SUMMARY OF 2003 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND MONTHLY FORECASTS

(An active hurricane season and a successful forecast)

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[This forecast as well as past forecasts and verifications are available via the World Wide Web: http://tropical.atmos.colostate.edu/forecasts/index.html] — also,

Brad Bohlander and Thomas Milligan, Colorado State University Media Representatives, (970-491-6432) are available to answer various questions about this forecast.

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HOW CSU SEASONAL HURRICANE FORECASTS ARE DIFFERENT THAN THE FORECASTS RECENTLY BEING ISSUED BY NOAA

Colorado State University (CSU) has issued seasonal hurricane forecasts for the last 20 years. These forecasts, which are now issued in early December of the prior year, and in the early part of the months of April, June and August of the current year, have steadily improved through continuing research. CSU forecasts now include individual monthly predictions and seasonal updates of Atlantic basin activity and monthly U.S. hurricane landfall probabilities which are issued in early August, early September and early October.

The National Oceanic and Atmospheric Administration (NOAA) has also recently begun to issue Atlantic basin seasonal hurricane forecasts, but they do not issue monthly forecasts or landfall probability forecasts. NOAA issues two forecasts per season and gives a range of numbers. The NOAA forecasts are independent of the CSU forecasts, although they utilize prior CSU research augmented with their own insights. The NOAA and the CSU forecasts will not necessarily be in agreement.

Special Note

Chris Landsea, Eric Blake and John Knaff (former Gray project graduate students) deserve (by virtue of their many contributions to our project climate studies) to be co-authors on this forecast. As each of these individuals now work for NOAA (or a branch of NOAA), they have been directed to remove their names from the CSU forecasts.

Acknowledgement

We are grateful to AIG - Lexington Insurance Company (a member of the American International Group) for providing partial support for the research necessary to make these forecasts. The National Science Foundation has also contributed to the background research necessary to make these forecasts.

DEFINITIONS

Atlantic Basin - The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño - (EN) A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years on average.

Hurricane - (H) A tropical cyclone with sustained low level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day - (HD) A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

Hurricane Destruction Potential - (HDP) A measure of a hurricane's potential for wind and storm surge destruction defined as the sum of the square of a hurricane's maximum wind speed (in 10^4 knots^2) for each 6-hour period of its existence.

Intense Hurricane - (IH) A hurricane which reaches a sustained low level wind of at least 111 mph (96 kt or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale (also termed a "major" hurricane).

Intense Hurricane Day - (IHD) Four 6-hour periods during which a hurricane has intensity of Saffir/Simpson category 3 or higher.

MATL - Sea surface temperature anomaly in the Atlantic between 30-50°N, 10-30°W

MPD - Maximum Potential Destruction - A measure of the net maximum destruction potential during the season compiled as the sum of the square of the maximum wind observed (in knots) for each named storm. Values expressed in 10^3 kt.

Named Storm - (NS) A hurricane or a tropical storm.

Named Storm Day - (NSD) As in HD but for four 6-hour periods during which a tropical cyclone is observed (or is estimated) to have attained tropical storm intensity winds.

NATL - Sea surface temperature anomaly in the Atlantic between 50-60°N, 10-50°W

NTC - Net Tropical Cyclone Activity - Average seasonal percentage mean of NS, NSD, H, HD, IH, IHD. Gives overall indication of Atlantic basin seasonal hurricane activity.

ONR - Previous year October-November SLPA of subtropical Ridge in eastern Atlantic between 20-30°W.

QBO - Quasi-Biennial Oscillation - A stratospheric (16 to 35 km altitude) oscillation of equatorial east-west winds which vary with a period of about 26 to 30 months or roughly 2 years; typically blowing for 12-16 months from the east, then reverse and blowing 12-16 months from the west, then back to easterly again.

Saffir/Simpson (S-S) Category - A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge intensity. One is a weak hurricane; whereas five is the most intense hurricane.

SLPA - Sea Level Pressure Anomaly - The deviation of Caribbean and Gulf of Mexico sea level pressure from observed long term average conditions.

SOI - Southern Oscillation Index - A normalized measure of the surface pressure difference between Tahiti and Darwin.

SST(s) - Sea Surface Temperature(s).

SSTA(s) - Sea Surface Temperature(s) Anomalies.

Tropical Cyclone - (TC) A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms, and other weaker rotating vortices.

Tropical Storm - (TS) A tropical cyclone with maximum sustained winds between 39 (18 ms^{-1} or 34 knots) and 73 (32 ms^{-1} or 63 knots) miles per hour.

TATL - Sea surface temperature anomaly in the Atlantic between 8-22°N, 10-50°W.

ZWA - Zonal Wind Anomaly - A measure of upper level ($\sim$ 200 mb) west to east wind strength. Positive anomaly values mean winds are stronger from the west or weaker from the east than normal.

1 knot = 1.15 miles per hour = 0.515 meters per second.

ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2003

Forecast Parameter and 1950–2000 Climatology (in parentheses)	6 December 2002	Update 4 April 2003	Update 30 May 2003	Update 6 Aug 2003	Update 3 Sept 2003	Update 2 Oct 2003	Observed 2003 Total
Named Storms (NS) (9.6)	12	12	14	14	14	14	14
Named Storm Days (NSD) (49.1)	65	65	70	60	55	70	71
Hurricanes (H)(5.9)	8	8	8	8	7	8	7
Hurricane Days (HD)(24.5)	35	35	35	25	25	35	32
Intense Hurricanes (IH) (2.3)	3	3	3	3	3	2	3
Intense Hurricane Days (IHD)(5.0)	8	8	8	5	9	15	17
Hurricane Destruction Potential (HDP) (72.7)	100	100	100	80	80	125	132
Net Tropical Cyclone Activity (NTC)* (100%)	140	140	145	120	130	155	168

* NTC is a combined measure of the yearly mean of six indices (NS, NSD, H, HD, IH, IHD) of hurricane activity as a percent deviation from the 1950-2000 annual average.

ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2003 and verifies the authors' seasonal and monthly forecasts of this activity. A forecast was initially issued on 6 December 2002 with updates on 4 April, 30 May, 6 August, 3 September and 2 October of this year. These forecasts also contained estimates of the probability of U.S. hurricane landfall during 2003. The 6 August update included forecasts of August-only, September-only and October-only tropical cyclone activity for 2003. Our 3 September forecast gave a seasonal summary to that date and included individual monthly predictions of September-only and October-only activity. Our 2 October forecast gave a seasonal summary to that date and included an October-only forecast. We are pleased with our 2003 seasonal forecasts. Most of our forecast numbers were considerably closer to reality than had a climatology forecast been used. Our earliest seasonal forecast (made 6 December 2002) should be considered the best of our forecasts when the extended lead time of the forecast is taken into consideration.

We are encouraged by our new individual monthly forecasts of August-only, September-only, and October-only tropical cyclone activity. The August-only forecast was close to perfect. Although our September-only forecast underestimated activity considerably, our October-only forecast showed forecast skill above climatology for most parameters.

VERIFICATION OF INDIVIDUAL MONTHLY FORECASTS

Our forecast and verification of August-only hurricane activity made in early August - a near perfect forecast.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	August 2003 Statistical Forecast	Adjusted August 2003 Forecast	August 2003 Verification
Named Storms (NS) (2.8)	2.51	3	3
Named Storm Days (NSD) (11.8)	7.31	8	6
Hurricanes (H) (1.6)	0.68	1	2
Hurricane Days (HD) (5.7)	3.81	4	2.5
Intense Hurricanes (IH) (0.6)	0.63	1	1
Intense Hurricane Days (IHD) (1.2)	0.42	0.5	1.25
Net Tropical Cyclone (NTC) (26.4)	17.91	22	26

Our forecast and verification of September-only hurricane activity made in early September - a significant under-forecast.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	September 2003 Statistical Forecast	Adjusted September 2003 Forecast	September 2003 Verification
Named Storms (NS) (3.4)	2.9	4	4
Named Storm Days (NSD) (21.7)	13.0	18	29
Hurricanes (H) (2.4)	1.6	2	3
Hurricane Days (HD) (12.3)	10.5	11	22.50
Intense Hurricanes (IH) (1.3)	0.4	1	1
Intense Hurricane Days (IHD) (3.0)	2.65	6.5	14
Net Tropical Cyclone (NTC) (48)	36	55	94

Our forecast and verification of October-only hurricane activity made in early October - a reasonably good forecast, but we did not anticipate the intensification of Kate into an intense hurricane.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	October 2003 Statistical Forecast	Adjusted October 2003 Forecast	October 2003 Verification
Named Storms (NS) (1.7)	1.8	3	3
Named Storm Days (NSD) (9.0)	9.5	19	21.50
Hurricanes (H) (1.1)	1.2	2	0
Hurricane Days (HD) (4.4)	4.7	7	5.50
Intense Hurricanes (IH) (0.3)	0.3	0	1
Intense Hurricane Days (IHD) (0.8)	0.9	0	1.5
Net Tropical Cyclone (NTC) (17)	18	21	28

1 Introduction

The Atlantic basin (including the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico) experiences more year-to-year hurricane variability than any other global tropical cyclone basin. The number of Atlantic basin hurricanes per season in recent years includes high years with 12 in 1969, 11 in 1995 and 10 in 1950 and 1998, and low years with 2 in 1982 and 3 in 1997, 1994, 1987, 1983, 1972, 1962, and 1957. Until the mid-1980s, there were no objective methods for predicting whether forthcoming hurricane seasons were likely to be active, inactive, or near normal. Recent ongoing research by the first author and his current and former colleagues (see Gray 1984a, 1984b, 1990; Landsea, 1991; Gray *et al.*, 1992, 1993, 1994a; Blake 2002; and Klotzbach 2002) indicate that the global atmosphere and oceans possess surprisingly strong precursor climate signals that extend to nearly a year in advance. It is possible to make skillful hurricane forecasts one to three seasons in advance. Individual monthly forecasts of 0 to 2 months in advance are also found to have substantial forecast skill. Our research now allows us to issue extended-range hurricane forecasts as early as December for next year's Atlantic basin hurricane activity with updates in early April, early June, and early August of the forecast year. Quite skillful individual August-only, September-only and October-only forecasts are also possible from early August. This end-of-season report compares our various monthly and seasonal forecasts for 2003 with the actual hurricane activity of 2003.

