

Preliminary Report
Hurricane Hugo
10-22 September 1989

Hugo was a classical Cape Verde hurricane that left a path of devastation across the Leeward islands, the Virgin Islands, Puerto Rico and South and North Carolina.

1. Synoptic history

Hugo's best track positions are shown in Figure 1 and best track position, central pressure and maximum one-minute wind speed are listed every six hours in Table 1. The origin of Hugo was detected on satellite imagery on 9 September when a cluster of thunderstorms moved off the coast of Africa and the official best track begins on the 10th when a tropical depression formed to the southeast of the Cape Verde Islands. Hugo moved westward at 18 knots across the tropical Atlantic Ocean, becoming a tropical storm on the 11th and a hurricane on the 13th while located about 1100 nautical miles east of the Leeward Islands.

Hugo gradually turned toward the west northwest and slowed its forward speed as it headed for the Leeward Islands in response to low pressure to the north of Puerto Rico which represented a weakness in the westward extension of the subtropical high pressure ridge.

Hugo's eye was over Guadeloupe at 0500 UTC on the 17th, as indicated by the landfall information listed at the bottom of Table 1. Continuing to decelerate and turning toward the northwest, the eye moved over St Croix at 0600 UTC on the 18th with a forward speed of eight knots. The hurricane then began to accelerate its forward speed and the eye moved over the island of Vieques, Puerto Rico at 1200 UTC and then over the extreme eastern tip of mainland Puerto Rico at 1300 UTC on the 18th.

Early on the 19th, the hurricane was north of Puerto Rico and moving toward the north northwest at 12 knots. By this time, the weakness in the subtropical high pressure ridge had diminished and the hurricane's motion was under the influence of the ridge and of an upper-level low pressure system centered over Georgia. Hugo's track curved gently to the northwest over the next few days as the low pressure center moved southwestward and altered the steering flow pattern. By the 21st, Hugo was centered a few hundred miles east of Florida and began a gradual turn and acceleration toward the north in response to the steering flow associated with a major extratropical low that was advancing eastward across the central U.S.

The final landfall was made on the South Carolina coast near Charleston at Sullivans Island at 0400 UTC on the 22nd with the eye moving northwestward at 23 knots. Moving inland and weakening, the center passed between Columbia and Shaw Air Force Base around 0800 UTC. By 1200 UTC, Hugo had weakened to a tropical storm and passed

just west of Charlotte, North Carolina to near Hickory.

The storm moved northward across extreme western Virginia, West Virginia, eastern Ohio and to near Erie, Pennsylvania by 0000 UTC on the 23rd and transformed into an extratropical storm. The storm was tracked for two more days as it moved northeastward across eastern Canada and into the far north Atlantic Ocean.

2. Meteorological statistics

Figures 2 and 3 show the curves of maximum one-minute wind speed and minimum central pressure, respectively, versus time, along with the plot of the satellite, aircraft reconnaissance and surface data used to construct these curves. Table 2 lists a selection of the relevant surface observations.

Both Air Force and NOAA aircraft participated in the reconnaissance of this hurricane. The first aircraft reached the hurricane on 15th, several hundred miles east of the Leeward Islands and reported a central pressure of 918 millibars, a wind speed of 165 knots at an altitude of 1500 feet and a surface wind speed of 140 knots. This turned out to be Hugo's maximum intensity. During the following seven days, there were 76 aircraft penetrations of the eye of the hurricane, for an average of one center fix every 2 hours.

On the 17th, just before Hugo's eye passed over Guadeloupe, an aircraft reported 135 knots at 700 millibars. A surface pressure of 941.4 millibars has since been reported from Guadeloupe. It is estimated that the hurricane's maximum one-minute surface wind had decreased to 120 knots at this time. A report of 40 knots with a gust to 68 knots has been received from St. Maarten and the center passed about 75 nautical miles to the southwest of this island. The maximum surface wind was again estimated at 120 knots when the eye passed over St Croix at 0600 UTC on the 18th.

When the eye passed over the island of Vieques, Puerto Rico, it is estimated that the maximum one-minute wind speed had decreased to 110 knots. On the island of Culebra, just north of Vieques, an anemometer reading of a gust to 148 knots was reported from the ship Night Cap located in the harbor there. Maximum wind speeds were also estimated at 110 knots one hour later when the eye passed over the eastern tip of Puerto Rico. However, the highest recorded wind speed over land was 90 knots with a gust to 104 knots at Roosevelt Roads. The highest winds reported at San Juan International Airport were 67 knots with a gust to 80 knots. Rainfall totals ranged up to a maximum of 9.20 inches at Gurabo in the eastern interior of Puerto Rico. The lowest surface pressure reading from Puerto Rico was 946.1 millibars at Roosevelt Roads.

