ANNUAL SUMMARY

Atlantic Hurricane Season of 2003

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ABSTRACT

The 2003 Atlantic hurricane season is described. The season was very active, with 16 tropical storms, 7 of which became hurricanes. There were 49 deaths directly attributed to this year's tropical cyclones.

1. Introduction

There were 16 named tropical cyclones of at least tropical storm strength in the Atlantic basin during 2003, 7 of which became hurricanes. Table 1 lists these tropical storms and hurricanes, along with their dates, maximum 1-min wind speeds, minimum central sea level pressures, deaths, and U.S. damage. Figure 1 shows the "best tracks" of this season's storms.

The numbers of tropical storms and hurricanes during 2003 are above the long-term (1944–2003) averages of 10 named storms, of which 6 become hurricanes. There have been three seasons with 16 or more named tropical cyclones in the 60 seasons since 1944, and this places the 2003 season in the upper fifth percentile of seasonal number of named tropical cyclones. Another measure of seasonal activity is the National Oceanic and Atmospheric Administration's (NOAA) accumulated cyclone energy index, which is defined as the sum of the squares of the maximum wind speed, every 6 h, for all tropical storms and hurricanes in a season. By this measure, the 2003 season ranks in the upper twelfth percentile of seasons, for all seasons since 1944.

Fabian, Isabel, and Kate were major hurricanes, category 3 or higher on the Saffir–Simpson hurricane scale (Simpson 1974). Fabian and Isabel were exceptionally long-lived and intense.

There were two U.S. hurricane landfalls. Claudette struck Texas near Matagorda Island as a category-1 hurricane, and Isabel's category-2 landfall on the Outer Banks of North Carolina brought hurricane conditions to portions of North Carolina and Virginia and record flood levels to the upper Chesapeake Bay. Elsewhere, Erika made landfall on the northeastern Mexico's Gulf Coast as a category-1 hurricane, Fabian was the most destructive hurricane to hit Bermuda in over 75 yr, and Juan was the worst hurricane to hit Halifax, Nova Scotia, in over 100 yr.

This season's tropical cyclones took 49 lives in the Atlantic basin, including 25 in the United States. Total damage in the United States is estimated at 3.6 billion dollars, mostly from Hurricane Isabel.

One April tropical storm and two December tropical storms extended the season before and after the usual June-through-November period. Ana was the first April tropical storm on record, and the year 1887 was the only other year with two December storms.

Section 2 describes the individual cyclones that attained at least minimal tropical storm strength. In addition, there were five tropical depressions that did not reach tropical storm strength. These are described in section 3. Section 4 gives a brief verification of National Hurricane Center (NHC) official track and intensity forecasts for this season.

The individual summaries are based on NHC poststorm analyses that result in a best track for each cyclone, consisting of 6-h estimates of center position, maximum 1-min, 10-m wind speed, and minimum central surface pressure. A description of the various observational data used to track tropical cyclones is given by Franklin et al. (2001). The life cycle of each cyclone is defined to include tropical and subtropical depres-

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Table 1. Atlantic tropical storms and hurricanes of 2003.

Name	Class*	Dates**	Max 1-min wind speed (kt)	Min sea level pressure (mb)	Direct deaths	U.S. damage ($ million)
Ana	T	20–24 Apr	50	994	2	
Bill	T	29 Jun–2 Jul	50	997	4	50
Claudette	H	8–17 Jul	80	979	1	180
Danny	H	16–21 Jul	65	1000		
Erika	H	14–17 Aug	65	986	2	
Fabian	H	27 Aug–8 Sep	125	939	8	
Grace	T	30 Aug–2 Sep	35	1007		
Henri	T	3–8 Sep	50	997		
Isabel	H	6–19 Sep	145	915	17	3370
Juan	H	24–29 Sep	90	969	2	
Kate	H	25 Sep–7 Oct	110	952		
Larry	T	1–6 Oct	55	993	5	
Mindy	T	10–14 Oct	40	1002		
Nicholas	T	13–23 Oct	60	990		
Odette	T	4–7 Dec	55	993	8	
Peter	T	7–11 Dec	60	990		

* T—tropical storm, maximum sustained winds 34–63 kt; H—hurricane, maximum sustained winds 64 kt or higher.
** Dates based on UTC time and include tropical depression stage.

sion, tropical storm, and hurricane stages, but not the extratropical stage. An archive of tropical cyclone reports is located on the NHC Internet home page at http://www.nhc.noaa.gov/pastall.shtml. These reports contain the complete best track as well as a detailed description of each storm. The storm summaries in section 2 below represent abridged versions of the tropical cyclone reports.

2. Individual tropical storm and hurricane summaries

a. Tropical Storm Ana, 20–24 April

Ana is the first tropical storm on record in April in the North Atlantic basin. The only other tropical or subtropical cyclone known to have occurred in April is a subtropical storm between Puerto Rico and Bermuda from 21 to 24 April 1992.

A nontropical low formed about 210 n mi (1 n mi = 1853.248 m) south-southwest of Bermuda on 18 April when an upper-level trough interacted with a frontal system. Moving generally northward, the low produced sporadic bursts of central convection. After turning northwestward, the low looped back toward the southeast on 20 April. The central convection became better organized and the low separated from the frontal system. It is estimated the low became Subtropical Storm Ana at 0600 UTC 20 April about 215 n mi west of Bermuda.

Based on satellite microwave data showing a warm core, it is estimated that Ana became a tropical storm near 0000 UTC 21 April with winds of 50 kt (1 kt = 0.514791 m s^{-1}). This was the peak intensity of the system. Ana gradually turned toward the east-northeast by 23 April while gradually weakening, and it merged with a cold front on the next day about 810 n mi east of Bermuda.

Ana continued east to east-northeastward as an extratropical low through 26 April and then was aborbed by a frontal system between the Azores and Portugal.

Satellite microwave wind data showed that a tight inner wind core formed within the nontropical low early on 19 April. However, geostationary infrared satellite imagery showed that the cyclone was still attached to the frontal system at that time. The cylone separated from the front about 24 h later and is estimated to have become subtropical at that time. Ana's transition to a tropical cyclone is based on data from the Advanced Microwave Sounder Unit on the NOAA polar-orbiting satellites. This sensor indicated that an upper-level warm core formed by late on 20 April, and Ana is estimated to have become tropical by 0000 UTC 21 April. However, experimental cyclone phase diagrams (Hart 2003) suggest that the transition might have occurred 6–18 h earlier.

Although Ana did not come close to land, it generated large swells that caused a boat to capsize at Jupiter Inlet, Florida, on 20 April. Two people onboard drowned.

b. Tropical Storm Bill, 29 June–2 July

Bill made landfall on the Louisiana coast just west of Cocodrie as a tropical storm with 50-kt winds.

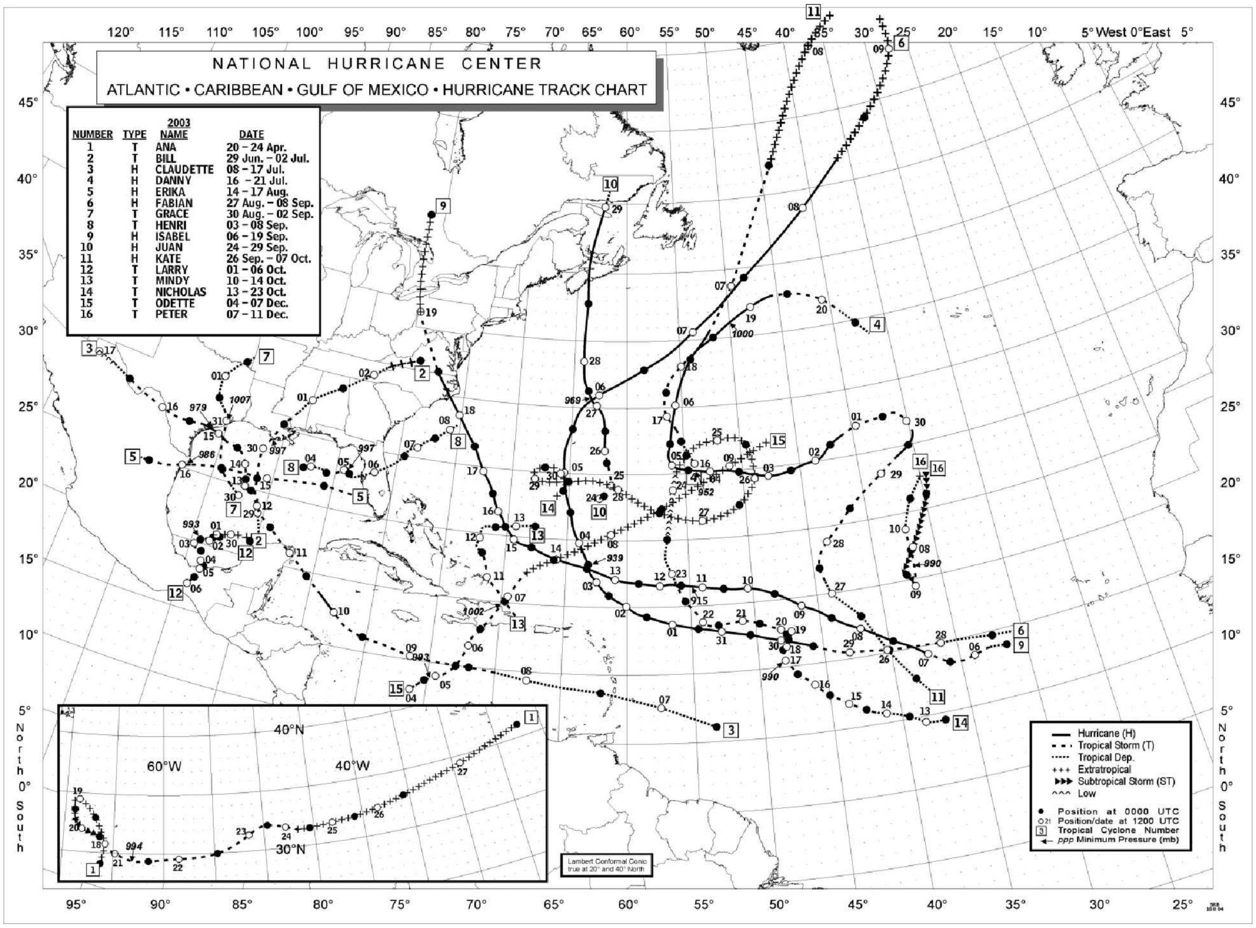

FIG. 1. Tracks of Atlantic basin tropical storms and hurricanes of 2003.

1) SYNOPTIC HISTORY

The interaction of a tropical wave and a mid- to upper-level low resulted in the formation of a surface low pressure area over the Yucatan Peninsula on 28 June. This low was accompanied by a large area of cloudiness and thunderstorms that extended eastard over the northwestern Caribbean Sea. When the low moved toward the north-northwest over water and away from the Yucatan Peninsula, convection became better organized, and it is estimated that a tropical depression formed at 0600 UTC 29 June. The depression strengthened to Tropical Storm Bill 6 h later.

Bill moved on a north-northwesterly to northerly track and gradually intensified. It turned toward the north-northeast and reached its peak intensity of 50 kt, with a minimum pressure of 997 mb, at 1800 UTC 30 June when the cyclone's center was very near the Louisiana coast. Bill made landfall about 20 n mi west of Cocodrie, near King Lake, on the south coast of Louisiana at its peak intensity around 1900 UTC 30 June. Thereafter, Bill weakened to a tropical depression while moving across central Mississippi and Alabama. It became an extratropical low near the Tennessee–Virginia border at 1800 UTC 2 July and then was absorbed by a frontal system.

2) METEOROLOGICAL STATISTICS

Bill is estimated to have reached tropical storm staus based on a report of 38 kt from the ship HG3Q located to the northeast of the cyclone center at 1200 UTC 29 June. Bill's peak intensity of 50 kt and minimum pressure of 997 mb were based on a report from a reconnaissance plane of 66 kt at 850 mb and a minimum surface pressure of 997 mb from Lumcon Marine Center, near Cocodrie, respectively. Table 2 is a list of significant surface observations. Rainfall totals ranged up to near 160 mm in southern Louisiana and up to near 100 mm in Mississippi. Storm surge flooding ranged up to 1.7 m above normal tide levels over southern Louisiana and Mississippi.

TABLE 2. Selected surface observations for Tropical Storm Bill, 29 Jun–2 Jul 2003.

	Minimum sea level pressure		Maximum surface wind speed				
Location	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)	Storm surge (m)[c]	Total rain (mm)
Louisiana							
Slidell	1/0009	1001.7	1/0006	36	45		159
Boothville	30/2223	1008.0	30/1901	32	45		
New Orleans Lakefront Airport	30/2314	1000.7	30/2340	38	46		155
New Orleans International Airport	30/2246	998.3	30/2247	35	40		89
Rigolets			30/2320	40	48	0.9	
Mandeville			01/0110	43	54	1.5	
Mid Lake Causeway			30/2110	38	51	0.9	
Belle Chase Naval Air Station			30/2145		36		
Industrial Canal						1.5	
South Shore Harbor						1.1	
Frenier						1.4	
Caillou Bayou						1.3	
Grand Isle						1.0	
Lumcon Marine Center	30/1720	997.7	30/1746	43			
Lumcon Ponchartrain	1/0008	996.0	30/2208	41	54		
Terrebone Bay	30/1944	997.8	30/1994	50	58		
Turtle Cove			30/2345	38	44		
Southeast			30/2354		42		
Citrus			30/2004		48		
Venice			30/1459	34			
Houma			30/1003	39			
Mississippi							
Keesler Air Force			30/0307		45	1.2	
Gulfport			1/0054	37	45		104
Pascagoula			1/0221		36		100
Point Cadete						1.4	
Waveland						1.5	
Bayou Bienvenue						1.7	
Bayou Dupre						1.6	
NOAA buoy and C-MAN							
42007			1/0250	34	46		
42040			30/2050	36	49		
BURL1			30/1840	49	67		
GDIL1			30/2050	36	49		
LA Offshore Oil Port[d]			30/2025	56[e]	67		

[a] Date/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] One hundred fifty feet above sea level.
[e] Five-minute-average wind.

3) DEATHS AND DAMAGES

There were four deaths associated with Bill. A 10-yr-old boy drowned in Holly Spring Creek in Raleigh, North Carolina; a man was killed by a falling tree in Atlanta, Georgia; and two swimmers drowned at Panama City Beach, Florida, in rip currents produced by Bill. Much of the wind damage was downed branches and trees that caused power outages across the eastern portion of southeastern Louisiana and coastal Mississippi. The most significant storm surge floods occurred in coastal sections of southeastern Louisiana, primarily in southern Terrebone Parish where a levee was breached and overtopped in the Montegut area. This resulted in some homes being flooded. An F1 tornado (on the Fujita scale) touched down in Reserve, Louisiana, around 1710 UTC 30 June, hitting a private school and causing significant damage to several buildings. It then hit a mobile home park, damaging at least 20 homes. There was a total of 30 tornadoes from Louisiana through North Carolina. The Property Claim Services Division of the American Insurance Services Group, the Insurance Services Office, Inc., reports that insured losses due to Bill totaled 22 million dollars in Louisiana. Total losses for Louisiana and Mississippi are estimated at 50 million dollars.

