ANNUAL SUMMARY

Atlantic Hurricane Season of 2004

JAMES L. FRANKLIN, RICHARD J. PASCH, LIXION A. AVILA, JOHN L. BEVEN II, MILES B. LAWRENCE, STACY R. STEWART, AND ERIC S. BLAKE

Tropical Prediction Center, National Hurricane Center, NOAA/NWS, Miami, Florida

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ABSTRACT

The 2004 Atlantic hurricane season is summarized, and the year's tropical and subtropical cyclones are described. Fifteen named storms, including six "major" hurricanes, developed in 2004. Overall activity was nearly two and a half times the long-term mean. The season was one of the most devastating on record, resulting in over 3100 deaths basinwide and record property damage in the United States.

1. Introduction

The 2004 Atlantic hurricane season was among the most devastating on record. The year's storms claimed over 3100 lives, the second largest toll in three decades; 60 of these occurred in the United States. The United States suffered a record \$45 billion in property damage, enduring landfalls from five hurricanes (Charley, Frances, Gaston, Ivan, and Jeanne) and the eyewall passage of a sixth (Alex) that avoided landfall on the North Carolina Outer Banks by less than 10 miles. In addition, Bonnie, Hermine, and Matthew made landfall in the United States as tropical storms. Florida, the "Sunshine State," became known as the Plywood State after being battered by Charley, Frances, Ivan, and Jeanne. The islands of the Caribbean were also hard hit. Charley struck Cuba as a major hurricane [maximum 1-min winds of greater than 96 kt (1 kt = 0.5144 m s^{-1}), corresponding to category 3 or higher on the Saffir–Simpson hurricane scale (Saffir 1973; Simpson 1974)]. Ivan was also a major hurricane in the Caribbean, causing extensive destruction on Grenada, Jamaica, and Grand Cayman, and Jeanne produced catastrophic flash floods in Haiti that killed thousands and left hundreds of thousands homeless.

Fifteen named storms developed in 2004, including Nicole, a subtropical storm (Table 1; Fig. 1). Nine of the named systems became hurricanes, and of these, six became major hurricanes. One additional tropical depression did not reach storm strength. These totals are considerably above the long-term (1944–2003) means of 10.2 named storms, 6.0 hurricanes, and 2.6 major hurricanes. August alone saw the formation of eight tropical storms, a new record for that month. The season also featured intense and long-lived hurricanes. Ivan, a category 5 storm, twice reached a minimum pressure of 910 mb, a value surpassed by only five other previous tropical cyclones in the Atlantic basin historical record. In addition, Ivan was a major hurricane for a total of 10 days, a new record for a single storm since reliable records began in 1944. In terms of "accumulated cyclone energy" (ACE; the sum of the squares of the maximum wind speed at 6-h intervals for tropical storms and hurricanes), overall activity this year was 234% of the long-term (1944–2003) mean. Only two seasons since 1944 (1950 and 1995) have had higher ACE values. The 2-month period of August–September 2004 registered the highest 2-month ACE accumulation on record.

The above-normal levels of activity in 2004 continued a tendency that began in 1995 for greater numbers of storms. This appears to be due, in part, to sea surface temperatures (SSTs) over the North Atlantic Ocean that have been considerably warmer during the past 10 yr than during the preceding decade. In fact, 2004 was the second warmest year since 1948, as measured by SSTs between 10° and 20°N in the tropical Atlantic Ocean and Caribbean Sea during the peak months of the hurricane season. SST anomalies for August and

Corresponding author address: James L. Franklin, Tropical Prediction Center, National Hurricane Center, NOAA/NWS, 11691 SW 17th Street, Miami, FL 33165-2149.
E-mail: James.Franklin@noaa.gov

TABLE 1. 2004 Atlantic hurricane season statistics.

No.	Name	Class[a]	Dates[b]	Maximum 1-min wind (kt)	Minimum sea level pressure (mb)	Direct deaths	U.S. damage ($ million)
1	Alex	H	31 Jul–6 Aug	105	957	1	5
2	Bonnie	T	3–13 Aug	55	1001	3	Minor[c]
3	Charley	H	9–14 Aug	125	941	15	15,000
4	Danielle	H	13–21 Aug	95	964		
5	Earl	T	13–15 Aug	45	1009		
6	Frances	H	25 Aug–8 Sep	125	935	8	8900
7	Gaston	H	27 Aug–1 Sep	65	985	8	130
8	Hermine	T	27–31 Aug	50	1002		
9	Ivan	H	2–24 Sep	145	910	92	14,200
10	Jeanne	H	13–28 Sep	105	950	3000+	6,900
11	Karl	H	16–24 Sep	125	938		
12	Lisa	H	19 Sep–3 Oct	65	987		
13	Matthew	T	8–10 Oct	40	997		Minor[c]
14	Nicole	ST	10–11 Oct	45	986		
15	Otto	T	29 Nov–3 Dec	45	995		

[a] T = tropical storm and ST = subtropical storm, wind speed 34–63 kt (17–32 m s^{-1}); H = hurricane, wind speed 64 kt (33 m s^{-1}) or higher.
[b] Dates begin at 0000 UTC and include tropical and subtropical depression stages but exclude extratropical stage.
[c] Only minor damage was reported, but the extent of the damage was not quantified.

September 2004 are given in Fig. 2. It can be seen that nearly the entire tropical Atlantic during the peak of the hurricane season was warmer than normal, the exception being cool anomalies in the extreme western Atlantic that largely reflect up-welling from Frances and Jeanne. Particularly large anomalies were present in the eastern Atlantic north of 15°N; these may have contributed to an unusually favorable thermodynamic environment for tropical waves. Large-scale steering patterns in 2004, however, differed significantly from those occurring over much of the past decade, which had been characterized by a midlevel trough near the eastern coast of the United States that took many storms out to sea before they could make landfall. In contrast, persistent high pressure over the eastern United States and the western Atlantic during 2004 (Fig. 3) kept this year's storms on more westerly tracks. The season also featured lower than normal vertical wind shear over the Caribbean Sea and western Atlantic (Fig. 4); this combination allowed hurricanes approaching the Caribbean and North America to maintain much of their intensity. It remains to be seen whether the synoptic-scale patterns observed during 2004 represent a 1-yr anomaly or something more ominous.

2. Storm and hurricane summaries

The individual cyclone summaries that follow are based on the National Hurricane Center's (NHC) poststorm meteorological analyses of a wide variety of (often contradictory) data types described below. These analyses result in the creation of a "best track" database for each storm, consisting of 6-hourly representative estimates of the cyclone's center location, maximum sustained (1-min average) surface (10 m) wind, minimum sea level pressure, and maximum extent of 34-, 50-, and 64-kt winds in each of four quadrants around the center. The life cycle of each cyclone (corresponding to the dates given in Table 1) is defined to include the tropical or subtropical depression stage, but does not include remnant low or extratropical stages. The tracks for the season's tropical storms and hurricanes are shown in Fig. 1 (see http://nhc.noaa.gov/pastall.shtml).[1]

For storms east of 55°W longitude, or those not threatening land, the primary (and often sole) source of information is geostationary and polar-orbiting weather satellite imagery, interpreted using the Dvorak (1984) technique. For systems posing a threat to land, in situ observations are also generally available from aircraft reconnaissance flights conducted by the 53rd Weather Reconnaissance Squadron ("Hurricane Hunters") of the Air Force Reserve Command (AFRC), and by the National Oceanic and Atmospheric Administration (NOAA) Aircraft Operations Center (AOC). During reconnaissance flights, minimum sea level pressures are either measured by dropsondes released at the circulation center or extrapolated hydrostatically from flight level. Surface (or very near surface) winds in the eye-

[1] Tabulations of the 6-hourly best-track positions and intensities can be found in the NHC Tropical Cyclone reports. These reports contain storm information omitted here due to limitations of space, including additional surface observations and a forecast and warning critique.

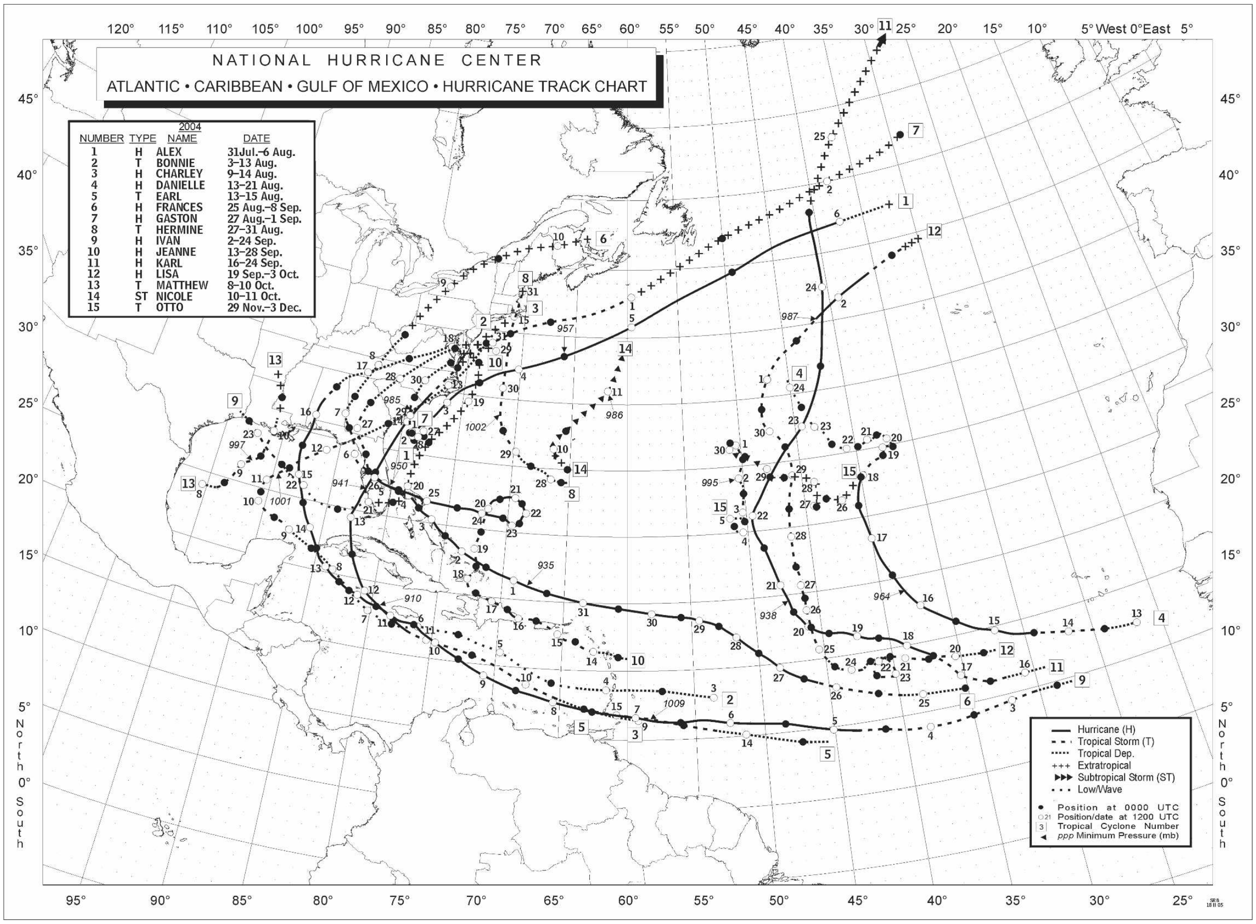

FIG. 1. Tracks of tropical storms, hurricanes, and subtropical storms in the Atlantic basin in 2004.

wall or maximum wind band are often measured directly using GPS dropwindsondes (Hock and Franklin 1999), but more frequently are estimated from flight-level winds using empirical relationships derived from a 3-yr sample of GPS dropwindsonde data (Franklin et al. 2003). During NOAA reconnaissance missions, surface winds can be estimated remotely using the Stepped-Frequency Microwave Radiometer (SFMR) instrument (Uhlhorn and Black 2003). When available, satellite and reconnaissance data are supplemented by conventional land-based surface and upper-air observations, ship and buoy reports, and weather radars. In key forecast situations, the kinematic and thermodynamic structure of the storm environment is obtained from dropsondes released during operational "synoptic surveillance" flights of NOAA's Gulfstream IV jet aircraft (Aberson and Franklin 1999).

Several satellite-based remote sensors play an important role in the analysis of tropical weather systems. Foremost of these is multichannel passive microwave imagery [e.g., from the Tropical Rainfall Measuring Mission (TRMM) satellite], which over the past decade has provided radar-like depictions of systems' convective structure (Hawkins et al. 2001) and is of great help in assessing system location and organization. The SeaWinds scatterometer on board the Quick Scatterometer (QuikSCAT) satellite (Tsai et al. 2000) provides surface winds over large oceanic swaths. While the QuikSCAT generally does not have the horizontal resolution to determine a hurricane's maximum winds, it can sometimes be used to estimate the intensity of weaker systems and to determine the extent of tropical-storm-force winds. In addition, it can be helpful in determining whether an incipient tropical cyclone has acquired a closed surface circulation. Finally, information on the thermal structure of cyclone cores is provided by the Advanced Microwave Sounder Unit (AMSU; Velden and Brueske 1999). Intensity estimates derived from such data can in some cases be superior to Dvorak classifications (Herndon and Velden 2004).

A number of organizations have developed Web sites that have proven to be extremely helpful for tropical

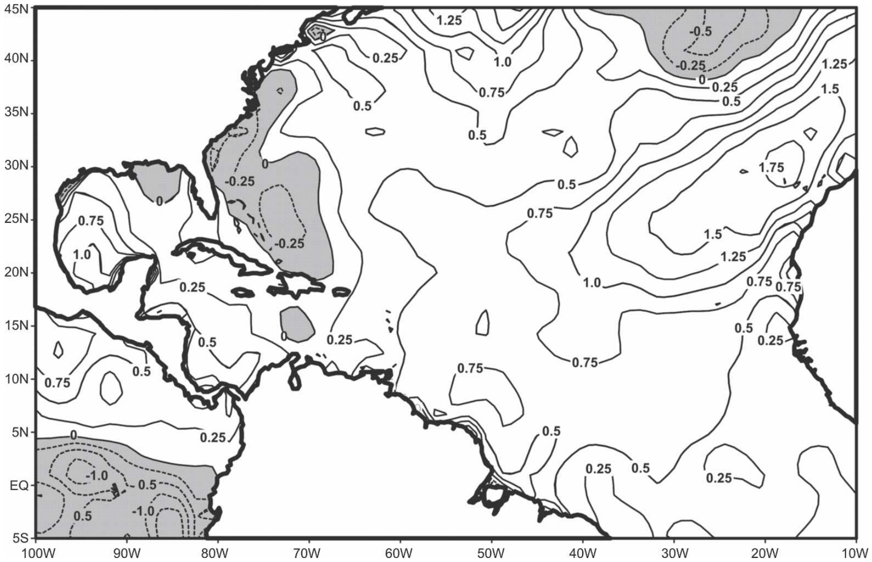

FIG. 2. Anomaly from the long-term (1968–96) mean of sea surface temperature (°C) for August–September 2004. Negative anomalies (below-normal temperatures) are shaded. Data provided by the NOAA–Cooperative Institute for Research in Environmental Sciences Climate Diagnostics Center, Boulder, CO (http://www.cdc.noaa.gov/), based on the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis project (Kistler et al. 2001).

cyclone forecasting and postanalysis. These include the Naval Research Laboratory (NRL) Monterey Marine Meteorology Division Tropical Cyclone Page (http://www.nrlmry.navy.mil/tc_pages/tc_home.html), with its comprehensive suite of microwave products; the cyclone phase diagnostics page of Florida State University (http://moe.met.fsu.edu/cyclonephase/), which is frequently consulted to help categorize systems as tropical, subtropical, or nontropical; and the tropical cyclone page of the University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies (http://cimss.ssec.wisc.edu/tropic/tropic.html), which contains a variety of useful satellite-based synoptic analyses.

In the cyclone summaries below, U.S. damage estimates have been generally estimated by doubling the insured losses reported by the American Insurances Service Group (AISG) for events exceeding their minimum reporting threshold ($25 million). The reader is cautioned, however, that the uncertainty in estimating meteorological parameters for tropical cyclones pales in comparison to the uncertainty in determining the cost of the damage caused by these cyclones when they make landfall. Descriptions of the type and scope of damage are taken from a variety of sources, including local government officials, media reports, and local National Weather Service (NWS) Weather Forecast Offices (WFOs) in the affected areas. Tornado counts are based on reports provided by the WFOs. Hard copies of these various reports are archived at the NHC.

Although specific dates and times in these summaries are given in coordinated universal time (UTC), local time is implied whenever general expressions such as "afternoon," "midday," etc. are used.

a. *Hurricane Alex: 31 July–6 August*

Alex brought category 1 hurricane conditions to the North Carolina Outer Banks as its center passed just offshore, and later strengthened to a category 3 hurricane at an unusually high latitude.

1) SYNOPTIC HISTORY

Three distinct weather systems may have played a role in the genesis of Alex. On 26 July, shower activity increased several hundred miles to the east of the northwestern Bahamas. This activity was associated with a weak surface trough, likely of midlatitude origin. Disorganized showers persisted just to the east of the Bahamas, in the diffluent region to the east of an upper-level low, for the next couple of days. On 28 July, when a tropical wave reached the area, the extent and organization of the convection began to increase. Analyses show that a broad area of surface low pressure formed early on 30 July just northeast of the central Bahamas. The low moved northwestward, and over the next 36 h the circulation slowly became better defined. By 1800 UTC 31 July, when the low center was located about 175 n mi east of Jacksonville, Florida, the system had

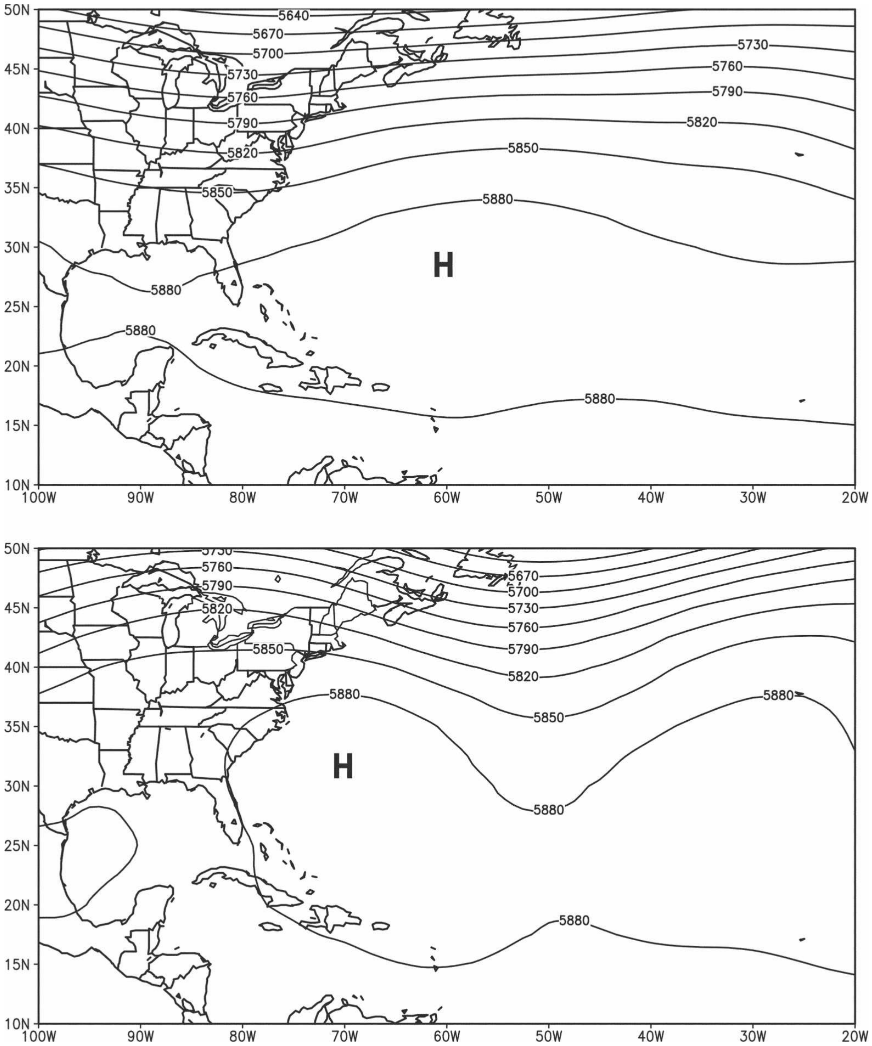

FIG. 3. Mean 500-mb heights (m) for (top) September 1995–2003, and (bottom) September 2004. The location of maximum height in the western Atlantic is indicated by "**H**." Source of data same as in Fig. 2.

enough convective organization to be classified as a tropical depression.