2 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

Our forecasts, which are issued at four separate lead times prior to the most active portion of the hurricane season with two updated forecasts issued during the active portion of the season, are based on values of predictive indices derived from various global and regional weather and climate factors which the authors have shown to be related to subsequent seasonal variations of Atlantic basin hurricane activity during the last 53 years (1950-2002). Figures 1-3 show the geographic locations for some of the forecast parameters we use. The development of each new forecast emphasizes the analysis of the current and likely trends in the previously noted precursor oceanic and atmospheric conditions associated with hurricane activity during the following season. The various global predictors we use for our statistical seasonal forecasts are given in Table 1, and the predictors we use for our statistical monthly forecasts are given in Table 2.

Our different lead-time forecast schemes are created by maximizing the pre-season forecast skill from a combination of the above predictors for the period 1950-2001. Space restrictions do not allow for maps of the locations or discussions of the physics of all of these predictors. See our prior individual forecasts which are given on this Web site for maps of the locations and discussions of each of these seasonal and monthly predictions. We also use an analog methodology whereby we look for those years with specific precursor climate signals similar to the current forecast year.

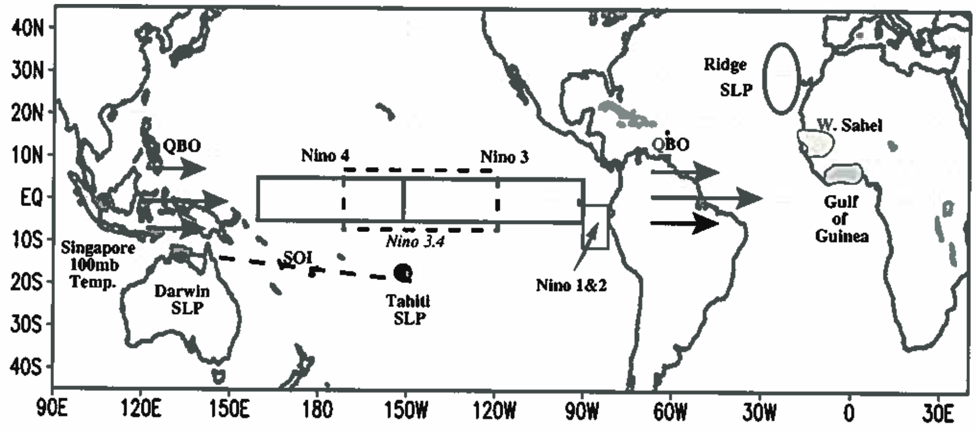


Figure 1: Areas from which specific oceanographic and meteorological parameters used as predictors in our seasonal forecasts are obtained.

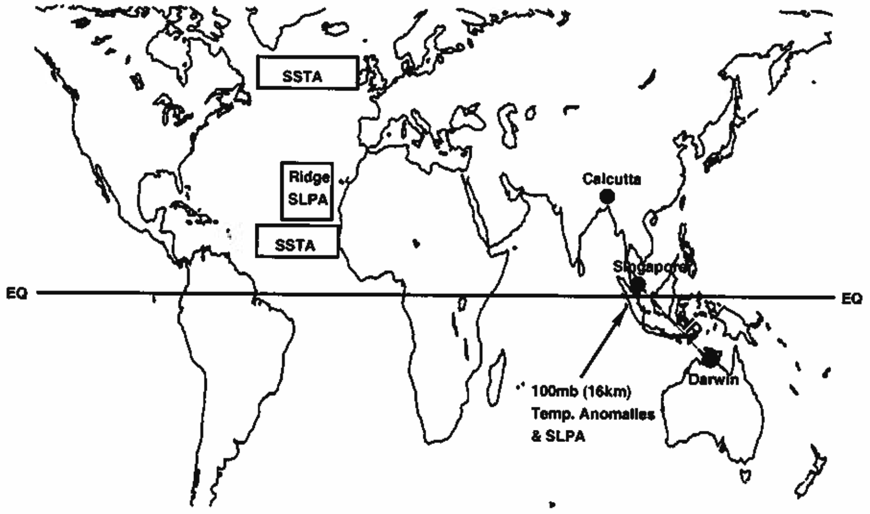


Figure 2: Additional predictor locations which are also considered in formulating our Atlantic seasonal hurricane forecasts.

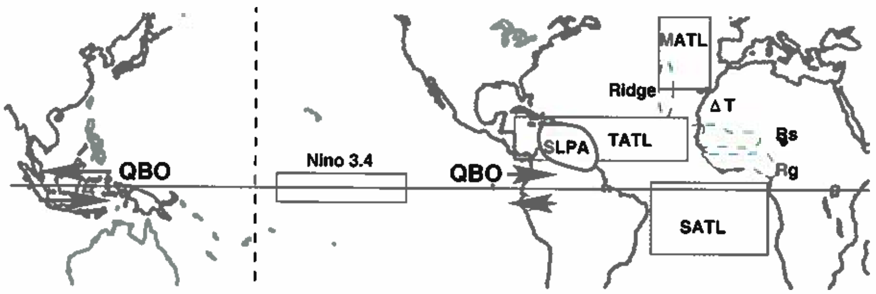


Figure 3: Additional meteorological parameters used in our earlier late May and early August forecast schemes.

A variety of atmosphere-ocean conditions interact with each other to cause year-to-year and month-to-month hurricane variability. The interactive physical linkages between these many physical parameters and hurricane variability are complicated and cannot be well elucidated to the satisfaction of the typical forecaster making short range (1-5 days) predictions where changes in the momentum fields are the crucial factors. Seasonal and monthly forecasts, unfortunately, must deal with the much more complicated interaction of the energy-moisture fields with the momentum fields.

We find that there is a rather high (50-70 percent) degree of year-to-year hurricane forecast potential if one combines 4-5 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 4-5) do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain the portion of the variance of seasonal hurricane activity not associated with the other variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but have an important influence when included with a set of 4-5 other predictors. One strives for independence of predictors.

In a five-predictor empirical forecast model, the contribution of each predictor to the net forecast skill can only be determined by the separate elimination of each parameter from the full 5 predictor model and noting the skill degradation. When taken from the full set of predictors, one parameter may degrade the forecast skill by 25-30 percent, while another degrades the forecast skill by only 10-15 percent. An individual parameter that, through elimination from the forecast, degrades a forecast by as much as 25-30 percent may in fact, by itself, show much less direct correlation with the predictand. A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 4-5 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many atmospheric-oceanic variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. It follows that any seasonal or climate forecast scheme showing significant hindcast skill must be empirically derived. No one can completely understand the full and complex atmosphere-ocean system or develop a reliable physical understanding of the myriad non-linear interactions in the system.

3 Tropical Cyclone Activity for 2003

Table 3 and Fig. 4 summarize the Atlantic basin tropical cyclone activity which occurred in 2003. All of the seasonal forecast parameters of NS, NSD, H, HD, IH, IHD, HDP and NTC were above the long-period average as predicted in our seasonal forecasts.

4 Individual 2003 Tropical Cyclone Characteristics

Tropical Storm Ana: Ana was the first Atlantic tropical storm on record to form in the month of April. It developed from a non-tropical area of low pressure and was originally classified as a subtropical storm. Ana became a tropical system on April 22 after a satellite AMSU pass reported a warm core system. The system reached its maximum intensity of 45 knots at this initial tropical

Table 1: New predictors utilized in our statistical seasonal forecasts issued in early December, early April, and late May respectively. We were not able to obtain any significant increase in hindcast skill incorporating June and July data into our August statistical forecast, and therefore we simply use the late May statistical forecast as our first guess for our early August forecast. We then alter this seasonal forecast by the results of our three individual monthly forecasts of August, September and October.

Early December Forecast

Predictor and Sign of Correlation	Location
November 500 MB Geopotential Height (+)	(67.5-85°N, 50°W-10°E)
November SLP (+)	(7.5-22.5°N, 125-175°W)
October-November SLP (-)	(45-65°N, 120-160°W)
September-November SLP (-)	(15-35°N, 75-95°W)
September 500 MB Geopotential Height (+)	(35-55°N, 100-120°W)
July 50 MB U (-)	(5°S-5°N, 0-360°)

Early April Forecast

Predictor and Sign of Correlation	Location
February-March 200 MB V (-)	(35-62.5°S, 70-95°E)
February 200 MB U (-)	(5°S-10°N, 35-55°W)
February SLP (+)	(0-45°S, 90-180°W)
February SST (+)	(35-50°N, 10-30°W)
Previous November 500 MB Geopotential Height (+)	(67.5-85°N, 50°W-10°E)
Previous September-November SLP (-)	(15-35°N, 75-95°W)

Late May Forecast

Predictor and Sign of Correlation	Location
May SST (+)	(20-40°N, 15-30°W)
February-March 200 MB V (-)	(35-62.5°S, 70-95°E)
February 200 MB U (-)	(5°S-10°N, 35-55°W)
February SLP (+)	(0-45°S, 90-180°W)
February SST (+)	(35-50°N, 10-30°W)
Previous November 500 MB Geopotential Height (+)	(67.5-85°N, 50°W-10°E)
Previous September-November SLP (-)	(15-35°N, 75-95°W)

Table 2: Predictors utilized in our monthly forecasts for August-only, September-only and October-only Atlantic tropical cyclone activity, respectively. See section 5.3 (page 19) for a discussion of our monthly predictions and the timetable of their release.

