A Reanalysis of the 1931 to 1943 Atlantic Hurricane Database

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ABSTRACT

A reanalysis of the Atlantic basin tropical storm and hurricane database ("best track") for the period of 1931 to 1943 has been completed. This reassessment of the main archive for tropical cyclones of the North Atlantic Ocean, Caribbean Sea and Gulf of Mexico was necessary to correct systematic biases and random errors in the data as well as to search for previously unrecognized systems. Methodology for the reanalysis process for revising the track and intensity of tropical cyclone data is largely unchanged from that of the preceding couple of decades and has been detailed in a previous paper on the reanalysis. The Accurate Environmental Forecasting's numerical weather prediction-based windfield model was utilized here to help determine which states were impacted by various hurricane force winds in several U.S. landfalling major hurricanes during this era. The 1931-1943 dataset now includes 23 new tropical cyclones, excludes five systems previously considered tropical storms, makes generally large alterations in the intensity estimates of most tropical cyclones (at various times both toward stronger and weaker intensities), and typically adjusts existing tracks with minor corrections. Average errors in intensity and track values are estimated for both open ocean conditions as well as for landfalling systems. Finally, highlights are given for changes to the more significant hurricanes to impact the United States, Central America and the Caribbean for this time period.

1. Introduction

This paper details efforts to re-analyze the National Hurricane Center's (NHC's) North Atlantic hurricane database (or HURDAT2 – Landsea and Franklin 2013), also called the "best track" since they are the "best" post-season determination of tropical cyclone (TC) tracks and intensities for the period of 1931 to 1943. Previous work on the reanalysis which has been officially included into the HURDAT2 data set includes the period of 1851 to 1910 (Landsea et al. 2004a), 1911 to 1920 (Landsea et al. 2008), 1921 to 1930 (Landsea et al. 2012) and 1992's Hurricane Andrew (Landsea et al. 2004b). Additionally, revisions to the hurricane database have been proposed for the period of 1944 through 1953 (Hagen et al. 2012). As the methodology and observational data are nearly identical to that reported for the 1911 to 1930 reanalysis efforts, the reader is referred to Landsea et al. (2008, 2012) for discussion of data sets utilized and general methodology employed. One important new tool – the Accurate Environmental Forecasting's numerical weather prediction based windfield model (hereafter, the AEF wind model) (Dickinson et al. 2004) – was employed for analyzing the wind field for some U.S. major hurricanes of this era to provide an additional method for determining which states were impacted by various hurricane force winds.

2. New Datasets and Methodology

The limited observational capabilities of the 1930s and early 1940s were quite similar to that of the previous few decades: measurements from unfortunately placed ships at sea and from coastal weather stations (Landsea et al. 2004a, 2008, 2012). Methodology for re-examining the existing track, intensity, and classification of TCs, for uncovering previously unidentified TCs, and for potentially removing TCs from the database is detailed in Landsea et al. (2008, 2012) and is unchanged from what was utilized here for 1931 to 1943.

One new study that was considered in the reanalysis efforts was the storm surge observations and modeling work by Jarvinen (2006). This paper addressed several very destructive U.S. landfalling hurricanes from the framework of observed storm surge observations and matched them based upon storm surge runs from the SLOSH model (Sea, Lake, and Overland Surges from Hurricanes, Jelesnianski et al. 1992). His results provided suggested revised tracks, central pressures, and maximum sustained winds for hurricanes that included the 1935 Labor Day hurricane and the 1938 Great New England hurricane.

The reanalysis efforts also incorporated output from the AEF wind model to provide objective guidance on what category hurricane force winds affected which states for several destructive landfalling U.S. hurricanes. The AEF wind model (Dickinson et al. 2004) is based on the operational Geophysical Fluid Dynamics Laboratory (GFDL) hurricane forecast model (Kurihara et al., 1998) which uses a multiply nested movable mesh system to depict the interior structure of tropical cyclones. The GFDL model has been extensively modified to permit simulations of the wind field produced by a hurricane with a prescribed track and intensity. The AEF wind model is a dynamical model that utilizes the physical balances in the dynamic equations to determine how a hurricane will respond to local variability in the surface conditions (primarily topography and surface roughness). The AEF wind model incorporates a high-resolution boundary layer (eight vertical levels below 1000 meters) combined with high-resolution information about topography and land use. The model input comes from data describing the tropical cyclone location, maximum wind, and structure (i.e., radius of maximum winds and radii of 50 and 34 kt winds, if available). (Note that as the HURDAT2 database is provided in 5 kt increments, knots will be the unit of preference here. 1 kt = 0.5144 m/s.) The AEF wind model is well suited to study recent or historical hurricane events.

The last hurricane season included in this report – 1943 – heralded the first use of aircraft reconnaissance for monitoring tropical cyclones in the Atlantic basin. The first two flights – quite serendipitously – were those by U.S. Col. Joseph P. Duckworth, an officer of the Army Air Corps, into a hurricane making landfall near Houston, Texas on July 27th, 1943. As documented in Sumner (1943), “this is the first time…that a plane has been intentionally flown through the center of a hurricane.” (A detailed report by Duckworth about these flights – previously unpublished – is included in the on-line supplement to this paper.) Later in the same season came the first operational report available to the U.S. Weather Bureau office in Miami, Florida, where the primary U.S. hurricane analysis and forecasting was newly being conducted (in conjunction with the U.S. Navy and the U.S. Army Air Corps). As described in Hagen et al. (2012), beginning with this newly centralized office for hurricane prediction, an archive of microfilm imagery of the hand-drawn surface weather maps has been maintained at the National Hurricane Center library. Figure 1 shows this first real-time report (provided by two-way radio) received by the Miami Weather Bureau on August 16th, 1943 of a tropical storm east of the United States. Additional ad-hoc hurricane flights were taken later in the season. Such monitoring evolved over the next few years into a formalized reconnaissance program by the U.S. Navy and the U.S. Army Air Corps (now the U.S. Air Force), which allowed for the advance notification of potentially landfalling hurricanes to affect the United States and countries throughout the Caribbean and Central America.

3. Track, Intensity and Frequency Error Estimates

Given that the observational datasets for TCs during 1931 to 1943 were nearly the same as for previous decades and that the methodology for reanalysis had not substantially changed, estimates for errors and biases are unchanged from the previous decades (Table 1). The estimated average position errors do depend on whether the TC was out over the open ocean or making landfall, the former being significantly uncertain (~100 nm) and the latter more accurate (~60 nm). (Before the 1920s, some coastal areas were not sufficiently monitored to allow for a more accurate assessment of position compared with the open ocean cases – Landsea et al. [2008].) It is estimated that the intensity measurements for 1931 to 1943 were in error an average of 20 kt over the open ocean, with a substantial bias toward underestimating the true intensity (Tables 2 and 3). For TCs landfalls during the 1930s and early 1940s, errors in the intensity estimates are smaller - ~15 kt – and likely have a negligible bias as nearly all coastlines around the western North Atlantic, Gulf of Mexico and Caribbean Sea were substantially settled and monitored by then. These estimated errors are the same as the preceding couple of decades. Landsea et al. (2008, 2012) have additional information on the position and intensity error estimates for the reanalysis database relevant for this decade.

Methodology developed by Vecchi and Knutson (2008) allows for more reliable estimates of the number of "missing" TCs before the advent of satellite imagery. Their results suggest that about one tropical cyclone was missed every other year during the 1930s, but this increased to about two to three per year during 1940-43 due to much lower ship observation availability during World War II. Landsea et al. (2010) also indicated that there had been an extreme increase in the number of short-lived (less than or equal to a two day duration of tropical storm or greater intensity) TCs in the last couple of decades, which is likely due to better technology and monitoring of these short-lived and typically very weak systems (Villarini et al.

2011). Additionally, Vecchi and Knutson (2010) applied the same methodology toward estimates in the number of missed hurricanes, either those missed completely from the HURDAT2 database or those wrongly considered to be only of tropical storm intensity. The results of these incomplete sampling studies will be put into the context of the results of the reanalysis, which has led to a substantial change in the frequency of TCs and hurricanes.

4. Results:

a. Overall activity:

A summary of the yearly changes to HURDAT2 is provided in Figure 2 and Table 4. Figure 2 shows the revised and comparison track maps for the individual seasons from 1931 to 1943. It is apparent that most of the track changes introduced for these years are fairly minor (less than a 120 nmi alteration in position at anytime during the TC's lifetime) as readily seen in the comparison maps, though there are some more dramatic alterations on occasion (e.g., Storm #9 in 1932, Storm #8 in 1934, and Storm #10 in 1942). Despite making relatively minor changes overall, nearly every existing TC was adjusted for at least some portion of its track.

In addition to track alterations of existing systems, 23 new TCs were discovered and added into HURDAT2 and five existing systems in HURDAT2 were reanalyzed to not be a tropical storm and thus removed from the database. Of the 23 new TCs that had sufficient observational evidence to document their existence and were thus added into HURDAT2, there were 4 in 1931 and 1932; 3 in 1934; 2 in 1933, 1935, 1937 and 1938; 1 in 1936, 1939, 1940 and 1942; and no new systems in 1941. Of these 23, six of the new TCs were landfalling systems: Storm #5, 1931 in the Dominican Republic, Storm #12, 1931 in Mexico and Belize, Storm #6, 1934 in the United States, Storm #1, 1935 in the Dominican Republic, Storm #7, 1940 (as a hurricane) in the Azores, and Storm #1, 1942 in Mexico. Thus while the majority of newly discovered tropical cyclones were over the open ocean, on occasion the reanalysis is able to add new landfalling tropical cyclones even in the first half of the 20th Century. Of the five systems during 1931 to 1943 that were removed from the database, two (original Storm #7, 1933 and Storm #17, 1933) were determined to have only reached tropical depression intensity; two (original Storm #1, 1934 and Storm #7, 1938) were reanalyzed to have been extratropical in structure at the times that tropical storm force winds occurred; and, finally, one was removed because it was the continuation of an earlier, pre-existing tropical cyclone (original Storm #4, 1933).

Table 4 lists the original and revised tallies of tropical storms and hurricanes, hurricanes, major hurricanes (Category 3, 4 and 5 on the Saffir-Simpson Hurricane Wind Scale [SSHWS]), and Accumulated Cyclone Energy (ACE – an index for overall TC activity that takes into account the total frequency, intensity and duration of TCs, Bell et al. 2000). ACE is calculated by summing the squares of the estimated 6-hourly maximum wind speed in knots to be found in HURDAT2 for all periods while the system is either a tropical storm or hurricane.

The average number of recorded tropical storms and hurricanes increased from 10.0 per year in the original HURDAT2 to 11.4 after the reanalysis (Table 4), a 14% increase. This net increase accounts for the new systems that were added into the database as well as the removal of systems that were discarded from HURDAT2. The revised value is close to the long-term average of 12.1 per year recorded in most recent (1981-2010) base period climatology. However, as described earlier, a direct comparison of the total frequency of TCs during the

1930s-early 1940s to the modern climatology is complicated by the occurrence of “missed” TCs in the earlier years due to the lack of satellite imagery and vastly improved monitoring capability available now. In the original HURDAT2, of the 130 TCs, only 11 were short-lived. With the reanalysis, of the 148 TCs for the 1931-43 period, 23 are now indicated to be short-lived TCs. Six of the newly described short-lived TCs were due to a decrease in the original duration recorded, seven were brand new TCs not previously recorded, and one previous short-lived TC was removed from HURDAT2. To better homogeneously compare the 1930s-early 1940s to the more recent era, one must estimate the number of “missed” TCs of medium to long durations in the 1931-43 period and remove the likely spurious influence of the short-lived TC trends. Using the results of Landsea et al. (2010), an average of about one medium to long-lived TC every two years was missed during 1931-1939 and about 1.5 per year were missed during 1940-43. Thus the best adjusted total of medium to long-lived TCs from 1931 to 1943 is about 10.4 per year (9.6 recorded per year plus 0.8 missed per year), which suggests that this period was more active than today’s 1981 to 2010 climatology of 8.4 per year.

Measured hurricane frequency (Table 4) had a small increase from 4.8 to 5.3 per year, which would appear to be below the 6.4 per year in the modern era climatology. However, Vecchi and Knutson (2011) estimated that HURDAT2 missed about one hurricane per year from 1931 to 1939 and about two hurricanes per year from 1940 to 1943. Including these undersampling estimates into the newly observed values suggests a total of about 6.5 hurricanes per year occurred during 1931 to 1943, quite similar to the modern climatology.

Similarly, the major hurricane and ACE averages (Table 4) show modest increases in recorded values. Major hurricanes went from 1.6 up to 2.0 per year (2.7 per year in the modern climatology), and ACE increased from 84.0 to 91.2 per year (104.4 per year in the modern climatology). With regards to ACE, the records for four years had a substantial increase in activity (ACE higher by at least 10.0 – 1932, 1933, 1935, and 1940); one year had a large decrease in activity (ACE lower by at least 10.0 – 1934); and the remaining eight years had minor increases in overall intensity, duration and frequency. In general, large changes to intensity (at least a 20 kt alteration at some point in the TC's lifetime) were recorded – both upward and downward – for the majority of individual TCs, typically with more significant changes than those introduced for track. Currently, no method exists for quantifying the amount of "missed" major hurricanes, and ACE for the era of the 1930s to early 1940s. Consequently, any direct comparison of these quantities to the modern era would not be appropriate and the provided modern era numbers should be used cautiously in general comparisons of major hurricanes and ACE to the study period.

b. Continental United States Hurricanes:

Table 5 summarizes the continental U.S. hurricanes for the period of 1931 to 1943 and the states impacted by these systems. U. S. hurricanes are defined as those hurricanes that are analyzed to cause maximum (1 min) surface (10 m) winds of at least 64 kt for an open exposure on the coast or inland in the continental United States. Hurricanes that make a direct landfall with the circulation center (eye) of the system crossing the coast as well as those that make a close bypass are considered. In addition to the parameters common to HURDAT2 (e.g. latitude, longitude, maximum winds and central pressure), the U.S. hurricane compilation also includes the outer closed isobar, the mean size of the outer closed isobar, and - when available - the radius of maximum wind (RMW). These parameters provide information regarding the size of the hurricanes, which can vary considerably from system to system. For these TCs, winds listed in HURDAT2 at landfall are now consistent with the assigned Saffir-Simpson Hurricane Scale category, which was not the case in the original HURDAT2 database before the reanalysis efforts. For most U.S. hurricanes of this era, a central pressure observation or quantatively-derived estimate was obtained from original sources, which was then used to determine maximum wind speeds through the application of one of the Brown et al. (2006) pressure-wind relationships. In cases where there was no central pressure value directly available, the estimated winds at landfall were used via the pressure-wind relationship to back out a reasonable central pressure. In either case, the objective was to provide both an estimate of the maximum wind and a central pressure at landfall for all U.S. hurricanes.

