ANNUAL SUMMARIES

Atlantic Hurricane Season of 1994

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ABSTRACT

The 1994 Atlantic hurricane season had only three hurricanes forming from just seven tropical storms. Several of these tropical cyclones, however, caused loss of life and great damage. Gordon, as a tropical storm, produced floods that killed more than 1100 people in Haiti. Alberto, Beryl, and Gordon hit the United States, causing 38 deaths and nearly $1 billion in damage over the southeastern states.

1. Introduction

The 1994 hurricane season was peculiar for several reasons. There were no hurricanes in the normally active months of September and October for the first time since track records became relatively reliable in the mid-1940s. On the other hand, two hurricanes developed in November for only the second time in that 50-yr period. The other occasion was 1980. Furthermore, none of the hurricanes reached category 3 (1-min surface wind speed reaching at least 49 m s^{-1}) status on the Saffir–Simpson scale (Simpson 1974). The last time this occurred was in 1986. Normally, there are two such "major" hurricanes (categories 3, 4, or 5) in a season.

Although the United States escaped the fury of hurricanes in 1994, it was hit by three systems at tropical storm strength, Alberto, Beryl, and Gordon. They caused nearly one billion dollars in damage. Torrential rains associated with the remnants of Alberto caused 30 fatalities in Alabama and Georgia.

For the fifth consecutive year, hurricanes did not directly affect the Caribbean. Hugo, in 1989, was the last hurricane to strike that area, and its effects were limited to the northeast sector. Nevertheless, rainfall and mud slides associated with Gordon during its tropical storm stage killed 1122 people in Haiti. This is the largest number of fatalities associated with a tropical cyclone in the Atlantic hurricane basin since 1979 when Hurricane David killed at least 2000 people in the Dominican Republic.

The season had seven tropical storms, and three of those became hurricanes. This activity continued a trend that began in 1991 of fewer than normal tropical storms and hurricanes. (The past 50-yr average is nine tropical storms developing into six hurricanes.) The tropical storm and hurricane tracks for 1994 are shown in Fig. 1. Table 1 shows additional season statistics.

The limited activity in 1994 is briefly examined in relation to three commonly discussed large-scale features of the tropical environment, the vertical wind shear, surface pressure patterns, and sea surface temperature (SST).

Strong vertical shear of the horizontal wind over the Tropics inhibits development and strengthening of tropical cyclones by separating deep convection from the low-level circulation (Gray 1968). Indeed, during August and September 1994 (Fig. 2), the magnitude of the vertical shear was relatively small where tropical cyclones formed and was larger to the north where no formation occurred. The computed anomalies from the 1975–94 mean of the magnitude of the vertical wind shear, on the other hand, are somewhat contradictory and provide less satisfying insight. The anomaly for the August–October 1994 period (Fig. 3) is considered fairly representative of both general day-to-day and average conditions. The shear was smaller than normal over most of the belt in which tropical cyclone development was expected but was not observed. Hence, for this period, the vertical shear parameter does not in itself easily explain the dearth of activity during these climatologically most active months. In November (not shown), Hurricanes Florence and Gordon developed in regions of even larger negative shear anomalies (i.e., more favorable conditions for development) than were observed in August–October.

Large-scale surface pressure anomalies might be related to tropical storm activity through the associated wind fields. Specifically, a large north–south shear of

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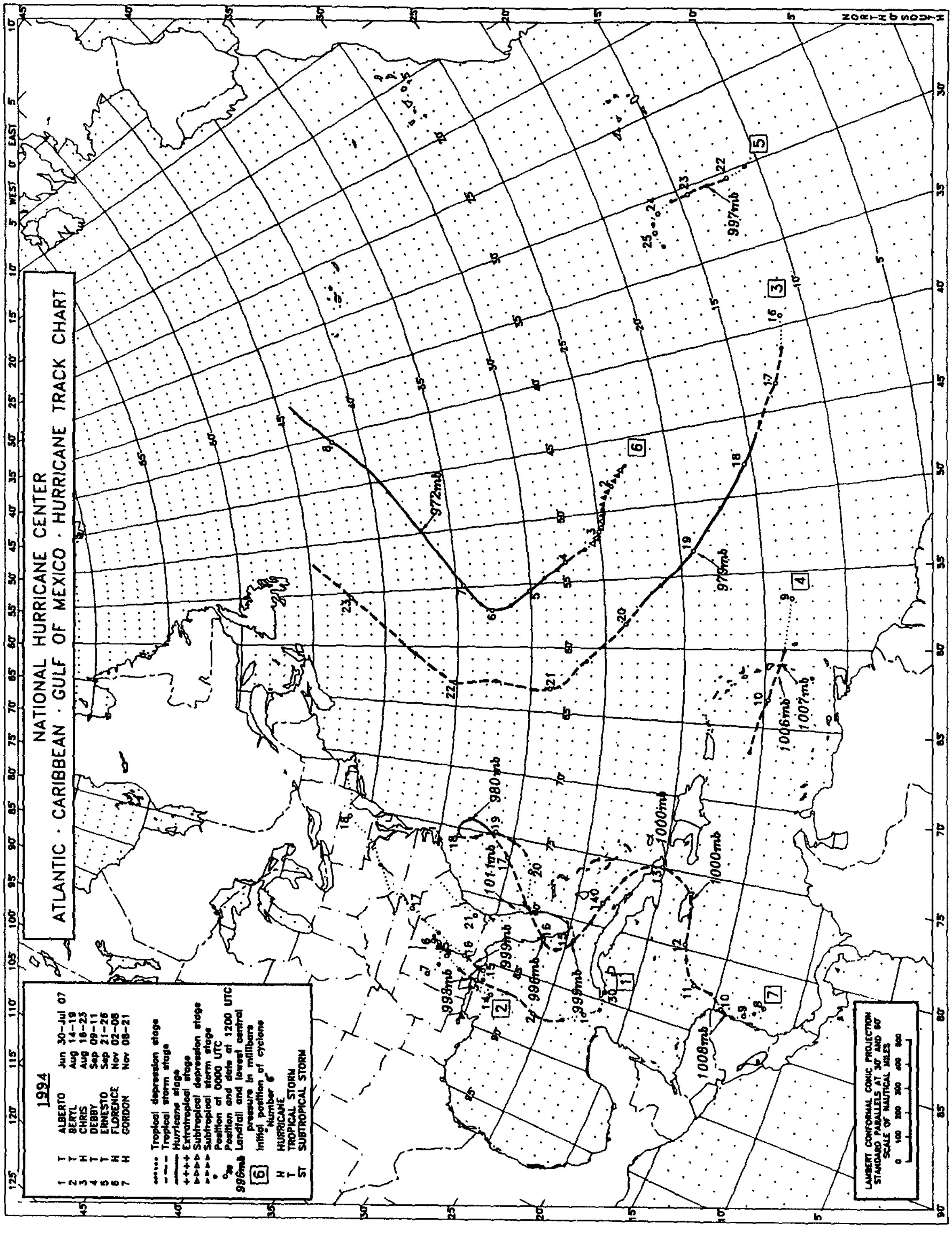

FIG. 1. Tropical storm and hurricane tracks for 1994.

TABLE 1. 1994 Atlantic hurricane season statistics.

Number	Name	Class[a]	Dates[b]	Maximum sustained wind (m s^{-1})[c]	Lowest pressure (mb)	United States damage (millions of dollars)	Deaths
1	Alberto	T	30 Jun–7 Jul	28	993	500	30
2	Beryl	T	14–19 Aug	26	999	73	0
3	Chris	H	16–23 Aug	36	979	0	0
4	Debby	T	9–11 Sep	31	1006	0	9
5	Ernesto	T	21–26 Sep	26	997	0	0
6	Florence	H	2–8 Nov	49	972	0	0
7	Gordon	H	8–21 Nov	39	980	400	1145

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

[b] Dates begin at 0000 UTC and include tropical depression stage.

[c] Wind speed over a 1-min span at surface (10 m).

the easterly zonal wind is conducive for tropical cyclone development (Gray 1968). Throughout the September–October period, above-normal surface pressures (and, likely, associated subsidence) prevailed south of 20°N from Africa westward to the Caribbean region. Concurrently, below-normal pressures dominated the subtropical latitudes (Climate Analysis Center 1994a,b). We infer from this pressure pattern a weakening or southward shift of the high pressure ridge that normally lies east–west across the subtropical north Atlantic. Either would be consistent with decreased tropical cyclone formation. (In the case of a southward shift, the zone of largest ambient vorticity would be located from about 5° to 10°N, where the close proximity to South America would hinder development).

The SST distribution is also an important parameter for genesis and intensification of tropical cyclones. Simpson and Hebert (1973) suggested that SST anomalies of −1° to −3°C in 1972 could explain the lack of activity that year. In September and October 1994, the SSTs were slightly below normal over the tropical northeastern Atlantic, with anomalies to about −0.5°C (Climate Analysis Center 1994a,b). Hence, SSTs, like wind shear and surface pressure, occurred in patterns that were consistent with the observed tropical cyclone activity. Yet none of these factors by themselves explain the limited hurricane activity during the 1994 season.

2. Tropical storm and hurricane summaries

a. Tropical Storm Alberto, 30 June–7 July

Tropical Storm Alberto caused minor damage and no casualties when it came ashore in the Florida pan-

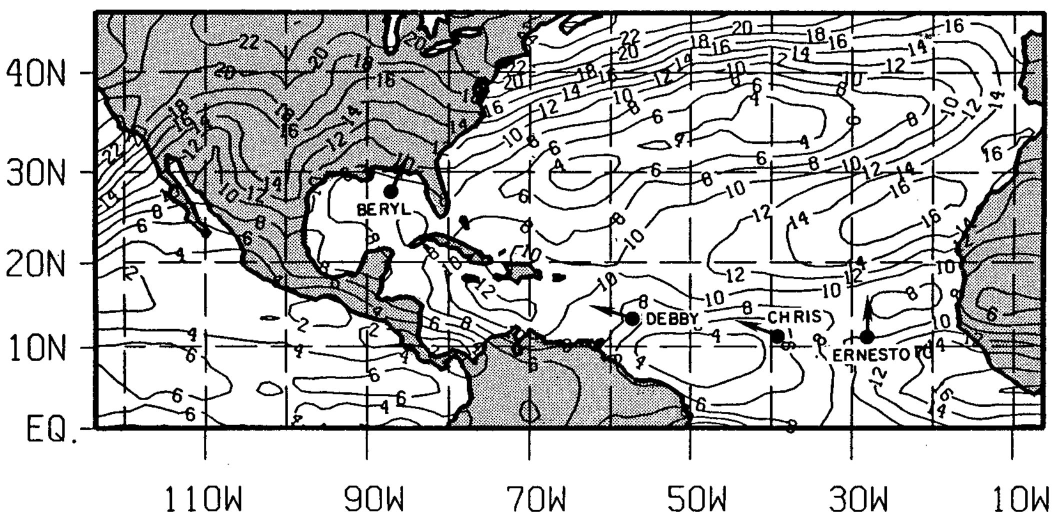

FIG. 2. Mean magnitude of the vertical shear of the horizontal wind (approximately 900 mb minus 200 mb) for August and September 1994. Contour interval is 2 m s^{-1}. Dots show the location where 1994 tropical storms formed (became tropical depressions) in those two months, and arrowheads show direction of motion of the systems during early stages of development.