4) Warnings

A tropical storm watch was issued from San Luis Pass, Texas, to Morgan City, Louisiana, at 1500 UTC on 29 June. A tropical storm warning was issued from High Island, Texas, to Pascagoula, Mississippi, including Lake Ponchartrain, at 2100 UTC on the same day. Bill made landfall near the middle of the warning area about 22 h after the warning was issued. However, the landfall location was just east of the eastern limit of the watch area.

c. *Hurricane Claudette, 8–17 July*

Hurricane Claudette made landfall on the northeastern Yucatan Peninsula of Mexico as a tropical storm, and as a category-1 hurricane in Texas.

1) Synoptic history

Claudette formed from a tropical wave that moved westward across the coast of Africa on 1 July. The wave showed signs of convective organization on 6 July and was well enough organized on satellite imagery to be classified as a tropical depression on 7 July near the Windward Islands. However, the wave was moving westward at 20–25 kt at the time, and neither surface observations nor an investigative flight by the U.S. Air Force Reserve Hurricane Hunters indicated that the system had a closed surface circulation.

The wave continued rapidly westward with a further increase in organization. Satellite intensity estimates suggested the system was near tropical storm strength by 1500 UTC 8 July. However, a second investigative flight could not find a closed center at that time. Finally, near 1800 UTC the plane found a small area of southwesterly winds that indicated a closed circulation and the wave is estimated to have become Tropical Storm Claudette while located about 200 n mi south of Hispaniola.

Claudette continued quickly westward through 9 July while slowly strengthening, and then turned northwestward with some deceleration on the following day. It formed a small eye and strengthened to a 70-kt hurricane for a few hours on 10 July, but became disorganized and weakened to 50 kt before making landfall on the northeastern Yucatan Peninsula of Mexico near 1000 UTC 11 July.

The storm moved northwestward into the southern Gulf of Mexico on 11 July. A north-northwestward jog occurred on 12 July while Claudette became a little better organized. The storm meandered erratically northwestward on 13 July, then turned northward later that day. These track changes were likely due to a combination of 1) weakening of a mid-upper-level ridge along the northern Gulf Coast caused by a developing trough over the eastern United States, and 2) reformation of the center caused by strong but asymmetric convection to the northeast. This change in motion was accompanied by some decrease in the shear, and while the center remained mostly exposed, Claudette slowly strengthened on 13 July.

A building deep-layer ridge over the western United States and the western Gulf Coast states forced Claudette to gradually turn west-northwestward late on 14 July. An eyewall formed and Claudette again became a hurricane at 0600 UTC 15 July. A faster west-northwestward motion brought the center of Claudette to the Texas coast at Matagorda Island (just east of Port O'Connor) at 1530 UTC that day (Fig. 2). Strengthening continued up to landfall, with estimated maximum winds increasing to 80 kt and the central pressure falling to 979 mb.

Claudette turned westward just after landfall and weakened to a tropical storm at 0000 UTC 16 July. It then turned west-northwestward again while moving into northern Mexico later that day. This motion continued until dissipation. Claudette was slow to lose organization, as the radar and satellite presentations of its structure remained distinct for more than 24 h after landfall. Surface data indicate the system maintained tropical storm strength until 0000 UTC 17 July. The low-level circulation dissipated over the mountains of northwestern Mexico later that day. However, the mid- and upper-level moisture and vorticity continued west-northwestward, eventually crossing southern California into the Pacific.

2) Meteorological statistics

The maximum flight-level winds observed by the aircraft were 85 kt at 0334 UTC 9 July (at an altitude of 457 m) and at 1517 UTC 15 July (at 700 mb). The latter observation was made as the eye of Claudette was crossing the Texas coast. Global positioning system (GPS) dropsondes deployed by the aircraft reported surface winds of 73 kt at 1526 UTC 10 July and 70 kt at 1516 UTC 15 July.

Early on 9 July, in the central Caribbean, an aircraft

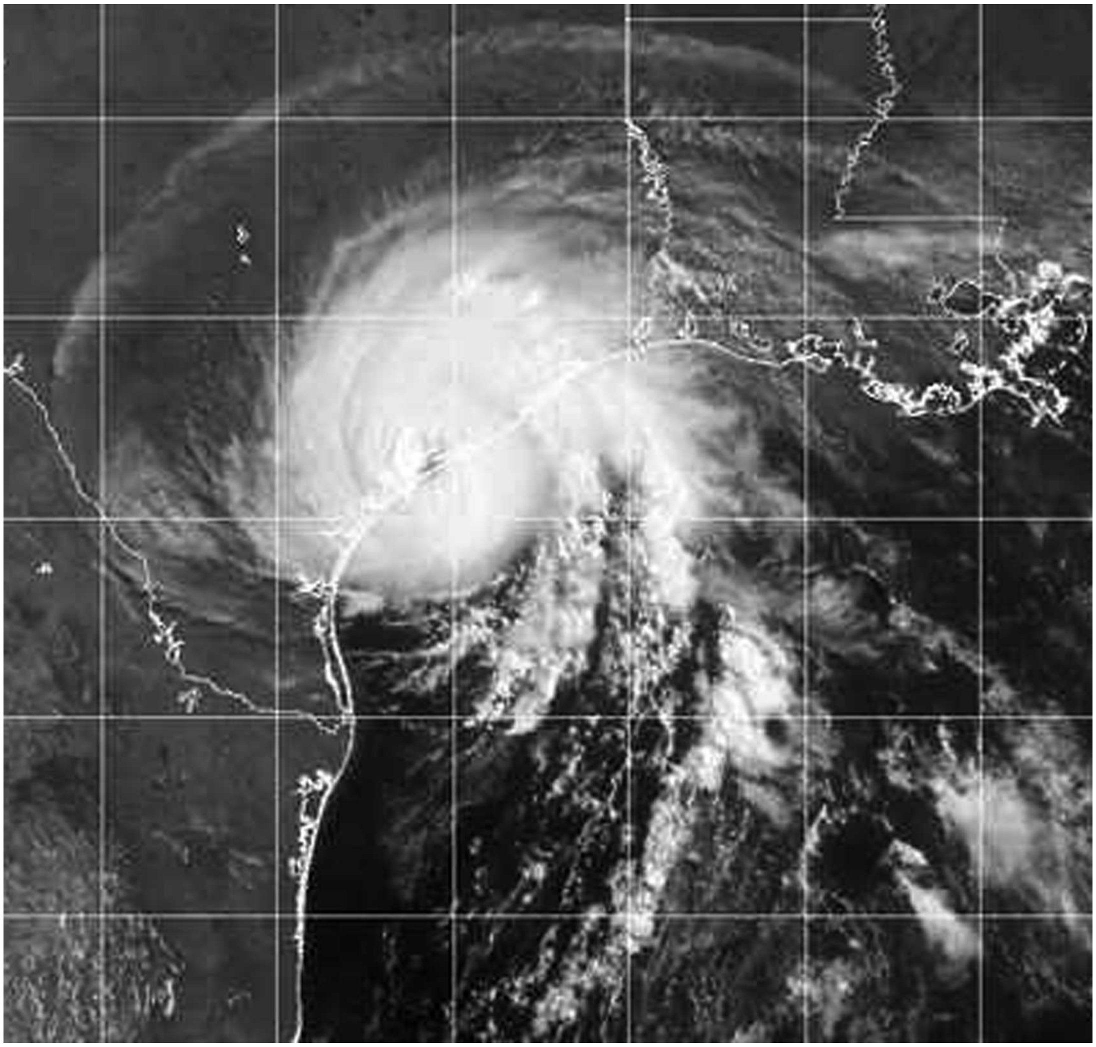

FIG. 2. *Geostationary Operational Environmental Satellite-12* (*GOES-12*) visible satellite image of Hurricane Claudette at 1532 UTC 15 Jul 2003. The center is on the coast of Texas and maximum winds are estimated at 80 kt at the time of this image (courtesy of Naval Research Laboratory, Monterey, CA).

reported an 85-kt wind speed at 850-mb flight level and a central pressure of 1001 mb. Two hours later, a pass through the same part of the storm showed flight-level winds of only 56 kt. Based on this, the 85-kt wind speed was not considered representative, and it is estimated that Claudette remained a tropical storm and the best-track wind speed was 60 kt at 0600 UTC 9 July. However, it is possible that Claudette briefly reached minimal hurricane intensity at this time. Claudette is estimated to have become a hurricane at 1200 UTC on 10 July based on a 73-kt dropsonde surface wind observation.

Hurricane conditions occurred over portions of the middle Texas coast. The maximum sustained wind reported by an official observing site was a 10-min average of 65 kt at the Remote Automated Weather Stations (RAWS) site on Matagorda Island, Texas (Table 3). The Texas Coastal Ocean Observation Network (TCOON) station at Port O'Connor reported a 6-min average sustained wind of 62 kt with a gust to 78 kt in the western eyewall. Victoria, Texas, reported 54-kt sustained winds with a gust to 72 kt, although these data are incomplete due to a power failure. Tropical storm conditions occurred along much of the middle and upper Texas coast. Cotulla, Texas, reported sustained winds of 36 kt with a gust to 46 kt at 0246 UTC 16 July, while Del Rio, Texas, reported a gust to 47 kt.

Tropical storm–force winds also occurred well inland over portions of southwestern Texas, including 38-kt sustained winds with a gust to 50 kt at the Terrell County airport at 1658 UTC 16 July. Other reports of tropical storm wind gusts occurred at Mt. Locke in the

TABLE 3. Selected surface observations for Hurricane Claudette 8–17 July 2003.

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Texas								
Alice (KALI)	15/2242	1003.3	15/21033		35			9
Angleton (KLBX)	15/1253	1005.6	15/1331		43			66
Aransas RAWS			15/1857		64			119
Bay City (KBYY)	15/1448	1002.1	15/1528	36	50			42
Clear Lake TCOON							1.7	
Copano Bay TCOON							0.7	
Colorado River Bypass USGS							1.7	
Corpus Christi Airport (KCRP)	15/2031	1004.2	15/2018		34			10
Corpus Christi N.A.S. (KNGP)			15/2141		36			17
Corpus Christi Bob Hall Pier NOS			16/0800		44	0.8		
Cotulla (KCOT)	16/0146	997.9	16/0246	36	46			46
Del Rio (KDRT)			16/1253	31	47			
Eagle Point NOS	15/0924	1008.8	15/1124	38	46	1.3		
East Matagorda Bay TCOON[e]			15/1500	51	71			
Freeport NOS						1.6		
Freeport TCOON			15/1354	40	56			
Freeport USGS			15/1200		44		2.8	
Galveston Bay/Moses Lake USGS							1.5	
Galveston Airport (KGLS)	15/1052	1008.7	15/1253	38	47			51
Galveston North Jetty NOS	15/1224	1007.6	15/0830	40	54	1.2		
Galveston Pier 21 NOS	15/1224	1008.6				1.1		
Galveston Pleasure Pier NOS	15/1030	1007.3	15/1048	42	54	1.6		
Galveston South Jetty TCOON[e]			15/0600	35	52		2.7	
George West RAWS			15/2218		55			73
Guadalupe Pass (KGDP)			17/0451	38	45			
Highland Bayou Diversion Channel USGS							1.9	
Highland Bayou/Hitchcock USGS							1.8	
Hondo (KHDO)	16/0151	1008.4	16/0625		44			
Houston Clover Field (KLVJ)	15/0853	1010.0	15/0942		34			
Houston Hobby Airport (KHOU)	15/1153	1010.6	15/1104		35			28
Houston Port USGS							2.3	
Ingleside TCOON[e]			15/1900		39		0.8	
Jamaica Beach NWS COOP	15/1215	1008.0	15/0744	36	48		1.7	63
Kemah USGS			15/1200		35		1.8	
LaMarque USGS							1.5	
Marfa (KMRF)			16/2115		36			
Matagorda Colorado River Locks[f]							2.4	
Matagorda RAWS			15/1800	65				
McMullen County			16/0218		53			
Mesquite Point TCOON[e]			15/1000	31	38		1.1	
Morgans Point NOS	15/1118	1009.8	15/1148	39	46	1.5		
Mt. Locke			16/1820		46			
NWS Station 1 TCOON	15/1642	1002.7	15/1912		47			
Orange Grove			15/2245		35			
Palacios[e] (KPSX)	15/1153	1003.1	15/1153		35			
Pearland (KLVJ)	15/1053	1010.0	15/1039		34			42
Port Aransas TCOON[e]			15/1748		37		1.0	
Port O'Connor TCOON			15/1506	62	78		1.9	
Rockport (KRKP)	15/1800	999.7	15/1800		36			51
Rockport NOS						0.6		
Rollover Pass TCOON							1.1	
Round Point TCOON[e]	15/1100	1009.8	15/1200		40		1.6	
S. Bird Island TCOON[e]			16/0800		35			

TABLE 3. (*Continued*)

Location	Minimum sea level pressure: Date/time (UTC)	Minimum sea level pressure: Pressure (mb)	Maximum surface wind speed: Date/time (UTC)[a]	Maximum surface wind speed: Sustained (kt)[b]	Maximum surface wind speed: Gust (kt)	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
Sabine Pass North NOS						0.8		
San Antonio Stinson Airport (KSSF)			16/0053		42			
San Bernard RAWS			15/1200	35				67
Seadrift TCOON[e]			15/1600	41	53		1.1	
Terrell County Airport (K6R6)			16/1658	38	50			
The Bowl			17/0604		61			
Victoria[e] (KVCT)	15/1800	994.9	15/1818	54	72			
Victoria RAWS			15/1830	53	71			
West Galveston Bay TCOON	15/1100	1004.4	15/0848	41	58		1.6	
White Point TCOON			15/2006		38		0.7	
Louisiana								
Cameron USGS[e]			15/1000		37		0.9	
Jamaica								
Montego Bay			09/1622		40			
NOAA buoy and C-MAN								
NOAA Buoy 42001	14/0800	1011.4	12/1710	36[h]	50			
NOAA Buoy 42019	15/1100	990.3	15/0810	47[h]	60			
NOAA Buoy 42035	15/0900	1008.0	15/0700	37	49			
NOAA Buoy 42041			14/1117		39			
Port Aransas C-MAN (PTAT2)	15/2000	1003.8	15/1930	33[h]	44			
Sea Rim State Park C-MAN (SRST1)	15/1000	1010.7	15/1000	45	54			
TABS Buoy N[g]	14/2009	1007.9	14/2039		56			
TABS Buoy V[g]	14/1709	1010.6	14/1609		46			
Oil rigs[i]								
East Cameron 312			14/1830	65				
East Cameron 377			14/1830	74				
ENSCO 7500			14/0600	39				
Eugene Island 322A			14/1100	65	83			
Garden Banks 128			14/1545	65	80			
Garden Banks 298			14/1830	80				
Garden Banks 426			14/1300	68	74			
Garden Banks 657			14/2000	40	48			
Green Canyon 158			14/1203	36				
KW60			14/1700	40	44			
Unofficial reports								
Texas								
Bloomington Dow Chemical			15/1650	60				
Brazos TXDOT			15/1430	38				
Clear Creek TXDOT			15/1400	35				
Clear Creek at Seabrook							1.7	
Fort Davis Weather Underground			15/2208		37			
Galveston Causeway TXDOT			15/1100	37				
Hartman TXDOT			15/1200	34				
Kemah TXDOT			15/0830	47				
Long Mott Dow Chemical			15/1827	68	83			
Point Comfort Formosa Plastics			15/1545	70	87			
Port Lavaca Co-op			15/1800		63			
Port O'Connor (Whitener)	15/N/A	980.0	15/N/A	83	93			
Rawlings Bait Camp							1.0	
Schroeder Skinner Ranch Weather Underground	15/1900	993.1	15/1900	37	57			81
Tivoli Co-op			15/N/A		57			

TABLE 3. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Victoria (Sudduth)			15/ N/A	54	65			
Wadsworth South Texas Nuclear Plant			15/1400	44	73			

[a] Date/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; NOS and TCOON stations averaging periods are 6 min; RAWS stations report 10-min-average sustained winds.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide from TCOON stations is water height above mean lower low water (MLLW). For other stations it is water height above National Geodetic Vertical Datum (1929 mean sea level) unless noted.
[e] Incomplete record—more extreme values may have occurred.
[f] Note that Colorado River Locks at Matagorda reading was taken from a high water mark in a boathouse referenced to MLLW.
[g] Station destroyed—more extreme values may have occurred.
[h] Ten-minute average.
[i] Oil rig anemometer heights are generally 100–200 ft; wind averaging periods are unknown.