There were 25 U.S. hurricanes (seven were major hurricanes) during the 1931 to 1943 period after the reanalysis. No U.S. hurricanes were recorded in 1931 or 1937. The total of 25 U.S. hurricanes represents one more hurricane than the original HURDAT2 database contained. Storm #7 in 1934 is now considered as being a hurricane landfall in New York (as well as a hurricane impact both in North Carolina and New Jersey), while previously the system was considered to have transitioned to an extratropical cyclone before landfall. For existing U.S. hurricanes, none were upgraded a Category, 17 were unchanged in Category, while seven were downgraded by a Category: Storm #5, 1933 from a Category 2 in Texas originally to a Category 1; Storm #7, 1933 from a Category 2 in North Carolina and Virginia originally to a Category 1 in both states; Storm #12, 1933 from a Category 3 in North Carolina originally to a Category 2; Storm #1, 1934 from a Category 3 in Louisiana originally to a Category 2; Storm #3, 1934 from a Category 2 in Texas originally to a Category 1; Storm #5, 1936 from a Category 3 in Florida originally to a Category 2; and Storm #13, 1936 from a Category 2 in North Carolina originally to a Category 1.   No original U.S. hurricanes were removed as such from HURDAT2 during the 1931-1943 time period. Because of the downgrades listed above for Storm #12, 1933, Storm #1, 1934, and Storm #5, 1936, three major hurricanes were removed from the U.S. hurricane list, while no new major hurricanes impacting the United States were introduced.

Notable hurricanes that affected the continental United States for 1931 through 1943 (Blake et al. 2007) include Storm #2, 1932 – the “Freeport Hurricane” – in Texas, Storm #3, 1935 – the “Labor Day Hurricane” – in Florida and Georgia, and Storm #5, 1938 – the “Great New England Hurricane” - in New York and New England.

The Freeport Hurricane struck the upper coast of Texas on August 14th, 1932. The hurricane killed 40 people upon impact primarily due to storm surge and wind-caused destruction. The cyclone is reanalyzed to have had a rather small inner core with radius of maximum wind of only 10 nm and a central pressure of 935 mb. This central pressure suggests an intensity of 125 kt from the Brown et al. (2006) north of 25^{o}N intensifying cyclones pressure-wind relationship. Intensity at landfall is assessed slightly higher because of the smaller-than-climatologically-expected RMW (Vickery et al. 2000) at 130 kt – Category 4 on the Saffir-Simpson Hurricane Wind Scale – making it one of seven Category 4 hurricanes to strike the Texas Coast going back to at least 1880, when reliable records began for the Texas coast. Originally, the cyclone was assessed in HURDAT2 as having 125 kt at the last synoptic time before landfall and being Category 4, so little intensity changes were introduced for this U.S. major hurricane.

The most intense hurricane (by central pressure) ever known to have struck the United States impacted the Florida Keys on September 3rd, 1935. The “Labor Day” hurricane, so named as it made landfall on Labor Day, killed around 408 people, due an enormous storm surge and extreme wind-caused effects, which is the 8th most deadly in the continental United States history. The lowest sea level pressure ever recorded in the United States - a central pressure of 892 mb – suggests an intensity of 164 kt from the Brown et al. (2006) intensifying subset of cyclones south of 25°N pressure-wind relationship and 162 kt from the Brown et al. (2006) intensifying subset of cyclones north of 25°N pressure-wind relationship (the hurricane made landfall close to the 25° latitude). The somewhat compensating effects of a slow moving – 7 kt – translational velocity along with an extremely tiny radius of maximum wind - 5 nm - led to an analyzed intensity at landfall of 160 kt - Category 5. This value is second only to the 165 kt[1] currently listed in HURDAT2 for 1969's Camille along the Mississippi coast in the last synoptic time before landfall. There have been only three Category 5 hurricanes to strike the United States at that intensity: the 1935 Labor Day hurricane, 1969's Camille and 1992's Andrew in southeast Florida, since relatively complete records for the United States began around 1900. The 160 kt landfall intensity for the Labor Day hurricane represents a 20 kt increase from that originally in HURDAT2, a major change, though the original value also was within the Category 5 range. It is of note that public interest continues for this historic hurricane, as two recent non-technical books have been published about it – Drye (2002) and Knowles (2009).

The Great New England hurricane made landfall in New York and then Connecticut on September 21st, 1938. 256 people perished during its landfall, primarily due to the extreme storm surge that accompanied this hurricane. If the same hurricane were to strike the same area today, it is estimated that the impact would cause around $41 billion in direct damages (Blake et al. 2007). The system had a large – 40 nm – radius of maximum wind to accompany its central

[1] This value of 165 kt at landfall for Camille will also be assessed as part of the continuing reanalysis work and thus should be considered official, but tentative.

pressure of 941 mb at its first landfall in New York (and about 946 mb at the Connecticut landfall), but it had a very quick translational velocity of about 40 kt. The 941 mb central pressure suggests an intensity of 103 kt from the Landsea et al. (2004a) north of 35°N pressure-wind relationship. The highest reliable wind observation recorded on land that was not influenced by terrain effects was a 1 min 95 kt value at Fishers Island, NY. Because of somewhat compensating effects of the very quick translational velocity along with a large – 40 nm – radius of maximum wind, the assessed intensity was 105 kt at the New York landfall and 100 kt at the Connecticut landfall. The hurricane was retained as a Category 3 hurricane at its landfall in New York and New England, though the peak sustained winds at landfall in New York were increased from 85 kt[2] in the original HURDAT2 database to 105 kt in the revision. The 105 kt landfall intensity makes it the strongest hurricane on record to strike New York and New England back to the advent of HURDAT2 in 1851. However, there is evidence (e.g. Boose et al. 2001, Jarvinen 2006) that the 1635 Colonial Hurricane was as strong or slightly stronger than the 1938 hurricane at landfall. Like the Labor Day hurricane, the devastating Great New England hurricane of 1938 continues to generate public interest as evidenced by the non-technical book by Scotti (2003).

c. Major Hurricanes outside of the Continental U.S.:

Outside of the continental United States, twelve major hurricanes made landfall either in the Lesser Antilles, Greater Antilles, Central America, and Mexico during 1931 to 1943 (Table

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[2] The discrepancy between the Category 3 original assessment for U.S. landfall of this hurricane with the 85 kt winds existing originally in HURDAT2 is quite a common problem in the existing dataset. Much of the discrepancy is due to reliance primarily upon the central pressure by Taylor and Hebert (1975) to provide the original Saffir-Simpson Hurricane Wind Scale Category at landfall in the United States, while the practice today at the National Hurricane Center and within the reanalysis is to determine the maximum winds at landfall and then let these provide the appropriate category.

6). This was an exceptionally busy and destructive period with four cyclones (two were major landfalling hurricanes) in the top 20 list of all-time most fatalities in the history of the Atlantic basin (Rappaport and Partagás 1995). Of the twelve, five were newly designated to be a major hurricane after the reanalysis: Storm #9 – "San Ciprián" – in 1932 that struck Puerto Rico, the winds from which were increased from 95 to 125 kt at landfall; Storm #8 in 1933 that struck Bahamas and Cuba, the winds from which were increased from 70 to 140 kt in the Bahamas and 85 kt to 105 kt in Cuba; Storm #14 in 1933 that struck Mexico, the winds from which were increased from 90 to 120 kt; Storm #4 in 1938 that struck Mexico, the winds from which were increased from 85 to 105 kt; and Storm #5 in 1941 that struck Bahamas, the winds from which were increased from 90 to 105 kt.

Belize was impacted by a Category 4 hurricane that struck the country in September 1931, killing about 2,500 people primarily through storm surge (Rappaport and Partagás 1995). A peripheral pressure of 952 mb was observed at Belize City, which suggested at least 109 kt from the Brown et al. (2006) south of 25^{o}N pressure-wind relationship. A 115 kt intensity at landfall was analyzed, though this is conservative if the actual central pressure was substantially deeper than about 945-950 mb.

The Bahamas were impacted by two Category 5 hurricanes during this period – Storm #4 in September 1932 and Storm #8 in August 1933. A peripheral pressure of 931 mb measured at Great Abaco in the former storm suggests maximum winds of at least 128 kt from the subset of intensifying hurricanes from the Brown et al. (2006) north of 25^{o}N pressure-wind relationship. An intensity of 140 kt is analyzed at landfall for Storm #4, 1932 in the Bahamas. A peripheral pressure of 930 mb observed simultaneously with hurricane force wind from a ship in the latter storm suggests winds of at least 130 kt from the Brown et al. (2006) south of 25°N pressure-wind relationship. An intensity of 140 kt is analyzed at landfall for Storm #8, 1933 in the Bahamas. Both extreme hurricanes were limited in their destruction as the core of the cyclones avoided most towns and cities in the Bahamas.

Another major hurricane in 1932 – Storm #9, also known as "San Ciprián" – struck Puerto Rico in September 1932. This cyclone killed 257 people, primarily from wind-caused destruction. A central pressure of 943 mb was obtained by averaging two ship measurements near Ensenada Honda, with both being in the eye. This suggests maximum winds of 118 kt from the Brown et al. (2006) south of 25°N pressure-wind relationship. Due to a rather small radius of maximum wind – 5-10 nm, the intensity at landfall is assessed slightly higher at 125 kt.

The largest impact of any major hurricane was the devastating Category 4 hurricane that struck the Cayman Islands and Cuba in November 1932 (Storm #14, 1932) and killed over 3,100 people (Rappaport and Partagás 1995) primarily due to a storm surge that reached at least 6.8 m. While this system had an extremely low 918 mb central pressure at landfall in Cuba (Perez et al. 2000), a 30-35 nm radius of maximum wind and a low environmental pressure suggest an intensity – 130 kt – that is substantially lower than the Brown et al. south of 25°N pressure-wind relationship for that central pressure.

Two other cyclones caused enormous destruction and fatalities due to rain-caused flash floods and mudslides (Rappaport and Partagás 1995): Storm #1, 1934 in El Salvador and Honduras and Storm #6, 1935 in Haiti, Jamaica, and Honduras. The former cyclone spent several days while looping over Central America as a tropical storm and caused torrential rains which lead to the death of at least 3,000 people. The latter system reached hurricane status in the

Caribbean Sea while meandering for several days in October 1935, leading to devastating rainfall impacts with over 2,150 fatalities in Haiti, Honduras, and Jamaica. Neither cyclone reached major hurricane status, but both were in the top 20 largest loss of life systems in the history of the Atlantic basin (Rappaport and Partagás 1995).

To summarize the significant changes to the landfall intensity of these twelve major landfalling (non-continental U.S.) hurricanes (Table 6), four had large increases in landfall intensity (Storm #9, 1932 [San Ciprián] from 95 kt up to 125 kt in Puerto Rico; Storm #8, 1932 in the Bahamas from 70 kt up to 140 kt and in Cuba [El Huracán de Sagua y Cárdenas] from 85 kt up to 105 kt; Storm #14, 1933 from 90 kt up to 120 kt in Mexico; and Storm #4, 1938 from 85 kt up to 105 kt in Mexico), one had a large decrease in landfall intensity (Storm #17, 1933 from 125 kt down to 105 kt in the Bahamas), and the remainder had small or no alterations in landfall intensity.

5. Summary:

The hurricane reanalysis has been completed now through the early 1940s, up to the advent of aircraft reconnaissance. While the results provided here are just brief summaries of the thousands of changes introduced into the Atlantic hurricane database, all raw observations, the original and revised HURDAT2, annual track maps, metadata regarding changes for individual TCs, and comments from/replies to the National Hurricane Center's Best Track Change Committee can be found at : http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html.

Highlights of accomplishments attained for this stage of the Atlantic hurricane database reanalysis project for 1931 to 1943:

A) Track alterations were implemented for nearly all TCs in the existing HURDAT2, though the majority were for minor changes;

B) Intensity changes were incorporated into nearly all TCs with a much larger proportion with major alterations in their intensity compared with the track, either toward stronger or weaker winds;

C) 23 new TCs were discovered and added into HURDAT2, while five systems were removed from the database: one was the continuation of an earlier TC, two were only of tropical depression intensity at their peak, and two were extratropical cyclones);

D) While the frequency of TCs during the era was increased from 10.0 to 11.4 annually because of these net changes, smaller increases were noted for hurricane and major hurricane frequency. The overall activity - as denoted by Accumulated Cyclone Energy - was increased by about 9%;

E) 25 continental U.S. hurricanes were identified, one of which was newly analyzed to be a hurricane (rather than an extratropical storm) at landfall. Of the 24 original U.S. hurricanes, 17 had no changes introduced for the peak category, while seven were downgraded a category. Seven major continental U.S. hurricanes were analyzed for 1931 to 1943, which is three less than originally indicated in HURDAT2 due to adjusting the SSHWS Category downward from a 3 to a 2 at landfall;

F) Twelve major hurricanes struck other places in the Atlantic basin, five of which were newly classified as a major hurricane. Of the twelve, four had large (at least 20 kt) increases of intensity at landfall, while one had a large reduction in landfall winds;

G) Despite the reanalysis changes, there exists significant uncertainty in TC tracks, significant undercounts in TC frequency, and significant underestimation of TC intensity and duration, especially for those systems over the open ocean.

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Figure and Table captions:

Figure 1: First operational use of aircraft reconnaissance for tropical cyclone analysis and prediction on August 16th, 1943. The handwritten text states: "From Col. Harrison, USAAF (Recd by phone 7:15 pm) Tropical disturbance at 1825Z located 26N Long. 72 deg 10' West. Wind on northwest circumference at surface N-40 mph; at 8 thousand feet 325 deg - 37 mph. This is a personal airplane observation. (signed) Col Carlwark 9th Reg. Control Officer."

Figure 2: The revised (top) and comparison (with original storm numbers and tracks in blue underlying revised track) (bottom) Atlantic basin TC track map for 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, and 1943.

Figure 3: Original (top) and revised (bottom) track and coastal wind swaths (in kt) for the 1938 Great New England hurricane. The coastal wind swaths were obtained from the AEF wind model.

Table 1: Estimated average position uncertainty in the revised best track for the years 1851-1953 and in the existing best track for the late 1990s to late 2000s. Here and in the subsequent two tables "N/A" refers to "not applicable". (1851 to 1910 is discussed in Landsea et al. [2004a], 1911-1920 in Landsea et al. [2008], 1921-1930 in Landsea et al. [2012], 1931-1943 within this paper, 1944-1953 within Hagen et al. [2012], and late 1990s/late 2000s in Landsea and Franklin, [2013]. By the 1920s, nearly all coastal areas in the Atlantic basin were relatively settled and monitored – Landsea et al. [2008].)

Table 2: Estimated average intensity uncertainty in the revised best track for the years 1851-1953 and in the existing best tracks for the late 1990s, and late 2000s. (1851 to 1910 is discussed in

Landsea et al. [2004a], 1911-1920 in Landsea et al. [2008], 1921-1930 in Landsea et al. [2012], 1931-1943 within this paper, 1944-1953 within Hagen et al. [2012], and late 1990s/late 2000s in Landsea and Franklin, [2013]. By the 1920s, nearly all coastal areas in the Atlantic basin were relatively settled and monitored – Landsea et al. [2008].)

Table 3: Estimated average intensity error bias in the revised best track for the years 1851-1953 and in the existing best tracks for the late 1990s-late 2000s. Columns four through seven provide stratification of estimated bias by *actual* cyclone intensity when aircraft reconnaissance was monitoring the system but did not report a central pressure. (1851 to 1910 is discussed in Landsea et al. [2004a], 1911-1920 in Landsea et al. [2008], 1921-1930 in Landsea et al. [2012], 1931-1943 within this paper, 1944-1953 within Hagen et al. [2012], and late 1990s/late 2000s in Landsea and Franklin, [2013]. By the 1920s, nearly all coastal areas in the Atlantic basin were relatively settled and monitored – Landsea et al. [2008].)