As the depression approached a break in the subtropical ridge early on 1 August its forward motion slowed, and the cyclone remained nearly stationary for the next day or so about 115 n mi east-southeast of Savannah, Georgia. The depression remained poorly organized initially, due to northeasterly shear and an environment characterized by subsidence and dry air. However, an upper-level trough was approaching from the west, and in advance of this trough the northeasterly flow over the cyclone began to relax. The depression strengthened during this transition in the upper flow pattern, and it became a tropical storm at 1800 UTC 1 August.

Alex began to move northeastward early on 2 August, slowly approaching the coastline of the Carolinas over the next 36 h. Northeasterly shear continued to diminish, and the deep convection, which had previously been confined to the southwestern quadrant of the circulation, now became organized in bands to the east of the center. Alex strengthened, becoming a hurricane near 0600 UTC 3 August when it was centered about 65 n mi south-southeast of Cape Fear, North Carolina.

Aided by warm Gulf Stream waters and light shear, Alex continued to strengthen on 3 August as it neared the North Carolina Outer Banks. The hurricane's maximum sustained winds reached 85 kt (category 2) at 1200 UTC, and the minimum pressure fell to 972 mb at 1800 UTC. Alex made its closest approach to land near 1700 UTC, with its center located about 9 n mi southeast of Cape Hatteras, while the western eyewall of the hurri-

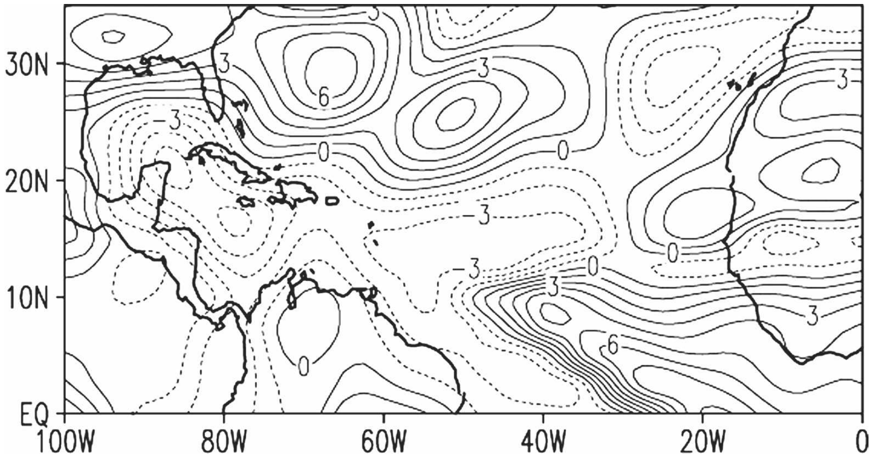

FIG. 4. Anomaly from the long-term (1971–2000) mean of 200–850-mb vertical wind shear (kt) for August–September 2004. Negative anomalies given by dashed contours. Source of data same as in Fig. 2.

cane raked the Outer Banks with sustained category 1 hurricane-force winds.

After passing the Outer Banks, Alex turned away from land and accelerated as it became embedded in a deep layer of west-southwesterly flow. Alex strengthened and became a major hurricane at 0000 UTC 5 August, with winds of 105 kt and a minimum pressure of 957 mb. At this time Alex was at 38.5°N latitude (385 n mi south-southwest of Halifax, Nova Scotia, Canada), moving east-northeastward at 20–25 kt, and over waters just above 26°C—factors not normally associated with major hurricanes. Only Hurricane Ellen of 1973 attained major hurricane status farther to the north. While the basic environmental current surrounding Alex was low in shear, the unexpected strengthening of Alex remains difficult to explain.

By late on 5 August Alex had moved north of the Gulf Stream over sub-20°C waters and was weakening rapidly. Moving at 40–45 kt, Alex weakened to a tropical storm after 0600 UTC 6 August and became extratropical a few hours later about 830 n mi east of Cape Race, Newfoundland, Canada. The circulation of Alex was absorbed into a larger extratropical low by 0000 UTC 7 August.

2) Meteorological statistics

Although the center of Alex remained offshore (and therefore the hurricane technically did not make landfall), the western portion of the eyewall passed over the North Carolina Outer Banks on 3 August. There was a relatively high density of surface observations in the area for this event, and these observations (Table 2) generally indicate that category 1 sustained winds were experienced in the Outer Banks. The highest gust accepted as accurate was an unofficial report from a storm chaser of 91 kt in Hatteras Village at 1814 UTC, with a maximum sustained wind report of 67 kt at about the same time. A 5-min mean wind of 65 kt was reported from a 10-m anemometer at Avon Pier. Not included in the table is an unofficial gust report of 104 kt at the Ocracoke Ferry office, believed to be in error based on nearby storm-chaser observations as well as the nature of the damage. As Alex brushed past the Outer Banks, its maximum sustained winds offshore were near 85 kt, an estimate based largely on dropsonde surface observations of 77 and 87 kt. The highest observed flight-level wind was 105 kt. Alex reached its estimated maximum intensity after all reconnaissance flights had ended; the peak wind estimate of 105 kt is based on a blend of subjective and objective Dvorak numbers (Velden et al. 1998).

The highest estimated surge values, near 1.8 m, occurred on the sound (west) side of the Outer Banks at Buxton and Ocracoke Village. Waters rose to 1 m above normal levels along the lower reaches of the Neuse and Pamlico Rivers.

The highest measured rainfall amount associated with Alex, 192 mm, occurred at Ocracoke, with 143 mm reported in Beaufort. Doppler radar data indicated a large area of 100–200-mm accumulations across extreme southeastern Craven County, eastern Carteret County, and extending northeastward across Hyde and Dare Counties.

3) Casualty and damage statistics

A 26-yr-old male drowned in strong waves and residual rip currents off Nags Head, North Carolina, two days after the passage of Alex.

TABLE 2. Selected surface observations for Hurricane Alex, 31 Jul–6 Aug.

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)			
North Carolina								
Cape Hatteras (HSE)	03/1551	991.2[e]	03/1623	38[e]	53			
Beaufort (MRH)	03/1356	999.2	03/1336	35	46			142.7
Ocracoke								191.8
Newport								73.2
Buxton					1.8			
Ocracoke Village					1.8			
North Carolina (unofficial)								
Wrightsville Beach Pier			03/		34			
Hatteras Village	03/1810	981	03/1814	67	91			
Avon			03/1715		76[e]			
Avon Pier			03/1735	65[f]	78			
Avon (Sound)			03/1900	64[f]	80			
Kure Beach			03/0900		34			
Bald Head Island			03/		37			
Buoys/C-MAN sites								
41025	03/1600	990.7[e]	03/1600	47[e]	62			
41013	03/0750	994.9	03/0710	35	45			
44140	05/2200	979.3						
Cape Lookout (CLKN7)	03/1300	994.7	03/1400	51	56			
Frying Pan Shoals (FPSN7)	03/1300	994.8	03/0900	33	45			
Duck (DUCN7)	03/2100	1002.7	03/1900	39	43		1.6[g]	

[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] 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] Record incomplete due to instrument failure.
[f] Five-minute average.
[g] Water height above mean lower low water.

Storm surge damage and beach erosion was significant in Dare and Hyde Counties on the Outer Banks. Significant wind and water damage occurred from Buxton southward and across Ocracoke Island, where hundreds of vehicles and homes were flooded from soundside surge. Hurricane-force winds produced minor structural damage to homes and businesses and caused extensive damage to trees and power lines. Insured damage from flooding was estimated to be about $2 million. The state of North Carolina estimated damage to public facilities in Dare and Hyde Counties to be near $767,000, and officials in Dare County estimated total damage there at near $2.4 million. The total damage from Alex is estimated to be not more than $5 million.

b. Tropical Storm Bonnie: 3–13 August

Bonnie developed from a tropical wave that crossed Dakar, Senegal, on 29 July and moved westward for several days accompanied by cloudiness, thunderstorms, and a well-defined cyclonic rotation at the midlevels. The shower activity became concentrated, and the system developed convective bands as it moved westward, becoming a tropical depression at 1200 UTC 3 August when the system was located about 360 n mi east of Barbados in the Lesser Antilles. However, the depression was moving westward rapidly, near 20 kt, and could not maintain a closed surface circulation. The system degenerated to an open wave on 4 August in the eastern Caribbean Sea, and the depression's remnants moved through the central Caribbean Sea over the next few days. Once the system reached the western Caribbean Sea, the forward motion slowed and persistent convection redeveloped. It is estimated that a small closed circulation reformed about 100 n mi southeast of the western tip of Cuba at 1200 UTC 8 August.

The regenerated depression moved west-northwestward across the Yucatan Channel and became a tropical storm near the northeastern tip of the Yucatan Pen-

TABLE 3. Selected surface observations for Tropical Storm Bonnie, 3–13 Aug 2004.

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)
Florida								
Apalachicola NOAA/National Ocean Service (NOS)						0.3	0.8	
Cedar Key NOS						0.6	1.6	
Cross City (KCTY)								81.8
Gainesville (KGNV)	12/1636	1010.2	12/1752	23	34			3.0
Perry (K40J)								79.0
Florida (unofficial)								
Alligator Point (Bald Point)	12/1629	1005.6	12/1140	30	35			34.3
Mary Esther (Florosa Elementary School)	12/1214	1010.2	12/0627		34			
Buoys/C-MAN								
42001			11/1440	51	66			
42036	12/1450	1009.5	12/1520	31	35			
42039	12/1250	1002.9	12/1030	37	47			
SGOF1	12/1600	1008.5	12/1300	32	40			

[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] 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).

insula on 9 August. Bonnie moved into the central Gulf of Mexico and then turned northeastward on 11 August, reaching its maximum intensity of 55 kt and 1001 mb at 1800 UTC that day. Strong southwesterly wind shear then became established over Bonnie and the cyclone began to weaken. Bonnie made landfall just south of Apalachicola, Florida, near St. Vincent and St. George Islands, around 1400 UTC 12 August with maximum winds near 40 kt. After moving inland, Bonnie weakened to a tropical depression and continued to move northeastward across eastern Georgia and the Carolinas. Bonnie produced roughly 30 tornadoes over the southeastern United States, and one of these resulted in three deaths in Pender County, North Carolina. Deep convection gradually diminished and Bonnie degenerated to a weak remnant low just south of Cape Cod, Massachusetts, on 14 August before becoming absorbed within a frontal boundary.

A reconnaissance mission into Bonnie late on 9 August is notable for its report of a closed eyewall 8 n mi in diameter at 2154 UTC. This feature was also observed in images from the Cancun, Mexico, radar earlier in the day (not shown). Yet the aircraft-estimated minimum central pressure was only 1006 mb and the highest 1500-ft flight-level winds encountered were only 56 kt, suggesting that Bonnie was at best a moderate tropical storm despite its apparent mesoscale organization. Tropical-storm-force winds at this time were limited to an area within about 25 n mi of the center. A reconnaissance flight on 12 August is also of interest for its encounter with a mesocyclone within Bonnie's circulation. At 0941 UTC, in the middle of Bonnie's weakening trend, the aircraft reported a minimum pressure of 995 mb sandwiched between values of 1010 and 1007 mb (at 0526 and 1123 UTC, respectively).

Selected surface observations for Bonnie are given in Table 3.

c. *Hurricane Charley: 9–14 August*

Hurricane Charley strengthened rapidly just before striking the southwestern coast of Florida as a category 4 hurricane. Charley was the strongest hurricane to hit the United States since Andrew in 1992 and, although small in size, caused catastrophic wind damage in Charlotte County, Florida. Serious damage occurred well inland over the Florida peninsula.

1) SYNOPTIC HISTORY

A tropical wave emerged from western Africa on 4 August. Radiosonde data from Dakar showed that this wave was accompanied by an easterly jet streak of around 55 kt near the 650-mb level, and the wave produced 24-h surface pressure falls of ~5 mb near the west coast of Africa. However, the initial satellite presentation of this system was not particularly impressive, showing only a small area of associated deep convection. As the wave progressed rapidly westward across the tropical Atlantic, the cloud pattern gradually became better organized, with cyclonic turning becoming more evident in the low clouds. Curved banding of the deep convection became better defined early on 9 August, and this, along with surface observations from the southern Windward Islands, indicated that a tropical depression had formed about 100 n mi south-southeast of Barbados by 1200 UTC 9 August.

Late on 9 August, the depression moved into the southeastern Caribbean Sea. A strong deep-layer high pressure area to the north of the cyclone induced a swift west-northwestward motion of 20–25 kt. With low vertical shear and well-established upper-level outflow, the depression strengthened into a tropical storm early on 10 August. Fairly steady strengthening continued while the storm moved into the central Caribbean Sea, and when Charley approached Jamaica on 11 August, it became a hurricane. By this time, the forward speed had slowed to about 14 kt. Charley's center passed about 35 n mi southwest of Jamaica around 0000 UTC 12 August. The hurricane then turned northwestward and headed for the Cayman Islands and western Cuba. It continued to strengthen, reaching category 2 status around 1500 UTC 12 August, just after passing about 15 n mi northeast of Grand Cayman.

As Charley neared the western periphery of a midtropospheric ridge, it turned toward the north-northwest, its center passing about 20 n mi east of the Isle of Youth at 0000 UTC 13 August. Charley strengthened just before it hit western Cuba, the eye crossing the coast very near Playa del Cajio around 0430 UTC 13 August. Cuban radar and microwave imagery suggest that the eye shrank in size, and surface observations from Cuba indicate that maximum winds were about 105 kt as the hurricane crossed the island. By 0600 UTC, the eye was emerging from the north coast of Cuba about 12 n mi west of Havana. Aerial reconnaissance observations indicate that Charley then weakened slightly over the lower Straits of Florida. Turning northward, the hurricane passed over the Dry Tortugas around 1200 UTC 13 August with maximum winds near 95 kt.

By the time Charley reached the Dry Tortugas, it came under the influence of an unseasonably strong deep-layer trough that had dropped from the east-central United States into the eastern Gulf of Mexico. In response to the steering flow on the southeast side of this trough, the hurricane turned north-northeastward and accelerated toward the southwest coast of Florida, intensifying rapidly as it did so. By 1400 UTC 13 August, the maximum winds had increased to near 110 kt, and just three hours later, Charley's maximum winds had increased to category 4 strength of 125 kt. Since the eye shrank considerably in the 12 h before landfall in Florida, these extreme winds were confined to a very small area—within only about 6 n mi of the center. Moving north-northeastward at around 18 kt, Charley (Fig. 5) made landfall on the southwest coast of Florida near Cayo Costa, just north of Captiva Island, around 1945 UTC 13 August with maximum sustained winds near 130 kt. Charley's eye passed over Punta Gorda at about 2045 UTC, and the eyewall struck that city and neighboring Port Charlotte with devastating results. Continuing north-northeastward and accelerating, the hurricane crossed central Florida, resulting in a swath of destruction across the state. The center passed near Kissimmee and Orlando around 0130 UTC 14 August, by which time Charley's maximum winds had decreased to around 75 kt. Charley was still of hurricane intensity, with maximum sustained winds of 65–70 kt, when the center moved off the northeast coast of Florida near Daytona Beach at about 0330 UTC 14 August.

After moving into the Atlantic, the hurricane restrengthened briefly while it accelerated north-northeastward toward the coast of South Carolina, but was already weakening when it came ashore near Cape Romain, South Carolina at about 1400 UTC 14 August with highest winds of about 70 kt. The center then moved just offshore before making a final landfall at North Myrtle Beach, South Carolina at around 1600 UTC 14 August, with an intensity near 65 kt. Charley soon weakened to a tropical storm over southeastern North Carolina, and began to interact with a frontal zone associated with the same strong trough that had recurved the cyclone over Florida. By 0000 UTC 15 August, as its center was moving back into the Atlantic in the vicinity of Virginia Beach, Virginia, Charley had become an extratropical cyclone embedded within the frontal zone. Charley's extratropical remnant moved rapidly north-northeastward to northeastward, and became indistinct within the frontal zone near southeastern Massachusetts just after 1200 UTC 15 August.

2) METEOROLOGICAL STATISTICS

Charley deepened quite rapidly as it approached the southwest coast of Florida. AFRC dropsonde measurements on 13 August indicate that the central pressure fell from 964 mb at 1522 UTC to 941 mb at 1957 UTC (just a few minutes after landfall), a deepening rate of about 5 mb h^{-1}. The hurricane's peak intensity, which occurred at landfall in Cayo Costa, Florida, is estimated

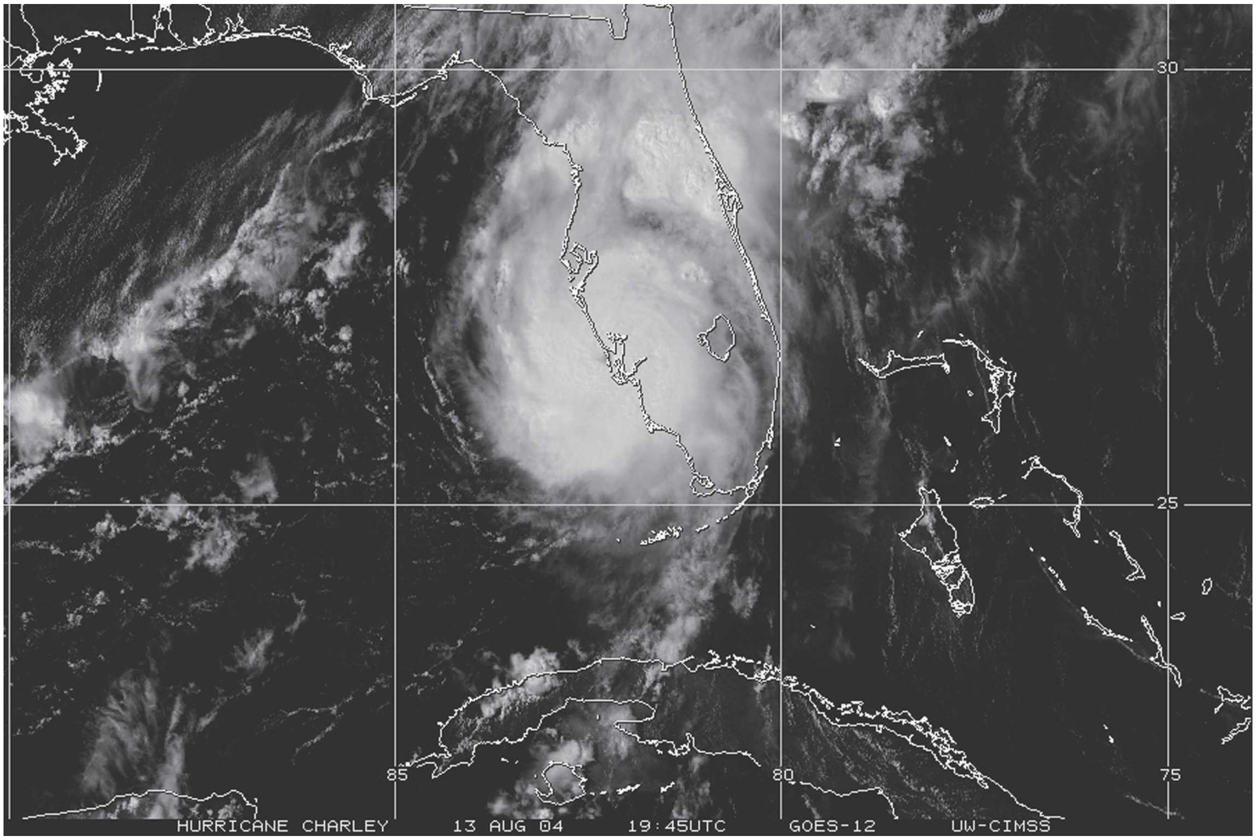

FIG. 5. *Geostationary Operational Environmental Satellite-12* (*GOES-12*) visible satellite image of Hurricane Charley at 1945 UTC 13 Aug 2004, near the time of landfall and the cyclone's maximum intensity (image courtesy University of Wisconsin).

to be 130 kt. This estimate is based on maximum 700-mb flight-level winds of 148 kt measured in the southeastern quadrant of the hurricane's eyewall at 1955 UTC 13 August. As usual, there were no official surface anemometer measurements of wind speeds even approaching this value near the landfall location. The wind sensor at the Punta Gorda Automated Surface Observing System (ASOS) site, which experienced the eyewall of Charley, stopped reporting after measuring a sustained wind of 78 kt at 2034 UTC and a gust to 97 kt at 2036 UTC. Ten minutes later, that site reported its lowest pressure, 964.5 mb. Since it is presumed that the center was closest to the Punta Gorda site at the time of lowest pressure, and since Charley's maximum winds covered an extremely small area, it is highly likely that much stronger winds would have been observed at the site had the wind instrument not failed. The few wind sensors that did survive indicate that Charley carried strong winds well inland along its path across the Florida peninsula. Orlando International Airport measured sustained winds of 69 kt, with a gust to 91 kt. Additional surface observations for Charley are given in Table 4.

