SUMMARY OF 2002 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHORS' SEASONAL ACTIVITY FORECAST

An Early Summer Successful Forecast of an Inactive Hurricane Season – But the Many Weak, Higher Latitude Tropical Storms That Formed Were Not Anticipated

(as of 21 November 2002)

By
William M. Gray[1], Christopher W. Landsea,[2] and Philip Klotzbach[3]

with advice and assistance from William Thorson[4] and Jason Connor[5]

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

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

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523
Phone Number: 970-491-8681

[1]Professor of Atmospheric Science

[2]Dr. Landsea, a former project member, is an employee of the NOAA Atlantic Oceanographic and Meteorological Laboratory. As part of his research to improve NOAA's climate forecasting ability, he also collaborates with researchers at Colorado State University on our CSU seasonal hurricane forecasts (see page 3 for more explanation). The CSU hurricane forecast is independent of the NOAA forecast and should not be construed as an official NOAA forecast.

[3]Research Associate

[4]Research Associate

[5]Research Associate

2002 ATLANTIC BASIN SEASONAL HURRICANE FORECAST

Tropical Cyclone Parameters and 1950-2000 Climatology (in parentheses)	7 Dec 2001	Updated 5 April 2002 Forecast	Updated 31 May 2002 Forecast	Updated 7 Aug 2002 Forecast	Updated 2 Sep Forecast	Observed 2002 Totals
Named Storms (NS) (9.6)	13	12	11	9	8	12
Named Storm Days (NSD) (49.1)	70	65	55	35	25	54
Hurricanes (H)(5.9)	8	7	6	4	3	4
Hurricane Days (HD)(24.5)	35	30	25	12	10	11
Intense Hurricanes (IH) (2.3)	4	3	2	1	1	2
Intense Hurricane Days (IHD)(5.0)	7	6	5	2	2	2.5
Hurricane Destruction Potential (HDP) (72.7)	90	85	75	35	25	31
Net Tropical Cyclone Activity (NTC)(100%)	140	125	100	60	45	80

VERIFICATION OF 2002 MAJOR HURRICANE LANDFALL FORECAST

	7 Dec Fcst. Prob.	5 Apr Fcst. Prob.	31 May Fcst. Prob.	7 Aug Fcst. Prob.	Climatology	Observed
1. Entire US Coastline	86%	75%	63%	49%	50%	0
2. FL Peninsula and East Coast	58%	57%	42%	28%	31%	0
3. Gulf Coast	43%	43%	35%	29%	30%	0
4. Caribbean and Bahama Region	Above Ave.	Above Ave.	Near Ave.	Below Ave.	51%	1

VERIFICATION OF AUGUST-ONLY AND SEPTEMBER-ONLY TROPICAL CYCLONE FORECASTS

Average August Climatology	Aug-only 2002 Forecast	Aug-only 2002 Verification	Average September Climatology	Sept-only 2002 7 Aug	Sept-only 2002 2 Sept	Sept 2002 Verification
NS (2.8)	4	3	3.4	3	3	8
NSD (11.6)	10	5.5	21.7	18	13	36.0
H (1.6)	1	0	2.4	2	2	4
HD (5.7)	4	0	12.3	6	7	8.0
IH (0.6)	0	0	1.3	1	1	1
IHD(1.3)	0	0	3.0	2	2	1.75
NTC (26.1%)	18	7	48	30	26	55.9

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

Seasonal hurricane forecasts have been issued for the last 19 years by the tropical meteorology research group of Prof. William Gray of the Department of Atmospheric Science at Colorado State University (CSU). The forecasts, which are issued in December of the prior year, and in April, June, and August of the current year, have steadily improved through continuing research. These forecasts now include individual monthly predictions of Atlantic basin activity and seasonal and monthly U.S. hurricane landfall probabilities.

The National Oceanographic and Atmospheric Administration (NOAA) has also recently begun to issue Atlantic basin seasonal hurricane forecasts. These NOAA forecasts are independent of our CSU forecasts although they utilize prior CSU research augmented by their own insights. The NOAA and CSU forecasts will typically differ in some aspects and details. Chris Landsea and Eric Blake, former CSU project members presently employed by NOAA, have made important contributions to both 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 sub-tropical 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 (see Appendix B).