Table 4: Original/revised tropical storm and hurricane, hurricane, major hurricane and Accumulated Cyclone Energy (ACE) counts. ACE is expressed in units of 10^4 kt^2.

Table 5: Continental U.S. Hurricanes for 1931 to 1943. Date/Time - day and time when the circulation center crosses the U.S. coastline (including barrier islands). Time is estimated to the nearest hour. Lat/Lon - Location is estimated to the nearest 0.1 degrees latitude and longitude. Max Winds - Estimated maximum (1 min) surface (10 m) winds to occur along the U. S. coast. SSHWS - The Saffir-Simpson Hurricane Wind Scale at landfall based upon estimated maximum 1-min surface winds. RMW - The radius of maximum winds, if available, to the nearest 5 nm. Central Pressure - The minimum central pressure of the hurricane at landfall. Central pressure values in parentheses indicate that the value is a simple estimation (based upon a wind-pressure relationship), not directly measured or calculated. OCI – The Outer Closed Isobar, or the sea

level pressure at the outer limits of the hurricane circulation as determined by analysis of the outer closed isobar (in increments of 1 mb). Size - This is the average radius of the OCI. States Affected - The impact of the hurricane upon individual U.S. states by Saffir-Simpson Hurricane Wind Scale (again through the estimate of the maximum 1-min surface winds at each state). (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, MD-Maryland, DE-Delaware, NJ-New Jersey, NY-New York, PA-Pennsylvania, CT-Connecticut, RI-Rhode Island, MA-Massachusetts, NH-New Hampshire, ME-Maine. In Texas, south is roughly from the Mexico border to Corpus Christi; central is from north of Corpus Christi to Matagorda Bay and north is from Matagorda Bay to the Louisiana border. In Florida, the north-south dividing line is from Cape Canaveral [28.45N] to Tarpon Springs [28.17N]. The dividing line between west-east Florida goes from 82.69W at the north Florida border with Georgia, to Lake Okeechobee and due south along longitude 80.85W. Occasionally, a hurricane will cause a hurricane impact (estimated maximum sustained surface winds) in an inland state. To differentiate these cases versus coastal hurricane impacts, these inland hurricane strikes are denoted with an "I" prefix before the state abbreviation. "(EX)" indicates that the system was originally considered to be an extratropical cyclone at landfall.) "*" - Indicates that the hurricane center did not make a U.S. landfall, but did produce hurricane force winds over land. Position indicated is point of closest approach. Winds stronger than indicated to impact the United States may have existed elsewhere in the hurricane. Central pressure in this case is the hurricane's value at the point of closest approach. "#" - Indicates that hurricane made landfall first over Mexico, but caused hurricane winds in Texas. The position given is that of Mexican landfall. The strongest winds impacted Mexico. The winds indicated here are lower than in HURDAT2 and are lower than they were over Mexico. Central pressure given is that at Mexican landfall.

Table 6: Major Landfalling non-continental U.S Hurricanes - 1931 to 1943. The names listed are unofficial ones that the hurricanes are known by at these locations. Max Winds are the estimated maximum 1-min surface (10 m) winds to occur at along the coast at landfall/closest approach. Saffir-Simpson is the estimated Saffir-Simpson Hurricane Scale at landfall based upon maximum 1-min surface winds. Central Pressure is the minimum central pressure of the hurricane at landfall/closest approach. Central pressure values in parentheses indicate that the value is a simple estimation (based upon a pressure-wind relationship), not directly measured or calculated. Original Winds are the winds in HURDAT2 that were originally provided at landfall/closest approach.

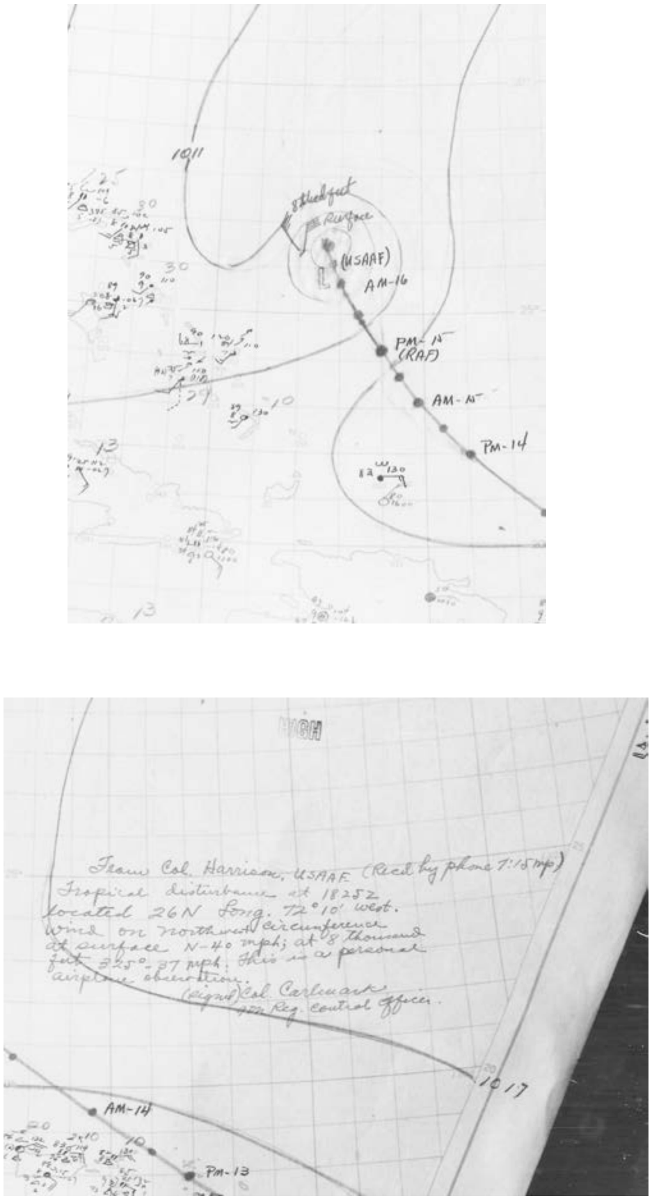
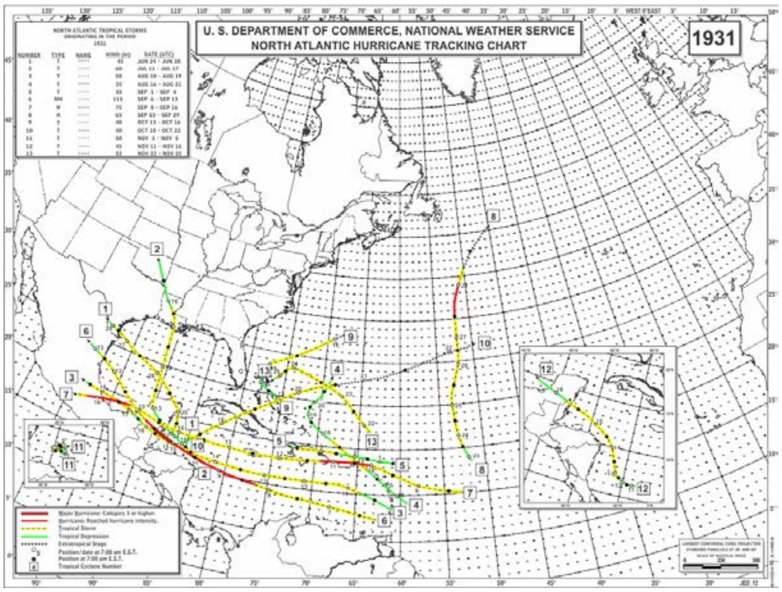


Figure 1: First operational use of aircraft reconnaissance for tropical cyclone analysis and prediction on August 16th, 1943. The handwritten text states: "From Col. Harrison, USAAF (Recd by phone 7:15 pm) Tropical disturbance at 1825Z located 26N Long. 72 deg 10' West. Wind on northwest circumference at surface N-40 mph; at 8 thousand feet 325 deg - 37 mph. This is a personal airplane observation. (signed) Col Carlwark 9th Reg. Control Officer."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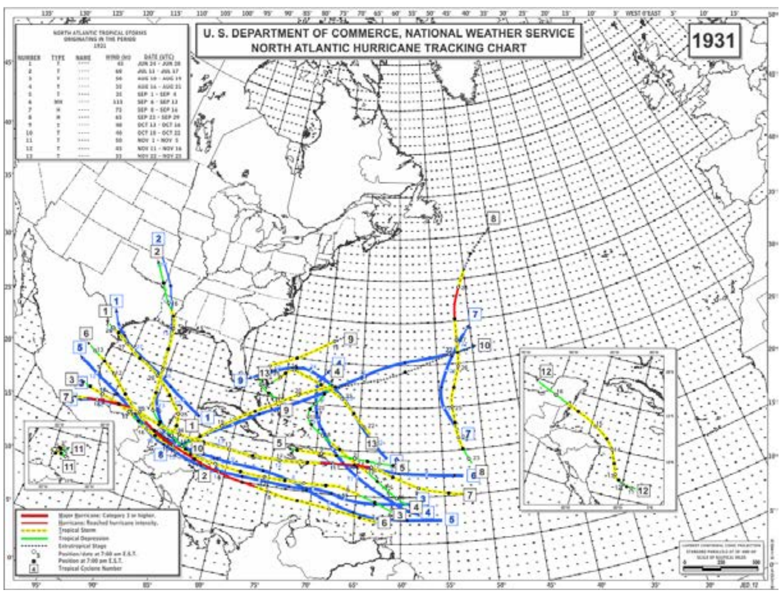
1931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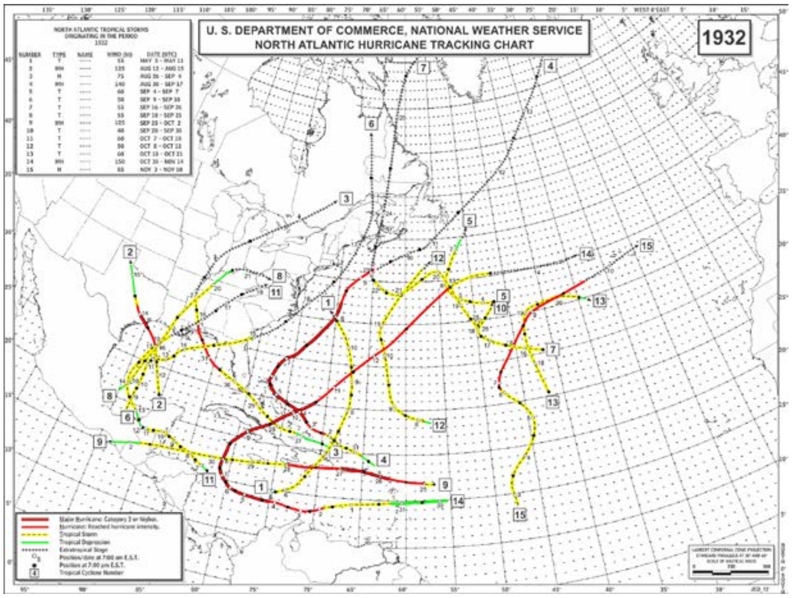
1931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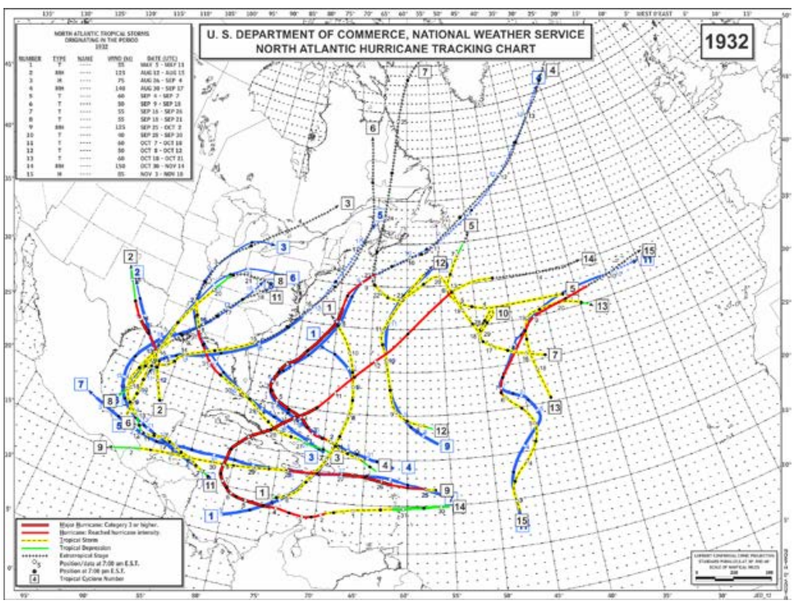
1932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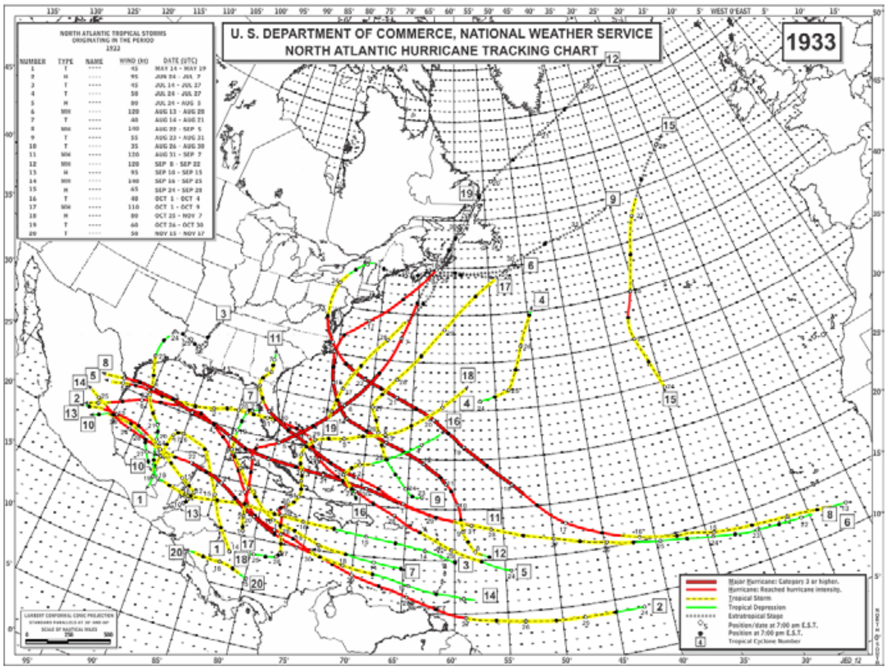
1932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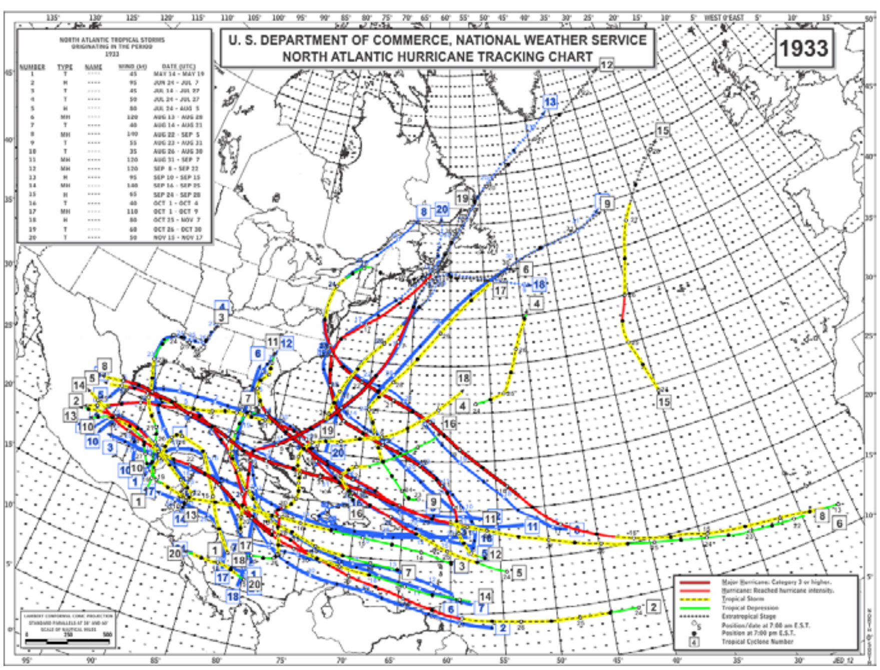
1933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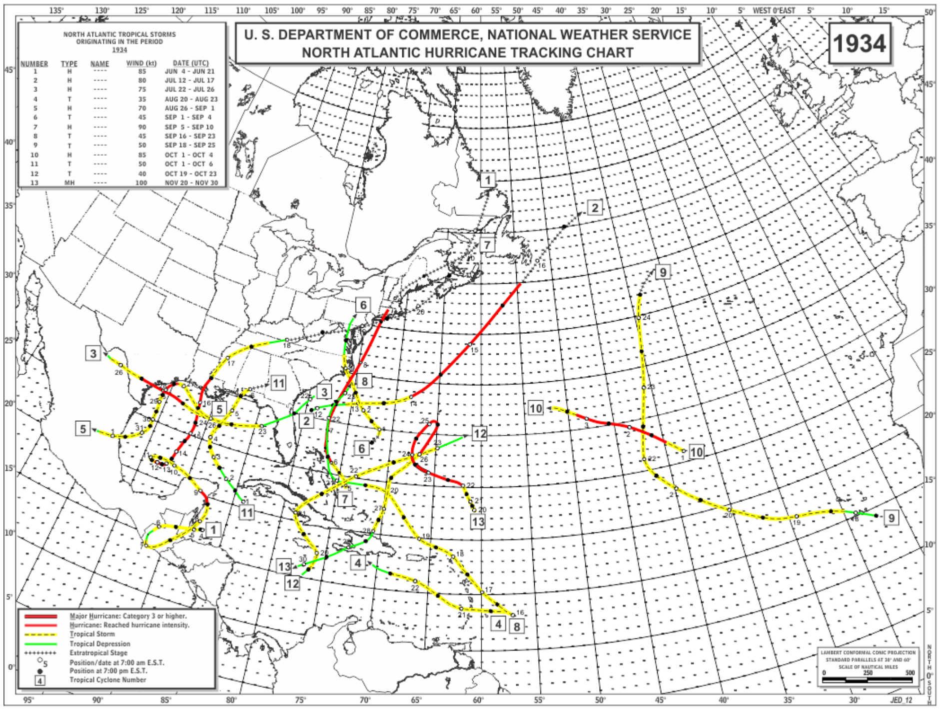
1933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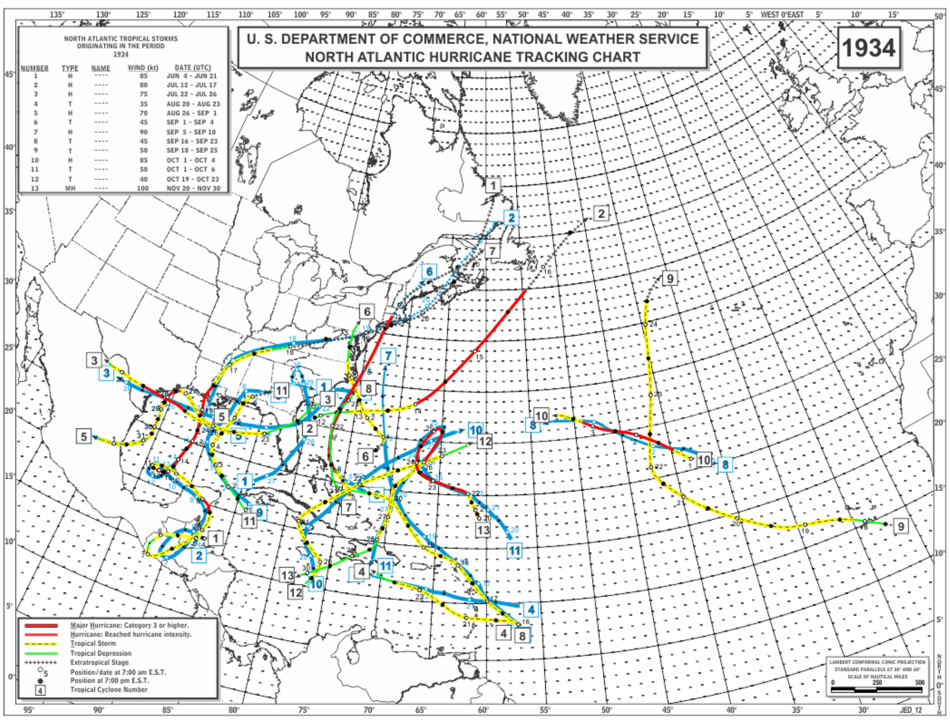
NORTH ATLANTIC HURRICANE TRACKING CHART
1934
NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1934
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 H ---- 85 JUN 4 - JUN 21
2 H ---- 80 JUL 12 - JUL 17
3 H ---- 75 JUL 22 - JUL 26
4 T ---- 35 AUG 20 - AUG 23
5 H ---- 70 AUG 26 - SEP 1
6 T ---- 45 SEP 1 - SEP 4
7 H ---- 90 SEP 5 - SEP 10
8 T ---- 45 SEP 16 - SEP 23
9 T ---- 50 SEP 18 - SEP 25
10 H ---- 85 OCT 1 - OCT 4
11 T ---- 50 OCT 1 - OCT 6
12 T ---- 40 OCT 19 - OCT 23
13 MH ---- 100 NOV 20 - NOV 30
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
SCALE OF NAUTICAL MILES
JED_12


