ANNUAL SUMMARIES

Atlantic Hurricane Season of 1991

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ABSTRACT

The 1991 hurricane season is summarized, including accounts of individual storms. Eight tropical storms were tracked, of which four became hurricanes. Only one tropical cyclone, Hurricane Bob, hit the United States.

1. Introduction

After three consecutive years of above-normal tropical cyclone activity in the Atlantic basin, 1991 was a relatively quiet year. Nevertheless, for residents of the New England coast, which was raked by Hurricane Bob, the season will have a lasting impression. There were no "Cape Verde" hurricanes (i.e., the canonical-type storms that develop from disturbances that move off the west coast of Africa and that later can produce devastating effects) in 1991. Inhabitants of the tropical regions, such as the Greater and Lesser Antilles, were never seriously threatened by a tropical cyclone; in fact, no system reached hurricane intensity south of 25°N. Another unusual aspect of the 1991 season was the complete absence of tropical storms and hurricanes over the Gulf of Mexico. This has occurred only two other times this century (1927 and 1962). Overall, the total of eight tropical storms, four of which became hurricanes, was below the long-term average of near ten and six, respectively. There were also four tropical depressions that failed to intensify into named storms.

In spite of their relatively high latitude of formation, the tropical cyclones of the 1991 season featured two major hurricanes [that is, category 3 or higher intensity on the Saffir–Simpson scale (Simpson 1974)], Bob and Claudette. Bob crossed the coast of Rhode Island as a category 2 hurricane and was the only hurricane to make landfall in the United States this season. This hurricane was the first to strike the northeast United States since Gloria in 1985. Seventeen people died due to Bob and the damage to the United States is estimated at $1.5 billion. Hurricane Claudette, which briefly reached category 4 status, was the strongest of the season, but spent its entire lifetime at sea. Figure 1 depicts the tracks of the tropical storms and hurricanes of 1991, and Table 1 provides additional statistics about the season.

African waves were not the primary source for named storms during 1991 (Avila and Pasch 1992). Only Tropical Storms Danny, Erika, and Fabian (none of which became hurricanes) developed from African waves. A zone within several hundred kilometers southwest through southeast of Bermuda was the "hot spot" for tropical cyclone formation this year. Within that area, nontropical "seedling" disturbances generated all of the significant storms. The season began with the formation of the depression that became Tropical Storm Ana on 2 July and concluded with the dissipation of an unnamed system on 3 November.

In an attempt to shed some light on the causes for the dearth of tropical cyclones over the deep tropics during 1991, the mean pattern of vertical wind shear is a likely candidate for study. Figure 2 shows the anomalies (from the 1975–91 average) of the magnitude of the vertical shear over the Atlantic basin averaged over August, September, and October of 1991. In this diagram negative values indicate that the strength of the wind shear was less than average. The locations of formation of tropical depressions that developed into tropical storms and those that did not during this period of 1991 are indicated on the chart. Clearly, the area of weaker-than-normal shear was over a subtropical belt—within which Bob, Claudette, and Erika had their genesis. The shear was stronger than normal over most of the Caribbean east of 80°W and the adjacent tropical Atlantic east of the Lesser Antilles. Aside from the dissipating Tropical Storm Danny, no tropical cyclones existed over that area.

The vertical shear tends to be dominated by the contribution from winds at the upper-tropospheric levels. For example, Fig. 3 shows the mean 200-mb flow for September 1991, the month that is typically the most active for tropical cyclogenesis. A salient feature of this

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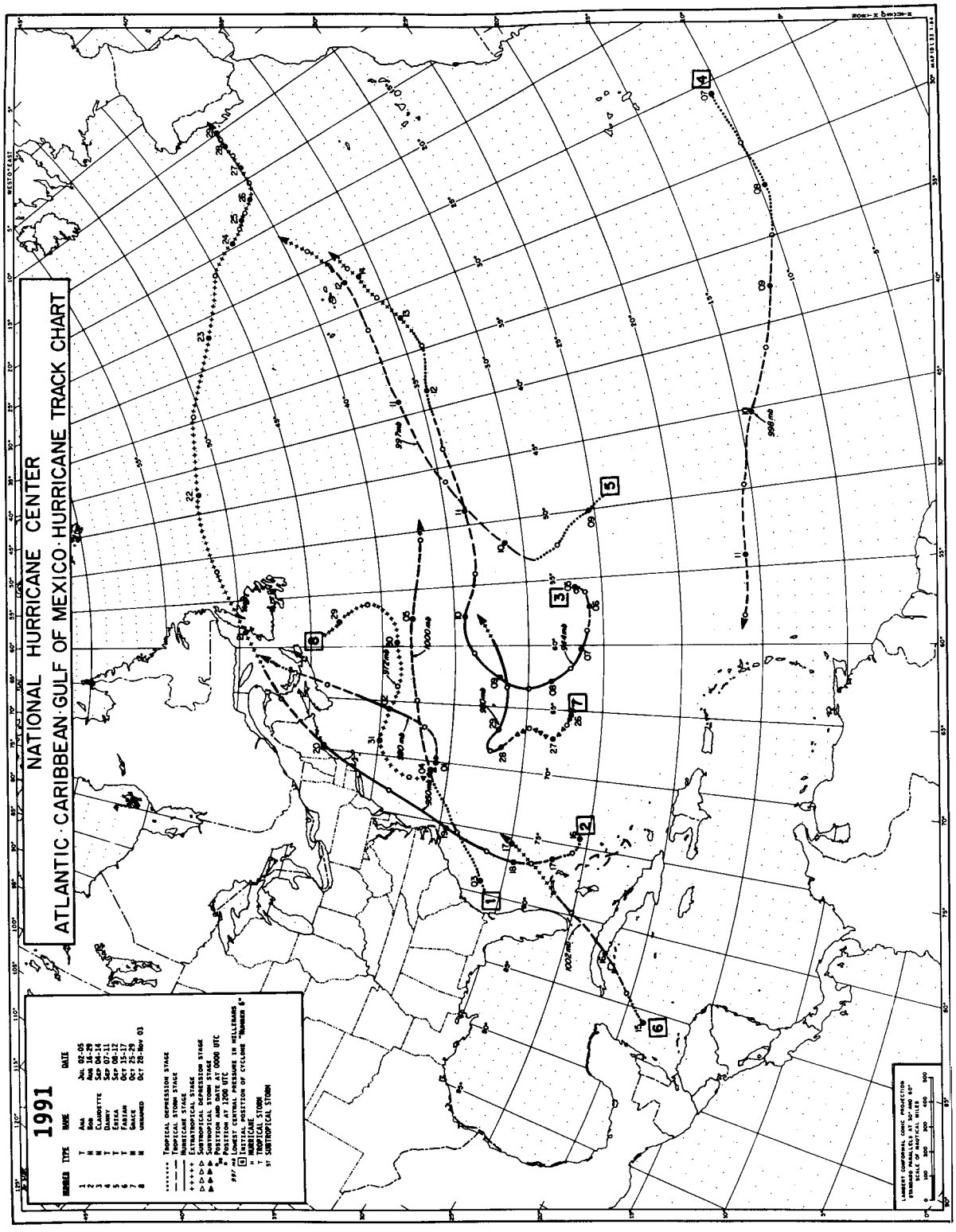

FIG. 1. Tropical-storm and hurricane tracks of 1991.

TABLE 1. Atlantic hurricane season statistics for 1991.

Number	Name	Class*	Dates**	Maximum 1-min wind ($m\ s^{-1}$)	Minimum sea level pressure (mb)	U.S. damage ($ billions)	Deaths
1	Ana	T	2–5 July	23	1000		
2	Bob	H	16–29 August	51	950	1.5	17
3	Claudette	H	4–14 September	59	944		
4	Danny	T	7–11 September	23	998		
5	Erika	T	8–12 September	26	997		
6	Fabian	T	15–17 October	21	1002		
7	Grace	H	25–29 October	46	980		
8	Unnamed	H	28 October–3 November	33	980		

* 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.
** Dates begin at 0000 UTC and include tropical-depression stage.

map is a broad swath of westerlies extending from the Caribbean across the adjacent tropical Atlantic. These stronger-than-normal westerlies were primarily responsible for the strong shear that effectively inhibited tropical cyclone development.