Davis Mountains, and at Guadalupe Pass and The Bowl in the Guadalupe Mountains. These winds were likely enhanced by mountainous terrain.

Tropical storm conditions likely occurred over portions of the northeastern Yucatan Peninsula, but there were no reports of tropical storm–force winds from that area. Winds gusted to tropical storm force at Montego Bay, Jamaica. Winds also gusted to tropical storm force on St. Lucia during the passage of the pre-Claudette tropical wave.

Many unofficial observations were received from the landfall area, with a selection included in Table 3. A storm chaser in Port O'Connor reported 83-kt sustained winds with a gust to 93 kt measured at the top of a vehicle with good exposure. While this observation is included in Table 3, it is notable that the winds are 15–20 kt higher than the nearby TCOON station and are considered to be in error. A report from Seadrift, Texas, indicated 84-kt sustained winds with a gust to 96 kt. However, an inspection of the site by Naional Weather Service (NWS) personnel showed that there may have been funneling of the winds across the instrument. Thus, the report is not included in Table 3.

Data from the NWS Weather Surveillance Radar-1988 Doppler units (WSR-88Ds) indicated winds of 95–105 kt between 1500- and 3000-m elevation in the northwest eyewall after Claudette made landfall. It is uncertain how to convert these winds to sustained surface winds over land. However, reduction factors derived from GPS dropsonde data over water suggest 85–90-kt sustained surface winds. A further reduction for land friction would reduce the radar winds to near or below the 75–80-kt range determined from the aircraft data.

Damage surveys were conducted by the staffs of NWS forecast offices in Corpus Christi and Houston. These surveys concluded the damage was consistent with category-1 sustained winds. Unpublished information from a damage survey by Haag Engineering also supports this determination.

Storm-surge flooding of up to 1.8 m above normal tide levels occurred near where the eye of Claudette made landfall. Storm tides (storm surge plus astronomical tide) of up to 2.7 m were measured in the Galveston–Freeport area (Table 3). Tides were up to 0.6 m above normal as far north as the southwestern Louisiana coast and as far south as the Baffin Bay, Texas, area.

Claudette moved quickly westward after landfall, which limited rainfall totals. The highest storm-total rainfall was 165 mm, four miles south-southeast of Tilden, Texas, and there were other reports of up to 150 mm amounts along the storm track. NWS WSR-88D data estimates that as much as 200 mm may have fallen in some areas. These rains caused minor flooding in southern Texas and some flash floods in southwestern Texas. Rainfall of up to 75 mm also occurred over portions of the Yucatan Peninsula and the Cayman Islands, with 82 mm reported in Cancun, Mexico.

Two tornadoes were reported during Claudette. An F1 intensity tornado damaged several buildings in Palacios, Texas. A second tornado touched down in Port Lavaca, Texas, causing damage to some homes.

3) Deaths and damages

Claudette is responsible for one direct and two indirect deaths. The direct death was a 13-yr-old boy crushed by a falling tree in Jourdanton, Texas. The first indirect death was a 33-yr-old woman who was hit by a falling limb after the storm was over. The second indirect death was at Navarre Beach, Florida, when a 71-yr-old man died after being pulled from surf generated by Claudette. Press reports suggest the man suffered a heart attack while swimming.

The Property Claim Services Division of the American Insurance Services Group, the Insurance Services Office, Inc., reported that Claudette caused 90 million dollars in damage to insured property in the United States. The total damage estimate is twice this, or 180 million dollars. No significant damage was reported from Mexico, the Cayman Islands, or Jamaica. Minor damage was reported in St. Lucia from the pre-Claudette tropical wave.

4) Warnings

Hurricane warnings for the Texas coast were issued about 24 h before the center made landfall. A hurricane watch was issued from Port O'Connor southward about 48 h before Claudette made landfall, while a hurricane watch was issued for the remainder of the landfall area about 30 h before the center made landfall. The first tropical storm warnings for the northeastern Yucatan Peninsula were issued 37 h before the center made landfall. Hurricane warnings issued on 10 July for the Yucatan Peninsula proved to be unnecessary, since Claudette weakened rapidly after being a hurricane for a few hours.

d. Hurricane Danny, 16–21 July

Hurricane Danny made a large looping path over the central North Atlantic Ocean. A large, well-organized tropical wave moved across the coast of Africa on 9 July. Soon thereafter, a disturbance separated from the wave and moved northwestward. Thunderstorm activity slowly increased over the following several days and Dvorak satellite classifications began late on 15 July. It is estimated that a tropical depression formed at 1200 UTC 16 July about 550 n mi east of Bermuda.

The depression developed outer convective bands and the cyclone became Tropical Storm Danny at 0000 UTC 17 July. For the next 24 h, Danny moved northwestward and then turned northeastward and gradually strengthened. Danny was upgraded to hurricane status with 65-kt winds on 18 July based on the appearance of an eye on satellite imagery.

As Danny moved eastward around the northern periphery of a subtropical Atlantic high pressure ridge, it encountered westerly vertical wind shear and cooler sea surface temperatures and weakened. Danny turned southeastward and weakened to a tropical depression on 20 July and then degenerated into a nonconvective remnant low pressure system on 21 July. The remnant low moved slowly southward and then westward around the south side of the subtropical ridge before making a small clockwise loop on 24–25 July about 1250 n mi east-northeast of Bermuda. After making the loop, the remnant circulation turned southwestward and began moving over warmer water. The remnant low pressure system continued moving southwestward and eventually dissipated on 27 July about 1080 n mi east of Bermuda, which is also about 550 n mi east of where Danny originated.

e. Hurricane Erika, 14–17 August

Erika made landfall on the Mexican Gulf of Mexico coast just south of the United States–Mexico border shortly after reaching hurricane strength, and was responsible for two deaths.

1) Synoptic history

Erika's origin was nontropical. A weak surface low detached from a decaying frontal system about 1000 n mi east of Bermuda on 8 August. This low moved southwestward and then westward for several days, while interacting with an upper-level low. The combined weather system produced gusty winds in the Bahamas early on 14 August, where there was an unofficial report of a gust to 51 kt from Abaco Island. Convection was vigorous while the system moved across Florida during the morning of 14 August and then a closed surface low formed near 1800 UTC, about 75 n mi west of Fort Myers, Florida. With winds already of tropical storm strength, the system immediately became Tropical Storm Erika.

A strong deep-layer high pressure system over the south-central United States helped steer Erika westward across the Gulf of Mexico at about 22 kt. Erika strengthened as the cyclone's central convection intensified and the low-level circulation became better defined late on 14 August. Strengthening continued on 15 August while Erika's forward speed decreased and convection took on a more banded structure. Late in the day, an eye was visible in land-based radar imagery. Erika became a hurricane and reached its maximum intensity of 65 kt at landfall near 1030 UTC 16 August while located about 40 miles south of

Matamoros, Mexico, near Boca San Rafael. The hurricane weakened rapidly after landfall and dissipated on 17 August over the mountains of northeastern Mexico.

2) Meteorological statistics

Despite an impressive and organized appearance on satellite imagery, the rapid westward motion of the pre-Erika disturbance hindered the development of a closed surface circulation. Data from reconnaissance aircraft, including dropsondes, were instrumental in determining when the disturbance became a tropical cyclone. Around 0800 UTC 14 August, aircraft flight-level data at 850 mb indicated the presence of a closed circulation just east of Key Largo, Florida. However a dropsonde revealed that the west winds measured by the aircraft were not present below flight level and advisories were not initiated until later in the day, when a new low-level circulation formed within the system over the eastern Gulf of Mexico.

Erika was never operationally upgraded to a hurricane. The highest flight-level observations from reconnaissance aircraft were 67 and 66 kt at 0213 and 0820 UTC 16 August, respectively. These observations were made at 700 mb and correspond to a surface wind of about 60 kt (the operational landfall intensity). A post-storm review of the Doppler velocity data revealed winds in excess of 85 kt over an area several miles across, in the eastern and northeastern (over water) portion of the eyewall near the time of landfall, from around 1000–1200 UTC, at an elevation of about 762 m. Adjustment of these (85 kt) winds to the surface, using a mean eyewall wind profile based on dropwindsonde observations (Franklin et al. 2003a), gives a surface wind estimate of 65 kt. There were no aircraft reconnaissance observations in this part of the cyclone after 0820 UTC. On the basis of the radar observations, Erika was posthumously upgraded to a hurricane. A pressure fall of at least 5 mb after the time of the 67-kt flight-level wind also suggests that Erika reached hurricane intensity. The estimated minimum pressure (986 mb) at landfall was determined by extrapolation of the pre-landfall deepening rate.

Selected surface observations from land stations and data buoys are given in Table 4. The strongest sustained wind observed over land was 35 kt (10-min mean) at San Fernando, Mexico, with a gust to 55 kt. In south Texas, sustained tropical storm force winds were observed in Brownsville.

In Magueyes, Mexico, 170 mm of rain was recorded. A number of other sites reported storm-total rainfall of 75 mm or more. In southern Texas, official and cooperative observing sites reported rainfall totals of less than 50 mm, although unofficial reports of up to 75 mm were also received from the Brownsville area. Doppler radar estimated isolated accumulations of 100–150 mm in Kenedy and Brooks counties.

3) Casualty and damages

Two persons died in Montemorelos, Mexico, when they tried to cross a bridge that was partially under water and their truck was swept away by flood waters. Damage to roofs and cars was reported in Matamoros, and numerous highways in northeastern Mexico were blocked by mud slides.

Isolated minor damage was reported in south Texas from minor coastal flooding and beach erosion on South Padre Island. There were no injuries or fatalities reported in the United States.

4) Warnings

A hurricane watch was issued at 0300 UTC 15 August for the southern Texas coast and for the northern Mexican coast about 31 h prior to landfall. A hurricane warning was issued at 1500 UTC 15 August, or about 19 h prior to landfall. The center of Erika came ashore roughly in the center of the hurricane warning area.

f. Hurricane Fabian, 27 August–8 September

Fabian was a long-lived and powerful Cape Verde hurricane that struck Bermuda with category-3 intensity. It caused extensive damage on that island, where it was reported to be the worst hurricane since 1926.

1) Synoptic history

Fabian began as a vigorous tropical wave that emerged from western Africa on 25 August and moved westward through the Cape Verde Islands a day later. By 27 August, the deep convection associated with the system became more consolidated in a circular area, and it is estimated that a tropical depression formed at 1800 UTC, centered about 365 n mi west of the westernmost Cape Verde Islands. The depression became a tropical storm around 1200 UTC 28 August, and a hurricane by 0000 UTC 30 August over the east-central tropical Atlantic Ocean. Fabian reached its estimated peak intensity of 125 kt at 1800 UTC 1 September when it was centered about 265 n mi east-northeast of the northern Leeward Islands. The hurricane maintained category-3 or -4 intensity on the Saffir–Simpson hurricane scale for almost a week.

Fabian was steered on a westward to west-northwest-

TABLE 4. Selected surface observations for Hurricane Erika, 14–17 Aug 2003.

Location	Minimum sea level pressure: Date/time (UTC)	Minimum sea level pressure: Pressure (mb)	Maximum surface wind speed: Date/time (UTC)[a]	Maximum surface wind speed: Sustained (kt)[b]	Maximum surface wind speed: Gust (kt)	Storm tide (mt)	Total rain (mm)
Texas							
Brownsville (BRO)	16/10043	1002.6	16/0947	34	41		28
Valley International Airport (HRL)	16/1143	1007.2	16/1143	27	35		13
McAllen/Miller (MFE)	16/1113	1009.7	16/0954	27	35		29
Bayview (PIL)	16/0930	1005.3	16/0956	30	38		21
Los Fresnos (Co-op)							42
Port Mansfield (Co-op)							37
Raymondville (Co-op)							40
Sarita (Co-op)							27
Falfurrias (Co-op)							28
NOAA buoys							
42020	16/1000	1009.4	16/0600		41		
42002	16/0100	1009.3	16/0030	34	42		
Texas Coastal Oceanic							
Bob Hall Pier			16/1400		35		
Bird Island			16/1300		35		
Baffin Bay			16/1300		34		
Port Isabel			16/0800		44		
S. Padre Island CG station			16/0800	36[c]	46		
Texas Tech Tower							
Port Isabel			16/0903	32	41		
Mexico							
Matamoros	16/1010	1002.3	16/0900	28[d]	39		8
San Fernando			16/1350	35[d]	55		70
El Cuchillo							21
Magueyes							170
Presa Cerro Prieto							102
Camacho							90
Presa La Boca							88
Monterrey Observatory							87
El Barretal							74

[a] Date/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] Averaging period unknown.
[d] Ten-minute average.

ward heading for several days by deep easterlies to the south of a subtropical ridge. The forward speed gradually decreased from 18 to 19 kt just after genesis to less than 10 kt by 2 September, as the tropical cyclone neared a weakness in the subtropical ridge produced by a midlevel cyclonic circulation over the southwestern North Atlantic. Then, the hurricane turned toward the northwest while continuing to decelerate over the next couple of days. A large midtropospheric trough nearing the east coast of the United States turned Fabian northward with increasing forward speed. Fabian struck Bermuda with an intensity close to 100 kt. The eastern eyewall of the hurricane moved over Bermuda around 2000 UTC on 5 September (Fig. 3). Observers on the western end of the island reported a brief blue sky and winds decreasing to 50–60 kt at various times between 1945 and 2115 UTC, indicating that they were in the eastern fringes of Fabian's eye.

