Atlantic Hurricane Season of 2000

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(Manuscript received 14 February 2001, in final form 14 May 2001)

ABSTRACT

The 2000 Atlantic hurricane season is summarized and the year's tropical and subtropical cyclones are described. While overall activity was very high compared to climatology, with 15 cyclones attaining tropical (or subtropical) storm intensity, much of this activity occurred outside of the deep Tropics, over open waters north of 25°N. The season's tropical cyclones were responsible for 54 fatalities, with most of these occurring in Central America in association with Hurricanes Gordon and Keith.

1. Introduction

By most measures, tropical cyclone activity in the Atlantic hurricane basin was above average in the year 2000. Including an unnamed subtropical storm that occurred in late October, there were 15 cyclones of at least tropical (or subtropical) storm strength (Table 1). Of these, eight became hurricanes, and three, Alberto, Isaac, and Keith, became ''major'' hurricanes [i.e., maximum 1-min average winds greater than 96 kt (1 kt = 0.5144 m s^{-1}), corresponding to category 3 or higher on the Saffir–Simpson hurricane scale (Simpson 1974)]. In addition to these systems, there were four depressions that failed to reach tropical storm strength. In an average season, there are 10 named storms, 6 hurricanes, and 2 major hurricanes. Although overall activity was above average, most of it occurred over the open waters of the Atlantic north of 25°N (Fig. 1), and indeed, four of the season's cyclones were subtropical for at least a portion of their life cycle. The season was also more compact than normal, with all of the named storms occurring during August, September, and October. Isaac and Keith were the strongest hurricanes of the season, each with peak winds of 120 kt.

Atlantic tropical cyclones were directly responsible for 54 deaths in 2000; most of these resulted from Hurricanes Gordon and Keith. Keith, the most destructive hurricane of the season, made landfall in Belize and the eastern Yucatan Peninsula of Mexico in early October. Apart from Keith, those systems that affected land were significantly weakened by hostile environmental conditions prior to landfall. There were no hurricane landfalls in the continental United States, but both Gordon and Helene came ashore in northern Florida as tropical storms. Only twice before (in 1951 and 1990) have there been as many as eight hurricanes in a season with no U.S. hurricane landfalls. Total U.S. damage for the season is estimated to be a modest $27 million. However, this does not include roughly $950 million in flood damage in south Florida caused, in part, by the precursor disturbance to Tropical Storm Leslie.

Section 2 below describes the 2000 season's tropical and subtropical cyclones that attained at least minimal tropical storm strength (34 kt). Weaker tropical cyclones and other tropical weather systems are discussed in section 3. Section 4 presents a verification of National Hurricane Center (NHC) official forecasts, and section 5 offers some concluding discussion about the 2000 season.

2. Storm and hurricane summaries

The individual cyclone summaries in this section are based on NHC's poststorm meteorological analyses. These analyses result in the creation of a ''best track'' database for each storm, consisting of 6-hourly representative estimates of the cyclone's location, maximum sustained (1-min average) surface (10 m) wind, and minimum sea level pressure. The life cycle of the cyclone is defined to include the tropical (or subtropical) depression stage, but does not include the extratropical stage.

For storms east of 55°W, or those not threatening land, the primary (and often sole) source of information is Geostationary Operational Environmental Satellite (GOES) and polar-orbiting weather satellite imagery, interpreted using the Dvorak (1984) technique. For sys-

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TABLE 1. Atlantic hurricane season statistics for 2000.

No.	Name	Class[a]	Dates[b]	Maximum 1-min wind in kt (m s^{-1})	Minimum sea level pressure (mb)	U.S. damage ($ millions)	Direct deaths
1	Alberto	H	3–23 Aug	110 (57)	950		
2	Beryl	T	13–15 Aug	45 (23)	1007		1
3	Chris	T	17–19 Aug	35 (18)	1008		
4	Debby	H	19–24 Aug	75 (39)	991	0.5	
5	Ernesto	T	1–3 Sep	35 (18)	1008		
6	Florence	H	10–17 Sep	70 (36)	985		3
7	Gordon	H	14–18 Sep	70 (36)	981	10.8	24[c]
8	Helene	T	15–25 Sep	60 (31)	986	16	1
9	Isaac	H	21 Sep–1 Oct	120 (62)	943		1
10	Joyce	H	25 Sep–2 Oct	80 (41)	975		
11	Keith	H	28 Sep–6 Oct	120 (62)	939		24
12	Leslie	T	4–7 Oct	40 (21)	1006	[d]	
13	Michael	H	15–19 Oct	85 (44)	965		
14	Nadine	T	19–21 Oct	50 (26)	999		
15	—	ST	25–29 Oct	55 (28)	976		

[a] T = tropical storm, wind speed 34–63 kt (17–32 m s^{-1}); H = hurricane, wind speed 64 kt (33 m s^{-1}) or higher; ST = subtropical storm, wind speed 34 kt (17 m s^{-1}) or higher.

[b] Dates begin at 0000 UTC and include tropical and subtropical depression stages but exclude extratropical stage.

[c] The timing of 23 deaths in Guatemala is uncertain; these may have occurred prior to tropical cyclone genesis.

[d] Although neither Leslie nor the subtropical depression from which it formed were responsible for damage, an antecedent disturbance combined with a stalled frontal boundary to produce $950 million in flood damage in south Florida.

tems posing a threat to land, in situ observations are also generally available from aircraft reconnaissance flights conducted by the 53d Weather Reconnaissance Squadron (''Hurricane Hunters'') of the Air Force Reserve Command (AFRC), and by the National Oceanic and Atmospheric Administration (NOAA) Aircraft Operations Center. During reconnaissance flights, minimum sea level pressures are either measured by dropsondes released at the circulation center or extrapolated hydrostatically from flight level. Surface (or very near surface) winds in the eyewall or maximum wind band are often measured directly using Global Positioning System (GPS) dropwindsondes (Hock and Franklin 1999), but more frequently are estimated from flight-level winds using empirical relationships derived from a 3-yr sample of GPS dropwindsonde data (Franklin et al. 2000). When available, satellite and reconnaissance data are supplemented by conventional land-based surface and upper-air observations, ship and buoy reports, and weather radars. In key forecast situations, the vertical kinematic and thermodynamic structure of the storm environment is obtained from dropsondes released during operational ''synoptic surveillance'' flights of NOAA's Gulfstream IV jet aircraft (Aberson and Franklin 1999).

Several satellite-based remote sensors are playing an increasingly important part in the analysis of tropical weather systems. Foremost of these is multichannel passive microwave imagery, which over the past decade has provided radarlike depictions of systems' convective structure (Hawkins et al. 2001), and is of great help in assessing system location and organization. Available for a full season for the first time in 2000, the SeaWinds scatterometer on board the National Aeronautics and Space Administration's Quick Scatterometer satellite (*QuikSCAT*; Tsai et al. 2000) provides surface winds over large oceanic swaths. While the *QuikSCAT* does not have the horizontal resolution to determine a cyclone's maximum winds, it can be used to estimate the extent of tropical storm force winds, and is often helpful in determining whether an incipient tropical cyclone has acquired a closed surface circulation. Finally, information on the thermal structure of cyclone cores is provided by the Advanced Microwave Sounder Unit (AMSU; Velden and Brueske 1999).

a. Hurricane Alberto, 3–23 August

Alberto, a classical ''Cape Verde'' hurricane that remained at sea throughout its existence, was the third longest lived tropical cyclone on record in the Atlantic basin. Its life cycle featured three intensifications to hurricane strength and a large, 8-day anticyclonic loop in its track (Fig. 1). There were no reports of damage or casualties associated with Alberto.

Alberto's existence as a tropical cyclone began when a depression developed from a tropical wave in the eastern tropical Atlantic just off the African coast on 3 August; the depression strengthened and became Tropical Storm Alberto the following day. Over the next several days Alberto moved between west and west-northwest, becoming a hurricane early on 6 August. Alberto turned northwestward on 8 August and weakened to a tropical storm the next day in increasing southeasterly wind shear; however, the shear relaxed and Alberto regained hurricane strength on 10 August. The hurricane then turned northward through a break in the subtropical ridge, passing about 300 n mi (1 n mi =

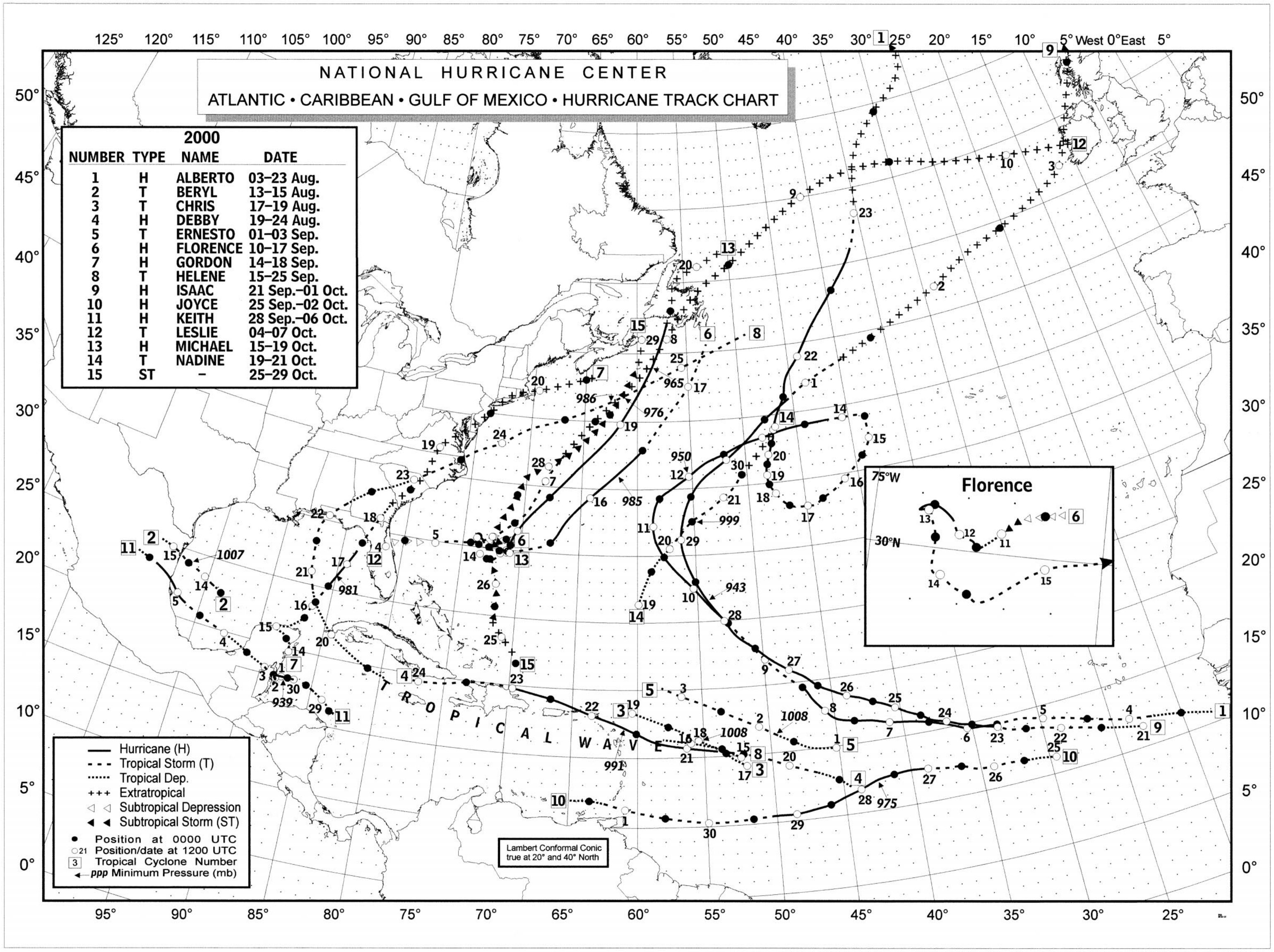

FIG. 1. Tracks of tropical storms, hurricanes, and subtropical storms in the Atlantic basin in 2000. A portion of the track of Hurricane Florence is shown in the inset.