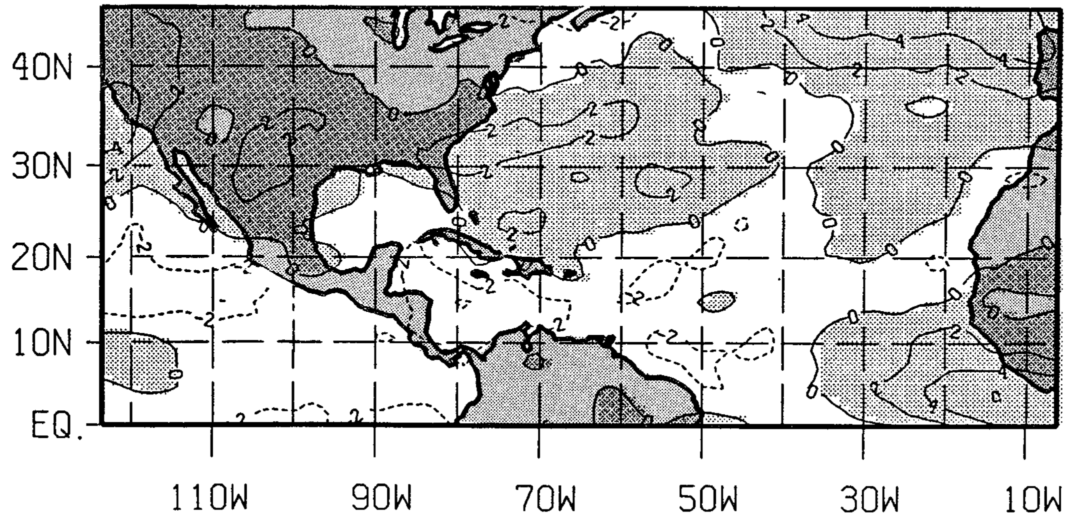

FIG. 3. Anomalies, from the 1975–94 mean, of the magnitude of the vertical shear of the horizontal wind (approximately 900 mb minus 200 mb) for August, September, and October of 1994. Contour interval is 2 m s^{-1}, with dashed contours for negative anomalies (i.e., weaker than normal shear).

handle. Although the winds quickly diminished after landfall, the remnants meandered for four days through eastern Alabama and western Georgia, producing record-breaking rainfall and floods that over the course of more than a week took 28 lives in Georgia and 2 lives in Alabama. Alberto caused damage estimated at $500 million.

1) SYNOPTIC HISTORY

Alberto's origin is traced to a tropical wave detected in Dakar, Senegal, rawindsonde data on 18 June. Satellite pictures indicated that the wave then progressed steadily westward for several days accompanied by a broad area of low clouds and a hint of dust. The wave produced showers over the Lesser Antilles, but little deep convection occurred until a cluster of thunderstorms developed over the waters just north of the Virgin Islands and Puerto Rico early on 26 June. When the convective activity neared the central Bahamas two days later, it was sheared apart by westerly winds aloft. The tropical wave moved across Cuba and the adjacent waters of the Caribbean Sea on 29 June and encountered a light vertical wind shear. Deep convection quickly increased and became concentrated over central Cuba and, by midday on 30 June, near the western tip of Cuba. The first reconnaissance flight into the area, by a National Oceanic Atmospheric Administration (NOAA) aircraft, indicated a well-defined circulation at 300-m altitude and a central pressure of 1008 mb at 1902 UTC. Based on those observations and earlier ship and land reports, it is estimated that the system became Tropical Depression One near 0600 UTC 30 June. The depression was then moving westward at about 4 m s^{-1}.

A low aloft located over the south-central Gulf of Mexico and a midlatitude short-wave trough that swept eastward across the northern Gulf put the depression in a modest, mainly southerly steering flow and shear. The depression gradually turned more to the north and remained rather poorly organized with a partially exposed low-level center seen on satellite pictures.

As the low aloft shifted toward the west and away from the depression, the shear diminished. The depression strengthened to become Tropical Storm Alberto early on 2 July. Later that day, the ship *Robert E. Lee* reported 23 m s^{-1} winds about 75 km to the north of Alberto's center.

Another short-wave trough approached the central Gulf states late on 2 July. The steering flow ahead of the trough axis brought Alberto northward at 6 m s^{-1} toward the Florida panhandle. Alberto continued to strengthen and its circulation center became more embedded within deep convection. Alberto was near its peak intensity, 993 mb and 28 m s^{-1} winds, when the center made landfall near Destin, Florida, at 1500 UTC 3 July. At that time, visible satellite pictures showed a recessed spot near the middle of the central cloud feature that may have indicated the first stages in the development of an eye. Figure 4 shows a GOES visible satellite image of Alberto and WSR-88D reflectivity pattern for Alberto near landfall.

Winds then quickly subsided and the central pressure rose rapidly, and Alberto weakened back to a tropical depression near 0000 UTC 4 July. Alberto's northward progress was then retarded and eventually halted when it was bypassed by the short-wave trough and blocked by an area of high pressure.

Surface data indicate that the cyclonic circulation spun down very slowly after that time. In addition, sat-

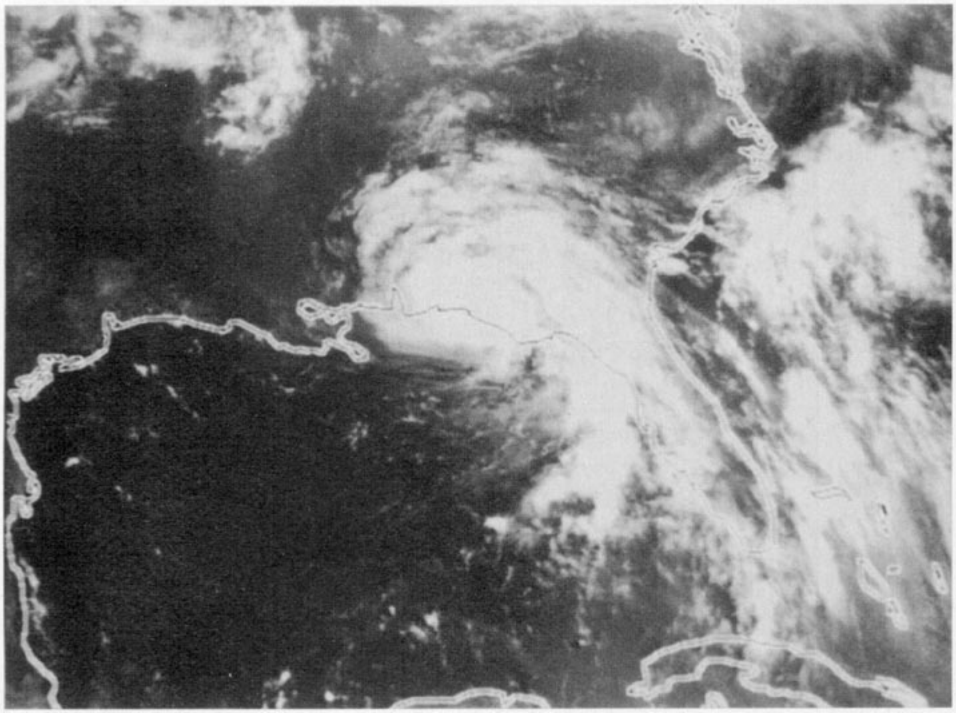

FIG. 4a. *GOES-7* visible satellite image of Tropical Storm Alberto at 1500 UTC 3 July 1994 when the cyclone was making landfall on the Florida panhandle.

ellite pictures and Doppler radar data continued to show a well-defined, cyclonically turning cloud and reflectivity pattern moving slowly through eastern Alabama and western Georgia until late on 7 July. The system produced locally torrential rain during that period, inducing numerous floods that continued many days after the tropical cyclone dissipated.

2) METEOROLOGICAL STATISTICS

The highest officially recorded 1-min wind speed at the surface was 18 m s^{-1} (Table 2a), observed at Eglin Air Force Base (AFB)/Valparaiso (VPS) and Hurlburt Field (HRT). The Coast Guard station at Destin recorded a gust to 22 m s^{-1}. VPS had a peak gust of 30 m s^{-1}. An unofficial gust to 37 m s^{-1} at 1405 UTC was reported from a portable anemometer in an open exposure in Destin. This is comparable to the highest wind speed just above the shoreline shown by the Eglin AFB/Valparaiso WSR-88D radar about 50 min later. The reconnaissance flight at about that time had peak winds of about 34 m s^{-1} at a flight level of 450 m. Alberto's estimated minimum pressure of 993 mb is based on reconnaissance measurements of that value and an unofficial observation of 994 mb at Destin.

A storm tide of 1.5 m was estimated near Destin. A 1-m (NGVD) storm surge was measured at Panama City, Panama City Beach, Turkey Point, and Apalachicola.

The Isle of Youth, Cuba, had about 250 mm of rain, while Alberto became organized into a depression. Rainfall totals for the landfall area in northwest Florida were about 125 mm. Record rains occurred farther to the north in association with the slowly weakening depression over the following several days (Table 2b). The Eglin Air Force Base WSR-88D radar indicated a roughly 90-km-wide swath of greater than 125 mm of rainfall extending from near Crestview, Florida, to west-central Georgia during the 35-h period ending near 2000 UTC 6 July. It also showed a maximum of 371 mm for that period. Americus, Georgia, received more than 530 mm of rain in a 24-h period ending on the morning of 6 July and 701.3 mm fell there from 4 to 7 July. When the depression headed westward on 6 July, heavy rains returned to the Florida panhandle and rainfall up to 200 mm was estimated to have fallen on the night of the 6–7 July near D'Iberville, Mississippi.

Many rivers and creeks in Georgia and in the Florida panhandle flooded. The Flint River crested above flood stage by about 7.3 m in Albany, Georgia. Some dams were overtopped and broken by the river torrents in Georgia.

No reports of tornadoes have been received at the National Hurricane Center (NHC, currently known as the Tropical Prediction Center).