There were nine tornadoes reported across the Florida peninsula in association with Charley, all of which occurred on 13 August. Single tornadoes were reported in Lee, Hendry, DeSoto, Hardee, and Osceola Counties, with two reported in Polk and Volusia Counties. The strongest tornado was in south Daytona Beach. This tornado struck around 2326 UTC, and produced a quarter-mile-long track of F1 damage. There were five tornadoes reported in eastern North Carolina on 14 August, in Onslow, Pitt, Hyde, Tyrrell, and Dare Counties. The tornado in Dare County produced F1 damage in Kitty Hawk. There were also two tornadoes observed in Virginia.

Because of the very limited extent of its strong winds, Charley produced an unusually modest storm surge for a category 4 hurricane. A surge of 1.3 m was measured by a tide gauge in Estero Bay, near Horseshoe Key and Fort Myers Beach. Storm surges of 1.0 and 1.1 m were measured on tide gauges on the Caloosahatchee River, near Fort Myers. There were also visual estimates of storm surges near 2 m on Sanibel and Estero Islands. Maximum rainfall totals from gauges in Florida ranged up to a little over 125 mm, but radar-estimated storm

TABLE 4. Selected surface observations for Hurricane Charley, 9–14 Aug 2004.

	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)
Grand Cayman Islands								
Grand Cayman	12/1300	1008.2	12/1142	21	34			22.9
Cayman Brac	12/0800	1008	12/1615	35	49			3.0
Cuba								
Punta del Este	13/0000	1001.7	13/0100	36	45			125.7
Nueva Gerona	13/0200	1006.2	13/0045	39	49			49.5
San Antonio de'los Banos	13/0453	989.4	13/0453	97	115			
Guira de Melena	13/0459	971.6	13/0450	92	116			98.6
Bauta	13/0530	971.0						84.8
Playa Baracoa	13/0605	974	13/0530	103	130			
Santiago de las Vegas	13/0501	990.7	13/0620	63	79			106.4
Casa Blanca	13/0530	1001.7	13/0630	61	76			56.4
Playa Cajio						4.0		
Florida								
Key West (KEYW)	13/1153	1009.8	13/1413	42	50			36.6
Key West Naval Air Station (NAS (KNOX)	13/1155	1010.2	13/1255	34	45			31.2
Marathon (KMTH)	13/0953	1012.4	13/1506		34			13.5
Summerland Key (NWS Handar)			13/1250	29	45			7.6
Big Pine Key (NWS Handar)			13/1350	31	39			9.4
Naples[e] (KAPF)	13/1905	1004.4	13/1806	38	48			44.5
Everglades City (KEGC)			13/1801	40	55			
Flamingo (KFLM)			13/1606	38	47			
Miami (KMIA)	13/1941	1013	13/1710	26	34			11.9
Fort Lauderdale (KFLL)	13/1929	1010	13/1900	25	33			10.4
West Palm Beach (KPBI)	13/2045	1013	13/2000	26	33			10.2
Brighton Reservation Co-op								48.8
Clewiston Co-op								41.9
Devils Garden Co-op								44.5
Marco Island Co-op								26.4
Golden Gate Co-op								52.8
Punta Gorda (KPGD)[e]	13/2046	964.5	13/2034	78	97			
Fort Myers (KFMY)	13/1953	998.1	13/2009	43	66			
Fort Myers (KRSW)	13/1957	1001.4	13/1949	53	68			
Winter Haven (KGIF)	13/2305	1000.3	13/2302	41	54			
Kissimmee (KISM)[e]			14/0035	53	65			132.1
Orlando (KMCO)[e]	14/0139	984.2	14/0134	69	91			53.6
Orlando (KORL)[e]	14/0129	980.7	14/0129	57	74			60.2
Sanford (KSFB)[e]	14/0213	983.4	14/0210	63	80			88.6
Lessburg (KLEE)	14/0158	1005.1	14/0135	29	34			
Patrick Air Force Base (AFB) (KCOF)			14/0044	28	43			
Daytona Beach (KDAB)[e]			14/0353	48	72			87.1
Ormond Beach (KOMN)			14/0315	59	76			
Melbourne (KMLB)	14/0100	1010.5	14/0222	29	39			36.6
Jacksonville NAS (KNIP)	14/0456	1012.4	14/0433	30	34			
Mayport NAS (KNRB)[e]	14/0529	1007.2	14/0430	37	46			
Fernandina Beach NOS	14/0700	1008.5	14/0742	18	28	0.3	0.8	17.0
Mayport NOS	14/0700	1008.3	14/0500	30	42	0.5	0.7	
Vilano Beach NOS (29.9°N, 81.3°W)			14/0500	27	44			
Bings Landing NOS (29.6°N, 81.2°W)	14/0500	1000.6	14/0500	18	57			
Cresent Beach NOS (29.8°N, 81.3°W)			14/0500	26	58			
Florida (unofficial)								
Key West Harbor	13/1200	1010.2	13/1612	32	44	0.4		
Cudjoe Key			13/1205		44			
Duck Key			13/0300	33	45			
Curry Hammock State Park								26.4

TABLE 4. (*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)			
Tavernier								17.8
Dry Tortugas/Fort Jefferson						1.8[f]		
Lake Okeechobee			13/2000	35				
Vanderbilt Beach[e]			13/1950		73			
Naples			13/1930		47			
Moore Haven			13/2045		36			
North Naples								190.0
Arcadia Emergency Operations Center (EOC)	13/2130	975.7	13/2140		90			
Charlotte County Airport			13/2035		139			
Charlotte County Medical Center			13/2035		150			
Port Charlotte			13/2000		61			
Storm chaser M. Sudduth, near Port Charlotte (27.0°N, 82.0°W)	13/2057	943.6	13/2046	80	115			
Storm chaser J. Leonard in Port Charlotte, near Faucet Memorial Hospital	13/2051	950.0						
Storm chaser M. Theiss, near Charlotte Harbor	13/2042	942.0						
Storm chaser J. Edds in Punta Gorda	13/2042[f]	943.0						
Big Carlos Pass (Lee County) (26.4°N, 81.9°W)	13/1954	997.1	13/1936	60	83			
Plant City			13/2355		54			
Fort Myers Beach			13/1930		56			
Fort Myers			13/2023		83			
Cape Coral			13/1940		78			
Matanzas Pass Fort Myers Beach						1.8		
Estero Bay Horseshoe Key						1.4		
Port Boca Grand						1.3		
Sarasota			13/2119		44			
Lakeland			13/2336		50			
Haines City			13/2325		67			
Lake Wales (10 miles east)			13/2300		65			
Poinciana			14/0000		39			
Archbold			13/2100		49			
National Aeronautics and Space Administration (NASA) Wind Tower 421 (28.78°N, 80.8°W)			14/0250	56	75			
NASA Wind Tower 22 (28.8°N 80.8°W)			14/0250	53	75			
Daytona Beach International Airport wind shear			14/0325		84			
Four miles southwest of Wimauma		1005.8	13/2200	35	48	0.7		
South Florida Water Management District stations								
WRWX (28.05°N, 81.40°W)	14/0015	991.3	13/2116		57			
S65DWX (27.31°N, 81.02°W)			13/2306		50			
S61W (28.14°N, 81.35°W)	14/0030	990.7	14/0028		78			
S65CW (27.40°N, 81.11°W)			13/2242		50			
S65DWX (27.31°N, 81.02°W)			13/2216		50			
L001 (27.14°N, 80.79°W)			13/2234		46			
Georgia								
St. Simons Island (KSSI)	14/0723	1009.5	14/0654	18	22	0.2	1.2	
Baxley Co-op								13.0
South Carolina								
Charleston (KCHS)	14/1258	1008	14/1322	25	33			25.9
North Myrtle Beach (KCRE)	14/1609	998	14/1538	36	50			38.6

TABLE 4. (*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)
Myrtle Beach (KMYR)			14/1550	35	45			
Myrtle Beach (Springmaid Pier NOS)	14/1542	998.2	14/1506	39[g]	53	1.8[f]	2.2	
South Carolina (unofficial)								
Downtown Charleston			14/1238	32[h]	44			53.1
Isle of Palms			14/1230	43	55			50.8
Hampton								38.9
Charleston Harbor						0.6[f]		
Oyster Landing (North Charleston County)						0.9		
Little River Fire Department					50			42.9
Myrtle Beach Pavilion					65			66.0
Loris					50			78.5
Conway								107.9
Conway Horry County EOC								100.8
Outland (Georgetown County)								75.4
North Carolina								
Wilmington (KILM)	14/1750	1005	14/1731	48	64			51.3
Southport (KSUT)			14/1700	33	51			57.4
Elizabethtown Co-op								84.3
Burgaw Co-op								84.3
Whiteville Co-op								81.8
New River (KNCA)	14/1815	1008.1	14/1929	42	57			
New Bern (KEWN)	14/1900	1012.1	14/1847	34	46			32.0
Cherry Point (KNKT)	14/1855	1014.1	14/1857	31	44			52.8
Beaufort (KMRH)	14/1756	1017.1	14/1915	32	43			35.6
Manteo (KMQI)	14/2120	1015.1	14/2200		35			
Washington (KOCW)	14/1900	1012.4	14/2001		50			
Edenton (KEDE)			14/2140	38	56			
Jacksonville (KOAJ)	14/1835	1012.4	14/1835		48			43.9
Kinston (KISO)	14/1920	1009	14/1920		40			
Elizabeth City (KECG)	14/2106	1011	14/2249	38	56			58.4
Greenville Co-op								128.3
Kinston Co-op								111.3
Richlands Co-op								86.6
Williamston Co-op								63.5
Wrightsville Beach NOS Johnnie Mercer Pier	14/1736	1007.3	14/1736	61[g]	74			
Sunset Beach NOS	14/1600	998	14/1500	46	53			
North Carolina (unofficial)								
Surf City					44			
Watha					39			
Wilmington battleship USS *North Carolina*					61			35.3
University of North Carolina (UNC) Wilmington Marine Science Center					72			54.4
Wrightsville Beach U.S. Coast Guard Station					63			
North Carolina State Port					80			
Bay Shore Estates					81			
Carolina Beach					61			
Myrtle Grove					55			
Southport					74			
Oak Island (39th Place West)					66			
Oak Island (43rd Street East)					53			
St. James Plantation					58			
Holden Beach					74			

TABLE 4. (*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)
Cedar Island			14/2000		42			
Brunswick County						2.4[f]		
Bald Head Island						0.9[f]		
New Hanover County Onslow Bay						1.5[f]		
Pender County						1.2[f]		
Onslow County						0.9[f]		
Carteret County Bogue Banks						0.9[f]		
Whiteville Columbus County Airport								47.8
Lumberton								15.7
Longwood								45.7
Moores Creek								39.6
Newport								58.4
Havelock								57.9
Perrytown								31.2
Virginia								
Norfolk (KORF)	14/2305	1013	14/2208	31	39			94.5
Norfolk NAS (KNGU)	14/2356	1013	14/2314	27	38			67.6
Hampton-Langley AFB (KLFI)			14/2214	30[f]	42[f]			
Wallops Island	14/2354	1017	14/2354	18	23			80.5
Chesapeake BBT NOS	15/0000	1013	14/2154	45	51			
Sewell's Point NOS	14/2212	1015	14/2336	38	49			
Kiptopeke NOS			14/2348	25	36			
Maryland								
Ocean City (KOXB)			15/0053	17	25			47.2
Maryland (unofficial)								
Ridge					16			52.6
Buoys/C-MAN								
41009	14/0150	1011.0	14/0150	35	44			
41012	14/0650	999.0	14/0450	37	47			
41004	14/1250	1001	14/1250	43	64			
41008	14/0850	1005	14/0850	33	43			
41013	14/1550	1014.4	14/1650	36	49			
Sand Key (SANF1)	13/1159	1007.8	13/1159	44	54			
Sombrero Key (SMKF1)	13/1059	1012.4	13/1449	41	56	0.6		
Long Key (LONF1)	13/1159	1012.0	13/1329	38	53	0.6		
Molasses Reef (MLRF1)	13/0853	1012.9	13/0359	34	47			
Dry Tortugas (DRYF1)[e]	13/1059	1004.7	13/1059	36	46			
Northwest Florida Bay University of South Florida (USF) (NFBF1)	13/1200	1011.6	13/1554	31	39	0.6		
St. Augustine (SAUF1)	14/0505	1000.7	14/0450	51	63			
Folly Beach (FBIS1)	14/1300	1005	14/1200	41	50			
U.S. Navy Tower (SPAG1) (31.4°N, 80.6°W)	14/1305	990						
Duck (DUCN7)	14/2100	1016.1	14/2200	32	47			
Cape Lookout (CLKN7)	14/1900	1015.9	14/2000	30	46			
Frying Pan Shoals (FPSN7)	14/1600	1014.4	14/1700	33	43			
Chesapeake Light (CHLV2)	14/2200	1013	14/2251	43	63			

[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] 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] Record incomplete due to instrument failure.
[f] Estimated.
[g] Six-minute average.
[h] Ten-minute average.

total precipitation amounts over central Florida were as high as 200 mm.

Observations from Cuba indicate that Charley was of category 3 intensity as it crossed the island; Playa Baracoa reported a sustained wind of 103 kt (Table 4). Storm surge heights of 4 m were determined from high water marks at Playa Cajio on the south coast. Rainfall totals of up to about 125 mm were reported in western Cuba.

3) Casualty and damage statistics

Charley was responsible for 15 direct deaths, including 10 in the United States. There were also four deaths in Cuba and one in Jamaica. Of the U.S. deaths, nine of these deaths occurred in Florida and one in Rhode Island. By hazard, the deaths are attributed to wind (8), fresh-water floods (1), and surf (1).

Insured damage in the United States from Hurricane Charley is estimated to be near $7.48 billion. The total damage is estimated to be near $15 billion, which makes Charley the second costliest hurricane in U.S. history, behind only Andrew of 1992.

d. Hurricane Danielle: 13–21 August

A vigorous westward-moving tropical wave moved across the west coast of Africa early on 12 August and spawned a tropical depression the following day about 210 n mi southeast of the southernmost Cape Verde Islands. The cyclone strengthened quickly, becoming a tropical storm at 0000 UTC 14 August and a hurricane 24 h later. Moving northwestward toward a weakness in the subtropical ridge, Danielle reached its estimated maximum intensity of 95 kt at 1800 UTC 16 August about 755 n mi west of the north-westernmost Cape Verde Islands. Shortly after Danielle reached its peak intensity, a large mid- to upper-level trough began to increase southwesterly vertical shear over the cyclone. Steady weakening ensued during the next three days while the cyclone moved northward. Danielle weakened to a tropical depression around 1800 UTC 20 August about 600 n mi south-southwest of the Azores Islands, and degenerated into a nonconvective remnant low pressure system by 1800 UTC the next day. The remnant low moved slowly northwestward and remained devoid of significant convection until it dissipated at 0000 UTC 25 August about 690 n mi west-southwest of the Azores Islands. There were no reports of damage or casualties associated with Danielle.

e. Tropical Storm Earl: 13–15 August

Earl formed from a tropical wave that moved from Africa to the eastern tropical Atlantic Ocean on 10 August. The wave developed into a tropical depression on 13 August while centered about 1000 n mi east of the Lesser Antilles. The cyclone was embedded in deep easterly flow to the south of a strong subtropical ridge, and moved westward at 18 to 25 kt during its short lifetime. Based on banding features observed on satellite imagery and the associated Dvorak intensity estimates, the depression is estimated to have strengthened to a tropical storm on 14 August about 325 n mi east of Barbados. Earl moved quickly across the southern Windward Islands on 15 August with maximum winds estimated at 45 kt, and briefly brought winds of at or near tropical storm force to Barbados, Grenada, St. Vincent, and the Grenadines. Shortly thereafter, even though satellite imagery suggested that the system was well organized, a hurricane hunter aircraft reported that the low-level circulation was not well defined. Earl degenerated to an open tropical wave later on 15 August, in almost the same location where Bonnie had done so two weeks earlier. The remnant wave continued westward to the eastern North Pacific Ocean where it developed into Hurricane Frank.

The highest sustained wind reports associated with Earl's passage through the Windward Islands were 30-kt observations from Barbados and St. Lucia. After Earl degenerated to an open wave, two ships reported tropical-storm-force winds associated with the fast-moving wave over the central Caribbean Sea.

There were no reports of casualties associated with Earl, and damage was minor. There were media reports of flooding and of damage to about a dozen roofs in Grenada. In nearby St. Vincent and the Grenadines, at least two roofs were destroyed and banana crops were damaged.

f. Hurricane Frances: 25 August–8 September

Frances was a Cape Verde tropical cyclone that passed through the Bahamas as a major hurricane and struck the Florida east coast as a category 2 hurricane.

1) Synoptic history

Frances developed from a vigorous tropical wave that crossed the west coast of Africa on 21 August. Convection associated with the wave gradually became better organized, and a tropical depression formed from the wave near 0000 UTC 25 August about 655 n mi west-southwest of the southern Cape Verde Islands.

The depression moved westward on the south side of the Atlantic subtropical ridge and intensified, becoming a tropical storm later on 25 August. Frances continued to strengthen as it turned west-northwestward, becoming a hurricane the next day and reaching an intensity of 115 kt on 28 August. Frances then weakened slightly as a result of an eyewall replacement, but restrengthened and reached its peak intensity of 125 kt (category 4) late on 31 August as it passed north of the Leeward and Virgin Islands. On 1–2 September, the center passed just north of the Turks and Caicos Islands and the southeastern Bahamas. During this time the hurricane underwent two more concentric eyewall cycles but with little apparent variation in maximum winds. Moderate westerly vertical shear developed late on 2 September, and Frances weakened during the next two days; however, it was still a category 3 hurricane, with winds of 100–110 kt, over the central Bahamas on 2–3 September and a category 2 hurricane, with winds of 85–90 kt, when it moved across the northwestern Bahamas on 3–4 September.

A high pressure ridge building west of the cyclone caused steering currents to weaken as Frances reached the northwestern Bahamas, and this resulted in a slow motion of the hurricane across the warm waters of the Gulf Stream on 4 September. The westerly shear also lessened at this time, but there was little change in intensity as Frances approached the Florida coastline. Hurricanes with large eyes are often observed to change intensity relatively slowly, and the limited response of Frances to a seemingly favorable environment may have been related to the structure of the hurricane's inner core, which featured a 50–70 n mi wide eye. Frances made landfall on the Florida east coast at the southern end of Hutchinson Island near 0430 UTC 5 September as a category 2 hurricane, with maximum sustained winds of near 90 kt.

After making landfall, Frances moved slowly west-northwestward across the Florida peninsula, weakening to a tropical storm just before its center emerged into the northeastern Gulf of Mexico near New Port Richey early on 6 September. Frances moved northwestward and made its final landfall near the mouth of the Aucilla River in the Florida Big Bend region, at about 1800 UTC that afternoon. A northwestward motion continued until 7 September, when Frances recurved northeastward into the westerlies over extreme eastern Alabama. Frances weakened to a tropical depression early on 7 September and then became extratropical over West Virginia early on 9 September, briefly producing gales as it accelerated northeastward across New York later that day. The cyclone then crossed northern New England and southeastern Canada, dissipating over the Gulf of St. Lawrence late on 10 September.

