h later
Unnamed	25 Sep–7 Oct	85	85	Major	Minor	No change
Hazel	5–18 Oct	120	115	Major	Major	Decay 6 h earlier
Unnamed	16–21 Nov	45	35	Minor	Minor	No change
Alice	30 Dec–6 Jan	70	80	Major	Major	Decay 6 h earlier

TABLE 5. Continental U.S. hurricanes (1954–63). The asterisks indicate bypassing storms (not a direct landfall) where the centers of the tropical cyclones stay offshore, and the wind speeds listed are the analyzed maximum wind experienced on land in the United States (the original HURDAT2 intensity value is left blank for those cases). Original intensity indicates the value in HURDAT2 at the last synoptic time before landfall. CP: central pressure. OCI: outermost closed isobar. ROCI: radius of the outermost closed isobar. RMW: radius of the maximum sustained winds.

Date	Name	Landfall time (UTC)	Location	Lat (°N)	Lon (°W)	Original intensity (kt)	Revised intensity (kt)	Category	CP (mb)	OCI (mb)	ROCI (n mi)	RMW (n mi)
31 Aug 1954	Carol	0300	Outer Banks, NC	—	—	—	75*	1	960	1007	225	25
		1400	East Hampton, NY	40.9	72.2	85	100	3	955	1010	325	20
		1500	New London, CT	41.3	72.0	85	100	3	957	1010	325	20
11 Sep 1954	Edna	0300	Outer Banks, NC	—	—	—	65*	1	943	1007	375	15
		1830	Martha's Vineyard, MA	41.4	70.5	90	95	2	950	1007	375	25
		1900	Hyannis, MA	41.7	70.3	90	95	2	952	1007	375	25
		1930	Wellfleet, MA	41.9	70.1	70	90	2	954	1007	375	25
15 Oct 1954	Hazel	1530	Sunset Beach, NC	33.9	78.6	110	115	4	938	1008	475	20
12 Aug 1955	Connie	1500	Morehead City, NC	34.7	76.7	70	85	2	962	1011	425	30
17 Aug 1955	Diane	1200	Carolina Beach, NC	34.0	77.9	75	60	TS	985	1011	400	40
19 Sep 1955	Ione	1100	Morehead City, NC	34.7	76.7	90	90	2	955	1013	375	25
24 Sep 1956	Flossy	1000	Mississippi delta, LA	29.1	89.4	80	75	1	980	1010	300	20
25 Sep 1956		0000	Destin, FL	30.4	86.4	65	75	1	974	1010	300	20
27 Jun 1957	Audrey	1330	Near TX/LA border	29.8	93.7	125	110	3	946	1003	200	15
27 Sep 1958	Helene	1800	Cape Lookout, NC	—	—	—	110*	3	938	1007	275	20
9 Jul 1959	Cindy	0400	Mt. Pleasant, SC	33.0	79.8	65	65	1	995	1017	125	20
25 Jul 1959	Debra	0500	Jamaica Beach, TX	29.1	95.2	75	75	1	980	1012	150	20
29 Sep 1959	Gracie	1700	Edisto Beach, SC	32.5	80.4	120	115	4	951	1013	300	10
10 Oct 1960	Donna	0700	Central Florida Keys	24.8	80.9	115	125	4	930	1009	250	20
10 Oct 1960		1600	Marco Island, FL	25.9	81.6	120	105	3	942	1009	300	20
12 Oct 1960		0400	Sneads Ferry, NC	34.6	77.3	95	90	2	958	1008	350	50
12 Oct 1960		1900	Brookhaven, NY	40.7	72.9	90	85	2	959	1004	350	50
12 Oct 1960		2000	Old Saybrook, CT	41.3	72.4	90	80	1	962	1004	350	50
15 Sep 1960	Ethel	2100	Gulfport, MS	30.4	89.0	80	70	1	980	1013	150	20
11 Sep 1961	Carla	2000	Matagorda Island, TX	28.3	96.4	125	125	4	931	1007	275	20
1962	None	—	—	—	—	—	—	—	—	—	—	—
17 Sep 1963	Cindy	1400	High Island, TX	29.6	94.3	65	55	TS	997	1014	150	—

TABLE 6. Continental U.S. tropical storms (1954–63). The asterisks indicate bypassing storms (not a direct landfall) where the centers of the tropical cyclones stay offshore, or landfall in Mexico but producing tropical storm force winds in the United States. The wind speed value listed is the analyzed maximum wind experienced on land in the United States (the original HURDAT2 intensity value is left blank for those cases). Debbie (1957) was removed as it is analyzed that it was an extratropical cyclone at landfall.