August-only Forecast

Issued in Early August

Predictor and Sign of Correlation	Location
July 200 MB V (-)	(4°S-8°N, 79-105°W)
July SLP (-)	(47-62°N, 156°E-164°W)
July SLP (-)	(25-37.5°N, 25-47.5°W)
July 200 MB U (-)	(35-40°S, 85-110°W)
July 500 MB Geo. Ht. (-)	(27.5-42.5°S, 72.5-95°E)
July 200 MB U (+)	(7.5-17.5°S, 145-180°E)
July 200 MB U (-)	(5°S-5°N, 85-110°W)
June 200 MB U (+)	(80-85°N, 45°W-10°E)
June SLP (+)	(18-30°N, 134-154°E)
April SLP (-)	(10°S-5°N, 35°W-15°E)
February SLP (-)	(52.5-75°N, 5°W-35°E)
January SLP (-)	(30-40°N, 95-110°W)

September-only Forecast

Issued in early August

Predictor and Sign of Correlation	Location
July 1000 MB U (+)	(5-15°N, 30-50°W)
July 200 MB Geo. Ht. (+)	(32-42°N, 100-160°E)
May 200 MB V (+)	(0-20°S, 15-30°E)
April 200 MB U (-)	(67.5-85°N, 110-180°E)
April 1000 MB U (-)	(12.5-30°S, 40°W-10°E)
February 1000 MB U (-)	(20-30°N, 15°W-15°E)
January-February 200 MB U (-)	(15-25°N, 120°E-160°W)

September-only Forecast

Issued in early September

Predictor and Sign of Correlation	Location
August SLP (-)	(0-30°S, 120-160°E)
August SLP (-)	(20-45°S, 60-90°E)
July-August 1000 MB U (+) (-)	(5-15°N, 30-50°W) - (22.5-35°N, 35-65°W)
July 200 MB Geo. Ht. (+)	(32-42°N, 100-160°E)
May 200 MB V (+)	(0-20°S, 15-30°E)
April 200 MB U (-)	(67.5-85°N, 110-180°E)
April 1000 MB U (-)	(12.5-30°S, 40°W-10°E)
February 1000 MB U (-)	(20-30°N, 15°W-15°E)
January-February 200 MB U (-)	(15-25°N, 120°E-160°W)

October-only Forecast

Issued in early August

Predictor and Sign of Correlation	Location
July 200 MB Geo. Ht. (+)	(20-35°N, 5-45°W)
July 200 MB U (+)	(35-47.5°S, 160°E-160°W)
June-July SLP (-)	(10-25°N, 10-40°W)
Previous November SLP (-)	(45-65°N, 115-145°W)

October-only Forecast

Issued in early September

Predictor and Sign of Correlation	Location
August SST (+)	(22.5-35°N, 120-150°E)
July-August 200 MB U (+)	(35-47.5°S, 160°E-155°W)
July-August SLP (-)	(12.5-27.5°N, 15-45°W)
Previous November SLP (-)	(45-65°N, 115-145°W)

October-only Forecast

Issued in Early October

Predictor and Sign of Correlation	Location
September 200 MB U (+)	(37.5-47.5°S, 0-30°W)
August SST (+)	(22.5-35°N, 120-150°E)
July-August 200 MB U (+)	(35-47.5°S, 160°E-155°W)
July-August SLP (-)	(12.5-27.5°N, 15-45°W)
Previous November SLP (-)	(45-65°N, 115-145°W)

Table 3: Observed 2003 tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds Knots /lowest SLP in mb	NSD	HD	IHD	HDP	NTC
TS	Ana	April 22-24	45 kt/996 mb	1.75				2.3
TS	Bill	June 29 - July 1	50 kt/997 mb	1.75				2.3
H - 1	Claudette	July 8-16	70 kt/981 mb	7.50	0.50		0.9	7.4
H - 1	Danny	July 17-20	65 kt/1005 mb	3.75	1.00		1.7	6.5
H - 1	Erika	Aug. 14-16	65 kt/986 mb	2.00	0.25		0.4	5.4
IH - 4	Fabian	Aug 28-Sept 8	125 kt/939 mb	11.00	10.00	7.50	44.7	47.3
TS	Grace	Aug 30-31	35 kt/1007 mb	0.75				2.0
TS	Henri	Sept 5-6	45 kt/997 mb	1.00				2.1
IH - 5	Isabel	Sept 6-19	140 kt/920 mb	13.25	11.50	8.00	61.1	50.8
H - 2	Juan	Sept 25-29	90 kt/970 mb	3.75	2.75		6.8	7.7
IH - 3	Kate	Sept 27-Oct 7	110 kt/952 mb	10.25	5.75	1.50	16.6	24.2
TS	Larry	Oct 2-6	50 kt/993 mb	4.25				3.2
TS	Mindy	Oct 10-12	40 kt/1002 mb	2.00				2.4
TS	Nicholas	Oct 15-23	60 kt/990 mb	8.25				4.5
Totals	14			71.25	31.50	17.00	132	168

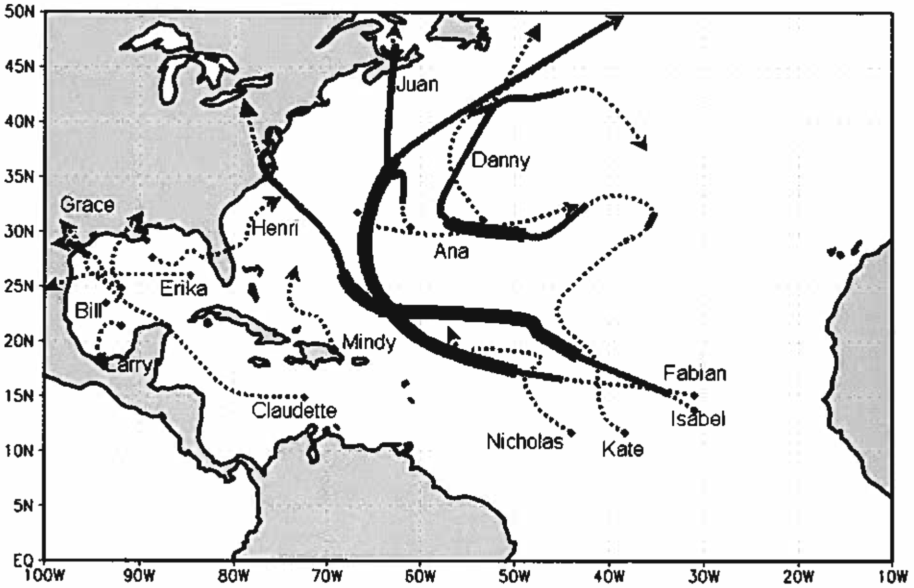


Figure 4: Tracks of 2003 Atlantic Basin tropical cyclones. Dashed lines indicate tropical storm intensity, a thin solid line is Cat 1 or 2 hurricane intensity, and a thick solid line is major hurricane (Cat 3-4-5) intensity.

storm advisory and then began to weaken due to increasing westerly shear over the system. Ana became assimilated into a frontal zone while tracking eastward across the open Atlantic on April 24.

Tropical Storm Bill: Bill developed from an area of deep convection over the central Gulf of Mexico on June 29. The system intensified slightly due to minimal wind shear conditions and warm sea surface temperatures. It then tracked almost due north through the Gulf of Mexico. It made landfall along the central Louisiana coast near Terrebone Bay as a 50 knot tropical storm on June 30. It then tracked northeast over land and dissipated near the Louisiana-Mississippi border.

Hurricane Claudette: Claudette developed from a tropical wave in the central Caribbean on July 8. It tracked westward under the influence of a mid-level ridge and then began to curve towards the northwest as the ridge began to break down. Claudette tracked across the tip of Yucatan bringing estimated winds of 45 knots at landfall. It then continued on a mostly northwestward track. Intensification was at first inhibited by persistent upper-level westerlies; however, an upper-level low later interacted favorably with the system by reducing its vertical wind shear. This allowed Claudette to briefly reach hurricane intensity. The system turned more towards the west and made landfall near Matagorda Bay, Texas as a 80 knot hurricane on July 15. It dissipated over inland Texas early on July 16. Three deaths in the U.S. were associated with Claudette, and it is estimated that the storm also did approximately 180 million dollars in damage.

Hurricane Danny: Danny formed from the northern part of a tropical wave and moved northward through the eastern Atlantic. It briefly reached hurricane status with maximum winds estimated at 65 knots on July 19 as it tracked around the northern part of a subtropical ridge. It then dissipated on July 20 as it turned northeastward and moved over the colder waters of the North Atlantic.

Hurricane Erika: Erika formed in the eastern Gulf of Mexico from an area of disturbed weather. It tracked westward across the Gulf of Mexico due to a large high pressure system over the central U.S. and intensified to a minimal 65 knot hurricane on August 16 due to the weakening of the vertical wind shear. Erika was upgraded to a hurricane in post-analysis based on radar Doppler wind measurements of 80 knots to the north of the center of the circulation. Erika then made landfall just south of Brownsville, Texas and dissipated over the higher terrain of Mexico on August 17. There was appreciable damage in the Brownsville area.

Intense Hurricane Fabian: Fabian was the first intense (or major) hurricane of the year. It developed in the far eastern Atlantic from a tropical wave on August 28. It tracked generally westward for the first few days of its existence due to a subtropical ridge to its north. Fabian was in a low-shear environment for the early part of its existence and intensified into a hurricane. By August 30, Fabian had intensified further and became a major hurricane. Its maximum intensity was reached on September 1 (125 kts, 939 mb) as it continued to move over an area of low shear and warm sea surface temperatures. Fabian turned towards the northwest and then to the north as it continued to move around the periphery of the subtropical ridge. Fabian tracked just to the west of Bermuda bringing Category 3 winds to the island and causing considerable damage with preliminary estimates ranging from 300 to 350 million dollars. Fabian weakened as it continued to track northward and then northeastward. It made its extratropical transition on September 8 as it moved towards Greenland.

Tropical Storm Grace: Grace developed from an area of disturbed weather in the western Gulf of Mexico on August 30. Any strengthening of this system was inhibited by an upper-level low to its west causing unfavorable wind shear. Grace never strengthened beyond minimal tropical storm status (35 knots). Grace tracked westward and made landfall near Port O'Connor, Texas on August 31. Considerable rainfall was reported from the system. Widespread areas along the southeast coast of Texas reported from 4-6 inches of rain. There were no reports of damage or casualties with this storm.