After raking Bermuda, the hurricane accelerated northeastward, weakening to below 100 kt after 1800 UTC 6 September. Fabian lost tropical characteristics on 8 September while located about 700 n mi east-northeast of Cape Race, Newfoundland. It turned northward the next day and merged with another extratropical cyclone between southern Greenland and Iceland.

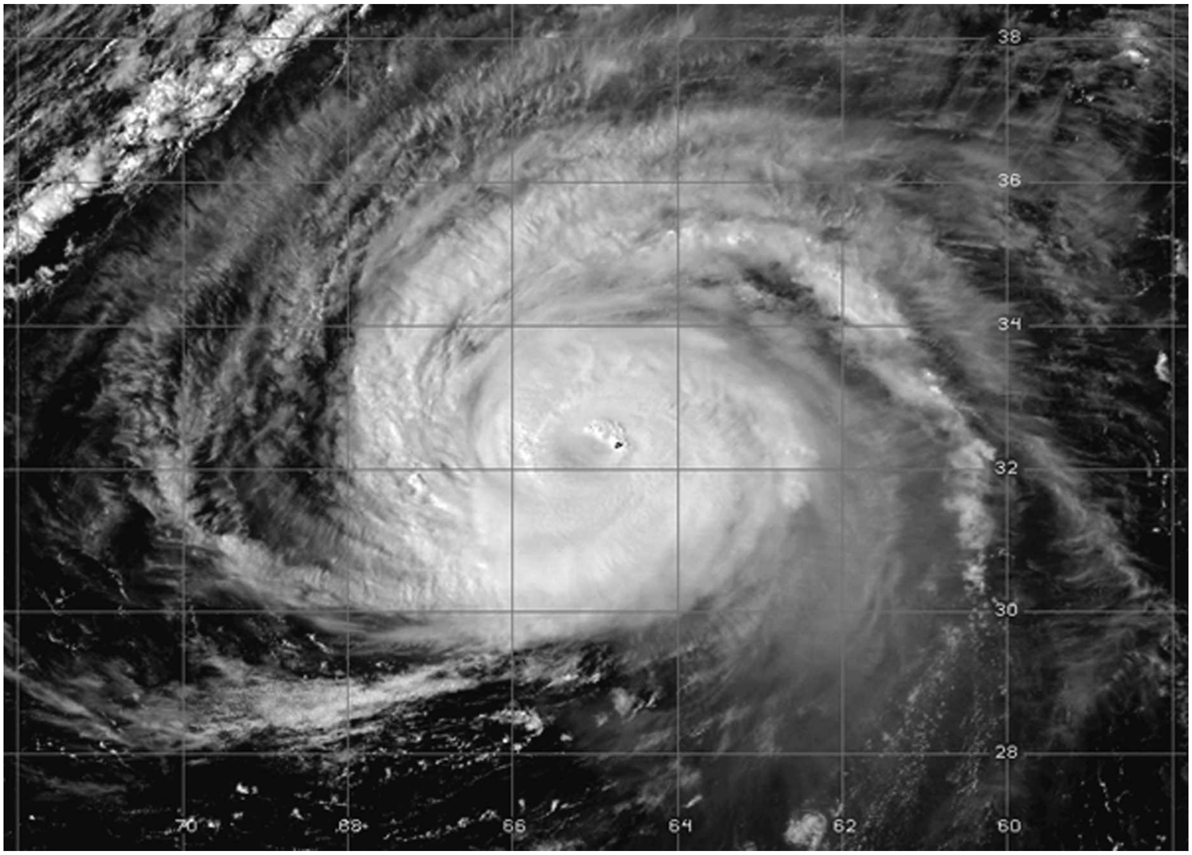

FIG. 3. *GOES-12* visible satellite image of Hurricane Fabian at 1915 UTC 5 Sep 2003. The eastern eyewall is over Bermuda and maximum winds are estimated at 100 kt at the time of this image (courtesy of CIMSS, University of Wisconsin—Madison).

2) Meteorological statistics

Fabian's peak intensity is estimated to be 125 kt, based on an aircraft reconnaissance wind of 140 kt at a flight level of 700 mb around 1917 UTC 1 September. A minimum central pressure of 942 mb was measured at that time. A lower central pressure of 939 mb was measured by NOAA at 2245 UTC 3 September, but maximum flight-level winds around that time supported an intensity of only 115 kt.

A 10-min average wind speed of 105 kt and a gust to 131 kt were measured by Cable and Wireless at an elevation of 280 ft above sea level. A 10-min wind speed of 104-kt winds, with gusts to 127 kt, were observed at Warwick Tower at an elevation of 67 m above ground level. Winds of 102 kt with a gust to 143 kt were measured by Bermuda Harbor Radio at an elevation of 78 m above sea level. These observations are unofficial and at elevations significantly higher than 10 m. They are, however, consistent with category-3 intensity. Unfortunately, because of a loss of power, the official wind measurements from the Bermuda Airport (TXKF) anemometer ended at 1935 UTC 5 September, and the extreme sustained and gust wind speed values were estimated by the observers.

3) Casualties and damages

Fabian was directly responsible for eight fatalities. A man drowned in a rip current near Cape Hatteras, North Carolina, on 4 September. Four people drowned when they and their vehicles were swept off a causeway in Bermuda on 5 September. Three fishermen drowned when their vessel sank about 350 n mi southeast of St. John's, Newfoundland, on 7 September.

Bermuda was hit hard by Fabian. There was extensive damage to vegetation and considerable roof damage to houses in exposed locations. Some buildings had more severe damage, due to inherent structural weakness in some cases and possibly due to tornadoes (which were not confirmed) in others. There were huge battering waves, estimated at 6–9 m, on the south shore of the island, on top of a storm surge estimated near 3 m. Property damage in Bermuda is estimated to be at least 300 million U.S. dollars.

4) Warnings

A hurricane watch was issued 35 h before Fabian hit Bermuda, and a hurricane warning was issued 29 h in advance.

g. Tropical Storm Grace, 30 August–2 September

Tropical Storm Grace was a short-lived tropical storm that moved inland along the upper Texas coast and produced little damage.

1) Synoptic history

Grace's origin was a strong tropical wave that moved off the west coast of Africa on 19 August. Satellite data indicated that the wave came close to developing into a tropical cyclone several times as it crossed the tropical Atlantic and Caribbean Sea. Finally, a tropical depression, and then Tropical Storm Grace, formed on 30 August over the west-central Gulf of Mexico.

An upper low located a few hundred miles to the west of Grace produced a persistent southerly to southwesterly upper-level shear, which limited development. Broad and somewhat disorganized, Grace moved northwestward on 31 August at about 15 kt.

Grace's low-level circulation remained poorly organized as it approached the Texas coast near Corpus Christi early on 31 August. A new center formed near Galveston, about 100 n mi north of what had previously been the center. This new circulation center moved inland near San Luis Pass, Texas, on the southwestern tip of Galveston Island at 1100 UTC with 35-kt winds. The original circulation center weakened and eventually dissipated before it made landfall. Grace continued to move northwestward and quickly weakened after landfall. Grace turned northward over northeastern Texas on 1 September and merged with a frontal zone.

2) Meteorological statistics

Two ships reported tropical storm–force winds associated with Grace and several offshore oil-drilling platforms observed tropical storm–force winds, but these measurements were made several hundred feet above the surface. Grace's estimated maximum 1-min surface wind speed of 35 kt is based on a blend of a reconnaissance 1500-ft flight-level spot wind report of 43 kt and two sustained 35-kt wind reports from Sea Rim State Park at 1000 and 1200 UTC 31 August 2003.

Maximum storm surge was around 0.6 m or less along the upper Texas coast, primarily on Galveston Island.

Rainfall across the Houston metropolitan area and the upper Texas coast was in the 75–125-mm range with some isolated reports in excess of 225 mm.

3) Casualty and damages

The main effect of Tropical Storm Grace was isolated heavy rainfall and some inland freshwater floods across the upper Texas coastal area. No deaths were reported.

4) Warnings

A tropical storm warning was issued at 1500 UTC on 30 August for the Texas coast from High Island to Corpus Christi, or about 21 h before landfall. The 35-kt wind observed at Sea Rim State Park was about 30 n mi outside of and northeast of High Island, which was the northeastern end point of the warning area. The unanticipated reformation of the surface low just before landfall is the reason for not having warnings extended far enough to the northeast.

h. Tropical Storm Henri, 3–8 September

Henri was a tropical storm with maximum 1-min surface winds of 50 kt in the eastern Gulf of Mexico. After weakening to a depression, it moved across central Florida, where it dumped up to 10 in. of rainfall.

Henri formed from a tropical wave that moved from Africa to the tropical Atlantic Ocean on 22 August. The wave reached the eastern Gulf of Mexico on 1 September where the northern portion became detached and nearly stationary, while the southern portion of the wave continued westward. By 1800 UTC 3 September, the associated convection and low-level circulation became well enough organized to become a tropical depression about 260 n mi west of Tampa, Florida.

The depression was embedded in the southern portion of a slow-moving midlatitude trough and moved very slowly eastward. The depression became a tropical storm at 0600 UTC 5 September and the cyclone's wind speed increased to its maximum value of 50 kt at 1800 UTC even though there was at least 20 kt of southwesterly vertical shear affecting the circulation. However, Henri soon succumbed and winds quickly weakened to 30 kt. Then Henri accelerated northeastward across north-central Florida on 6 September, preceded and accompanied by heavy rain. Moving over the southwestern North Atlantic Ocean, Henri's forward speed decreased on 7 September when it became trapped to the south of a shallow high pressure system. The depression then lost its well-defined low-level circulation center while becoming involved with a frontal zone. The broad and disorganized extratropical low remained nearly stationary off the coast of the Carolinas for several days and moved inland over North Carolina on 12–13 September.

On 5 September, a reconnaissance aircraft reported an 850-mb flight-level wind speed of 46 kt at 1116 UTC, along with a 997-mb surface pressure. Data buoy 42036, located in the northeastern Gulf of Mexico, reported a 10-min mean wind speed of 45 kt with a gust to 64 kt at 1720 UTC on the same day. This buoy also reported a surface pressure of 1001.7 mb at 1750 UTC. Henri was centered about 25 n mi east-southeast of the buoy at the time of the 45-kt wind speed. Based on these reports, Henri's highest 1-min wind speed is estimated to be 50 kt at 1800 UTC. The highest subjective Dvorak wind speed estimates were 55–65 kt.

Henri's rain affected much of Florida. There were 125–250 mm of rain in portions of Charlotte County. There was minor freshwater flooding in two areas: from Sarasota through Lee Counties, and a small portion of southern Hernando and extreme northern Pasco County. In southern Florida and in the Florida panhandle, rainfall totals were generally less than 50 mm. There were no deaths attributed to Henri and damage from flooding was generally minor.

Tropical storm warnings were issued for the northwestern Gulf Coast of Florida as soon as a tropical depression formed. This was about 60 h before landfall, as Henri moved eastward even slower than forecast. However, winds over land never reached tropical storm force as Henri weakened to a depression before landfall.

i. Hurricane Isabel, 6–19 September

Isabel was a long-lived Cape Verde hurricane that reached category-5 status on the Saffir–Simpson hurricane scale. The intensity was category 3 or higher for 8 days, category 4 or higher for over 5 days, and category 5 or higher for over 3 days, as Isabel moved across the western North Atlantic Ocean. It made landfall near Drum Inlet on the Outer Banks of North Carolina as a category-2 hurricane. Isabel is one of the most significant tropical cyclones to affect northeastern North Carolina and east-central Virginia since Hurricane Hazel in 1954 and the Chesapeake–Potomac Hurricane of 1933.

1) Synoptic history

Isabel formed from a tropical wave that moved westward across the coast of Africa on 1 September. The wave moved slowly westward and gradually became better organized. By 0000 UTC 5 September, there was sufficient organized convection for satellite-based Dvorak subjective intensity estimates to begin. Development continued, and it is estimated that a tropical depression formed at 0000 UTC 6 September. The depression became Tropical Storm Isabel 6 h later.

Isabel turned west-northwestward on 7 September and intensified into a hurricane. Isabel turned westward on 10 September and maintained this motion until 13 September on the south side of the Azores–Bermuda high pressure ridge. Isabel strengthened to a category-5 hurricane on 11 September with maximum sustained winds estimated at 145 kt at 1800 UTC that day. After this peak, the maximum winds remained in the 130–140-kt range until 15 September. During this period, Isabel displayed a persistent 35–45 n mi diameter eye. Figure 4 is a visible satellite image of Isabel on 12 September, when winds were estimated at 140 kt. Isabel approached a weakness in the western portion of the Azores–Bermuda high, which allowed the hurricane to turn west-northwestward on 13 September, northwestward on 15 September, and north-northwestward on 16 September

Increased vertical wind shear on 15 September caused Isabel to weaken. The system weakened below major hurricane status on 16 September. It maintained category-2 status with 85–90-kt maximum winds for the next two days while the overall size of the hurricane increased. Isabel made landfall near Drum Inlet, North Carolina, near 1700 UTC 18 September as a category-2 hurricane, then weakened as it moved across eastern North Carolina. It weakened to a tropical storm over southern Virginia, then became extratropical as it moved across western Pennsylvania on 19 September. Isabel then moved northward and was absorbed by a larger baroclinic system moving eastward across south-central Canada.

2) Meteorological statistics

The highest winds measured by reconnaissance aircraft were 158 kt at 700-mb flight level and 157 kt at 2560 m between 1700 and 1730 UTC 13 September. A 156-kt 700-mb wind was observed at 1719 UTC 12 September. Stronger winds were observed from GPS dropsondes in the eyewall, with a maximum of 203 kt reported at 806 mb (1372 m) at 1753 UTC 13 September. This is the strongest wind ever observed in an Atlantic hurricane.

Aircraft data on 12 September indicate that Isabel had winds near 140 kt. However, the maximum intensity based on satellite imagery was reached on 11 September before the first reconnaissance mission, and the satellite signature was less impressive at the time of the first mission. The maximum intensity estimate of 145 kt on 11 September is based on the aircraft data of 12 September and the satellite signature on the previous day. The minimum central pressure estimate of 915 mb on 11 September is based on similar reasoning.