2. Individual storms

a. Tropical Storm Ana, 2–5 July

Ana, the first tropical cyclone of the 1991 hurricane season, formed from a low- to midlevel disturbance that developed downward to the surface in the vicinity of the Bahamas. Satellite imagery suggested that the incipient stages of Ana may have begun as early as 25 June about 400 km east of Jacksonville, Florida. A weak surface low developed, and for the next several days the low moved west-southwestward toward the northwestern Bahamas, across south Florida, turning northward along Florida's west coast, and then northeastward toward the St. Augustine area. As the low emerged into the Atlantic, convection became organized and the system became a tropical depression about 160 km south of Charleston, South Carolina, at 1800 UTC 2 July.

The tropical depression began to accelerate toward the northeast while maintaining a course offshore of the coasts of South and North Carolina. An air force reserve unit reconnaissance plane reached the depression center at 1600 UTC 3 July and found 15 $m\ s^{-1}$ winds at the 500-m flight level and a central pressure of 1008 mb at the surface. Nevertheless, NOAA buoy 41001 (at 34.9°N, 72.9°W), at 1900 UTC the same day, reported 8-min sustained winds of 17 $m\ s^{-1}$ and a pressure of 1005.7 mb, indicating the formation of a tropical storm.

During Ana's east-northeast track at nearly 13 $m\ s^{-1}$, a ship located 40 km south of the storm's center estimated 23 $m\ s^{-1}$ sustained winds at 0900 UTC 4 July, which was the maximum intensity reported for Ana. Minimum central pressure at that time was estimated to be 1000 mb. On the 5th another vessel, the *Loyalty,*

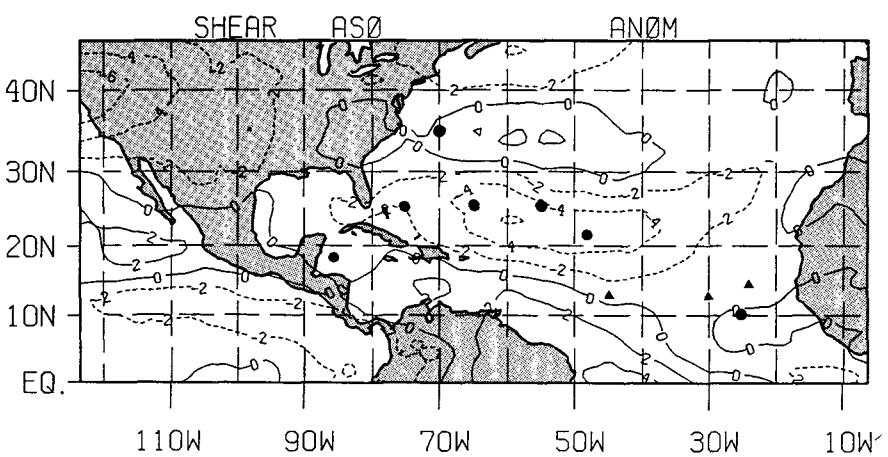

FIG. 2. Anomalies (from the 1975–91 average) of the magnitude of vertical wind shear (upper-minus lower-tropospheric winds) averaged over August, September, and October of 1991. Units are meters per second. Black circles denote locations of formation of tropical depressions that later reached tropical-storm strength, and black triangles indicate locations of formation of depressions that did not become tropical storms during this period.

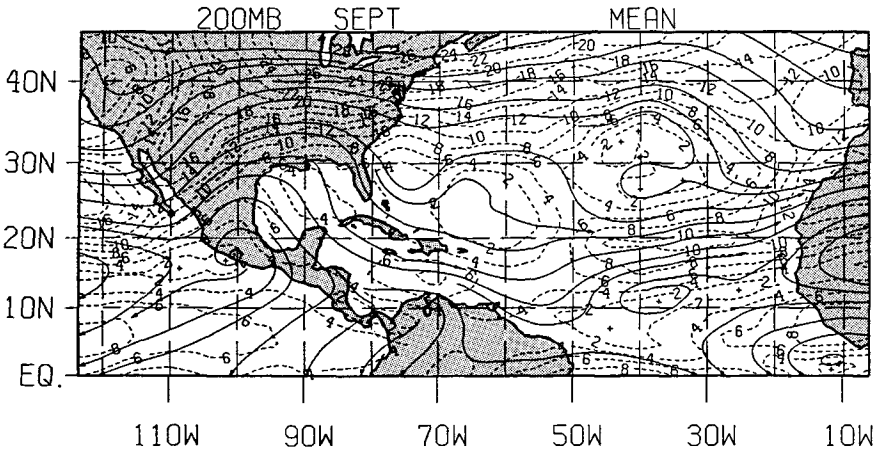

FIG. 3. Mean 200-mb flow for September 1991. Solid lines are streamlines and dashed lines are isotachs (m s^{-1}).

traveling along the path of the storm observed 18 m s^{-1} winds.

Ana continued moving generally eastward and lost its tropical characteristics by 1800 UTC 5 July over the cold waters of the North Atlantic, a little more than 1000 km southeast of Newfoundland.

b. Hurricane Bob, 16–29 August

1) SYNOPTIC HISTORY

Satellite imagery and synoptic analyses indicated that Bob originated from a large area of disturbed weather near Bermuda around 12 August. The disturbance moved toward the southwest and west with no significant change in organization for a few days until a weak surface low formed several hundred kilometers to the east of the Bahamas on 15 August. Animation of high-resolution visible satellite imagery during that period revealed only a broad, poorly defined cyclonic circulation of low clouds near a band of convection with little curvature.

An air force flight into the system reported a closed circulation at a flight level of 500 m and a maximum wind of 15 m s^{-1} at 0143 UTC on the 16th. Based on these data, it is estimated that the area of disturbed weather became a tropical depression at 0000 UTC 16 August, while centered 330 km east of Nassau in the Bahamas. The depression intensified to Tropical Storm Bob near 1800 UTC 16 August, based on reconnaissance that indicated a 26 m s^{-1} wind at the 500-m flight level and a surface pressure of 1005 mb. Satellite intensity estimates also supported upgrading the depression to Tropical Storm Bob at that time. Bob was then centered 220 km northeast of Nassau. The storm continued strengthening and began moving more toward the northwest under the influence of the deep-layer mean flow.

On 17 August, satellite imagery showed increased convective banding around a central dense overcast near the center. An air force reconnaissance plane at 1719 UTC encountered 37 m s^{-1} winds at the 500-m flight level, and a surface pressure of 987 mb was reported. The onboard aerial reconnaissance weather officer estimated surface winds at 33 m s^{-1}. Based on these reports, Bob became a hurricane around 1800 UTC on the 17th while centered 380 km east of Daytona Beach, Florida. The hurricane began turning toward the north and then north-northeast at an increasing forward speed. The steering flow was the result of the combined effects of the subtropical high pressure ridge over the Atlantic and a mid- to upper-level trough over the southeastern United States.

Deep convection became more concentrated near the center of the hurricane, and a well-defined eye appeared on satellite pictures late on 18 August (Fig. 4). Bob continued intensifying and the eye became even more distinct as it passed 45–55 km east of Cape Hatteras early on the 19th. An air force reconnaissance plane at 0412 UTC 19 August encountered 61 m s^{-1} winds at the 700-mb flight level. At 0621 UTC a surface pressure of 950 mb was measured when the eye was located about 165 km east-southeast of Norfolk, Virginia. These reports indicated that, at that time, Bob was a category 3 hurricane on the Saffir–Simpson hurricane scale.