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 5 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 (~ 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.

ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2002 and verifies the authors' seasonal forecasts of this activity. The latter were initially issued on 7 December 2001 with updates on 6 April, 7 June and 7 August of this year. These forecasts also contained estimates of the probability of U.S. hurricane landfall during 2002. The 7 August update included forecasts of August-only and September-only tropical cyclone activity for 2002. Although our December and April forecasts did not anticipate the subsequent observed low hurricane numbers, our early June and early August updates were able to anticipate most of the reduced hurricane activity of this year. The 2002 hurricane season was characterized by reduced numbers of hurricanes (4) and hurricane days (11). Although a total of 12 named storms formed in the Atlantic basin, most of these systems formed at high latitudes and were relatively weak. There were 2 intense (or major) hurricanes (Saffir/Simpson intensity category 3-4-5) (average is 2.3) with only 2.5 intense hurricane days (average is 4.7). Net Tropical Cyclone (NTC) activity was 80 percent of the 1950–2000 average or only half the average of the recent six busy seasons of 1995-1996 and 1998-2001. Hurricane Destruction Potential was only 43 percent of the average season.

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 authors (see Gray, 1984a, 1984b, 1990; Landsea, 1991; Gray *et al.*, 1992, 1993, 1994a) indicates that there are atmospheric and oceanic precursor climate signals for surprisingly skillful 3-to-11 month (in advance) predictions of Atlantic basin seasonal hurricane activity. This research now allows us to issue extended-range 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. This end-of-season report compares our forecasts for 2002 with the actual hurricane activity observed during the 2002 hurricane season.

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, are based on the 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. Figures 1-3 provide a summary of the geographic locations for which the various forecast parameters are obtained. 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 predictors include the following:

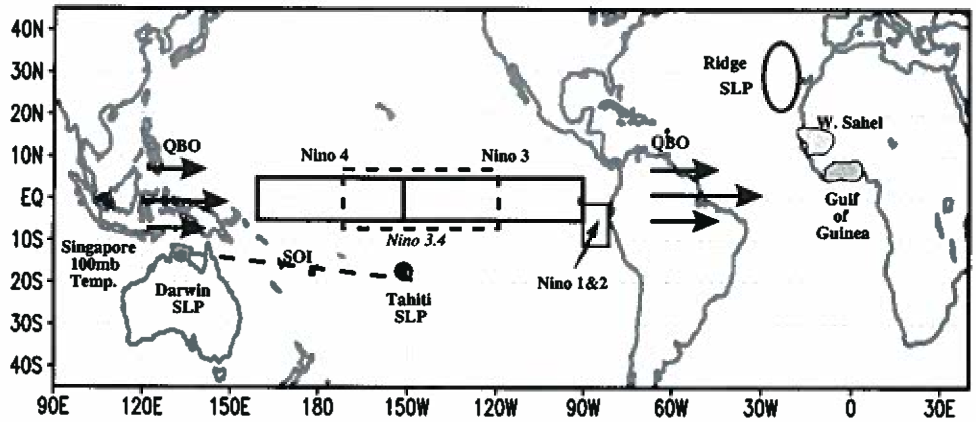

Figure 1: Areas from which specific oceanographic and meteorological parameters used as predictors in our seasonal forecasts are obtained.