2) Meteorological statistics

The AFRC and NOAA/AOC Hurricane Hunters flew 34 operational missions in Frances, including standard synoptic surveillance flights in the storm environment. The strongest flight-level winds reported by the reconnaissance aircraft included a NOAA report of 144 kt from 8000 ft at 1726 UTC 31 August, and an AFRC measurement of 138 kt from 700 mb at 1114 UTC 31 August, and again at 0543 UTC 2 September. The lowest aircraft-measured pressure was 935 mb at 0712 UTC 1 September.

Selected observations from Frances are given in Table 5. Frances brought hurricane conditions to much of the central and northwestern Bahamas and southeastern Florida. The maximum sustained wind reported from a land station was 87 kt at North Eleuthera in the northwestern Bahamas at 1000 UTC 3 September. The Coastal Marine Automated Network (C-MAN) station at Settlement Point on Grand Bahama Island reported a 10-min mean wind of 73 kt at 2320 UTC 4 September and a peak gust of 96 kt. San Salvador reported a peak gust of 104 kt at 1900 UTC 2 September.

In Florida, a U.S. Army Corps of Engineers station at Port Mayaca reported sustained winds of 74 kt at 0500 UTC 5 September, while a portable instrumented tower run by the Florida Coastal Monitoring Program (FCMP) at Fort Pierce reported 70-kt sustained winds at 0402 UTC 5 September, along with a peak gust of 94 kt. Unofficial reports include a sustained wind of 70 kt from the Jupiter police department and a gust to 94 kt in Martin County. The official landfall intensity estimate of 90 kt was based on flight-level winds, adjusted using the mean eyewall profile of Franklin et al. (2003). There were no observations along the immediate shoreline in the Fort Pierce area, where the strongest winds over land most likely occurred.

The lowest reported pressure from a land station in the Bahamas was 948.1 mb at San Salvador at 2000 UTC 2 September. In Florida, a storm chaser on southern Hutchinson Island reported an unofficial minimum pressure of 959.0 mb at 0525 UTC 5 September.

Frances produced notable storm surges along both the Atlantic and Gulf coasts of Florida. The highest measured storm surge was 1.8 m above mean sea level on the Florida east coast at the St. Lucie Lock. The Melbourne National Weather Service Forecast Office estimated the storm surge at 2.4 m near Vero Beach and 1.8 m around Cocoa Beach. Along the Gulf Coast, a storm tide of 1.8 m was estimated in Pinellas County, while storm tides of up to 1.7 m were estimated in the Florida Big Bend area. Frances also produced significant but unquantified storm surges in the Bahamas that inundated airports at Freeport and Marsh Harbor.

Frances produced heavy rains that resulted in freshwater flooding over much of the eastern United States

TABLE 5. Selected surface observations for Hurricane Frances, 25 Aug–8 Sep 2004.

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Strom tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Bahamas								
North Eleuthera	03/1400	958.6	03/1000	87				
North Norman Reef (NOAA/Coral Reef Early Warning System)	03/0400	992.0	03/0100	37	53			
San Salvador	02/2000	948.1	02/1900	59	104			138.9
Alabama								
Dothan (KDHN)	07/0359	992.8	06/1937	32	45			25.4
Florida								
Chekika[e]					47			
Clearwater Beach NOS	06/0000	984.1	05/1854	54[f]	64		1.3	
Crescent Beach NOS							2.0	
Daytona Beach (KDAB)	05/2000	994.9	05/1000	49	65			253.0
Fernandina Beach (K55J)[g]			06/0855		38			
Fernandina Beach NOS	06/0800	1002.7	06/0500		43	0.5	2.4	
Fort Lauderdale (KFXE)			04/1848		48			
Fort Lauderdale International Airport (KFLL)	05/0630	990.0	03/1916	36	48			108.2
Fort Myers (KFMY)	05/1922	992.2	05/1859	32	42			73.4
Fort Myers (KRSW)	05/1926	992.6	06/1010	31	40			112.8
Fort Myers NOS	05/1836	991.9	05/0700		37		1.2	
Gainesville (KGNV)	06/0044	991.0	05/2200	41	56			274.6
Jacksonville Cecil Field (KVQQ)			06/0034	27	39			232.9
Jacksonville Craig Executive Airport (KCRG)[g]	06/0753	998.6	05/2053	29	52			180.3
Jacksonville I-295 NOS							1.1	
Jacksonville International Airport (KJAX)	06/0922	998.2	06/0017	38	54			231.9
Jacksonville Main Street NOS							1.4	
Jacksonville NAS (KNIP)	06/0655	997.6	05/2246	42	54			161.8
Key West International Airport (KEYW)	05/0953	1002.9	05/1640	31	38			40.1
Key West NAS (KNQX)	05/0955	1002.9	05/1033		43			41.9
Key West NOS	05/1000	1003.6	04/2000		43	0.1	0.7	
Lake City (KLCQ)	06/1439	994.5	06/1909	29	41			
Lake Wales Ridge[e]			05/1246		43			
Leesburg (KLEE)[g]	05/1859	988.5	05/1949		52			164.1
Marathon (KMTH)	05/0853	1001.7	05/1928		37			39.9
Mariana (KMAI)	06/2323	990.8	06/1424	32	43			25.7
Matanzas River NOS							2.1	
Mayport (KNRB)	06/0955	997.6	06/0144	45	55			130.8
Mayport NOS							1.9	
Mayport NOS (Bar Pilots Dock)	06/0724	1001.7	06/0518	36[f]	49		1.8	
Mayport NOS (Degaussing Structure)	06/0800	1001.4	06/0900	35[f]	51			
McKay Bay			06/1318	38[f]	55			
Melbourne (KMLB)[g]	05/1858	995.9	04/2358		63			201.9
Merrit Island Airport	N/A	984.0	05/0935	64	78			
Miami International Airport (KMIA)	05/0807	995.0	05/1932	37	51			88.6
Miami (KMFL)			04/1940		44			78.5
Naples (KAPF)			05/2007	33	47			26.9
Naples NOS	05/0900	996.3	05/1200	36[f]	47		1.3	
Oasis[e]			04/2134		41			
Ocala (KOCF)	05/2255	987.8	05/1955		43			274.6
Ochopee[e]			05/0636		39			
Opa Locka (KOPF)	05/0548	993.0	05/1730	37	47			87.1
Orlando International Airport (KMCO)[g]	05/1052	989.4	05/0848	47	60			165.1

TABLE 5. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Strom tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Panama City (KPFN)	06/1835	993.9	05/2241	36	53			12.4
Panama City Beach NOS	06/2200	995.4	07/0700		39			
Pembroke Pines (KHWO)	05/0542	992.0	05/0035	35	47			128.0
Perry (K40J)	06/1615	987.1	06/1701	32	41			89.9
Port Manatee NOS							1.4	
Punta Gorda (KPGD)	05/1905	989.2	06/0538	40	50			
Racy Pojnt NOS			05/2100		55			
Red Bay Point NOS							1.0	
St. Augustine (KSGJ)	05/2205	999.0	05/2015	41	53			
St. Petersburg (KPIE)	05/2216	982.4	06/0619	38	49			137.4
St. Petersburg (KSPG)	05/2147	981.4	06/0101	38	50			159.3
St. Petersburg NOS	05/2054	981.7	06/0612	36[f]	47	1.1	1.4	
Sanford (KSFB)[g]	05/1457	989.8	04/2313	44	61			111.8
Sarasota (KSRQ)	05/2132	984.4	06/0850	36	46			119.1
Tallahassee (KTLH)	06/1910	984.4	05/1938	41	52			63.0
Tamiami Executive Airport (KTMB)	05/0827	996.0	05/2141	41	49			59.2
Tampa (KTPA)	05/2225	980.0	05/1905	39	47			145.8
Tenraw[e]			05/0723		44			
Trident Pier NOS	05/1300	989.1	05/1224	41[f]	57	1.3	2.2	
Vaca Key NOS	05/0900	1001.7	05/0300		36	0.3	0.7	
Vilano Beach NOS	05/2300	999.5	05/2300	33[f]	53			
Virginia Key NOS	05/0600	994.5	05/0836	38[f]	49		0.9	
West Palm Beach (KPBI)	05/0508	972.0	05/0656	56	71			344.4
Winter Haven (KGIF)[g]	06/1602	977.3	06/1559	40	50			
Florida (unofficial)								
Alligator Point[h]	06/1719	984.6	05/1920		48			
Arlington[h]	06/0730	1000.6	06/0625		36			
Boca Raton			03/2030		50			
Boca Raton Water Treatment			03/2054		61			
Boynton Beach	N/A	977.3	04/1420		61			
Boynton Beach			04/1723		66			
Boynton Beach								242.8
Clearwater[h]			06/1445	34	56			
Clermont[h]	05/1835	984.0	05/1600		56			
Delray			04/1835		52			
Deerfield Beach								203.2
Dunedin[h]	05/2315	982.3	05/1515		42			
Flagler Beach Fire Department	05/2300	994.9	04/1730		63			
Fred Howard (Pinellas County)			04/		61			
Fort Pierce[i]			05/0402	70	94			
Goldon Beach			04/1743		50			
Holder[h]	06/0030	987.7	06/0700		39			
Indian Harbor Beach	05/1259	981.9	05/1455	46	68			
Jacksonville[h]	06/0700	1000.2	06/0512		40			
Juno Beach[h]	05/0345	963.7	05/0830		55			
Jupiter Police Department (PD)			04/1655	70	78			
Jupiter Inlet			04/1300		79			
Kendall			04/1900		57			
Kendall			04/1940		64			
Lake Apopka[j]			05/1330		43			
Lake Winder[j]			05/1245		52			
Largo[h]	05/2100	981.9	05/1700		36			
Lawtey								342.9
MacClenny	06/0840	998.0	06/0010		41			260.4
Martin County			05/1145		92			
Melbourne								178.8

TABLE 5. (*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]	Strom tide (m)[d]	Total rain (mm)
Miami[h]	05/0617	995.1	05/0729		50			
NASA Tower 19[k]			05/1040	59	82			
NASA Tower 22[k]			05/1150	55	72			
NASA Tower 110[k]			05/1210	49	78			
New Port Richey[h]	06/0045	980.2	05/1630		43			
Odessa[h]	06/0000	979.6	05/1830		37			
Orlando Azalea Park[h]	05/1537	988.0	05/1305		50			
Orlando Pine Hills[h]	05/1815	987.7			46			
Ormond Beach PD			05/1620		50			
Oviedo								228.6
Ponce Inlet[j]			05/2215		36			
Port Orange								383.0
Port Mayaca (U.S. Army Corps of Engineers)	05/0645	964.7	05/0500	74				
Port Saint Lucie (Texas Tech University)			05/0329	67	83			
Port Salerno[i]	05/0550	962.8	05/0240	49	71			
Riviera Beach			04/0510		66			
St. James City[h]	05/1847	993.5	05/1350		37			
St. Lucie Lock (U.S. Army Corps of Engineers)	05/0600	962.1	05/0330	37		1.8		
St. Petersburg Beach[h]	05/2115	981.6	06/1110		50			
Sebastien[h]	05/1228	974.5	05/1128		71			
Seminole County Station 22	05/1214	988.8	05/1451		51			151.9
Seminole County Station 35	05/1514	989.5	05/1257		50			146.6
Sewall's Point	05/0345	962.0	05/0226	63	85			
Skyway Bridge, Tampa			05/1418		55			
Space Coast Regional Airport (Texas Tech University)			05/1529	60	78			
Summerland Key Marine Laboratory			05/1710	31	37			52.6
South Hutchinson Island	05/0525	959.0						
South Lakeland	05/2100	972.3	05/1800		63			305.1
Starke[h]	06/0600	996.8	06/1600		35			
Tampa Bay Crest[h]			06/1230		50			
Tampa University Village[h]	05/2242	977.2	05/1527	37	57			
Taylor								254.0
The Villages[h]	06/0000	987.7	05/1600		37			
Valrico[h]	05/2030	974.5	05/1210		49			
Vero Beach[i]			05/0435	49	71			
Vero Beach (Texas Tech University)			05/0907	59	73			
Virginia Key AOML	05/0551	992.0	04/2031		53			72.1
West Pasco	06/0400	990.6						
South Florida Water Management District Stations								
Central Miami-Dade	05/0630	995.4	05/0456		59			
Clewiston (CFSW)	05/0815	981.7	05/0745	32[l]	56			
East Lake Okeechobee (L006)	05/0730	975.3	05/0600	54[l]	79			149.1
East Lake Okeechobee (LZ40)	05/0730	972.6	05/0720		80			
Lake Tohopekaliga	05/1545	976.0	05/1345	48[l]	71			
Loxahatchee (LXWS)	05/0530	979.1	05/0600	49[l]	76			
North Lake Okeechobee (L001)	05/1000	969.5	05/0715	62[l]	83			148.3
NW Broward County	05/0745	986.9	04/2040		53			
NW Collier County	05/0900	994.6	05/1810		47			
West-central Collier Country	05/1100	996.6	05/0601		41			
SW Palm Beach County	05/0630	986.9	05/0456		59			
West Lake Okeechobee (L005)	05/0915	980.1	05/0845	52[l]	78			89.7
WRWX	05/1630	976.1	05/1510		59			

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]	Strom tide (m)[d]	Total rain (mm)
Florida Automated Weather Network (FAWN)								
Citra								166.6
Fort Pierce			05/0300	50				87.4
Hastings			05/0815	36				212.1
Kenansville								163.6
Live Oak								205.7
Ocklawaha								227.1
Okahumpka								186.7
Pierson								229.9
Putnam Hall								295.7
Tavares								295.7
Umatilla								225.0
USF Coastal Ocean Monitoring and Prediction System (COMPS) stations								
Buoy NA2	05/2210	989.5	05/1810	39	47			
Aripeka (APK)	06/0212	979.2					1.4	
Egmont Key (EGK)			05/1936	45	54		1.2	
Homosassa (HOM)	06/0318	983.5	06/1724	47	57		1.4	
New Port Richey (PAS)	06/0136	979.6	05/1712	31	44		1.5	
North Florida Bay (NFB)	05/0624	999.6	05/0048	33	42	0.2	1.5	
Shell Point (SHP)	06/1706	992.7					1.5[g]	
Tarpon Springs (TAS)	06/0036	980.7	05/2030		42		1.2	
Georgia								
Albany (KABY)	07/0042	991.8	0671942	38	59			115.1
Alma (KAMG)	07/0002	996.9	07/0237	35	39			164.1
Atlanta Hartsfield International Airport (KATL)	07/2151	998.3	07/0800		45			76.7
Bainbridge (KBGE)			06/1620		37			
Brasstown[e]			07/1206		39			
Byromville[e]			07/0005		37			
Brunswick (KBQK)	06/2319	1002.3	06/0221	27	38			
Columbus (KCSG)	07/0751	994.4	07/0251		39			89.7
Cook[e]			06/1804		34			
Douglas (KDQH)	06/2259	995.2	06/2259		35			
Fort Benning (KLSF)	07/0655	994.1	07/0155		39			99.1
Fort Pulaski NOS			06/1148	32[f]	39		2.4	
Gainesville (KGVL)	08/0553	1000.1	07/1008		34			15.8
Helen 7N[e]								280.9
Macon (KMCN)	07/0753	998.5	07/0337		44			143.8
Newnan[e]			07/0702		36			
Patterson (PATG1)								303.3
Plains[e]			06/2003		35			174.5
St. Simon's Island (KSSI)	06/2300	1001.9	06/1807	37	47			87.6
St. Simon Island NOS						0.6	2.5	
Savannah (KSAV)	07/2253	1004.8	06/2219		35			60.2
Savannah Hunter (KSVN)	07/2255	1005.1	06/2155		38			114.6
Valdosta (KVLD)	06/2105	993.2	06/0127	31	45			163.3
Waycross (KAYS)	06/2320	997.3	07/0140		39			
Waycross[e]			06/2304		40			168.7
Georgia (unofficial)								
Gannett Lake			06/0400		36			
Waycross 9SE			05/0204		45			

TABLE 5. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Strom tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Skidaway Institute Station (off Georgia coast)								
Tower R2 (31.4°N, 80.6°W)	07/2328	1005.7	06/1028	39	47			
Tower R6 (31.5°N, 80.2°W)	07/2100	1007.6	07/1300	35	47			
Tower R8 (31.6°N, 79.9°W)	07/2132	1006.3	06/0632	33	39			
North Carolina								
Linville Falls (JSRN7)								459.0
Lake Toxaway (LKTN7)								436.9
Virginia								
Big Meadows (BGMV2)								292.1
Pennsylvania								
Altoona (KAOO)								147.6
Ohio								
Zanesville (KZZV)								136.9
Buoys/C-MAN								
41008	07/2250	1004.8	06/0650	33	45			
41009[g]	05/1320	990.8	05/1450	52	66			
41010	04/2320	1003.6	04/1350	39	52			
41012	06/0050	1002.7	06/0100	41[m]	54			
42036	06/0850	989.6	06/0220	42[m]	55			
42039	06/1950	988.1	06/0450	33	41			
45012	09/1500	1002.0	09/1000	35	43			
Cedar Key (CDRF1)	06/1000	987.6	06/1120	43[m]	59	1.7		
Duck (DUCN7)	08/2300	1011.9	08/1940	25[m]	34			
Dunkirk (DBLN6)	09/1000	1002.2	09/1100	36	47			
Folly Beach (FBIS1)	08/0700	1008.4	06/1400	33	39			
Fowey Rocks (FWYF1)	05/0600	996.1	04/2000	53[m]	66			
Keaton Beach (KTNF1)	06/1600	985.6	06/1740	35[m]	45			
Lake Worth (LKWF1)	05/0500	972.5	05/0700	54	73			
Long Key (LONF1)	05/0800	1000.7	05/0200	34	45	0.2	0.5	
Molasses Reef (MLRF1)	05/0800	988.4	05/0940	42[m]	59			
St. Augustine (SAUF1)	05/2200	999.0	05/2200	56	71			
Sand Key (SANF1)	05/1000	1002.7	05/1840	37[m]	55			
Settlement Point (SPGF1)	04/1600	963.2	04/2320	73[m]	96			
Sombrero Key (SMKF1)	05/0800	1002.6	05/1740	46[m]	81		0.7	
Tyndall Tower (SGOF1)	06/1600	992.2	06/0450	48[m]	58			

[a] Data/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for C-MAN and land-based ASOS reports are 2 min; buoy averaging periods are 8 min.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above National Geodetic Vertical Datum (1929 mean sea level).
[e] National Interagency Fire Center Remote Automated Weather Station.
[f] National Ocean Service; 6-min average wind.
[g] Record incomplete due to instrument failure.
[h] Obtained from Weather Underground Web site (http://www.weatherunderground.com/weatherstation/index.asp).
[i] Florida Costal Monitoring Program (FCMP).
[j] St. John's River Water Management District.
[k] NASA towers are at the Kennedy Space Center and Cape Canaveral Air Force Station; elevation 54 ft.; all tower records are incomplete.
[l] Fifteen-minute average wind.
[m] Ten-minute average wind.

(Fig. 6). The maximum reported rainfall was 459 mm at Linville Falls, North Carolina, part of a swath of rains in excess of 250 mm along the Appalachian Mountains in western North Carolina and northeastern Georgia. Rainfall in excess of 250 mm also occurred over large portions of the central and northern Florida peninsula and southeastern Georgia, with a storm total of 402 mm at High Springs, Florida. Storm-total rainfalls of 125–250 mm were common elsewhere along Frances' track as a tropical cyclone, with reports of 75–150 mm along the extratropical portion of the track.

A total of 101 tornadoes were reported in association with Frances: 23 in Florida, 7 in Georgia, 45 in South Carolina, 11 in North Carolina, and 15 in Virginia.

3) Casualty and damage statistics

Frances is directly responsible for eight deaths: five in Florida, and one each in Georgia, Ohio, and the Bahamas. Of the U.S. deaths, three are attributed to wind, one to storm surge, one to freshwater floods, one to a tornado, and one to lightning.

Damage was extensive from Palm Beach County northward to Brevard County and inland along the track of Frances. Insured damage in the United States is estimated to be near $4.43 billion, of which $4.11 billion occurred in Florida. Total U.S. damage is estimated to be $8.9 billion. Extensive property damage also occurred in the central and northwestern Bahamas.

g. Hurricane Gaston: 27 August–1 September

Gaston was a category 1 hurricane that made landfall along the central South Carolina coast. After moving inland, Gaston produced heavy rainfall across portions of the Carolinas and Virginia. Flooding in the Richmond, Virginia, metropolitan area resulted in eight deaths.