The estimate of the maximum 1-min surface wind

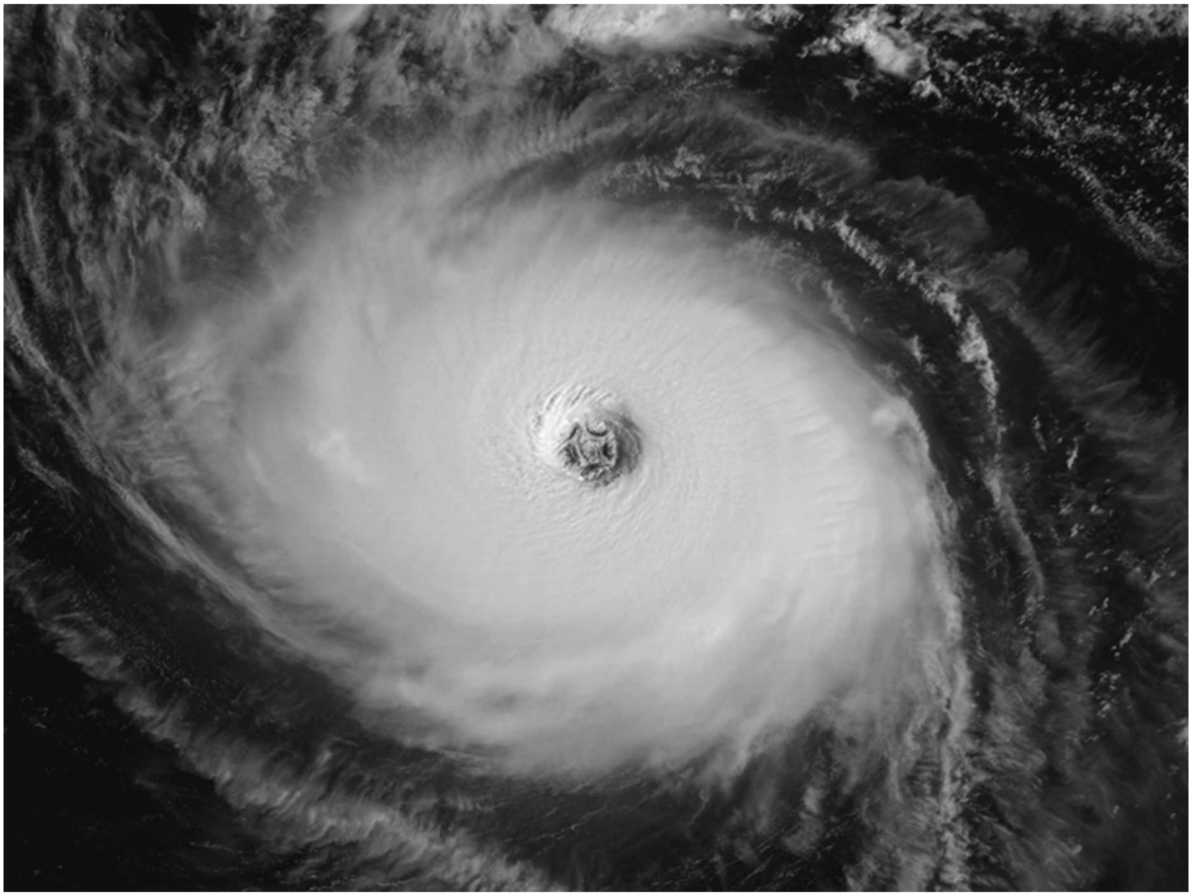

FIG. 4. *GOES-12* visible satellite image of Hurricane Isabel at 1315 UTC 12 Sep 2003. Maximum winds are estimated at 140 kt at the time of this image (courtesy of CIMSS, University of Wisconsin—Madison).

speed at landfall on 18 September is 90 kt, based on GPS dropsonde and stepped frequency microwave radiometer data.

Isabel brought hurricane conditions to portions of eastern North Carolina and southeastern Virginia. The highest observed sustained wind over land (Table 5) was 69 kt with a gust to 85 kt at an instrumented tower near Cape Hatteras, North Carolina, at 1622 UTC 18 September. A tower in Elizabeth City, North Carolina, observed 64 kt with a gust to 84 kt at 1853 UTC. The National Ocean Service (NOS) station at Cape Hatteras reported 68 kt with a gust to 83 kt before contact was lost. The Coastal Marine Automated Stations (C-MAN) at Chesapeake Light, Virginia, and Duck, North Carolina, reported similar wind speeds. Elsewhere in Virginia, Gloucester Point reported 60-kt with a gust to 79 kt at 2200 UTC 18 September, while the Norfolk Naval Air Station reported 50 kt with a gust to 72 kt at 2100 UTC that day. Unofficial reports from the affected area include a gust of 102 kt at Kitty Hawk, North Carolina, 93 kt at Gwynns Island, Virginia, 91 kt at Ocracoke, North Carolina, and 88 kt at New Bern, North Carolina. The wind record from the most seriously affected areas is incomplete, as several observing stations were either destroyed or lost power while Isabel passed.

Isabel brought tropical storm conditions to a large area from eastern North Carolina northward to the eastern Great Lakes and western New England. The C-MAN station at Thomas Point, Maryland, reported 42 kt with a gust to 58 kt at 0850 UTC 19 September. Reagan National Airport in Washington, D.C., reported 39 kt with a gust to 50 kt at 0139 UTC that day. Tropical-storm-force winds were reported at Kennedy and LaGuardia Airports in New York City, while a gust of 52 kt was reported in Middletown, Pennsylvania. Extratropical Isabel brought gale-force winds to portions of the eastern Great Lakes and southeastern Canada.

The lowest pressure observed by reconnaissance aircraft was 920 mb at 1712 and 1901 UTC 12 September. The lowest pressures observed on land were unofficial reports of 957 mb at Arrowhead Beach, North Caro-

TABLE 5. Selected surface observations for Hurricane Isabel, 6–19 Sep 2003.

	Minimum sea level pressure		Maximum surface wind speed					
Location	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
South Carolina								
Springmaid Pier			18/1545	24	39			
North Carolina								
Alligator River NWR RAWS			18/1900	50				95
Atlantic Beach (Clemson/UF Tower)	18/1645	962.8	18/1558	55	67			
Back Island RAWS			18/1813		53			42
Beaufort RAWS			18/1815		64			143
Beaufort (NOS)						1.8	0.8	
Burlington (KBUY)					48			
Cape Hatteras (Clemson/UF Tower)	18/1644	968.2	18/1622	69	85			
Cape Hatteras Pier NOS[e]	18/1518	974.0	18/1518	68	83	2.3	1.7	
Caswell Gamelands RAWS			18/2017		46			50
Cherry Point (KNKT)	18/1840	968.2	18/1818		62			133
Clinton (KCTZ)					40			
Craven County (Neuse River)							3.2	
Duke Forest RAWS			18/1907		53			43
Duck Corps of Engineers Pier NOS[f]	18/1918	984.0	18/2100	55	72	2.4	1.4	120
Elizabeth City (KECG)			18/1543	51[f]	64[f]			69
Elizabeth City (Clemson/UF Tower)	18/1940	981.9	18/1852	64	84			
Elizabethtown			18/2320	22	43			57
Erwin-Dunn (KHRJ)					38			
Fayetteville (KFAY)				35	50			
Fort Bragg (KFBG)					52			
Fort Bragg RAWS			18/2007		48			34
Franklinton (KLHZ)					39			
Goldsboro (KGSB)				35	51			
Greensboro (KGSO)					40			
Greens Cross RAWS			18/1708		50[f]			160
Greenville (KPGV)			18/1855	34	44			146
Henderson (KHNZ)					39			
Hoffman Forest RAWS			18/1509		50			60
Laurinburg (KMEB)					35			
Lumberton (KLBT)			18/1921	32	45			86
Manteo (KMQI)	18/1743	982.4	18/1843	44	68			
Nature Conservancy RAWS			18/1658		54			49
New Bern (KEWN)			18/1608		50[f]			0
New River (KNCA)	18/1756	981.7	18/1556	39	56			51
Newport (KMHX)	18/1730	968.9	18/1800		46			149
Oregon Inlet Marina NOS						1.6	1.4	
Pocosin Lake NWR RAWS			18/1823		64			151
Raleigh (KRDU)					39			
Rocky Mount (KRWI)				35	54			
Rocky Mount RAWS			18/2113		52[f]			107
Roanoke Rapids[f] (KRZZ)			18/2147	38	55			
Sanford (KTTA)					43			
Smithfield (KJNX)					34			
Sunny Point RAWS			18/2158		51			53
Turnbull Creek RAWS			18/2313		41			56
Washington (KOCW)	18/1944	963.5	18/1803	37	49			
Wilmington (KILM)	18/1843	990.5	18/2143	39	51			50
Wilmington (Clemson/UF Tower)	18/1730	990.8	18/1315		43			

TABLE 5. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed					
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
Virginia								
Back Bay NWR RAWS			18/1935	38	53			105
Blacksburg (WFO)			19/0120		34			
Chesapeake Bay Bridge Tunnel NOS	18/2154	992.4	18/2048	52	64	2.3	1.5	
Colonial Beach NOS[f]						1.6	1.1 (2.0)[g]	
Culpeper (KCJR)	19/0303	995.0						
Danville (KDAN)			18/1922		45			
Dulles Airport (KIAD)	19/0359	997.6	19/0122	32	42			50
Fort Belvoir (KDAA)								59
Fredericksburg (KEZF)								71
Gloucester Point NOS[f]						2.5	2.0	0
Gloucester Point (VIMS)			18/2200	60	79			
Great Dismal Swamp RAWS			18/1945		39			
Kingsmill NOS[f]						2.0	1.3	
Kiptopeake NOS			18/2342	39	60	2.0		
Langley AFB (KLFI)	18/2348	991.9	18/1808	46	66			68
Leesburg (KJYO)			19/0444		42			
Lewisetta NOS[f]	19/0012	997.3	19/0100	46	59	1.1	0.9	
Manassas (KHEF)	19/0335	997.0						
Melfa (KMFV)	18/2102	1000.0						
Money Point NOS			18/2318	38	52	2.5	1.7	
Newport News[f] (KPHF)	18/2237	990.2	18/1756	38	57			80
Norfolk Airport[f] (KORF)	18/2151	990.2	18/2049	41	64			64
Norfolk N.A.S. (KNGU)			18/2110	50	72			107
Oceana N.A.S. (KNTU)	18/2056	990.9	18/2056	48	60			
Portsmouth	18/2225	987.2						
Quantico (KNYG)	19/0355	996.8	19/0322	47	67			
Roanoke (KRNK)			18/2143		38			
Rappahannock Light NOS	18/2354	995.4	18/2318		60			
Richmond (KRIC)			19/0013	33	63			110
Scotland NOS[f]						2.1	1.5	
Sewells Point NOS	18/2130	991.4	18/1642	50	64	2.4	1.7	
Wakefield (KAKQ)								146
Wallops Island (KWAL)	19/0012	1003.1	18/1747	43	54			20
Wachapreague NOS[f]	18/2300	1001.8				1.7	0.8	
Wakefield WFO								144
Washington Reagan Airport (KDCA)	19/0359	999.3	19/0139	39	50			59
Windmill Point NOS						1.2		
District of Columbia								
National Academy of Science (DCNet)			19/N/A		62			
Washington NOS						2.4		
West Virginia								
Martinsburg	19/0654	997.3	19/0318	26	40			
Petersburg (W99)	19/0537	995.0						
Maryland								
Andrews AFB (KADW)			18/2051	33	60			
Annapolis NOS						2.2	1.9	
Baltimore NOS						2.5	2.2	
Baltimore (KBWI)	19/0358	1001.4	19/0211	38	48			82
Black NWR RAWS			18/2227		40			36
Cambridge NOS[f]	19/0154	1003.0	18/2054	37	49	1.9	1.6	56
Chesapeake City NOS						1.7	1.5	
Frederick			19/0543		43			
Hagerstown (KHGR)	19/0548	998.6	18/2328	34	45			

TABLE 5. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed					
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
Maryland Science Center (KDMH)	19/0301	1002.4						
Ocean City (KOXB)	18/2257	1006.1	18/2252	36	46	2.0		50
Patuxent River (KNHK)	19/0355	999.0	19/0355	48	60			
Salisbury (KSBY)	19/0331	1005.1	18/2009	32	44			53
Silver Springs (DCNet)			19/N/A		72			
Solomons Island NOS[f]	19/0018	1000.7	19/0106	45	56			
Tolchester Beach NOS	19/0354	1003.2	19/0124		38	2.4	2.1	
			Delaware					
Brandywine Shoal NOS	19/0424	1007.3	19/0742		54			
Delaware City NOS	19/0630	1005.6	19/0606	34	47	2.6	1.7	
Dover AFB (KDOV)			19/0419		53			
Georgetown (KGED)			19/0613		52			44
Lewes NOS	19/0336	1006.6	18/2024	46	54	2.0	0.9	
Prime Hook NWR RAWS			18/2127		44			27
Reedy Point NOS						2.6	1.5	
Wilmington (KILG)			19/0720		46			37
			New Jersey					
Atlantic City (KACY)			19/0034		42			
Atlantic City USGS	19/0300	1011.9	19/0100		46			
Barnegat Light USGS	19/0500	1014.6	19/1930		39			
Burlington NOS	19/0706	1010.4				3.2	2.0	
Cape May NOS	19/0500	1008.1	18/2124		47	2.0	0.9	
Cape May USGS	19/0100	1005.2	18/2100	34	53			
Forsythe NWR RAWS			19/0827		34			8
Keansburg USGS	19/0600	1014.6	19/0100		45			
Millville (KMIV)			19/0046		48			
Newark (KEWR)	19/0757	1013.9	19/0619	28	38			17
Point Pleasant USGS	19/0500	1014.6	19/0100		40			
Sandy Hook NOS	19/0736	1014.2	19/0142		39			
Ship John Shoal NOS	19/0518	1007.1	19/0206	47	62	2.4	1.4	
Tacony-Palmyra Bridge NOS						3.0	1.8	
Trenton (KTNT)			19/0304		38			
Wildwood (KWWD)			19/0835		41			33
Wrightstown			19/0337		47			
			Pennsylvania					
Allentown (KABE)			19/0907		41			
Altoona (KAOO)	19/0804	998.7	19/0429		37			
Capital City	19/0513	1003.0	19/0530		50			
Clearfield (KFIG)	19/0926	1000.3	19/0604		35			
Hazelton (KFET)								
Lancaster (KLNS)	19/0634	1004.4	19/0637		46			
Middletown	19/0509	1003.0	19/0517		52			
Mt. Pocono (KMPO)					40			
Philadelphia (KPHL)			19/0747		43			29
Philadelphia NOS	19/0530	1010.6	18/2312		37	2.9	1.6	
Reading (KRDG)			19/0735		43			
Scranton Wilkes-Barre (KAVP)					35			
Sherburne RAWS			19/1808		41			
Williamsport (KIPT)	19/0843	1003.0	19/0841		45			
York (KTHV)	19/0603	1002.7	19/0601		38			
			New York					
Binghamton (KBGM)					39			
Buffalo (KBUF)			19/2012		35			