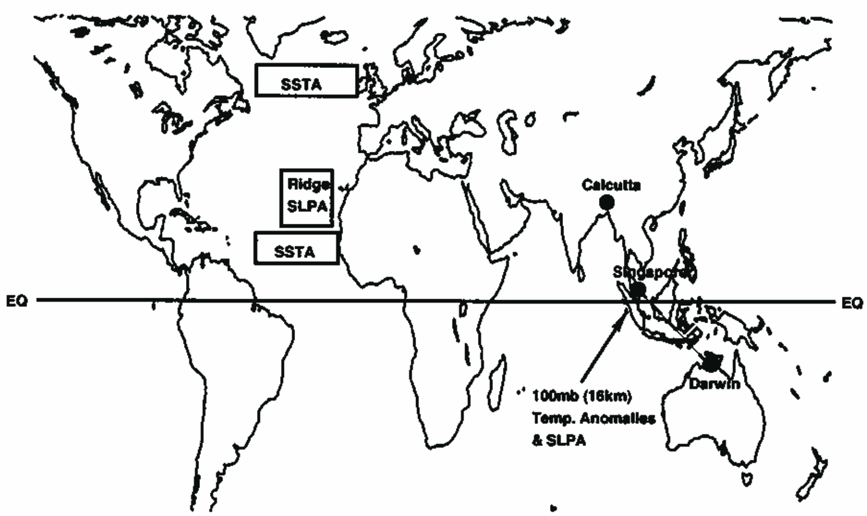

Figure 2: Additional predictor locations which are also considered in formulating our Atlantic seasonal hurricane forecasts.

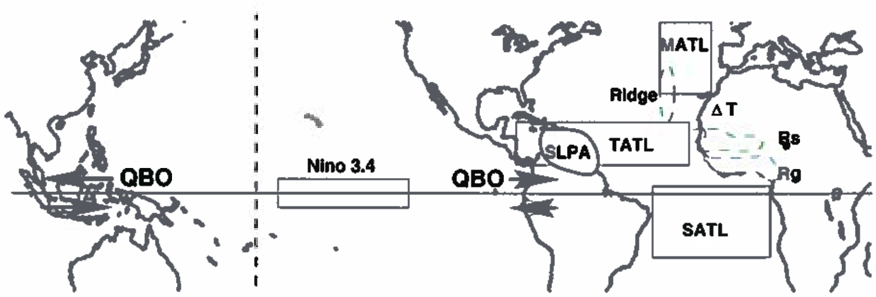

Figure 3: Additional meteorological parameters which are now used in our reformulated early June and early August forecasts.

(a) El Niño-Southern Oscillation (ENSO): El Niño events are characterized by anomalously warm sea surface temperature anomalies in the eastern equatorial Pacific areas termed Niño 1-2, 3, 3.4 and 4 (Fig. 1), a negative value of the Tahiti minus Darwin surface pressure gradient, and enhanced equatorial deep convection near the Dateline. These conditions alter the global atmospheric circulation fields contributing to anomalously westerly upper-level winds over the Atlantic basin which typically reduces Atlantic basin hurricane activity. Conversely, during La Niña seasons, anomalously cold sea surface temperatures are present, along with positive values of Tahiti minus Darwin surface pressure difference and reduced deep equatorial convection near the Dateline. La Niña seasons are usually associated with enhanced Atlantic basin hurricane activity.

(b) The stratospheric Quasi-Biennial Oscillation (QBO). The QBO refers to the variable east–west oscillating stratospheric winds encircling the globe near the equator. Other factors being equal, more intense (category 3-4-5) Atlantic basin hurricane activity occurs during seasons when equatorial stratospheric winds at 30 and 50 mb (23 and 20 km altitude, respectively) are from a westerly (versus easterly) direction.

(c) African Rainfall (AR): The incidence of intense Atlantic hurricane activity is typically enhanced when the prior year rainfall during June-September in the western Sahel region is above average and when August-November Gulf of Guinea rainfall during the prior year is also above average. The June-July rainfall of the year being forecast (in the western Sahel) is also a predictor for August through October hurricane activity. Other factors being equal, hurricane activity is typically suppressed if rainfall in the prior year (or season) in these two regions is below average.

(d) Strength of the October-November (prior year) and March northeast Atlantic Subtropical Ridge (ONR). When this surface pressure feature is anomalously weak during the prior autumn and current spring periods, eastern Atlantic trade winds are weaker. A weak ridge condition is associated with decreased mid-latitude cold water upwelling and advection off the northwest African coast as well as decreased evaporative surface cooling rates in this area of the Atlantic. In this way, a weak ridge leads to warmer tropical Atlantic SSTs which typically persist into the following summer period and contribute (other factors being constant) to greater seasonal hurricane activity. Conversely, less hurricane activity occurs when the October-November and spring pressure ridge is anomalously strong.