3) CASUALTY AND DAMAGE STATISTICS

Although 13 people were rescued offshore, no casualties are attributed to Alberto through about the first

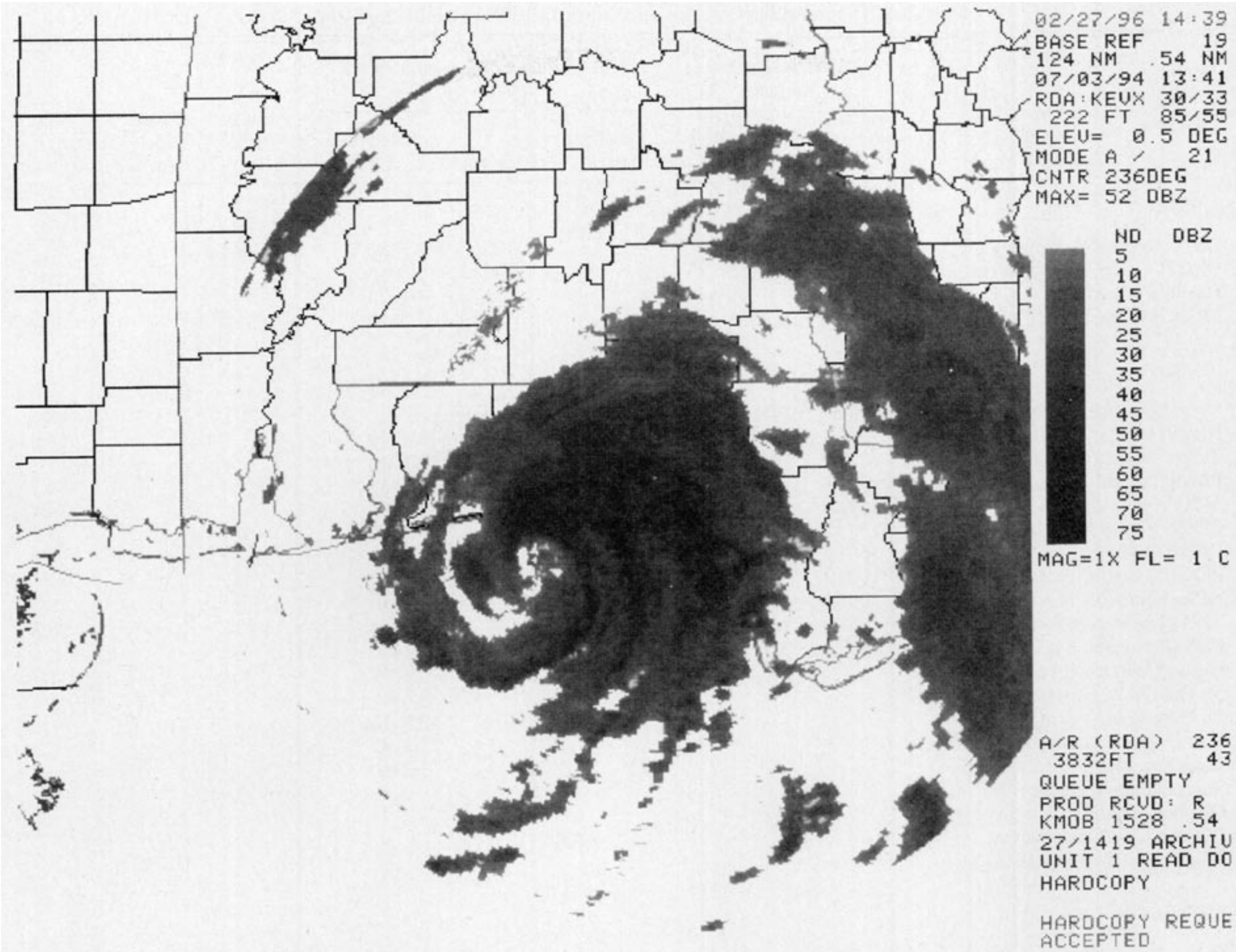

FIG. 4b. Reflectivity pattern from Eglin Air Force Base WSR-88D radar associated with Tropical Storm Alberto at 1341 UTC 3 July 1994, shortly before storm's landfall.

day following landfall. In general, mostly minor damage (e.g., limited beach erosion, downed trees, and power lines) occurred during that period. The most extensive beach erosion (up to 4 m) was reported on Cape San Blas.

Subsequent rains resulted in the failure of two hydroelectric dams and 82 small dams. The associated floods, in some instances, exceeded 100-yr event thresholds. The floods were directly responsible for the loss of 28 lives in Georgia and 2 in Alabama. Some of the fatalities were reported as much as a week after Alberto's landfall and days after the last vestiges of Alberto's circulation and rain disappeared.

The American Insurance Services Group preliminarily estimated Alberto's damage at $500 million, of which $250–300 million was insured. A component of the insured loss, damage to buildings and vehicles, was estimated at $70 million in Georgia, $15 million in Florida, and $10 million in Alabama and was likely to rise further. Crop losses alone accounted for a $100 million loss in Georgia. The total loss in Florida has been estimated at about $80 million.

About 20 000 people evacuated from Albany, Georgia, 2000 people left Bainbridge, Georgia, and about 4000 people were evacuated from the Florida panhandle because of the threat of freshwater flooding. Evacuations also occurred in parts of Alabama.

A total of 55 counties in Georgia, 13 in Florida, and 10 in Alabama were declared disaster areas.

4) WARNINGS

Tropical storm warnings were in effect for about a day for portions of the Yucatan peninsula. The initial tropical storm watches and warnings for the United States' gulf coast were centered well west of the eventual location of landfall. The warnings later shifted eastward in conjunction with a rightward swing of the official forecast tracks.

TABLE 2a. Tropical Storm Alberto selected surface observations, June–July 1994.

Location	Minimum sea level pressure: Pressure (mb)	Minimum sea level pressure: Date/time (UTC)	Maximum surface wind speed ($m\ s^{-1}$): Sustained wind	Maximum surface wind speed ($m\ s^{-1}$): Peak gust	Maximum surface wind speed ($m\ s^{-1}$): Date/time (UTC)[a]	Storm surge[b] (m)	Storm tide[b] (m)	Rain (storm total) (mm)
Alabama								
DHN (Dothan Municipal)	1004.9	3/2147	12[c]	20	3/1850			
OZR (Cainrns AAF/Ozark)	1004.2	3/2155	13[c]	20	3/2055			
Dauphin Island				15	3/1024			
MOB (Mobile/Bates Field)	1011.3	3/0851		7	3/2059			0.25
Florida								
VPS (Eglin AFB/Valparaiso)	999	3/1521	18[c]	30				108.5
HRT (Hurlburt Field)	1002	3/1409	18[c]	26	3/1340			68.8
TUPF (Turkey Pt.) DARDC				21	3/1018			
PAM (Tyndall Field)	1010.4	3/1355, 1455	12[c]	19	3/1455			34.3
WSO Apalachicola	1012.5	3/1610	12[c]	18	3/0734			74.4
CDKF (Cedar Key) DARDC			12[c]	18	3/1548			3.3
CEW (Crestview)	1004.5	3/1651	11[c]	18	3/1550, 1651			
PFN (Panama City/Bay County)	1009	3/1450	10[c]	18	3/1450			
NPA (Pensacola Naval Air Station)	1008.5	3/1255		18	3/1358			
TLH (Tallahassee Regional)	1011.0	3/2315	10[c]	14	3/1854			98.8
PNS (Pensacola Regional)	1009.0	3/1149, 1347	9[c]	13	3/1446			
Destin Coast Guard station				34				
St. George Is. (storm spotter)			26[d]		3/0445			
St. George Is. (storm spotter)			26[d]		3/0515			
East Dog Island (storm spotter)			14[c]		3/1145			
Cape San Blas (storm spotter)			22[d]	33	3/0400			
Shoreline of Apalachee Bay						0.6–0.9[e]		
Okaloosa Island to Destin							1.5[e]	
Panama City/Chico Bayou							0.5[f,g]	
Choctawhatchee Bay (WS4Y)							0.6[f,g]	
Louisiana								
Bayou Bienvunue							0.6	
Ship reports[c,d]								
NKRV (25.6°N, 85.7°W)	1015.1		18		2/1800			
Robert E. Lee (*KCRD*) (near 27.2°N, 87.0°W)	1003.3	2/1835[e]	22		2/1800			
Sanko Quest (*ELPY9*) (26.2°N, 87.0°W)	1002	3/1430	18–21	26	2/1440			
NDBC instruments[h]								
Buoy								
42036 (28.5°N, 84.5°W)	1010.8	3/0800	14	18	3/0400			
C-MAN								
CSBF1			15	17	3/1420, 1510			

[a] Time of 1-min wind speed unless only gust is given.

[b] *Storm surge* is water height above normal tide level. *Storm tide* is water height relative to National Geodetic Vertical Datum (NGVD), which is defined as mean sea level in 1929.

[c] The 1-min averaged wind. Usually an hourly observation near the top of the hour, with more extreme speed possible.

[d] Unknown averaging period.

[e] Estimated.

[f] Reported as "above normal."

[g] A more extreme value may have occurred.

[h] NOAA buoys report hourly an 8-min average wind. C-MAN station reports are 2-min average winds at the top of the hour and 10-min averages at other times. More extreme values may have occurred. Contact NDBC for additional details.

TABLE 2b. Selected additional rainfall accumulations (mm) associated with Alberto.

Location	Total	Location	Total	Location	Total	Location	Total
Alabama (3–8 July)							
Elba	356.7	Dothan	368.6	Ozark AWS	364.7	Huntsboro	256.8
Florida (2–8 or 3–8 July)							
Niceville	547.9	Caryville (before evacuation)	336.6	Valparaiso/Eglin	291.3	Chipley	228.9
Georgia (3–7 July)							
Americus 3SW	701.3	Byron/Experiment	421.9	Macon WSO	325.6	Newnan 4NE	220.0
Plains UGA	637.0	Preston 4SSE	388.6	Macon Auto	274.3	LA Grange GA Power	208.3
Cuthbert	606.3	Montezuma	328.8	Warner Robins AFB	250.0	Atlanta WSFO	191.8
Butler	600.2	Griffin/Experiment	362.7	Jackson	239.0	Columbus FT Benning	168.9
Buena Vista	525.8	George	338.6	Jonesboro	238.0	Albany	168.9

b. Tropical Storm Beryl, 14–19 August

1) SYNOPTIC HISTORY

A large upper-level low developed a few hundred kilometers north of Puerto Rico on 9 August. It moved westward and gradually became pronounced in the low- to midlevels of the troposphere. Although the low at upper-levels had weakened to a trough by the time it passed over south Florida on 12 August, there was evidence of an associated low- to midlevel cyclonic circulation off the southwest Florida coast by 1200 UTC on this day. Based on surface observations and ship reports, this feature became a weak 1014-mb surface low centered off the northwest coast of Cuba at 0000 UTC 13 August. The winds around the surface low were light and the associated cloudiness was disorganized.

The surface low moved generally toward the north-northwest for the next 24 h steered by the low-level flow. It became a tropical depression near 1200 UTC 14 August centered about 185 km south of Pensacola, Florida. The tropical depression drifted slowly northward in its early stages, while the poorly defined center was still becoming organized. Aircraft reconnaissance then indicated essentially no movement between 1630 and 2000 UTC 14 August. By 0000 UTC 15 August, both reconnaissance and satellite data suggested that the center of the depression had reformed to the east of the previously tracked center. At this time, the center was poorly defined on the Eglin AFB Doppler radar, but by 0600 UTC it was better defined in both base velocity and reflectivity data (not shown). The tropical depression drifted toward the east-northeast between 0000 and 1200 UTC 15 August and became better organized. Rains began spreading over portions of the west coast of the Florida peninsula and the Florida panhandle.

Based primarily on aircraft reconnaissance and surface reports, the depression is estimated to have strengthened into Tropical Storm Beryl at 1200 UTC 15 August. Between 1200 and 1800 UTC, the center moved erratically, possibly influenced by a mesocyclone noted to the south of Beryl's circulation center in both reflectivity and velocity data from the Eglin AFB Doppler radar. After 1800 UTC, Beryl drifted generally toward the north-northeast in response to an approaching midtropospheric trough. The storm made landfall near Panama City, Florida, around 0000 UTC on 16 August (Fig. 5).