Date	Name	Landfall time (UTC)	Location	Lat (°N)	Lon (°W)	Original Intensity (kt)	Revised Intensity (kt)
25 Jun 1954	Alicia	1400	Texas	25.0	97.6	—	60*
29 Jul 1954	Barbara	1000	Louisiana	29.7	92.8	35	50
1 Aug 1955	Brenda	1700	Louisiana	29.7	89.4	60	55
17 Aug 1955	Diane	1200	North Carolina	34.0	77.9	75	60
27 Aug 1955	Unnamed	0400	Louisiana	30.0	89.2	40	45
13 Jun 1956	Unnamed	1700	Louisiana	29.1	90.7	50	50
15 Oct 1956	Unnamed	2100	Florida	25.2	80.6	—	50
1 May 1957	Unnamed	1400	Louisiana	29.7	93.0	—	35
9 Jun 1957	Unnamed	0030	Florida	30.1	84.2	35	45
10 Aug 1957	Bertha	0600	Texas	29.7	93.9	45	55
8 Sep 1957	Debbie	1700	Florida	30.3	86.1	35	35
18 Sep 1957	Esther	1200	Louisiana	29.2	90.9	45	55
15 Jun 1958	Alma	0800	Texas	24.4	97.7	—	35*
6 Sep 1958	Ella	0600	Texas	27.5	97.2	40	50
30 May 1959	Arlene	2300	Louisiana	29.6	91.6	40	55
18 Jun 1959	Unnamed	0800	Florida	28.0	82.8	30	40
11 Jul 1959	Cindy	1200	Massachusetts	41.7	70.7	50	50
8 Oct 1959	Irene	1000	Alabama	30.3	87.6	45	40
18 Oct 1959	Judith	1400	Florida	26.7	82.3	45	55
24 Jun 1960	Unnamed	0400	Texas	26.9	97.4	40	50
29 Jul 1960	Brenda	0600	Florida	29.7	83.5	30	35
29 Jul 1960		2100	North Carolina	33.9	78.2	45	55
14 Sep 1961	Unnamed	1200	North Carolina	34.4	77.6	35	40
14 Sep 1961		2100	Virginia	37.1	76.0	35	45
15 Sep 1961		0600	New York	40.7	73.2	35	55
15 Sep 1961		0700	Connecticut	41.3	72.7	35	55
26 Sep 1961	Esther	0500	Massachusetts	41.3	70.3	40	50
26 Sep 1961		0600	Massachusetts	41.7	70.2	35	50
26 Sep 1961		1100	Maine	43.8	69.9	35	35
30 Jun 1962	Unnamed	2100	North Carolina	35.2	75.8	—	55
28 Aug 1962	Alma	1100	North Carolina	35.0	75.1	—	40*
1 Dec 1962	Unnamed	1800	North Carolina	33.7	74.3	—	40*
3 Jun 1963	Unnamed	0800	North Carolina	35.2	75.8	—	50
17 Sep 1963	Cindy	1400	Texas	29.6	94.3	65	55
26 Oct 1963	Ginny	0600	North Carolina	33.1	76.9	—	55*
29 Oct 1963	Ginny	0600	Massachusetts	38.1	68.8	—	35*

hurricane on the 6th, east of the Yucatan Peninsula. On the 7th, it crossed the Yucatan Channel and moved into the Gulf of Mexico where it continued northwestward, reaching major hurricane intensity early on the 8th. The hurricane made landfall in Texas late on the 11th with an estimated central pressure of 931 mb, suggesting maximum sustained winds of 123 kt from the north of 25°N pressure–wind relationship. Based on an RMW of 20 n mi (near the climatological average of 17 n mi), an intensity of 125 kt was analyzed at 2000 UTC on 11 September, unchanged from HURDAT2. After landfall, Carla steadily weakened and became extratropical on the 13th over Oklahoma. The system moved northeastward and dissipated early on the 16th over northern Canada.

c. Hurricane impacts outside the continental United States

Table 8 lists all hurricanes and tropical storms that made landfall outside the continental United States between 1954 and 1963. A few other tropical cyclones may have produced tropical storm or hurricane-force winds to the Caribbean islands, Mexico, Central America, or Bermuda but did not make landfall with the cyclone's wind center crossing a coastline. These cyclones are not included in this list.