There are no storm surge observations available from the Caribbean at this time. However, the SLOSH storm surge model

calculations, based on Hugo's track, indicate that water levels of three to four feet above normal tide levels occurred during the period of onshore winds at St Croix and along the eastern end of Puerto Rico and water levels of two to three feet above normal occurred along the north coast of Puerto Rico.

As Hugo moved away from Puerto Rico and headed for the southeastern U.S., its central pressure rose to 966 millibars on the 19th and the maximum winds decreased to 90 knots. Then, during the final 30 hours before landfall near Charleston, Hugo began to reintensify. Just before landfall, a reconnaissance measurement of 934 millibars and 140-knot winds at an altitude of 12000 feet are the basis of the estimate of the highest one-minute wind speed of 120 knots at landfall.

A report of 76 knots with a gust to 94 knots was received from downtown Charleston. The National Weather Service office at the Charleston airport measured 68 knots with a gust to 85 knots. A report of 74 knots with a gust to 93 knots was received from Folly Beach. A hurricane-chaser from Miami, Jim Leonard, measured 936.5 millibars with a portable barometer on the Savannah Highway just west of Charleston. A report of 933 millibars from Mt. Pleasant is unofficial. No wind observations are available from near Bulls Bay where the maximum one-minute winds of 120 knots are estimated to have occurred. The ship Snow Goose was anchored in the Sampit River five miles west of Georgetown and measured a pressure of 984.5 millibars and sustained winds of 104 knots from a three-cup Tradewind anemometer located on the ship's mast at 61-foot elevation.

Hugo was still estimated to be of hurricane strength when its center passed just west of Shaw Air Force Base where 58 knots with a gust to 95 knots and 959.6 millibars pressure were reported. Columbia, just west of the center, reported 46 knots with gusts to 61 knots. In North Carolina, 60-knots winds with gusts to 86 knots were reported from Charlotte as the center went by and Hickory had a gust to 70 knots. Sustained wind speeds in the 30 to 40 knot range were reported along and east of the weakening storm's path as it moved northward to Canada.

Few direct tide gage measurements of the storm surge water levels have been received. The tide station in Charleston near the Custom House measured a water level of 12.9 feet above mean lower low water which converts to a storm tide of 10.4 feet above mean sea level or a storm surge of 8.0 feet above the predicted normal astronomical tide height. As far north as Hatteras, North Carolina, the storm surge was reported at 4 feet above the predicted tide. In addition, a considerable number of high water marks gathered by survey teams indicate that the storm tide was 10 to 12 feet above mean sea level at Folly Beach and ranged to near 20 feet at Bulls Bay...13 to 16 feet at McClellanville...13 feet at Myrtle Beach...and to 8 to 10 feet at Holden Beach, North Carolina.

Rainfall totals along the southeast U.S. coast ranged from a trace at Jacksonville to 6.10 inches at Savannah to a maximum of 8.10 inches at Mt. Pleasant near Charleston to 2.30 inches at Myrtle Beach to 0.58 inches at Hatteras. A 150-mile wide swath of three to eight inches of rain spread inland across South Carolina. The swath continued over western North Carolina with a maximum of 6.91 inches reported at Boone. Rainfall totals were in the two- to four-inch range across western Virginia, West Virginia, western Pennsylvania, eastern Ohio and western New York.

3. Casualty and damage statistics

The total number of deaths associated with Hugo is estimated at 49, as follows:

South Carolina	13	Antigua and Barbuda	1
North Carolina	1	Guadeloupe	11
Virginia	6	Montserrat	10
New York	1	St. Kitts and Nevis	1
Puerto Rico	2		
U.S. Virgin Islands	3		

Damage figures are astronomical and Hugo is the costliest hurricane in U.S. history. The American Insurance Association reports 3.042 billion dollars as the preliminary estimate of insured property damage for the U.S. mainland, and 1.881 billion dollars for Puerto Rico and the U.S. Virgin Islands and these numbers are subject to upward revision. The Federal Emergency Management Agency estimate of money outlay is currently at .208 billion dollars for the U.S. mainland and .731 billion dollars for Puerto Rico and the U.S. Virgin Islands and is also subject to upward revision. "The State" newspaper, Columbia, South Carolina, reports a dollar damage estimate totalling 7.071 billion dollars for the U.S. mainland, 1.600 billion dollars for Puerto Rico and the Virgin Islands and another .450 billion dollars for other islands in the Caribbean, including Antigua and Barbuda, the British Virgin islands, Guadeloupe, Montserrat and St. Kitts and Nevis. Hurricane damage estimates for past storms have often been two to three times the insured property damage and it is possible that Hugo's international damage total will exceed ten billion dollars.