Onshore winds produced coastal flooding over the Big Bend area of Florida between Apalachicola and Cedar Key. Even after the center moved inland, aircraft reports indicated strong winds were slow to subside over the Apalachee Bay area. Doppler radar showed strong convective bands moving ashore over that area.

Winds diminished to below tropical storm force as Beryl weakened to a tropical depression over southwest Georgia around 1200 UTC 16 August. The weakening cyclone continued moving toward the north-northeast but with increasing forward speed. Although the winds associated with the dissipating stage of the tropical depression were not significant, a surface low pressure center could be tracked from Georgia through the western portions of the Carolinas, Virginia, and West Virginia, then northeastward through Maryland and Pennsylvania, and finally east-northeastward through New York to Connecticut. The low was then absorbed into a frontal trough by 0600 UTC 19 August.

Very heavy rains and tornadoes occurred in association with the dissipating stage of the tropical cyclone from Georgia into New York.

2) METEOROLOGICAL STATISTICS

There were four aircraft reconnaissance missions into Beryl, with a total of 13 center fixes during a 32-h period from near 1600 UTC 14 August to landfall near 0000 UTC 16 August. The peak flight-level wind reported while the storm's center was over water was

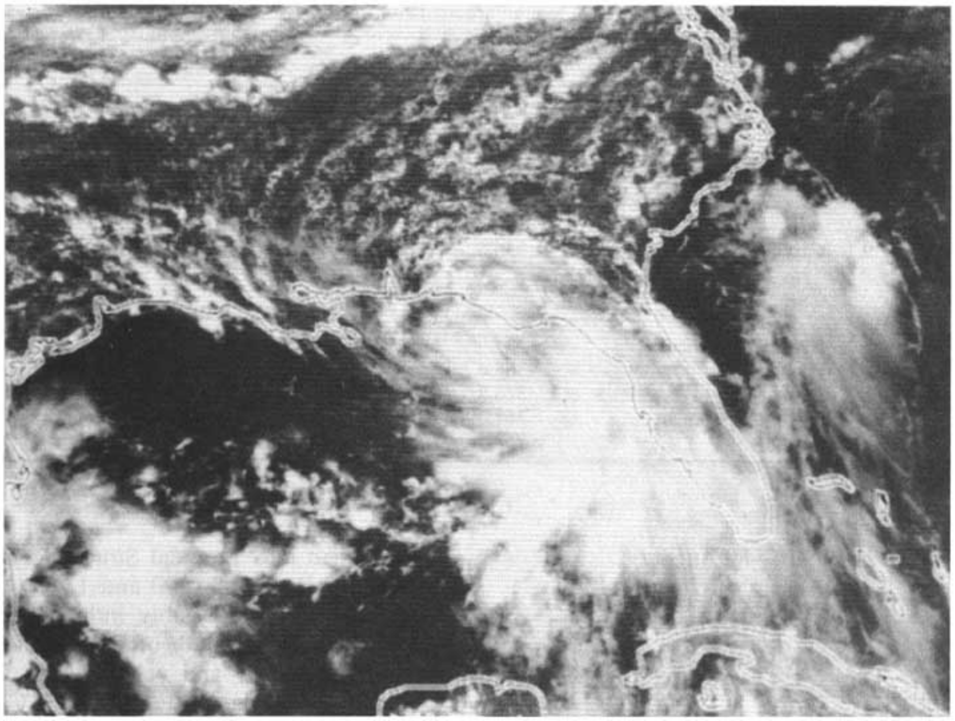

FIG. 5. *GOES-7* visible satellite image of Tropical Storm Beryl at 2001 UTC 14 August 1994, when the tropical storm was centered near the Florida panhandle.

31 m s^{-1} at an altitude of 450 m at 1739 UTC 15 August. A few hours after the center moved inland, the peak wind reported from the aircraft was 34 m s^{-1} over Apalachee Bay at 0415 UTC 16 August. The highest sustained wind reported by a land station was 24 m s^{-1} from Tallahassee at 0619 UTC, also after the center had moved inland. It is likely that the sustained winds over the Apalachee Bay area were somewhat higher at that time. Therefore, it is reasonable to assume that the estimated maximum sustained winds of 26 m s^{-1} with higher gusts at landfall persisted until at least 0600 UTC.

The lowest central pressure reported by U.S. Air Force reconnaissance aircraft was 1001 mb near landfall. However, that aircraft report stated that this pressure was extrapolated from 450 m just offshore while the circulation center was inland. The central pressure had been consistently falling prior to landfall, and it is estimated that the minimum central pressure dropped to 999 mb near 0300 UTC shortly after the storm made landfall. The lowest surface pressure reported by a land station was 1001.3 mb from Panama City as the storm center was passing very nearby.

Table 3a lists selected surface observations associated with Beryl. Reports of sustained tropical storm force winds are noted along the Big Bend area of Florida, from Shell Point and Turkey Point, as well as from Tallahassee.

Rainfall amounts in excess of 250 mm occurred in isolated locations in Florida, Georgia, South Carolina, and North Carolina. Table 3b lists supplementary rainfall totals. Several rivers from Florida to New York reached levels near or above flood stage as a result of the heavy rains.

The highest reported storm surge, not quite 1 m above the normal astronomical tide, came from a National Ocean Survey tide gauge at Apalachicola, Florida. It is likely that somewhat higher values occurred in the Big Bend area to the east of Apalachicola.

The number of tornadoes reported vary depending upon the source. A total of 23 confirmed tornadoes touched down in South Carolina. Five of these tornadoes touched down in Lexington County and another one in Henry County, Virginia. Some newspaper accounts, as well as preliminary National Weather Service reports, indicated as many as 37 tornadoes associated with the dissipating stage of Beryl.

3) CASUALTY AND DAMAGE STATISTICS

No deaths were directly attributable to Beryl. However, injuries occurred, including 37 related to tornadoes in Lexington County, South Carolina.

The preliminary total damage estimate is placed at \$73 million. The state damage estimates include \$40 million from South Carolina (\$37 million from tornado damage in Lexington County alone), \$15 million from Virginia (\$10 million from tornado damage near Martinsville), \$12 million from New York (primarily re-

TABLE 3a. Tropical Storm Beryl selected surface observations, August 1994.

Location	Minimum sea level pressure		Maximum surface wind speed (m s^{-1})			Storm surge (tide height above normal) (m)	Rain (storm total) (mm)
	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]		
Florida							
Panama City (PFN)	1001.4	15/2354	8		16/1048		
Tyndall AFB (PAM)	1001.7	16/0415	8	11	16/1015		20.8
Cape San Blas (CSVF)	1003.0	15/1800	14[b]	18	15/0700		
Apalachicola (AQQ)	1004.0	16/1130	14	24	15/1409	0.9	271.5
Turkey Point (TUPF)			21	29	16/0548		
Shell Point			19	24	16/0630		
Tallahassee (TLH)	1004.7	16/0740	24	29	16/0619		184.2
St. George's Isl. Cswy				30	15/2330		
Cedar Key (CDKF)			13	24	15/2148	0.6[c]	
NOAA buoy 42036 (28.5°N, 84.5°W)	1009.6	16/0000	16[d]	19	15/1900		

[a] Time of 1-min wind speed unless only gust is given.
[b] C-MAN stations report 2-min average winds.
[c] Estimated.
[d] NOAA buoys report 8-min average winds.

lated to flooding), and $5.9 million from Florida (primarily related to flooding).

4) WARNINGS

In the early stages, when the winds associated with Beryl were light and no significant strengthening was forecast, the main threat emphasized in public advisories was heavy rains. When the potential for strengthening became evident as the cyclone's forward speed decreased, the public advisories correctly emphasized the threat of coastal flooding as well as the continued concern for heavy rains. Tropical storm watches and warnings were issued for portions of northwest Florida.

The problems associated with the coastal flooding in the Apalachee Bay area from this tropical storm should serve as a reminder of the much larger problems that will occur in this region from a major hurricane. The highest storm surge potential anywhere in the United States, near 10–11 m, is in this vicinity.

c. Hurricane Chris, 16–23 August

Chris originated as a tropical wave that moved across the African coast and into the eastern tropical Atlantic on 11 August. Moving westward, the wave acquired significant convection and signs of rotation and became a depression on 16 August, midway between Africa and the Lesser Antilles.

The depression strengthened to a tropical storm by 17 August and to a hurricane on 18 August while moving toward the northwest at 5–8 m s^{-1}. This strengthening occurred even though there was evidence of shearing from an upper-level low located to the northwest. Chris remained a hurricane for almost two days before the strong vertical wind shear significantly disrupted the circular symmetry of the cloud pattern and caused weakening. Figure 6 shows Chris located over the open Atlantic.

The weakening storm turned northward on 20 August and northeastward on 21 August, moving on a trajectory around the western periphery of a persistent subtropical high pressure ridge anchored over the central north Atlantic Ocean. The maximum flight-level wind measured by reconnaissance aircraft was 31 m s^{-1} at 700 mb midday on 20 August. This was the first aircraft into Chris and, based on satellite intensity estimates, weakening had already begun. The central sea level pressure by then was up to 1009 mb. [Previously, on 19 August, Dvorak (1984) estimates gave a minimum pressure of 979 mb and a maximum 1-min surface wind speed of 36 m s^{-1}.] The center passed about 140 km east of Bermuda late on 21 August, but maximum winds were only 18 m s^{-1} at this time and these winds were on the east side of the center. Sustained winds at Bermuda remained below 8 m s^{-1}.

Accelerating northeastward, Chris strengthened again to 23 m s^{-1} while staying ahead of a cold front. By 24 August, the storm merged with an extratropical baroclinic zone southeast of Newfoundland and shortly lost its identity.

There were no casualties or damage from Chris. Tropical storm force winds did not occur at Bermuda but the island received 71.9 mm of rain associated with Chris. A tropical storm watch was issued for Bermuda at 0300 UTC 21 August and a tropical storm warning was issued at 0900 UTC on the same day. The warning was discontinued at 0000 UTC 22 August.

TABLE 3b. Supplementary rainfall totals (mm) associated with Beryl.

Location	Amount
Florida	
South Venice (VNCF1)	160.0
Perry	194.6
Quincy	144.3
Monticello	143.5
Georgia	
Tallula Falls	345.2
Cornelia	226.8
Cleveland	178.3
Elberton	170.2
Toccoa	156.7
Gainsville	148.3
Athens	141.0
Bainbridge	141.7
South Carolina	
Walhalla	260.1
Tuxedo	204.2
Salem	204.0
North Saluda	192.8
Lake Jocassee	184.4
Clemson	176.8
Anderson	157.5
Travelers Rest	154.9
Cleveland	153.4
Ceasars Head	142.2
Pickens	136.9
Chappells	125.5
Aiken	107.7
Antreville	103.1
North Carolina	
Lake Toxaway	345.0
Hendersonville	265.9
Lake Lure	254.0
Table Rock	237.7
Rosman	237.5
Mount Mitchell	235.7
Wilkesboro	201.2
Lenoir	195.9
Pisgah Forest	187.2
Highlands	185.7
Blowing Rock	178.8
W. Kerr Scott Reservoir	178.6
Virginia	
Gordonsville	151.9
The Plains	114.0
Glasgow	110.2
Winchester	110.0
Pennsylvania	
Harrison Park	106.7
Canton	105.4
Trout Run	126.7
Cammal	102.6
New York	
Tully	107.7
Southport	99.1
Elmira	94.0

d. Tropical Storm Debby, 9–11 September

Tropical Storm Debby lasted only two days, but locally heavy rain and gusty winds from the cyclone, as well as its remnants, led to the deaths of nine people near its track across the eastern Caribbean Sea and adjacent islands.