(e) Atlantic Sea Surface Temperature Anomalies (SSTA) in three regions [(MATL; 30-50°N, 10-30°N and TATL; 6-22°N, 18-60°W) during April through June] and [NATL; 50-60°N, 10-50°W and TATL during the previous year.]: [See Fig. 3 (bottom) for the location of these areas]. Warmer SSTAs in these areas enhance deep oceanic convection and, other factors aside, provide conditions more conducive for Atlantic tropical cyclone activity. Cold water temperatures provide unfavorable conditions for TC activity.

(f) Caribbean Basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric (12 km) Zonal Wind Anomaly (ZWA): Spring and early summer SLPA and ZWA have moderate predictive potential for hurricane activity occurring during the following August through October months (Fig. 3). Negative anomalies (i.e., low pressure and easterly zonal wind anomalies) imply enhanced seasonal hurricane activity (easterly 200 mb shear) while positive values imply suppressed hurricane activity (westerly 200 mb shear).

Our four different lead-time forecast schemes are created by maximizing the pre-season forecast skill from a combination of the above predictors for the period 1950-2000. We also use an analog methodology whereby we look for those years with specific precursor climate signals similar to the current forecast year.

3 Statistical Summary of 2002 Atlantic Tropical Cyclone Activity

The 2002 Atlantic hurricane season officially ends on 30 November. As of late November, there have been 4 hurricanes with a total of 11 hurricane days during the 2002 season. The total named storms (i.e., the number of hurricanes plus tropical storms) was 12, yielding 54 named storm days. There were 2 intense or major (Cat. 3-4-5) hurricanes this season. All designated hurricane intensity parameters were below their long-term average. The 2002 season ratio of named storms to hurricanes was 12/4 = 3.0. The average ratio is 9.6/5.9 or 1.6. Figure 4 and Table 1 show the tracks and give statistical summaries, respectively, for the 2002 season. Table 2 characterizes 2002 seasonal tropical cyclone activity in terms of annual average percentage of activity for the period of 1950-2000. Note that 2002 hurricane activity was much below the seasonal averages for 1995–2001, particularly for the most intense cyclones. Figure 5 shows the U.S. landfalling tropical cyclones of 2002, and Table 3 lists the seven landfalling named storms by date and intensity. Only Lili (category 2) was of hurricane strength.

Table 1: Summary of information for named tropical cyclones occurring during the 2002 Atlantic season. Information on Tropical Storms (TS), Hurricanes (H) and Intense Hurricanes (IH) and the highest Saffir/Simpson category of each is shown. (Based on information supplied by the National Hurricane Center).

Highest Intensity Category	Name	Dates	Peak Sustained Winds (kts)/ lowest SLP in mb	NSD	HD	IHD	HDP	NTC
TS	Arthur	Jul.14-16	50kt/997mb	1.75				2.3
TS	Bertha	Aug.4-5,7-9	35/1008	0.50				1.9
TS	Cristobal	Aug.5-8	40/999	2.25				2.5
TS	Dolly	Aug.29-Sep.4	55/994	5.75				3.7
TS	Edouard	Sep.1-6	55/1002	3.00				2.8
TS	Fay	Sep.5-7	50/999	1.50				2.2
H-1	Gustav	Sep.8-12	80/964	2.00	1.00		1.6	5.9
TS	Hanna	Sep.12-14	45/1001	1.50				2.2
IH-3	Isidore	Sep.14-15,17-26	110/934	8.75	3.75	1.75	13.1	23.2
TS	Josephine	Sep.17-19	50/1004	1.50				2.2
H-1	Kyle	Sep.20-Oct.11	75/980	15.25	2.75		5.6	11.6
IH-4	Lili	Sep.21-Oct.4	125/938	10.25	3.25	0.75	11.00	20.0
Total				54.00	10.75	2.50	31.30	80.50

By most measures, 2002 was an inactive hurricane year, particularly in comparison with the enhanced activity of the recent period of 1995-1996 and 1998-2001.

4 Characteristics of Individual Storms During the 2002 Season

Tropical Storm Arthur: Arthur developed from a non-tropical area of low pressure near Cape Hatteras, North Carolina on July 14th and moved rapidly east northeastward as it

Table 2: Summary of 2002 hurricane activity in comparison with long-term (1950–1990) and recent (1995-2001) annual average conditions.