Meanwhile, the damage estimate is temporarily placed at seven billion dollars for the U.S. mainland and two billion dollars for Puerto Rico and the Virgin Islands and one half billion dollars for the other island countries in the Caribbean. These estimates are believed to be accurate within about plus or minus 50 percent.

4. Forecast and warning critique

Table 3 lists the various watches and warnings and their time of issuance. A selection of warning lead times is as follows: Guadeloupe 30 hours; St Croix 35 hours; Puerto Rico 42 hours; South Carolina 18 hours.

U.S. DEPARTMENT OF COMMERCE
NOAA - NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART

HURRICANE HUGO TRACK

- HURRICANE
- - - TROPICAL STORM
- DEPRESSION
- EXTRATROPICAL

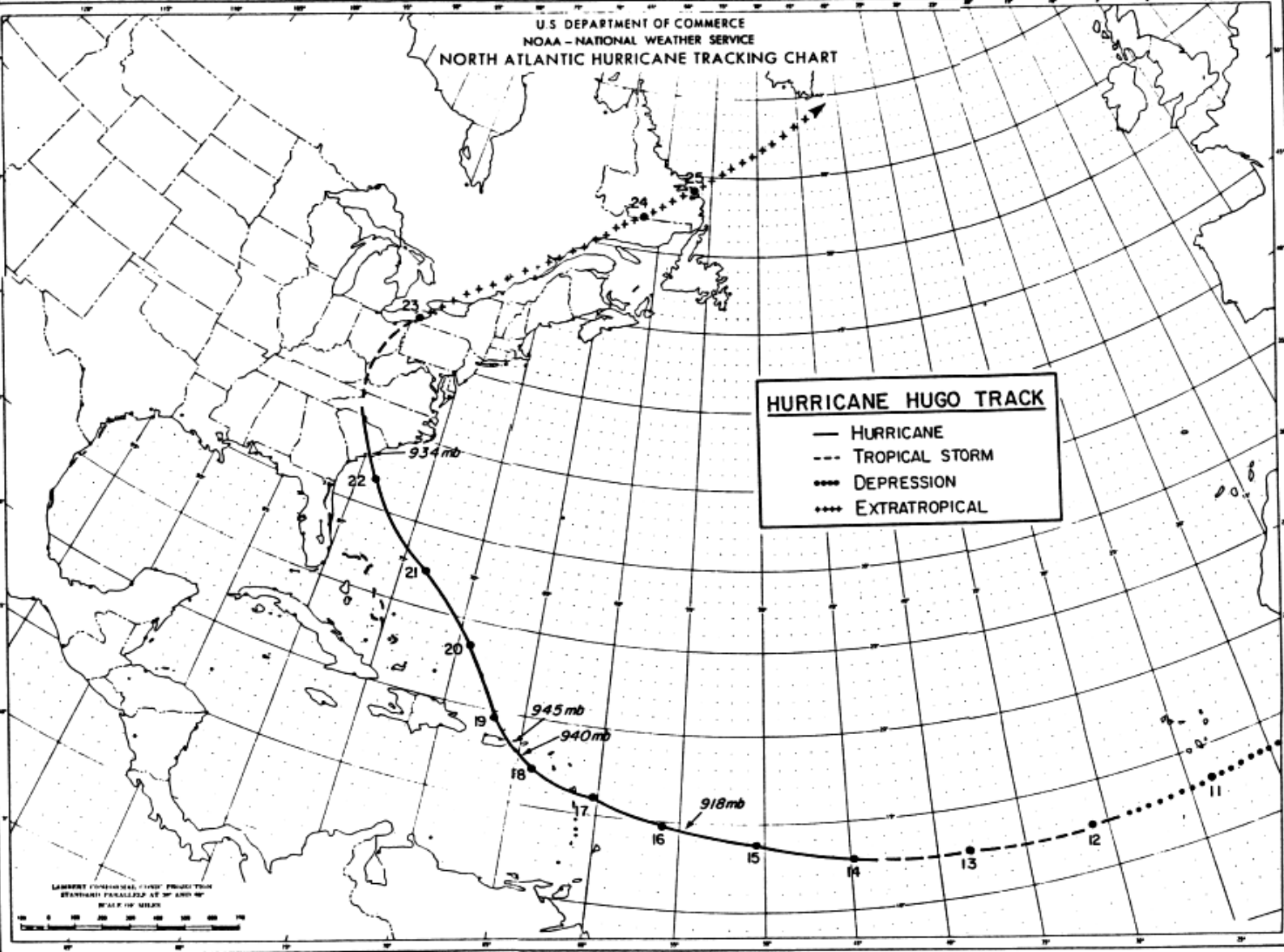


Table 4 lists the average official track forecast errors along with the errors of several guidance models. The official errors are quite small for Hurricane Hugo. For example, the 24-hour average forecast error of 65 nautical miles during Hugo compares with the previous ten-year average official error of 111 nautical miles and the 72-hour Hugo error of 154 nautical miles compares with the previous ten-year average of 342 nautical miles. It is also noted that some of the guidance models also had very small errors.

There was a left bias to the official forecasts for the period when Hugo was turning from west northwestward to northwestward. This was as Hugo was moving across the islands of the Caribbean and for the following two days and this is a normal bias for National Hurricane Center track forecasts in this area during recurvature situations. Also, there was a slight right bias for two forecasts on the 21st just before landfall, indicating that the track would be across eastern North Carolina and requiring a last-minute northward extension to the hurricane warning which, using hindsight, turned out to be unnecessary.