Bob moved parallel to the U.S. mid-Atlantic coast and headed toward New England on a course similar to that of Hurricanes Carol and Edna in 1954. The hurricane weakened while accelerating toward the north-northeast over waters that became significantly cooler off of the mid-Atlantic coast. The eye was partially filled with clouds when it passed just east of Long Island, New York. The western side of the weakened eyewall passed over Montauk Point on the eastern tip of the island. The eye passed over Block Island at 1720

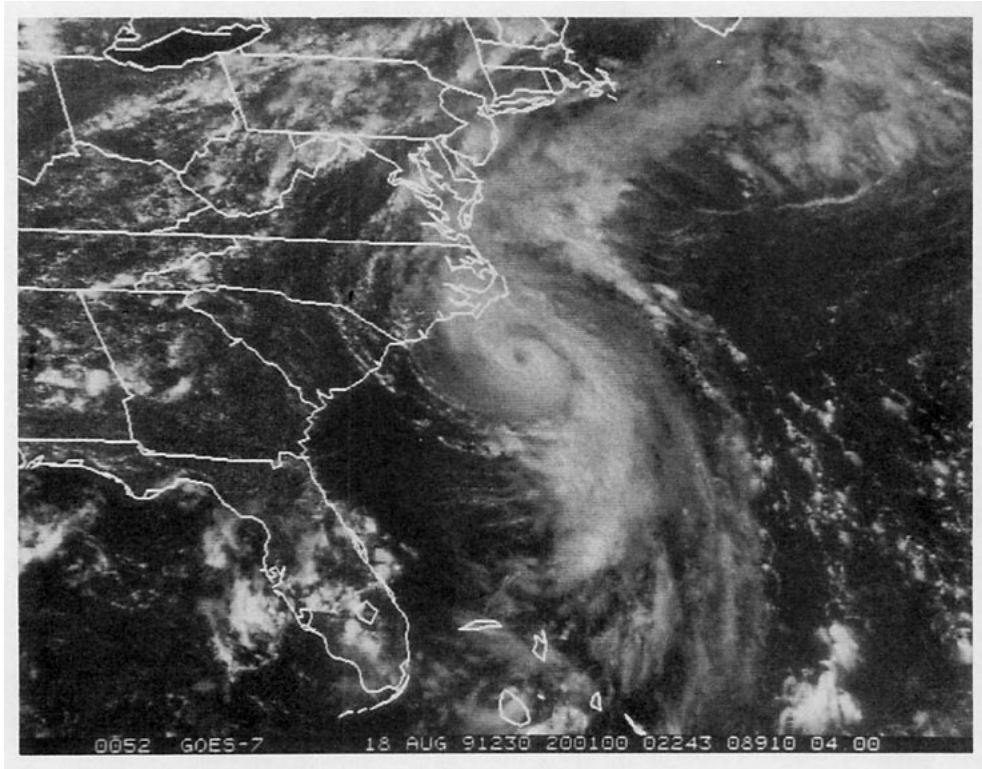

FIG. 4. GOES visible satellite image of Hurricane Bob at 2001 UTC 18 August 1991, as the eye was becoming distinct.

UTC and moved over Newport, Rhode Island, near 1800 UTC. Aircraft reconnaissance personnel observed that, just prior to landfall, less than 50% of the center was surrounded by an eyewall. By the time of landfall on Rhode Island, Bob was moving toward the north-northeast at 14 m s^{-1} with maximum sustained winds of a category 2 hurricane.

Bob crossed Rhode Island and Massachusetts, with the center moving between Boston and Scituate; it then moved over Massachusetts Bay. The hurricane continued to weaken and began losing tropical characteristics as its center passed just offshore of the southern coast of Maine and made final landfall as a tropical storm near Rockland, Maine, at 0130 UTC 20 August. After crossing Maine and New Brunswick, Bob became extratropical over the Gulf of St. Lawrence by 1800 UTC on the 20th. It then crossed northern Newfoundland and the central North Atlantic along 50°–55°N before moving southeastward and dissipating near the coast of Portugal on 29 August.

2) METEOROLOGICAL STATISTICS

Table 2a lists a selection of surface observations from standard reporting sites. Table 2b lists unofficial wind reports made with private wind gauges and collected by the *Cape Cod Times*.

Table 2c lists selected hourly observations made by NOAA's National Data Buoy Center (NDBC) platforms near the path of Bob. The NOAA buoys report an 8-min average sustained wind, and the Coastal-Marine Automated Network (C-MAN) reports give 2-min average sustained winds. Since these observations were reported only once per hour, they are not likely to be the extreme values that occurred at the sites. As a case in point, the continuous wind data from the Diamond Shoals C-MAN (received well after the event) showed a peak gust of 55 m s^{-1}.

The wind measurements of 47 and 45 m s^{-1} from Block Island were reported as peak gusts. However, both of these values were at the upper limit of the equipment range and were reportedly maintained (and probably exceeded) for a short period (<1 min). An observer on Block Island reported the eye overhead at 1720 UTC 19 August, with the approximate duration of light winds from 30 to 40 min.

As the eye moved over Newport, the navy ship USS *Valdez,* anchored in Narragansett Bay, reported a pressure of 964.0 mb at 1815 UTC 19 August. A cooperative observer in Adamsville, Rhode Island, just east of the track, reported a pressure of 964.1 mb at 1820 UTC. These values are close to the 965-mb pressure reported from an air force reconnaissance plane at 1737 UTC just prior to the Newport landfall. Among the unofficial wind reports, the peak gusts of 56 m s^{-1} observed at Woods Hole and Brewster, Massachusetts, represent the highest measured surface wind speeds in Bob.

TABLE 2a. Hurricane Bob, selected surface observations, August 1991.

Location	Minimum sea level pressure		Maximum surface wind speed ($m\ s^{-1}$)			Storm surge[b] (m)	Storm tide[b] (m)	Rain (storm total) (mm)
	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]			
North Carolina								
Wilmington WSO	1005.5	18/2055	8	13	18/1950			17.3
Wrightsville Beach						0.6		
Atlantic Beach						0.3		
Cedar Island			15	26	19/0100			
Cape Hatteras-Pamlico Sound side	985.0	19/0200	23	33	19/0257	0.8–1.4		134.6
Duck[c]			28	29	19/0446	0.4		
Virginia								
Norfolk WSO	1002.4	19/0650	13	18	19/0350	0.3		7.4
Chesapeake Bay Bridge Tunnel[c]						0.3		
Maryland								
Assateague Island								44.9
Ocean City[c]	999.0	19/1010	18	28	19/1015	0.4		
Delaware								
Indian River Coast Guard Station			17	23	19/1100			
Georgetown State Police								30.1
Bridgeville State Police								20.6
Cape Henlopen	1003.4	19/1359						
Lewes State Police	1004.4	19/1415						42.4
Lewes						0.4		
Dover AFB								46.7
Odessa State Police								13.2
Wilmington WSO			7	11	19/1431			11.2
Break Water Harbor						0.3		
New Jersey								
Sandy Hook[c]						0.7		
Ocean City				26	19/1240			
Ventnor City Fishing Pier			13	20	19/1120	0.5		57.4
Atlantic City WSO	997.4	19/1325	13	16	19/1350			33.5
State Marina in Atlantic City			13	19	19/1146			72.6
Loveladies				29	19/1245			
Seaside Heights				23	19/1235			
Newark Arpt	999.9	19/1650	11	14	19/1350			55.1
Morristown	1002.7	19/1555	8	13	19/1645			
Caldwell	1001.4	19/1645	8		19/1454			
Teterboro	1001.0	19/1645	7	11	19/1345			
Englewood								76.1
Forked River								75.4
Paramus								71.9
Garfield								61.7
Marlboro								51.4
Bridgewater								39.9
Clifton								39.6
Chatham								38.9
New Providence								38.6
Stanhope								34.8
Bloomingdale								32.5
Lebanon								26.7
Washington								23.1
New York								
Farmingdale	995.2	19/1520	22	32	19/1520			
Westhampton Beach	984.8	19/1545	14	27	19/1545			
Islip	991.6	19/1550	15	22	19/1550			150.1
La Guardia Arpt	1000.0	19/1550	14	23	19/1550			70.4
JF Kennedy Arpt	997.6	19/1442	14	21	19/1450			66.0

TABLE 2a. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed ($m\ s^{-1}$)			Storm surge[b] (m)	Storm tide[b] (m)	Rain (storm total) (mm)
	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]			
New York (*Continued*)								
White Plains	1000.0	19/1545	9	14	19/1510			73.9
Fire Island	989.5	unknown	28	33	unknown			
Eatons Neck	999.7	19/1600	23		19/1600			
Rockaway	999.0	19/1400	15	28	19/1400			
Montauk Coast Guard	968.5	19/1700	31	39	19/1800		3.0 (est.)	98.8
Montauk Lighthouse				45	19/1640			
Montauk Harbor			26		19/1705			
9 n mi west of Montauk Lighthouse	967.5	19/1705	15		19/1212			
Nicoll Bay	992.2	19/1705	18	26	19/1705			
Mount Sinai			21	28	19/1705			158.6
Bartletts Reef			18		19/1705			
Tobay Beach	1001.4	19/1705	18		19/1705			
Ambrose Tower			21		19/1705			
South Shore Raritan Bay	1001.4	19/1705	10		19/1705			
Hitherhills State Park				39	unknown			
West Gilgo Beach				31	unknown			
Bridgehampton								178.9
East Hampton								172.7
Brookhaven Lab	987.1	19/1630		30	19/1730			162.6
Noyack								121.9
Mattituck								119.4
Mattituck South								104.4
Babylon								101.6
Bethpage								165.1
Plainview								152.4
Mineola								105.2
Valley Stream								80.0
New Hyde Park								76.2
Willets Point[c]						2.0		
Oceanside								67.3
Brooklyn Marine Park								62.7
The Battery[a]						0.5		
Valley Cottage								99.1
Tappan								78.4
Pearl River								77.8
Sparkill								66.0
Mount Ivy								64.0
West Haverstraw								62.5
New City								62.0
Pomona								61.5
Chestnut Ridge								57.2
Pelham Manor								80.3
Yorktown								69.1
Peekskill								46.0
Ardsley								37.9
Middletown								127.0
Port Jervis								37.9
Connecticut								
Bridgeport WSO	992.1	19/1728	12	23	19/1550			119.9
Bridgeport[c]						1.5		
Thomaston								91.9
Hartford WSO	994.2	19/1730	32	48	19/1838			102.9
Hartford Brainard Field				35	19/1546			
Wethersfield				56	19/1730			145.5
Glastonbury								128.0
Bristol								137.2
Mansfield								152.9