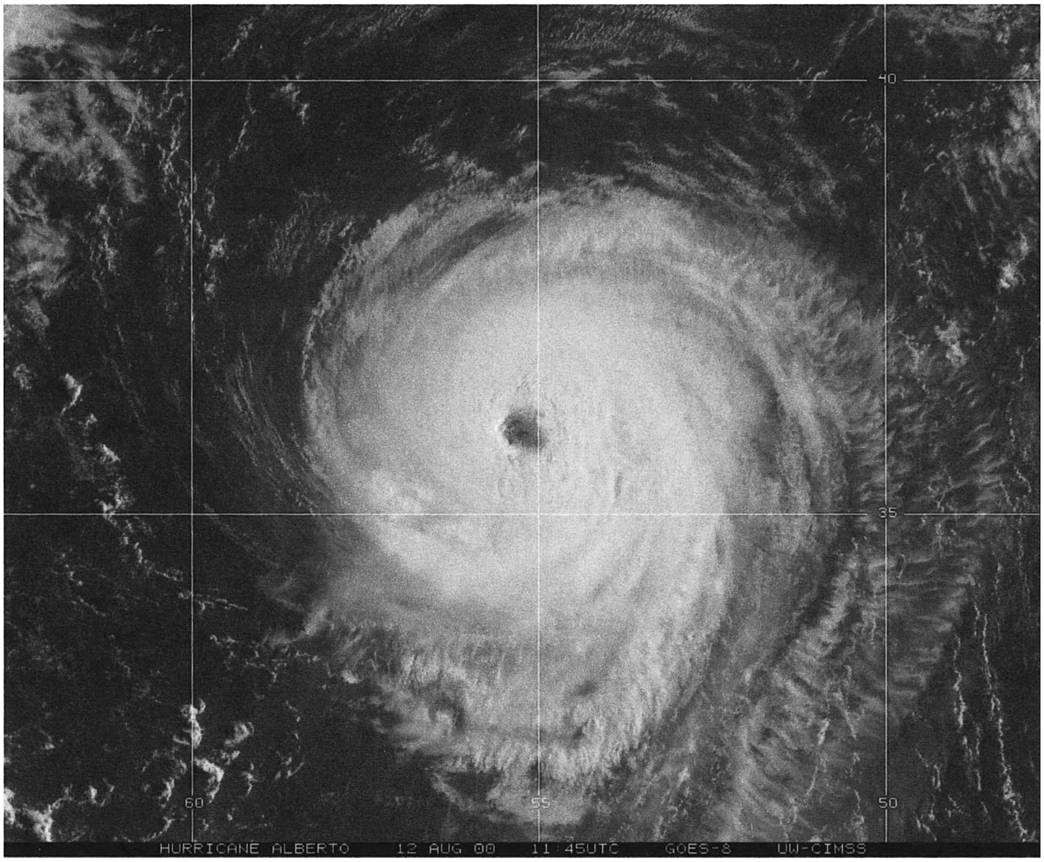

FIG. 2. *GOES-8* visible satellite image of Hurricane Alberto at 1145 UTC 12 Aug 2000, near the time of peak intensity [courtesy Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin.]

1.853 km) east of Bermuda on 11 August. Alberto continued to strengthen as it began a turn to the northeast, and its peak intensity of 110 kt was attained on 12 August, shortly after the turn. Satellite imagery (Fig. 2) at this time showed Alberto with a 50 n mi wide eye.

For the next two days, the hurricane moved to the east-northeast, and weakened to a tropical storm as its convection diminished under increasing upper-level westerly flow. During this time, near midday on 13 August, Alberto was about 550 n mi south-southeast of Cape Race, Newfoundland, a location it would subsequently return to in 8 days. The trough in the westerlies that had been providing the steering flow unexpectedly left the storm behind, and strong ridging developed to the north and west of the cyclone. This produced a southward turn on 15 August that was the start of a large, lazy, generally westwardly looping trajectory over the next 5 days between Bermuda and the Azores. During this time Alberto attained hurricane status for a third time, developing a 60 n mi wide eye and winds of 90 kt on 20 August. After completing the loop on 21 August, Alberto continued generally to the north-northeast, and finally became extratropical on 23 August about 800 n mi southwest of Reykjavik, Iceland. Alberto passed over western Iceland as an extratropical gale on 24 August.

Conventional observations in Alberto were scarce. A report of 44-kt winds and a 1007.8-mb pressure from the ship MZYF3 (name unknown) at 0600 UTC 4 August was the basis for the initial upgrade to tropical storm status. Another ship report [34-kt winds at 0600 UTC 3 August from the *Conti Sydney* (call sign DEHU)] suggests that Alberto may have become a tropical storm earlier than indicated in the best track. However, this observation was not consistent with concurrent Dvorak technique intensity estimates and has been discounted.

b. Tropical Storm Beryl, 13–15 August

Beryl, which formed in the southwestern Gulf of Mexico on 13 August (Fig. 1), had its origins in the same tropical wave that spawned Hurricane Alberto. In contrast to the powerful and long-lived Alberto, Beryl had a brief existence as a weak and poorly organized tropical storm; nevertheless, it was responsible for one death (from flooding) when it made landfall in northeast Mexico.

While the northern portion of the tropical wave that emerged from the African coast on 3 August quickly developed the closed circulation that became Alberto, the southern portion of the wave axis continued westward, generating little or no deep convection until it reached the Yucatan Peninsula of Mexico on 12 August. A broad area of low pressure then developed in association with the wave, and moved into the Bay of Campeche early on 13 August. By late in the day a tropical depression had formed, likely not long before an AFRC Hurricane Hunter aircraft found a definite closed surface wind circulation. The depression moved to the west-northwest, becoming a tropical storm early on 14 August. With most of its strongest winds occurring in rainbands south of the center, the storm moved slowly west-northwestward, and made landfall with 45-kt winds in northeast Mexico about 30 n mi north of La Pesca, Mexico, shortly after midnight (local time) on 15 August. Beryl dissipated over the mountains of northern Mexico later that day.

c. Tropical Storm Chris, 17–19 August

Chris was a short-lived system that became a depression about 600 n mi east of the Lesser Antilles on 17 August (Fig. 1) and, based on Dvorak intensity estimates, appears to have briefly reached minimal tropical storm status at 1200 UTC on 18 August. Almost immediately thereafter, Chris's satellite presentation deteriorated, and an AFRC reconnaissance aircraft in the cyclone 5 h later could not find any tropical storm force winds. In an increasingly sheared environment Chris weakened rapidly, and the cyclone dissipated on 19 August northeast of the Leeward Islands.

d. Hurricane Debby, 19–24 August

Debby struck the islands of the northeast Caribbean as a hurricane with 65-kt winds, but its effects there were relatively minor. Just when the hurricane began to pose a significant threat to south Florida, it weakened abruptly and unexpectedly.

1) SYNOPTIC HISTORY

A strong tropical wave moved off the west coast of Africa on 16 August, accompanied by winds to near 50 kt at the 650-mb level over Dakar, Senegal. A low-level circulation center could be identified by 0000 UTC 18 August but the system lacked the convective organization required of a tropical depression. As the disturbance moved westward at around 15 kt, it gradually became better organized, becoming a tropical depression about 900 n mi east of the Windward Islands by 1800 UTC on 19 August (Fig. 1).

Vertical shear was weak over the area and anticyclonic outflow developed aloft. In this environment, the cyclone strengthened and became Tropical Storm Debby near 0600 UTC on 20 August. A pronounced midlevel ridge to the north of the cyclone kept Debby on a west-northwestward track. By midday on 20 August, microwave imagery indicated that the low-level center was displaced a bit to the southwest of the mid- to upper-level center, a pattern suggestive of a southwesterly shearing environment. Radiosonde data from the Lesser Antilles indicated that the increased shearing resulted from unusually strong lower-tropospheric easterlies. Nonetheless, the storm strengthened further and reached hurricane strength by 0600 UTC 21 August. By this time, infrared satellite imagery also showed the signature of a sheared system; however, Debby continued to strengthen and reached its peak intensity of 75 kt a little later on 21 August (Fig. 3).

The strengthening ceased by late on 21 August. Debby had maximum winds of 65 kt when its center moved across the extreme northern Leeward Islands from 0600 to 1200 UTC on 22 August. Continuing west-northwestward, the center moved over the British Virgin Islands around 1500 UTC on 22 August, and passed about 30 n mi off the northeast coast of Puerto Rico a few hours later. Dropsonde data from a synoptic surveillance mission early on 23 August show that increased upper-tropospheric flow had further enhanced the southwesterly shear affecting Debby. Although the shear disrupted the system's organization, Debby maintained hurricane force winds until around 1200 UTC on 23 August.

The weakening storm turned toward the west and moved along the northern coast of Hispaniola. Although the mountainous landmass of that island may have played some role in the weakening by restricting inflow from the south and disrupting the southern part of the cyclone's circulation, it appears that vertical shear was primarily responsible. Around midday on 23 August, a distinct low-cloud circulation center was evident just to the north of Hispaniola, displaced well to the west of the main area of deep convection. The cyclone continued westward, entering the Windward Passage around 0000 UTC on 24 August. It dissipated near the south coast of eastern Cuba on the morning of 24 August. The remnant open wave continued to track westward, spreading locally heavy showers and gusty winds over Cuba, the Straits of Florida, and southern Florida over the next couple of days.