Tropical Storm Henri: Henri formed from a tropical wave in the eastern Gulf of Mexico on September 5. Considerable shear persisted over Henri throughout much of its lifetime, and the system was slow to strengthen. It briefly reached an intensity of 45 knots before weakening. A mid-level trough imposed additional southwesterly shear on Henri, and it weakened back to a tropical depression before making landfall near Tampa, FL on September 6. The system was monitored for signs of regeneration into a tropical storm as it tracked northeastward into the Atlantic, but southwesterly shear prevented any intensification from occurring.

Intense Hurricane Isabel: Isabel developed from a tropical wave on September 6 about 600 miles west of the Cape Verde Islands. Wind shear was low around the system as it tracked westward across the Atlantic, and it became a hurricane on September 7. Conditions favored further development, and Isabel became the second intense hurricane of the season on September 8. The storm remained intense for the next eight days as it tracked westward and then northwestward across the open Atlantic. Isabel became a Category 5 hurricane on September 11; the first Category 5 hurricane in the Atlantic basin since Mitch (1998). It reached its maximum intensity of 140 knots and 920 millibars the following day. It began to weaken as it neared the North Carolina coast and encountered stronger wind shear and cooler sea surface temperatures. Isabel made landfall near Ocracoke Island, NC as a Category 2 hurricane with estimated winds at landfall of 85 knots. Isabel tracked northwestward across the eastern United States before dissipating near Erie, PA on September 19. Copious rainfall amounts were reported with Isabel with several stations in Maryland and Virginia reporting over six inches of rainfall. It was responsible for 30 deaths, and insured damage is estimated at one billion dollars.

Hurricane Juan: Juan formed from a frontal zone located near Bermuda on September 25. It intensified into a hurricane on September 26 while tracking almost directly northward towards Nova Scotia. Juan reached a maximum intensity of 90 knots while continuing its northward track towards the Canadian Maritimes. It made landfall near Halifax, Nova Scotia as a Category 1 hurricane on September 28 with estimated sustained winds at landfall of 70 knots. Juan made extratropical transition on September 29 between Prince Edward Island and Labrador. Eight deaths have been attributed to the storm, and the system did approximately 100 million dollars in damage.

Intense Hurricane Kate: Kate developed from a tropical wave between the Cape Verde Islands and the Leeward Islands on September 27. An upper-level cyclone steered Kate towards the northeast for the first few days of its life as a tropical cyclone. The system briefly gained hurricane status on September 29 and then weakened as an upper-level low turned the system towards the west. It then entered an area of less shear and regained hurricane status on October 1. Low wind shear helped the system to continue its strengthening, and it reached Category 3 status on October 3. It is unusual for a major hurricane to develop at such a high latitude that late in the season.

A trough of low pressure caused Kate to turn towards the north and then the northeast, and the storm weakened as it began to encounter the midlatitude westerlies and cooler sea surface temperatures. Kate was declared extratropical on October 7 as it was tracking about 400 miles east of Newfoundland.

Tropical Storm Larry: Larry formed from a frontal boundary in the southern Gulf of Mexico on October 2. Larry was under weak steering flow for most of its lifetime, as it was trapped between ridges to its east and its west. It intensified to a 50 knot tropical storm late in the day on October 3 due to light shear conditions, but the system began to interact with land as it slowly drifted southward into the Bay of Campeche. Larry maintained its 50-knot intensity until making landfall on October 5 near Coatzacoalcos, Mexico. The storm then dissipated over land. Larry was responsible for five deaths in Mexico.

Tropical Storm Mindy: Mindy developed from a tropical wave near the northeastern coast of the Dominican Republican on October 10. A large trough along the southeast coast of the United States steered Mindy towards the northwest, and the system intensified slightly to 40 knots on October 11. Strong southwesterly vertical shear due to an approaching trough caused Mindy to weaken to a tropical depression on October 12. Advisories on tropical depression Mindy were continued until late on October 13 when the low-level circulation center became well-separated from the center of convection, and the system was reclassified as a remnant low.

Tropical Storm Nicholas: Nicholas formed from a tropical wave on October 14 about 1100 miles east of the Windward Islands. This is the farthest east that a storm has developed in the tropics this late in the season since storm 12 of the 1950 season. Nicholas strengthened initially with moderate westerly vertical wind shear and upper-level diffluence. A shortwave near the Lesser Antilles caused Nicholas to track northwestward followed by a turn more towards the north over the next few days. Strong southwesterly shear inhibited the system's intensification. Nicholas reached its maximum strength of 60 knots on October 17 despite persistent southwesterly shear. The shear eventually took its toll on the system, and it weakened back to a 45 knot storm on October 19 while continuing a slow northward track. Nicholas then tracked more towards the west as it moved around the southwestern edge of a mid-level ridge. Nicholas underwent a few brief periods of weakening and strengthening over the next couple of days while tracking west. Southwesterly shear never relaxed with Nicholas, and the final advisory on the system was written on October 23. The remnants of Nicholas were absorbed by a frontal zone over the next couple of days.

U.S. Landfall. Figure 5 shows the tracks of all 2003 tropical cyclones which impacted the U.S. Only hurricanes Claudette and Isabel come ashore in the U.S. Erika became a hurricane just before coming ashore just south of the Mexico-U.S. border. Tropical storm winds and significant damage occurred near Brownsville, TX.

4.1 Special Characteristics of the 2003 Hurricane Season

- Ana became the first tropical cyclone on record to form in the Atlantic basin in April.
- A very active early season. Four named storms formed by July 17. Since 1950, the only years that have already had their fourth named storm by this early in the season were 1959 and 1997.
- 14 named storms formed this year. The only years since 1950 with more named storms forming were 1969 (17 NS), 1995 (19 NS), and 2001 (15 NS).
- An extraordinary number of intense hurricane days (17 IHD). Only 1961 (20.75 IHD) has had more intense hurricane days than this year.

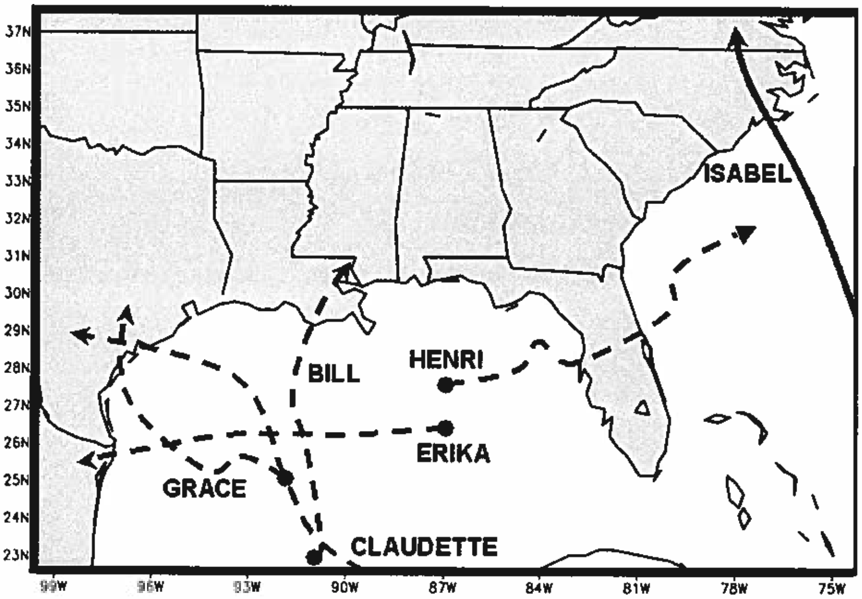


Figure 5: Tropical cyclones making US landfall (TS Bill, Category 1 Hurricane Claudette, TS Grace and Category 2 Hurricane Isabel). TS Henri was downgraded to a tropical depression before it crossed over central Florida. Although Erika's landfall was south of the U.S. border, it made a significant impact on Brownsville and the south Texas coast.

- Isabel was the first landfalling East Coast hurricane since Floyd (1999). It has now been seven years since an intense hurricane struck the East Coast of the United States. The last storm to do so was Fran (1996).
- Isabel was the longest lived intense hurricane (8 IHD) since Luis (1995 - also 8 IHD).
- The remarkable longevity of Fabian (7.5 IHD) and Isabel (8 IHD) as intense hurricanes. Since 1900, there has never been a year where two storms have each compiled greater than 6 intense hurricane days.
- Isabel reached Category 5 status on September 11. It is the first system in the Atlantic to be classified as a Category 5 hurricane since Mitch (1998).
- A very active September. The observed September NTC value (94) was the third highest on record, trailing only 1961 (141) and 1950 (98).
- A generally active season. The observed seasonal NTC of 168 places this year in 7th place for the largest NTC value since 1950.
- An intense hurricane formed in October (Kate). We have now had an intense hurricane in October in 6 of the last 9 years (since 1995). In the 18 years preceeding 1995, only one October intense hurricane was observed.
- Despite a near-record number of intense hurricane days in September, we observed the fewest September hurricanes (3) since 1999.

- Isabel and Fabian alone accounted for nearly 100 NTC units.

5 Verification of Individual 2003 Lead Time Forecasts

Table 4 shows a comparison of our 2003 forecasts for six different lead times along with this year's observed numbers. Our seasonal forecast numbers for this year worked out, in general, very well. We consistently forecast an above average hurricane season for 2003, and that is what occurred. Based on July and August global data, we slightly reduced our seasonal forecasts of 6 August and 3 September.

Table 4: Verification of our 2003 seasonal hurricane predictions.