TABLE 2a. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed ($m\ s^{-1}$)			Storm surge[b] (m)	Storm tide[b] (m)	Rain (storm total) (mm)
	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]			
Connecticut (*Continued*)								
Ellington								96.0
Plainfield								147.8
Putnam								127.3
Thompson								127.8
Mystic	977.0	unknown				1 (est.)		
New London[c]						1.5		
Groton Long Point						1 (est.)		
Stonington				27	unknown			146.6
Norwich								142.7
Groton EOC								177.8
U.S. Coast Guard Cutter Pt. Knoll (5 n mi SW of Groton)			33	45	unknown			
Rhode Island								
Providence WSO	972.5	19/1815	19	28	19/1727			63.8
Providence[c]						2.0		
Providence Hurricane Barrier						2.0		
Scarborough State Beach							4.2	
Sakonnet Point				45	unknown		3.1–5.0	
Newport							1.8–4.5	
Newport[c]						1.7		
Newport State Airport			33	43	unknown			
Narragansett			40	48	unknown		4.2	
Westerly State Airport			23	33	19/1645			
Block Island	966.0	19/1720		47[d]	19/1630			
Block Island Power Station				45[d]	19/1715			
Narragansett Bay								
USS *Valdez* 41.5°N, 71.3°W	964.0	19/1815	32	39	19/1730			
USS *Samuel B. Roberts* 41.6°N, 71.3°W	967.5	19/1825	32	42	unknown			
USS *Capodanno* 41.5°N, 71.4°W	967.2	19/1757	29		19/1656			
Adamsville	964.1	19/1820		31	unknown			15.0
Clayville								132.3
Woonsocket								90.2
Foster								178.1
Ashaway	982.4	unknown		39	19/1910			158.2
West Warwick				45	unknown			
Warwick EOC	971.2	unknown		38	unknown			
Middletown	971.9	19/1830		37	19/1659			
Point Judith	965.8	unknown		38	unknown			
Massachusetts								
Chatham	982.7	19/1900	33	43	19/1945		3.4–4.3	4.6
Westover AFB	994.2	19/1826		26	19/1823			102.9
Brimfield								137.9
Ware								100.8
Milton Blue Hill Observatory	974.6	19/1945	28	35	19/1832			65.5
Boston	976.3	19/1959	21	29	19/1909			56.1
Cape Cod Canal							2.3–4.0	
New Bedford Hurricane Barrier			39	49	19/1820	1.8		
Provincetown NOAA Ship *Oregon II*	976.0	19/1945	44	49	19/1935			

TABLE 2a. (*Continued*)

Location	Minimum sea level pressure		Maximum surface wind speed (m s^{-1})			Storm surge[b] (m)	Storm tide[b] (m)	Rain (storm total) (mm)
	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]			
Massachusetts (*Continued*)								
South Weymouth Naval Air Station	970.9	19/1945						
Cape Cod Coast Guard Air Station	984.3	19/1845						
Otis Air Natl Guard			25	42	19/1855			
Mattapoisett							3.1–4.1	
Wareham							2.5–4.7	
Onset							3.5–3.7	
Pocasset							3.4–3.8	
Woods Hole[c]						1.8		
Blackstone				21	19/2000			109.0
Plymouth Bay				38	19/1850			
Boston Harbor[c]				32	19/1845	1.1		
Nahant				30	19/1855			
Plum Island				27	19/2140			
New Hampshire								
Concord	993.8	19/2051	15	19	19/2037			101.1
Pease AFB				27	19/2213			
Nashua				26	19/2045			
Manchester				24	19/2045			
Keene				19	19/1935			
Laconia				16	19/2314			
Lebanon				10	19/1750			
Maine								
Portland[c]	985.1	19/2258	18	27	19/2250	0.8		198.9
Rockland	981.0	20/0114						
Kennebunkport[c]						0.6		
Biddeford[c]						1.2		
Wiscasset			31	41	19/2300			
Blue Hill			29	42	20/0000			
Booth Bay	982.5	20/0045		26	19/2203			70.6
Canada								
Nova Scotia								
Yarmouth			13	22	20/0200			56.9
Digby			20	30	20/0500			
Halifax			13	19	20/0900			
Amherst	1002.7	20/0900	18	27	20/1200			
New Brunswick								
St. John	999.8	20/0700	18	27	20/0642			32.8
Fredericton	995.7	20/0700	10	19	20/0200			45.7

[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] Denotes National Ocean Service tide gauge.
[d] Value was at upper limit of equipment range.

As Bob emerged over the cooler waters of Massachusetts Bay, the maximum sustained surface winds continued to decrease. NOAA buoys 44013 (42.4°N, 70.8°W) and 44007 (43.5°N, 70.1°W), along with the Mantinicus Rock (43.8°N, 68.9°W) and Mt. Desert Rock (44.0°N, 68.1°W) C-MAN stations, all reported maximum sustained winds below hurricane force, justifying the downgrading of Bob to a tropical storm before final landfall near Rockland, Maine.

Six confirmed tornadoes were reported in association with Bob, four in North Carolina and two in New York on Long Island. Thirteen additional unconfirmed tornadoes were reported, including nine in the wooded areas on Hatteras Island, two in Rhode Island, and two in Massachusetts.

Initial survey results by the U.S. Army Corps of Engineers suggest that the highest *storm-surge* values occurred in Massachusetts and Rhode Island, where wind-driven water was funneled into Buzzards and Narragansett bays. Visual and measured *high-water*

TABLE 2b. Unofficial wind reports on Hurricane Bob, August 1991.

Location	Maximum surface wind speed ($m\ s^{-1}$) Sustained	Peak gust	Date/time (UTC)*
Massachusetts			
Edgartown		50	unknown
Edgartown		42	19/1730
Cape Pogue	40	49	19/1745
Nantucket	38	46	19/1917
Woods Hole Ship *Betty Schouest*	38	56	19/1730
Falmouth		45	19/1830
East Falmouth		42	19/1830
East Falmouth		27	unknown
Centerville	33	37	19/1830
West Yarmouth		39**	unknown
West Yarmouth		40	unknown
South Yarmouth		50	unknown
South Dennis		37**	19/1840
Harwich Port		44	19/1800
Harwich Port	33	40	19/2000
South Harwich	26	35	19/1900
South Chatham	33	39	19/1900
South Chatham	38	42	unknown
Chatham	37	41	19/1900
Chatham	29	31	19/1900
East Orleans	40		19/1900
North Eastham	31	33	19/1930
Truro		41	19/2015
North Truro	35	46	19/1900
North Truro	45	53	19/1930
North Truro	40	45	19/1930
Provincetown	44	45**	19/1915
Brewster	33	56	19/2000
Brewster		53	19/1930
East Sandwich	28	37	19/1900
East Sandwich		39	19/1830
Sandwich	29	38	19/1900
Sandwich	21	35	19/1745
Sagamore Beach	29	35	19/1900
Buzzards Bay	40	51	19/1740
Bourne		43	unknown
Pocasset	22	32	19/1900
North Falmouth		45**	unknown
West Falmouth	28	42	19/1800
Forestdale	33	38	19/1800
Westport		42	unknown

* Time of sustained wind speed unless only gust is given.