1) SYNOPTIC HISTORY

Debby formed from a westward-moving tropical wave that entered the eastern tropical Atlantic on 4 September. Satellite pictures showed that the system was quite large and that it comprised several clusters of strong convection when located midway between Africa and the Lesser Antilles islands late on 7 September.

At 1200 UTC 9 September, a ship located about 230 km southeast of Barbados reported a light north wind just ahead of the system. About 12 h later, surface observations and satellite pictures suggested that a surface circulation center was located just west or northwest of Barbados. NOAA was then conducting the first reconnaissance flight into this system. At a flight-level of 450 m, 26–31 m s^{-1} winds were measured in a 35–55-km-wide band that was centered in the vicinity of thunderstorms about 75 km north through east of the center. They also estimated surface winds of 26 m s^{-1}. A few hours later, this part of the system passed over Martinique. Surface observations from Martinique and a nearby ship indicate that, despite the disorganized appearance on satellite pictures (e.g., Fig. 7), the system was then a tropical storm with 1-min wind speeds of about 31 m s^{-1}. It is estimated that about 18 h earlier (at 1200 UTC 9 September) the system had become a tropical depression with a strong circulation aloft. In the vicinity of Martinique, the winds were efficiently conveyed to the surface by thunderstorms.

The tropical cyclone moved toward the west-northwest at about 9 m s^{-1}. Westerly vertical wind shear affected the growth of the cyclone by limiting the amount and intensity of thunderstorms and by displacing most of that activity 100–275 km to the east of the low-level circulation center. The flight-level and estimated surface wind speeds reported by the Air Force Reserve Hurricane Hunter's near 1200 UTC 10 September were not as strong as noted earlier but, just 6 h later, returned to magnitudes that were comparable to those found on the NOAA flight. Meanwhile, the winds at Martinique only slowly abated as the storm receded. Hence, while some fluctuation in surface wind speed likely occurred in association with the variations in deep convection, it is estimated that the surface wind speeds in Debby remained around 26–31 m s^{-1} through 10 September.

Even though the system continued to produce locally strong winds on 11 September, its circulation became more disrupted by the strong wind shear. By 0200 UTC, a closed circulation center could not be identified by the crew aboard the reconnaissance aircraft. The cyclone is analyzed then as degenerating back to a vigorous tropical wave.

The wave continued to produce locally heavy rain and gusty winds that spread across Hispaniola on 11

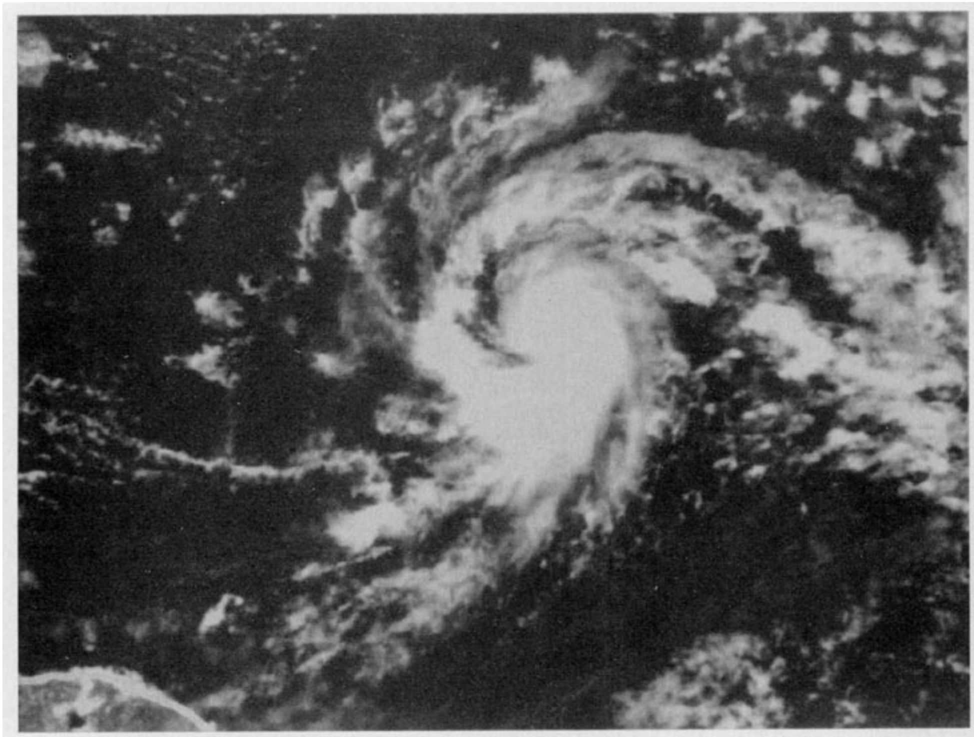

FIG. 6. *Meteosat-3* visible image of Hurricane Chris at 1700 UTC 17 August 1994, when the tropical cyclone was located over the open tropical Atlantic.

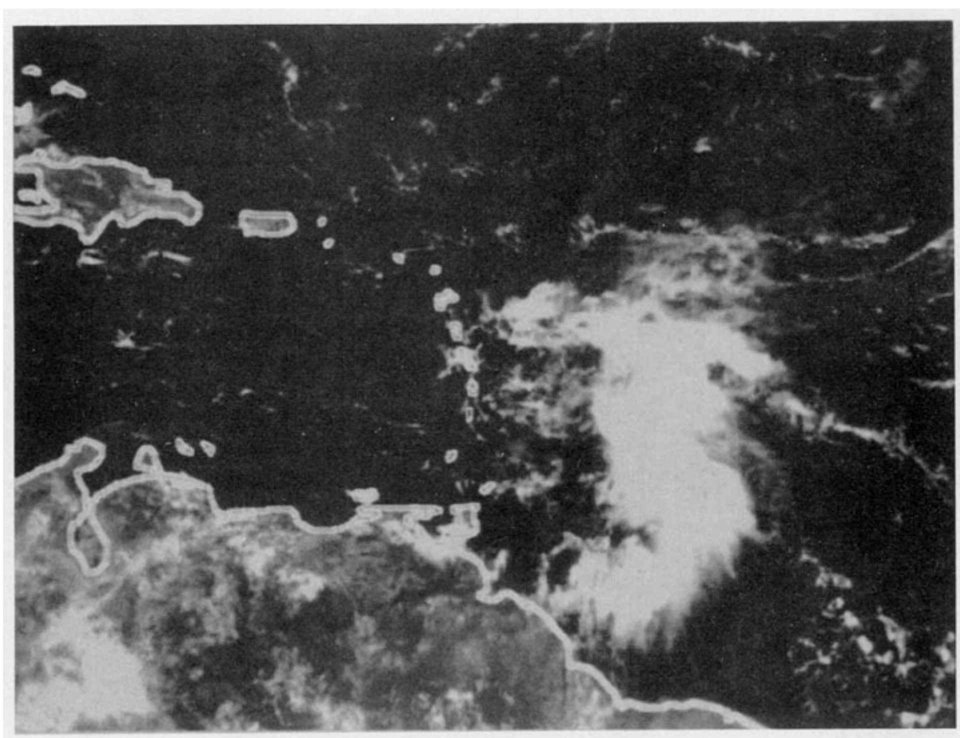

FIG. 7. *Meteosat-3* visible satellite image of Debby at 1600 UTC 9 September 1994 during the storm's developing stage.

September. These conditions advanced westward before diminishing over the northwest Caribbean Sea and adjacent portions of Mexico on 15 September. Satellite pictures indicate that some of the activity could also have spread into the southeastern Gulf of Mexico.

2) METEOROLOGICAL STATISTICS

The 31 m s^{-1} maximum 1-min surface wind speed is primarily based on hourly reports from two observation sites in Martinique (Table 4). At Le Vauclin, on the southeast coast, 10-min winds of 29 m s^{-1} with a gust to 44 m s^{-1} were recorded. At the Morne des Cadets observatory, the maximum 10-min wind was 28 m s^{-1} with a gust to 43 m s^{-1}. (The maximum 1-min wind speed is usually a little higher than the associated 10-min average.) The nearby ship *PJRB* (name unknown) reported a sustained wind of 23 m s^{-1} at 0600 UTC, and this likely does not represent the storm's maximum wind at that time.

In addition, the meteorological service of the Dominican Republic reported gusts to 28 m s^{-1} on 11 September, but this could have come after Debby ceased to exist as a tropical cyclone.

The ship *PJRB* reported 1000.7 mb at 0600 UTC 10 September. This pressure is believed to be incorrect. A pressure of 1007.0 mb would have been more appropriate for that time at their location.

An isohyet analysis (not shown) by the meteorological service of Martinique indicates that about one-half of that island had at least 100 mm of rain. The largest total was 183.8 mm at Saint Joseph/Rabuchon.

3) CASUALTY AND DAMAGE STATISTICS

A total of four people were killed (in two landslides) and 24 injured in St. Lucia. There was one drowning in Martinique and another (a fisherman) off the southwest coast of Puerto Rico. Three deaths (apparently related to downed power lines) were reported in the Dominican Republic. The deaths in the Dominican Republic occurred on 11 September, possibly after Debby had reverted back to a tropical wave.

The Associated Press indicated that the worst damage occurred in St. Lucia, where rains caused landslides that blocked main roads. Two inches of silt covered the runways at the main international airport. The rains caused floods that washed away hillside shacks, eight bridges, and portions of some roadways. Water was chest-high in the village of Anse La Raye. Debby's winds damaged banana plantations in St. Lucia.

In Martinique, some towns were flooded, while wind-felled trees blocked some roads. The banana crop was also damaged in Martinique. About 20 000 residents lost power and schools were closed.

The meteorological service of the Dominican Republic reported that some rivers flooded.

The number of people left homeless in the area affected by Debby was estimated to be in the hundreds.

e. Tropical Storm Ernesto, 21–26 September

Ernesto was a relatively short-lived tropical storm that spent its existence over the open waters of the eastern Atlantic Ocean. It developed from a tropical wave that emerged from the coast of western Africa on 18 September. It is interesting to note that this was one of several strong-looking waves (in terms of amount and organization of deep convection) to appear over the extreme eastern tropical Atlantic in the latter part of September. These waves came after a period of quietude (i.e., weak-looking systems) during the clima-

TABLE 4. Tropical Storm Debby selected surface observations, September 1994.

	Minimum sea level pressure		Maximum surface wind speed (m s^{-1})		
Location	Pressure (mb)	Date/time (UTC)	Sustained wind*	Peak gust	Date/time (UTC)
Land Sites					
Le Vauclin, Martinique			29	44	10/0600
Mornes des Cadets, Mart.			28	43	10/0700
TFFF Le Lamentin, Mart.	1007	10/0600	16	26	10/0600, 0700, 0800
TDCF (Dominica)			14	21	10/1200
TBPB (Barbados)	1009	09/2100, 2200	12		10/0400
Hewanorra, St. Lucia	1008	10/0600	14	18	10/1145
Vigie, St. Lucia			13	21	10/1200
Ship reports					
ELQN2 (16.3°N, 59.7°W)			19		10/1500
PJRB (14.5°N, 61.1°W)	1000.7**	10/0600	23		10/0600

* Averaging period is 10 minutes, except 1-min at St. Lucia and unknown for ships. Observations are hourly for land sites and 3 or 6 h for ships; time is for sustained wind.