2) METEOROLOGICAL STATISTICS

The strongest wind report from reconnaissance aircraft in Debby was 88 kt, measured at an altitude of 1500 ft (457 m) on 21 August. This implies a surface wind of 75 kt (Franklin et al. 2000), which is the estimated peak intensity for the cyclone. Interestingly, the minimum central pressure was about 1004 mb at that time, well above the values typically associated with even minimal hurricane intensity. A central pressure of 991 mb was measured about 12 hours *after* the occurrence of Debby's estimated peak winds.

Wind gusts to 48 kt were reported at Antigua late on

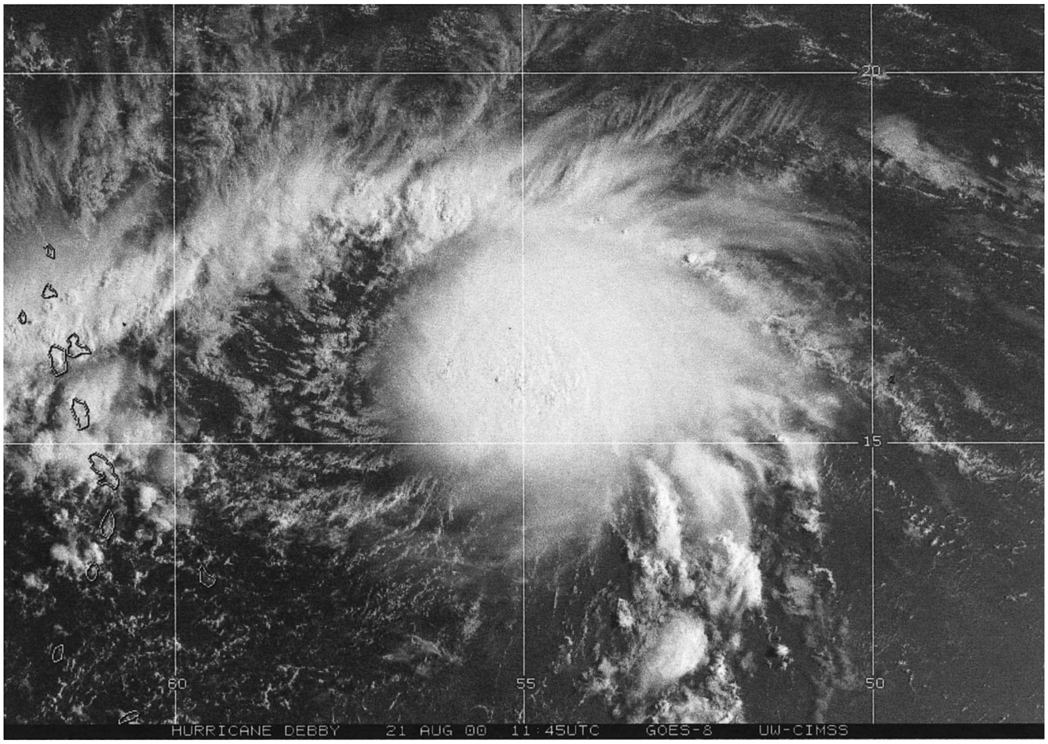

FIG. 3. *GOES-8* visible satellite image of Hurricane Debby at 1145 UTC 21 Aug 2000, near the time of peak intensity (courtesy CIMSS, University of Wisconsin.)

21 August during the passage of a band of convection in advance of the hurricane. Maximum sustained winds there were only 25 kt. Wind observations from Guadeloupe include gusts to 52 and 37 kt at Raizet Airport and La Desirade, respectively. At St. Barthelemy, which was in the eye at 0915 UTC on 22 August, a gust to 76 kt was reported at 0837 UTC, with a reported maximum (10 min) sustained wind of 43 kt. At St. Maarten, sustained winds of 33 kt with gusts to 56 kt were reported near 0900 UTC, with a minimum pressure of 998 mb at 1000 UTC. There were no measurements of sustained tropical storm force winds from the U.S. Virgin Islands or Puerto Rico; however, wind gusts of 39 and 37 kt were reported from St. Thomas and St. Croix, respectively, on 22 August.

Rainfall totaled 320.8 mm at Rio Piedras and 261.1 mm at Rio de la Plata, Puerto Rico. These heavy rains occurred mainly after the center of Debby had moved northwest of the island.

3) CASUALTY AND DAMAGE STATISTICS

There were no deaths directly attributable to Debby; however, a man died in Puerto Rico when he fell off the roof of his home while trying to remove a satellite antenna.

In Puerto Rico, there were reports of mud slides and damaged or collapsed bridges resulting from the heavy rains. Over 400 homes were reportedly affected by flood waters, and 5 homes suffered moderate to severe structural damage. The total damage estimate is $0.5 million.

There was moderate damage to the roofs of a few structures in Barbuda. Some damage to fruit trees and utility poles occurred in several islands of the extreme northern Leewards. There was also some damage from storm surge and wave action along the northern coast of the Dominican Republic.

Debby produced beneficial rains in drought-stricken eastern Cuba.

4) WARNINGS

Debby triggered the issuance of hurricane or tropical storm warnings for the islands of the Lesser Antilles from Dominica northward, including the British and U.S. Virgin Islands. The hurricane warning for the northern Leeward Islands was issued 15–18 h prior to the arrival of the center in that area. Warnings were also issued for portions of the Dominican Republic, Haiti, and Cuba, as well as for the Turks and Caicos Islands and the southeastern and central Bahamas. Although no watches or warnings were issued for south Florida, an evacuation of nonresidents from the Florida Keys was ordered, based on the potential threat reflected in official 3-day forecasts and the long lead time necessary to complete evacuations there. This evacuation resulted in a significant loss of tourism revenue for Monroe County.

e. Tropical Storm Ernesto, 1–3 September

Ernesto was very similar to Chris in its origin, track, structure, and ultimate destiny. It originated from a tropical wave, which developed a depression about 900 n mi east of the Lesser Antilles on 1 September and strengthened to Tropical Storm Ernesto on 2 September. An upper-level low to the northwest of the cyclone generated strong, persistent vertical wind shear, which prevented the storm from developing further, and Ernesto dissipated into a tropical wave on 3 September well north of the Leeward Islands.

f. Hurricane Florence, 10–17 September

Florence was a category 1 hurricane of subtropical origin that passed within about 65 n mi of Bermuda.

During the first week of September, a cold front edged off the North American continent and became stationary over the western subtropical Atlantic. A weak wave along the front amplified slowly on 8–9 September, and then deepened more rapidly on 10 September underneath an upper-level cold low. During the day the flow pattern around the developing low became less wavelike and more circular; it is estimated that the low had lost its surface frontal structure and become a subtropical depression by 1800 UTC on 10 September, when it was about 325 n mi west-southwest of Bermuda. Convection was present west of and close to the circulation center, but very limited in areal coverage at this time; it is presumed that the upper circulation was still cold core. After 0000 UTC on 11 September, the convection began to increase in depth and coverage while it rotated to the south side of the low-level circulation center. An AMSU temperature cross-section analysis suggests a weak warm core had developed by 1243 UTC on 11 September, and it is estimated that the subtropical depression had become tropical near 0600 UTC.

The convective burst early on 11 September continued to rotate around to the east side of the low-level circulation center, where it was associated with a rapid increase in wind speed. The depression had reached tropical storm strength by 1200 UTC and hurricane strength by 1800 UTC that day, the latter event occurring when Florence was about 425 n mi west-southwest of Bermuda. The strong winds, however, were confined to a very small area near the edge of the convection, and after 0000 UTC on 12 September, when the cyclone entrained some drier midtropospheric air and the convection collapsed, Florence's winds temporarily weakened below hurricane strength. Later on 12 September, pressure falls, the development of an elliptical eyewall, and a return of hurricane force winds were reported by a reconnaissance aircraft.

On 11 September, Florence moved very slowly westward under the influence of a midlevel ridge along the mid-Atlantic coast; however, this flow was soon balanced by ridging to the southeast of the cyclone and Florence moved little from 12 to 14 September. By 1200 UTC on 13 September, central pressures began to rise and Florence again weakened to a tropical storm, due in part perhaps to local reduction of the sea surface temperatures under the hurricane. [Sea surface temperature analyses from the Applied Physics Laboratory, Johns Hopkins University (not shown), indicated decreases of up to 6°C near the cyclone center during this time.] North-northwesterly shear increased as well on 14 September, and the maximum winds dropped to 40 kt.

An approaching short-wave trough in the westerlies broke the steering stalemate and began to accelerate the tropical storm to the east-northeast on 15 September. With most of the convection and strong winds in its southeast quadrant, Florence strengthened late on 15 September and turned to the northeast. Florence attained hurricane strength for the third time at 0000 UTC on 16 September, when it was about 175 n mi west-southwest of Bermuda. The hurricane made its closest approach to Bermuda, passing about 65 n mi to the northwest of the island, around 0800 UTC on 16 September. Later on 16 September an eye was briefly apparent as Florence reached its peak intensity of 70 kt. Weakening ensued over cooler waters, and Florence became a tropical storm for the fourth time at 0000 UTC 17 September, when it was about 425 n mi northeast of Bermuda. After 1800 UTC on 17 September, when it was about 125 n mi south of St. Johns, Newfoundland, the circulation of Florence was absorbed by the extratropical surface low associated with the short-wave trough.

Observations of note with Florence include a *QuikSCAT* analysis from 1014 UTC 11 September, which suggested that the maximum winds at that time were at least 40 kt, and was the basis for the designation of the cyclone as a tropical storm. Florence's first upgrade to a hurricane was based on an aircraft reconnaissance report of 79 kt at a flight altitude of 1500 ft (457m), a speed that implies 67 kt at the surface using the standard reduction for that altitude (85%).

The ship *Global Mariner* (3EZZ5) reported winds of 49 kt and a pressure of 1005.2 mb at 0000 UTC on 17 September. Bermuda reported a maximum sustained wind of 36 kt with a peak gust of 50 kt at 0400 UTC on 16 September. The minimum pressure observed there was 1007.5 mb, and the storm total precipitation was 11.9 mm. At various times hurricane and tropical storm warnings were posted for Bermuda. The tropical storm warning was issued about 20 h in advance of the observed sustained tropical storm force winds.

There were no reports of damage associated with Florence. However, rip currents generated by the hurricane were blamed for three surf deaths in North Carolina on 12 September.

g. Hurricane Gordon, 14–18 September

Gordon was the first of the season's two tropical storms to make landfall in the United States, but is more notable for its deadly effects in Guatemala.

1) Synoptic history

A tropical wave crossed the west coast of Africa on 4 September and tracked westward across the tropical Atlantic. The wave moved through the Lesser Antilles on 9–10 September, producing locally heavy rainfall and wind gusts of 25–30 kt there. Over the next few days, convection associated with the wave became better organized and the system developed a depression near the northern coast of the Yucatan Peninsula on 14 September.