** Value was at upper limit of equipment range, or equipment became inoperable beyond this value.

marks, which contain *both* storm-surge and astronomical tide heights and, in some cases, the effects of breaking waves, were also highest there. [Note: Storm-surge values derived from National Ocean Service (NOS) tide gauges listed in Table 2a have the effects of tide height and wave effects removed.] High-water marks at the upper end of Buzzards Bay ranged from 2.6 to 4.7 m. A storm-surge height of 1.8 m was calculated from tide-gauge data for the eastern and western shores of Buzzards Bay, at Woods Hole, and New Bedford, respectively. In Rhode Island, high-water marks between 3.1 and 5 m were measured near Sakonnet Point. These values include wave effects due to exposure on the coast. A storm-surge height of 2 m occurred at the Providence hurricane-barrier tide gauge. The effect of storm surge being "funneled" up Long Island Sound is reflected in the Willets Point NOS tide-gauge data. This gauge, which is located at the west end of the Sound, had a storm surge of 2 m. The surge occurred almost 2 h after landfall when the hurricane was abeam of Boston.

3) CASUALTY AND DAMAGE STATISTICS

Seventeen deaths were associated with Bob and are distributed as follows: South and North Carolina, 1 each; New York, 2; Connecticut, 6; New Hampshire, 2; Maine, 3; and Nova Scotia (Canada), 2. Three people survived for ten days on a life raft after their 12-m boat sank in high seas off Cape Hatteras during Bob.

The American Insurance Association preliminary estimate of insured property damage for the United States is $782 million. This includes $4 million for North Carolina, $75 million for New York, $40 million for Connecticut, $115 million for Rhode Island, $525 million for Massachusetts, $2 million for New Hampshire, and $21 million for Maine. The addition of flood claims, uninsured property damage, and the cost of cleanup increases the total damage estimate from Hurricane Bob to $1.5 billion. Without adjustments for inflation, Bob would rank 5th or 6th on the list of costliest twentieth-century U.S. hurricanes. With adjustments for inflation, Bob will rank 13th or 14th on that list. These damage figures make Bob the most recent of a string of hurricanes that were very costly to the northeast United States. Other prominent destructive hurricanes in this area include Gloria in 1985, Agnes in 1972, Donna in 1960, Diane in 1955, Carol in 1954, an unnamed hurricane in 1944, and the New England Hurricane of 1938.

Power to an estimated 2.1 million homes and businesses was knocked out, primarily on the Outer Banks of North Carolina, on Long Island, and over portions of New England.

4) WARNINGS

Hurricane warnings were issued for a long stretch of the U.S. east coast, from the coast of North Carolina northward from Little River Inlet to Eastport, Maine, including Pamlico and Albermarle sounds and Long Island Sound. About 20 h lapsed between the time the hurricane warning that included Newport, Rhode Island, was issued and the time the eye passed over Newport. Tropical-storm warnings were issued for lower Chesapeake Bay south of the mouth of the Patuxent River, including the greater Norfolk area. Tropical-storm warnings were also issued for the northwest Bahamas.

TABLE 2c. Hurricane Bob, selected NDBC observations, August 1991.

Platform/location	Minimum sea level pressure		Maximum wind speed (m s^{-1})		
	Pressure (mb)	Date/time (UTC)	Average*	Peak gust	Date/time (UTC)
Cape Lookout C-MAN CLKN7/34.6°N, 76.5°W	998.3	19/0000	16	21	18/2200
Diamond Shoals C-MAN DSLN7/35.2°N, 75.3°W	962.1	19/0200	44	50	19/0300
Chesapeake Light C-MAN CHLV2/36.9°N, 75.7°W	998.2	19/0700	24	27	19/0500
Delaware Bay buoy 44009/38.4°N, 74.7°W	994.8	19/1000	22	28	19/1000
Five Fathom buoy 44012/38.8°N, 74.6°W	994.9	19/1100	24	29	19/1100
Long Island buoy 44025/40.3°N, 73.2°W	987.3	19/1500	23	32	19/1600
Ambrose Light C-MAN ALSN6/40.5°N, 73.8°W	997.5	19/1500	23	25	19/1500
Nantucket buoy 44008/40.5°N, 69.4°W	1000.6	19/1700	24	29	19/1900
Buzzards Bay C-MAN BUZM3/41.4°N, 71.0°W	970.8	19/1800	34	40	19/1700
Boston buoy 44013/42.4°N, 70.8°W	973.4	19/2000	23	30	19/1900
Gulf of Maine buoy 44005/42.7°N, 68.6°W	992.6	19/2300	23	28	19/1900
Isle of Shoals C-MAN IOSN3/43.0°N, 70.6°W	975.3	19/2100	24	27	19/2100
Portland buoy 44007/43.5°N, 70.1°W	979.9	19/2300	21	27	19/2100
Matinicus Rock C-MAN MISM1/43.8°N, 68.9°W	983.3	20/0100	29	33	20/0100
Mt. Desert Rock C-MAN MDRM1/44.0°N, 68.1°W	990.6	20/0200	27	31	20/0200

* The NOAA buoy reports listed above are 8-min average winds, and C-MAN station reports are 2-min average winds.

c. *Hurricane Claudette, 4–14 September*

Claudette developed over the subtropical Atlantic and, although small, was quite intense for a brief period. An upper-level disturbance of nontropical origin was noted several hundred kilometers east of the northeast coast of Florida on 1 September. This system moved eastward, passing by Bermuda. The upper-level impulse induced the formation of a quasi-stationary low-level disturbance about 925 km southeast of Bermuda on 3 September. Convection associated with the disturbance increased and became concentrated near 27°N, 57°W by 0000 UTC 4 September. The cloud pattern became better organized, with satellite imagery showing two hooking convective bands at 1200 UTC on the 4th. Satellite intensity estimates indicated the formation of a tropical depression about 6 h later. Little movement was detected at that time.

Development was steady, and Claudette became a tropical storm around 1200 UTC 5 September, while commencing a slow southwestward motion. The upper-tropospheric environment was favorable for continued strengthening, with a large anticyclone located over the storm area and a digging trough to the east. A large upper-level cyclone was situated to the south-southwest, over the northeast Caribbean Sea. These features created an efficient outflow mechanism, and Claudette deepened at a faster-than-normal rate. Based on satellite intensity estimates, hurricane status was reached shortly after 0600 UTC 6 September. Claudette, then moving westward, continued to strengthen rapidly. The first reconnaissance flight, near 1800 UTC on the 6th, revealed that Claudette was a strong hurricane with estimated maximum surface winds of 51 m s^{-1} and minimum central pressure of 965 mb. A well-defined eye had appeared on visible imagery several hours earlier. Claudette was a compact cyclone with an eye of 11 km in diameter and hurricane-force winds extending outward only about 37 km from the center. At that time, the hurricane turned more to the west-northwest, moving around a 500-mb anticyclone and heading for Bermuda.

There was no aircraft reconnaissance of Claudette during the period between 2016 UTC 6 September and 1610 UTC 7 September. On the basis of satellite-derived intensity estimates, the hurricane reached its peak strength during this time period. The 3-h-averaged objective Dvorak T number (Dvorak 1984) reached a

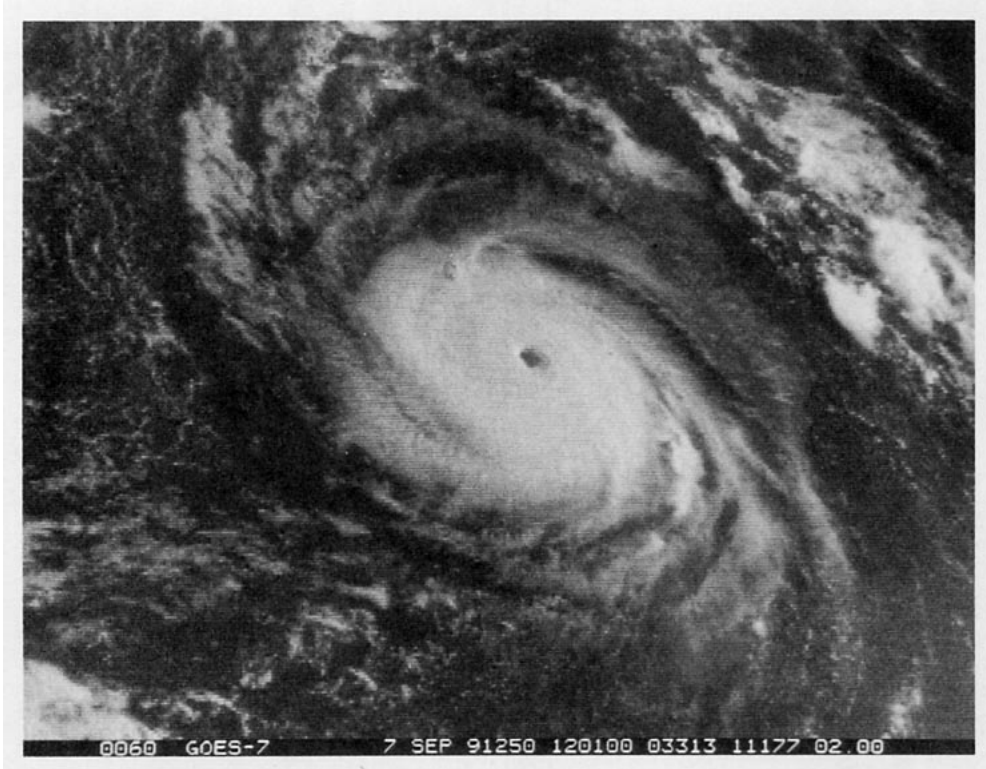

FIG. 5. GOES visible satellite image of Hurricane Claudette at 1201 UTC 7 September 1991, a short time after peak intensity.