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1934
NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1934
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 H ---- 85 JUN 4 - JUN 21
2 H ---- 80 JUL 12 - JUL 17
3 H ---- 75 JUL 22 - JUL 26
4 T ---- 35 AUG 20 - AUG 23
5 H ---- 70 AUG 26 - SEP 1
6 T ---- 45 SEP 1 - SEP 4
7 H ---- 90 SEP 5 - SEP 10
8 T ---- 45 SEP 16 - SEP 23
9 T ---- 50 SEP 18 - SEP 25
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11 T ---- 50 OCT 1 - OCT 6
12 T ---- 40 OCT 19 - OCT 23
13 MH ---- 100 NOV 20 - NOV 30
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Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
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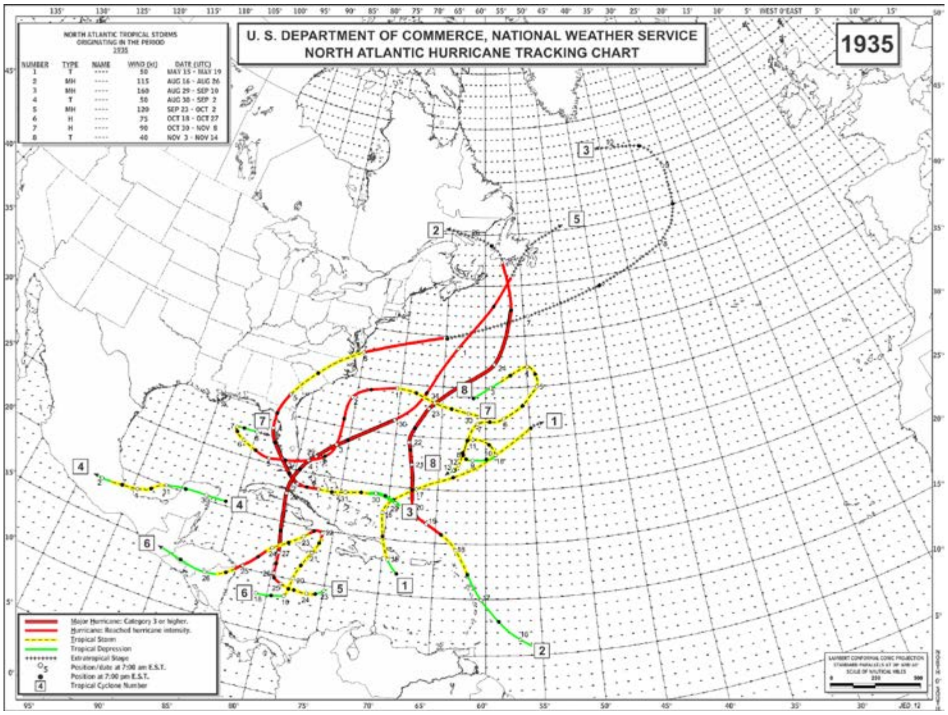
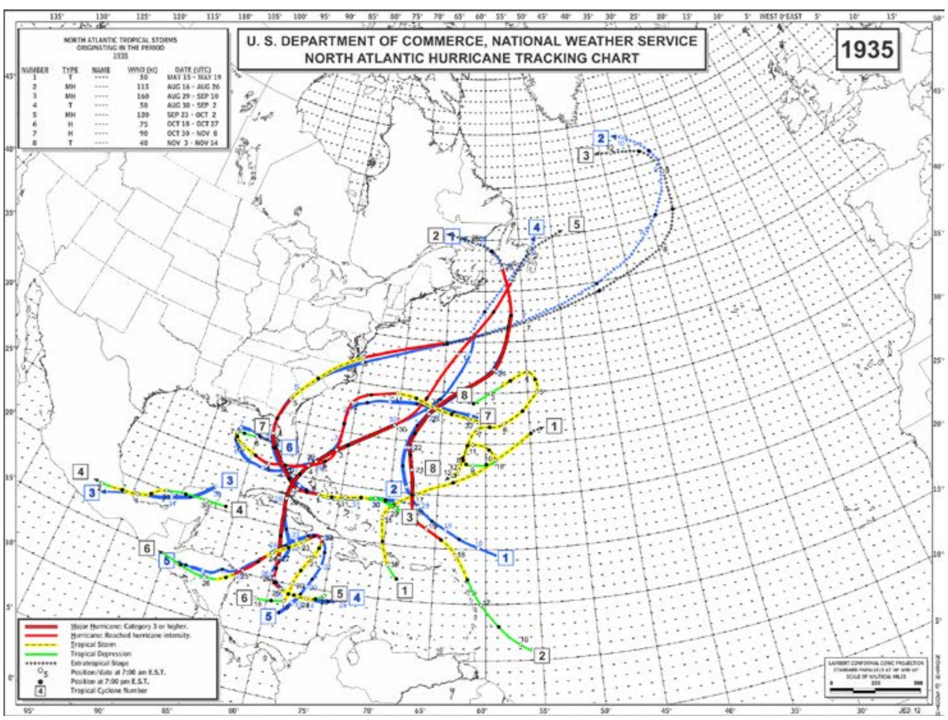
LAMBERT CONFORMAL CONIC PROJECTION
SCALE OF NAUTICAL MILES
JED_12