The most intense hurricane was Hurricane Janet in 1955, which made landfall as a category 5 hurricane on Swan Island and the Yucatan Peninsula of Mexico. Chetumal, Mexico, measured a central pressure of

TABLE 7. Original vs revised hurricane impacts for U.S. states by Saffir–Simpson category (1944–53). ATX: south Texas; BTX: central Texas; CTX: north Texas; LA: Louisiana; MS: Mississippi; AL: Alabama; AFL: northwest Florida; BFL: southwest Florida; CFL: southeast Florida; DFL: northeast Florida; GA: Georgia; SC: South Carolina; NC: North Carolina; VA: Virginia; NJ: New Jersey; NY: New York; CT: Connecticut; RI: Rhode Island; MA: Massachusetts; and ME: Maine. Boldface means the intensity was increased and italics that it was decreased. Increases (decreases) to maximum U.S. landfall category are indicated in boldface (italics).

Year	Name	Original	Revised	Changes
1954	Carol	NY3 CT3 RI3 NC2	NY3 CT3 RI3 **MA2** *NC1*	NC −1, add MA2
1954	Edna	MA3 ME1	**NC1** *MA2* **NY1** RI1	Add NC1, NY1, RI1, MA −1, Remove ME1
1954	Hazel	SC4 NC4 MD2	SC4 NC4	Remove MD2
1955	Connie	NC3 VA1	*NC2* VA1	NC −1
1955	Diane	NC1	*TS*	Remove NC1
1955	Ione	NC3	*NC2*	NC −1
1956	Flossy	LA2 AFL1	*LA1* AFL1	LA −1
1957	Audrey	CTX4 LA4	*CTX2 LA3*	CTX −2, LA −1
1958	Helene	NC3	NC3	None
1959	Cindy	SC1	SC1	None
1959	Debra	CTX1	CTX1	None
1959	Gracie	SC3	**SC4**	SC +1
1960	Donna	BFL4 DFL2 NC3 NY3 CT2 RI1 MA1 NH1 ME1	BFL4 **CFL4** *DFL1 NC2* **VA1** *NY2 CT1* RI1 MA1	Add CFL4, VA1, DFL −1, NC −1, NY −1, CT −1, Remove NH1, ME1
1960	Ethel	MS1	**LA1** MS1	Add LA1
1961	Carla	BTX4	BTX4 **CTX3 ATX1**	Add CTX3, ATX1
1963	Cindy	CTX1	*TS*	Remove CTX1

914 mb around 0600 UTC 28 September, suggesting sustained maximum winds of 146 kt from the intensifying subset of the Brown et al. (2006) south of 25°N pressure–wind relationship. In part because of the fast forward speed of about 20 kt, an intensity of 150 kt was analyzed at that time, the same as originally shown in HURDAT2, making Janet one of the strongest hurricanes ever at landfall. The only other known hurricanes to have made landfall along any coastline with intensity greater than or equal to Janet's were the 1935 Labor Day hurricane with 160 kt and Hurricane Camille in 1969, Hurricane David in 1979, and Hurricane Dean in 2007 with 150 kt.

The deadliest hurricane of this decade, and one of the deadliest in the recorded history of the Atlantic basin, was Hurricane Flora in 1963. This system made landfall as a major hurricane in Haiti and eastern Cuba but produced tremendous freshwater flooding, which caused most of the casualties. Flora made landfall in southwest Haiti as a category 4 hurricane with maximum sustained winds of 130 kt, and after crossing the Tiburon Peninsula, made landfall in southeast Cuba as a category 3 hurricane. These values are unchanged from original HURDAT2.

The largest revision to a landfall intensity was for Hurricane Hilda. It occurred on September 19th at 1200 UTC on 1955. Originally HURDAT2 had an intensity of 60 kt, and the reanalyzed intensity is 105 kt based on the observations from Tampico, Mexico. The eye of Hilda passed over Tampico with a central pressure of 952 mb. A central pressure of 952 mb yields 111 kt from the intensifying subset of the south of 25°N pressure–wind relationships. An intensity of 105 kt is selected for 1200 UTC on the 19th due to an RMW larger than normal based on reconnaissance aircraft data.