Forecast Parameter	1950–2000 Mean	Obs. 2002	2002 in percent as 1950-2000 ave. season Climatology	2002 in percent of ave. season between 1995-2001
Named Storms (NS)	9.6	12	125	90
Named Storm Days (NSD)	49.1	54	110	72
Hurricanes (H)	5.9	4	68	48
Hurricane Days (HD)	24.5	11	45	29
Intense Hurricanes (IH)	2.3	2	87	52
Intense Hurricane Days (IHD)	5.0	2.5	50	29
Hurricane Destruction Potential (HDP)	72.7	31	43	26
Net Tropical Cyclone Activity (NTC)	100%	80	80	52

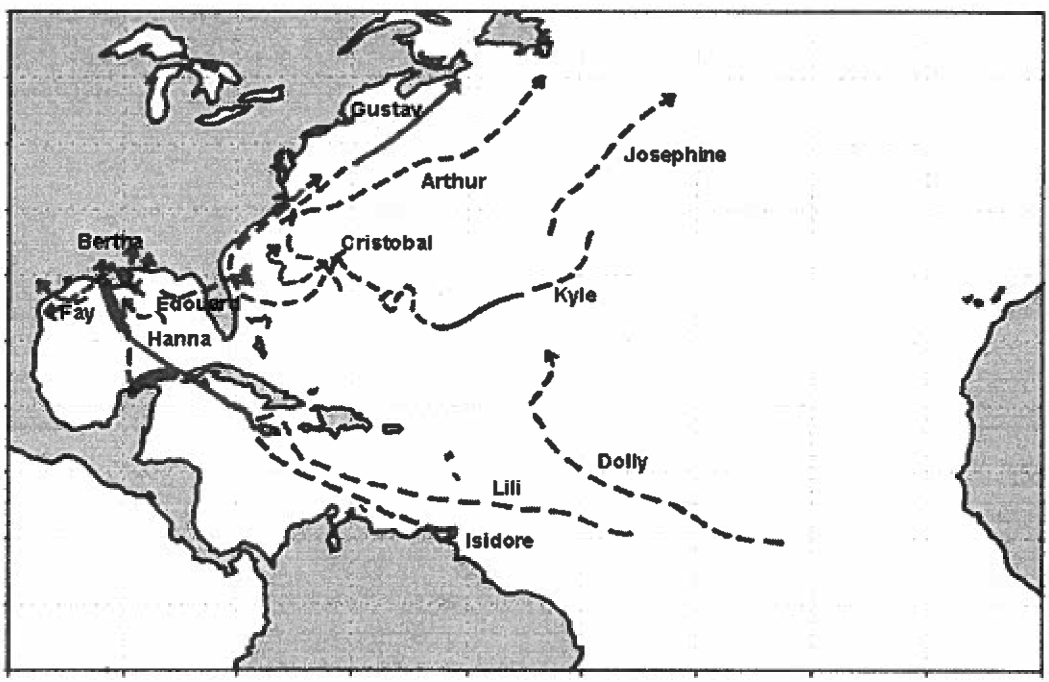

Figure 4: Tracks of the 12 named tropical cyclones of 2002. Dashed lines indicate the tropical storm intensity stage, thin solid lines indicate the Saffir/Simpson hurricane category 1-2 stage, and thick lines show the intense (or major) hurricane category 3-4-5 stage.