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1935
NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1935
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 50 MAY 15 - MAY 19
2 MH ---- 115 AUG 16 - AUG 26
3 MH ---- 160 AUG 29 - SEP 10
4 T ---- 50 AUG 30 - SEP 2
5 MH ---- 120 SEP 23 - OCT 2
6 H ---- 75 OCT 18 - OCT 27
7 H ---- 90 OCT 30 - NOV 8
8 T ---- 40 NOV 3 - NOV 14
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number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ORIGINATING IN THE PERIOD
1935
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4 T ---- 50 AUG 30 - SEP 2
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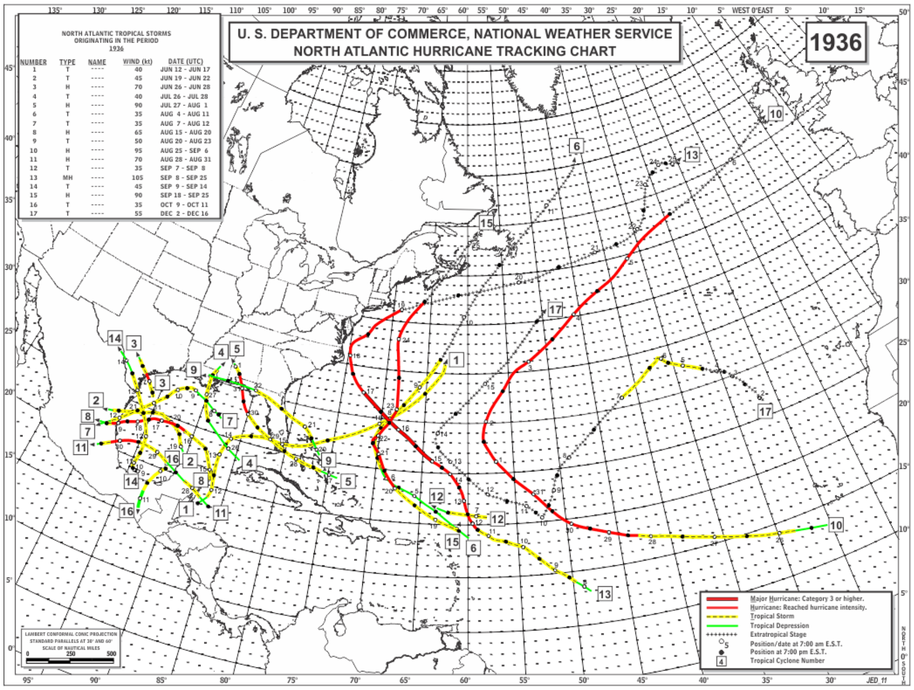
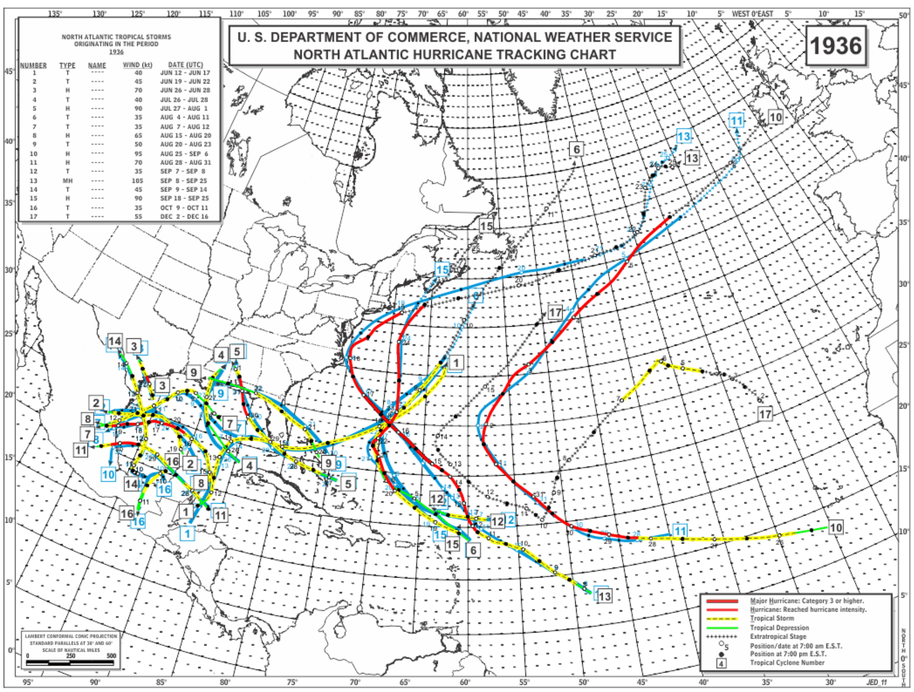
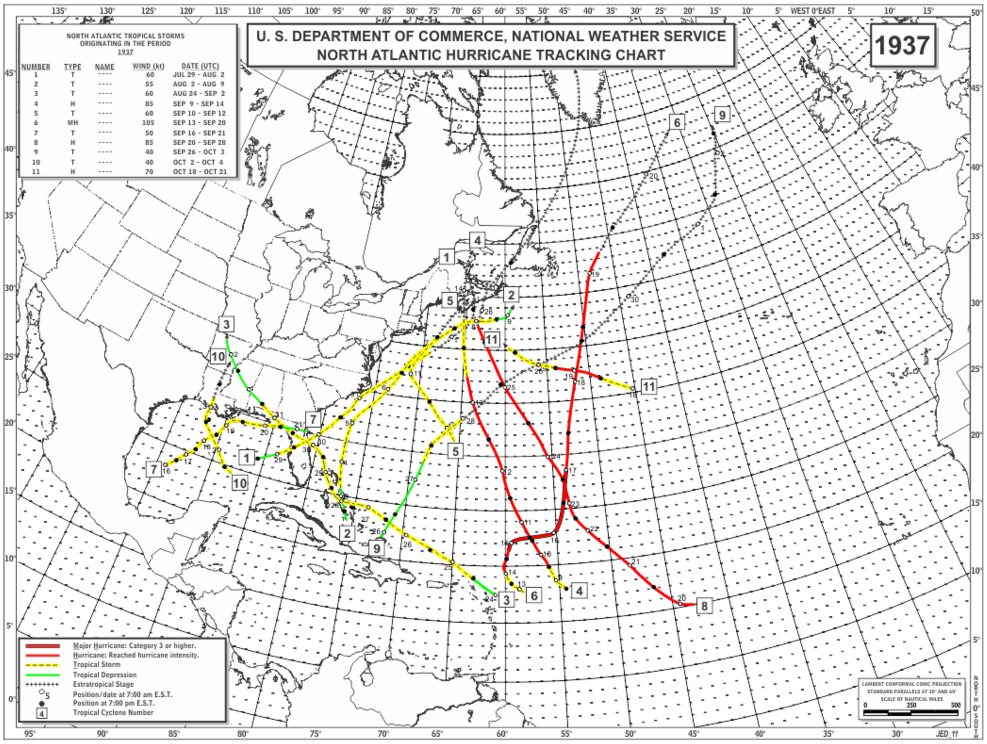
Tropical Cyclone Number


NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1936
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 40 JUN 12 - JUN 17
2 T ---- 45 JUN 19 - JUN 22
3 H ---- 70 JUN 26 - JUN 28
4 T ---- 40 JUL 26 - JUL 28
5 H ---- 90 JUL 27 - AUG 1
6 T ---- 35 AUG 4 - AUG 11
7 T ---- 35 AUG 7 - AUG 12
8 H ---- 65 AUG 15 - AUG 20
9 T ---- 50 AUG 20 - AUG 23
10 H ---- 95 AUG 25 - SEP 6
11 H ---- 70 AUG 28 - AUG 31
12 T ---- 35 SEP 7 - SEP 8
13 MH ---- 105 SEP 8 - SEP 25
14 T ---- 45 SEP 9 - SEP 14
15 H ---- 90 SEP 18 - SEP 25
16 T ---- 35 OCT 9 - OCT 11
17 T ---- 55 DEC 2 - DEC 16
U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1936
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
JED_11


NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1936
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 40 JUN 12 - JUN 17
2 T ---- 45 JUN 19 - JUN 22
3 H ---- 70 JUN 26 - JUN 28
4 T ---- 40 JUL 26 - JUL 28
5 H ---- 90 JUL 27 - AUG 1
6 T ---- 35 AUG 4 - AUG 11
7 T ---- 35 AUG 7 - AUG 12
8 H ---- 65 AUG 15 - AUG 20
9 T ---- 50 AUG 20 - AUG 23
10 H ---- 95 AUG 25 - SEP 6
11 H ---- 70 AUG 28 - AUG 31
12 T ---- 35 SEP 7 - SEP 8
13 MH ---- 105 SEP 8 - SEP 25
14 T ---- 45 SEP 9 - SEP 14
15 H ---- 90 SEP 18 - SEP 25
16 T ---- 35 OCT 9 - OCT 11
17 T ---- 55 DEC 2 - DEC 16
U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1936
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
JED_11


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1937
NORTH ATLANTIC TROPICAL STORMS ORIGINATING IN THE PERIOD 1937
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 60 JUL 29 - AUG 2
2 T ---- 55 AUG 2 - AUG 9
3 T ---- 60 AUG 24 - SEP 2
4 H ---- 85 SEP 9 - SEP 14
5 T ---- 60 SEP 10 - SEP 12
6 MH ---- 105 SEP 13 - SEP 20
7 T ---- 50 SEP 16 - SEP 21
8 H ---- 85 SEP 20 - SEP 28
9 T ---- 40 SEP 26 - OCT 3
10 T ---- 40 OCT 2 - OCT 4
11 H ---- 70 OCT 18 - OCT 21
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
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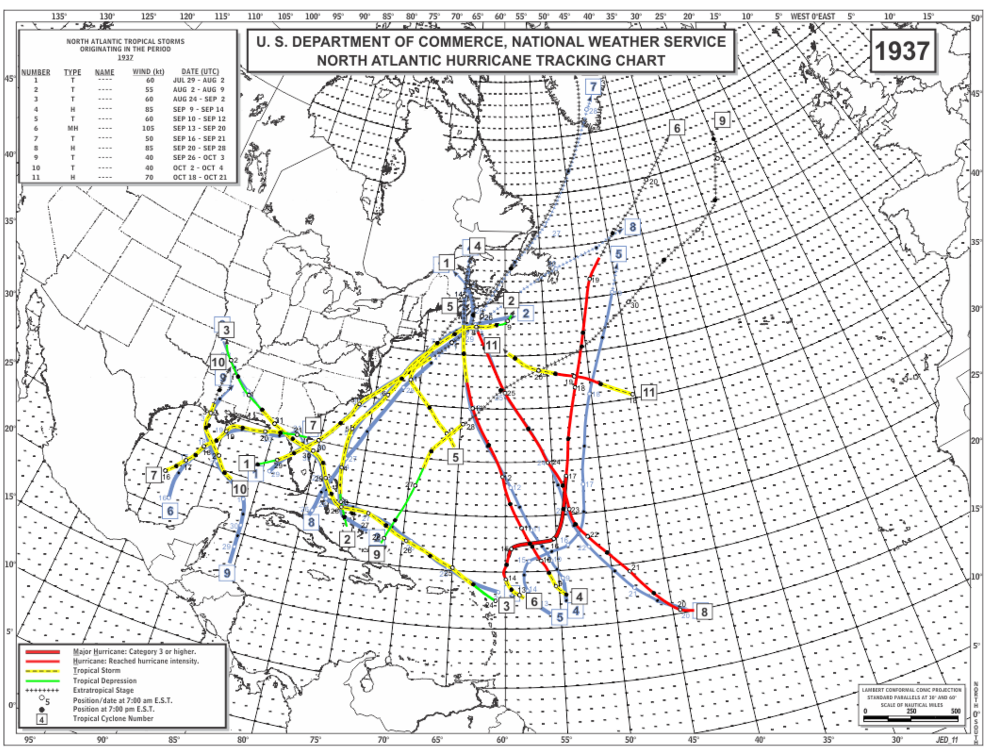
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
JED_11


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1937
NORTH ATLANTIC TROPICAL STORMS ORIGINATING IN THE PERIOD 1937
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 60 JUL 29 - AUG 2
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3 T ---- 60 AUG 24 - SEP 2
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6 MH ---- 105 SEP 13 - SEP 20
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Position/date at 7:00 am E.S.T.
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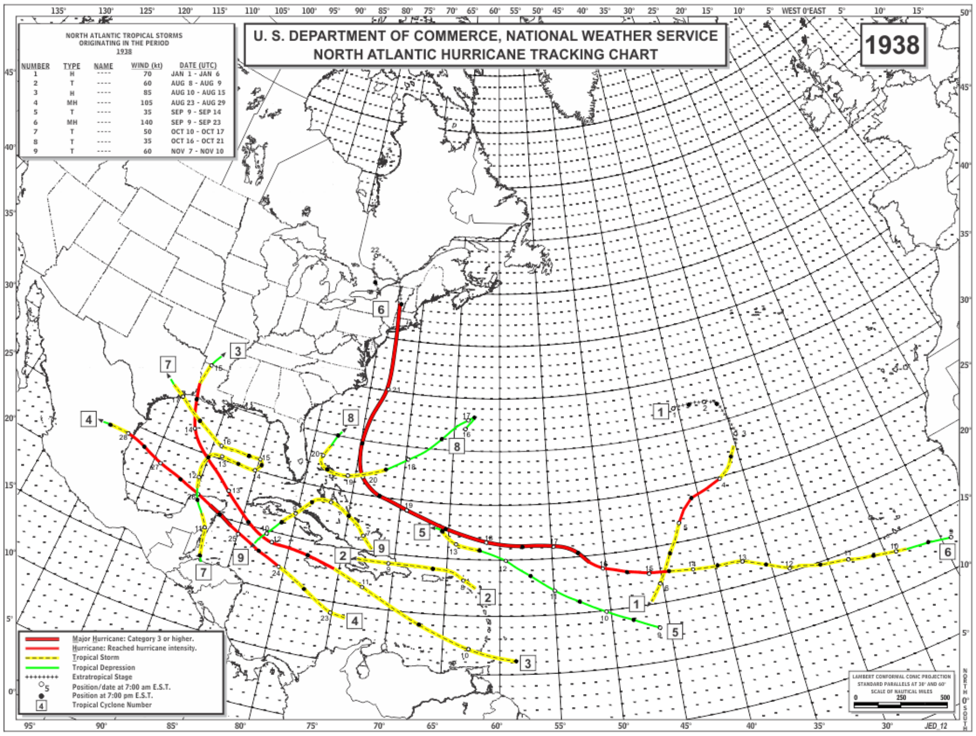
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
JED_11


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1938
NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1938
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 H ---- 70 JAN 1 - JAN 6
2 T ---- 60 AUG 8 - AUG 9
3 H ---- 85 AUG 10 - AUG 15
4 MH ---- 105 AUG 23 - AUG 29
5 T ---- 35 SEP 9 - SEP 14
6 MH ---- 140 SEP 9 - SEP 23
7 T ---- 50 OCT 10 - OCT 17
8 T ---- 35 OCT 16 - OCT 21
9 T ---- 60 NOV 7 - NOV 10
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
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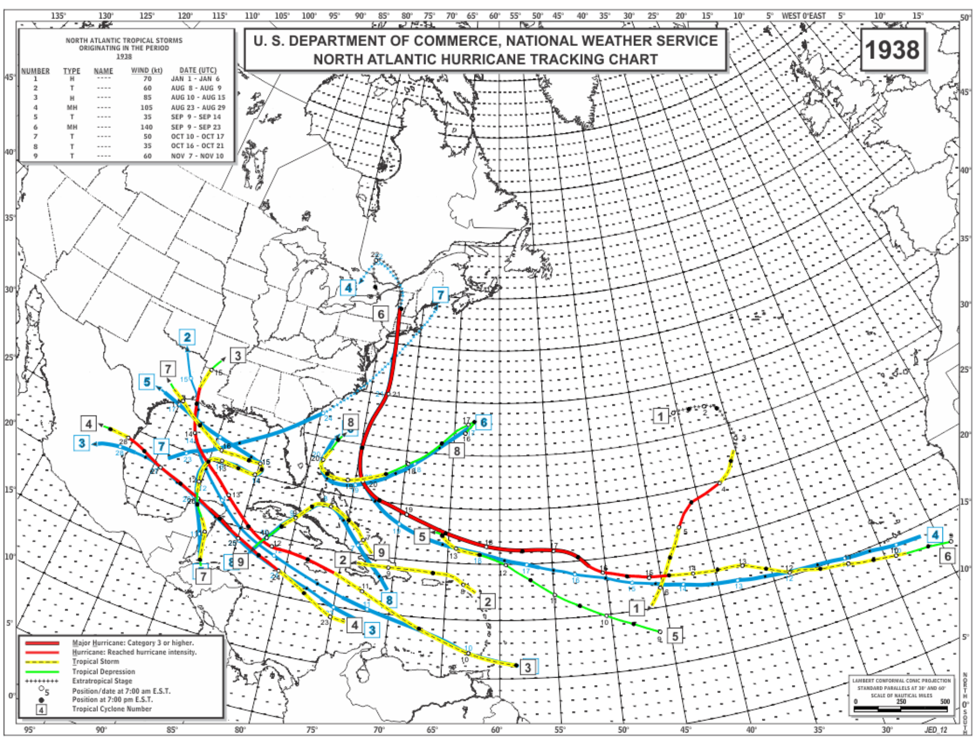
WEST 0° EAST
JED_12