The depression moved inland over the Yucatan peninsula late on 14 September, and moved northwestward into the Gulf of Mexico late on 15 September. The system's organization then quickly increased, and the depression became a tropical storm at 0000 UTC on 16 September and a hurricane 24 hours later. Once over the Gulf, Gordon moved on a steady northeastward track toward the Big Bend area of Florida, reaching its peak intensity of 70 kt and 981 mb at 0600 UTC on 17 September. Thereafter, weakening began due to a combination of increasing vertical shear ahead of an approaching midlevel trough, and the entrainment of midlevel dry air from south of the hurricane. A reconnaissance report at 1328 UTC indicated that the minimum surface pressure had risen to 990 mb, and Gordon had become a tropical storm by 0000 UTC 18 September. It continued northeastward and made landfall just northwest of Cedar Key, Florida, at 0300 UTC on 18 September with 55-kt winds. Gordon weakened to a tropical depression, and became extratropical by 1800 UTC when its circulation merged with a frontal boundary over southeast Georgia. The remnant circulation produced little significant weather while it moved northeastward along the east coast of the United States for the next 3 days. It was absorbed by a large extratropical low pressure system over eastern Canada on 21 September.

2) Meteorological statistics

A report of easterly winds of 64 kt from the ship *P&O Nedlloyd Genoa* (MYMX5) located about 30 n mi northeast of the center, indicated that Gordon had become a hurricane by 0000 UTC 17 October. The maximum wind reported by reconnaissance aircraft was 89 kt, measured at 850 mb at 0544 UTC on 17 September, which implies a surface wind of 71 kt using the standard adjustment factor of 80% for this flight altitude.

Selected surface observations associated with Hurricane Gordon are given in Table 2. The highest sustained wind report from a land-based station was 39 kt at St. Petersburg. The Cedar Key Coastal Marine Automated Network (C-MAN) station reported a maximum 10-min mean wind of 45 kt. The largest rainfall was also recorded at Cedar Key (122.7 mm). Even though Gordon was moving at only about 10 kt, precipitation was light due to the entrainment of dry air into the storm circulation. Maximum storm tides (i.e., water height above sea level based on the National Geodetic Vertical Datum of 1929) along the Florida west coast generally ranged from 0.9 to 1.5 m from the Tampa Bay area northward to Cedar Key. Gordon is known to have produced two tornadoes during its landfall on 17 September. The first (of unknown intensity) occurred around 1845 UTC on the Florida west coast in Cape Coral. A second (F0) tornado touched down around 2030 UTC near the town of Ponce Inlet in Volusia County.

3) Casualty and damage statistics

Twenty-three deaths have been attributed to Gordon in Guatemala as a result of flooding, although it is possible that some or all of these deaths occurred before the system became a tropical cyclone. In the United States, Gordon was responsible for the death of a surfer who drowned in heavy seas near Pensacola, Florida.

Most of the $10.8 million in damage in the United States was due to downed power lines and trees. Numerous homes along the immediate Florida west coast from the Tampa Bay area northward to Cedar Key experienced some minor roof damage. The Cape Coral tornado severely damaged at least one home. Some coastal roads and highways experienced flooding from the storm surge and had to be temporarily closed.

4) Warnings

Tropical storm warnings were issued at various times along the Florida west coast from Bonita Beach northward to Indian Pass, and on the U.S. east coast from Titusville, Florida, to Little River Inlet, South Carolina. A hurricane warning was issued along the Florida west coast from Anna Maria Island northward to the Ochlockonee River. The tropical storm warning was issued about 24 hours before the onset of tropical storm conditions.

h. Tropical Storm Helene, 15–25 September

Helene was the second tropical storm of the season to make landfall in the United States.

1) Synoptic history

Helene had its origins in a tropical wave that crossed the African coast on 10 September. A depression developed out of the wave about 500 n mi east of the Leeward Islands on 15 September, but by the time the first reconnaissance aircraft encountered the system on the following day, it had weakened back to an open wave (albeit one with 55-kt winds at an altitude of 1500 ft). The remnants of the depression brought heavy rain and gusty winds to the northeastern Leeward Islands on 17 September. The disturbance continued westward through the Caribbean Sea, and reorganized to a tropical

TABLE 2. Selected surface observations for Hurricane Gordon, 14–18 Sep 2000.

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
	Day/time (UTC)	Pressure (mb)	Day/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Buoys								
42003	17/0200	998.5	17/0020	43	57			
42036			17/1722		51			
41009			17/2000		35			
42036			17/2100	37	41			
41004			18/0900		35			
41008			18/1700		37			
Florida								
Bellair Beach						1.5		
Cedar Key						1.2		122.7
Cross City	18/0543	997.6	18/0229	29	37			
Gainesville	18/0604	1004.4						
Jacksonville			18/1302		36			
Leesburg			17/1908	35				
Patrick AFB			18/1855	27	39			
Perry-Foley	18/0612	1005.1	18/0242	24	34			
Punta Gorda			17/1552	32				
St. Petersburg (KPIE)			17/1800	39				
St. Petersburg (KSPG)			17/1529	38		0.9		
Tampa						1.1		
Titusville	17/2250	1011.8	17/1650	15	30			
C-MAN stations								
CDRF1 (Cedar Key)	18/0300	999.3	18/0110	45[e]	59			
KTNF1 (Keaton Beach)	18/0500	1003.7	18/0015		36			
SAUF1 (St. Augustine)	18/0900	1008.2	18/0540	32[e]	40			

[a] Day/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for C-MAN and land-based Automated Surface Observing System (ASOS) reports are 2 min; buoy averaging periods are 8 min.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above sea level based on National Geodetic Vertical Datum of 1929.
[e] 10-min averaging period.

depression on 19 September about 100 mi east of Grand Cayman. The poorly organized depression moved across western Cuba and into the eastern Gulf of Mexico, where it strengthened into Tropical Storm Helene on 21 September, 6 days after having first become a depression. Helene accelerated toward the north and reached a maximum intensity of 60 kt later that day in a seemingly marginally favorable environment. Intensification ended abruptly when the vertical shear increased. Helene then became highly asymmetric in its distribution of high winds and rainfall, with the significant weather located to the east of the center. Helene began to weaken, making landfall near Fort Walton Beach, Florida, around 1200 UTC on 22 September with maximum sustained winds of only 35 kt. Helene further weakened to a depression and moved northeast across the southeastern states. With the center of the depression still over land in eastern North Carolina, the system began to reintensify on 23 September, and it regained tropical storm status before moving back out into the Atlantic. Helene moved rapidly northeastward and again developed winds of 60 kt early on 25 September following the development of a burst of deep convection. The storm was absorbed by a cold front later that day.

2) METEOROLOGICAL STATISTICS

Selected surface observations from Helene are given in Table 3. Flooding was reported across the Florida panhandle and Georgia with 200–250 mm of rain recorded in the Tallahassee area. In the Gulf of Mexico, the ship *Cherry Valley* (WIBK) reported winds of 54 kt at 2100 UTC on 21 September. Hourly observations from the ship *Koeln Express* (9VBL) on 25 September, when it reported sustained winds of 56 kt and a pressure of 988.2 mb, were critical in determining the intensity and structure of the cyclone during the reintensification phase over the North Atlantic.

3) CASUALTY AND DAMAGE STATISTICS

As a tropical depression, Helene spawned an F2 intensity tornado that killed one person in South Carolina. Flood damage, mainly in Florida, is estimated to be $16 million.

4) WARNINGS

During Helene's first brief period as a tropical depression east of the Lesser Antilles, tropical storm warn-

TABLE 3. Selected surface observations for Tropical Storm Helene, 15–25 Sep 2000.

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
	Day/time (UTC)	Pressure (mb)	Day/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Lesser Antilles								
Guadeloupe			17/????		48			
Antigua								79.8
Buoys (Gulf of Mexico)								
42003	21/0900	1009.1	21/1014	32	39			
42039	22/0800	1010.1	22/0043	31	41			
Florida								
Apalachicola								242.8
Cape San Blas C-MAN	22/0900	1010.7	22/1211	26	46			
Destin Airport (DTS)			22/1118	24	35	0.3		
Hurlburt Field	22/1110	1005.7						
Panama City Beach			22/0900	23	39	0.3		
Pensacola Beach			22/0930	23	38	0.3		
Perdido Key			22/0730	20	34			
Sopchoppy								241.3
Tallahassee (KTLH)								199.6
Valparaiso	22/1155	1005.7						
North Carolina (C-MAN)								
Cape Lookout	23/2100	1009.9	23/1902	36[e]	45			
Diamond Shoals	24/0200	1008.5	23/2243	51[e]	61			
Duck Pier	24/0400	1009.3	23/2215	38	45			
Frying Pan Shoals	23/2100	1011.1	23/1825	40	47			

[a] Day/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for C-MAN and land-based ASOS reports are 2 min; buoy averaging periods are 8 min.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above sea level based on National Geodetic Vertical Datum of 1929.
[e] 10-min averaging period.

ings were issued for the Leeward Islands from Montserrat northward to Anguilla. A second set of tropical storm warnings were issued for portions of western Cuba. No sustained tropical storm force winds were observed in either case. In the United States, tropical storm warnings were issued from the Louisiana–Mississippi border eastward to the mouth of the Aucilla River in Florida, about 21 hours prior to landfall of the tropical storm within the warning area near Fort Walton Beach.

i. Hurricane Isaac, 21 September–1 October

Isaac, the second major hurricane of the season, was a Cape Verde hurricane that resembled Alberto in its genesis, track, size, and strength. Isaac was tied with Keith as the strongest hurricane of the season. Swells generated by Isaac resulted in the drowning of one man off Long Island, New York.

Isaac originated from a tropical wave that emerged from western Africa on 20 September. This wave was already well defined when it entered the eastern Atlantic, with curvature in the associated deep clouds indicating some convective organization. On the following day, the cloud pattern became even better organized and a tropical depression formed about 200 n mi south of the Cape Verde Islands. A midtropospheric ridge was present over the eastern Atlantic to the north of the tropical cyclone, and this provided a west-northwestward steering current for several days. Vertical wind shear was weak, and this allowed the system to gradually strengthen into Tropical Storm Isaac by 0000 UTC on 22 September. Strengthening continued, and Isaac became a hurricane around 1200 UTC on 23 September. The hurricane then quickly strengthened to 105 kt by 0000 UTC on 24 September.