1) Synoptic history

The genesis of Gaston can be traced to a cold front that moved off the coast of the Carolinas into the Atlantic on 22 August, and drifted southward the following day before stalling on 24 August. Surface observations indicate that a broad low formed along the weakening front on 25 August. Thunderstorm activity associated with the low remained sporadic and disorganized until late on 26 August, when the convective activity began to increase and acquire a more banded structure. Early morning visible and microwave satellite images on 27 August suggest that the low had developed into the seventh tropical depression of the season by 1200 UTC that day, about 115 n mi east-southeast of Charleston, South Carolina. It is of note that the frontal zone from which Gaston formed also initiated the development of Tropical Storm Hermine two days later.

Steering currents were weak initially and the depression drifted slowly southward. Convective banding continued to increase on 27 August and the depression slowly strengthened, becoming a tropical storm early the next day as it drifted westward about 130 n mi southeast of Charleston. Strengthening continued on 28 August, and the first reconnaissance aircraft to reach the cyclone found maximum flight-level winds of 59 kt shortly after 1800 UTC.

Early on 29 August steering currents became better defined, with the development of a mid- to upper-level ridge northeast of Gaston and the approach of a midlatitude trough over the Appalachians. Gaston began moving northwestward toward the South Carolina coast, and the forward motion of the cyclone increased from about 3 to 7 kt. Radar and satellite imagery showed that Gaston continued to get better organized as it approached the coast. Doppler radar observations indicate that Gaston reached hurricane strength just before it made landfall near Awendaw, South Carolina, between Charleston and McClellanville, around 1400 UTC 29 August, with maximum sustained winds estimated near 65 kt. The tropical cyclone then steadily weakened while moving northward across northeastern South Carolina.

At 0000 UTC 30 August, Gaston weakened to a tropical depression over northeastern South Carolina. Gaston then turned north-northeastward ahead of the trough moving over the eastern United States and the cyclone crossed eastern North Carolina and southeastern Virginia during the day. Data from the Chesapeake Light C-MAN site and a ship near the mouth of Chesapeake Bay indicated that Gaston had regained tropical storm strength by 0000 UTC 31 August, while the center was still inland near Yorktown, Virginia. Tropical-storm-force winds at this time were confined to a small area over water southeast of the center, and the primary impact of Gaston in Virginia was flooding produced by 150–300-mm rains that occurred over about an 8-h period.

The center of Gaston moved across the southern portion of Chesapeake Bay and crossed the Delmarva Peninsula shortly before 0600 UTC 31 August. The tropical cyclone then accelerated northeastward, passing about 60 n mi south of Nantucket Island, Massachusetts later that day. Gaston strengthened slightly as it continued to accelerate to the east-northeast, before becoming ex-

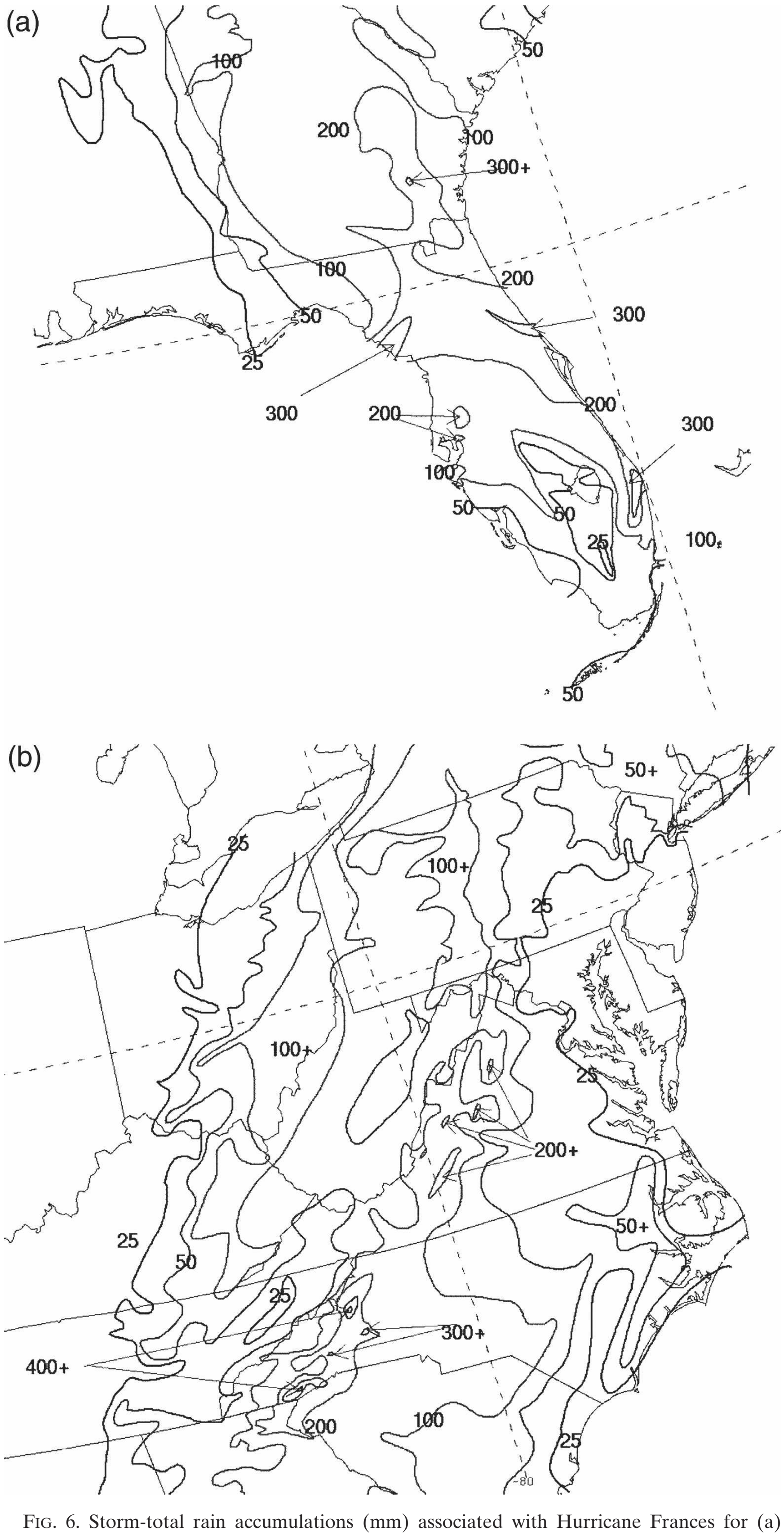

FIG. 6. Storm-total rain accumulations (mm) associated with Hurricane Frances for (a) Florida and (b) the Mid-Atlantic states. Analysis provided by the NWS/Hydrometeorological Prediction Center.

tratropical south of the Canadian Maritimes at 1200 UTC 1 September. The extratropical remnants of Gaston were finally absorbed by a larger extratropical system on 3 September about 750 n mi south-southeast of Reykjavik, Iceland.

2) Meteorological statistics

Gaston was strengthening up until landfall, and was operationally assessed to be a strong tropical storm when it crossed the coast. However, a poststorm analysis of Doppler velocity data from the Charleston and Wilmington NWS radars showed that Gaston had winds aloft that supported reclassification to a hurricane. The Wilmington radar observed a roughly 3 n mi wide patch of average winds of 71 kt or more in the southeast quadrant between 1130 and 1200 UTC on 29 August. These winds were observed at an altitude of about 11 000 ft, and would correspond to roughly 64 kt at the surface using standard adjustment factors. The Charleston radar observed a similarly sized area in the northwest quadrant that also supported 64-kt surface winds. Neither radar had a good look at the northeast quadrant, where the strongest winds would have been expected. Based on these observations, Gaston was posthumously upgraded to a hurricane.

There were no land-based observations of hurricane force surface winds, although the landfall area was not particularly well sampled. A gust to 71 kt was recorded by a Carolinas Coastal Ocean Observing and Prediction System station just south of Capers Island, South Carolina, with a minimum pressure of 985.1 mb (Table 6). A gust to 70 kt was recorded by a storm chaser on the nearby Isle of Palms. The highest surge reported was over 1.2 m inside of Bulls Bay.

In South Carolina, rainfall was heaviest in a swath from Berkeley and western Williamsburg Counties through Florence and Darlington Counties. Kingstree reported 267 mm of rainfall, which produced urban flooding of up to 1.5 m. Radar data suggest that up to 380 mm may have fallen in some areas. Flash floods occurred in Lake City. One F1 tornado was reported in Marlboro County. Rains tapered off somewhat as Gaston moved through North Carolina, with accumulations there being generally less than 150 mm. Two tornadoes were confirmed in North Carolina on 29 August: an F0 in Scotland County and an unrated tornado in Hoke County.

Gaston produced very heavy rains and flash floods as it moved through southeastern Virginia on 30 August, with the most severe conditions in the Richmond metropolitan area. Two locations in Richmond reported over 300 mm of rain. Most of this rain occurred during an 8-h period late on 30 August. The cyclone also produced a dozen F0 tornadoes in eastern Virginia.

3) Casualty and damage statistics

Flash floods in the Richmond area directly resulted in eight fatalities. Five of these were from motorists attempting to drive through flooded roadways, including one who drove around a barricade to do so. Three individuals were killed during rescue attempts.

Scattered freshwater flooding occurred in South Carolina. In Berkeley County, 20 structures were severely damaged or destroyed, and dozens of other structures suffered minor flooding damage. Winds associated with Gaston caused minor damage to roughly 3000 structures in Charleston, Berkeley, and Dorchester Counties.

In Virginia, Gaston washed out roads and bridges. Damage was concentrated in Chesterfield, Dinwiddie, Hanover, Henrico, and Prince George Counties. About 350 homes and 230 businesses were either damaged or destroyed. Tornadoes downed trees and damaged roofs.

Insured losses associated with Gaston are reported to be $20 million in South Carolina, $15 million in North Carolina, and $30 million in Virginia. Total damage is estimated to be near $130 million.

h. Tropical Storm Hermine: 27–31 August

An area of showers detached from a decaying frontal zone in the western Atlantic on 26 August, and the next day a tropical depression formed from the disturbance about 200 n mi south of Bermuda. The intensity of the convection fluctuated during the following couple of days as the depression moved toward the west-northwest, but the overall organization of the system increased. The cyclone became a tropical storm on 29 August, and reached its peak intensity of 50 kt the next day. Hermine moved northward and gradually weakened under strong northerly shear caused by the upper-level outflow of Hurricane Gaston. Hermine reached the southern coast of Massachusetts near New Bedford as a minimal tropical storm at 0600 UTC 31 August, and became extratropical shortly thereafter. The impact of Hermine was quite limited; the cyclone brought wind gusts to tropical storm force over eastern Massachusetts, and rainfall amounts were generally less than 10–15 mm. There were no reports of damage or casualties.

i. Hurricane Ivan: 2–24 September

Ivan, one of the strongest tropical cyclones on record in the Atlantic basin, was a long-lived Cape Verde hurricane that reached category 5 strength on three occasions. Ivan carved a path of destruction through the Caribbean, striking Grenada, Jamaica, the Cayman Islands, and Cuba as a major hurricane. Ivan also made landfall as a major hurricane in the United States, causing over $14 billion in damage.

1) SYNOPTIC HISTORY

Ivan developed from a large tropical wave that moved across the west coast of Africa on 31 August. Already accompanied by a closed surface circulation and an impressive upper-level outflow pattern, the precocious wave began to develop banded convection early on 1 September, and Dvorak satellite classifications were initiated later that day. Convective activity increased and it is estimated that a tropical depression formed around 1800 UTC 2 September about 365 n mi south-southwest of the Cape Verde Islands. The depression reached storm intensity on 3 September and continued to strengthen. By 0600 UTC 5 September, Ivan had become a hurricane about 1000 n mi east of the southern Windward Islands. Within 18 h, Ivan's estimated minimum pressure had fallen by roughly 40 mb, its winds had increased from 65 to 115 kt, and Ivan had become the southernmost storm on record to reach major hurricane status, at 10.2°N. Ivan's eyewall convection then eroded and the hurricane's winds decreased to about 90 kt over the next 24 h, but Ivan had regained category 3 strength by the time the center passed about 6 n mi south of Grenada near 2130 UTC 7 September. This track took the northern eyewall of the major hurricane directly over the island.

After passing Grenada and entering the southeastern Caribbean Sea, Ivan strengthened again and became a category 5 hurricane south of the Dominican Republic, its winds reaching 140 kt at 0600 UTC 9 September. Ivan's forward motion slowed while the extremely dangerous hurricane moved west-northwestward across the central Caribbean Sea toward Jamaica. Ivan weakened back to a category 4 hurricane late on 9 September, but abruptly reintensified late on 10 September as it neared the island. Although hit hard, Jamaica was spared a direct category 5 strike by an eyewall replacement cycle that halted development, coupled with a last-minute turn to the west on 11 September that kept the center of Ivan at least 20 n mi offshore.

As Ivan moved west-northwestward away from Jamaica it reacquired category 5 status, reaching its peak intensity at 0000 UTC 12 September, with maximum winds of 145 kt and a minimum pressure of 910 mb (Fig. 7). Although Ivan was weakening while the center passed south of Grand Cayman on 12 September, the hurricane still brought sustained winds of category 4 strength onshore, producing a storm surge that overswept nearly all of the island.

On 13 September, Ivan approached a weakness in the subtropical ridge over the central Gulf of Mexico and turned northwestward. As Ivan moved over the deep reservoir of warm water in the northwestern Caribbean Sea, the hurricane's upper-tropospheric outflow was enhanced by south-southwesterly upper-level flow ahead of an approaching trough. This combination of favorable conditions may have helped Ivan maintain category 5 strength for 30 h, an unusually long period. Ivan's eastern eyewall clipped the sparsely populated extreme western tip of Cuba near 0100 UTC 14 September as its center passed through the Yucatan Channel.

Shortly after emerging over the southern Gulf of Mexico early on 14 September, Ivan turned north-northwestward and then northward. Gradual weakening occurred as moderate southwesterly flow ahead of a large mid- to upper-level trough over the central United States caused vertical shear to increase across the hurricane. As Ivan neared the northern U.S. Gulf Coast, the upper-level wind flow ahead of the trough increased and became more westerly, which increased the vertical shear further and advected dry air into the hurricane's core. Despite the unfavorable environment, Ivan weakened only slowly and made landfall at approximately 0650 UTC 16 September, just west of Gulf Shores, Alabama. The strongest winds at landfall, 105 kt (category 3), occurred over a narrow area near the Alabama–Florida border on the east side of Ivan's 40–50 n mi wide eye.

After Ivan moved across the barrier islands of Alabama, the hurricane turned north-northeastward across eastern Mobile Bay, and later weakened to a tropical storm over central Alabama and to a depression over northeastern Alabama. Ivan moved northeastward for the next 36 h, producing gusty winds, heavy rains, and tornadoes over the southeastern United States before the circulation merged with a frontal system and became extratropical over the Delmarva Peninsula around 1800 UTC 18 September.

During the extratropical transition, the upper portions of Ivan's circulation were sheared off to the northeast and separated from the surface low. A distinct remnant low-level feature, however, remained identifiable in surface and rawinsonde data even after Ivan merged with the frontal system. Over the next 3 days, the remnant surface low separated from the front, moved south and southwestward in the western Atlantic, and eventually crossed the Florida peninsula on

TABLE 6. Selected surface observations for Hurricane Gaston, 27 Aug–1 Sep.

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)
South Carolina								
Charleston (KCHS)	29/1330	999	29/1457	37	48			102.9
Florence (KFLO)	30/0058	998.6	29/2300	30	41			110.7
North Myrtle Beach (KCRE)	29/2234	1004.7	30/0040	31	39			42.9
Myrtle Beach (KMYR)			29/1945	35	45			11.9
Myrtle Beach (Springmaid Pier NOS)	29/2124	1002.6	29/2200	39[e]	50			
South Carolina (unofficial)								
South Capers Island	29/1254	985.1	29/1124	46[f]	71	0.6		
Downtown Charleston			29/0818	28[g]	42			117.6
Pineville			29/1820	37[g]	51			127.3
Isle of Palms	29/1350	987	29/1239		70			
Georgetown			29/1820		43			
Jamestown								179.1
Fort Moultrie								128.3
Charleston Harbor						0.3	2.1[h]	
Bulls Bay Charleston County						~1.4		
Loris								72.9
Outland Georgetown County								99.3
Lake City								163.8
Hartsville								71.4
Darlington Airport								152.4
Darlington								141.0
McColl								148.3
Mullins								56.9
Pee Dee								86.6
Dillon								113.3
Cades								249.7
Kingstree								266.7
Georgetown								96.5
Andrews								134.6
North Carolina								
Lumberton (LBT)	30/0641	1001.4	30/0326	27	35			85.6
Wrightsville Beach NOS Johnie Mercer Pier	29/2300	1008.8	30/0412	33[e]	38			
Sunset Beach Pier NOS	29/2200	1005.8	29/2100		36			
North Carolina (unofficial)								
Carolina Beach			30/0250		39			
Lumberton 3SE								85.3
Longwood								68.1
Fair Bluff								76.5
Red Springs								154.9
Virginia								
Richmond (RIC)								169.7
Wakefield								63.8
Chesapeake Bay Bridge Tunnel NOS			31/0142	37	45			
Kiptopeke NOS			31/0236	38	48			
Rappahannock Light NOS	31/0224	1000.9	31/0506	34	39			
Sewells Point NOS			31/0118	35	43			
Yorktown NOS	30/2342	1001.4	30/1900	32	42			
Virginia (unofficial)								
Ashland								269.5
Richmond (Math and Science Center)								312.4
Richmond (West End)								320.0
Richmond (Science Museum)								166.6

TABLE 6. (*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)
Richmond (St. Christopher's School)								162.6
Mechanicsville								271.8
Chester								157.5
Winterpock								144.5
Sandston								205.7
Buoys/C-MAN								
41004	29/0850	996						
44004	31/1500	1012.2	31/1700	33[g]	43			
44008	31/2000	1000.4	31/2200	31	42			
44009	31/0700	1003.3	31/0940	27[g]	34			
44011	01/0200	1001.4	01/0310	28[g]	38			
44014	30/2300	1009.7	31/0500	28	36			
44137	01/0820	1000.4	01/0920	30	43			
Navy Tower R8 (TYBG1)	29/0532	1004.3	29/0432	39	47			
Navy Tower R2 (SPAG1)	29/0800	1003						
Duck (DUCN7)	30/2100	1009.7	31/0100	29	40			
Folly Beach (FBIS1)	29/1200	998	29/1200	32[g]	44			
Chesapeake Light (CHL V2)	31/0200	1006	31/0150	44[g]	51			

[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] 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] Six-minute average.
[f] Two-minute average.
[g] Ten-minute average.
[h] Water height above mean lower low water.

21 September and emerged over the southeastern Gulf of Mexico that afternoon. As the remnant low moved westward across the warm water of the Gulf, showers and thunderstorms started developing and the low began to reacquire tropical characteristics. By 1800 UTC 22 September the system had become a tropical depression again over the central Gulf of Mexico, and 6 h later had regained tropical storm strength about 120 n mi south of the mouth of the Mississippi River. Ivan turned northwestward, weakened, and made its final landfall as a tropical depression in extreme southwestern Louisiana around 0200 UTC 24 September. Ivan dissipated later that morning about 20 n mi northwest of Beaumont, Texas.

2) METEOROLOGICAL STATISTICS

Ivan's track is notable in many respects. From initial genesis to final dissipation, Ivan existed in some form for 22.5 days and took a path over 5600 n mi long. The system's redevelopment into a tropical cyclone after becoming extratropical is almost unprecedented in the Atlantic record.[2] Ivan developed at an unusually low latitude, becoming one of only a dozen tropical cyclones to reach storm strength south of 10°N, and was the southernmost system on record to reach major hurricane status. Ivan spent 10 days as a major hurricane (although not consecutively), the longest period since the reconnaissance era began in 1944, and 8 consecutive days at category 4 or higher, also a record for that period. Ivan's minimum pressure of 910 mb has been surpassed only by five other previous Atlantic tropical cyclones: Gilbert (1988, 888 mb), the Labor Day Hur-

[2] Storm number 3 in 1899 is another example. There was considerable debate as to whether the second genesis in the Gulf of Mexico should be given a new name and counted as a separate tropical cyclone. The decision to rename the system Ivan was based on NWS policy that "within a basin, if the remnant of a tropical cyclone redevelops into a tropical cyclone, it is assigned its original number or name." Given the length of time that Ivan's low-level remnant lacked tropical characteristics, it would not be unreasonable to consider Ivan the Second as a distinct tropical cyclone.