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1938
NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1938
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 H ---- 70 JAN 1 - JAN 6
2 T ---- 60 AUG 8 - AUG 9
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4 MH ---- 105 AUG 23 - AUG 29
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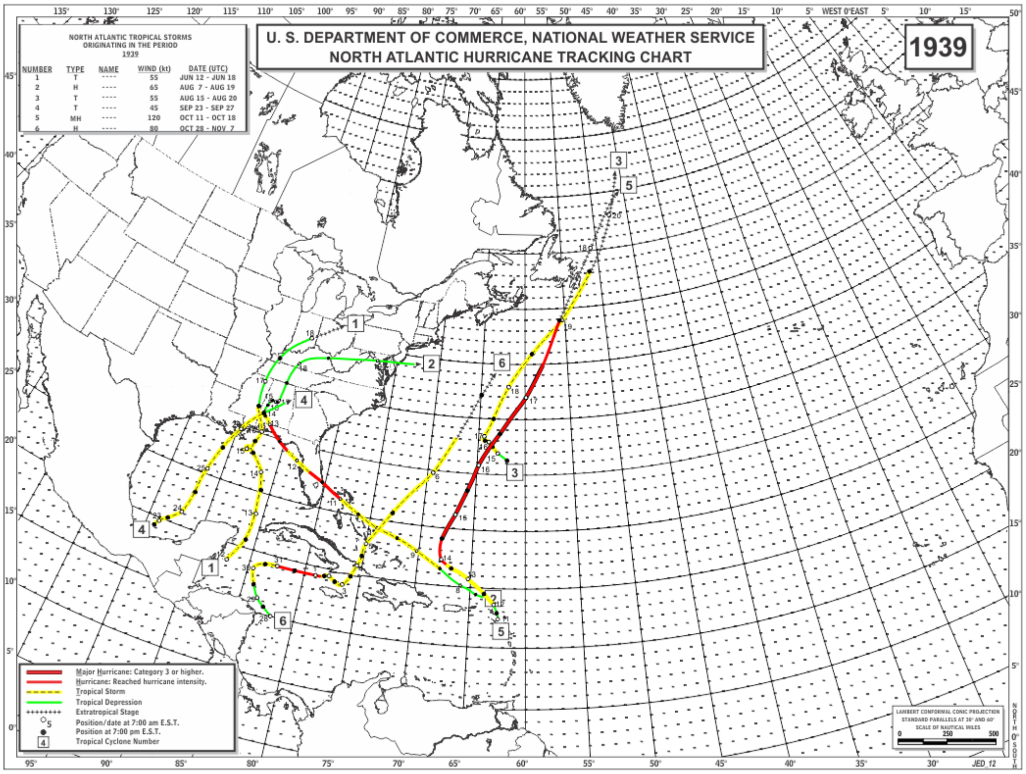
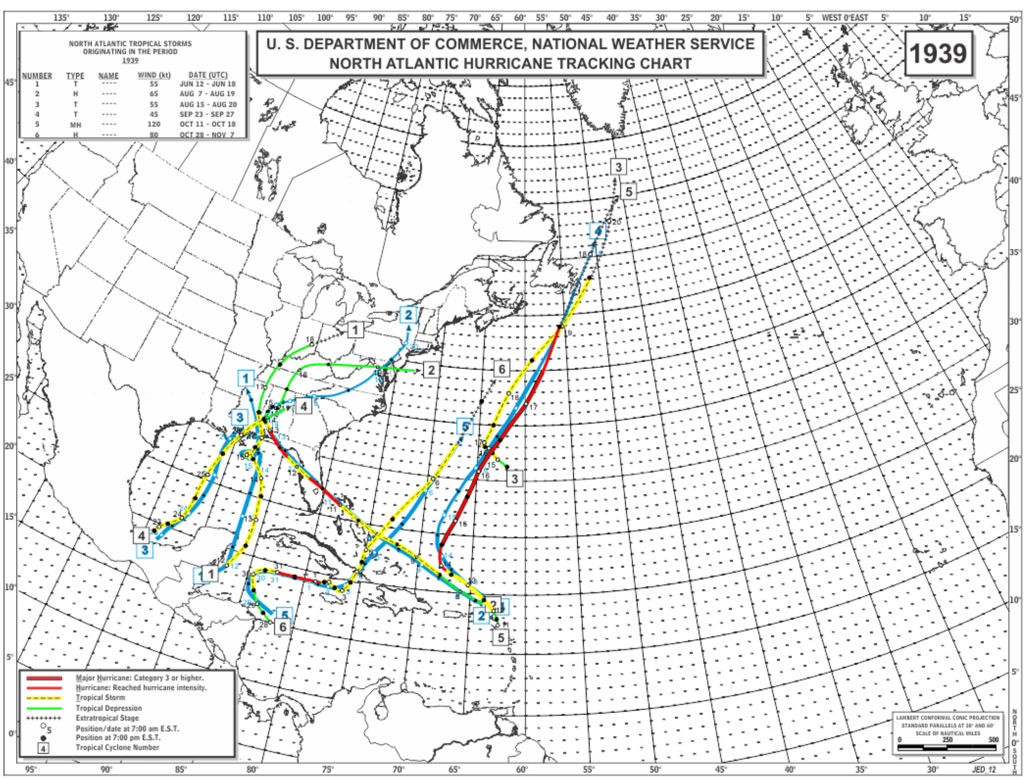
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
WEST 0° EAST
JED_12


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1939
NORTH ATLANTIC TROPICAL STORMS ORIGINATING IN THE PERIOD 1939
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 55 JUN 12 - JUN 18
2 H ---- 65 AUG 7 - AUG 19
3 T ---- 55 AUG 15 - AUG 20
4 T ---- 45 SEP 23 - SEP 27
5 MH ---- 120 OCT 11 - OCT 18
6 H ---- 80 OCT 28 - NOV 7
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
JED_12


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
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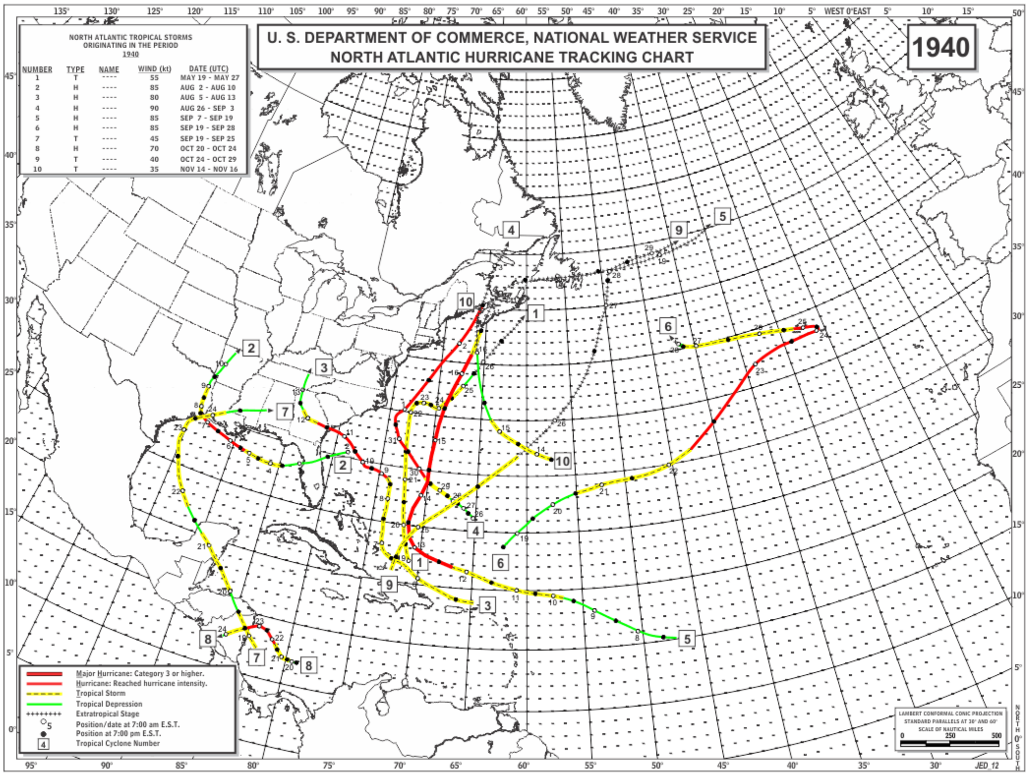
U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1940
NORTH ATLANTIC TROPICAL STORMS ORIGINATING IN THE PERIOD 1940
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 55 MAY 19 - MAY 27
2 H ---- 85 AUG 2 - AUG 10
3 H ---- 80 AUG 5 - AUG 13
4 H ---- 90 AUG 26 - SEP 3
5 H ---- 85 SEP 7 - SEP 19
6 H ---- 85 SEP 19 - SEP 28
7 T ---- 45 SEP 19 - SEP 25
8 H ---- 70 OCT 20 - OCT 24
9 T ---- 40 OCT 24 - OCT 29
10 T ---- 35 NOV 14 - NOV 16
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
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LAMBERT CONFORMAL CONIC PROJECTION
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SCALE OF NAUTICAL MILES
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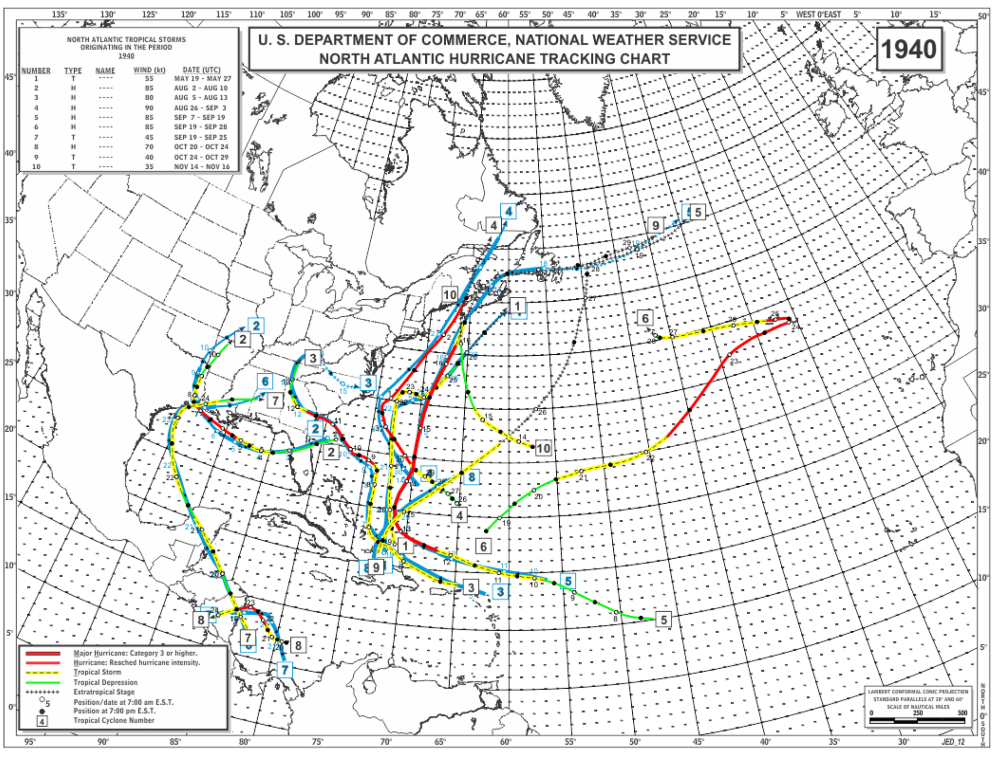
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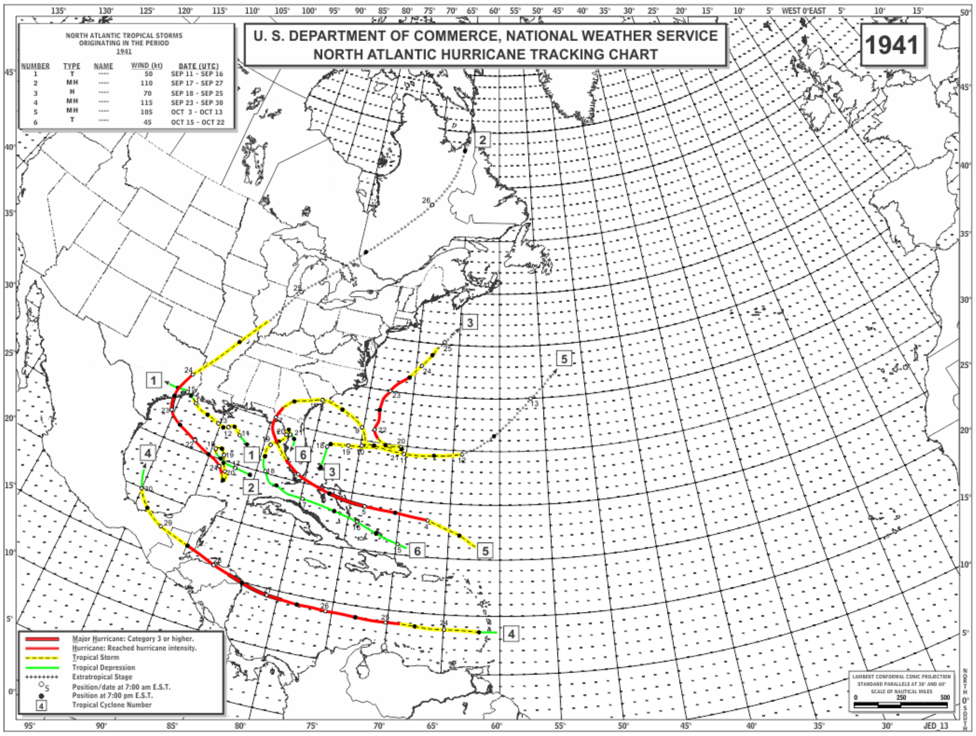
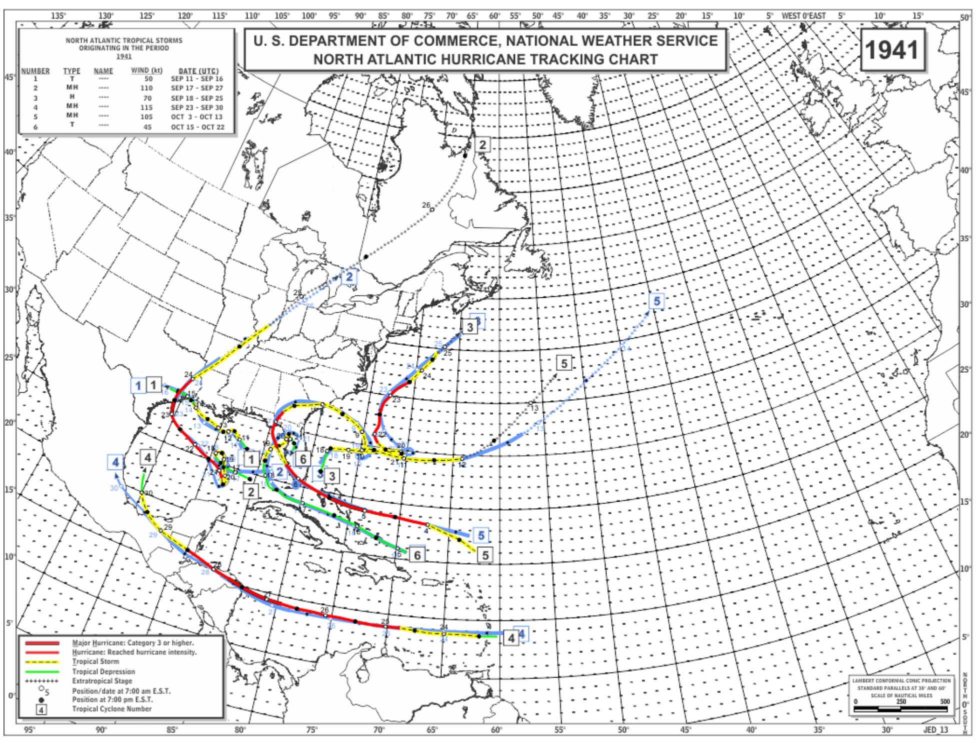