TABLE 5. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Farmingdale (KFMG)	19/0902	1016.3	19/0725	28	36			
Monticello (KMSV)					38			
New York Kennedy Airport (KJFK)	19/0815	1015.2	19/0802	35	43			4
New York LaGuardia Airport (KLGA)	19/0827	1014.9	19/0736	35	44			7
Saranac Lake (KSLK)			19/1827		38			
Shinnecock Inlet			18/2330	30	45			
Syracuse (KSYR)					35			
Utica (KUCA)					37			
Watertown (KART)			19/1605		35			
Wellsville (KELZ)			19/0958		35			
Vermont								
Burlington (KBTV)			19/1940		40			
Rutland (KRUT)			19/1535		35			
Canada								
Burlington					39			
Hamilton					36			
Long Point				37	42			
Point Petre					43			
Port Colburne				35	44			
Toronto Island					43			
Toronto Pearson Airport (CYYZ)			19/1350		39			
NOAA buoys and C-MAN								
NOAA Buoy 41001	18/0900	997.7	18/0150	40[h]	51			
NOAA Buoy 41002	18/0800	978.8	18/0540	52[h]	70			
NOAA Buoy 44004			18/2331		35			
NOAA Buoy 44009	19/0000	1006.6	19/2200	38	51			
NOAA Buoy 44014	18/1900	995.5	18/1250	43[h]	60			
NOAA Buoy 44017	19/0900	1018.5	18/2300	29	36			
NOAA Buoy 44025	19/0800	1015.0	19/0100	30	38			
NOAA Buoy 45005	19/1300	1002.6	19/2100	27[h]	35			
NOAA Buoy 45008	19/1700	1002.6	20/0030	28	34			
NOAA Buoy 45012	19/1700	1004.2	19/1220	32[h]	41			
Canadian Buoy 45135				34	42			
Canadian Buoy 45139				32	40			
Canadian Buoy 45160				32	40			
Ambrose Tower (ALSN7)	19/0700	1014.1	19/2350	44[h]	52			
Chesapeake Light (CHLV2)	18/2100	990.6	18/2140	65[h]	83			
Cape Lookout (CKLN7)	18/1600	964.9	18/1530	60[h]	79			
Dunkirk (DBLN6)	19/1500	1000.3	19/1900	31	39			
Diamond Shoals Light (DSLN7)	18/1600	970.5						
Duck (DUCN7)	18/1900	984.4	18/1930	66[h]	82			
Frying Pan Shoals (FPSN7)	18/1700	993.4	18/1610	63[h]	77			
Lake St. Clair (LSCM4)	19/1400	1004.1	19/2100	31	36			
South Bass Island (SBOI1)	19/1400	1003.8	19/2050	32[h]	36			
Thomas Point Light (TPLM2)	19/0500	1001.1	19/0850	42[h]	58			
Unofficial observations								
North Carolina								
Arrowhead Beach	18/2030	957.0						
Hobucken (Leonard)	18/1750	958.0						
Kitty Hawk	18/1925	984.5	18/N/A		102			

TABLE 5. (*Continued*)

Location	Minimum sea level pressure Date/time (UTC)	Pressure (mb)	Maximum surface wind speed Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
New Bern (Weather Underground)	18/1912	970.1	18/1327	80	88			
Ocracoke			18/1545		91			
Gwynns Island			19/0042		93			

[a] Date/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; NOS stations averaging periods are 6 min; RAWS stations report 10-min-average sustained winds.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above National Geodetic Vertical Datum (1929 mean sea level).
[e] Station destroyed—more extreme values may have occurred.
[f] Incomplete record—more extreme values may have occurred.
[g] Subsequent survey storm surge value.
[h] Ten-minute average.

lina, and 958 mb from a storm chaser in Hobucken, North Carolina. The lowest pressures from official observation sites were 962.8 mb from an instrumented tower in Atlantic Beach, North Carolina, at 1645 UTC 18 September, and 963.5 mb at Washington, North Carolina, at 1944 UTC that day.

Isabel produced storm surges of 2–2.5 m above normal tide levels near the point of landfall along the Atlantic coast of North Carolina. Farther north, storm surge values ranged from 1 to 2 m along the Virginia coast, 0.6 to 1.2 m along the Maryland, Delaware, and New Jersey shorelines, and 0.3–0.6 m along the coast of Long Island and in the Long Island Sound.

In the North Carolina estuaries, storm surge values were generally 1–2 m above normal tide levels over the eastern portions of the Pamlico Sound and most of the Albemarle Sound. Values of 2–3 m above normal tide levels were observed in the western end of the Pamlico Sound with a maximum value of 3.2 m reported on the Neuse River in Craven County.

Storm surges of 1–1.5 m above normal tide levels were observed over the central portions of the Chesapeake Bay and 1.5–2 m along the shore of the southern portion of the Bay in the vicinity of Hampton Roads, Virginia. Surge values of 2–2.5 m above normal levels occurred in the upper reaches of the Chesapeake Bay near Annapolis and Baltimore, Maryland, and in most of the main stem rivers draining into the Chesapeake Bay. Even higher surges occurred at the heads of the rivers, with values of 2.6 m above normal levels at the Richmond City locks along the James River in Virginia and nearly 2.4 m along the Potomac River in Washington, D.C. Water levels exceeded previous record levels established in the Chesapeake—Potomac Hurricane of 1933 in Washington, D.C., Baltimore, and Annapolis.

Storm surges in Delaware Bay were generally 1–1.2 m at the mouth of the bay and 1.5–2 ft at the head of the bay and along the Delaware River in the vicinity of Philadelphia, Pennsylvania.

Rainfall from Hurricane Isabel ranged to 175 mm over large portions of eastern North Carolina, east-central Virginia, and Maryland. Rainfall totals of 200–300 mm with locally higher amounts occurred in the Shenandoah Valley in northern Virginia. Upper Sherando, Virginia, reported a storm total of 513 mm. Lesser amounts up to 100 mm occurred elsewhere over eastern Virginia and the Delmarva Peninsula.

One tornado occurred in association with Hurricane Isabel. It touched down in the Ocean View section of Norfolk, Virginia, at approximately 2200 UTC 18 September according to law enforcement officials. No Fujita scale rating was assigned to the tornado since its damage could not be distinguished from the other hurricane-related wind damage in the area.

3) CASUALTIES AND DAMAGES

Isabel is directly responsible for 17 deaths: 10 in Virginia, 2 in New Jersey, and 1 each in North Carolina, Maryland, New York, Rhode Island, and Florida. The deaths in Florida and Rhode Island were from high surf generated by the hurricane. Isabel was indirectly responsible for 34 deaths: 22 in Virginia, 6 in Maryland, 2 in North Carolina and Pennsylvania, and 1 each in New Jersey and the District of Columbia.

Isabel caused widespread wind and storm surge damage in coastal eastern North Carolina and southeastern Virginia. Storm surge damage also occurred along Chesapeake Bay and the associated river estuaries, and wind damage occurred over portions of the remaining area from southern Virginia northward to New York. The insured property damage reported by the Property Claim Services Division of the American Insurance Services Group, the Insurance Services Office, Inc. totals $1.685 billion to $925 million in Virginia, $410 million in Maryland, $170 million in North Carolina, $80 million in Pennsylvania, $45 million in New York, $25 million in New Jersey, $20 million in Delaware, and $10 million in West Virginia. The total damage for Isabel is estimated to be about twice that of the insured damage, or $3.37 billion.

4) WARNINGS

A hurricane watch was issued for the landfall area 50 h before the center made landfall. A hurricane warning was issued 38 h before landfall.

j. Hurricane Juan, 24–29 September

Juan made landfall near Halifax, Nova Scotia, as a category-2 hurricane and is one of the most damaging tropical cyclones in modern history for Halifax.

1) SYNOPTIC HISTORY

Juan's origin was a large tropical wave that crossed the coast of Africa on 14 September and continued westward over the tropical Atlantic. On 20 September, the shower activity increased significantly but remained disorganized. By then, the wave was located about 600 n mi east of the Lesser Antilles and was interacting with a large upper-level low. This low was associated with the outflow of powerful Hurricane Isabel, then located well to the northwest, and partly associated with the midoceanic upper-level trough. The wave spawned a middle-level circulation that moved northwestward away from the Lesser Antilles around the upper low and then interacted with a frontal zone. A low-level circulation developed on 23 September, but it took another day to make the transition to a tropical cyclone, when the deep convection increased near the center and banding and outflow features developed. It is estimated that a tropical depression formed at 1200 UTC 24 September, about 300 n mi southeast of Bermuda. The cyclone became a tropical storm 12 h later, and then developed an eye and became a hurricane by 1200 UTC 26 September.

Juan moved toward the north and northwest as the subtropical ridge to the northeast of the cyclone briefly expanded westward. The cyclone gradually intensified and reached its maximum intensity of 90 kt, with a minimum pressure of 969 mb, at 1800 UTC 27 September. Figure 5 is a satellite view of Juan with 90-kt winds on 28 September. Juan then turned northward again with an increase in forward speed, and made landfall near Halifax, Nova Scotia, between Prospect and Peggy's Cove around 0300 UTC 29 September with estimated 1-min winds of 85 kt and a minimum pressure of 973 mb. The cyclone crossed Nova Scotia as a weakening hurricane and became a tropical storm over Prince Edward Island. It then merged with a large extratropical low by 1800 UTC 29 September in the Gulf of St. Lawrence.

2) METEOROLOGICAL STATISTICS

The estimate that Juan made the transition from a surface low in a frontal zone to a tropical cyclone is partially based on Advanced Microwave Sounding Unit data showing a weak warm core at mid- to upper levels of the cyclone. The timing of when Juan became a tropical storm is based on a quick scatterometer (QuikSCAT) pass at 0925 UTC 25 September showing winds between 40 and 45 kt. In addition, as the developing center passed near the drifting buoy 41537, the surface pressure dropped to 992.6 mb at 2000 UTC. Juan was upgraded to hurricane status on 26 September based on the appearance of an eye on visible and infrared satellite imagery.

The center of Juan passed over a Canadian buoy (44142) between 2300 UTC 28 September and 0000 UTC 29 September, producing a wind change from east at 54 kt to southwest at 37 kt. The buoy's lowest pressure was 974.7 mb.

The estimated intensity of 85 kt at landfall is primarily based on a report from McNab's Island in Halifax Harbor. An anemometer at this location reported a 2-min wind of 81 kt and is elevated 10 m above the surface. In addition, there was an oil rig in Halifax Harbor whose instrument, at an elevation of 62 m, failed at 99 kt. Radar observations from Halifax indicate that the eye diameter at landfall was 18 n mi. Table 6 lists a selection of surface observations from Canada associated with Juan.

3) CASUALTIES AND DAMAGES

Hurricane Juan made landfall in Nova Scotia as one of most powerful and damaging hurricanes to ever affect Canada. The last time that the city of Halifax was hit by the eyewall of a hurricane was 22 August 1893.

There were two direct deaths associated with Juan due to falling trees. In addition, three indirect deaths occurred in a house fire speculated to have been started by candles during power outages. Halifax Harbor recorded an all-time record water level of 1.5 m above the normal tide levels, which resulted in extensive flooding

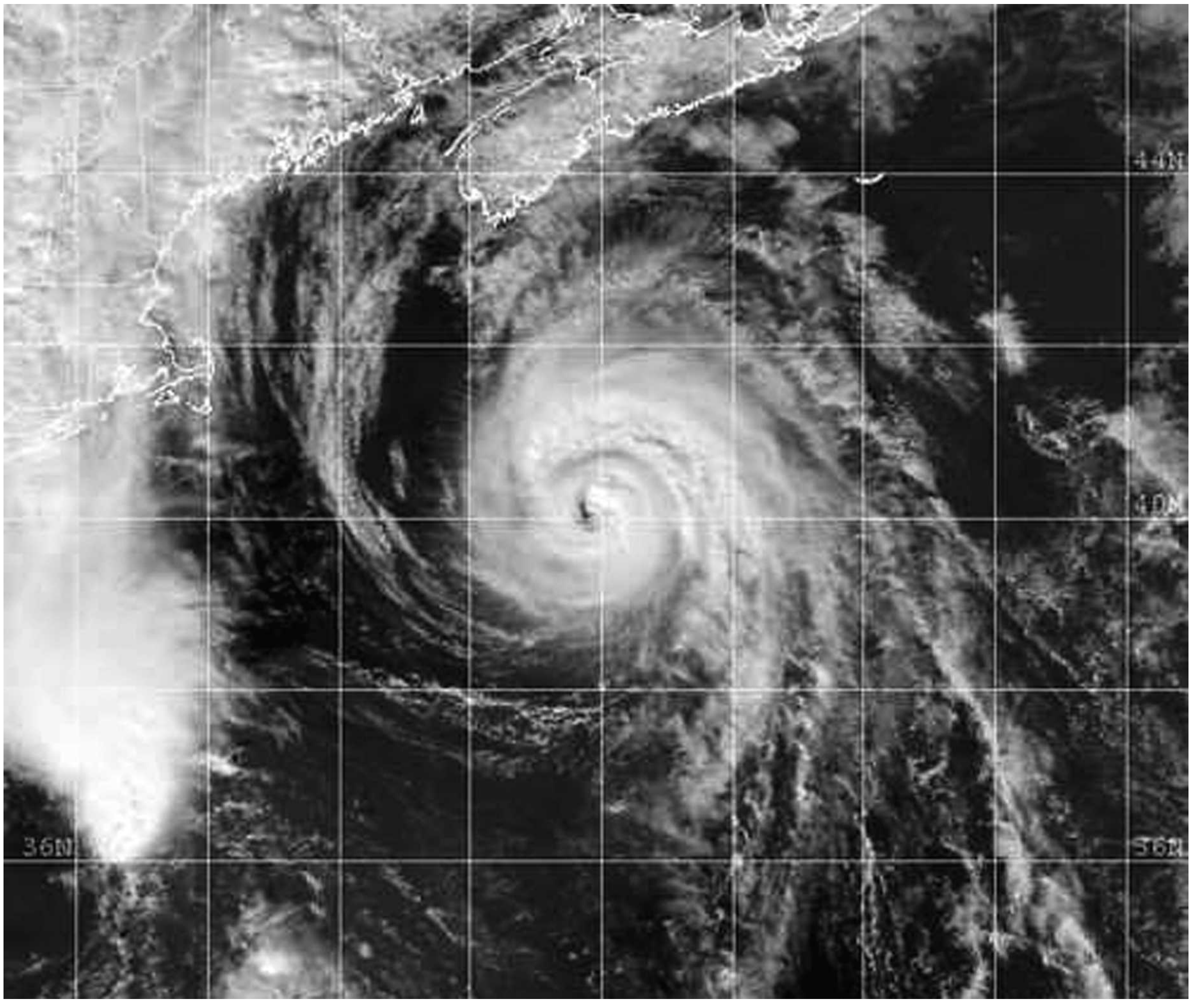

FIG. 5. *NOAA-16* visible satellite image of Hurricane Juan at 1752 UTC 28 Sep 2003. Maximum winds are estimated at 90 kt at the time of this image (courtesy of Naval Research Laboratory, Monterey, CA).

of the Halifax and Dartmouth waterfront properties. Hundreds of thousands of maritimers lost power in Nova Scotia and Prince Edward Island.