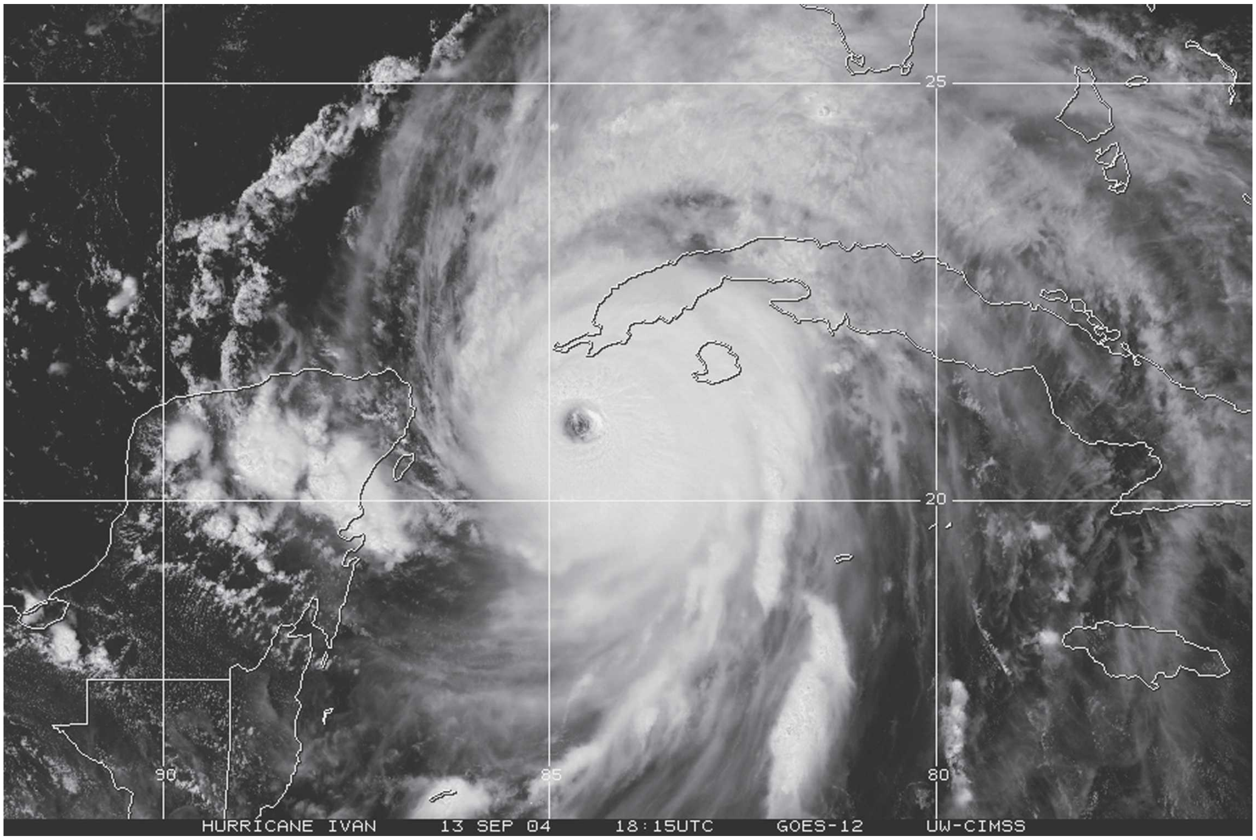

FIG. 7. *GOES-12* visible satellite image of Hurricane Ivan at 1815 UTC 13 Sep 2004, near the time of maximum intensity (image courtesy University of Wisconsin).

ricane (1935, 892 mb), Allen (1980, 899 mb), Camille (1969, 905 mb), and Mitch (1998, 905 mb).

A total of 112 reconnaissance fixes were made in Ivan: 95 by the AFRC and 17 by NOAA/AOC. In addition, the NOAA Gulfstream-IV jet aircraft made 12 synoptic surveillance flights around the periphery of the hurricane. Ivan's official maximum wind estimate of 145 kt is based on a flight-level (700 mb) reconnaissance observation of 161 kt at 1917 UTC 11 September, when Ivan was located about 45 n mi west-southwest of the western tip of Jamaica. The lowest aircraft-reported central pressure was 910 mb, measured at 0005 UTC 12 September and again at 2053 UTC 13 September.

Selected surface observations for Ivan are given in Table 7. The highest surface wind observation from Ivan occurred on Grand Cayman at 1345 UTC 12 September, where sustained winds of 130 kt and a gust to 149 kt were reported. The highest U.S. report was from a storm chaser near Gulf Shores, Alabama, who measured sustained 77-kt winds with a gust to 99 kt at 0602 UTC 16 September. The highest official wind report in the United States was 76 kt sustained with a gust to 93 kt at the Pensacola Naval Air Station, Florida, at 0629 UTC 16 September. The lowest (unofficial) pressure observed in the United States was a storm-chaser report of 943.1 mb in Fairhope, Alabama.

Ivan's estimated intensity at its first U.S. landfall is 105 kt. This estimate is based on a reconnaissance observation of 120 kt at 700 mb just south of Gulf Shores, Alabama, at 0724 UTC 16 September, on National Weather Service Weather Surveillance Radar-1988 Doppler (WSR-88D) observations of 120–122-kt inbound velocities at an altitude of 1800 m over a period of several hours, and on surface measurements from the SFMR instrument on the NOAA P-3 aircraft. The SFMR data were evaluated by the NOAA Hurricane Research Division (F. D. Marks Jr. 2004, personal communication; http://www.aoml.noaa.gov/hrd/project2005/SFMR.pdf), which concluded that the SFMR had measured surface winds of 99 kt at 0135 UTC 16 September about 58 n mi south of the Alabama coast. Ivan's strongest winds over land most likely occurred over Perdido Key, to the west of the Pensacola Naval Air Station and to the east of the FCMP portable wind tower at Gulf Shores, Alabama.

Rainfall exceeding 250 mm occurred on several of

TABLE 7. Selected surface observations for Hurricane Ivan, 2–24 Sep 2004.

Location	Minimum sea level pressure		Maximum surface wind speed			Storm surge (m)[c]	Strom tide (m)[d]	Total rain (mm)
	Date/time (UTC)	Pressure (mb)	Date/time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Windward Islands								
Point Salines, Grenada (TGPY)			07/2100	64	101			
Windward Islands (unofficial)								
Calivigny Island, Grenada	07/1955	969.0	07/1955	80	100			
4SE Princkly, Grenada			07/2230	70				
St. Georges Harbour, Grenada	07/1950	978.0	07/2230	60				
Tobago (HAM Radio 9 Y4PDE)								
Trinidad (HAM radio VE7KSN)	07/2159	980.0						
Cayman Islands								
Cayman Brac	12/0300	997.0	12/0200	44	58			125.0
Grand Cayman	12/1345	970.0	12/1500	130	149	3.0		308.4
Jamaica								
Kingston	11/0129	991.5	11/0217	55[e]		1–2		418.3
Ritchies								720.8
Jamaica (unofficial)								
2W Kingston			10/2300	39	59			
Kingston			11/0055		57			
Cuba								
Cabo de San Antonio			14/0050[f]	96	104			
Cuba–Francia (78309)	14/0000	1001.6	14/0043	45	56			258.1
La Fe (78321)	13/1850	1001.0	13/1248	51	64			159.0
La Palma (78316)	14/0100	1000.3	14/0620	49	61			112.5
Isabel Rubio (78313)	14/0200	990.1	14/0200	61	76			338.6
Nueva Gerona (Isle of Youth)	13/1800	1000.1	13/1457	55	69			143.8
Pinar del Rio (78315)	13/2310	997.7	14/0140	54	67			195.3
Pinar del Rio (south coast)						3.7		
Paso Real de San Diego (78317)	13/2340	1001.5	14/0140	42	52			141.0
Punta del Este (78324)	13/2200	1000.7	14/0030	49	61			120.7
San Juan y Martinez (78314)	14/0100	996.0	13/2340	47	59			144.5
Santa Lucia (78312)	14/0200	994.7	14/0220	61	76			152.4
Mexico (unofficial)								
Cancun			13/0225	44				
Isla Mujeres			13/2200	38				
Alabama								
Alabaster (KEET)	17/0053	991.7						152.4
Alberta								174.0
Alexander City (KALX)			16/1500		36			
Anniston (ANNA1)								194.1
Anniston (KANB)	17/0053	991.5						
Ariton Co-op (ARTA1)								135.1
Baldwin County						4.6		
Bellwood Co-op (BELA1)								139.2
Bessie								147.6
Birmingham (KBHM)	17/0053	989.6	16/1653		42			249.2
Blakely Co-op (BLKG1)								165.1
Blount Springs								134.4
Brookley/Mobile (KBFM)	16/0656	956.0						
Coden								160.0
Cullman (K3A1)			16/1740		39			
Daleville Co-op (DALA1)								147.8
Daphne								190.5
Dothan (KDHN)	16/0752	1000.6	16/1900	38	47			150.9
Elba Co-op (EBBA1)								139.2
Evergreen (EVRA1)								191.8

TABLE 7. (*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]	Strom tide (m)[d]	Total rain (mm)
Flat Rock (FLRA1)								204.2
Florence (C0168)			17/0050		37			
Fort Payne 6NE (LRWA1)								185.4
Fort Payne (K4A9)			16/1920		45			
Gadsden (KGAD)			16/1735		37			
Geneva Co-op (GVAA1)								208.3
Helena								119.9
Huntsville (KHSV)	16/2353	994.3	16/2153		40			
Huntsville (KMDQ)			16/2242		35			
Jackson Shoals								102.9
Ketona								246.1
Lauderdale (RLDM6)			16/1113		47			
Lower Bryant Landing NOS						1.0		
Manchester								110.5
Maxwell AFB (KMXF)	16/1755	989.9	16/1257	31	57			248.4
Millers Ferry (MRFA1)								296.2
Mobile (KMOB)	16/0725	964.4	16/0644	51	65			141.2
Mobile 2S								251.5
Mobile 3S								160.0
Mobile 7S								165.9
Mobile 10S								203.2
Mobile County						2.7		
Montgomery (KMGM)	16/1753	989.5	16/1353	32	50			
Muscle Shoals (KMSL)	16/2253	998.7	16/2110		40			
Newton Co-op (NEWA1)								138.9
Ozark/Fort Rucker (KOZR)	16/1055	999.8	16/0955		38			154.9
Robertsdale								237.5
Selma (SELA1)								225.3
Silverhill (3S)								258.1
Spanish Fort			16/0800		51			203.2
Talladega								142.2
Tannehill								247.9
Troy (KTOI)	16/1755	994.7	16/1128		37			
Trussville (TRSA1)								227.8
Tuscaloosa (KTCL)	16/1353	996.7	16/1453		43			
Valley Head (VYHA1)								210.1
Wing 6NE (OPNA1)			16/1022		58			
Wedowee								132.1
Alabama (unofficial)								
Andalusia								253.0
Fairhope			16/0418		63			
Fairhope (storm chaser)	16/	943.1						
Fairhope FCMP Tower 2 (30.48°N, 87.88°W)			16/0644	59	77			
Grand Bay			16/0517		62			
Gulf Shores Airport Doppler on Wheels (DOW3)			16/	73	95			
Gulf Shores (Texas Tech University)			16/0615	70	89			
Gulf Shores (storm chaser M. Sudduth)	16/0647	947.2	16/0602[e]	77	99			
Mobile (Wallace Tunnel)			16/0940		51			
Mobile (WKRG-TV)			16/0604		64			
Semmes	16/0830	967.5	16/0500	49	51			127.0
Mobile Bay (USNS *Fisher*)	16/0830	957.0						
USS *Alabama*			16/0635[e]		91			
Ram Powell VK-956 Oil Rig (29.05°N, 88.10°W)	15/2256[f]	952.6	15/2256[f]	102[g]	135[g]			

TABLE 7. (*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]	Strom tide (m)[d]	Total rain (mm)
Wolf Bay/Orange Beach Sailboat *Odalisque*			16/0600[f]		126[h]			
Wolf Field Airport			16/0515	66	87			
Florida								
Apalachicola (KAAF)								104.4
Baker (BAKF1)								264.4
Bay County						3.0		
Big Pine Key								53.8
Bristol Co-op (BRLF1)								177.8
Bruce Co-op (BRUF1)								179.1
Chipley Co-op (CHPF1)								137.7
Crestview (CRVF1)								195.1
Dixie County						1.2		
Eglin AFB (KVPS)	16/0755	991.6	16/0755	46	70			188.7
Escambia County						4.6		
Franklin County						1.5		
Gulf County (St. Joseph State Park)						1.8		
Hillsborough County (Hillsborough Bay)						1.1		
Huntsville (KHSV)								94.7
Jefferson County						1.2		
Key West (KEYW)			14/0903	36	46	0.3		28.2
Levy County (Cedar Key)						0.6		
Lowry Mill Co-op (LOWA1)								186.2
Marianna Co-op (MALF1)								134.1
Mayport NAS (KNRB)			21/0355		34			
Milligan (MLGF1)								287.3
Mossy Head Co-op (MHDF1)								235.2
Munson								165.1
Nettles Island (NETF1)								193.5
Niceville								166.4
Okaloosa County						2.7		
Panama City (KPFN)	16/0853	999.9	16/1700	30	60			
Pensacola (KPNS)	16/0645	970.2	16/0650	67	87			
Pensacola NAS (KNPA)	16/0656	965.8	16/0629	76	93			203.2
Pensacola (WEAR-TV)								401.1
Perry (K40J)			16/1749		41			
Saint Augustine (KSGJ)			21/0300		36			
Santa Rosa County						4.6		
Seminole 5NE								205.7
Tallahassee (KTLH)			16/1605	33	47			
Taylor County						1.2		
Walton County						3.0		
Wakulla County						1.5		
Florida (unofficial)								
Carabelle Beach	15/2216	999.0	15/2216	28	37			
Crestview								213.4
Cudjoe Key			13/1348		36			
Destin			16/0652	60	77			
Eglin AFB 5S Harold	16/0850	981.4						
Eglin 10S Harold	16/0740	982.1	16/0710		78			145.3
Eglin 10N Mary Esther	16/0820	986.8	16/0730		75			
Eglin 5NE Semmole	16/0920	992.1	16/0940		75			205.7
Eglin 5SW Mossy Head	16/0900	991.0						
Eglin 8SW Mossy Head			16/0710		60			

TABLE 7. (*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]	Strom tide (m)[d]	Total rain (mm)
Eglin 10S Mossy Head	16/0900	994.2						226.6
Eglin 2SW Mary Esther			16/0850		103[i]			
Fort Walton								153.9
Molino Fire Department			16/0855		70			
Pensacola FCMP Tower 1 (30.48°N, 87.19°W)			16/0649	69	92			
Pensacola Police Department			16/0644		108[h]			342.9
St. George Island	16/0150	1005	16/0150	39				
West Pensacola			16/		84			
Georgia								
Chickamauga (FTOG1)								196.9
Clayton 10W (TCLG1)								199.9
Columbus (KCSG)	16/2151	997.1	16/2227		39			
Ellijay 7NW (MTNG1)								183.9
Helen (HELG1)								217.7
Helen 7N (BRSG1)			17/0306		61			
Hurst 3SE (HSTG1)								213.9
Lafayette 5SW (LFYG1)								184.9
Mountain City 2N (MTCG1)								180.3
Nacoochee (NACG1)								233.7
Pine Mountain (PIMG1)								198.1
Preston Co-op (PRSG1)								141.5
Tallula Falls (TLUG1)								200.2
Titus (TUSG1)								235.5
Louisiana								
Bootheville			16/0000		52			26.7
Calcasieu Pass—East Jetty						0.5		
Cameron Prairie NWR								105.2
Cocodrie			16/0000		36			
Grand Isle—East Point						0.5		
Lake Charles (KLCH)	23/2346	1012.5	24/0217	23	30			29.5
Lake Pontchartrain—midlake			16/0330	35	46			
New Orleans (KNEW)	16/0125	994.2	16/0206	41	48			2.0
New Orleans (KMSY)	16/0644	998.0	15/2138	33	40			
Pointe a la Hache—northeast Bay Gardene			16/0400		60			
Rockefeller NWR								81.8
Slidell (KASD)	16/0147	994.2	16/0011	32	37			6.6
SW Pass NOS						0.9		
Mississippi								
Biloxi Bay NOS						1.0		
Biloxi Harbor—Pointe Cadet			16/0245	47	68			
Columbus AFB (KCBM)	16/1955	995.8	16/1855		35			
Gholson 8W (GHLM6)								135.9
Gulfport (KGPT)[e]	16/0703	983.7	16/0059	40	53			43.2
Keesler AFB (KBIX)	16/0655	982.9	16/0644	42	62			83.3
Meridian NAS (KNMM)	16/1555	992.0	16/1255	30	51			
Orange Grove—Interstate 10			16/0715		46			
Pascagoula 3NNE								144.8
Pascagoula (KPQL)[e]	16/0536	975.6	15/2349	37	51			29.2
Pass Christian—U.S. Coast Guard Merril Shell Bank Lighthouse			16/0500		64			
Van Cleave (BCVM6)								94.7
Waveland NOS	16/0636	989.4	16/0242	34	49	1.0		

Table 7. (*Continued*)

	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]	Strom tide (m)[d]	Total rain (mm)
Mississippi (unofficial)								
Pascagoula/Jackson County EOC			16/0600		76			159.8
Waveland Hancock County EOC			16/0430		53			
New Hampshire								
Jaffrey (AFN)								185.4
New Jersey								
Columbia (CMBN4)								139.7
New York								
Deposit (DEPN6)								136.4
Fishs Eddy (FSHN6)								137.2
Stuyvesant 5N (STYN6)								129.8
Windham (WDMN6)								138.4
North Carolina								
Black Mountain (MMTN7)								229.9
Boone (KTNB)			17/0801		45			
Cruso								431.8
Canton 10SSW (SNBN7)								226.6
Daniel Ridge (DNRN7)								209.6
Hawk (HAKN7)								180.8
Highlands (HILN7)								207.3
Highlands (TVA)								300.5
Hogback (IHBN7)								226.6
Jonas Ridge (JSRN7)								227.3
Laurel Springs (LRLN7)			17/0810		51[e]			
Plumtree (PLMN7)								205.2
Rich Mountain (RCMN7)								205.2
Rosman 6E (CFFN7)								198.9
Spruce Pine 3SE (SPPN7)								182.9
Yancey (YNCN7)								190.5
Ohio								
Albany (ABNO1)								216.7
Pennsylvania								
Blakeslee (TBYP1)								208.3
Scrub Oak (SCBP1)								211.3
Tennessee								
McDonald								280.2
Sweetwater (SWET1)								228.3
Whitwell 7SE (PCFT1)			16/2106		51			
Texas								
Beckville (BEKT2)								199.6
Eagle Point—Galveston Bay						0.5		
Galveston Pier 21						0.5		
Matagorda Island (MIRT2)			24/0512		47			
Sabine Pass North						0.4		
Steinhagen Lake (TBLT2)								179.6
Virginia								
Big Meadows (BGMV2)								145.3
Strasburg (STGV2)								139.7
TS121 RAWS (37.9°N, 81.9°W)			17/2214		34			
West Virginia								
Gallipois Dam (GALW2)								150.9
Moundsville (MOUW2)								195.1

TABLE 7. (*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]	Strom tide (m)[d]	Total rain (mm)
C-MAN/Buoys								
SW Pass (BURL1)	15/2300	983.6	15/2310	72	87			
SW Pass (BURL1)	23/0500	1013.8	23/0300	35				
Chesapeake Light (CHLV2)	18/0400	1001.8	18/2230	39	48			
Dauphin Island (DPIA1)	16/0705	952.7	16/0405	63	89			
Duck (DUCN7)	19/0300	1011.4	19/0400	38	47			
Grand Isle (GDIL1)	16/0000	994.2	15/2310	46	61			
Galveston Pier (GLPT2)	23/2200	1012.2	22/0900		32	0.5		
Isle Dernieres (ILDL1)	23/0900	1013.7	23/0900	35				
Sand Key (SANF1)	13/1200	1010.9	13/1200	36	42			
Tyndall AFB C (SGOF1)	15/2100	1005.2	15/2200	49	62			
Ship Island Pass (SIPM6)[e]	15/2300	997.4	15/2300	38				
South Timbalier Block 52 (SPLL1)	16/0200	999.6	16/0200	42				
S. Timbalier Block 52 (SPLL1)	23/0700	1011.9	23/0700	36				
Thomas Point (TPLM2)			18/1740	34	41			
U.S. Navy Tower 8 (TYBG1)	21/0726	1016.6	21/0726	35				
42001	15/1050	995.2	15/0950	37				
42003	15/0750	993.5	15/0230	55	72			
42007[e]	16/0350	976.0	16/0350	49	68			
42036			15/2020	34	49			
42039	15/2350	995.1	15/2150	45	62			
42040	16/0150	955.3	15/2300	55	73			
42041	15/1950	997.6	15/1950	35				
44017	18/1650	1006.9	18/1650	35				

[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] Storm surge is water height above normal astronomical tide level.
[d] Storm tide water height above National Geodetic Vertical Datum (1929 mean sea level).
[e] Record incomplete due to instrument failure.
[f] Estimated.
[g] Elevation 122 m.
[h] Elevation 22 m.
[i] Elevation 61 m.

the Caribbean islands and caused extensive freshwater flooding and/or mud slides. Rainfall totals include 721 mm from Jamaica, 411 mm from Tobago, 339 mm from western Cuba, and 308 mm from Grand Cayman. In the United States, rainfall totals exceeded 200 mm in numerous locations from Alabama and the Florida panhandle northeastward across the eastern Tennessee Valley. Highest reported totals include 401 mm in Pensacola and 432 mm in Cruso, North Carolina. Widespread flooding resulted from these rains, which fell on ground already saturated by Tropical Storm Bonnie and Hurricane Frances.