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1941
NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1941
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 50 SEP 11 - SEP 16
2 MH ---- 110 SEP 17 - SEP 27
3 H ---- 70 SEP 18 - SEP 25
4 MH ---- 115 SEP 23 - SEP 30
5 MH ---- 105 OCT 3 - OCT 13
6 T ---- 45 OCT 15 - OCT 22
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
JED_13



U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
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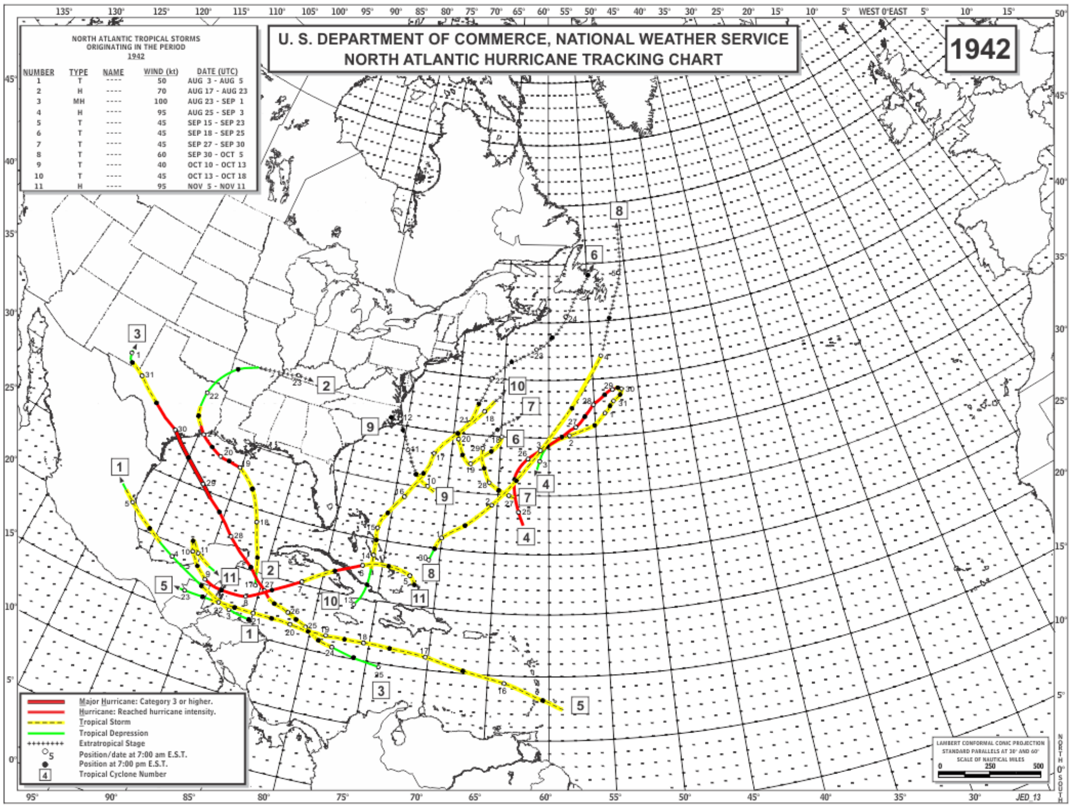
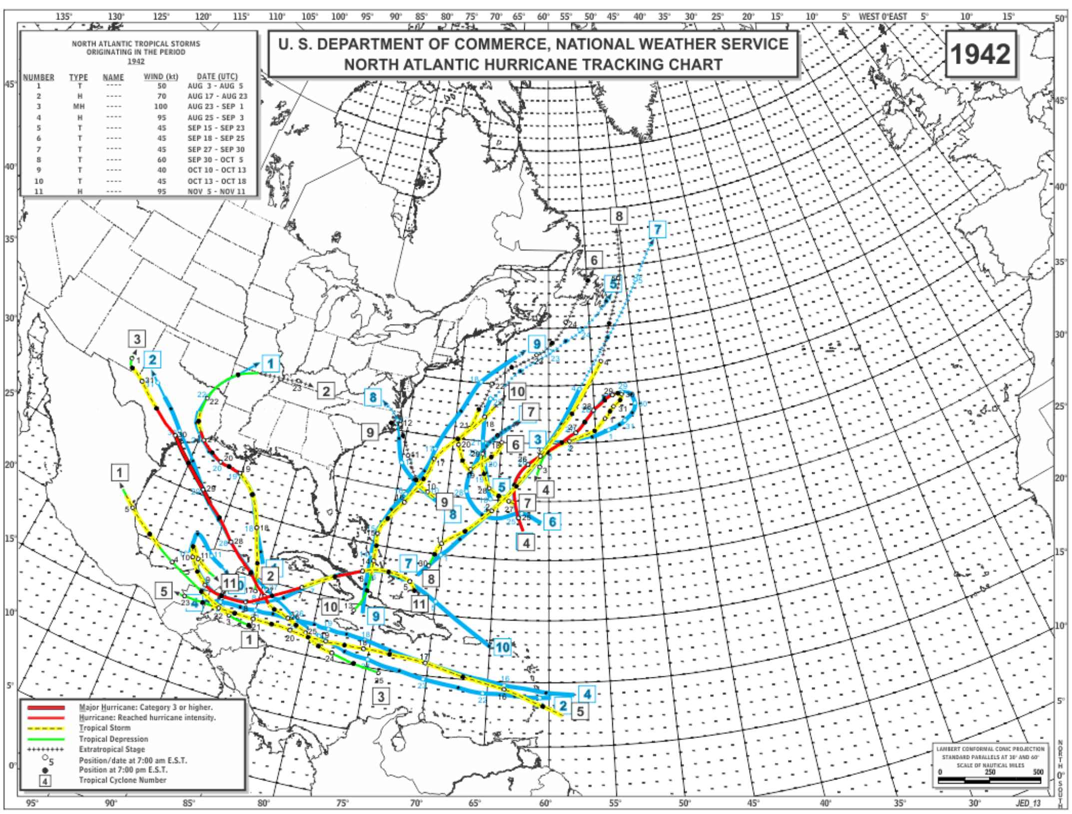
SCALE OF NAUTICAL MILES
JED_13


U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1942
NORTH ATLANTIC TROPICAL STORMS ORIGINATING IN THE PERIOD 1942
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 T ---- 50 AUG 3 - AUG 5
2 H ---- 70 AUG 17 - AUG 23
3 MH ---- 100 AUG 23 - SEP 1
4 H ---- 95 AUG 25 - SEP 3
5 T ---- 45 SEP 15 - SEP 23
6 T ---- 45 SEP 18 - SEP 25
7 T ---- 45 SEP 27 - SEP 30
8 T ---- 60 SEP 30 - OCT 5
9 T ---- 40 OCT 10 - OCT 13
10 T ---- 45 OCT 13 - OCT 18
11 H ---- 95 NOV 5 - NOV 11
Major Hurricane: Category 3 or higher.
Hurricane: Reached hurricane intensity.
Tropical Storm
Tropical Depression
Extratropical Stage
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
0 250 500
JED_13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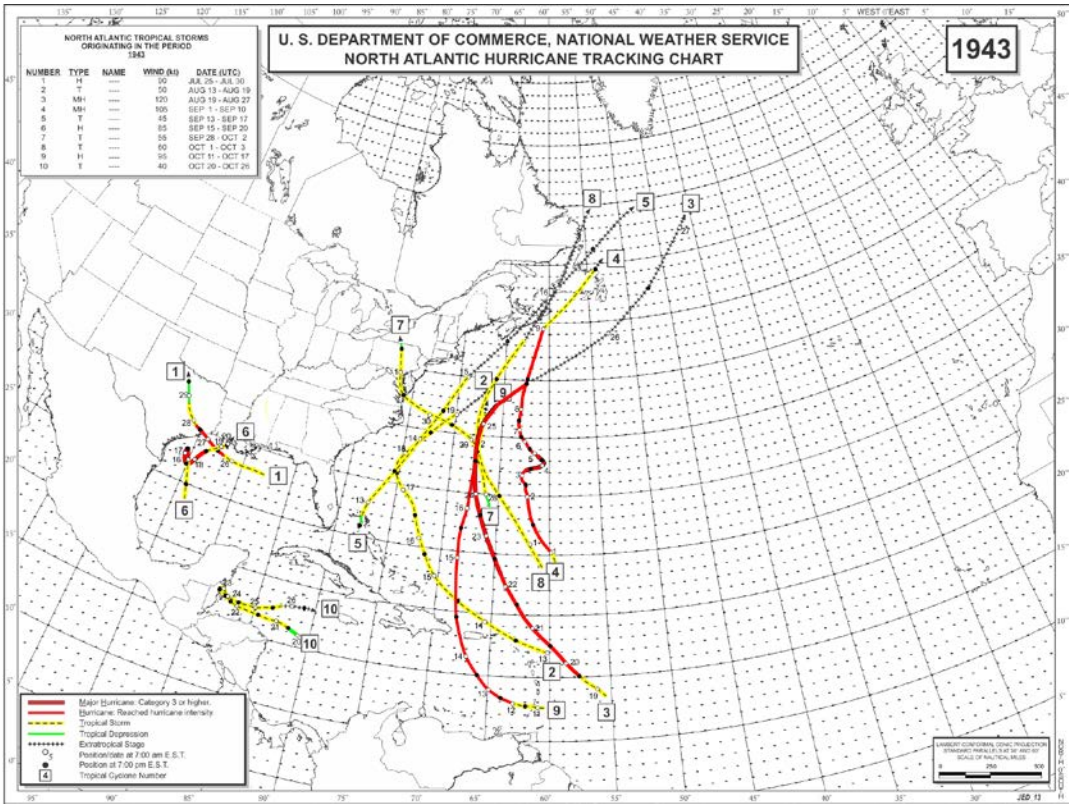
0 250 500
JED_13


NORTH ATLANTIC TROPICAL STORMS
ORIGINATING IN THE PERIOD
1943
NUMBER TYPE NAME WIND (kt) DATE (UTC)
1 H ---- 90 JUL 25 - JUL 30
2 T ---- 50 AUG 13 - AUG 19
3 MH ---- 120 AUG 19 - AUG 27
4 MH ---- 105 SEP 1 - SEP 10
5 T ---- 45 SEP 13 - SEP 17
6 H ---- 85 SEP 15 - SEP 20
7 T ---- 55 SEP 28 - OCT 2
8 T ---- 60 OCT 1 - OCT 3
9 H ---- 95 OCT 11 - OCT 17
10 T ---- 40 OCT 20 - OCT 26
U. S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
1943
Major Hurricane: Category 3 or higher.
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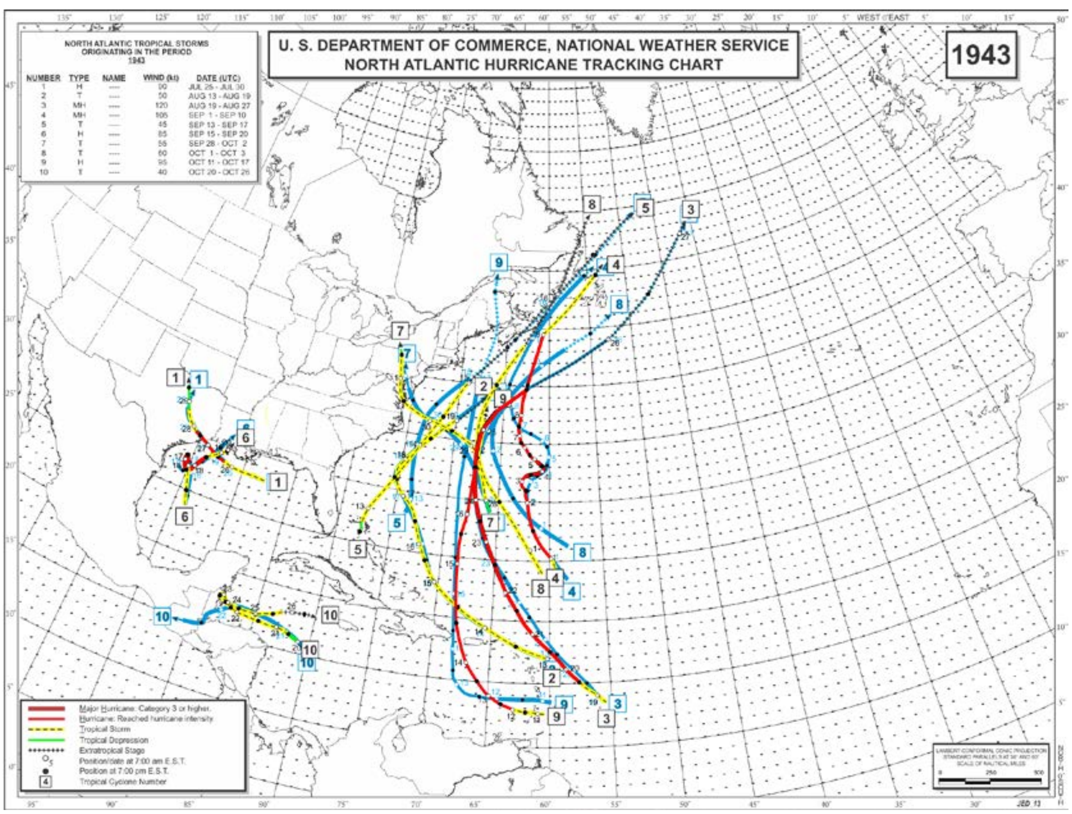
Position/date at 7:00 am E.S.T.
Position at 7:00 pm E.S.T.
Tropical Cyclone Number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Tropical Cyclone Number

Figure 2: The revised (top) and comparison (with original storm numbers and tracks in blue underlying revised track) (bottom) Atlantic basin TC track map for 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, and 1943.