Looking over the public advisories, it is noted that from 2200 UTC on the 20th to 2200 UTC on the 21st, the highest sustained winds increased from 105 mph to 135 mph. During this same period, the wind forecast contained in all of the public advisories was "little significant change in strength is likely". It is important for users of National Hurricane Center products to appreciate the limitations in tropical cyclone intensity forecasting, as here is a situation where a tropical cyclone goes from a category two to a category four hurricane on the Saffir/Simpson Scale during the 30 hours prior to landfall. Fortunately, in this case, the response of state and local officials and of the general public of South Carolina was excellent. A massive evacuation of the coastal barrier islands was 90 percent complete several hours before landfall and this allowed a margin of safety which accomodated the increase in strength described above.

Miles Lawrence
15 November 1989

Table 1. Preliminary best track, Hurricane Hugo,
10-25 September 1989

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat (N)	Lon (W)			
1200	13.2	20.0	1010	25	Trop Depression
1800	13.3	21.8	1010	25	
11/0000	13.2	23.7	1009	30	
0600	13.0	25.5	1007	30	
1200	12.8	27.3	1005	30	Trop Storm
1800	12.5	29.2	1003	35	
12/0000	12.5	31.0	1002	40	
0600	12.5	32.9	1000	45	
1200	12.5	34.8	998	45	
1800	12.6	36.7	996	50	
13/0000	12.6	38.2	994	55	
0600	12.7	40.0	992	55	Hurricane
1200	12.8	41.8	990	60	
1800	12.8	43.5	987	65	
14/0000	12.9	44.9	984	70	
0600	13.0	46.3	980	80	
1200	13.2	47.8	975	85	
1800	13.6	49.1	970	90	
15/0000	13.8	50.5	962	100	
0600	14.0	51.9	957	110	
1200	14.2	53.3	940	125	
1800	14.6	54.6	918	140	
16/0000	14.8	56.1	923	135	
0600	15.1	57.3	927	130	
1200	15.4	58.4	940	120	
1800	15.8	59.4	941	120	
17/0000	16.1	60.4	941	120	
0600	16.4	61.5	943	120	
1200	16.6	62.5	949	125	
1800	16.9	63.5	945	125	
18/0000	17.2	64.1	934	130	
0600	17.7	64.8	940	120	
1200	18.2	65.5	945	110	
1800	19.1	66.4	958	105	
19/0000	19.7	66.8	959	100	
0600	20.7	67.3	962	90	
1200	21.6	68.0	964	90	
1800	22.6	68.6	966	90	
20/0000	23.5	69.3	963	90	
0600	24.4	70.1	957	90	
1200	25.2	71.0	958	95	
1800	26.3	72.2	953	95	
21/0000	27.2	73.4	950	100	
0600	28.0	74.9	950	100	
1200	29.0	76.1	948	110	
1800	30.2	77.5	944	120	