During 1954–63, major hurricane landfalls occurred in Haiti (2), Mexico (2), Cuba (1), Belize (1), Honduras (Swan Island; 1), and Bahamas (1). Originally Janet, in 1955, was analyzed as a major hurricane landfall in Grenada, but the reanalysis decreased the intensity from 100 kt to 90 kt. A similar downward revision was made for Hurricane Katie in 1955, which made landfall in the Dominican Republic. The intensity of Hurricane Ella in 1958 at landfall in Cuba was significantly decreased from 100 to 70 kt. Hurricane Carrie, in 1957, is analyzed to have made landfall in the Azores with an intensity of 75 kt. The original HURDAT2 indicated no landfall in the Azores. Hurricane Donna, in 1960, moved across the Bahamas, making two landfalls. Originally HURDAT2 indicated that the system was a category 4 hurricane (130 kt) at landfall but the reanalysis decreased the intensity to category 3 (105 kt). Hurricane Debbie, in 1961, was originally analyzed to have made landfall in Ireland as a category 1 hurricane, but the reanalysis concluded that it had already acquired extratropical characteristics well before Irish landfall. Nonetheless, the system was a powerful extratropical cyclone that caused hurricane-force winds and damages. Hurricane Arlene struck Bermuda in 1963 and the intensity at landfall has been increased from 75 to 95 kt.

TABLE 8. Changes to noncontinental U.S. landfalling tropical cyclones (including Puerto Rico and U.S. Virgin Islands) (1954–63). Note that the intensity is the strongest analyzed sustained wind in the cyclone, which may not be that experienced at the coast, especially for small island landfalls.

Date	Name	Landfall time (UTC)	Location	Lat (°N)	Lon (°W)	Category	Original intensity (kt)	Revised intensity (kt)
25 Jun 1954	Alice	1400	Mexico	25.0	97.6	1	70	95
12 Sep 1954	Florence	1100	Mexico	20.4	96.8	TS	65	55
27 Sep 1954	Gilda	1700	Belize	16.7	88.4	TS	60	55
6 Oct 1954	Hazel	0000	Grenada	12.2	61.6	1	75	65
12 Oct 1954		0900	Haiti	18.3	74.2	3	85	105
13 Oct 1954		0000	Haiti	19.6	73.4	2	85	85
13 Oct 1954		1400	Bahamas	21.0	73.1	2	85	85
13 Oct 1954		2300	Bahamas	22.6	73.5	2	90	85
2 Jan 1955	Alice	2100	St. Martin	18.0	63.0	1	65	65
5 Sep 1955	Gladys	2200	Mexico	23.1	97.8	1	50	65
13 Sep 1955	Hilda	2100	Cuba	20.2	74.2	1	70	70
15 Sep 1955		0300	Cayman Islands	19.3	81.2	1	75	65
16 Sep 1955		1400	Mexico	19.7	87.7	3	95	105
19 Sep 1955		1100	Mexico	22.3	97.7	3	60	105
23 Sep 1955	Janet	0000	Grenada	12.5	61.4	2	100	90
27 Sep 1955		1700	Swan Island	17.4	83.9	5	145	140
28 Sep 1955		0500	Mexico	18.4	87.8	5	150	150
29 Sep 1955		1800	Mexico	19.8	96.4	2	85	85
17 Oct 1955	Katie	0500	Dominican Republic	18.0	71.7	2	100	90
26 Jul 1956	Anna	2100	Mexico	21.7	97.5	1	70	75
11 Aug 1956	Betsy	1730	Guadeloupe	16.0	61.7	2	80	90
12 Aug 1956		1230	Puerto Rico	18.0	66.0	2	80	85
12 Sep 1956	Dora	1800	Mexico	20.9	97.3	TS	50	50
22 Sep 1957	Carrie	1600	Azores	38.7	27.3	1	70	75
15 Jun 1958	Alma	0800	Mexico	24.9	97.6	TS	35	55
1 Sep 1958	Ella	1200	Haiti	18.2	73.4	2	95	95
2 Sep 1958		0000	Cuba	20.0	76.2	1	100	70
3 Sep 1958		1100	Cuba	21.8	82.7	TS	55	55
3 Sep 1958		1700	Cuba	22.1	84.0	TS	60	60
14 Sep 1958	Gerda	2100	Dominican Republic	18.0	71.2	TS	60	50
20 Sep 1958		0800	Mexico	24.5	97.7	TS	—	40
6 Oct 1958	Janice	0300	Cuba	22.0	80.3	TS	45	50
6 Oct 1958		1600	Bahamas	24.2	78.0	TS	55	55
6 Oct 1958		2100	Bahamas	25.1	77.1	TS	60	60
6 Oct 1958		2300	Bahamas	25.5	76.8	1	60	65
18 Aug 1959	Edith	1000	Dominica	15.3	61.3	TS	50	50
10 Jul 1960	Abby	1100	St. Lucia	13.9	60.9	TS	65	55
15 Jul 1960		0600	Honduras	16.3	86.6	1	70	70
15 Jul 1960		1400	Belize	16.5	88.4	1	65	70
4 Sep 1960	Donna	2200	Barbuda	17.7	61.8	3	135	110
5 Sep 1960		0400	Sint Marrten	18.1	63.0	3	130	110
8 Sep 1960		0600	Bahamas	22.2	74.3	3	130	105
8 Sep 1960		1600	Bahamas	22.4	75.8	3	130	105
19 Sep 1960	Florence	0900	Bahamas	21.1	73.1	TS	35	35
23 Jul 1961	Anna	1200	Honduras	15.8	84.3	1	90	70
24 Jul 1961		0100	Honduras	16.1	86.9	1	85	75
24 Jul 1961		1000	Belize	16.4	88.5	1	80	75
6 Sep 1961	Debbie	1300	Cape Verde Islands	15.0	23.4	TS	—	40
1 Oct 1961	Frances	0800	Guadeloupe	16.1	61.6	TS	40	50
3 Oct 1961		0500	Dominican Republic	18.3	68.5	TS	50	45
31 Oct 1961	Hattie	1200	Belize	17.1	88.3	4	120	130
9 Aug 1963	Arlene	1530	Bermuda	32.3	64.8	2	75	95
25 Sep 1963	Edith	0700	St. Lucia	14.0	60.9	2	75	85
27 Sep 1963		1000	Dominican Republic	18.4	69.1	TS	65	60
28 Sep 1963		1800	Turks and Caicos	21.8	72.2	TS	35	35