4) WARNINGS

A tropical storm warning was issued for Bermuda at 2100 UTC 25 September and was discontinued at 1800 UTC 26 September when Juan passed about 200 n mi to the east of the island. Heavy rain and strong wind warnings were issued by the Canadian Hurricane Center as early at 0600 UTC 26 September for portions of Nova Scotia and Prince Edward Island, or almost 3 days in advance of landfall.

k. Hurricane Kate, 25 September–7 October

Kate had a long and rather unusual track over the east-central Atlantic. It became a powerful hurricane at subtropical latitudes.

A tropical wave crossed the coast of western Africa on 21 September and moved slowly westward, passing near the Cape Verde Islands on 23 September. Although the convection was not well organized, a low-level circulation center was located several hundred miles west-southwest of the Cape Verde Islands on 24 September. Cloudiness and deep convection gradually became better organized into curved bands, and it is estimated that a tropical depression formed about 800 n mi west-southwest of the Cape Verde Islands at 1800 UTC 25 September.

The tropical cyclone moved northwestward for two days toward a weakness in the subtropical ridge over the central Atlantic Ocean. Meanwhile, south-southwesterly upper-level flow caused strong vertical shear over the depression, and the low-cloud center was intermittently exposed to the southwest of the main area of deep convection. Around 1800 UTC 27 September,

TABLE 6. Selected surface observations for Hurricane Juan, 24–29 Sep 2003.

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Canada								
Nova Scotia								
Shearwater	29/0400	987.5	29/0349	54	70	1.5	2.9	56
McNabs's Island	29/0400	982.1	29/0324	81	95			
Halifax International Airport	29/0400	987.4	29/0404	54	77			74
Beaver Island	29/0440	998.3	29/0440	55	71			
Lunenburg	29/0400	990.2	29/0200	36	57			
Caribou Point	29/0546	996.3	29/0546	46	64			18
Confederation Bridge	29/0600	984.9	29/0600	60	74			
Hart Island	29/0600	1010.1	29/0640	46				940
CHC (West of CYAW)	29/0310	984.3						86
Prince Edward Island								
North Cape	29/0800	989.6	29/0700	37	48			
Charlottetown	29/0700	991.2	29/0617	50		1.3	2.9	20
East Point	29/0700	1000.8	29/0700	36	52			6
Iles de la Madeleine	29/0800	1000.6	29/0900	40	58			

[a] Date/time is for sustained wind when both sustained and gust are listed.
[b] Reports are 2-min sustained.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above National Geodetic Vertical Datum (1929 mean sea level).

deep convection increased near the center, and satellite-based estimates indicate that the cyclone became Tropical Storm Kate. Even though the system continued to experience moderate southwesterly shearing, it strengthened further while turning northward and northeastward. Kate became a hurricane for a brief period late on 29 September. Then, while weakening, the cyclone took a hairpin turn around the eastern side of a midtropospheric cyclonic circulation. By 1 October, Kate was moving west-southwestward on the northern side of the cyclonic circulation. It also regained hurricane strength that day. Kate continued west-southwestward, guided by the steering flow between an anticyclone to its north and the cyclonic circulation centered to its south. There was a relaxation of vertical shear over the area, and as Kate moved over progressively warmer waters, it strengthened significantly. By 2 October, a well-defined eye appeared on geostationary satellite images and the hurricane strengthened to its peak wind intensity estimated at 110 kt at 1800 UTC 4 October, while centered about 565 n mi east-southeast of Bermuda (Fig. 6).

Then the western portion of the hurricane's central dense overcast became partially eroded, signifying a weakening trend. On 5–6 October, the cyclone turned northward, then accelerated north-northeastward ahead of a deep-layer trough. Kate weakened below hurricane strength on 7 October while accelerating north-northeastward over cooler waters. Kate also began losing tropical characteristics when cold-air clouds wrapped around the center over the southern semicircle, and the remaining central convection weakened and became disorganized. The system completed its transition to extratropical status by 0000 UTC 8 October, but remained a formidable extratropical storm for two more days while moving northeastward to eastward across the northern Atlantic. It merged with another extratropical low near Scandinavia on 10 October.

Kate's estimated peak intensity, 110 kt at 1800 UTC 4 October, is based on a 3-h average objective Dvorak t-number of 5.8.

l. Tropical Storm Larry, 1–6 October

Tropical Storm Larry moved inland from the Bay of Campeche to over southeastern Mexico, causing widespread freshwater floods and five deaths.

1) SYNOPTIC HISTORY

A tropical wave moved across the coast of western Africa on 17 September. Under hostile vertical shear, the wave continued uneventfully across the tropical Atlantic Ocean and Caribbean Sea. On 27 September, a weak surface low pressure system developed on the wave axis located in the western Caribbean Sea. The

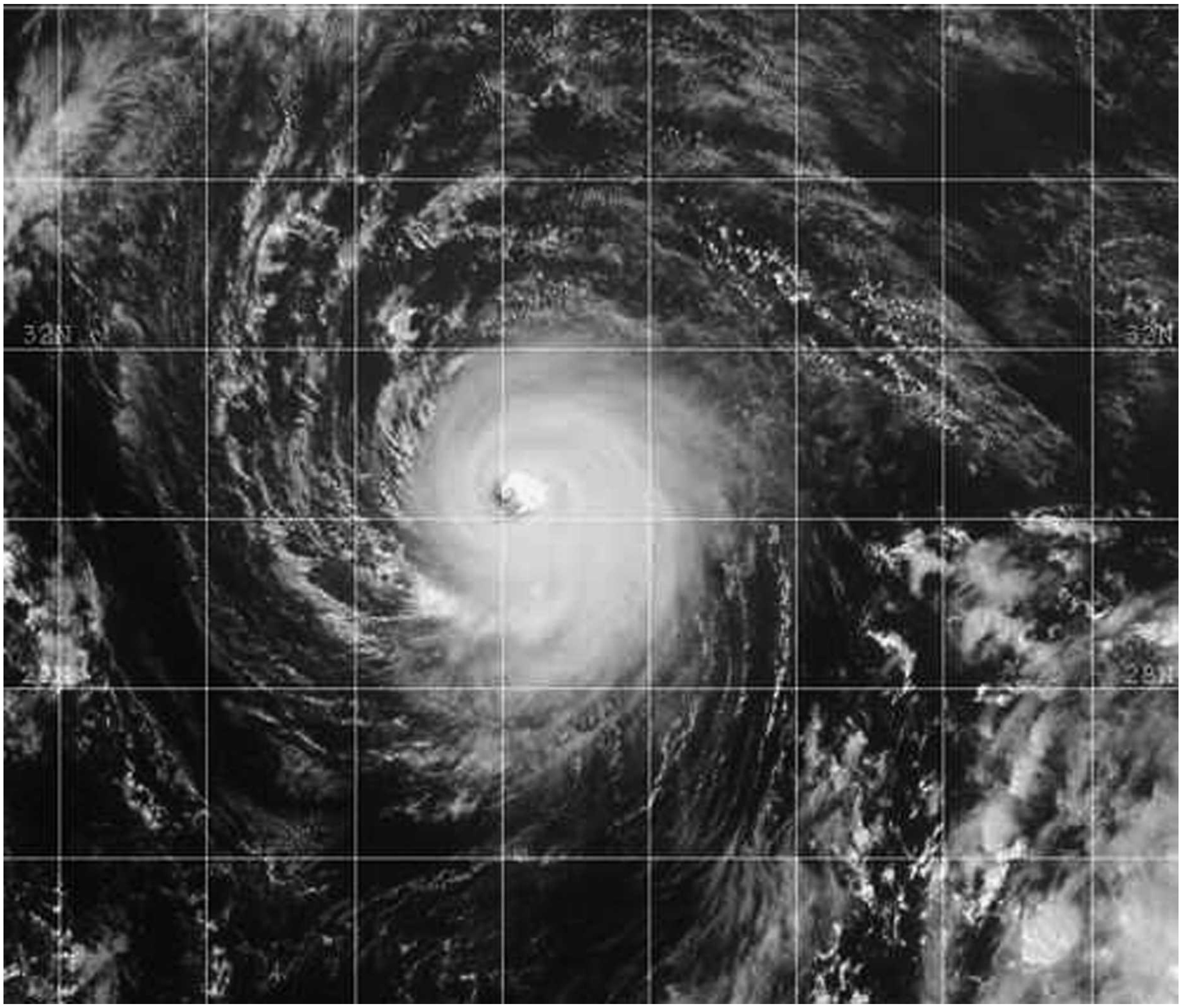

FIG. 6. *GOES-12* visible satellite image of Hurricane Kate at 1745 UTC 4 Oct 2003. Maximum winds are estimated at 110 kt at the time of this image (courtesy of Naval Research Laboratory, Monterey, CA).

low nearly formed into a tropical depression before it moved west-northwestward over the northern Yucatan Peninsula on 29 September. On the next day, the low had crossed the Yucatan Peninsula into the southern Gulf of Mexico and merged with a stationary frontal boundary and its associated horizontal temperature gradient. High pressure over the northern Gulf of Mexico combined with the frontal low pressure system to produce gale-force winds over the central and southern Gulf of Mexico, including the Bay of Campeche.

By 1 October, the gale center had drifted slowly westward into the Bay of Campeche and its convection became organized into curved band features. A reconnaissance flight indicated the horizontal temperature gradient had been replaced with warmer and homogeneous tropical air. It is estimated that the extratropical gale center made the transition into Tropical Storm Larry at 1800 UTC while centered about 260 n mi east-southeast of Tampico, Mexico.

Larry meandered slowly westward for two days and gradually strengthened. The cyclone reached its peak intensity of 55 kt at 0000 UTC 3 October about 160 n mi east-northeast of Vera Cruz, Mexico. Larry maintained that intensity for nearly three days while drifting erratically southward. Larry made landfall around 1000 UTC 5 October, near Paraiso in the state of Tabasco. By the next day, Larry weakened to a remnant low over the state of Vera Cruz. The remnant low moved southwestward and dissipated on 8 October over the eastern Pacific Ocean.

2) METEOROLOGICAL STATISTICS

Larry's maximum intensity of 55 kt at 0000 UTC 3 October is based on a reconnaissance 457-m flight-level wind speed of 66 kt at 1932 UTC 2 October. The National Meteorological Service of Mexico reported that heavy rainfall occurred over the states of Vera Cruz and Tabasco, causing localized floods and mud slides. The rainfall total of 161 mm at Villahermosa, Mexico, was the largest official amount reported.

3) Casualty and damages

The government of Mexico reported five deaths caused by freshwater floods.

4) Warnings

Gale warnings were issued for a portion of the Gulf of Mexico coastline for the pre-Larry extratropical low pressure system about 24 h before it became a tropical storm. The government of Mexico issued a tropical storm warning and hurricane watch approximately 61 h in advance of the time of landfall.

m. Tropical Storm Mindy, 10–14 October

Mindy was a tropical storm with maximum sustained winds of 40 kt. Mindy produced heavy rain over portions of Puerto Rico and the Dominican Republic.

Mindy originated from a tropical wave that moved from Africa to the Atlantic Ocean on 1 October. The wave axis neared the Mona Passage on 9 October where there was a weakness in the subtropical ridge. On 10 October, in strong southwesterly vertical shear, the wave developed a weak low-level circulation that moved northwestward across the eastern Dominican Republic. Later that day, the circulation, accompanied by rather disorganized convection, moved over the Atlantic Ocean and became Tropical Storm Mindy with 40-kt winds. The center of Mindy passed near the Turks and Caicos Islands on 11 October, but heavy rain and tropical storm–force winds remained east of these islands. Mindy weakened to a depression on 12 October and then turned eastward ahead of an approaching short-wave trough in the westerlies. Devoid of deep convection, the remnant swirl of low clouds dissipated early on 14 October while located about 400 n mi south-southwest of Bermuda.

A reconnaissance aircraft flew into the system as it moved away from the Dominican Republic. At first, aircraft wind observations at 1500-ft flight level did not show a closed circulation. But by 2146 UTC 10 October, a closed circulation was observed, along with a minimum surface pressure of 1002 mb. These aircraft data are the basis for identifying Mindy as a tropical cyclone at 1800 UTC. An aircraft-measured wind speed of 54 kt at a flight level of 457 m, along with subjective Dvorak satellite estimates of 35–45 kt, are the basis for assigning a wind speed of 40 kt to Mindy at its inception as a tropical cyclone.

Grand Turk reported a sustained wind speed of 27 kt and a minimum pressure of 1007.1 mb on 11 October as Mindy passed just east of this location.

Mindy produced periods of heavy rain over portions of Puerto Rico and eastern Dominican Republic, but there were no reports of damages or casualties.

n. Tropical Storm Nicholas, 13–23 October

Nicholas was a long-lived tropical storm that remained over the Atlantic far from land.

Nicholas developed from a tropical wave that moved westward across the coast of Africa on 9 October. A broad low pressure area formed along the wave axis on 10 October, and convection slowly became better organized during the following two days. It is estimated that a tropical depression formed near 0000 UTC 13 October about 790 n mi west-southwest of the southern Cape Verde Islands.

The cyclone formed in an area of southerly to southwesterly vertical wind shear, and it would remain in such an environment through its lifetime. The system moved slowly west-northwestward and gradually strengthened, becoming Tropical Storm Nicholas late on 14 October. It then moved northwestward for three days, reaching a peak intensity of 60 kt on 17 October. A slow and erratic northward motion occurred from 18 to 20 October while Nicholas gradually weakened. The storm turned west-northwestward later on 20 October and westward on 21 October. This was accompanied by slight reintensification. Nicholas again turned northwestward on 22 October and weakening resumed. The cyclone became a depression on 23 October as it turned northward, and it became a nonconvective remnant low on 24 October. The low merged with a cold front later that day, and became extratropical about 505 n mi east-southeast of Bermuda.

After becoming extratropical, the remnant low made a large anticyclonic loop from 24 to 28 October. A second anticyclonic loop took place on 29–31 October, which was followed by a small cyclonic loop early on 1 November while the Nicholas low separated from the frontal system. The Nicholas remnant was finally absorbed into a nontropical low pressure area late that day about 300 n mi south-southwest of Bermuda. This low, which developed sporadic bursts of central convection, moved westward to the Florida peninsula on 3 November and then northwestward to the northern coast of the Gulf of Mexico on 5 November.