Forecast Parameter and 1950–2000 Climatology (in parentheses)	6 December 2002	Update 4 April 2003	Update 30 May 2003	Update 6 Aug 2003	Update 3 Sept 2003	Update 2 Oct 2003	Observed 2003 Total
Named Storms (NS) (9.6)	12	12	14	14	14	14	14
Named Storm Days (NSD) (49.1)	65	65	70	60	55	70	71
Hurricanes (H)(5.9)	8	8	8	8	7	8	7
Hurricane Days (HD)(24.5)	35	35	35	25	25	35	32
Intense Hurricanes (IH) (2.3)	3	3	3	3	3	2	3
Intense Hurricane Days (IHD)(5.0)	8	8	8	5	9	15	17
Hurricane Destruction Potential (HDP) (72.7)	100	100	100	80	80	125	132
Net Tropical Cyclone Activity (NTC)(100%)	140	140	145	120	130	155	168

5.1 Analog Year

The average of the analog forecast years that we chose that appeared in at least two of our three extended range (5 December 2002, 4 April 2003 and 30 May 2003) forecasts are given in Table 5.

Table 5: Analog years that appeared in at least two of our three analog forecasts.

Year	NS	NSD	H	HD	IH	IHD	HDP	NTC
1952	7	40	6	23	3	4.00	70	93
1954	11	52	8	32	2	8.50	91	123
1958	10	56	7	30	4	8.25	94	133
1964	12	71	6	43	5	9.75	139	160
1998	14	88	10	49	3	9.50	149	168
Ave. of 5 best analog years	10.8	61	7.4	35	3.4	8.00	109	135
2003 Activity	14	71	7	32	3	17	132	168

In all cases we shaded the analog year numbers upward. For H, HD and IH the five chosen analog years were very close to what was observed. For the other parameters the chosen analog years to 2003 somewhat underpredicted activity. Overall, we judge our chosen analog years to be a precursor indication of the year's hurricane activity.

5.2 Preface: Aggregate Verification of our Last Five Yearly Forecasts

We are making progress in better understanding and are consequently improving seasonal prediction skill (as demonstrated by the last five years of our seasonal verification). This implies that skillful extended range seasonal prediction is indeed possible. With more research this understanding and skill will continue to improve. The last five years of seasonal forecasts have shown an improved level of forecast skill. We define forecast skill as the degree to which we are able to predict the variation of seasonal hurricane activity parameters from their long term climatology. The latter is expressed as the ratio of our forecast error to the observed difference from climatology. Hence, forecast skill is defined as:

Forecast Error/Seasonal Difference from Climatology

For example, if there were a year with five more tropical storms than average and we had predicted two more storms than average, we would give ourselves a skill score of 2 over 5 or 40 percent. By this measure, each of the eight parameters of our seasonal forecasts have shown some degree of forecast skill at all lead times. Table 6 shows our average skill score for the last five years at different lead times for all parameters.

Table 6: Last five years' (1999-2003) average percent of variation of our forecasts from climatology as a function of different forecast lead times (in percent). A value of 55 means that we have predicted 55 percent of the variability from climatology or that we were unable to explain 45 percent of the variability from climatology.

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	26	38	59	42
NSD	29	35	89	66
H	7	29	67	69
HD	18	34	42	57
IH	26	41	55	55
IHD	15	20	21	41
HDP	38	40	51	66
NTC	51	59	67	69

Each of our last five yearly forecasts have shown skill. Figure 6 displays the percent variation from climatology of the average of these five yearly forecasts for NTC while Fig. 7 does the same for HDP. Our forecast skill improves as our lead time decreases.

For the two parameters that are a combination of predictors like Net Tropical Cyclone (NTC) activity and Hurricane Destruction Potential (HDP), we show significant skill from the early December forecast (51% and 38%) and very high skill (69% and 66%) from the early August (Figs. 6 and 7) forecast of these two parameters.

Of course there are significant amounts of unexplained variance in a number of the individual parameter forecasts. Even though the skill on some of these parameter forecasts is quite low, there is a great curiosity in wanting to know how active the coming hurricane season is going to be.

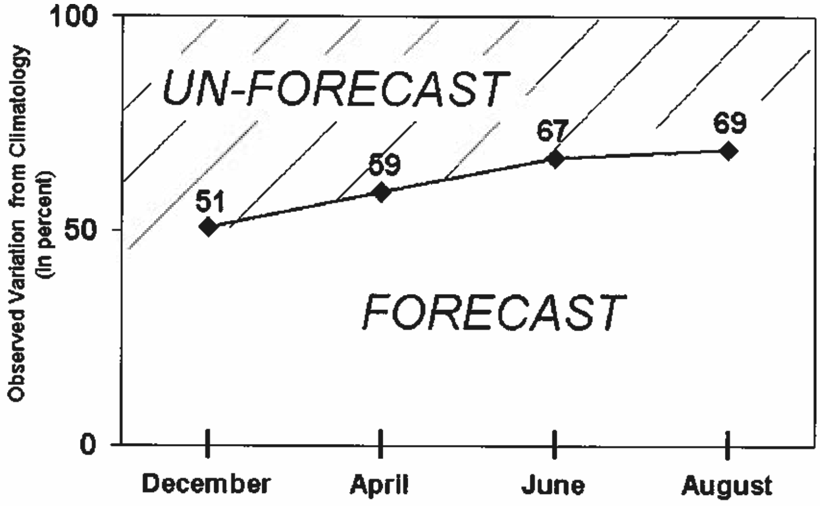


Figure 6: Last five-year average percent of Net Tropical Cyclone (NTC) activity which was forecast at the four individual lead times of early December, early April, early June and early August.

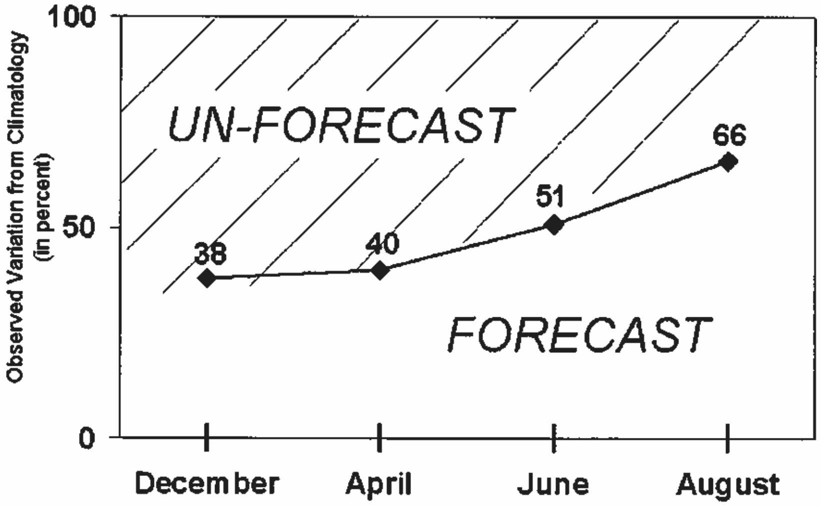


Figure 7: Last five-year average percent of Hurricane Destruction Potential (HDP) which was forecast at the four individual lead times of early December, early April, early June and early August.

5.3 Predictions of Individual Monthly Atlantic TC Activity

A new aspect of our climate research is the development of TC activity predictions for individual months. On average, August, September and October have about 26%, 48%, and 17% or 91% of the total Atlantic basin NTC activity. August-only monthly forecasts have now been made for the last four seasons, and this is our second year for making September-only forecasts. This is the first year that we have issued an October-only forecast.

There are often monthly periods within active and inactive hurricane seasons which do not conform to the overall season. To this end, we have recently developed new schemes to forecast August-only, September-only and October-only Atlantic basin TC activity by the beginning of each of these three months. These efforts have been recently documented in CSU project reports by Eric Blake (2002) for our August-only forecast and by Phil Klotzbach (2002) for our September-only forecast - see the last page for references. Klotzbach is presently documenting our new October-only forecast.

Quite skillful August-only, September-only and October-only prediction schemes have been developed based on 51 years (1950-2000) of hindcast testing using a statistically independent jackknife approach. Predictors are derived from prior months, usually June and July (NCEP global reanalysis) data for all three (August-only, September-only and October-only) individual monthly forecasts and include August's data for the early September forecast of September-only and October-only forecasts. We included data through September for our early October forecasts. Table 7 gives an outline and timetable of the different forecasts and verifications we issue after the end of July.

Table 7: Timetable of the issuing of our after-July monthly forecasts (in early August, early September, and early October), the times of their verifications, and dates of seasonal updates. Note that we make three separate October-only forecasts; two separate September-only forecasts; and one separate August-only forecast. Seasonal updates are issued in early September and early October.

Times of Fcst. and/or Verification	Based on Data Through	**Forecasts**			
Early August	July	Forecast for August	Forecast for September	Forecast for October	Full Season Forecast
Early September	August	August Verification and Seasonal Update	Forecast for September	Forecast for October	Remainder of Season Forecast
Early October	September		September Verification and Seasonal Update	Forecast for October	Remainder of Season Forecast

5.4 August-only 2003 Forecast

Eric Blake spent from 1998-2001 as a graduate student at Colorado State University. His research efforts went into the development of an Atlantic basin August-only hurricane forecast scheme which was used for our 6 August 2003 forecast. See Blake (2002) for background information. Blake attained a high degree of hindcast skill for the period of 1950-2000. Note that Blake's August-only forecast scheme showed a near-perfect result for this August (see Table 8).

Table 8: CSU forecast and verification of August-only hurricane activity made in early August.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	August 2003 Statistical Forecast	Adjusted August 2003 Forecast	August 2003 Verification
Named Storms (NS) (2.8)	2.51	3	3
Named Storm Days (NSD) (11.8)	7.31	8	6
Hurricanes (H) (1.6)	0.68	1	2
Hurricane Days (HD) (5.7)	3.81	4	2.5
Intense Hurricanes (IH) (0.6)	0.63	1	1
Intense Hurricane Days (IHD) (1.2)	0.42	0.5	1.25
Net Tropical Cyclone (NTC) (26.4)	17.91	22	26

5.5 September-only 2003 Forecast

Table 9 summarizes our statistical and adjusted forecasts of Atlantic tropical cyclone activity for September 2003 issued on 6 August and 3 September, respectively.

Table 9: Independent September-only forecasts for 2003 including 6 August statistical forecast for September, 6 August adjusted forecast for September, 3 September statistical forecast for September and 3 September adjusted forecast for September.