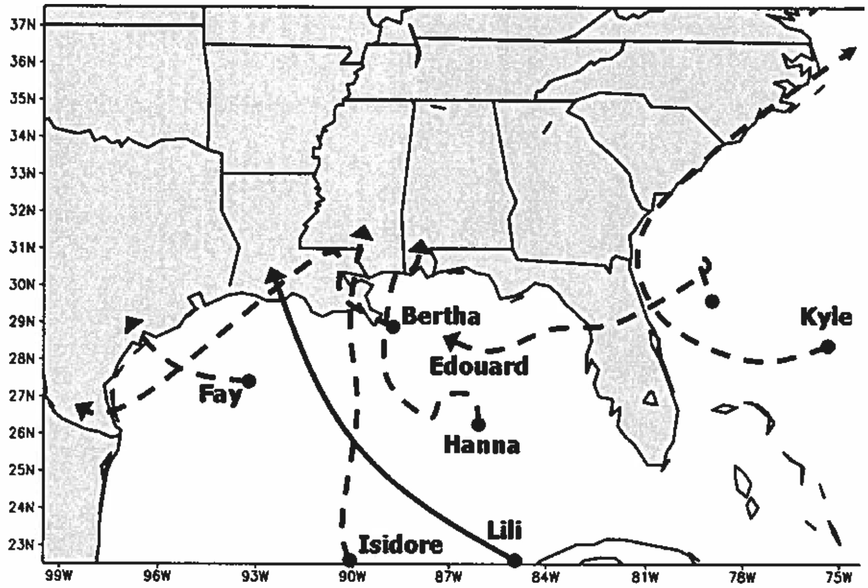

Figure 5: All 2002 U.S. landfalling tropical cyclones.

Table 3: 2002 U.S. landfalling tropical cyclones.

Name	Landfall Date	Intensity at Landfall: Sustained Winds (mph)	(kts)	Minimum Pressure (mb)
Bertha	8/5/02	40	35	1008
Edouard	9/4/02	40	35	1008
Fay	9/7/02	60	50	999
Hanna	9/14/02	50	45	1002
Isidore	9/26/02	65	55	987
Kyle	10/11/02	45	40	1008
Lili	10/3/02	100	85	962

was pushed along by a midlatitude trough. The storm reached its maximum intensity of 50 knots on July 15th then accelerated northeastward and became extratropical on July 16 after encountering the cool waters off the coast of Newfoundland.

Tropical Storm Bertha: Bertha developed from a system in the northern Gulf of Mexico on August 4 and headed northwest making landfall early on August 5th near New Orleans, LA as a weak (35 knot) tropical storm. The system weakened as it moved over land and turned southwest around a high pressure system located in the central United States. As it emerged back over the warm waters of the Gulf of Mexico, it was reclassified as a tropical depression and eventually made landfall between Corpus Christi and Brownsville, TX heavy heavy rains.

Tropical Storm Cristobal: Cristobal formed from a low pressure area about 150 miles off the South Carolina coast on August 5th. The system drifted slowly southward and then eastward due to a weak steering environment. It strengthened slightly to a 40 knot tropical storm despite an unfavorable shear environment due to an upper-level trough. The storm's circulation began to merge with that of the advancing trough, and it completed its extratropical transition on August 8th.

Tropical Storm Dolly: Dolly was the first system to form from a tropical wave developing several hundred miles southwest of the Cape Verde Islands on August 29th. It strengthened to its maximum intensity of 55 knots on August 30th due to a combination of low shear conditions and warm sea surface temperatures. The system then moved into an area of increasing westerly shear and weakened to a minimal tropical storm. A strong upper-level trough located to the north of Dolly began turning it northward, and the system eventually became absorbed by a front on September 4th.

Tropical Storm Edouard: Edouard developed from a tropical disturbance off the east coast of Florida on September 1st. Despite strong northwesterly shear, Edouard strengthened to a 55 knot storm while aimlessly drifting off the coast of Florida for several days. Eventually the shear began to take its toll, and the system weakened to a 35 knot tropical storm before making landfall near Daytona Beach on September 4th. It weakened to a tropical depression over Florida and drifted slowly westward into the Gulf of Mexico eventually dissipating due to strong shear on September 6th.

Tropical Storm Fay: Fay formed from a large, broad low in the northwest Gulf of Mexico on September 5th. Weak southwesterly shear allowed the system to strengthen somewhat to a 50 knot tropical storm, but the circulation remained broad and ill-defined throughout its lifetime. Shear increased somewhat as Fay moved slowly northwest, and it made landfall near Palacios, Texas on September 7th dumping 5 to 10 inches of rain over portions of southwest Texas before dissipating over land.

Hurricane Gustav: Gustav became classified as a subtropical depression while moving northeast off the coast of North Carolina on September 8th. A mid-tropospheric ridge caused Gustav to turn northwest and head towards North Carolina, and the system strengthened to a subtropical storm during this time. Gustav slowly began acquiring tropical characteristics while moving northwest and was officially classified as a tropical storm on September 10th. The center of Gustav came within 20 miles of Cape Hatteras lashing the Outer Banks with tropical storm-force winds before turning northeast due to a developing trough. Baroclinic assistance helped Gustav intensify into the first hurricane of the year on September 11th as it moved northeastward, and it eventually became extratropical but not before making landfall as a weak Category 1 hurricane over eastern Nova Scotia and then western Newfoundland on September 12th.