** Probably was 1007.0 mb.

tological "peak" of the Atlantic hurricane season, late August to early September.

It is estimated that the tropical depression stage of Ernesto began at 1800 UTC 21 September when the system was located about 925 km southwest of the Cape Verde Islands and was moving slowly northwestward. At upper-tropospheric levels, a southwesterly flow prevailed in the environment of the depression. However, the vertical shear was apparently just weak enough to permit the system to strengthen. While the depression was developing, a midtropospheric trough dominated the east-central subtropical Atlantic. This created a southerly steering flow over the tropical cyclone. The cyclone turned northward and became a tropical storm around 1200 UTC 22 September. Additional strengthening occurred on 22 September and Ernesto reached its peak intensity, estimated near 26 m s^{-1}, around 0000 UTC 23 September. Figure 8 shows a Meteosat visible satellite image of Ernesto a few hours before peak intensity.

As the storm moved farther north, it entered a region of stronger upper-tropospheric flow and stronger shear. Steady weakening began on 23 September. Most of the deep convection associated with Ernesto was gone by 1200 UTC 24 September, and Ernesto diminished to a tropical depression around that time. Moving very slowly, the system (then a swirl of low clouds with isolated thunderstorms) turned northwestward, then westward, by 25 September. By about 0000 UTC, the cyclonic circulation inferred from the cloud pattern was very weak and Ernesto was dissipating. Notwithstanding, a remnant disturbance with occasionally deep convection was steered west-southwestward to westward by the lower-tropospheric winds for several days. The remnant disturbance was last identifiable about 1450 km to the east of the Leeward Islands at 1800 UTC 29 September.

f. Hurricane Florence, 2–8 November

Hurricane Florence developed from a low pressure system that formed at the end of October along a stationary frontal band about 1850 km to the east-southeast of Bermuda. The low gradually acquired a closed surface circulation when the portion of the front in its vicinity dissolved during the first day or two of November.

A curved band of deep convection developed to the north through northeast of the low on 2 November. Ship reports indicate that the system's strongest surface winds were then associated with a distant portion of the convective band, about 350 km to the northeast of the center. These features are characteristic of a subtropical cyclone. It is estimated that the cyclone became a subtropical depression at 0000 UTC 2 November. Ship reports of 18 m s^{-1} winds in the convective band support designating the system a subtropical storm for part of the day on 2 and 3 November.

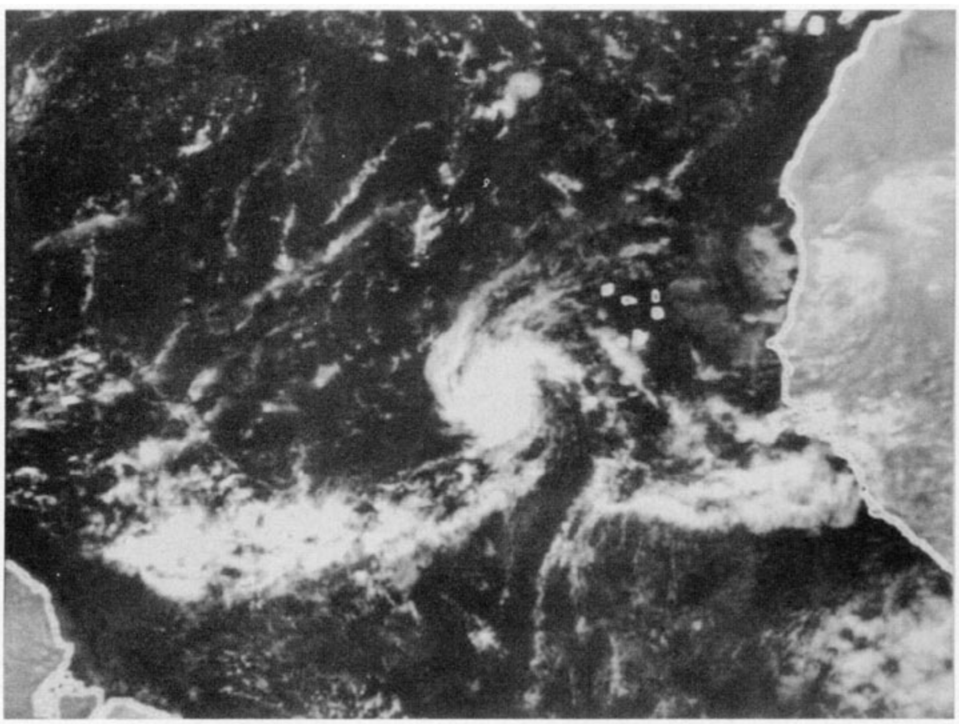

FIG. 8. *Meteosat-5* visible satellite image of Tropical Storm Ernesto at 1600 UTC 22 September 1994, when the storm was located over the far east Atlantic.

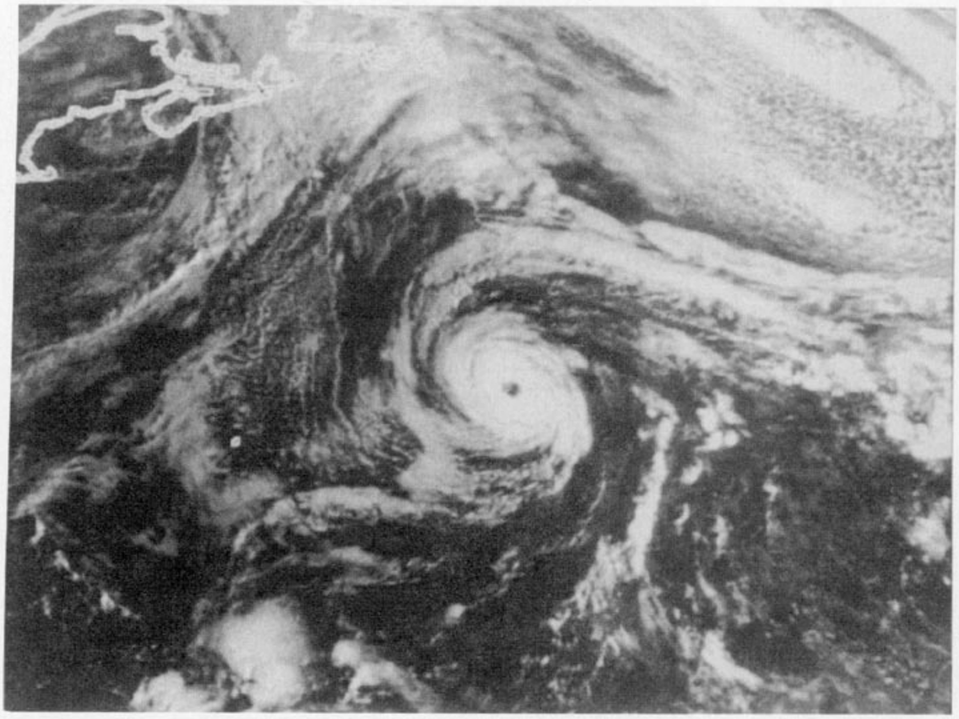

FIG. 9. *Meteosat-3* visible satellite image of Hurricane Florence at 1200 UTC 7 November 1994, showing the hurricane with a large eye.

The distant area of associated convection weakened on 3 November and ship reports suggest that maximum wind speeds decreased to about 18 m s^{-1}. However, deep convection then became concentrated near the circulation center and the system made a transition from subtropical to tropical. It is estimated that the cyclone became Tropical Storm Florence at 0000 UTC 4 November.

Florence moved toward the northwest at about 4 m s^{-1} before turning toward the north at a decreased speed on 6 November. Although upper-level outflow was restricted to the south, the cyclone strengthened early in this period. Satellite pictures revealed a partially developed eye for the first time around 1700 UTC 4 November, and the system reached hurricane strength about that time. The eye was occasionally noted, but analyses of satellite pictures implied no significant change in strength over the following three days. The only reconnaissance mission in Florence, near 1800 UTC 6 November, encountered 37 m s^{-1} maximum winds at a flight level of about 3 km and a central pressure of 982 mb.

The hurricane was located about 1300 km to the east of Bermuda when it reached the westernmost point of its track near 1200 UTC on 6 November. The hurricane had become nearly stationary at that point. It then turned toward the northeast and accelerated in response to a large and powerful midlatitude storm that approached Florence from the Canadian maritime provinces. Only 24–30 h later, the associated steering currents were moving Florence toward the northeast at nearly 20–25 m s^{-1}.

A distinct eye surrounded by moderately deep convection was seen on satellite pictures on 7 November, and the hurricane is estimated to have reached its peak intensity of 49 m s^{-1} and 972-mb central pressure at 0000 UTC 8 November. Florence was then within a narrowing sector of warm air between the large storm to its northwest and another to the northeast. The eye diameter widened from about 35 to 55–65 km. The eye associated with Florence is seen in Fig. 9. The eye remained apparent until about 1800 UTC, when Florence began moving over water temperatures below 20°C, and was overtaken and absorbed by the rapidly moving cold front previously located to its northwest.

The maximum intensity inferred from application of the Dvorak technique to satellite imagery was about 39–46 m s^{-1} for Florence. However, this technique does not include an adjustment to the wind speed that accounts for the translational speed of exceptionally fast moving cyclones. The estimated maximum intensity of 49 m s^{-1} for Florence on 8 November incorporates an attempt to make a reasonable adjustment for that characteristic. There were no surface observations to confirm or reject this estimate. Florence did not directly affect land and the NHC received no reports of damages or casualties.

g. *Hurricane Gordon, 8–21 November*

Gordon, a complex system, followed an unusual, erratic path over the western Caribbean, Florida, and the southwestern Atlantic (cf. Figs. 1, 10). Its torrential rains caused a catastrophic loss of life in Haiti and extensive agricultural damage in south Florida.

1) SYNOPTIC HISTORY

Disturbed weather was noted over the southwestern Caribbean Sea during much of the first week of November. Convection over the area was enhanced by the passage of two tropical waves during this period. The second of these waves induced the formation of a lower-tropospheric cyclonic circulation, as indicated by rawindsonde data, just to the north of Panama around 0000 UTC 6 November. Early on 8 November, the associated deep convection became concentrated in a cluster not far offshore of the southeast coast of Nicaragua. By 1800 UTC that day, satellite intensity estimates and surface observations implied the presence of a 13 m s^{-1} cyclonic circulation. The tropical depression stage of Gordon began at this time.