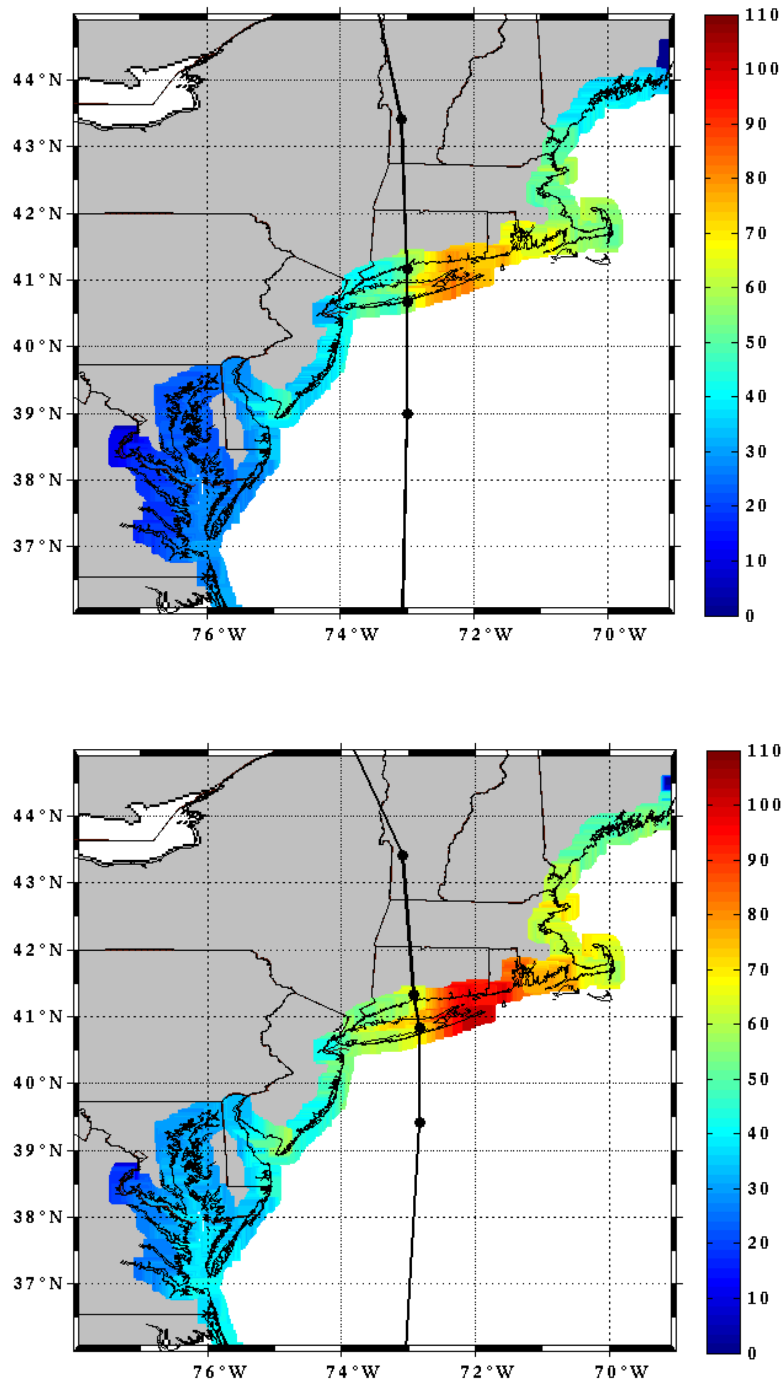

Figure 3: Original (top) and revised (bottom) track and coastal wind swaths (in kt) for the 1938 Great New England hurricane. The coastal wind swaths were obtained from the AEF wind model.

Table 1: Estimated average position uncertainty in the revised best track for the years 1851-1953 and in the existing best track for the late 1990s to late 2000s. Here and in the subsequent two tables "N/A" refers to "not applicable". (1851 to 1910 is discussed in Landsea et al. [2004a], 1911-1920 in Landsea et al. [2008], 1921-1930 in Landsea et al. [2012], 1931-1943 within this paper, 1944-1953 within Hagen et al. [2012], and late 1990s/late 2000s in Landsea and Franklin, [2013]. By the 1920s, nearly all coastal areas in the Atlantic basin were relatively settled and monitored – Landsea et al. [2008].)

Dates	Landfall along settled coast	Open ocean with aircraft reconnaissance	Open ocean without aircraft reconnaissance (or landfall along unpopulated coast)
1851-1885	60 nm	N/A	120 nm
1886-1943	60 nm	N/A	100 nm
1944-1953	20 nm	35 nm	80 nm
Late 1990s-Late 2000s	12 nm	15 nm	25 nm

Table 2: Estimated average intensity uncertainty in the revised best track for the years 1851-1953 and in the existing best tracks for the late 1990s, and late 2000s. (1851 to 1910 is discussed in Landsea et al. [2004a], 1911-1920 in Landsea et al. [2008], 1921-1930 in Landsea et al. [2012], 1931-1943 within this paper, 1944-1953 within Hagen et al. [2012], and late 1990s/late 2000s in Landsea and Franklin, [2013]. By the 1920s, nearly all coastal areas in the Atlantic basin were relatively settled and monitored – Landsea et al. [2008].)

Dates	Landfall along settled coast	Open ocean with aircraft central pressure	Open ocean with aircraft, no central pressure	Open ocean without aircraft reconnaissance (or landfall along unpopulated coast)
1851-1885	15 kt	N/A	N/A	25 kt
1886-1943	15 kt	N/A	N/A	20 kt
1944-1953	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

Table 3: Estimated average intensity error bias in the revised best track for the years 1851-1953 and in the existing best tracks for the late 1990s-late 2000s. Columns four through seven provide stratification of estimated bias by *actual* cyclone intensity when aircraft reconnaissance was monitoring the system but did not report a central pressure. (1851 to 1910 is discussed in Landsea et al. [2004a], 1911-1920 in Landsea et al. [2008], 1921-1930 in Landsea et al. [2012], 1931-1943 within this paper, 1944-1953 within Hagen et al. [2012], and late 1990s/late 2000s in Landsea and Franklin, [2013]. By the 1920s, nearly all coastal areas in the Atlantic basin were relatively settled and monitored – Landsea et al. [2008].)

Dates	Landfall along settled coast	Open ocean with aircraft central pressure	Open ocean with aircraft, no central pressure (30-60 kt)	Open ocean with aircraft, no central pressure (65-95 kt)	Open ocean with aircraft, no central pressure (100-115 kt)	Open ocean with aircraft, no central pressure 120 kt +)	Open ocean without aircraft reconnaissance (or landfall along unpopulated coast)
1851-1885	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
1944-1953	0 kt	0 kt	+ 3 kt	+ 5 kt	0 kt	-10 kt	-10 kt
Late 1990s-Late 2000s	0 kt	0 kt	N/A	N/A	N/A	N/A	0 kt

Table 4: Original/revised tropical storm and hurricane, hurricane, major hurricane and Accumulated Cyclone Energy (ACE) counts. ACE is expressed in units of 10^4 kt^2.

Year	Tropical Storms & Hurricanes	Hurricanes	Major Hurricanes	ACE
1931	9/13	2/3	1/1	39/48
1932	11/15	6/6	4/4	136/170
1933	21/20	10/11	5/6	213/259
1934	11/13	6/7	0/1	60/48
1935	6/8	5/5	3/3	95/106
1936	16/17	7/7	1/1	108/100
1937	9/11	3/4	0/1	61/66
1938	8/9	3/4	1/2	73/78
1939	5/6	3/3	1/1	34/34
1940	8/9	4/6	0/0	52/68
1941	6/6	4/4	2/3	61/52
1942	10/11	4/4	1/1	66/63
1943	10/10	5/5	2/2	94/94
Average 1931-1943	10.0/11.4	4.8/5.3	1.6/2.0	84.0/91.2
Average 1981-2010	12.1	6.4	2.7	104.4

Table 5: Continental U.S. Hurricanes for 1931 to 1943. Date/Time - day and time when the circulation center crosses the U.S. coastline (including barrier islands). Time is estimated to the nearest hour. Lat/Lon - Location is estimated to the nearest 0.1 degrees latitude and longitude. Max Winds - Estimated maximum (1 min) surface (10 m) winds to occur along the U. S. coast. SSHWS - The Saffir-Simpson Hurricane Wind Scale at landfall based upon estimated maximum 1-min surface winds. RMW - The radius of maximum winds, if available, to the nearest 5 nm. Central Pressure - The minimum central pressure of the hurricane at landfall. Central pressure values in parentheses indicate that the value is a simple estimation (based upon a wind-pressure relationship), not directly measured or calculated. OCI – The Outer Closed Isobar, or the sea level pressure at the outer limits of the hurricane circulation as determined by analysis of the outer closed isobar (in increments of 1 mb). Size - This is the average radius of the OCI. States Affected - The impact of the hurricane upon individual U.S. states by Saffir-Simpson Hurricane Wind Scale (again through the estimate of the maximum 1-min surface winds at each state). (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, MD-Maryland, DE-Delaware, NJ-New Jersey, NY-New York, PA-Pennsylvania, CT-Connecticut, RI-Rhode Island, MA-Massachusetts, NH-New Hampshire, ME-Maine. In Texas, south is roughly from the Mexico border to Corpus Christi; central is from north of Corpus Christi to Matagorda Bay and north is from Matagorda Bay to the Louisiana border. In Florida, the north-south dividing line is from Cape Canaveral [28.45N] to Tarpon Springs [28.17N]. The dividing line between west-east Florida goes from 82.69W at the north Florida border with Georgia, to Lake Okeechobee and due south along longitude 80.85W. Occasionally, a hurricane will cause a

hurricane impact (estimated maximum sustained surface winds) in an inland state. To differentiate these cases versus coastal hurricane impacts, these inland hurricane strikes are denoted with an "I" prefix before the state abbreviation. “(EX)” indicates that the system was originally considered to be an extratropical cyclone at landfall.) “*” - Indicates that the hurricane center did not make a U.S. landfall, but did produce hurricane force winds over land. Position indicated is point of closest approach. Winds stronger than indicated to impact the United States may have existed elsewhere in the hurricane. Central pressure in this case is the hurricane's value at the point of closest approach. “#” - Indicates that hurricane made landfall first over Mexico, but caused hurricane winds in Texas. The position given is that of Mexican landfall. The strongest winds impacted Mexico. The winds indicated here are lower than in HURDAT2 and are lower than they were over Mexico. Central pressure given is that at Mexican landfall.

#/Date	Time	Lat	Lon	Max Winds	SSHWS	RMW	Central Pressure	OCI	Size	States Affected	Original Assessment
None - 1931											
2-8/14/1932	0400Z	29.0N	95.2W	130	4	10	935	1011	200	CTX4,BTX1	CTX4
3-9/01/1932	0500Z	30.2N	88.1W	75	1	---	979	1009	200	AFL1,AL1,MS1	AL1
5-7/30/1933	1600Z	27.1N	80.1W	65	1	---	988	1018	150	CFL1	CFL1
5-8/5/1933#	0100Z	25.8N	97.2W	80	1	25	975	1010	200	ATX1	ATX2
6-8/23/1933	1000Z	35.8N	75.6W	80	1	40	963	1008	300	NC1,VA1,MD1	NC2,VA2
8-9/5/1933	0400Z	26.1N	97.2W	110	3	20	(940)	1010	225	ATX3	ATX3
11-9/4/1933	0500Z	26.9N	80.1W	110	3	15	948	1013	175	CFL3	CFL3
12-9/16/1933*	1200Z	35.2N	75.4W	85	2	40	952	1013	275	NC2,VA1	NC3
1-6/16/1934	1900Z	29.7N	91.7W	85	2	30	966	1004	275	LA2	LA3
3-7/25/1934	1700Z	28.1N	96.8W	75	1	25	979	1009	225	ATX1	ATX2
7-9/8/1934*	1000Z	35.3N	75.3W	65	1	---	(975)	1014	200	NC1	(EX)
7-9/8/1934*	2200Z	39.7N	73.4W	65	1	---	(984)	1017	200	NJ1	(EX)
7-9/9/1934	0200Z	40.7N	73.0W	65	1	---	(989)	1018	200	NY1	(EX)
3-9/3/1935	0200Z	24.8N	80.8W	160	5	5	892	1010	300	CFL5,BFL5	CFL5
3-9/4/1935	2200Z	29.6N	83.4W	85	2	20	965	1012	350	AFL2,IGA1	AFL2
7-11/4/1935	1800Z	25.9N	80.1W	85	2	10	973	1012	225	CFL2,BFL1	CFL2
3-6/27/1936	1600Z	27.9N	97.0W	70	1	5	987	1013	150	BTX1	ATX1
5-7/31/1936	1400Z	30.4N	86.6W	90	2	20	964	1013	200	AFL2,IAL1	AFL3
13-9/18/1936*	1000Z	35.6N	74.8W	75	1	35	964	1016	325	NC1,VA1	NC2
None – 1937											
3-8/15/1938	0100Z	29.8N	93.4W	65	1	15	(995)	1010	100	LA1	LA1
6-9/21/1938	2000Z	40.7N	72.9W	105	3	40	941	1011	350	NY3	NY3
6-9/21/1938	2100Z	41.3N	72.9W	100	3	40	946	1011	350	CT3,RI3,MA2	CT3,RI3,MA3
2-8/11/1939	2300Z	27.2N	80.2W	65	1	---	(987)	1012	100	CFL1	CFL1
2-8/13/1939	0600Z	30.4N	86.4W	65	1	---	985	1015	200	AFL1	AFL1
2-8/7/1940	2100Z	29.7N	94.1W	85	2	10	972	1011	225	CTX2,LA2	CTX2,LA2
3-8/11/1940	2000Z	32.1N	80.8W	85	2	25	972	1014	225	SC2,GA1	SC2,GA2
2-9/23/1941	2200Z	28.8N	95.6W	110	3	20	(942)	1007	250	CTX3,BTX2	CTX3

5-10/6/1941	1000Z	25.5N	80.2W	85	2	10	(980)	1015	125	CFL2,BFL1	CFL2,BFL1
5-10/6/1941	1100Z	25.5N	80.3W	85	2	10	(980)	1015	125	CFL2,BFL1	CFL2,BFL1
5-10/7/1941	0900Z	29.9N	84.6W	80	1	20	982	1015	125	AFL1,IGA1	AFL2
2-8/21/1942	1300Z	29.5N	94.6W	65	1	---	(992)	1010	125	CTX1	CTX1
3-8/30/1942	0900Z	28.3N	96.6W	100	3	20	950	1007	250	BTX3,CTX2	BTX3
1-7/27/1943	1800Z	29.5N	94.6W	90	2	15	967	1013	250	CTX2	CTX2

Table 6: Major Landfalling non-continental U.S Hurricanes - 1931 to 1943. The names listed are unofficial ones that the hurricanes are known by at these locations. Max Winds are the estimated maximum 1-min surface (10 m) winds to occur at along the coast at landfall/closest approach. Saffir-Simpson is the estimated Saffir-Simpson Hurricane Scale at landfall based upon maximum 1-min surface winds. Central Pressure is the minimum central pressure of the hurricane at landfall/closest approach. Central pressure values in parentheses indicate that the value is a simple estimation (based upon a pressure-wind relationship), not directly measured or calculated. Original Winds are the winds in HURDAT2 that were originally provided at landfall/closest approach.

#/Date	Name	Location	Max Winds	SSHWS	Central Pressure	Original Winds
6-9/10/1931	------	Belize	115	4	(948)	110
4-9/5/1932	------	Bahamas	140	5	(918)	140
9-9/26/1932	San Ciprián	Puerto Rico	125	4	943	95
14-11/9/1932	El Huracán de Santa Cruz del Sur	Cuba, Caymen Islands	130	4	918	115
14-11/10/1932	------	Bahamas	110	3	(947)	105
8-8/31/1933	------	Bahamas	140	5	(918)	70
8-9/1/1933	El Huracán de Sagua Y Cárdenas	Cuba	105	3	954	85
11-9/3/1933	------	Bahamas	120	4	945	120
14-9/22/1933	------	Mexico	120	4	(943)	90
17-10/5/1933	------	Bahamas	105	3	(955)	125
1934 – None						
5-9/28/1935	El Huracán de Cienfuegos	Cuba	105	3	955	105
5-9/29/1935	------	Bahamas	115	4	(945)	100
1936 – None						
1937 – None						
4-8/26/1938	------	Mexico	105	3	(958)	85
1939 – None						
1940 – None						
4-9/27/1941	------	Nicaragua, Honduras	115	4	(948)	105
5-10/5/1941	------	Bahamas	105	3	962	90
1942 – None						
1943 – None						