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat (N)	Lon (W)			
22/0000	31.7	78.8	935	120	
0600	33.5	80.3	952	85	
1200	35.9	81.7	975	55	Trop Storm
1800	38.5	81.8	987	40	
23/0000	42.2	80.2	988	35	extratropical
0600	46.0	74.5	990	40	
1200	49.0	69.0	992	40	
1800	51.0	65.0	993	40	
24/0000	52.0	62.0	994	40	
0600	52.5	60.5	993	40	
1200	53.0	59.5	991	40	
1800	53.5	58.5	989	40	
25/0000	54.0	57.0	983	40	
0600	56.0	52.0	979	40	
1200	58.0	46.0	974	40	

Landfall:

Guadeloupe					
17/0500	16.3	61.3	941	120	Hurricane
St Croix					
18/0600	17.7	64.8	940	120	Hurricane
Vieques, Puerto Rico					
18/1200	18.2	65.5	945	110	Hurricane
Fajardo, Puerto Rico					
18/1300	18.3	65.6	946	110	Hurricane
Sullivans Island, South Carolina					
22/0400	32.8	79.8	934	120	Hurricane

TABLE 2. Hurricane Hugo selected surface observations September 1989.

Location	Minimum sea-level pressure		Maximum surface wind speed (knots)			Storm surge (tide height above normal) (ft)	Rain (storm total) (in)
	Pressure (mb)	Date/time (UTC)	1-minute average	Peak gust	Date/time (UTC)*		
Guadeloupe	941.1						
St. Maarten Juliana Airport			40	68	18/0200		
Puerto Rico							
Gurabo							9.20
Isla de Culebra				148			
Isla Verde	970.3	18/1415					
Luquillo	956	18/1300					
Roosevelt Roads	946.1	18/1250	90	104	18/1158		
San Juan	970.3	18/1444	67	80	18/1350		3
Florida							
Jacksonville	1003.5	22/0200	18	22	21/2035		T
St. Augustine			14	26	21/1900		
Georgia							
Fort Pulaski						1.4	
St. Simons Island			20	40	22/0100		
Savannah Light Tower	989.6	22/0300	50	59	22/0400		
Savannah WSO	993.5	22/0353	30	47	22/0553		6.10
South Carolina							
Beaufort	984	22/0455	27	44	22/0700		5.94
Charleston AFB	943.2	22/0423					
Charleston city			76	94	22/0340	8.0	6.37
Charleston Pier P	942						
Charleston WSO	942.1	22/04??	68	85	22/0503		5.90

TABLE 2.(cont.) Hurricane Hugo selected surface observations September 1989.

Location	Minimum sea-level pressure		Maximum surface wind speed (knots)			Storm surge (tide height above normal) (ft)	Rain (storm total) (in)
	Pressure (mb)	Date/time (UTC)	1-minute average	Peak gust	Date/time (UTC)*		
South Carolina							
Charleston							
Savannah hwy	936.5	22/0405					
Columbia AT&T	971.7	22/0800		86	22/0654		
Columbia WSFO			46	61	22/0609		
Florence	989.1	22/0750	39	54	22/0547		
Folly Beach C-MAN	940	22/0400	74	93	22/0400		
Georgetown EOC			69		22/0300		3.74
Mt. Pleasant	933	22/0405	71	83	22/0345		8.10
Myrtle Beach AFB	993.5	22/0455	45	66	22/0555		2.30
Sampit River	984.5	22/0442	104				
Shaw AFB	959.6	22/0655	58	95	22/0655		
Summerville							5.98
North Carolina							
Asheville	989.9	22/1150	20	32	22/1050		1.93
Boone							6.91
Cape Fear River				61	22/0545		
Carolina Beach						3 (est.)	
Charlotte	978.0	22/0945	60	86	22/1003		3.16
Greensboro	998.1	22/1153	37	47	22/1108		1.43
Hatteras	1013.1	22/0730	23	30	22/0050	4	0.60
Hickory	980.5		30	70	22/1046		
Holden Beach				51	22/0555	6 (est.)	
Ocean Isle						7 (est.)	
Raleigh	1004.6	22/0930	25	40	22/1050		0.45
Wilmington	1004.5	22/0500	26	46	22/0452		0.79
Virginia							
Norfolk	1008.8	22/1950	23	32	22/2050	0.2	0.21

*Time of 1-minute wind speed unless only gust is given.