There was limited upper-level outflow from the system, primarily to the north and northeast, which favored very slow strengthening. The depression moved toward the coast of Nicaragua, and a U.S. Air Force Hurricane Hunter plane investigating the system found that the center was very near the coast by 1800 UTC 9 November. Spot wind reports from the aircraft suggested that the cyclone was nearing storm strength. However, the close proximity to land apparently inhibited further intensification. The center hugged the coast of Nicaragua from 0000 to 1200 UTC on 10 November and is estimated to have moved just onshore near Puerto Cabezas at 0600 UTC. Then, in response to a trough aloft to the northwest, the tropical cyclone turned northeast, moving back over the western Caribbean, and strengthened into Tropical Storm Gordon by 1800 UTC. Data from Hurricane Hunter flights into Gordon showed that little additional intensification occurred over the ensuing 24 h as the storm moved slowly north-northeastward. Surface and aircraft data showed that Gordon consisted of a broad cyclonic circulation, which covered much of the western Caribbean. Embedded within that broad circulation was a smaller-scale vortex that helped to define Gordon's center.

Visible satellite pictures on 11 November revealed that Gordon was being sheared by upper-level west-southwesterly flow. On 12 November, Gordon turned east-northeastward and eastward, heading for Jamaica. Although bursts of strong convection were occurring near and east of the estimated storm center, the system remained disorganized with maximum sustained winds near 21 m s^{-1}. The low-level center of Gordon was clearly exposed on visible satellite pictures on 12 November. Gordon's center moved across eastern Jamaica early on 13 November and accelerated further, nearing eastern Cuba by 1200 UTC that same day. As Gordon passed near Guantanamo, Cuba, the center became disorganized and difficult to locate. However, it is estimated from surface synoptic reports that the center that was previously being tracked moved rapidly northward across Cuba and was nearing the southern Bahamas by 1800 UTC 13 November. Around that time, Gordon's structure started to become more complicated.

While Gordon was crossing Cuba, an upper-tropospheric trough, which had been intensifying along 80°W north of 20°N, was cutting off a cyclonic circulation near the Straits of Florida. This upper-level system appeared to induce surface cyclogenesis in the vicinity of the central Bahamas. From 1800 UTC 13 November through 0000 UTC 14 November, there were multiple low-level centers embedded within a broader-scale circulation that covered most of central-eastern Cuba and the Bahamas. This larger circulation had accompanied Gordon since the tropical cyclone's inception but was strengthened and modified by the influence of the upper-level cyclone. After 0000 UTC 14 November, the cloud pattern and surface wind field resembled that of a subtropical cyclone, with a center of circulation becoming dominant just to the south of the central Bahamas.

A deep-layer ridge near the U.S. mid-Atlantic coast and a larger-scale deep-layer cyclone (within which Gordon was embedded) provided a steering current that carried Gordon, in its transformed state, west-northwestward. As a result of the increased surface pressure gradient between the broad low that accompanied Gordon and the high to the north, winds increased to near gale force over portions of the Florida peninsula late on 13 November. The center of Gordon passed south of the western Bahamas on 14 November and moved across the Straits of Florida early on 15 November. During this time, there was a lack of deep convection near the center and strongest winds were well-removed from the center. Radiosonde data were indicative of a cold-core system, except over the eastern portion of the circulation where warmer mid-tropospheric air was still prevalent.

As Gordon moved over the Straits of Florida, U.S. Air Force Hurricane Hunters estimated that the center was rather close to the coast of Cuba. However, the circulation was broad at this time, with light winds covering much of the southern Straits. Just before dawn on 15 November, radar observations from Key West suggested a reformation of Gordon's center just to the south of the lower Florida Keys, closer to deep convection. A special radiosonde release from Key West at 0600 UTC showed midtropospheric warming near the center of cyclone, indicating that Gordon was beginning to become more completely tropical. The center moved northwestward over the lower Keys and decelerated over the extreme southeast Gulf of Mexico. Early on 16 November, Gordon turned northward, and

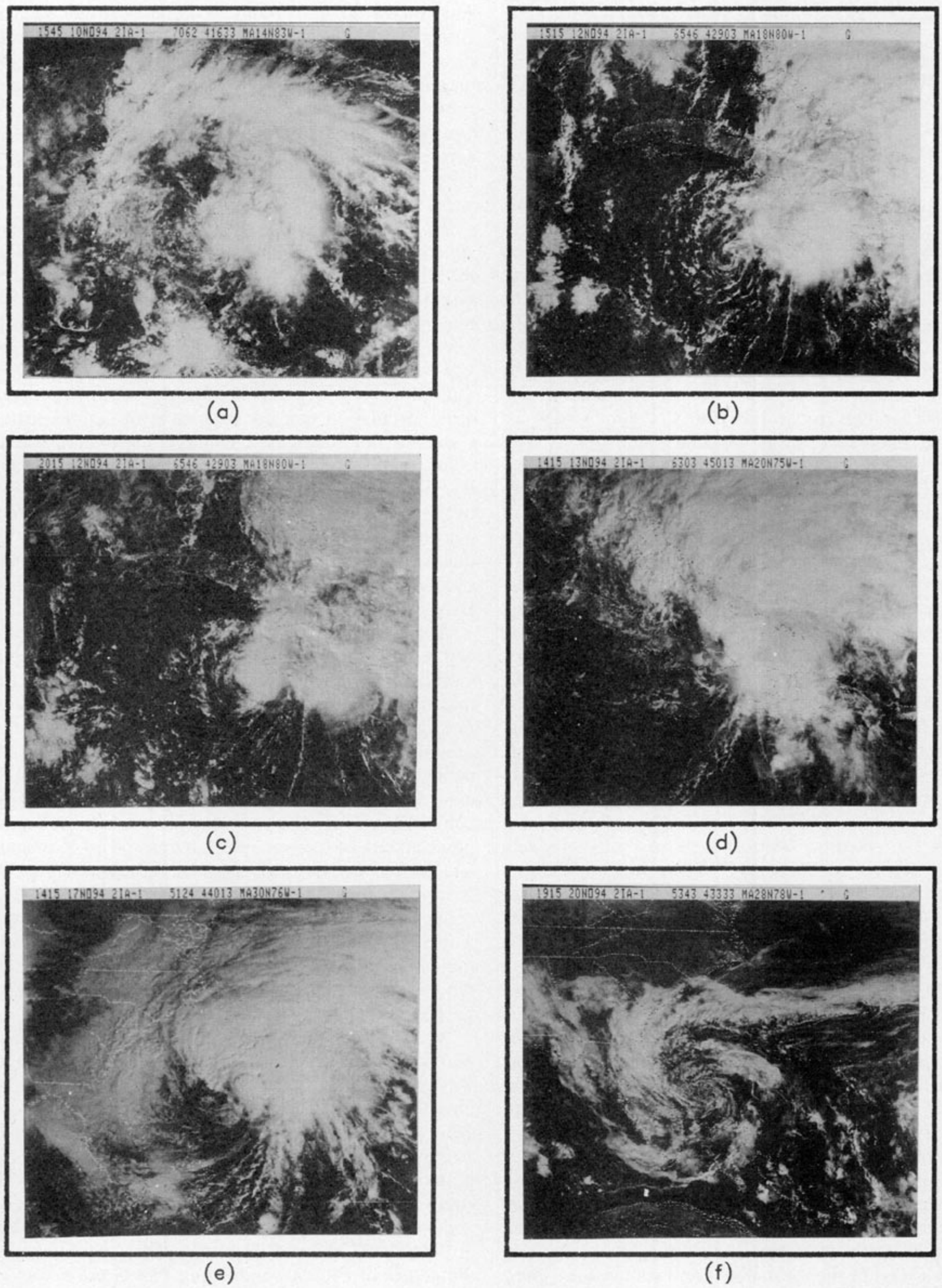

FIG. 10. (a)–(f) Time sequence of *GOES-7* visible satellite images from 10 to 20 November, showing Hurricane Gordon. Time of images are indicated at the top left corner of the image.

then north-northeastward, recurving under the influence of a mid- to upper-tropospheric shortwave trough moving eastward from the central United States. By 1300 UTC that day, the center crossed the southwest coast of Florida near Fort Myers. Maximum sustained winds were then near 23 m s^{-1}.

Gordon crossed the Florida peninsula, and its center emerged over the Atlantic just north of Verc Beach around 2200 UTC 16 November. Central pressure was falling, and based on a report from the ship *Hoegh Dyke*, the maximum winds increased to near 28 m s^{-1} shortly after Gordon moved back over the water. Gordon's northeastward motion increased on 17 November, and it strengthened into a hurricane. Just when it appeared to be headed safely out to sea, however, the hurricane abruptly slowed down and turned northward, then northwestward, and then west-northwestward, threatening the coast of North Carolina. This turn of events could be attributed to a midtropospheric ridge that built over the eastern United States behind the short-wave trough that had brought about Gordon's latest recurvature and the fact that the trough essentially "out ran" Gordon. The center of the hurricane came within about 150 km of the Outer Banks at 1200 UTC 18 November before turning southward and south-southeastward. Gordon weakened to a tropical storm around 1800 UTC 18 November as it entrained cooler, drier air into its circulation and was affected by northwesterly shear. Turning southward and then southwestward, weakening Gordon executed a "figure 8" track off the southeast U.S. coast. Gordon lost most of its deep convection on 19 November and weakened to a depression early on 20 November. The weakening depression turned westward and west-northwestward, crossing the coast of Florida near Cape Canaveral as an inconsequential tropical cyclone. Gordon turned northward, then north-northeastward, crossed Georgia, and dissipated over South Carolina.

2) METEOROLOGICAL STATISTICS

Table 5 lists selected surface observations taken during Gordon. A number of observing sites reported sustained winds of tropical storm force. Some regional maxima are of interest. In Florida, the highest known sustained wind speed measurement from a land station, 24 m s^{-1}, was from Virginia Key. A peak gust of 37 m s^{-1} was recorded by an amateur meteorologist in southern Dade County. A 10-min average wind speed of 32 m s^{-1} was obtained from Diamond Shoals lighthouse off the North Carolina Outer Banks. The 31 m s^{-1} 1-min winds with peak gusts to 54 m s^{-1}, reported from the Guantanamo U.S. Navy base, occurred in a thunderstorm microburst and is not considered representative of the intensity of the tropical storm when it was near that site. There were a number of ship reports of tropical storm force winds associated with Gordon. Ships *Advantage* and *Tropic Sun* reported the highest sustained winds, 35 m s^{-1}, and ship *Star Evviva* reported the lowest pressure, 987 mb.

The Hurricane Hunter unit carried out numerous missions into Gordon, providing valuable information on the cyclone's position, intensity, and wind distribution. Gordon's peak intensity is estimated to have occurred around 0000 UTC 18 November, when reconnaissance data indicated a minimum pressure of 980 mb. Peak flight-level (700 mb) winds of 49 m s^{-1} were measured at 0123 UTC. This suggests maximum 1-min surface winds near 39 m s^{-1}.

Gordon produced heavy rains over Jamaica, eastern Cuba, and Hispaniola. In Hispaniola the persistent southerly flow to the east of the broad circulation that accompanied Gordon, combined with upslope motion over steep topography, generated prolonged rains that led to disastrous floods and mud slides. Gordon also dumped heavy rains over the Florida peninsula, except for the west coastal area north of Fort Myers. Storm total rainfall amounts of 150–225 mm occurred over most of the eastern third of the peninsula, with totals to almost 280 mm in Volusia County, 320 mm over portions of Dade County, and as high as 400 mm in Broward County.