Nearly every location on Grand Cayman became submerged at some point during Ivan's passage, a consequence of a 3-m storm surge topped by large battering waves. A storm surge of 3.0–4.6 m occurred from Destin, Florida, to Mobile Bay. Storm surge values of 1.8–2.7 m were observed from Destin eastward to St. Marks in the Florida Big Bend region. The Tampa Bay area, well away from the hurricane's strong winds, experienced a 1.0-m surge.

Ivan, responsible for an outbreak of 117 tornadoes over the period 15–17 September, is among the top tornado-producing cyclones on record. Thirty-seven of these occurred in Virginia, 25 in Georgia, 18 in Florida, 9 in Pennsylvania, 8 in Alabama, 7 in South Carolina, 6 in Maryland, 4 in North Carolina, and 3 in West Virginia. At least two of these tornadoes were of F2 intensity.

3) CASUALTY AND DAMAGE STATISTICS

The direct death toll from Ivan stands at 92: 39 in Grenada, 25 in United States, 17 in Jamaica, 4 in Dominican Republic, 3 in Venezuela, 2 in Cayman Islands, and 1 each in Tobago and Barbados. The U.S. deaths occurred in Florida (14), North Carolina (8), Georgia (2), and Mississippi (1). The breakdown of U.S. deaths by hazard is as follows: tornado (7), storm surge (5), freshwater floods (4), mud slides (4), wind (3), and surf (2).

Damage was extensive throughout the Caribbean. In Barbados, over 175 homes were completely destroyed. In Grenada, Ivan became the worst hurricane disaster since Janet in 1955, with more than 14 000 homes damaged or destroyed, and at least 80% of the nutmeg trees destroyed. At least 47 000 homes were damaged in Jamaica, and most of the island's utilities were damaged. Ninety-five percent of the homes and other structures in the Cayman Islands were damaged or destroyed. In Cuba, roofs were torn off homes in extreme western Pinar Del Rio Province, and flooding damaged houses, as well as fishing and farm installations.

Ivan is the third most costly hurricane disaster in the United States, with damage estimated to be near $14.2 billion. The AISG reports an insured loss estimated at $7.11 billion. Damage was most severe in the Pensacola area, where Ivan was the most destructive hurricane in more than 100 yr. Portions of the Interstate 10 bridge system over Pensacola Bay were severely damaged from surge and wave action; about a quarter-mile of the bridge collapsed into the bay. The U.S. Highway 90 causeway across the northern part of the bay was also heavily damaged. To the southwest of Pensacola, Perdido Key bore the brunt of Ivan's fury and was essentially leveled. In the Alabama and Florida panhandle areas, widespread overwash occurred along much of the coastal highway system. In addition, extensive beach erosion caused severe damage to or the destruction of numerous beachfront homes and condominium buildings. Some buildings collapsed due to scouring of the sand from underneath the foundations by wave action.

Ivan's effects were far-reaching. Ivan left more than 1.8 million people without power across nine states. The Minerals Management Service of the Department of the Interior reported that the normal daily flow of 475 000 barrels of oil and 1.8 billion cubic feet of natural gas from the Gulf of Mexico was disrupted for more than 4 weeks. A total of 12 large pipelines and 6 drilling platforms sustained major damage; another 7 platforms were completely destroyed. Millions of acres of woodlands and forests were destroyed.

Some damage estimates outside the United States were provided by the Caribbean Development Bank. These include $1.85 billion in the Cayman Islands, $815 million in Grenada, and $360 million in Jamaica.

j. Hurricane Jeanne: 13–28 September

Jeanne produced catastrophic flash floods in Haiti that killed over 3000 people, and later struck the east coast of Florida as a major hurricane. Jeanne was the fourth hurricane to hit the state of Florida in 2004, and the second to strike Florida's Treasure Coast in a 3-week span.

1) SYNOPTIC HISTORY

Jeanne formed from a tropical wave that moved from Africa to the eastern tropical Atlantic Ocean on 7 September. There was little development until the wave neared the Leeward Islands, where a tropical depression formed on 13 September about 85 n mi east-southeast of Guadeloupe. The cyclone moved slowly to the west-northwest in the flow to the south of the Atlantic subtropical ridge, becoming a tropical storm the next day while still affecting the islands. Continuing west-northwestward, Jeanne moved slowly over the Virgin Islands as it strengthened, making landfall on 15 September in southeastern Puerto Rico with 60-kt winds. After crossing Puerto Rico and entering the Mona Passage, Jeanne reached hurricane strength before moving inland again at the eastern tip of the Dominican Republic at 1100 UTC 16 September.

Jeanne spent nearly 36 h over the rough terrain of Hispaniola, generating torrential rainfall before emerging into the Atlantic north of the island as a poorly organized depression. Late on 18 September, Jeanne's low-level center of circulation moved westward and dissipated away from the system's deep convection; however, a new center developed, giving the appearance of a brief northeastward motion of the cyclone near the Turks and Caicos Islands (Fig. 1).

Meanwhile, steering currents in the western Atlantic were weakening. The midlevel remnants of Hurricane Ivan had combined with an extratropical short-wave trough over the northeastern United States and moved into the western Atlantic, eroding the subtropical ridge to the north of Jeanne. Jeanne moved slowly through and north of the southeastern Bahamas over the next couple of days while it gradually regained the strength it had lost over Hispaniola. Jeanne became a hurricane again at 1800 UTC 20 September, and then began a slow anticyclonic loop about 500 n mi east of the northwestern Bahamas. Jeanne strengthened at first, reaching category 2 intensity early on 22 September, but weakened the next day within a relatively dry environment and over the cooler waters upwelled during its loop and also earlier by Frances.

By 23 September, high pressure had built in over the northeastern United States and the western Atlantic, causing Jeanne to turn westward and increase its forward speed. Moving away from the cooler waters, Jeanne became a major hurricane at 1200 UTC 25 September as the center moved over Abaco and then Grand Bahama Island. At 0400 UTC 26 September, the center of Jeanne's 50 n mi wide eye crossed the Florida coast near Stuart, at virtually the identical spot that Frances had come ashore 3 weeks earlier. Maximum winds at the time of landfall are estimated to be near 105 kt.

Jeanne weakened as it moved across central Florida, becoming a tropical storm at 1800 UTC 26 September near Tampa, and then weakening to a depression a day later over central Georgia. The depression was still accompanied by heavy rain when it moved over the Carolinas, Virginia, and the Delmarva Peninsula on 28 and 29 September before merging with a frontal zone and becoming extratropical at 0000 UTC on 29 September.

2) Meteorological statistics

Selected observations from Jeanne are given in Table 8. Jeanne's rains were the primary hazard for the islands of the Caribbean. Extreme rain accumulations occurred in Puerto Rico and Hispaniola, with 603 mm reported at Camp Garcia in Vieques, resulting in historical flooding levels at many riverside locations within Puerto Rico. The St. Thomas airport reported 308 mm of rain, and there were unofficial reports of 300-mm rains in Guadeloupe and islands nearby. Wind reports include a sustained wind of 45 kt in St. Croix and 43 kt in San Juan.

Jeanne's estimated intensity at its Florida landfall, 105 kt, is based in part on reconnaissance aircraft wind speeds of 113 kt measured at 700 mb at 1429 UTC on 25 September and again at 0228 UTC on 26 September, adjusted to the surface using the standard 0.90 adjustment factor. The latter observation was made about 1.5 h prior to landfall, just offshore of Sebastian, Florida, and about 35 n mi north of the hurricane's center. Further supporting this estimate is an SFMR surface measurement of 99 kt, also obtained within 1.5 h of landfall just offshore of Sebastian. A NOAA/Hurricane Research Division evaluation of the SFMR data for Jeanne (F. D. Marks Jr. 2004, personal communication; http://www.aoml.noaa.gov/hrd/project2005/SFMR.pdf) concluded that this observation appeared to be reasonable. Unfortunately, there were no surface observations at the coast near Sebastian to confirm whether these category 3 winds reached the shoreline. The minimum surface pressure in Jeanne is estimated to be 950 mb at the time of landfall on the Florida east coast, based primarily on an observation of 952.9 mb at Fort Pierce, located 15 to 20 n mi north of where the center crossed the coast. A dropsonde measured a 951-mb surface pressure a few hours earlier.

The highest land-based sustained surface wind report was 79 kt at the Melbourne NWS office. This was observed at 0818 UTC when the center was about 45 n mi southwest of the observing site. A measurement of 69 kt was made on the north shore of Lake Okeechobee at 0515 UTC. The observations indicate that a swath of hurricane-force sustained winds, about 90 n mi wide, affected the Florida east coast from near Cape Canaveral southward to near Stuart. The highest wind gust reported in Florida was 111 kt at Fort Pierce Inlet, and a 106-kt gust was reported from Vero Beach. Sustained hurricane-force winds spread westward and inland about halfway across Florida and tropical-storm-force winds affected a large portion of the remainder of central Florida.

A storm surge of 1.2 m above normal astronomical tide levels was measured at Trident Pier at Port Canaveral, Florida, about an hour after landfall. Storm surge flooding of up to 1.8 m above normal tides likely occurred along the Florida east coast from the vicinity of Melbourne southward to Fort Pierce. On the Florida west coast, a negative storm surge of about 1.4 m below normal tides was measured at Cedar Key when winds were blowing offshore. This was followed by a positive surge of about 1.1 m above normal when winds became onshore.

Widespread rainfall of up to 200 mm accompanied Hurricane Jeanne as it moved across eastern, central, and northern Florida. A narrower band of 280–330 mm was observed in the vicinity of the eyewall track over Osceola, Broward, and Indian River counties of east central Florida. A secondary radar-estimated rainfall maximum of around 280 mm was observed over Duval and Nassau Counties in northeast Florida. Rainfall amounts of 100–175 mm accompanied Jeanne across central Georgia and the western portions of the Carolinas and Virginia.

3) Casualty and damage statistics

Media reports indicate that the death toll in Haiti is over 3000, including nearly 2900 in the mud-crusted coastal city of Gonaives, and that some 200 000 people in Gonaives lost their homes, belongings, and livelihoods in the hurricane.

There were six direct deaths in the Unites States: one in Puerto Rico, three in Florida, one in South Carolina, and one in Virginia. In Puerto Rico, a woman was killed by falling debris from a collapsing home. In Clay County, Florida, a boy was playing outside during high winds when a tree limb fell, striking him on the head. In Brevard County, Florida, a man driving his truck onto

TABLE 8. Selected surface observations for Hurricane Jeanne, 13–28 Sep 2004.

	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)
Florida								
Craig Field (KCRG)	15/1653	999.9	15/1929	37	55			31.2
Cross City (KCTY)	27/0313	982.1	26/2149	39	54			140.0
Daytona Beach (KDAB)	26/1908	993.6	26/1520	45	55			58.7
Fargo (FFPG1)								179.1
Fernandina Beach NOS	27/0800	999.4				0.8	2.8	
Fort Lauderdale (KFXE)	26/0200	990.8	26/0053	35	49			18.8
Fort Pierce (KFPR)	26/0413	952.9	26/0215	45	76			
Gainesville (KGNV)	26/2333	985.1	27/0345	38	52			124.5
Jacksonville (KJAX)	27/0011	995.9	27/0013	40	48			118.1
Mayport NAS (KNRB)	26/2338	998.0	27/0004	44	49	0.7	2.4	48.3
Mayport Bar Pilot Station NOS	26/2354	998.3				0.6	2.3	
Melbourne NWS			26/0818	79				155.4
Melbourne (KMLB)[e]	26/0458	986.8	25/2343	52	68			153.4
NAS Jacksonville (KNIP)	26/2355	995.9		44	55			105.7
Ocala (KOCF)	26/2215	980.0	27/0515	30	44			176.8
Orlando (KMCO)	26/1555	985.1	26/1055	53	67			
Orlando (KORL)[e]	26/0807	994.2	26/0501	34	47			137.2
Ocilla (OCIGI)								142.2
Palm Bay Co-op			26/0819		74			226.8
Port Canaveral USCG			26/0610		76			
Palm Beach (KPBI)	26/0200	974.2	26/0153		60			231.1
Pompano Beach (KPMP)	26/0200	989.5	26/0127	40	58			66.5
Sanford (KSFB)	26/1943	988.8	26/1302	46	60			111.0
St. Augustine (KSGJ)	26/2315	997.0	26/1955	42	53			80.3
Tallahassee (KTLH)	27/0808	990.2	27/0601	29	42			30.7
Trident Pier Port Canaveral NOS						1.2		
Vero Beach (KVRB)[e]								129.0
Ashburn (ASHG1)								143.5
Bell 4 WNW (BLLF1)								175.3
Lakeland (LAKG1)								218.2
Live Oak (LVOF1)								276.4
Mayo (MAYF1)								193.0
Tifton (TFTG1)								228.1
Florida (unofficial)								
STN 22 (28.66°N, 82.35°W)[f]	26/1730	987.8	26/1200		57			127.3
STN 34 (28.82°N, 82.34°W)[f]	26/1900	990.1	26/2030		47			114.8
STN 65 (28.61°N, 82.19°W)[f]	26/1600	988.6	26/1104		49			
S65 DWX (27.31°N, 81.02°W)[g]			26/0545	45	88			
L001 (27.14°N, 80.79°W)[g]	26/0700	960.4	26/0515	69[h]	91[h]			
L005[g]	26/0645	974.4	26/0808		82			
L006[g]	26/0615	974.9	26/0646		79			
LXWS[g]			26/0334		77			
Fort Pierce Inlet (27.48°N, 80.3°W)			26/0528		111[i]			
Jensen Beach (27.26°N, 80.23°W)					91			
Juno Beach (26.875°N, 80.070°W)	25/2250	959.6	25/2235	34	62			
Kenansville								304.0
Lakeland (south)	26/1500	968	26/1100		71[e]			205.5
NASA Wind Tower 1[j] (28.43°N, 80.57°W)			26/0340	39	73			
NASA Wind Tower 19[j] (28.74°N, 80.7°W)			26/0745	50	68			
NASA Wind Tower 22[j] (28.8°N, 80.74°W)			26/1855	50	66			
NASA Wind Tower 1007[j] (28.53°N, 80.77°W)			26/0955	50	72			
Port Saint Lucie	26/0424	953.7	26/0213	49	74			

TABLE 8. (*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)
Sebastian[k]			26/0647	71	88			
Sebastian					92[e]			
Sebastian (27.81°N, 80.48°W)	26/0235	971.4	26/0400	71	79			
Port Saint Lucie CW0572	26/0424	953.7						
Vero Beach KF4PKB	26/0625	965.5						
Vero Beach[k]			26/0417	68	106			
Wimauma 4SW		984	26/1524	48	70			65.5
Georgia								
Fort Pulaski NOS						0.8	2.8	
Moody AFB (KVAD)								182.4
Savannah (KSAV)	27/2153	1003	27/1640	29	38			24.9
St. Simons Island NOS						0.4	2.9	
Valdosta (KVLD)	27/0849	987.8	27/0119	35	45			136.7
Georgia (unofficial)								
Homerville								208.8
Nahunta								115.3
Rocky Ford								81.0
South Carolina								
Charleston (KCHS)	28/0856	1006	28/0622	28	36	0.4	2.1	25.7
Fripps Inlet NOS						0.6	2.5	
Puerto Rico and Virgin Islands								
San Juan	15/1908	1004.1	15/1734	43	62			151.9
St. Croix Airport	15/0750	1003.1	15/0800	45	54			155.7
St. Thomas Airport	15/0813	1010.2	15/1755	34	44			307.8
Aibonito 1S (ALPP4)								474.2
Corozal (ZDBP4)								362.0
Jayuya near Bo. Saliente (JAZP4)								375.9
Lago De Matrullas–Orocovis (OROP4)								388.1
Queb. Blanca near San Lorenzo (SLGP4)								376.9
Rio Icacos near Naguabo (NGIP4)								468.4
Rio Mameyes near Sabana (MSAP4)								434.1
Rio Matrullas Alert gage (ZDDP4)								386.1
Rio Turabo near Borinquen (CAKP4)								361.2
Vieques—Camp Garcia (WVEP4)								603.3
Puerto Rico (unofficial)								
Cayey Spotter			15/1425		63			
Hapenney Beach			15/1230		54			
Virgin Islands								
Charlotte Amalie, St. Thomas (XTCP4)								324.4
Turpentine Run, St. Thomas (XTFP4)								307.1
Virgin Islands (unofficial)								
Maria Hill Spotter St. Croix	15/1156	995.8	15/1150		83			194.3
St. Croix east end	15/0746	1007.8	15/0616		63			126.7
Guadeloupe (unofficial)								
Southwestern Guadeloupe								177.8+
Marie-Galante								304.8+
C-MAN/buoys								
Cedar Key (CDRF1)	26/2056	987.6	26/1800	30	40			
Egmont Key (EGKF1)			26/1818	46	55			
Lake Worth (LKWF1)	26/0300	974.2	26/0300	52	82			
Port Richey (PTRF1)			26/2130	44				
Settlement Point (SPGF1)	25/2100	961.8	26/0000	77	86			
St. Augustine (SAUF1)	26/2105	995.4	27/0150	48	65			

TABLE 8. (*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)			
Tarpon Springs (TARF1)			26/2106	44				
41008	27/1250	1003	27/1450	29	38			
41010	25/2200	1000.5	25/2300	33	43			
41012	26/2250	999.4						
42036	26/2350	997.6	26/1850	31	41			

[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] 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] Record incomplete due to instrument failure.
[f] Seminole County Mesonet.
[g] South Florida Water Management District.
[h] Anemometer height 9 m AGL.
[i] Davis Weather Wizard II anemometer, 16 m AGL.
[j] Anemometer height 9 m AGL.
[k] Florida Coastal Monitoring Program.

a flooded roadway had his vehicle carried into a drainage canal where he drowned. In Indian River County, Florida, an elderly woman was leaving her home to go to a shelter when a door blown open by wind threw her to the ground, causing fractures. She was hospitalized for her injuries and died a few days later. In Fairfield County, South Carolina, a man died in a tornado, and in Patrick County, Virginia, a woman drowned in a flash flood.