TC Parameters and 1950-2000 Sep. Clim. (in parentheses)	6 Aug. Stat. Fcst. (for Sep.)	6 Aug. Adjusted Forecast	3 Sep. Stat. Fcst. (for Sep.)	3 Sep. Adjusted Forecast	Observed Sep. 2003 Activity
NS (3.4)	3.1	4.0	2.9	4.0	4.0
NSD (21.7)	13.25	14.0	13.0	18.0	29.0
H (2.4)	1.4	2.0	1.6	2.0	3.0
HD (12.3)	6.0	6.0	10.5	11.0	22.50
IH (1.3)	0.3	1.0	0.4	1.0	1.0
IHD (3.0)	1.25	1.25	2.65	6.50	14
NTC (48)	28.7	33	36.0	55	94

Our September 2003 forecast was quite good for the numbers of storms (i.e., named storms, hurricanes and intense hurricanes), but we significantly understimated the longevity of the storms. Hurricanes Fabian and Isabel both had over six consecutive intense hurricane days; the first observed occurrence of this phenomena since routine airplane reconnaissance became available in 1950. Approximately average activity was observed in August, but conditions became quite favorable for tropical cyclones in September. Atlantic trade winds were very weak for virtually the entire month, and the consequent reduction in wind shear allowed Fabian and Isabel to strengthen and remain intense for long periods of time. Isabel became the first Category 5 hurricane in September since Hugo (1989). The tropical Atlantic was also warmer than normal which helped fuel these two intense hurricanes. Isabel made landfall near Ocracoke Island, NC as a Category 2 system and became the first hurricane to make landfall along the U.S. East Coast since Floyd (1999). September was especially notable for the large number of intense hurricane days during the month. This was the most intense hurricane days observed in September since 1961. Overall, the September NTC value of 94 placed September 2003 third all time behind only the Septembers of 1961 and 1950.

Our initial September forecast (made on 6 August) was not successful. Most of the early pre-August season predictors were negative. The best predictor of September activity, Atlantic trade wind strength, was running about average. By the time the September forecast was issued, our statistical forecast increased. This was due to a relaxation of the trades. Our adjusted forecast was raised to an above-average forecast for September due to more favorable conditions and an already-existent Intense Hurricane Fabian. Despite these increases, our early September forecast still underestimated September tropical cyclone activity considerably.

5.6 October-only 2003 Forecast

Table 10 summarizes our statistical and adjusted forecasts of Atlantic tropical cyclone activity for October 2003 issued on 6 August, 3 September, and 2 October respectively.

Table 10: Independent October-only forecasts for 2003 including 6 August statistical forecast for October, 6 August adjusted forecast for October, 3 September statistical forecast for October, 3 September adjusted forecast for October, 2 October statistical forecast for October, and 2 October adjusted forecast for October.

TC Parameters and 1950-2000 Oct. Clim. (in parentheses)	6 Aug. Stat. Fcst. (for Oct.)	6 Aug. Adjusted Forecast	3 Sep. Stat. Fcst. (for Oct.)	3 Sep. Adjusted Forecast	2 Oct. Stat Fcst. (for Oct.)	2 Oct. Adjusted Forecast	Observed Oct. 2003 Activity
NS (1.7)	2.2	3.0	1.9	3.0	1.8	3.0	3.0
NSD (9.0)	12.0	12.0	10.0	12.0	9.5	19.0	21.5
H (1.1)	1.5	2.0	1.2	2.0	1.2	2.0	0.0
HD (4.4)	5.9	6.0	5.0	6.0	4.7	7.0	5.5
IH (0.3)	0.4	0.0	0.3	1.0	0.3	0.0	1.0
IHD (0.8)	1.1	0.0	0.9	1.0	0.9	0.0	1.5
NTC (17)	23	19	19	30	18	21	28

Our October 2003 forecast was quite successful. Our October forecast generally caught the somewhat above-average number of storms and days that actually occurred. Our final forecast issued on October 2 did not forecast an intense hurricane. Kate intensified into a major hurricane early in the month. October was notable for two long-lived cyclones, Kate (10.25 NSD, 5.75 HD, 1.50 IHD) and Nicholas (8.25 NSD). Although most tropical cyclone parameters other than named storm days were near-normal for the month, our final adjusted October forecast was quite accurate in predicting this large number of named storm days. One reason our early October update predicted a large number of named storm days was that Kate had already been in existence for several days at the time of the forecast update and was forecast to remain a named storm for another 5-7 days. The reason one major hurricane was observed in October and no hurricanes were observed is that Kate had already briefly been a hurricane during the month of September, and therefore Kate was counted as a hurricane during September.

Predictors for October were generally mixed to slightly positive which is why our forecasts generally were quite close to climatology. Our best predictor, sea level pressure in the tropical Atlantic, was near normal which helped add confidence to a near-normal forecast for October 2003.

6 Landfall Probabilities for 2003

A new initiative in our research involves efforts to develop forecasts of the seasonal probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events cannot be accurately forecast, the net seasonal probability of landfall (relative to climatology) can be forecast with statistical skill. With the premise that landfall is a function of varying climate conditions, a probability specification has been accomplished through a statistical analysis of all U.S. hurricane and named storm landfalls during the last 100 years (1900–1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions. Net landfall probability is statistically related to the overall Atlantic basin Net Tropical Cyclone Activity (NTC) and to climate trends linked to multi-decadal variations of the Atlantic Ocean thermohaline circulation (as measured by recent past years of North Atlantic SSTA). Table 11 gives verifications of our landfall probability estimates for 2003.

Active research continues on this technique, and full documentation of the methodology for estimating hurricane landfall probability is being prepared. Landfall probabilities include specific forecasts of the probability of landfalling tropical storms (TS) and hurricanes of category 1, 2, 3, and 4-5 intensity for each of 11 units of the U.S. coastline (Fig. 8). These 11 units are further subdivided into 96 regions based on coastal population. Statistics are also being developed for each 100 km (65 mile) segment of the entire U.S. coastline.

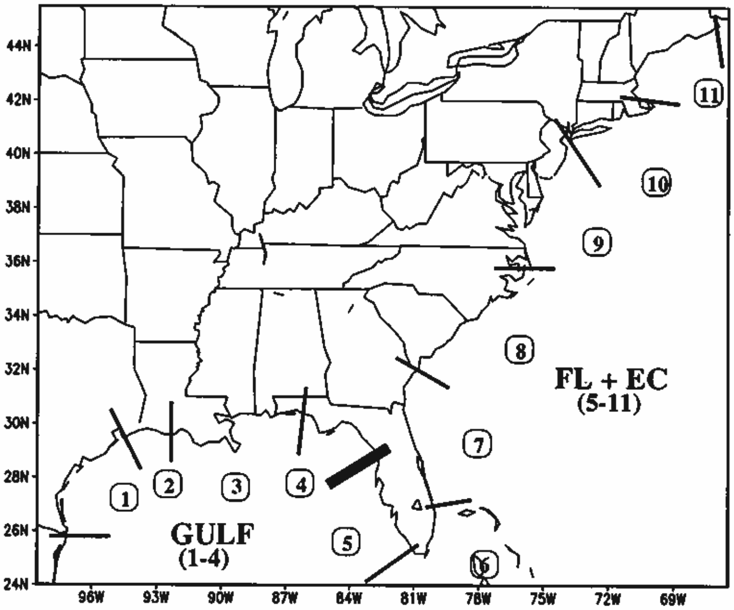


Figure 8: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

Figure 9 offers a summary and a general outline of the landfall probability estimate methodology.

Table 11: Estimated forecast probability (percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes, and category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (region 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2003 at various lead times. The mean annual percentage of one or more landfalling systems during the last 100 years is given in parentheses in the August 6 forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast and Table (c) is for the Florida Peninsula and the East Coast.

(a) The entire U.S. (Regions 1-11)

	Forecast Date				
	6 Dec.	4 Apr.	30 May	6 Aug.	Observed Number
TS	85%	85%	86%	84% (80)	3
HUR (Cat 1-2)	79%	79%	79%	75% (68)	2
HUR (Cat 3-4-5)	68%	68%	69%	63% (52)	0
All HUR	93%	93%	94%	91% (84)	2
Named Storms	99%	99%	99%	98% (97)	5

(b) The Gulf Coast (Regions 1-4)

	Forecast Date				
	6 Dec.	4 Apr.	30 May	6 Aug.	Observed Number
TS	66%	66%	67%	64% (59)	3
HUR (Cat 1-2)	51%	51%	52%	48% (42)	1
HUR (Cat 3-4-5)	38%	38%	39%	36% (30)	0
All HUR	70%	70%	70%	67% (61)	1
Named Storms	90%	90%	90%	88% (83)	4

(c) Florida Peninsula Plus the East Coast (Regions 5-11)

	Forecast Date				
	6 Dec.	4 Apr.	30 May	6 Aug.	Observed Number
TS	56%	56%	57%	55% (51)	0
HUR (Cat 1-2)	56%	56%	57%	53% (45)	1
HUR (Cat 3-4-5)	48%	48%	49%	43% (31)	0
All HUR	77%	77%	78%	74% (62)	1
Named Storms	90%	90%	91%	88% (81)	1

These landfall forecast probabilities will be supplemented with additional probability values for each 100 km coastal segment receiving tropical storm force winds (≥ 40 mph), sustained hurricane force winds (≥ 75 mph), and major hurricane (category 3-4-5) force winds (≥ 115 mph). Discussions of potential tropical cyclone-spawned hurricane destruction within each of the 96 different U.S. coastal regions are also in preparation.