There were six tornadoes confirmed in association with Gordon, all in Florida. Four of these were in Palm Beach County: one in Delray Beach; one in Jupiter; one in Gulf Stream; and one in Lake Worth. A tornado touchdown was also reported in southern Volusia County in the Iron Bend area. By far the most significant tornado occurred in southern Brevard County near the towns of Micco and Barefoot Bay. This tornado originated as a waterspout and moved onshore along a west-northwest path, striking the Snug Harbor/Barefoot Bay mobile home communities. Its remnant, a funnel cloud, was last sighted near Interstate 95 in southern Brevard County.

3) CASUALTY AND DAMAGE STATISTICS

Although the exact death count will probably never be known, flooding and mud slides due to Gordon caused a catastrophic loss of life in Haiti. For this summary, we relied on a report from the United Nations Department of Humanitarian Affairs, Geneva, on 21 December 1994, which stated that the death toll in Haiti was "finally estimated" at 1122.

United Press International (UPI) reports indicate that there were six deaths in Costa Rica. Other reports show five deaths in the Dominican Republic, two in Jamaica, and two in Cuba.

There was a total of eight deaths in Florida directly attributable to Gordon. One man drowned off Ft. Lauderdale Beach in Broward County in a rip current while rescuing his 8-yr-old son. One male surfer drowned off Haulover Beach in north Dade County. One woman drowned along a north Dade beach. One man drowned and one woman nearly drowned in Dade County when a car plunged into the Miami River during heavy rains.

TABLE 5. Hurricane Gordon selected surface observations, November 1994.

Location	Minimum sea level pressure		Maximum surface wind speed (m s^{-1})			Storm surge (tide height above normal) (m)	Rain (storm total) (mm)
	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]		
Florida							
NOAA buoy 41010 (28.9°N, 78.5°W)	988.2	17/0700	18[b]	24	17/0800		
NOAA buoy 41006	990.2	17/1000	18[b]		17/0600		
Vero Beach Airport (VRB)	994.9	16/2151	19		15/0423		160.0
Melbourne (Palm Bay)	995.0	16/1630	15	19	15/1625		167.4
Melbourne Airport (MLB)	996.3	16/2250	20		15/2028		233.7
Melbourne Beach				23	15/2019		
Naples Airport (APF)	996.3	16/1155	10	15	16/0816, 1031		
NOAA Buoy 41009 (28.5°N, 80.2°W)	996.4	17/0000	15[b]	23	16/0900		
Fort Myers (FMY)	996.6	16/1355					
Regional SW Airport (RSW)			14	23	16/1648		
West Palm Beach (PBI)	998.0	16/2145	18	25	16/0404		225.3
Lake Worth C-MAN	998.9	16/2100	21[c]	27	14/1300		
Fort Lauderdale Executive Airport (FXE)	998.6	16/2147	13	15	16/1747		
Miami Beach (MIBF1)			18	25	14/1448	0.6[d]	146.3
NOAA buoy 42037 (24.5°N, 81.4°W)	998.9	15/1000	13[b]	18	14/1400, 1600		
Long Key C-MAN	999.1	15/0800	15[c]	18	14/1700		
Fort Lauderdale–Hollywood International Airport (FLL)	999.3	16/1950	14	21	15/1050		
West End (Grand Bahama) C-MAN			14[c]	18	14/1800		
Sombrero Key C-MAN	999.4	15/0800	18	20	14/2200		
Key West (EYW)	999.7	15/0920	13	22	14/2030	2.1	
Sand Key C-MAN	999.9	15/0800	19[c]	22	14/1900		
Molasses Reef C-MAN	1000.2	15/0700	20[c]	26	14/1300		
Miami International Airport (MIA)	1000.0	16/2000	13	22	15/1506		
Tamiami Airport West Kendall (TMB)	1000.3	16/1950	13	19	15/0247		166.6
Opa-Locka (OPF)	1000.3	16/2247	13	20	15/1547		
Orlando Airport	1000.3	16/2150	9	14	17/0050		
AOML (Virginia Key)	1001.0	16/2200	24	29	15/0540		171.7
Miami (12245 SW 71 Ct)	1001.3	16/2010	11	37	15/0605		269.2
Fowey Rocks C-MAN	1001.0	16/2000	24[c]	28	15/0800		
Homestead AFB (HST)	1001.4	16/2055					334.0
Dry Tortugas C-MAN	1000.4	15/1900	16[c]	21	14/2200		
Daytona Beach	1001.8	16/1930, 2100					271.8
Hialeah (4391 W. 9 Ct.)	1003.7	16/1959	10	15	15/0359		131.8
Saint Augustine C-MAN	1004.8	16/2200	14[c]	19	17/0000		
Cooperstown (central Broward County)							408.9
Andytown (central Broward County)							406.4
Fort Lauderdale (Dixie Water Plant)							327.9
Hollywood							310.1
North Dade County (Norwood Water Plant)							297.9
North Miami (Keystone Point)							281.7
Boynton Beach							274.1
Coral Springs							256.3
Palm Beach Gardens							247.7
West Perrine							241.3
Boca Raton							232.2
Sanford							223.5
Titusville							222.3
Melbourne NWSO							215.9
Vero Beach 4W							213.3
Stuart							202.0
Belle Glade							144.3
Orlando MCO							147.3
Clewiston							104.4
Imokalee							95.5
Moore Haven							86.1
Naples (Naples Conservatory)							61.7

TABLE 5. (*Continued*)

Location	Minimum sea level pressure: Pressure (mb)	Minimum sea level pressure: Date/time (UTC)	Maximum surface wind speed ($m\ s^{-1}$): 1-min average	Maximum surface wind speed ($m\ s^{-1}$): Peak gust	Maximum surface wind speed ($m\ s^{-1}$): Date/time (UTC)[a]	Storm surge (tide height above normal) (m)	Rain (storm total) (mm)
North Carolina							
Diamond Shoals C-MAN	999.5	18/0900	32[c]	39	18/0700		
Buxton	1000.2	18/1030	23	23	18/1043	0.8	32.8
MCAS Cherry Point	1001.3	18/0555	11	18	18/1430		28.4
MCAS New River	1002.7	18/0610	12	21	18/1156		7.6
WSO Wilmington (ILM)	1004.5	18/1050	14	19	18/1750		3.8
NOAA buoy 41002 (32.3°N, 75.2°W)	992.5	19/0100	18[b]	19	18/2300		
NOAA buoy 41001 (34.7°N, 72.6°W)	1002.7	18/0300	24[b]	32	18/0300		
NOAA buoy 41004 (32.5°N, 79.1°W)	1004.5	17/1000	18[b]	23	17/1000		
Bahamas							
Cockburn, S. Salvador	1000.7	14/0000					
NOAA buoy 41016 (24.6°N, 76.5°W)	1000.7	14/0900	20		14/0000		
Nassau			10	17	13/1500		
Kemp's Bay, Andros			21		14/0000		
Cuba							
Guantanamo	999.0	13/0900	31	54	13/0858		
Jamaica							
Kingston	1002.0	13/0429	13		12/2300		

[a] Time of 1-min wind speed unless only gust is given.
[b] NOAA buoys report 8-min average winds.
[c] C-MAN stations report 2-min average winds.
[d] Estimated.

One man drowned in Dade county when a car plunged into a canal during heavy rains. Two men drowned when a boat was overturned at Hillsboro Inlet in Broward county by swells from Gordon (then located off the Georgia coast). One man was killed by trauma to the head received during the tornado in Brevard county. This tornado also caused 40 injuries (six people hospitalized, two serious injuries).

Most of Gordon's damage in Florida was due to freshwater flooding of agricultural areas (vegetables and tropical fruits were the most severely affected crops) in Dade and Collier Counties. In south Florida, some trees, power lines, and traffic signals were blown down. Power was disrupted to 425 000 customers. Gordon caused a 154-m Turkish cargo vessel to drag anchor off Ft. Lauderdale, running it aground less than 45 m off the beach.

Tornadoes in Jupiter and Gulf Stream caused no known damage; the tornado in Delray Beach caused minor damage; and the tornado in Lake Worth uprooted several trees and damaged two business and 39 homes. The Volusia County tornado knocked down numerous trees and did minor damage to homes. The Brevard County tornado did considerable damage in the Snug Harbor/Barefoot Bay mobile home communities. About 62 mobile homes were destroyed, 46 received major damage, and 181 had minor damage.

A 15-m sailboat was disabled about 185 km off of Norfolk, Virginia. The vessel's crew of three was rescued via helicopter by the U.S. Coast Guard.

TABLE 6. Official average track forecast errors (km), by storm, Atlantic, 1994, excluding extratropical, subtropical, and tropical depression stages.

	Forecast period (h): 0	12	24	36	48	72
1994 average	22	96	191	282	389	634
(number of cases)	(112)	(98)	(84)	(72)	(62)	(50)
1984–93 average	30	96	187		369	560
1994 departure from 1984–93 average	−25%	00%	+02%		+06%	+13%

TABLE 7. Official wind speed forecast errors (m s^{-1}), Atlantic, 1994. Error = forecast − observed.

	Forecast period (h)					
	0	12	24	36	48	72
1994 mean	−1.3	−1.2	−0.7	−0.5	−0.7	+0.2
1994 mean absolute	2.4	3.8	5.2	6.3	7.6	9.5
Max. absolute error (No. of cases)	−15 (112)	−15 (97)	−15 (83)	−21 (72)	+21 (62)	−23 (50)
1984–93 mean	−0.9	−0.8	−1.1		−2.2	−2.5
1984–93 mean absolute	2.5	4.0	5.9		8.4	10.6
1994 departure from 1984–93 mean absolute	−04%	−05%	−13%		−10%	−10%

There was significant beach erosion along portions of the Florida east coast and the North Carolina coast. Five homes were destroyed along the Outer Banks. However, those structures had already been condemned due to damages received one year earlier in Hurricane Emily.

Gordon caused an estimated $275 million in agricultural losses in Florida. Insured property damage, not including that covered by the Federal Flood Insurance Program, is estimated at $60 million. Additional damage to property covered by the Flood Program, uninsured property, utilities, and public works brings the total damage estimate from Gordon in the United States to near $400 million.

4) WARNINGS

Predicting the track of Gordon proved to be a challenge for forecasters. The objective track prediction models frequently had trouble handling this atypical system and often gave conflicting guidance; this translated into some large official forecast errors. Due to Gordon's complex track, watches and warnings were required for portions of Cuba, Jamaica, Hispaniola, the Bahamas, and portions of the eastern United States coast.

The tropical storm warning issued for southeast Florida and the Keys on 14 November replaced a gale warning that had been in effect since the previous day. This was done to heighten awareness of the weather situation, even though the predicted wind conditions had not changed significantly.

3. Verification

There were 112 verifiable official forecasts for tropical storms and hurricanes in the Atlantic basin in 1994. The average track errors shown in Table 6, along with a comparison to the previous 10-yr average. The 72-h errors are 13% larger than the previous 10-yr average. Errors for other periods were comparable to the 10-yr averages.

Errors of the official wind speed forecast are presented in Table 7. The 1994 bias (mean) is closer to zero than the most recent 10-yr averages (not in the table), especially at 36 through 72 h. The absolute mean average error is smaller than the previous 10-yr average at all time periods.

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