Later that day, the cloud pattern became less organized; core convection became asymmetric and the eye less well defined. This may have been mainly the result of internal fluctuations, because the large-scale atmospheric environment appeared to remain favorable for strengthening. Isaac's winds decreased to about 90 kt on 25 September, when west-southwesterly vertical shear became evident over the system; slightly cooler ocean waters may have also played a role in the weakening of the hurricane. By around 1200 UTC on 26 September, the hurricane's winds had decreased to an estimated 75 kt. Later on 26 September, the shear relaxed somewhat, and deep convection became more symmetric around the center. This was followed by restrengthening of the cyclone on 27 September. A distinct eye again became visible, and Isaac reattained category 3 status around 0000 UTC 28 September. The hurricane turned toward the northwest about that time. Isaac con-

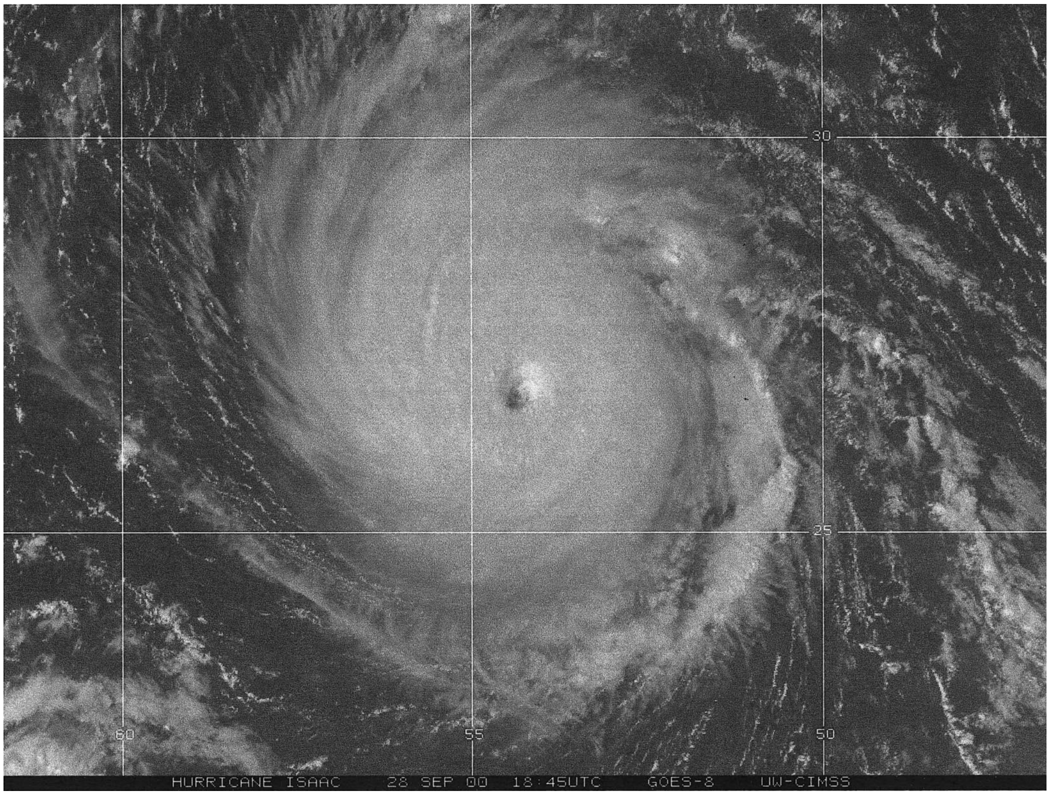

FIG. 4. *GOES-8* visible satellite image of Hurricane Isaac at 1845 UTC 28 Sep 2000, near the time of peak intensity (courtesy CIMSS, University of Wisconsin.)

tinued to intensify, and reached its peak strength of 120 kt (category 4) around 1800 UTC on 28 September. (Fig. 4).

Not long after reaching its maximum intensity, the hurricane turned north-northwestward. Continuing its movement around the western periphery of a midtropospheric anticyclone, Isaac turned northward and then north-northeastward. The center passed about 450 n mi east of Bermuda on 29 September. When the cyclone moved over cooler waters, the maximum winds gradually decreased, and were down to category 1 intensity on 30 September. By this time, Isaac was accelerating northeastward. The system weakened to a tropical storm on 1 October, and became extratropical later that day. Isaac's remnant, a strong extratropical cyclone with winds of 55–60 kt, moved rapidly east-northeastward over the Atlantic. By 3 October, the cyclone turned north-northeastward, skirting the western British Isles. The system's maximum winds had decreased to near 45 kt by this time. Early on 4 October, the cyclone merged with a larger extratropical low to the north of Scotland.

Even though Isaac remained far to the east of the U.S. eastern seaboard, swells generated by this large and powerful hurricane caused a boat with four passengers to capsize in Moriches Inlet, (Long Island), New York, on 30 September. One of the passengers drowned.

j. Hurricane Joyce, 25 September–2 October

A depression developed from a tropical wave about 350 n mi southwest of the Cape Verde Islands on 25 September, and became Tropical Storm Joyce the next day. Forming in a similar location to Alberto and Isaac, Joyce initially appeared to be developing in a similar fashion, when the cyclone developed an eye on 27 September and reached an intensity of 80 kt early on 28 September. However, while Alberto and Isaac moved northwestward and became powerful hurricanes over subtropical latitudes, Joyce moved generally westward and encountered the persistent hostile shear that had earlier weakened Chris, Debby, and Ernesto, and had nearly destroyed the system that ultimately became Helene. Dropwindsonde data just east of the Windward Islands from a Gulfstream-IV synoptic surveillance mission indicate that the immediate environment of Joyce was particularly dry, and this dryness may also have contributed to a gradual weakening that began on 28 September.

Joyce moved through the southern Windward Islands as a minimal tropical storm on 1 October, producing sustained winds of 30 kt at Barbados and 26 kt at Tobago. The storm continued to weaken, and dissipated in the southeastern Caribbean Sea on 2 October. There

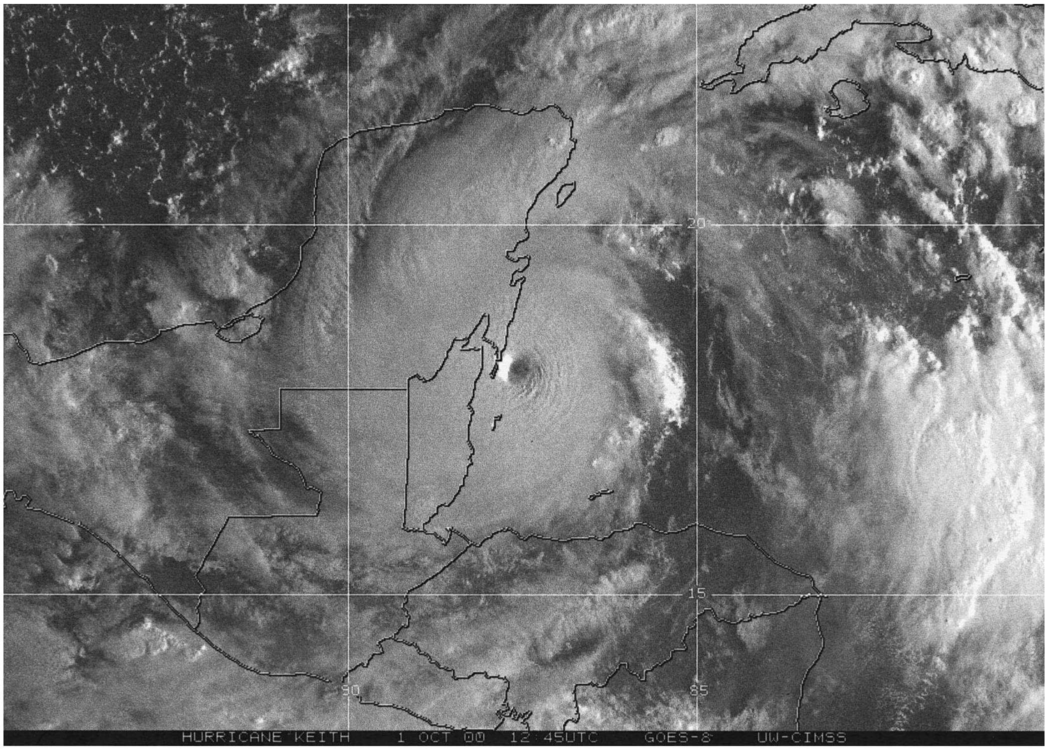

FIG. 5. *GOES-8* visible satellite image of Hurricane Keith at 1246 UTC 1 Oct 2000, about 6 hours after the time of peak intensity (courtesy CIMSS, University of Wisconsin.)

were no reports of damage or casualties associated with Joyce.

k. Hurricane Keith, 28 September–6 October

Keith, tied with Isaac as the strongest hurricane of the season, was the only major hurricane to make landfall in 2000, striking the coastal islands of Belize and then lingering in the area for a day and a half. Keith subsequently crossed the Yucatan, moved into the Gulf of Mexico, and made landfall in northeastern Mexico as a category 1 hurricane.

1) SYNOPTIC HISTORY

A tropical wave that crossed the African coast and entered the eastern Atlantic on 16 September began to develop in the western Caribbean Sea on 27 September. The disturbed weather continued to organize and became a tropical depression about 60 n mi north-northeast of Cape Gracias a Dios, Nicaragua, on 28 September. The depression moved slowly to the northwest and became a tropical storm late on 29 September.

Over the next day and a half Keith deepened with great dispatch, its central pressure falling 61 mb, from 1000 to 939 mb, in about 37 h. On 1 October, Keith (Fig. 5) became the third major hurricane of the season and the second category 4 hurricane, with 120-kt peak winds. When the eyewall of the hurricane moved over Ambergris Cay and Caye Caulker, Belize, near 1800 UTC on 1 October, Keith had weakened but was still a category 3 hurricane with winds of 110 kt. A combination of high pressure over the Gulf of Mexico and a tropical disturbance (that was to become Tropical Storm Leslie) near western Cuba weakened the steering currents, and Keith moved little for the next 36 h. Keith gradually but significantly weakened while battering the coastal islands of Belize on 1–2 October and, finally, made landfall in mainland Belize 25 n mi north of Belize City, as a tropical storm around 0300 UTC 3 October.

While slowly crossing the Yucatan Peninsula Keith weakened to a depression, but regained tropical storm strength after emerging into the Bay of Campeche on 4 October. Moving west-northwestward, Keith became a hurricane again on 5 October, and made landfall 20 n mi north of Tampico, Mexico, with 80-kt maximum winds. Keith dissipated over northeastern Mexico on 6 October.

2) METEOROLOGICAL STATISTICS

Keith was extensively sampled by reconnaissance aircraft. The maximum flight-level wind reported during the storm was 133 kt at 850 mb at 2220 UTC 1 October. While standard reductions would imply a corresponding surface wind of about 105 kt, a GPS dropwindsonde in the eyewall at 0600 UTC that day suggested that the surface winds were at least 115 kt. The estimated minimum pressure, 939 mb, is lower than the observed minimum dropsonde pressures of 942 mb, because this particular dropsonde did not splash in the center of the eye. The final value was chosen based on hydrostatic considerations using aircraft and dropsonde thermodynamic data.