maximum of 6.2 near 1000 UTC 7 September. This equates to a central-pressure estimate of 944 mb, which made Claudette a category 4 hurricane on the Saffir–Simpson scale. Considerable filling took place shortly thereafter, since a NOAA research plane indicated a pressure of 959 mb 6 h later. Weakening was also implied from visible satellite images on the morning of the 7th. This rate of filling, although large, is not unprecedented. For instance, Hurricane Allen of 1980 filled even more rapidly over water during several periods of its lifetime (Lawrence and Pelissier 1981). Figure 5 is a visible satellite picture of Claudette shortly after peak intensity.

After 1600 UTC 7 September, Claudette weakened steadily but at a more gradual rate. The hurricane turned northwest, then northward by 1200 UTC 8 September. At that time, a short-wave trough at 500 mb moved off the U.S. east coast. Under this steering influence, Claudette continued turning clockwise during the day and began moving north-northeastward with increasing forward speed late on 8 September.

Hurricane warnings were posted briefly for Bermuda. The hurricane passed about 205 km east-southeast of that island at its closest approach, late on the 8th. The highest sustained winds at Bermuda were only about 10 m s^{-1} with gusts to 14 m s^{-1}, and a few showers occurred there as the fringes of the hurricane passed over late that day. After turning toward the east-northeast on 9 September, the hurricane dropped east-southeast early on 10 September while weakening to a tropical storm. Most of its deep convection had been lost due to upper-level southwesterly wind shear. This east-southeastward motion was likely due in part to the influence of the circulation of Tropical Storm Erika, which was centered a few hundred kilometers to the east-southeast at the time. The storm continued to weaken while accelerating in a general eastward direction until it dropped below tropical-storm strength around 1800 UTC 11 September. Claudette then decelerated and became extratropical while located a few hundred kilometers west-southwest of the Azores. The weak low moved toward the Azores, dissipating in the vicinity of those islands on 14 September.

Based on reports received to date, no ships encountered Claudette when it was a severe hurricane; however, there was a report of 23 m s^{-1} winds from a ship located about 37 km south of the center at 0900 UTC 10 September, when Claudette was in its weakening stage.

d. Tropical Storm Danny, 7–11 September

Tropical Storm Danny was the first named Atlantic storm of the 1991 season to form from purely tropical origins. A marked wind shift was noted at low levels in the Dakar soundings on 5 September as a tropical wave emerged from the northwest coast of Africa. As the wave moved westward, the associated cloudiness

quickly acquired a banding-type pattern while over the far eastern Atlantic. Analysis of Meteosat images suggested that the wave led to the formation of a tropical depression by 0000 UTC 7 September while centered 500 km south-southwest of the southwesternmost Cape Verde Island.

The depression moved toward the west around 8 m s^{-1} and strengthened into Tropical Storm Danny at 1200 UTC 8 September based on Dvorak satellite intensity estimates. Under the influence of a strong subtropical ridge to the north, Danny moved toward the west or west-northwest across the central tropical Atlantic at about 8–10 m s^{-1} for a couple of days, with little change in strength. Danny's estimated minimum surface pressure and maximum surface winds were 998 mb and 23 m s^{-1} at 0000 UTC 10 September. As Danny approached the Lesser Antilles, the flow around an upper-level low centered near 22°N, 60°W resulted in a shearing environment that led to a weakening of the storm. Danny was downgraded to a tropical depression at 1200 UTC on 11 September while centered 330 km east of Guadeloupe. Later that morning, an air force plane was unable to find more than a broad and ill-defined area of cyclonic turning, characteristic of a tropical wave. The cloudiness and showers associated with the remnants of Danny then moved toward the northwest and north, eventually merging with a frontal cloud band over the north-central Atlantic.

e. Tropical Storm Erika, 8–12 September

The tropical wave that produced Erika exited the northwest coast of Africa on 2 September. It passed over the Cape Verde Islands on the 3d with most of the shower activity confined to the southern portion of the wave. From 4 to 6 September, the system appeared on satellite imagery mainly as a very large swirl of low-level clouds. However, deep convection began increasing on the 7th, and by 1800 UTC 8 September the system had become a tropical depression according to satellite intensity estimates. At that time, the depression was midway between Claudette, located near Bermuda, and Danny, which was heading for the Lesser Antilles.

The depression moved west-northwest around the southern periphery of a weak subtropical ridge and became Tropical Storm Erika near 1800 UTC on 9 September. The circulations of Erika and Hurricane Claudette interacted briefly on the 10th, and then Erika accelerated toward the northeast.

Erika reached its peak intensity of 26 m s^{-1} and minimum pressure of 997 mb on 10 September while heading toward the Azores. The island of Santa Maria, Azores, experienced sustained 18 m s^{-1} winds with a peak gust of 30 m s^{-1} at 0300 UTC 12 September. The airfield there was closed for several hours. There were no reports of damage, injuries, or deaths related to Erika. Erika became extratropical just east of the Azores.

f. Tropical Storm Fabian, 15–17 October

Tropical Storm Fabian had a typical October western Caribbean development. A cold front moved into the northwest Caribbean on 11–12 October and produced northeasterly winds and showers over Florida and Cuba. At that time, a tropical wave with axis near Jamaica was moving slowly westward. On 13 October the front and the tropical wave interacted in the Gulf of Honduras. Surface reports indicated that pressures began to fall along the coast of Honduras while satellite images showed an increase in convective activity over that area.

The upper trough that brought the front southward moved out of the area, allowing an upper-level ridge to develop over the region of disturbed weather. A NOAA plane was dispatched to the area on 15 October. A 1006-mb low-level pressure center and 18 m s^{-1} surface winds were found near 1300 UTC on that day, and based on these data, the system was classified as a tropical storm southwest of the Isle of Youth, Cuba.

Cold fronts moving southward over the Gulf of Mexico and Caribbean in October and November are generally associated with large high pressure areas to their north. This configuration frequently produces large pressure gradients and winds of near-tropical-storm force to the north of the frontal zone before any circulation center forms. That is, by the time a surface circulation center is detected, winds already exceed tropical-storm force over a significant portion of the system. That was the case for Fabian, where a tropical-depression stage may not have taken place. However, a postanalysis of available data indicates that if the tropical-depression stage occurred, it was likely for a short period from 0000 through 1200 UTC 15 October.

Fabian was a poorly organized storm with limited banding features and restricted upper-level outflow. Most of the squalls and tropical-storm-force winds were located primarily to the east of its center. Fabian moved northeastward with increasing forward speed, and near 2100 UTC 15 October, the center crossed the Isle of Youth near Punta del Este, Cuba. Three hours later, the center passed over mainland Cuba near the Peninsula de Zapata. Shortly thereafter, Fabian emerged over the waters in the vicinity of Varadero. The storm then moved over the Straits of Florida, where an air force plane reported 21 m s^{-1} winds and a 1002-mb central pressure at 0834 UTC 16 October; this was Fabian's maximum intensity. Thereafter, the storm accelerated northeastward and became extratropical as it merged with a frontal system later on that day.

Tropical-storm warnings were issued for Cuba from Havana eastward to Ciego de Avila including the Isle of Youth. Tropical-storm warnings were also posted for the Bahamas from Great Inagua northwestward. A tropical-storm watch was issued for the Florida Keys.