TABLE 8. (*Continued*)

Date	Name	Landfall time (UTC)	Location	Lat (°N)	Lon (°W)	Category	Original intensity (kt)	Revised intensity (kt)
30 Sep 1963	Flora	1800	Tobago	11.2	60.7	2	105	90
4 Oct 1963		0100	Haiti	18.2	73.0	4	125	130
4 Oct 1963		1800	Cuba	20.0	74.9	3	105	105
7 Oct 1963		0000	Cuba	20.7	78.1	2	80	85
9 Oct 1963		0600	Bahamas	22.3	72.8	2	75	85
28 Oct 1963	Helena	0200	Antigua	17.0	61.8	TS	35	35
29 Oct 1963	Ginny	1730	Canada	43.8	65.8	2	90	90

5. Summary

The hurricane reanalysis is now completed through the early 1960s, when satellite imagery first became available. The decade 1954–63 averaged 11.2 tropical storms, 5.9 hurricanes, and 2.5 major hurricanes annually. This is near the current climatology (1981–2010) of 12.1, 6.4, and 2.7, respectively. However, the record remains incomplete due to lack of satellite coverage and inability of aircraft reconnaissance to cover the whole basin (Vecchi and Knutson 2008). Vecchi and Knutson (2011) estimated that about one hurricane every two years was missed from the mid-1950s to the early 1960s, either erroneously considered to be a tropical storm or completely left out of the database. Now that the reanalysis is complete for this decade, adding in the estimated number of missed hurricanes results in about 6.5 hurricane per year, which is still near the current era climatology.

In terms of landfalls, these seasons were active for the Caribbean and the United States. Fourteen hurricane landfalls were identified in the United States; seven were major hurricanes. Donna and Carla were the strongest hurricanes to hit the United States with maximum sustained winds of 125 kt. Many of the hurricanes in the Caribbean had multiple landfalls, especially the two most significant ones, Janet and Flora. Janet was the strongest hurricane analyzed during this decade and also the strongest at landfall. It hit the Yucatan Peninsula as a category 5 with a peak intensity of 150 kt. Twenty new tropical cyclones were added to the database, increasing the number of tropical cyclones from 92 to 112. Of the 20 new tropical cyclones, only one reached hurricane intensity. No tropical cyclones were removed from the existing record. However, the numbers of hurricanes and of major hurricanes decreased slightly.

The number of category 5 hurricanes in this decade was substantially decreased from six in the original HURDAT2 to one, because the intensities were overestimated originally, except for Janet. However, as discussed in Hagen and Landsea (2012), the mission design for aerial reconnaissance at the time was such that extreme hurricanes were often not sampled adequately for intensity. Without central pressure measurements (common for extreme hurricanes with small eyes), many peak intensities for the 1950s and 1960s will remain unknown and likely low biased.

The tracks of nearly all tropical cyclones in the original HURDAT2 were altered, but most changes were minor. Changes were also made to the intensity of nearly all tropical cyclones. Most intensity alterations were major, either toward stronger or weaker maximum winds (sometimes both during the lifetime of a single cyclone). Despite the reanalysis changes, uncertainty still exists in the intensity and track of many of the tropical cyclones. Uncertainty and a low bias due to undersampling remain in the number of storms that formed during this decade and their duration, especially over the open ocean where the data are sparse.

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