The core of Keith missed most observing stations. The maximum reported wind from any official station was 40 kt (sustained) with gusts to 55 kt at Tampico, Mexico, at 1445 UTC 5 October. The Philip Goodson International Airport in Belize City reported sustained winds of 30 kt and a peak gust of 53 kt. Amateur radio operators reported measured winds of 90–110 kt in San Pedro (on Ambergris Cay) and Caye Caulker, Belize, on 1 October, but the reliability of these observations is unknown. The only ship to report tropical storm force winds in Keith was the *Edyth L* (C6YC) which reported 60-kt winds and a 1009.0-mb pressure in the northwestern Caribbean Sea at 1800 UTC 30 September.

The only known storm surge observation was from the west side of Caye Caulker, where a 1.2–1.5-m surge occurred. Tides of 1.2 m *below* normal were noted on the Belize mainland coast while the center of Keith was just offshore of the coastal islands. Reports were also received that northerly winds associated with Keith had temporarily blown the water out of the Bay of Chetumal, and that people were walking on the exposed bay bottom. This was a potentially deadly situation, as the water could have quickly returned had Keith moved and the winds shifted.

Keith's slow motion contributed to copious rainfall over portions of Central America, especially Belize. The largest storm total was 829.8 mm at the international airport in Belize City. Table 4 summarizes the available rainfall data.

TABLE 4. Selected storm-total rainfall observations for Hurricane Keith, 28 Sep–6 Oct 2000.

Location	Rainfall (mm)
Mexico	
Chetumal	245.1
Juan Serabia	355.1
Obregon	212.1
Sabinas	366.5
Belize	
Barton Creek	74.2
Belize Zoo	468.1
Belmopan	328.7
Bigfalls Plantation	142.0
Blue Creek Orange Walk	448.1
Central Farm	264.4
Chaa Creek	166.6
Consejo	266.1
Gallon jug 1	205.7
Gallon jug 2	208.3
Gallon jug 3	208.1
Gallon jug 4	243.8
Goodson International Airport Belize City	829.8
Libertad	189.5
Mayan King	91.2
Melinda	166.6
Middlesex	254.0
Punta Gorda Agricultural Station	47.5
Pomona	164.3
Rum Point	78.7
Savannah	61.5
Spanish Lookout	250.2
St. Johns College	627.1
Towerhill	203.5

3) CASUALTY AND DAMAGE STATISTICS

Reports from the Meteorological Service of Belize and the media indicate the death toll from Keith was 24, comprising 5 casualties in Belize, 12 in Nicaragua, 6 in Honduras, and 1 in Mexico. The deaths in Belize occurred when two catamarans broke loose during the storm, and five of the deaths in Honduras occurred when an aircraft disappeared near Roatan Island. The other deaths are apparently due to flooding from heavy rains. The estimated damage in Belize, including agriculture losses, is near $225 million. Much of the property damage occurred on Ambergris Cay and Caye Caulker.

There are no reports of damage or casualties from Keith's final landfall in northeastern Mexico. Heavy rains in Guatemala caused flooding in 10 towns, but no estimates of the damage are available.

4) WARNINGS

Warnings were posted for the Mexican portion of the Yucatan Peninsula late on 29 September and early on 30 September. However, most of these areas were not seriously affected by Keith. Hurricane warnings for the landfall area in Belize were issued about 21 hours before the eyewall of Keith arrived over the coastal islands. After Keith entered the Gulf of Mexico, hurricane warnings were issued for the Mexican coast from Tuxpan to La Pesca, also about 21 hours prior to landfall.

l. Tropical Storm Leslie (Subtropical Depression One), 4–7 October

Leslie was a short-lived tropical storm that is most notable for its complex history and the effects of its precursor disturbance in southeastern Florida.

The immediate precursor to Tropical Storm Leslie was a subtropical depression that formed inland near the east coast of central Florida at 1200 UTC on 4 October. Interestingly, the disturbance that led to the subtropical cyclone was a *tropical* wave that entered the eastern Caribbean Sea on 27 September. Although its signature in satellite imagery was extremely weak for some time prior to this point, this was likely the same tropical wave that spawned Hurricane Isaac.

Upon entering the Caribbean Sea, the wave was accompanied by disorganized and sporadic thunderstorm activity over northern sections of South America. On 29 September, the tropical wave and accompanying thunderstorm activity moved north-northwest off the coast of Columbia into the central Caribbean Sea. For the next 2 days, the disorganized cluster of thunderstorms (the disturbance to the east of Keith in Fig. 5) moved to the north-northwest around the circulation of Hurricane Keith. By 1200 UTC 2 October, a distinct midlevel circulation was evident in satellite imagery just south of western Cuba, near the Isle of Youth. This circulation moved northward across western Cuba and the Straits of Florida, and by 1200 UTC on 3 October it entered the extreme southeastern Gulf of Mexico. Satellite and radar images then showed a large area of showers and thunderstorms extending east of the midlevel circulation center from the Florida Straits northward across the Florida Keys into extreme south Florida. During the early afternoon of 3 October, a NOAA reconnaissance aircraft investigated the disturbance in the southeast Gulf of Mexico, and found an elongated trough of low pressure at a flight level of 1500 ft, but no well-defined surface circulation center.

As the disturbance moved north toward the west coast of Florida, it interacted with a stalled frontal boundary across southern Florida. During the afternoon and evening of 3 October, a band of very heavy rainfall became stationary across southeast Florida. Widespread rainfall, with accumulations of 300–450 mm, occurred in a swath extending from southwest Miami-Dade County to extreme southeast Broward County, and two (F0) tornadoes touched down in Miami-Dade County.

After 0000 UTC on 4 October, the midlevel circulation began moving northeast and passed near Sarasota, Florida, around 0600 UTC; however, the associated shower and thunderstorm activity remained well southeast of the disturbance in the frontal trough. Surface observations show the remnants of the frontal trough remaining over south Florida for several hours after the passage of the midlevel circulation center. They also show that by 1200 UTC 4 October, as the midlevel center continued northeastward over central Florida, a well-defined surface low and circulation developed just east of Orlando. At this time the convection was still located well southeast of the surface low, with the strongest winds approximately 150 n mi from the center. Given this structure, as well as the presence of a nearby upper-level cold-core short-wave trough, the system at this stage is considered to have been a subtropical depression.

At 1800 UTC on 4 October, the depression moved just offshore near Daytona Beach, Florida. Reconnaissance aircraft data at this time confirmed that the strongest flight-level winds (30–35 kt) remained well southeast of the center. The system moved slightly north of east overnight, and early morning satellite imagery on 5 October suggested that the low-level center was located closer to the deep convection. Reconnaissance data near 1200 UTC 5 October confirmed that the wind field had contracted, and that the maximum flight-level winds (44 kt) were within 75 n mi of the center. On this basis, the subtropical depression is considered to have become Tropical Storm Leslie, about 200 n mi east of St. Augustine, Florida. It remained a weak tropical storm while it moved to the east-northeast on 5 October.

Leslie briefly threatened Bermuda, but turned to the northeast early on 7 October and passed about 250 n mi to the west of the island. The circulation of Leslie became entangled with a cold frontal boundary, and the cyclone became extratropical by 1800 UTC on 7 October, when it was about 325 n mi north-northwest of Bermuda. The remnant extratropical low moved rapidly northeastward, crossing Newfoundland late on 8 October, and was tracked for another couple of days as it raced east-northeastward across the North Atlantic toward the British Isles.

There were few significant meteorological observations associated with Leslie. At 0000 UTC on 6 October, the ship *Kent Voyageur* (8PNK) reported winds of 36 kt about 60 n mi southeast of Leslie. There were no land-based reports of tropical storm force winds. At 1800 UTC on 7 October (at the time of extratropical transition), the ship *P&O Nedlloyd Auckland* (PDHW), about 200 n mi southeast of the center, reported winds of 33 kt.

No significant rainfall amounts are associated directly with either Subtropical Depression One or Tropical Storm Leslie. The interaction of the antecedent disturbance with the frontal trough over south Florida, however, produced a number of rainfall totals in excess of 380 mm for the 48-h period ending 0700 eastern daylight time 4 October. These include 444.5 mm in South Miami, 401.1 mm at the Miami Weather Forecast Office (near Sweetwater), and 388.6 mm at Miami International Airport.

There were no reports of damage or casualties associated with either Subtropical Depression One or Leslie. The interaction of the antecedent disturbance with the frontal trough over south Florida, however, resulted in damage estimated at $950 million, $500 million of which were agricultural losses, and three deaths indirectly attributable to the flooding, two from drowning as a result of vehicles driving into deep water, and one from a fall.

m. Hurricane Michael, 15–19 October

Michael originated from a nontropical upper-level cold low. The low lingered over warm waters about 400 n mi northeast of the Bahamas for several days, developing into a subtropical depression on 15 October, a subtropical storm on 16 October, and then a tropical storm early on 17 October when convection increased near the center. Michael then deepened rapidly, becoming a hurricane only 18 h after becoming a tropical storm. As a strong midtropospheric trough began to approach Michael from the west, the hurricane began to move rapidly north-northeastward toward the Canadian Maritime Provinces, reaching a peak intensity of 85 kt