Surface observations at Cayo Largo, along the south coast of central Cuba, indicated a wind shift from east-

southeast to south. At that station, wind gusts to 18 m s^{-1} and a drop in pressure from 1012 to 1008 mb in 6 h were experienced as the center of Fabian passed just to the west. The town of La Fe, on the northern portion of the Isle of Youth, reported a minimum pressure of 1004.9 mb at 2100 UTC on the 15th when Fabian was crossing that island.

The primary impact of Fabian on Cuba was heavy rainfall during a 12–24-h period on the 15th over the central part of the island. The highest reported rainfall was 157 mm at Caonao, near Cienfuegos on the south coast of central Cuba. Large rainfall accumulations were also reported at the following central Cuba locations: Antonio Maceo (sugar mill), 145 mm; Punta del Este, 140 mm; and Calimete, Matanzas, 119 mm. Most of the total of 140 mm of rain at Punta del Este was received during a 6-h period as Fabian moved over that region. No reports of casualties or damage associated with Fabian have been received at the National Hurricane Center.

g. Hurricane Grace, 25–29 October

The incipient circulation of Grace formed from a midlevel low between Bermuda and the Dominican Republic on 23 October. The circulation slowly developed downward, reaching the surface about 580 km south of Bermuda by 1800 UTC on the 25th. The surface depression was initially subtropical in character with a broad area of light winds near the center and strongest winds located at a radius of several hundred kilometers. The strongest winds increased to 17 m s^{-1} at Bermuda and nearby ships by 0600 UTC on the 26th, indicating that the subtropical depression had intensified to a subtropical storm.

Cloudiness near Bermuda, which originated a few days earlier near the U.S. southeast coast, became increasingly convective and banded as it was enveloped by the expanding circulation. The clouds gradually wrapped inward toward the circulation center from the west between 25 and 27 October. Convection began to persist near the center at about 1800 UTC on the 27th, at which time the first reconnaissance flight into the system revealed that winds had become strongest near the circulation center. These characteristics are consistent with the presence of a tropical system, indicating that the subtropical storm had been transformed into Tropical Storm Grace. The organization and concentration of convection continued to increase near the center late on the 27th. Based on satellite intensity estimates and a reconnaissance report estimating surface wind speeds of 33 m s^{-1}, Grace became a hurricane at 0000 UTC 28 October.

Grace initially followed a sinuous course toward the northwest at about 5 m s^{-1}. As it did so, an extratropical cyclone formed well to the north, off the coast of the Canadian maritimes. The extratropical cyclone rapidly became powerful and the strong, mostly westerly deep-layer mean flow around its southern flank quickly came to dominate the steering of Grace. The hurricane slowed and made a hairpin turn toward the east on 28 October, followed by a marked acceleration, from about 2 m s^{-1} at midday on the 28th to around 20 m s^{-1} only 24 h later.

The rapid eastward motion of the vortex resulted in a very asymmetrical surface wind distribution with relatively light winds occurring to the north of the center. Wind speeds of only about 10 m s^{-1} were observed at Bermuda as the hurricane center passed by about 85 km to the south near 0800 UTC. On the other hand, a reconnaissance aircraft encountered an area of winds at the 850-mb flight level that exceeded 51 m s^{-1} about 55 km south of the center, with a peak wind of 57 m s^{-1}. Using these data, the maximum intensity of Grace is estimated to have been 46 m s^{-1} at 1400 UTC 29 October.

Grace turned toward the east-northeast during the afternoon of 29 October and was overtaken by a vigorous cold front associated with the extratropical cyclone. The merger occurred near 1800 UTC 29 October, when the rapidly moving cold front undercut and quickly destroyed Grace's low-level circulation. Animation of satellite imagery showed that the remnant mid- and upper-level moisture from Grace became caught up in the outer part of the extratropical cyclone circulation, far from the extratropical storm center. The remnants became indistinguishable within a day of the merger.

Bermuda reported tropical- (or subtropical-) storm-force winds on 3-h observations and one intermediate observation, all more than 15 h prior to the closest approach of the hurricane, and before passage of the intense cold front at about 0810 UTC 29 October. The highest of those winds was 19 m s^{-1} at 0300 UTC on the 27th. The peak gust of 27 m s^{-1} occurred during the previous hour. There were no reports of damages or casualties on Bermuda due to Grace.

Grace was a relatively large system, owing to its early subtropical nature. It generated large swells, from about 5 m at buoy 41001 offshore from North Carolina to about 3 m near the Florida coast. Because these swells were noted near the U.S. southeast coast prior to the passage of the cold front, they are attributed directly to Grace. Those waves, in combination with spring tides, caused isolated minor beach erosion, but no reported significant damage or casualties from North Carolina southward through Florida.

As the extratropical cyclone intensified, Grace became only a secondary contributor to subsequent extraordinary sea conditions reported over much of the western North Atlantic during the last week of October and first few days of November. Treacherous swells, surf, and associated coastal flooding occurred behind the cold front along portions of the Atlantic shoreline extending from Puerto Rico and the Dominican Re-

public to the Bahamas, the United States, Canada, and Bermuda. While irrefutable evidence is not available, there were probably no casualties or damages then that could be attributed directly to Grace. Instead, it is believed that the much larger extratropical cyclone was the primary phenomenon at blame.

A hurricane warning was issued for Bermuda about 10 h prior to Grace's closest approach to that island. Although Grace then produced only modest wind speeds at Bermuda, the island would have experienced hurricane-force winds had the center been about 90 km farther north. Shortly after Grace passed by, Bermuda experienced sustained winds around 17 m s^{-1} with gusts to 31 m s^{-1}. Along Bermuda's north shore, these winds destroyed four or five boats and caused minor damage to vegetation. These winds were apparently gales associated with the cold front, and not a direct part of the Grace circulation.

h. Unnamed hurricane, 28 October–3 November

The aforementioned extratropical cyclone was initially noted several hundred kilometers east of the coast of Nova Scotia at 1800 UTC 28 October. The associated deep-layer circulation was soon to become a dominant feature over the extreme western Atlantic. The cyclone steadily strengthened while drifting southeastward, and then southwestward. By 30 October, the low was moving westward and it reached its peak intensity as an extratropical storm around 1200 UTC when it was located about 630 km south of Halifax, Nova Scotia. Its minimum central pressure was about 972 mb and the maximum sustained winds were near 40 m s^{-1}. At this time, the storm was causing phenomenal seas and strong winds along the U.S. east coast, and locally major damage along much of the western Atlantic shoreline due to tidal flooding and wave action. Peak wave heights of 30.8 and 24.4 m were indicated by a Canadian buoy and a ship, respectively, over the open Atlantic several hundred kilometers south of Nova Scotia.

After reaching peak intensity as an extratropical system, the low turned southwestward, and then southward, as the central pressure gradually rose to about 998 mb by 0000 UTC 1 November. This southward motion, however, brought the low center over a section of the Gulf Stream with sea surface temperatures near 26°C. With the low moving over warmer waters, convection began increasing in bands around the center. By 0600 UTC on the 1st, central convection had increased to the point where a tropical cyclone (estimated to be of tropical-storm intensity) could be identified within the central area of the low. Visible satellite pictures around 1500 UTC showed that an eye was forming and thus the inner system was near hurricane intensity at that time. Figure 6 is a visible satellite picture of the hurricane near its peak intensity.