Dvorak satellite intensity estimates suggested that

Nicholas could have been a hurricane near 1200 UTC 17 October. However, several microwave images made near that time showed that the cyclone was partly sheared, with no evidence of an eye or of well-defined convective bands, and it is estimated that Nicholas did not reach hurricane strength and that the maximum winds were 60 kt.

The remnants of Nicolas became involved in a complex weather pattern between 27 October and 1 November, and the exact time of dissipation is uncertain. Operationally, the nontropical low that crossed Florida was occasionally referred to as the remnants of Nicholas in tropical weather outlooks issued by the National Hurricane Center. Postanalysis suggests, instead, that this system absorbed the remnants of Nicholas.

o. *Tropical Storm Odette, 4–7 December*

Odette was a rare December tropical storm that made landfall in the Dominican Republic and was responsible for eight deaths. It was the first December tropical storm on record to form in the Caribbean Sea.

As the 2003 Atlantic hurricane season came to a nominal close on 30 November, a stationary front extended across eastern Cuba southwestward into the Caribbean Sea. An area of low pressure developed in the frontal zone on 1 December just north of Panama, where it remained nearly stationary for two days while the front gradually retreated northward and separated from the surface low. During this time, convection increased and became organized and, by 3 December, a distinct midlevel circulation had developed about 120 n mi north of the surface center. A weak tropical wave moved into the area and this event coincided with an increase in the overall organization of the system early on 4 December. A tropical depression formed at 1200 UTC that day about 300 n mi south of Kingston, Jamaica.

The depression strengthened and became a tropical storm at 1800 UTC 4 December about 285 n mi south-southeast of Kingston. Moving east-northeastward, Odette continued to strengthen despite moderate southwesterly shear, and late in the day microwave imagery indicated a formative eyewall. By 1200 UTC the next day, when the first reconnaissance aircraft reached the system, the convective structure was deteriorating and the central pressure was rising. Odette turned north-northeastward with increased forward speed, and strengthened slightly on 6 December, reaching its peak intensity of 55 kt at 0600 UTC. During the day, the forward speed of the system slowed again although the convection continued to advance northeastward at a more rapid rate; this lack of vertical organization was typical of Odette throughout its lifetime. Odette weakened slightly to 50 kt by the time it made landfall near Cabo Falso on the Barahona peninsula of the Dominican Republic around 2300 UTC 6 December.

The circulation center became disrupted during its overnight passage across the Dominican Republic, but tropical storm–force winds were maintained in the convection east of the center. Odette then accelerated northeastward in advance of an approaching cold front, and became extratropical when the low became embedded in the frontal zone near 1800 UTC 7 December. Odette's extratropical remnant raced northeastward with a distinct circulation for another 2 days within the frontal zone before dissipating after 1800 UTC 9 December.

As noted above, microwave imagery indicated a formative eyewall late on 4 December, but this feature weakened by the time the first reconnaissance aircraft reached the cyclone. Scatterometer data are also suggestive that Odette may have been stronger than indicated in the best track on 4 December, but the data were not consistent from pass to pass and have been largely discounted.

The largest reported rainfall amount was 230 mm at Isla Saona, Dominican Republic. A wind gust to 50 kt was reported from Santo Domingo.

The government of the Dominican Republic attributes eight deaths and 14 injuries directly to Odette, with most of these from mud slides or flash floods. There were also two indirect deaths (due to heart attacks) associated with the cyclone. Press reports indicate that Odette downed trees and power lines, and damaged buildings, bridges, and large areas of agricultural land. Approximately 35% of the banana crop was destroyed. Media reports indicate little apparent impact from the storm in Haiti.

p. *Tropical Storm Peter, 7–11 December*

The occurrence of Odette and Peter is the first time since 1887 that two tropical storms have formed in December.

A large extratropical storm was centered in the far eastern Atlantic on 5 December. This system cut off from the westerlies and moved southward for two days. By 7 December, convection developed and it is estimated that the gale center became a subtropical storm at 1800 UTC 7 December. As the cyclone moved farther south over warmer waters, the convection became concentrated near the center and it developed well-defined cyclonically curved bands of convection suggesting that the cyclone had acquired tropical characteristics. It is estimated that Peter became a tropical storm at 0600 UTC 9 December and reached its maximum winds of 60 kt and a minimum pressure of 990 mb around 1800 UTC 9 December while located about 700 n mi west-northwest of the Cape Verde Islands. By then, Peter was moving northward ahead of an approaching cold front. This was the same frontal system that had absorbed Tropical Storm Odette a few days earlier. Thereafter, the effects of strong upper-level winds and lower sea surface temperatures caused weakening, and by 1200 UTC 10 December, Peter was a tight swirl of low clouds with estimated winds of 30 kt. Peter continued to move toward the north and north-northeast over cooler waters and became an extratropical low by 0600 UTC 11 December. A few hours later, the system was absorbed by a cold front.

Visible satellite imagery and microwave data suggested the development of an eye feature that was best defined around 1515 UTC 9 December. In general, the presence of an eye feature on satellite imagery would correspond to a tropical cyclone of hurricane intensity, and the 3-h average objective Dvorak t-number was 4.0 or 65 kt during that period. However, this eye feature was transient and by 1800 UTC it had begun to dissipate. It is estimated that Peter's highest wind speed was 60 kt.

3. Tropical depressions

Tropical Depression 2 formed from a tropical wave that crossed the west coast of Africa into the Atlantic Ocean on 6 June. Dvorak satellite classifications and visible satellite imagery indicate that the system developed a closed circulation and became a tropical depression around 0000 UTC 11 June. The depression moved westward at a forward speed of about 17 kt, and the system's deep convection almost immediately became displaced to the northeast of the surface center. The depression degenerated into an open wave about 825 n mi east-southeast of Barbados after 1800 UTC that day.

Tropical Depression 6 formed from a tropical wave that moved across the coast of Africa on 14 July. Moving westward at 20 kt, the system developed enough organized convection to be classified as a tropical depression by 19 July, at a location about 900 n mi east of the Lesser Antilles. The depression moved westward for two days and was approaching the Lesser Antilles on 21 July when data from a U.S. Air Force Reserve reconnaissance aircraft showed that the system did not have a closed low-level circulation. The open tropical wave continued westward across the Caribbean for a few more days. Forecasts issued on 19 and 20 July brought the depression to hurricane intensity in three days, and watches and warnings were issued for several islands in the eastern Caribbean Sea. However, the depression weakened to an open wave, bringing only a few showers across the islands.

The tropical wave that produced Tropical Depression 6 over the tropical Atlantic Ocean continued westward, while an area of deep convection split off toward the northwest, moved across Hispaniola on 23 July, and approached the southeast coast of Florida on 24 July. Radiosonde data and satellite images suggest that a mid- to lower-tropospheric circulation associated with the convection then moved northward near the east coast of Florida. Satellite images and surface observations indicate that Tropical Depression 7 formed about 50 n mi east of Daytona Beach, Florida, by 1200 UTC 25 July. As it moved north-northwestward over the cooler shelf waters near the northeast Florida and Georgia coasts, its maximum winds did not strengthen beyond 30 kt. The cyclone made landfall along the central Georgia coast about 35 n mi south of Savannah around 0600 UTC 26 July, and dissipated over Georgia about a day later. Rainfall totals ranging up to 75 mm were reported over portions of Georgia and South Carolina.

Short-lived Tropical Depression 9 developed from a strong tropical wave that moved across the west coast of Africa on 14 August and moved westward across the tropical Atlantic Ocean for several days. The shower activity gradually increased as the wave approached the Lesser Antilles. The cloud pattern became better organized over the eastern Caribbean Sea and, based on a west wind reported by a ship, it is estimated that a tropical depression formed at 1800 UTC 21 August. Initially, the upper-level environment appeared to be favorable for strengthening. However, strong upper-level southwesterly winds became established over the depression and weakening began. Data from an Air Force reconnaissance plane at 1800 UTC 22 August indicated that the depression had lost its closed circulation just south of Hispaniola.

Tropical Depression 14 developed from a tropical wave that crossed the west coast of Africa on 6 September. The wave was associated with a broad surface circulation almost immediately, and by 8 September, the system possessed enough organized convection to be considered a tropical depression about 250 n mi southeast of the southernmost Cape Verde Islands. The cyclone moved slowly to the west-southwest initially, but an upper-level low dropped southward to the west of the depression and caused it to accelerate to the north-northwest on 9 September. Under southerly shear, the convection became separated from the circulation center and the circulation began to elongate.

TABLE 7. A homogeneous set of official and CLIPER average track forecast errors in the Atlantic basin for the 2003 season for all tropical cyclones, including depressions. Ten-year averages for the period 1993–2002 are also given for the 12- through 72-h forecasts.

	Forecast period (h)						
	12	24	36	48	72	96	120
2003 official error (n mi)	37	64	93	123	161	191	223
2003 CLIPER error (n mi)	49	103	164	221	334	467	617
No. of cases	362	327	291	256	197	156	125
1993–2002 official error (n mi)	45	81	116	150	224		
No. of cases	2983	2724	2480	2229	1818		
2003 official error relative to 1993–2002 official error (%)	−18%	−21%	−20%	−18%	−28%		
2003 official error relative to 2003 CLIPER error (%)	−24%	−37%	−43%	−44%	−52%	−59%	−64%

The depression dissipated on 10 September over the western Cape Verde Islands.

4. Forecast verification

The NHC issues an official forecast, every 6 h, of the position (latitude and longitude of the circulation center) and the intensity (maximum 1-min wind speed at 10 m above the surface) for all tropical cyclones in the Atlantic and eastern North Pacific basins. These forecasts are valid at 12, 24, 36, 48, 72, 96, and 120 h from the initial synoptic time of the forecast (0000, 0600, 1200, or 1800 UTC). It is noted that 2003 is the first year that 96- and 120-h forecasts were issued. Forecasts are verified by comparison with the "best track" described in section 1 above. Forecasts are verified for all tropical and subtropical cyclones, including depressions. A track forecast error is defined as the great circle distance between a forecast position valid at a particular time and the best-track position for the same time. An intensity forecast error is defined as the magnitude of the difference between a forecast wind speed for a particular time and the best-track wind speed for the same time.

Table 7 lists the average Atlantic basin official track forecast errors for 2003. For comparison, the average official track errors for the previous 10 yr are also listed. The 2003 average track errors range from 37 n mi at 12 h to 161 n mi at 72 h and are from 18% to 28% smaller than the previous 10-yr official average errors. There are no previous 10-yr averages to compare to this season's 96- and 120-h average forecast errors. Table 7 also lists the average errors for a climatology and persistence (CLIPER) track model (Aberson 1998). The CLIPER model represents a "no skill" level of forecast accuracy and the 2003 average official errors are from 24% to 64% smaller than their corresponding CLIPER errors.

Average official track forecast errors have decreased over the years (Franklin et al. 2003b) in consonance with advances in numerical weather prediction. Figure 7 is a plot of official yearly average official track fore-

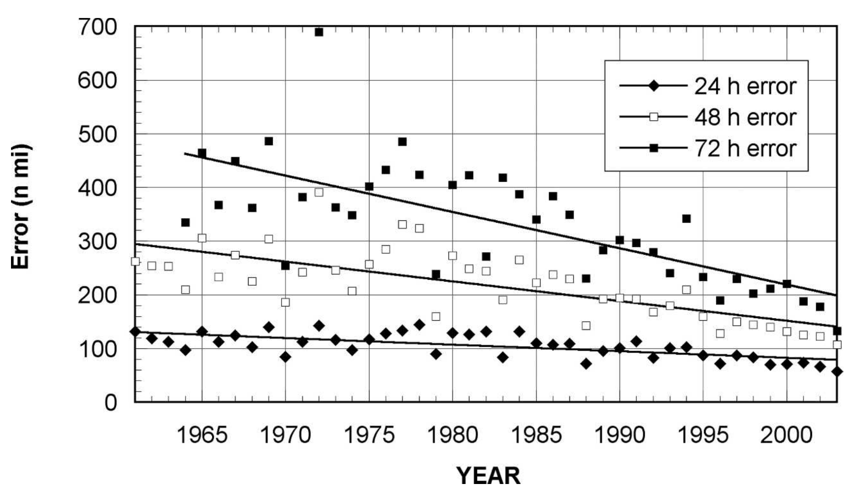

FIG. 7. Official yearly average 24-, 48-, and 72-h track forecast errors and linear trend lines. Tropical depressions are not included.

TABLE 8. A homogeneous set of official and SHIFOR average intensity forecast errors in the Atlantic basin for the 2003 season for all tropical cyclones, including depressions. Ten-year averages for the period 1993–2002 are also given for the 12- through 72-h forecasts.

	Forecast period (h)						
	12	24	36	48	72	96	120
2003 official error (kt)	5.2	7.9	9.5	11.6	14.8	17.0	20.6
2003 SHIFOR error (kt)	6.9	10.9	14.5	17.3	20.6	21.9	24.0
No. of cases	362	327	291	256	197	156	125
1993–2002 official error (kt)	6.2	9.8	12.6	15.2	18.9		
No. of cases	2970	2711	2465	2214	1818		
2003 official error relative to 1993–2002 official error (%)	−16%	−19%	−25%	−24%	22%		
2003 official error relative to 2003 SHIFOR error (%)	−25%	−28%	−34%	−33%	−28%	−22%	−14%

cast errors since 1961, for the 24-, 48-, and 72-h forecasts. Linear trend lines are also plotted. Depressions are not included in this dataset, as it was not possible to obtain depression forecasts from the early part of the period. It is seen that the 2003 official track forecast errors are the smallest of record at all forecast periods. It is also noteworthy that the 2003 official 120-h track error of 223 n mi is about the same magnitude as 48-h errors from the early 1980s.

Table 8 lists the average Atlantic basin official intensity forecast errors for 2003, along with the average errors for the previous 10 yr. Official intensity errors are 16% to 25% smaller than the previous 10-yr averages. Table 8 also lists the average errors for the "no skill" Statistical Hurricane Intensity Forecast (SHIFOR) climatology and persistence model (Jarvinen and Neumann 1979). Average official errors are from 14% to 33% smaller than their corresponding SHIFOR errors.

Trends of intensity forecast errors have not been as large as those of track errors. There have been modest improvements of the 24- and 48-h intensity forecasts, but the 72-h official intensity errors have decreased very little. While global models have made dramatic advances in tropical cyclone track forecasting, these models are not yet resolving the inner-core structure, which plays such an important role in the intensification process. The current state-of-the-art operational intensity forecast guidance is the statistical/dynamical Statistical Hurricane Intensity Prediction Scheme (SHIPS) model (DeMaria and Kaplan 1999).

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