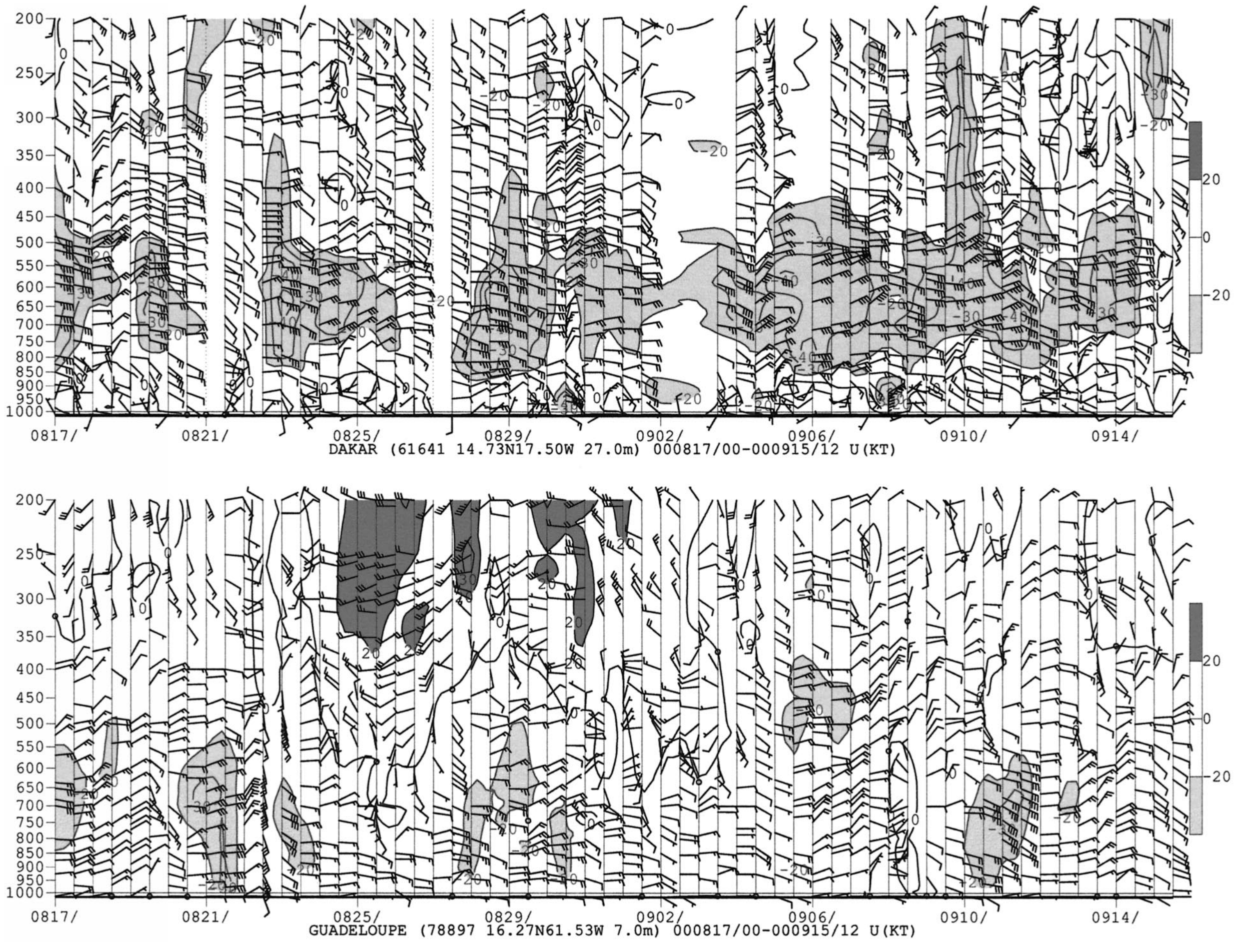

FIG. 6. Vertical time section of wind at (top) Dakar and (bottom) Guadeloupe from 15 Aug to 15 Sep 2000. Wind barbs follow the standard convention where half-barbs, full barbs, and pennants represent 5, 10, and 50 kt, respectively. Shading and contours indicate the *u*-component magnitude (kt).

around 1800 UTC 19 October about 65 mi east of Sable Island, Nova Scotia. From 0600 to 1800 UTC on 19 October, Michael's minimum pressure fell 21 mb, from 986 to 965 mb. Michael was overtaken by the cold front associated with the midlevel trough around 2100 UTC on 19 October, and became extratropical just prior to landfall in Newfoundland with 75-kt winds on 19 October.

Observations of Michael include a maximum flight-level wind of 95 kt, reported by a reconnaissance aircraft at an altitude of 1500 ft at 1829 UTC on 19 October. The ship *MSC Xingang* (3EHR6) reported winds of 80 kt and a pressure of 965.5 mb near the eastern eyewall at 1700 UTC on 19 October. During the landfall of the extratropical cyclone along the south coast of Newfoundland, Sagona Island reported sustained winds of 69 kt with gusts to 93 kt, and a minimum pressure of 967.7 mb.

The Meteorological Service of Canada and the National Research Council of Canada conducted a research mission into Michael, releasing 16 GPS dropwindsondes in the core and environment of the cyclone from their Convair 580 aircraft on 19 October (Canadian Hurricane Centre 2000, personal communication). One of these sondes, dropped at 1646 UTC, reported a surface wind of 75 kt. This mission, which occurred near the time of the cyclone's extratropical transition, when reconnaissance observations are rarely available, has the potential to add to our understanding of the transition process.

There are no reports of casualties associated with Michael. The extratropical remnant caused tree and light structural damage in Newfoundland.

n. Tropical Storm Nadine, 19–21 October

A tropical depression formed on 19 October about 450 n mi southeast of Bermuda from the interaction between a tropical wave and a strong upper-level trough. The depression moved northeastward, becoming a tropical storm on 20 October with 50-kt winds, and then passed well east of Bermuda. Nadine then accelerated northeastward and became an extratropical cyclone ear-

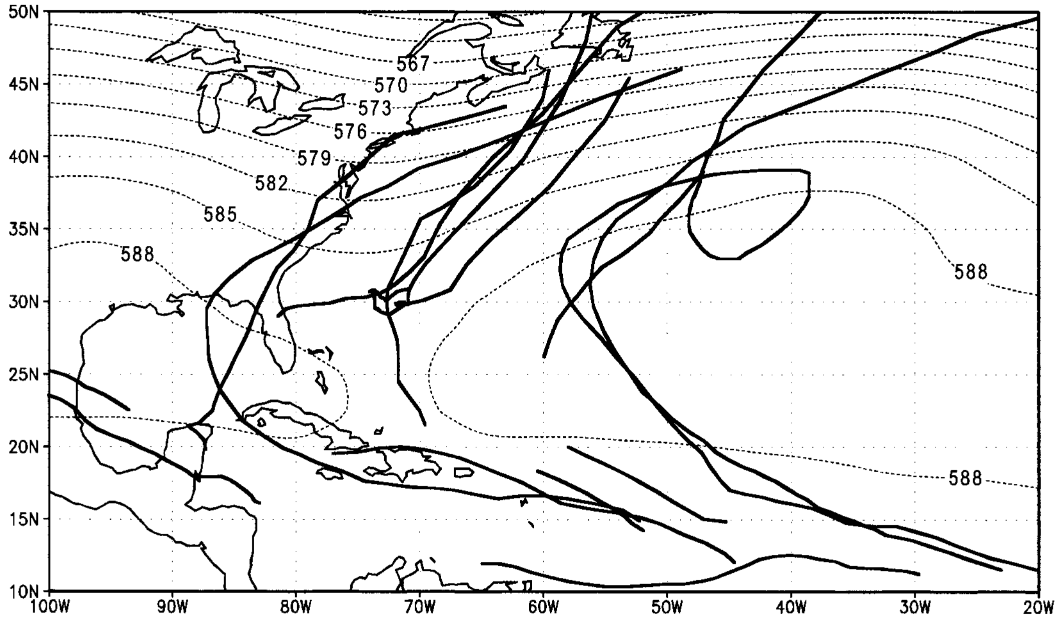

FIG. 7. Mean 500-mb heights (dam, dashed lines) for Aug–Oct 2000, and tracks of the tropical storms, subtropical storms, and hurricanes in 2000 (solid lines). Height data provided by the NOAA–Cooperative Institute for Research in Environmental Sciences Climate Diagnostics Center, Boulder, CO (http://www.cdc.noaa.gov/).

ly on 22 October well to the southeast of Newfoundland. There are no reports of casualties or damage associated with Nadine.

o. Subtropical storm, 25–29 October

An extratropical low pressure system formed just east of the Turks and Caicos Islands near 0000 UTC 25 October, in response to an upper-level cyclone interacting with a frontal system. The low initially moved northwestward and, in combination with a strong surface high to the north, developed into a gale center 6 h later. By 1800 UTC that day it had developed sufficient organized convection to be considered a subtropical storm.

The cyclone turned northward, and this motion continued for 24 hours while the system slowly intensified. The storm jogged north-northwestward late on 26 October; this was followed by a north-northeastward turn and acceleration on 27 October. During this time, the system produced intermittent bursts of central convection while reconnaissance aircraft indicated a large (75–100 n mi) radius of maximum winds. This evolution was in contrast to that of Hurricane Michael; although of similar origin to the subtropical storm, Michael developed persistent central convection and completed a transition to a warm-core hurricane.

After reaching an intensity of 50 kt early on 27 October, little change in strength occurred during the next 24 h. The storm turned northeastward and accelerated further on 28 October in response to a large cold upper-level cyclone moving southward over southeastern Canada. With a last burst of organized convection late on 28 October, the storm reached an estimated peak intensity of 55 kt. A strong cold front moving southward off the New England coast then overtook the system, and the storm became extratropical near Sable Island, Nova Scotia, around 0600 UTC on 29 October. The extratropical low weakened rapidly and lost its identity near eastern Nova Scotia later that day.

3. Other tropical weather systems

a. Tropical depressions

In addition to the systems described in section 2 previously, there were four tropical depressions that did not intensify to tropical storm strength.

Tropical Depression One formed on 7 June from a tropical wave that had entered the Bay of Campeche the day before. Although the depression dissipated within 24 hours of its genesis, the remnant low spread rains and locally gusty winds over portions of the southwestern Gulf of Mexico and adjacent coastal areas on 9–10 June. There were no reports of casualties or damage.

Tropical Depression Two formed from a tropical wave on 23 June, soon after it moved from Africa to the far eastern tropical Atlantic Ocean and when it was centered a little over 300 n mi southeast of the Cape Verde Islands. The depression moved due westward at 15–20 kt for nearly 3 days and weakened to an open wave on 25 June in the central tropical Atlantic. Scatterometer surface wind data suggest that the depression may have attained tropical storm strength for a short period on 23 June.

The antecedent disturbance to Tropical Depression Four was a low that disengaged from a frontal zone in the central subtropical Atlantic on 4 August, and then moved southwestward over the next few days. The tropical depression had formed by 8 August, when an AFRC reconnaissance aircraft found a well-defined low-level circulation with a modest amount of organized convection. The depression was very small and generated limited convection during the next 2 days while it moved westward toward the east coast of Florida. On 10 August, the depression was about 70 n mi east of Cape Canaveral when it abruptly turned northeastward in advance of a deep-layer trough over the eastern United States. The depression dissipated the following day.

A reconnaissance wind report at 1500 ft of 47 kt could be used to argue that the depression attained tropical storm status. However, these winds are judged to have been unrepresentative of the cyclone's maximum sustained wind and so the system has not been designated as a tropical storm.

Tropical Depression Nine formed over the northwestern Gulf of Mexico from the interaction of a persistent low-level trough and a cluster of convection, associated with a tropical wave, that moved north-northwestward from the Yucatan Peninsula. A poorly defined low-level center formed about 160 n mi south of Lake Charles, Louisiana, on 8 September. Surface observations indicate the center moved north-northwestward and crossed the Gulf coast near Sabine Pass, Texas, around 1000 UTC 9 September. The cyclone dissipated over land later that day.

Squalls with gusts to tropical storm force occurred well to the east of the center late on 8 September. These include a 39-kt gust at buoy 42001 at 2100 UTC, a 35-kt gust at buoy 42041 at 2200 UTC, and a 34-kt gust at the Southwest Pass C-MAN station at 2000 UTC. Rainfall associated with the cyclone affected portions of Louisiana and Mississippi. There are no reports of damage or casualties.

b. Tropical waves

Using the methodology described by Avila et al. (2000), 63 tropical waves were tracked from Dakar, Senegal, westward across the tropical Atlantic, the Caribbean Sea, and Central America between May and November 2000. Most of these waves continued to be tracked westward into the northeastern Pacific basin. The long-term average number of waves observed for the 1967–99 period is 61.