The cyclone had turned southeastward, then east-

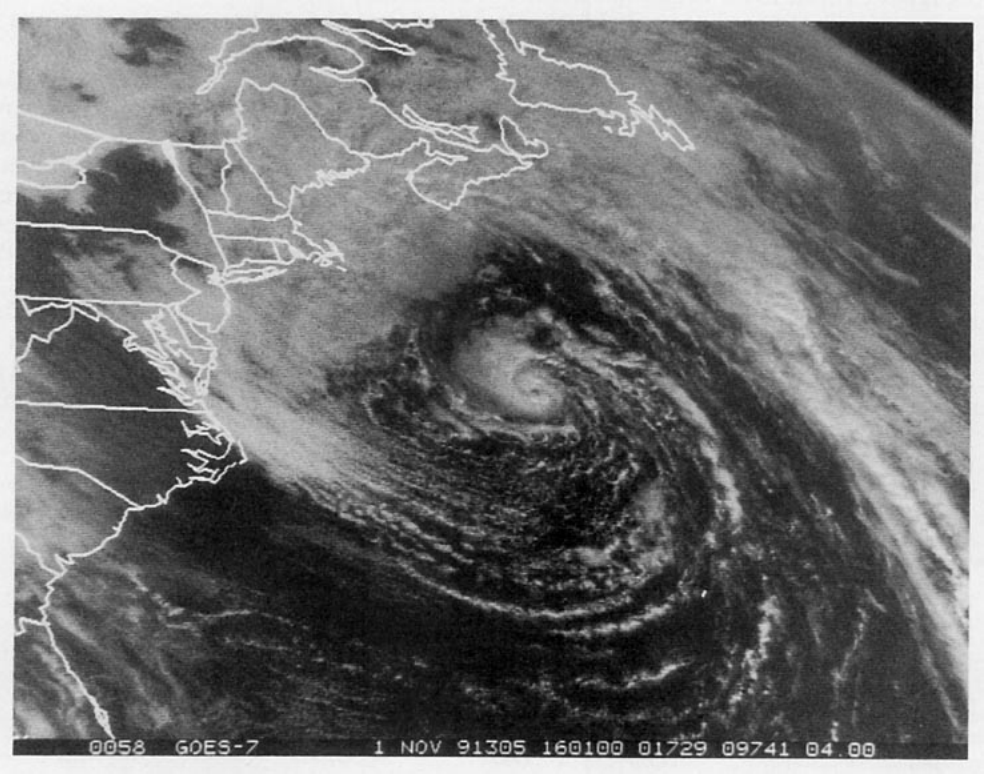

FIG. 6. GOES visible satellite image of the unnamed hurricane at 1601 UTC 1 November 1991, near the time of peak intensity.

ward and northeastward as it executed a counterclockwise loop. An air force plane confirmed that the system was already of hurricane intensity when they investigated it around 0000 UTC 2 November. That mission found maximum flight-level (850-mb) winds of 44 m s^{-1}, a 4°C air temperature rise in the center and an extrapolated central surface pressure of 981 mb. The radius of maximum winds was about 55 km, much in contrast to the structure of the extratropical storm, which had a broad area of gale-force winds that extended well over 500 km from its center, and no clearly defined maximum-wind radius.

Although the formation of a tropical cyclone in the center of a nontropical low is rather unusual, it is not unprecedented. Hurricane Karl in November 1980 developed within the center of a deep-layer, nontropical cyclone over the eastern Atlantic (Lawrence and Pelissier 1981). A few other analogous cases can be cited. Since the central portion of these deep-layer cyclones is a region of small temperature gradient and hence light vertical wind shear, then, given the presence of sufficiently warm sea surface temperatures, tropical cyclone development is allowable.

The cyclone accelerated northeastward, crossing the path previously traversed by the extratropical storm, and made landfall in Nova Scotia near Halifax, around 1400 UTC 2 November, as a rapidly weakening tropical storm. Dissipation occurred just to the north of Nova Scotia, about 10 h after landfall.

Several vessels passed close to the extratropical storm center on 30 October and reported winds of 25–31 m s^{-1}. A ship, noted in the previous section to have reported seas to 24.4 m, also reported winds to 41 m s^{-1} at 1200 UTC 30 October while located several hundred kilometers northwest of the storm center. A NOAA buoy, identification number 44011 (located at 41.1°N, 66.6°W), measured maximum sustained winds of 25 m s^{-1} with gusts to 33 m s^{-1} and a significant wave height of 11.9 m near 1500 UTC 30 October. Another NOAA buoy, number 44008 (located at 40.5°N, 69.5°W), measured maximum sustained winds of 27 m s^{-1} with gusts to 32 m s^{-1} and a significant wave height of 9.5 m near 0000 UTC 31 October. After the system became a tropical cyclone, a Bahamian ship, located about 200 km southwest of the center, reported winds from 20° at 23 m s^{-1} and pressure of 1006.5 mb at 0600 UTC 2 November.

By the time the storm made landfall in Nova Scotia on 2 November, considerable weakening had taken place. The lowest reported pressure was 998.1 mb around 1430 UTC at Shearwater, near Halifax. According to the Maritimes Weather Service in Bedford, Nova Scotia, the Canadian Coast Guard at Chebucto Head (about 15 km south of Shearwater) reported sustained winds from the southeast at 21 m s^{-1} with gusts to 23 m s^{-1}. An automated station at Beaver Island, located on the coast about 95 km to the east-northeast of the landfall point, had maximum sustained winds from 180° at 19 m s^{-1} with gusts to 21 m s^{-1} and a minimum pressure of 1005.7 mb around 1600 UTC. It is conceivable that slightly higher winds could have occurred along the coast between this site and the landfall point. Only some light rainfall was reported in association with the storm in the Halifax area.

As was the case with Hurricane Grace, it appears that practically all of the significant effects that were felt along the western Atlantic shoreline during the last few days of October were attributable to the extratropical stage of the unnamed hurricane. This hurricane was, to a great extent, a separate event from the strong extratropical storm that wreaked major coastal damage along the East Coast, from Florida through Canada, and even over portions of the Atlantic shorelines of the Greater Antilles. By the time the tropical system had formed, the extratropical system was waning, and conditions were improving on the coasts. The damage that had been created by the extratropical system was continuing to receive major media attention at that juncture. Naming the system (which clearly met all of the meteorological criteria to be designated as a hurricane) at that time would probably have caused major confusion on the part of the media, emergency management officials, and the public. Since the hurricane was expected to be rather transient and primarily of concern to marine interests, it was decided to handle all associated warnings in enhanced high seas and offshore and coastal waters forecasts. This decision was made by the National Hurricane Center in consultation

TABLE 3. Comparison of 1991 Atlantic official track forecast errors (km) with previous 10-yr average. A track forecast error is defined as the great-circle distance between a forecast position and a postanalysis best-track position for the same time. Cases include all tropical storms and hurricanes (except the unnamed hurricane) and their extratropical stages for winds higher than tropical-storm force.

	Forecast period (h)					
	0	12	24	36	48	72
1991 average	28	109	221	300	358	487
(number of cases)	(87)	(72)	(61)	(48)	(35)	(21)
1981–90 average	33	104	198		392	608
1981–90 (average number of cases)	(152)	(149)	(130)		(98)	(71)
1990 departure from 1980–89 average	−17%	+5%	+11%		−9%	−20%
1991 range	0–170	0–293	9–615	56–863	65–619	44–915

TABLE 4. Official maximum 1-min wind-speed forecast errors (m s^{-1}) for tropical storms and hurricanes in the Atlantic basin, 1991. Cases include all tropical storms and hurricanes (except the unnamed hurricane) and their extratropical stages for winds higher than tropical-storm force for which a wind forecast was made. Error = forecast − observed.

	Forecast period (h)					
	0	12	24	36	48	72
1991 mean	−0.1	+0.6	+1.1	+2.1	+3.2	+8.7
1991 mean absolute	2.3	4.1	7.6	9.9	11.3	12.3
Number of cases	87	70	58	44	34	21
Maximum error	+10, −10	−18	+26	−28	−31	+21
1981–90 mean	0.6	−0.8	−1.3		−2.6	−1.9
1981–90 average number of cases	149	145	127		92	65
1981–90 mean absolute	2.7	4.2	5.9		8.0	9.8
1991 departure from 1981–90 mean absolute	−13%	−2%	+29%		+40%	+26%

with the National Meteorological Center, the National Weather Service forecast offices along the East Coast, the U.S. Navy, and the Atmospheric Environment Service Maritimes Weather Center in Canada. Based on reports to date, this process provided all necessary warnings.

3. Verification

Every year, the National Hurricane Center's "official forecasts" of location (center position) and intensity (maximum 1-min wind speed) of all named storms are quantitatively evaluated relative to the "best tracks" of these storms. The best track consists of locations and intensities obtained from a postanalysis of all available data. The official forecasts, made at 6-h intervals, are for 12, 24, 36, 48, and 72 h.

Table 3 compares the track forecast errors for 1991 with the previous 10-yr average. It can be seen that the 1991 averages at 12 and 24 h are somewhat larger than the previous 10-yr average, while the 0-, 48-, and 72-h errors are smaller than the previous 10-yr average. The small number of cases (only 21 at 72 h) for 1991 precludes making any meaningful generalizations about this year's performance.

Official wind-speed forecast errors are listed in Table 4. The mean wind-speed errors show a positive bias (i.e., wind speed was overforecast) at all forecast periods, while the previous 10-yr average shows a negative bias. The mean absolute errors for 1991 beyond 12 h are larger than the corresponding previous 10-yr averages. Again, 1991 had relatively few cases, so any conclusions drawn from this year's intensity forecast statistics should be considered dubious.

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