The AISG reports insured property losses in the United States of \$3.44 billion. Total U.S. damage is estimated to be near \$6.9 billion.

k. Hurricane Karl: 16–24 September

Karl formed from a strong tropical wave that moved westward across the coast of Africa on 13 September. Shower activity increased on 14 September, and a tropical depression formed near 0600 UTC 16 September about 340 n mi southwest of the southern Cape Verde Islands. The depression initially moved westward south of the subtropical ridge and strengthened into a tropical storm later that day. Over the next few days Karl moved generally northwestward over the open waters of the central Atlantic, becoming a hurricane on 18 September, and a major hurricane, the sixth and last of the season, on 19 September. Karl's estimated peak intensity of 125 kt occurred on 21 September. Karl turned northeastward the next day in response to a deep-layer baroclinic trough developing north of the hurricane, began to weaken, and became extratropical on 25 September about 510 n mi east of Cape Race. As an extratropical low, Karl moved northeastward and eastward across the North Atlantic Ocean and the North Sea, eventually reaching Norway before being absorbed into another extratropical low late on 28 September.

l. Hurricane Lisa: 19 September–3 October

Developing from a tropical wave that crossed the African coast on 16 September, Lisa had a relatively interesting history for a storm that remained entirely at sea. Early on 19 September the wave showed enough organization to warrant a Dvorak classification, and by 1800 UTC that day the system had developed into a tropical depression, about 450 n mi west-southwest of the Cape Verde Islands. The synoptic-scale environment was not particularly favorable for development—the depression was located between Hurricane Karl about 650 n mi to its west-northwest and a large and convectively active tropical wave just a few hundred miles to its southeast. Despite outflow from Hurricane Karl impinging on the depression from the north, a small organized core developed and the depression rapidly strengthened on 20 September, becoming a tropical storm by 1200 UTC and reaching an estimated intensity of 60 kt 18 h later. The northerly shear prevailed, however, and Lisa gradually weakened over the next couple of days. Meanwhile, the wave disturbance was approaching Lisa from the east, and the two systems began a Fujiwhara interaction. Lisa turned southward on 22 September and then eastward the next day as the convection from the two systems became hard to distinguish. Although Lisa weakened to a tropical depression on 23 September, it was able to maintain a small but distinct low-level circulation throughout its merger with the disturbance. Lisa completed its cyclonic loop early on 24 September, its intensity oscillating with variations in the northerly wind shear.

On 25 September Lisa turned sharply northward ahead of a deep mid- to upper-level trough moving southeastward into the central Atlantic. Lisa moved northward for five days as a tropical storm, nearly reaching hurricane intensity on 29 September when an upper-level trough in the westerlies cut off to the southwest of Lisa, reducing the southwesterly shear over the storm. During this time satellite images showed a ragged eye ringed by shallow convection. The following day Lisa crossed some cooler water upwelled by Hurricane Karl, convection diminished, and the cyclone's winds dropped to 45 kt, even though the eye feature remained distinct.

On 1 October, Lisa turned northeastward and accelerated ahead of an approaching shortwave trough in the westerlies. Southwesterly shear diminished and Lisa restrengthened over 25°C waters. Early on 2 October, cloud tops cooled significantly around the eye and Dvorak estimates reached as high as 77 kt. Based on the satellite classifications, it is estimated that Lisa became a hurricane, after 13 days of existence as a tropical cyclone, at 0600 UTC 2 October, about 625 n mi southeast of Cape Race. At this time, water temperatures under the cyclone were close to 23°C. Lisa was a hurricane for less than 12 h before the cloud pattern began to deteriorate rapidly. Lisa lost tropical characteristics by 0600 UTC 3 October, and was absorbed into a frontal zone a few hours later, about 1000 n mi east-southeast of Cape Race.

m. Tropical Storm Matthew: 8–10 October

Matthew's precursor disturbance was a weak tropical wave that moved across the west coast of Africa on 19 September. The wave was poorly defined between Africa and the Lesser Antilles because of its close proximity to (then) Tropical Storm Lisa and another large disturbance in the tropical Atlantic, but became convectively active when it interacted with an upper-level low in the eastern Caribbean Sea. The shower activity associated with the wave reached the Bay of Campeche on 5 October, stalled, and gradually became better organized. Over the next couple of days, upper-level ridging developed over the convection and surface pressures began to fall, and on 7 October, data from a reconnaissance aircraft indicated a broad area of low pressure had formed just east of Tampico, Mexico. The system continued to develop, and a tropical depression formed near 1200 UTC 8 October about 180 n mi southeast of Brownsville, Texas. By 1800 UTC that day the cyclone had strengthened into a tropical storm.

Matthew moved eastward initially, but gradually turned to the northeast and north around a large mid- to upper-level low over western Texas. It is estimated that Matthew reached its peak intensity of 40 kt at 1800 UTC 9 October. Matthew made landfall just west of Cocodrie, Louisiana around 1100 UTC 10 October with maximum winds of 35 kt. After landfall, Matthew weakened quickly to a depression and was absorbed by a frontal system by 1200 UTC 11 October.

Table 9 shows selected surface observations in Louisiana associated with Matthew. The maximum rainfall reported was 412 mm at Reserve in St. John Parish. An 83-kt wind gust from the BURL1 site appears to have been produced by an isolated convective cell, and is not considered representative of the strength of the tropical storm. The highest surge reported was 1.8 m at Frenier. Matthew is known to have spawned one tornado, near Golden Meadow.

Local newspapers reported that Grand Isle suffered extensive beachfront erosion. In Terrebonne Parish about 20 homes were flooded by the combination of rains and storm surge. Overall, damage was minor and there were no reported deaths or injuries.

n. Subtropical Storm Nicole: 10–11 October

Nicole's genesis appears to be associated with an upper-tropospheric trough and a decaying frontal system that were over the southwestern North Atlantic during the first week of October. Although a persistent low-level trough also extended northward from the Lesser Antilles at this time, analysis of satellite images and surface data suggest that the tropical trough was not related to the development of the subtropical cyclone. By 8 October, a broad area of surface low pressure became evident about 400 n mi southeast of Bermuda, and although it lacked a single, well-defined center of circulation, this system began to produce gale force winds that affected Bermuda on 9 October (at 2055 UTC, the island reported 37-kt sustained winds, with a gust to 52 kt). Around 0000 UTC 10 October, a better-defined low-level circulation developed about 140 n mi to the south of Bermuda, and a distinctly curved cloud band developed over the northwestern semicircle of the system shortly thereafter. It is estimated that a subtropical storm formed at 0600 UTC 10 October, centered about 120 n mi southwest of Bermuda—the subtropical designation being based on the cloud pattern, which lacked deep convection over the center, and the location of the strongest winds, which were more than 100 n mi from the center.

TABLE 9. Selected surface observations for Tropical Storm Matthew, 8–10 Oct 2004.

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)			
Louisiana								
New Orleans Lakefront Airport (KNEW)	10/1205	1003.7	10/1306	33	41			103.1
Slidell (KASD)								131.1
Baton Rouge (KBTR)								188.5
New Orleans (KMSY)								190.5
Lumcon	10/1000	1001.7	10/0200		34			
Louisiana State University (LSU) Agricultural Station Citrus			10/1506		38			138.9
Tambour Bay	10/1000	999.7						
Cocodrie						1.1		
Mandeville						1.6		
Frenier						1.8		
Galliano								362.7
Thibodaux								239.5
LSU Agricultural Station Sugarcane								330.7
Houma								225.0
Paradis								220.5
Reserve								412.2
C-MAN								
SW Pass (BURL1)	10/1200	1004.0	10/0940	42	48			
Grand Isle (GDIL1)	10/1100	1002.8	10/0927		40	1.1		

[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] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water above National Geodetic Vertical Datum (1929 mean sea level).

Nicole moved northwestward initially, but turned northeastward due to the presence of a midtropospheric trough that was moving off the northeast coast of the United States. Nicole's center passed about 50 n mi to the northwest of Bermuda around 0000 UTC 11 October; sustained winds reached 39 kt at Bermuda as Nicole passed by. Early on 11 October, some deep convection developed closer to Nicole's center, suggesting that the system was beginning to acquire fully tropical characteristics. Deep convection failed to wrap around the center, however, and strong upper-level southwesterly flow sheared the convection away from the center. The storm did not strengthen significantly while it accelerated northeastward to north-northeastward, and it soon came under the influence of a strong extratropical cyclone that was centered just south of Nova Scotia. Nicole was absorbed by this cyclone shortly after 1800 UTC 11 October.

o. Tropical Storm Otto: 29 November–3 December

A cold front emerged off the east coast of the United States on 21 November and moved slowly eastward before stalling about midway between Bermuda and the Azores early on 25 November. Around 0000 UTC 26 November, an extratropical occluded low developed along the front about 1000 n mi southwest of the Azores Islands in response to forcing from a strong upper-level trough. The occluded surface low quickly deepened and developed a large area of gales later that day, while the upper-level trough continued to dig southward and cut off to the south of the occluded surface low. The surface and upper-level lows moved generally southwestward at 5–10 kt in tandem for the next three days. Late on 28 November, weak ridging formed over the surface low and convective banding features began to develop near its center; this was concurrent with the dissipation of the surface frontal structure. Satellite classifications suggest that the system became a subtropical storm about 1000 n mi east-southeast of Bermuda near 1200 UTC 29 November.

Otto moved northwestward through a weakness in the midlevel subtropical ridge located to its north. Convection continued to increase, and AMSU data suggest that Otto had acquired enough of a warm core to be

TABLE 10. Homogenous comparison of official and CLIPER5 track forecast errors in the Atlantic basin for the 2004 season for all tropical and subtropical cyclones. Long-term averages are shown for comparison.

	Forecast period (h)						
	12	24	36	48	72	96	120
2004 average official error (n mi)	33	58	80	101	151	213	295
2004 average CLIPER5 error (n mi)	43	91	146	201	311	413	495
2004 average error relative to CLIPER5 (%)	−24%	−37%	−46%	−50%	−51%	−49%	−40%
2004 number of cases	389	363	335	307	267	228	194
1994–2003 average official error (n mi)*	44	78	112	146	217	248	319
1994–2003 average CLIPER5 error (n mi)*	53	107	166	226	333	521	671
1994–2003 average error relative to CLIPER5 (%)*	−17%	−27%	−33%	−36%	−35%	−52%	−53%
1994–2003 number of cases	3172	2894	2636	2368	1929	421	341
2004 official error relative to 1994–2003 mean (%)*	−26%	−27%	−29%	−31%	−30%	−14%	−7%
2004 CLIPER5 error relative to 1994–2003 mean (%)*	−19%	−15%	−12%	−11%	−6%	−21%	−26%

* Averages for 96 and 120 h are for the period 2001–03.

considered a tropical storm at about 1200 UTC 30 November, when the cyclone was about 700 n mi east of Bermuda. For the next 2 days, Otto meandered over relatively cool water, and by 2 December, Otto was weakening in response to midlevel dry air entrainment and increasing vertical shear. Convection diminished and Otto degenerated into a nonconvective remnant low pressure system on 3 December about 800 n mi southeast of Bermuda. The remnant low dissipated two days later about 800 n mi northeast of the northern Leeward Islands.

3. Nondeveloping tropical depressions

Only one tropical depression did not attain tropical storm strength in 2004. Tropical Depression 10 originated from a tropical wave that crossed the coast of Africa on 29 August. The wave was accompanied by a well-organized area of disturbed weather that passed just north of the Cape Verde Islands early on 30 August, but the system became less organized over the next several days as it recurved to the northeast. On 7 September, a low-level circulation was evident about 630 n mi southwest of the westernmost Azores, accompanied by deep convection sufficiently close to the center to qualify the system as a tropical depression. Southwesterly shear prevented the cyclone from strengthening, however, and by 9 September the deep convection had become sheared far enough away from the center to cause the system to degenerate to a remnant low. The low turned southeastward and east-southeastward, and dissipated on 10 September about 230 miles west-southwest of the southernmost Azores.

4. Forecast verifications and warnings

For all operationally designated tropical cyclones in the Atlantic basin, the NHC issues an "official" forecast of the cyclone's center position and maximum 1-min surface wind speed. These forecasts are issued every 6 h, and each contains projections valid 12, 24, 36, 48, 72, 96, and 120 h after the forecast's nominal initial time. At the conclusion of the season, the forecasts are evaluated by comparing the forecast positions and intensities to the corresponding poststorm-derived best-track positions and intensities for each cyclone. Forecasts are included only if the system was a tropical or subtropical cyclone at both the forecast and the verifying time; extratropical and remnant low stages are excluded. The verifications include the depression stage.

Track forecast error is defined as the great-circle distance between a cyclone's forecast center position and the best-track position at the forecast verification time. Table 10 presents the results of the NHC official track forecast verification for the 2004 season, along with results averaged for the previous 10-yr period 1994–2003. It is seen from the table that mean official track forecast errors were smaller in 2004 than for the previous 10-yr period (by roughly 25%–30% out to 72 h), and in fact, all-time records for forecast accuracy were set at all time periods through 72 h. Not only were the 12–72-h forecasts more accurate in 2004 than they had been over the previous decade, but the forecasts were also more skillful. To assess skill, the track forecast error can be compared with the error from CLIPER5,[3] a climatology and persistence model that represents a "no skill" baseline level of accuracy (Neumann 1972; Aberson 1998). A comparison of forecast errors relative to CLIPER5 shows that 12–72-h forecast skill was roughly 40% higher in 2004 than over the preceding decade. An examination of annual skill scores (not shown), how-

[3] CLIPER5 and SHIFOR5 are 5-day versions of the original 3-day CLIPER and SHIFOR models.

TABLE 11. Homogenous comparison of official and SHIFOR5 intensity forecast errors in the Atlantic basin for the 2004 season for all tropical and subtropical cyclones. Long-term averages are shown for comparison.

	Forecast period (h)						
	12	24	36	48	72	96	120
2004 average official error (kt)	7.4	10.2	12.4	13.9	17.0	19.8	22.6
2004 average SHIFOR5 error (kt)	8.8	13.6	17.3	20.3	24.3	25.5	26.7
2004 average error relative to SHIFOR5 (%)	−16%	−25%	−28%	−32%	−30%	−23%	−16%
2004 number of cases	389	363	335	307	267	228	194
1994–2003 average official error (kt)*	6.1	9.7	12.3	14.8	18.5	19.7	21.2
1994–2003 average SHIFOR5 error (kt)*	7.9	12.2	15.5	17.9	20.8	24.1	23.1
1994–2003 average error relative to SHIFOR5 (%)*	−23%	−21%	−21%	−17%	−11%	−18%	−8%
1994–2003 number of cases	3163	2886	2625	2356	1928	421	341
2004 official error relative to 1994–2003 mean (%)*	21%	5%	1%	−6%	−8%	1%	7%
2004 SHIFOR5 error relative to 1994–2003 mean (%)*	11%	11%	12%	13%	17%	6%	16%

* Averages for 96 and 120 h are for the period 2001–03.

ever, suggests that forecast skill has changed little over the past three seasons, after a sharp increase in skill in the late 1990s. The record low forecast errors set in 2004 are at least partly attributable to the nature of the season, which featured slowly moving storms as well as numerous storms traversing the deep Tropics, that is, systems typically associated with low CLIPER5 errors.

The NHC began making 96- and 120-h forecasts in 2001 (although they were not released publicly until 2003), so the "long-term" record for these forecast periods is rather short. Official track errors in 2004 for 96 and 120 h were somewhat smaller than the 2001–03 period means, although the unusually low CLIPER5 errors in 2004 indicate that these longer-range forecasts were slightly less skillful in 2004 than in previous years.

Forecast intensity error is the absolute value of the difference between the forecast and best-track intensity at the forecast verifying time. Table 11 presents the results of the NHC official intensity forecast verification for the 2004 season, along with results averaged for the preceding 10-yr period. Skill in a set of intensity forecasts is assessed using the error from Statistical Hurricane Intensity and Forecast Model (SHIFOR5) (Jarvinen and Neumann 1979; Knaff et al. 2003), the climatology and persistence model for intensity that is analogous to the CLIPER5 model for track. The table shows that mean intensity errors in 2004 were mostly within about 10% of the previous 10-yr means. SHIFOR5 forecast errors in 2004 were mostly 10%–20% larger than their previous 10-yr means, which indicates that this year's storms were somewhat more difficult than normal to forecast. A review of annual errors and skill scores suggests that intensity forecast skill has improved slightly over the past few seasons, even though raw errors have remained nearly constant.

NHC defines a hurricane (or tropical storm) warning as a notice that 1-min mean winds of hurricane (or tropical storm) force are expected in a specified coastal area within the next 24 h. A watch is defined as a notice that those conditions are possible within the next 36 h. Table 12 lists lead times associated with those tropical cyclones that affected the United States in 2004. Be-

TABLE 12. Watch and warming lead times for hurricanes (H) and tropical storms (TS) affecting the United States in 2004. For cyclones with multiple landfalls, the most significant is given. If multiple watch/warning types were issued, the type corresponding to the most severe conditions experienced over land is given.

Storm	Landfall or point of closest approach	Watch/warning type (H/TS)	Watch lead time (h)	Warning lead time (h)
Alex	Cape Hatteras, NC	H	None issued	20
Bonnie	St. Vincent Island, FL	TS	35	23
Charley	Cayo Costa, FL	H	35	23
Frances	Hutchinson Island, FL	H	73	61
Gaston	Awendaw, SC	H	17	14
Hermine	New Bedford, MA	TS	None issued	13
Ivan	Gulf Shores, AL	H	51	42
Jeanne	Hutchinson Island, FL	H	43	31
Matthew	Cocodrie, LA	TS	None issued	15

cause observations are generally inadequate to determine when hurricane or tropical storm conditions first reach the coastline, for purposes of this discussion the lead time is defined as the time elapsed between the issuance of the watch or warning and the time of landfall or closest approach of the center to the coastline. Such a definition will usually overstate by a few hours the actual lead time available, particularly for tropical storm conditions. The table includes only the most significant (i.e., strongest) landfall for each cyclone, and only verifies the strongest conditions occurring on shore. Issuance of warnings for non-U.S. territories is the responsibility of the governments affected and is not tabulated here.

The table shows that while 24-h notice was not always achieved in 2004, ample warning was given for the season's most significant events (Charley, Frances, Ivan, and Jeanne). The lead time for Frances, in fact, was longer than desirable, resulting from Frances' forward motion slowing more than anticipated. Lead times for the Alex and Gaston hurricane warnings were less than desirable due to unexpected strengthening of these systems. In the case of Matthew, a strong pressure gradient was already producing gale-force winds over the northeastern Gulf of Mexico during the genesis of the tropical cyclone, and the tropical storm warning was issued to supersede a preexisting gale warning on the coast. Although not listed in the table, the Bermuda Weather Service handled Subtropical Storm Nicole in a similar fashion, issuing a gale warning for Bermuda more than a day before the subtropical cyclone formed.

While numerous records for accuracy were set in 2004, forecasts for Hurricane Charley garnered considerable attention for a perceived lack of accuracy, with many residents of the Charlotte Harbor area expressing surprise at the hurricane's landfall, despite the fact that a hurricane warning had been in effect there for 23 h. This surprise resulted from an unwarranted focus on specific NHC forecast track positions issued in the final 24 h before landfall, which showed Charley's track intersecting the coastline in the Tampa Bay area. Charley's landfall at Cayo Costa was about 60 n mi south as measured along the coastline from Tampa. Yet the forecast errors at Charley's landfall were not unusually large; the 12-h forecast verifying at 1800 UTC 13 August had an error of 29 n mi, better than 45% of all 12-h forecasts issued in 2004, and the 24-h error verifying at the same time was only 40 n mi, better than 64% of the 24-h forecasts issued in 2004. The potential for a large apparent landfall error had been anticipated; the NHC Tropical Cyclone Discussion product accompanying the initial Florida hurricane warning stated, "Because Charley is expected to approach the west coast of Florida at a sharply oblique angle . . . it is unusually difficult to pinpoint Charley's landfall . . . as small errors in the track forecast would correspond to large errors in the location and timing of landfall." No one near the landfall location should have been unprepared for the arrival of Charley. Neither should they have been unprepared for a category 4 hurricane. The NHC intensity forecast made 24 h prior to landfall indicated that Charley would strengthen from category 2 to category 3. NHC routinely recommends in off-season training sessions for decision makers to prepare for one category higher than the NHC is forecasting, due to limitations in intensity forecast skill. Charley's rapid strengthening just prior to landfall is an example of why that recommendation is made.

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