Figure 6 shows time–height sections of wind for Dakar and Guadeloupe from 15 August to 15 September 2000. On an annual basis, this 4-week period is when the tropical waves are typically most well defined and convectively active, and is nearly coincident with the climatological peak of tropical cyclone genesis in the Atlantic basin. Periodic cyclonic wind shifts and the accompanying midlevel easterly jet can be seen in the figure associated with the passage of wave axes. The magnitude of the easterly jet is seen to reach 30–40 kt near the wave axes in the vicinity of Dakar. The location and intensity of the midlevel easterly jet is considered of great importance to the structure of tropical waves (Burpee 1972).

By the time the waves reached Guadeloupe, in the eastern Caribbean Sea, the wind shifts became less distinct and the midlevel jet weaker. It is also clear from Fig. 6 that the waves moved from an environment of deep easterly flow to one dominated by upper-level westerlies and stronger vertical wind shear. This changing environment modulated the potential of the tropical waves to trigger tropical cyclogenesis.

Over the period 1967–97, 63% of all tropical storms developed from tropical waves (Avila et al. 2000). The tropical storms of the 2000 season had a similar genesis distribution, with the development of 10 of the 14 (71%) directly associated with a tropical wave. However, this contribution is smaller than in 1998 and 1999, when waves triggered 86% and 91% of the named storms, respectively. These two seasons were characterized by a larger number of intense hurricanes originating from waves in the deep Tropics at a time when low shear and an unstable environment prevailed. In 1997, on the other hand, even though the waves were not significantly different in structure, the wind shear was high over the deep Tropics and the contribution from waves to tropical cyclones was only 28%.

4. Forecast verifications

For all operationally designated tropical and subtropical cyclones in the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico, the NHC issues an ''official'' forecast of the cyclone's center position and maximum 1-min surface wind speed. These forecasts are issued at 6-hourly intervals, valid 12, 24, 36, 48, and 72 h after the nominal (synoptic) forecast time. After the hurricane season ends, the forecasts are evaluated by comparing the forecast positions and intensities to the corresponding poststorm derived best track parameters for each cyclone. Forecasts are excluded from the verification if the cyclone was subtropical, extratropical, or below tropical storm strength at either the forecast time or at the verifying time.

Track forecast error is defined as the great circle distance between a cyclone's forecast position and the best track position at the forecast verification time. Table 5 presents the results of the NHC official track forecast verification for the 2000 season, along with results averaged for the 10-yr period 1990–99. To assess the degree of *skill* in a set of forecasts, the forecast error can be compared with the error from a climatology and persistence model (CLIPER) that represents a ''no skill'' baseline level of accuracy (Neumann 1972). It is seen

TABLE 5. Homogeneous comparison of official and CLIPER track forecast errors (n mi) in the Atlantic basin for the 2000 season. Longer-term averages for the 10-yr period 1990–99 are shown for comparison.

	Forecast period (h)				
	12	24	36	48	72
Average official error for 2000	39	71	102	132	221
Average CLIPER error for 2000	48	103	168	236	372
Average error for 2000 relative to CLIPER	−20%	−31%	−40%	−44%	−41%
No. of cases	228	201	178	163	136
Average 1990–99 official error	46	85	122	157	233
Average 1990–99 CLIPER error	54	111	173	232	339
Average error for 1990–99 relative to CLIPER	−15%	−24%	−29%	−32%	−31%
No. of cases	2054	1837	1644	1464	1160
Official error for 2000 relative to 1990–99 mean	−16%	−17%	−17%	−16%	−5%
CLIPER error for 2000 relative to 1990–99 mean	−11%	−8%	−2%	2%	10%

from the table that mean official forecast errors were smaller in 2000 than for the previous 10-yr period (by 16%–17% through 48 h, and by 5% at 72 h). This is consistent with the improvement trend recently reported by McAdie and Lawrence (2000). Not only were the forecasts more accurate in 2000 than they were over the previous decade, but the forecasts were also more skillful; a comparison of forecast errors relative to CLIPER for the 2000 season with those from the longer period shows, in fact, that forecast skill in 2000 was about 30% higher than the mean over the preceding decade. Forecast skill in 2000 was also higher than in 1999 (Lawrence et al. 2001). One likely contributing factor to the improved official forecasts was a significant change in the way the National Centers for Environmental Prediction (NCEP) global forecast Aviation Model initializes the hurricane vortex; as a result, the NCEP global model's handling of tropical cyclones was much improved in 2000. Performance of the NCEP global model is particularly important, because it not only provides direct track forecast guidance to the forecasters, but its analysis and forecast fields are also used as input to other track models, including the NOAA/Geophysical Fluid Dynamics Laboratory's model (GFDL; Kurihara et al. 1998).

It should be noted that while average track errors for the season were relatively small, several very large errors occurred. Some of the largest (up to 939 n mi at 72 h) were associated with Alberto's unexpected loop between Bermuda and the Azores. Even some of the modest errors had significant impact, such as Debby's anticipated threat to south Florida and subsequent partial evacuation of the Florida Keys.

Two individual forecast situations are noteworthy. The numerical track predictions of Debby from 0000 UTC 23 August are of particular interest, since GPS dropwindsonde data from a synoptic surveillance mission appeared to have a significant impact on some of the numerical track forecast models. In comparison to earlier forecasts, there was a significant southward shift in the model tracks. This was particularly noticeable in the U.K. Met Office global model (UKM), whose 72-h forecast shifted from near or just east of Florida, to near western Cuba. Dropsonde measurements of the steering flow at this time showed that there was a strong midlevel anticyclone to the north of Debby, and that a trough was bypassing the hurricane. Sensitivity runs of the UKM from the above initial time, conducted after the event with and without the dropsonde input, confirmed that the track forecast improvements were attributable to these data (J. Heming 2000, personal communication).

Longer-range official track forecasts for Keith were considerably worse than the 10-yr average, as the former had a persistent northward bias. In this case, the official forecasts tended to follow the Aviation, GFDL, and

TABLE 6. Homogeneous comparison of official and SHIFOR intensity errors (kt) in the Atlantic basin for the 2000 season. Longer-term averages for the 10-yr period 1990–99 are shown for comparison.

	Forecast period (h)				
	12	24	36	48	72
Average official error for 2000	7.3	11.2	14.1	16.1	17.7
Average SHIFOR error for 2000	8.6	13.3	17.2	19.4	18.6
Average error for 2000 relative to SHIFOR	−15%	−16%	−18%	−17%	−5%
(No. of cases)	(228)	(201)	(178)	(163)	(136)
Average 1990–99 official error	6.9	10.7	13.5	16.1	19.5
Average 1990–99 SHIFOR error	8.5	12.4	15.1	17.7	20.5
Average error for 1990–99 relative to SHIFOR	−19%	−14%	−11%	−9%	−5%
No. of cases	2050	1831	1642	1458	1158
Official error for 200 relative to 1990–99 mean	6%	5%	4%	0%	−9%
SHIFOR error for 2000 relative to 1990–99 mean	1%	7%	14%	10%	−9%

UKM models, all of which performed poorly with this storm. Some residual difficulties with the initialization of the hurricane vortex contributed to the problems with the Aviation and GFDL models, but the poor analysis of Tropical Storm Leslie's antecedent disturbance in the Caribbean Sea to the east of Keith may have played an even more important role.

Forecast intensity error is the absolute value of the difference between the forecast and best track intensity at the forecast verifying time; that is, this statistic does not consider the forecast bias. Table 6 presents the results of the NHC official intensity forecast verification for the 2000 season, along with results averaged for the 10-yr period 1990–99. To assess the degree of skill in a set of intensity forecasts, the forecast error can be compared with the error from the Statistical Hurricane Intensity Forecast Model (SHIFOR; Jarvinen and Neumann 1979), the climatology and persistence model for intensity that is analogous to the CLIPER model for track. The table shows that mean intensity errors in 2000 were slightly larger than their previous 10-yr mean from 12 to 36 h, but somewhat lower at 72 h. However, SHIFOR forecast errors in 2000 were also larger than their previous 10-yr means from 12 to 48 h, which suggests that this year's storms were more difficult than normal to forecast. Intensity forecast *skill* in 2000 met or exceeded the 10-yr average at all time periods except 12 h.

5. Concluding discussion

In the late spring of 2000, many were anticipating an active season that would include an increased risk of hurricane landfall (e.g., Gray et al. 2000). A NOAA press release on 10 August predicted above average overall activity and warned of ''an above-average risk of hurricane landfall along the coastal United States.'' Although the 2000 season was in fact active by historical standards (in terms of number of systems), it was a season of relatively little impact, particularly in the United States. This was due in part to the mean circulation pattern in the midtroposphere during August, September, and October (Fig. 7), which featured a major trough along the U.S. east coast. As a result, offshore northeastward tracks in the western North Atlantic were commonplace. Furthermore, when developing systems approached the Caribbean from the east, they encountered persistent southwesterly or westerly vertical wind shear. This shear was a key factor in the demise of Chris, Debby, and Ernesto, and delayed the development of Helene. While the three strongest hurricanes in 2000 developed from tropical waves, Alberto and Isaac became intense at subtropical latitudes, where the environment was more favorable than in the deep Tropics. Keith became very intense within a very limited favorable area of the northwestern Caribbean Sea. While certainly progress has been made in anticipating certain measures of overall seasonal activity, there remains no way to accurately predict the corresponding impact of that activity. Indeed, the correlations between tropical cyclone activity and either damage (Landsea et al. 1999) or deaths in the United States are very small.

Acknowledgments. The authors would like to thank Chris Velden and David Stettner of the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin, for the satellite imagery presented here. Tropical Prediction Center colleagues Drs. Stephen R. Baig and James Gross produced the seasonal track chart and the forecast verification statistics, respectively. Dr. Jiann-Gwo Jiing provided the rawinsonde time section analysis, and Daniel Jimenez assisted in the preparation of the tables.

A number of Internet sites outside of NOAA have become important sources of data for the preparation of operational forecast products and poststorm analysis. These include the Naval Research Laboratory's http://kauai.nrlmry.navy.mil/sat-bin/tc_home for microwave imagery, and CIMSS's http://cimss.ssec.wisc.edu/tropic/ and http://cimss.ssec.wisc.edu/tropic/amsu/index.html for numerous innovative analyses based on satellite-derived wind vectors and AMSU-based thermal cross-sectional analyses, respectively. AMSU analyses are also provided by the Cooperative Institute for Research in the Atmosphere (http://www.cira.colostate.edu/ramm/tropic/amsustrm.asp).

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