Table 3. Warning summary, Hurricane Hugo, September 1989

date/time(UTC) action	location
15/1900 hurricane watch	St Lucia through St Martin and the British Virgin Islands
tropical storm watch 15/2200 hurricane warning	Barbados and St Vincent St Lucia through St Martin and the British Virgin Islands
tropical storm warning hurricane watch 15/2300 hurricane warning	Barbados and St Vincint U.S. Virgin Islands and Puerto Rico Martinique and Guadeloupe
16/1900 hurricane warning tropical storm warning tropical storm warning discount.	Puerto Rico and U.S. Virgin Islands St Lucia Barbados and St Vincent
17/1000 tropical storm warning discount. 17/1300 hurricane warning discount. 17/1600 hurricane watch	St Lucia Matinique northward through Barbuda Dominican Republic: La Romana to Puerto Plata
18/0100 hurricane watch hurricane warning discount. 18/0230 hurricane warning hurricane watch	Southeastern Bahamas and Turks and Caicos Islands St Martin and surrounding islands Dominican Republic: La Romana to Puerto Plata Dominican Republic: Puerto Plata to Montecristi and La Romana to Caucedo
18/1300 hurricane warning 18/2200 hurricane watch discount.	Southeastern Bahamas and Turks and Caicos Islands Dominican Republic: Puerto Plata to Montecristi and La Romana to Caucedo
19/0100 hurricane warning discount. 19/0230 tropical storm warning 19/0700 tropical storm warning discount.	Puerto Rico, U.S. and British Virgin Islands Dominican Republic: La romana to Puerto Plata Dominican Republic
19/1600	

tropical storm warning	Southeastern Bahamas and Turks and Caicos Islands
hurricane watch	Central Bahamas
20/0230	
tropical storm warning	Central Bahamas
tropical storm warning discount.	Turks and Caicos Islands
20/1000	
tropical storm warning discount.	Southeastern Bahamas
tropical storm warning	Northwestern Bahamas
20/1600	
hurricane watch	Abaco and Grand Bahama Islands
all other warnings discount.	Bahamas
20/2200	
hurricane watch	St Augustine FL to Cape Hatteras NC
21/1000	
hurricane warning	Fernandina Beach FL to Cape Lookout NC
tropical storm warning and a hurricane watch	St Augustine to Fernandina Beach
hurricane watch	Cape Lookout to Cape Hatteras
21/1600	
tropical storm warning and a hurricane watch	North of Cape Lookout to Virginia Beach VA
tropical storm watch	North of Virginia Beach to Cape Henlopen DE
21/1900	
hurricane warning	Cape Lookout to Oregon Inlet NC including Pamlico Sound
	North of Oregon Inlet to Cape Henlopen including Albemarle Sound and Chesapeake Bay
tropical storm warning and a hurricane watch	
21/2200	
all warnings discount.	South of Fernandina Beach
22/0800	
all warnings discount.	Savannah southward
22/1000	
all hurricane warnings discount.	
22/1300	
tropical storm warning	Virginia Beach to Manasquan NJ
tropical storm warning discount.	South of Virginia Beach
22/1600	
tropical storm warning discount.	Virginia Beach to Manasquan
tropical storm wind warning	Coastal and offshore waters Cape Henlopen to Eastport ME
23/0500	
gale warning	NJ through New England

Table 4. Hurricane Hugo average track forecast errors (nautical miles), non-homogeneous sample.

model	forecast period (hours)					
	0	12	24	36	48	72
Official (no. of cases)	10 (43)	33 (43)	65 (41)	98 (39)	122 (37)	154 (33)
BAM	51 (17)	50 (17)	84 (16)	123 (15)	154 (14)	268 (13)
CLIPER	10 (43)	37 (43)	73 (41)	119 (39)	161 (37)	216 (33)
NHC83	12 (42)	38 (42)	61 (40)	88 (38)	106 (36)	178 (32)
QLM	7 (19)	81 (19)	90 (18)	119 (17)	172 (16)	268 (14)
SANBAR	8 (15)	28 (15)	55 (15)	92 (14)	141 (13)	302 (11)

Figure Captions

- Fig. 1. Best track positions for Hurricane Hugo, September 1989.
- Fig. 2. Best track minimum-central-pressure-versus-time curve for Hurricane Hugo, September 1989.
- Fig. 3. Best track maximum-sustained-wind-versus-time curve for Hurricane Hugo, September 1989.

4