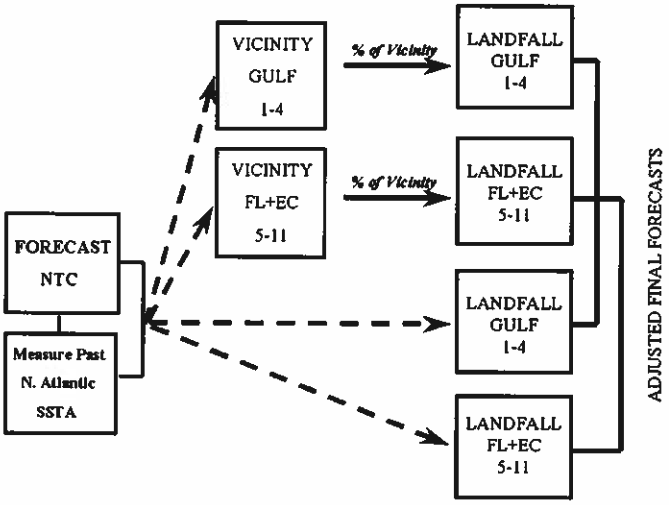


Figure 9: General flow diagram illustrating how forecasts of U.S. hurricane landfall probability are made. We forecast NTC and use an observed measure of the last few years of North Atlantic (50-60°N, 10-50°W) SSTA*. Regression equations are then developed from the combination of forecast NTC and measured SSTA* values. A regression is then developed from U.S. hurricane landfall measurements of the last 100 years, and separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

7 Increased Level of Atlantic Basin Hurricane Activity During Seven of the Last Nine Years - But Decreased U.S. Major Hurricane Landfall

7.1 Increased Activity Since 1995

A major reconfiguration of the distribution of Atlantic SST anomalies began in mid-1995 and has largely persisted through the present. North Atlantic SSTs have become about 0.4 to 0.6°C warmer than normal since 1995 and tropical Atlantic August-October upper tropospheric 200 mb winds have increased from the east, bringing about a significant decrease in tropospheric vertical wind shear. Figures 10 and 11 show the changes in SSTA and 200 mb zonal wind anomaly (ZWA) during 1995-2003 from the prior 25-year period of 1970-1994. These changes are well associated with the large increase in major hurricane activity in the Atlantic basin during seven of the last nine years. As noted several times before, we hypothesize that these strong broadscale SST changes are associated with basic changes in the strength of the Atlantic Ocean thermohaline circulation

(ATC). This interpretation is consistent with changes in a long list of global atmospheric circulation features during the last nine years which conform to a prominent shift into hurricane-enhancing Atlantic circulation patterns, particularly the enhancement of major hurricane activity. Historical and geographic evidence going back thousands of years indicates that shifts in the Atlantic multi-decadal thermohaline circulation tend to occur on periods of 25–50 years. If the recent nine-year shift follows prior occurrences, it is likely that enhanced intense Atlantic basin hurricane activity will persist through the early decades of the 21st century in contrast with the diminished activity that persisted from 1970-1994.

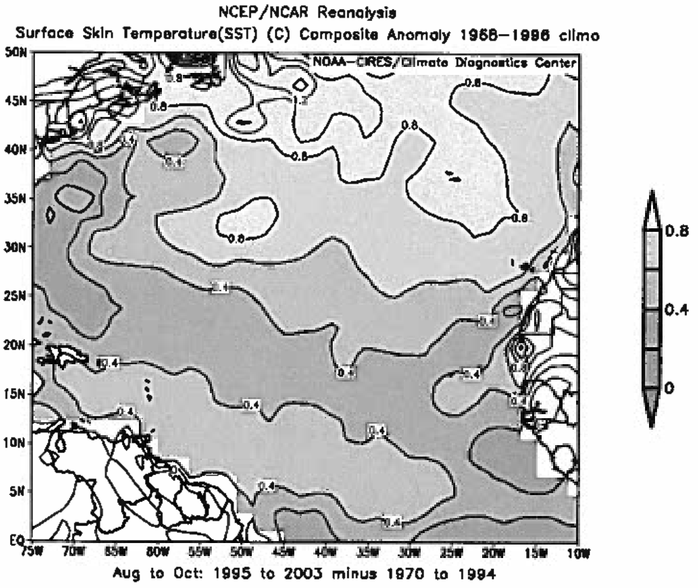


Figure 10: Increase of August-October SSTA (in °C) during 1995-2003 in comparison with the previous 25-year period of 1970-1994.

Despite El Niño-linked reductions of Atlantic basin hurricane activity during 1997 and 2002, the last nine years (1995-2003) constitute the most active nine consecutive years on record. Table 12 provides a summary of the total number of named storms (101), named storm days (567), hurricanes (62), hurricane days (288), major hurricanes (29), major hurricane days (76) and Net Tropical Cyclone activity (1232) that have occurred during the recent active seven of the last nine-year period of 1995-1996, 1998-2001, and 2003. The seven-year annual average of NS, NSD, H, HD, IH, IHD and NTC during these years has been 143, 206, 151, 254, 261, 362 and 234 percent, respectively above the averages of the prior 25-year period of 1970–1994. These trends toward increased hurricane activity give strong support to the suggestion that we have indeed entered a new era of enhanced major hurricane activity.

7.2 Theory for the Recent Increase in Major Hurricane Activity

The oceanic and atmospheric temperature change in the northwest Atlantic around Greenland and Iceland has been observed to undergo significant monthly to multi-decadal and longer time

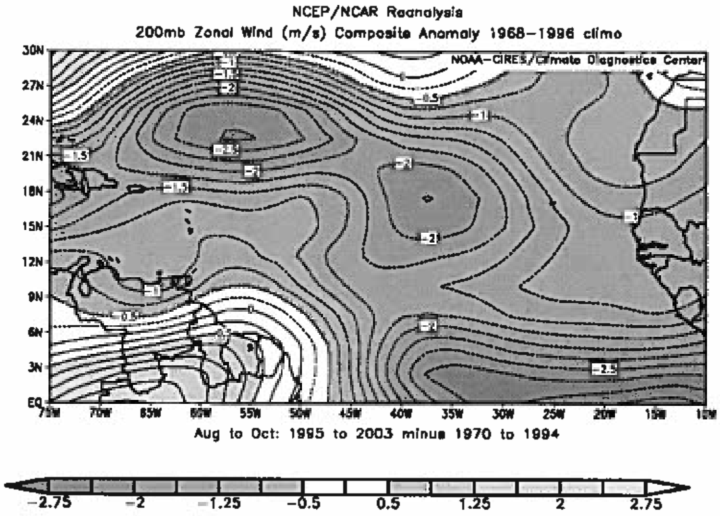


Figure 11: Decrease of August-October 200 mb ZWA between 1995-2003 in comparison with previous 25-year period of 1970-1994.

Table 12: Comparison of recent seven of the last nine years (1995-1996, 1998-2001, 2003) hurricane activity with climatology and with the prior quarter century period of 1970–1994.

Year	Named Storms (NS)	Named Storm Days (NSD)	Hurricanes (H)	Hurricane Days (HD)	Cat 3-4-5 Hurricanes (IH)	Cat 3-4-5 Hurricane Days (IHD)	Net Tropical Cyclone Activity (NTC)
1995	19	121	11	60	5	11.50	229
1996	13	78	9	45	6	13.00	198
1998	14	80	10	49	3	9.25	168
1999	12	77	8	43	5	15.00	193
2000	14	77	8	32	3	5.25	134
2001	15	63	9	27	4	5.00	142
2003	14	71	7	32	3	17.00	168
TOTAL	101	567	62	288	29	75.25	1230
Seven-year Ave. 1995-96,98-01, 03	14.3	81	8.9	41	4.14	10.86	176
Ratio 7 active yr/climatology in percent	149	165	151	167	180	215	176
Ratio 7 active yrs/1970–94 in percent	143	206	151	254	261	362	234

scale changes. We hypothesize that these changes in North Atlantic SSTAs are to a substantial degree a result of variations in the Atlantic Thermohaline Circulation (ATC). These ATC changes are believed to be caused by a combination of North Atlantic upper ocean salinity variations and atmospheric circulation features. The longer the time scale the greater becomes the dominance of salt. The shorter the time scale the more the atmosphere combines with the ocean salt content to bring about changes in the North Atlantic deep water formation. It is observed that when North Atlantic SSTAs are positive (and the ATC is thus diagnosed to be strong) we also simultaneously observe Atlantic basin conditions where:

1. the equator to 70°N Atlantic Ocean average SSTAs are positive,
2. Atlantic SLPA from the equator to 50°N are lower than average, and the Atlantic atmospheric and ocean gyres are consequently weaker than average,
3. the NAO and AO circulations are weaker,
4. South Atlantic (equator to 30°S) SSTAs are negative,
5. summertime rainfall in Africa is enhanced,
6. major hurricane activity in the Atlantic is enhanced.

The opposite conditions occur when the North Atlantic SSTA are observed to be negative, and we diagnose that the Atlantic ATC is weaker than average. It is likely that the salt content of the North Atlantic plays the dominant role in these ATC changes.

7.3 Downturn in U.S. Major Hurricane Landfall Despite Atlantic Basin Major Hurricane Increase

During the 104 years between 1900 and 2003, 114 category 1-2 hurricanes and 73 category 3-4-5 hurricanes made landfall along the U.S. coast. However, the annual incidence of landfall in Florida and the East Coast was nearly twice as great during the first 67 years (1900–1966) as it was during the recent 38-year period (1966-2003). Given the much greater incidence of major U.S. hurricanes in terms of landfall numbers during the earlier portions of the last century, our luck at having fewer intense hurricane landfalls than specified by the long period climatology has now extended for over three decades.

Good fortune has been manifest during recent years as a persistent upper-air trough located along the U.S. East Coast much of the time during hurricane season. The presence of this upper-level trough caused a large portion of otherwise northwest moving major hurricanes to recurve to the north before they reached the U.S. coastline.

For the Florida Peninsula and the U.S. East Coast, these same considerations are even more skewed. During the 39 years since 1965, only 8 landfalling major hurricanes (an average of 0.2 per year) have struck the Florida Peninsula and U.S. East Coast. However, between 1900–1965 there were 29 major landfall events along this same coastline with a mean incidence of 0.44 per year. Hence, the first six decades of the 20th century along the Florida Peninsula and East Coast had twice the number of major hurricanes make landfall per year than has occurred during the last three and a half decades. It cannot be presumed that this recent downturn in U.S. major hurricane landfall events along the Florida Peninsula and East Coast will continue. Climatology will eventually right itself, and we must expect a great increase in landfalling major hurricanes in the coming decades.

Beginning about 1990, we have suggested that the era of greatly reduced intense Atlantic hurricane activity that began during the late 1960s was likely coming to an end and that the U.S. and Caribbean coastal regions should expect a long term increase in landfalling major hurricanes (Gray 1990). Such an increase is an ominous prospect considering the large increases in U.S. and Caribbean coastal population in recent years and that, when hurricane destruction is normalized for coastal population, inflation, and wealth per capita [see Pielke and Landsea (1998)], it is found that major hurricanes cause about 85 percent of all U.S. tropical cyclone-linked destruction.

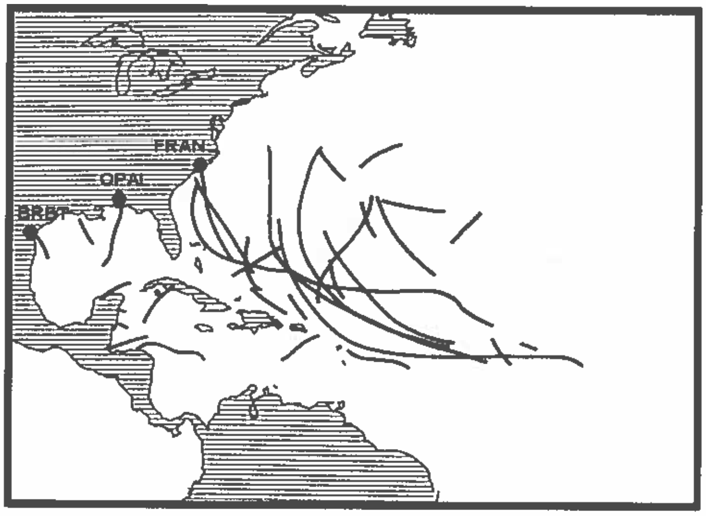
Surprisingly, the large upturn of Atlantic basin major hurricanes (32) during the last nine years (1995-2003) has been attended by a reduction in major hurricane landfall events which is even more pronounced than what occurred in the 1970-94 period. This is particularly true of Florida and East Coast landfall of major hurricanes where only one landfall has occurred (Fran). The number of developing major hurricanes making U.S. landfall in Florida and the U.S. East Coast during the last nine years has been only one-eighth as great as the 16 separate major hurricane events during the 18-year period of 1944-1961. Of the 32 major hurricanes that developed in the Atlantic basin during the last nine years (1995-2003), only three [Bret (1999) and Opal (1995) along the Gulf Coast and Fran (1996) along the East Coast] made landfall. Table 13 compares intense or major landfall frequency during these two periods. It is Florida and the U.S. East Coast (not the Gulf Coast) where the large differences occur in major hurricane landfall between these two periods.

The last 40 years have seen a great increase in Florida and U.S. East Coast population and wealth per capita. When the inevitable return to conditions more typical of the climatological averages occurs during coming decades, it is inevitable that we will see U.S. hurricane-spawned damage rise to unprecedented levels.

Table 13: Comparison of U.S. intense (or major) hurricane landfall events during the two most active recent major hurricane periods of 1944-1961 versus 1995-2003.

		Number of Major Hurricane Landfalls	
	No. of Atlantic Basin Major Hurricanes	Gulf Coast (Regions 1-4)	Florida and East Coast
1944-1961 (18 years)	63	3	16
1995-2003 (9 years)	32	2	1
Annual Ratio of Difference (Earlier to Later Period)	0.98	0.75	8

Figure 12 shows the tracks of all intense or major hurricanes between 1995-2003. Despite there being 32 major hurricanes during thie 9-year period, only three (Bret, Opal and Fran) or less than 1 in 10 crossed the U.S coastline. Of these 32 major hurricanes only one (Fran) made landfall along Florida and the East Coast.



1995-2003 Intense Hurricane Tracks (32 tracks)

Figure 12: 1995-2003 intense (or major) hurricane tracks (32 tracks). Note the clustering and recurvature of most tracks northeast of the Bahamas. Only three of these 32 major hurricanes (Bret, Opal and Fran) made landfall.

During the 18-year active hurricane seasons of 1944-1961, there were 16 major hurricanes crossing different sections of the U.S. coastline - an annual Florida-East Coast frequency eight times greater than the last nine years. This was not due to an annual increase in the number of named storms during this period but to major difference in the locations and tracks of these major hurricanes.

This is due to the more frequent upper-level trough conditions which have existed over the U.S. East coast during the recent 1995-2003 period in comparison with the similar active period of 1944-1961. Easterly winds south of the sub-tropical ridge were also stronger during the 1944-1961 period. This caused the major hurricanes to move further west and to make recurvature less prevalent.

8 The 1995-2003 Upswing in Atlantic Hurricanes and Global Warming

In contrast with the large increase in Atlantic basin major hurricane activity during seven of the last nine years, total global hurricane and typhoon activity during the period 1995–2003 has undergone a small decrease. It is only in the Atlantic basin where hurricane activity has shown a sharp rise. Various groups and individuals have suggested that the large upswing in Atlantic hurricane activity (since 1995) may be in some way related to the effects of increased human-generated greenhouse gases such as carbon dioxide (CO_2). There is no reasonable scientific way that such an interpretation of this recent upward shift in Atlantic hurricane activity can be made. The effects of anthropogenic greenhouse gas warming, even if a physically valid hypothesis, are a very slow and gradual process that, at best, might be expected to bring about small changes in the global circulation over periods of 50 to 100 years. Hence, greenhouse gas-linked warming could not be responsible for the abrupt and dramatic upturn in hurricane activity which has occurred since 1995. Also, the large downturn in Atlantic basin major hurricane activity between 1970-1994 would need to be reconciled with proposed long-term global warming scenarios during this period. Atlantic intense (or category 3-4-5) hurricane activity decreased 40-50 percent during 1970–1994 from the levels which occurred during the 1950–1969 or the recent 1995-2003 period. There have been 89 Atlantic basin hurricanes during the 29 years of 1950–1969, 1995-2003 versus 38 in the 25 years of 1970–1994, an annual difference of two to one. Even if human-induced greenhouse gas increases were shown to be causing global temperature increases during the last 25 years, there is no way to physically relate such small global temperature changes to this high level of hurricane activity. Hurricane activity is not related to global mean temperature.

9 Forthcoming Update Forecasts of 2004 Hurricane Activity

We will be issuing our first forecast for the 2004 season on Friday, 5 December 2003. This 5 December forecast will include the dates of all of our follow-on updated 2004 forecasts. All of these forecasts will be available at our Web address given on the front cover

(http://tropical.atmos.colostate.edu/forecasts/index.html).

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12 Verification of Previous Forecasts

Table 14: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 1999-2003. Verification of our earlier year forecasts for the years 1984-1998 are given in our late November seasonal verifications (on this Web location).

1999	5 Dec 1998	Update 7 April	Update 4 June	Update 6 August	Obs.
No. of Hurricanes	9	9	9	9	8
No. of Named Storms	14	14	14	14	12
No. of Hurricane Days	40	40	40	40	43
No. of Named Storm Days	65	65	75	75	77
Hurr. Destruction Potential(HDP)	130	130	130	130	145
Major Hurricanes (Cat. 3-4-5)	4	4	4	4	5
Major Hurr. Days	10	10	10	10	15
Net Trop. Cyclone (NTC) Activity	160	160	160	160	193

2000	8 Dec 1999	Update 7 April	Update 7 June	Update 4 August	Obs.
No. of Hurricanes	7	7	8	7	8
No. of Named Storms	11	11	12	11	14
No. of Hurricane Days	25	25	35	30	32
No. of Named Storm Days	55	55	65	55	66
Hurr. Destruction Potential(HDP)	85	85	100	90	85
Major Hurricanes (Cat. 3-4-5)	3	3	4	3	3
Major Hurr. Days	6	6	8	6	5.25
Net Trop. Cyclone (NTC) Activity	125	125	160	130	134

2001	7 Dec 2000	Update 6 April	Update 7 June	Update 7 August	Obs.
No. of Hurricanes	5	6	7	7	9
No. of Named Storms	9	10	12	12	15
No. of Hurricane Days	20	25	30	30	27
No. of Named Storm Days	45	50	60	60	63
Hurr. Destruction Potential(HDP)	65	65	75	75	71
Major Hurricanes (Cat. 3-4-5)	2	2	3	3	4
Major Hurr. Days	4	4	5	5	5
Net Trop. Cyclone (NTC) Activity	90	100	120	120	142

2002	7 Dec 2001	Update 5 April	Update 31 May	Update 7 August	Update 2 Sept	Obs.
No. of Hurricanes	8	7	6	4	3	4
No. of Named Storms	13	12	11	9	8	12
No. of Hurricane Days	35	30	25	12	10	11
No. of Named Storm Days	70	65	55	35	25	54
Hurr. Destruction Potential(HDP)	90	85	75	35	25	31
Major Hurricanes (Cat. 3-4-5)	4	3	2	1	1	2
Major Hurr. Days	7	6	5	2	2	2.5
Net Trop. Cyclone (NTC) Activity	140	125	100	60	45	80

2003	6 Dec 2002	Update 4 April	Update 30 May	Update 6 August	Update 3 Sept	Update 2 Oct	Obs.
No. of Hurricanes	8	8	8	8	7	8	7
No. of Named Storms	12	12	14	14	14	14	14
No. of Hurricane Days	35	35	35	25	25	35	32
No. of Named Storm Days	65	65	70	60	55	70	71
Hurr. Destruction Potential(HDP)	100	100	100	80	80	125	129
Major Hurricanes (Cat. 3-4-5)	3	3	3	3	3	2	3
Major Hurr. Days	8	8	8	5	9	15	17
Net Trop. Cyclone (NTC) Activity	140	140	145	120	130	155	168