Tropical Storm Hanna: Hanna formed late on September 11th in the north-central Gulf of Mexico. The development region was under considerable shear, and Hanna was slow to strengthen. Shear weakened slightly allowing Hanna to reach its maximum intensity of 45 knots on September 13th while moving northward towards the Gulf Coast. It made landfall as a 45 knot tropical storm near Mobile, Albama on September 14th. Again, rainfall was the biggest problem from this storm as widespread rainfall amounts of 4-8 inches were reported in Alabama.

Intense Hurricane Isidore: Isidore was the first intense hurricane of the season developing from a tropical wave near the Windward Islands on September 14th and moving rapidly westward. The system degenerated to a tropical wave as it interacted with land on September 15th; however, it reformed south of Jamaica on September 17th as it emerged over the warm waters of the Caribbean Sea. The system strengthened slowly at first due to moderate southwesterly shear and then more rapidly as it moved into a favorable environment of low shear and high upper oceanic heat content. Isidore was upgraded to a hurricane on September 19th and made landfall as a Category 2 hurricane over western Cuba on September 20th. Strong winds and heavy rain battered western Cuba dumping as much as 20-30 inches of rain in some places. Isidore then turned westward, entered the southern Gulf of Mexico and reached intense hurricane status on September 21st. She reached her maximum intensity of 110 knots and a 934 mb central pressure while heading towards the Yucatan Peninsula and made landfall there as a strong Category 3 hurricane. More than two feet of rain and strong winds were felt throughout the Yucatan from Isidore. It stalled over the peninsula and rapidly weakened to a minimal tropical storm. A mid-tropospheric ridge east of the tropical cyclone eventually forced Isidore to move northward over the Gulf of Mexico where it reintensified to a strong tropical storm before making landfall near New Orleans, LA on September 26th. Up to 20 inches of rainfall was recorded in Louisiana and four fatalities from the storm.

Tropical Storm Josephine: Josephine developed from a low pressure area about 700 miles east of Bermuda on September 17th and moved rapidly northeastward while reaching minimal tropical storm strength. The system was absorbed by a midlatitude trough on September 19th and reached its maximum intensity of 50 knots while undergoing extratropical transition in the North Atlantic.

Hurricane Kyle: Kyle was the third-longest tropical cyclone on record falling only to Hurricane Inga (1969) and Hurricane Ginger (1971) in terms of longevity. It developed from a non-tropical low southeast of Bermuda and became classified as a subtropical depression on September 20th. The system was in a very weak steering flow throughout most of its existence drifting slowly southwestward over the first few days of its lifetime while becoming a tropical storm on September 22nd. Moderate vertical shear and fairly cool sea surface temperatures kept Kyle from any significant intensification over the next few days. By September 25th, Kyle had reached warmer waters due to its continued southwestward drift and intensified slowly into a hurricane. After reaching a maximum intensity of 75 knots and 980 mb, the system weakened to a tropical storm as it encountered considerable northerly shear. During the next few days, Kyle underwent several classification changes from tropical storm to tropical depression and back again while gradually heading westward. Eventually, Kyle neared the United States mainland as a tropical depression and had a brief convective outburst that allowed it to refire into a tropical storm. Kyle then paralleled the coast of South Carolina and North Carolina dumping 3-5 inches of rainfall in its path. Finally, Kyle became extratropical as it interacted and merged with an upper-level trough.

Intense Hurricane Lili: Lili was the most intense hurricane of the season developing from a tropical wave about 500 miles east of the Lesser Antilles on September 21. It strengthed briefly to near-hurricane strength after passing through the Lesser Antilles but weakened rapidly due to shear and became a tropical wave south of Haiti on September 26. However, the system rapidly regenerated into a tropical storm later on September 26 and strengthened while tracking between Haiti and Jamaica as the southerly shear imposing on the system relaxed. A deep layer anticyclone continued to steer Lili northwest, and it made landfall over western Cuba as a strong Category 1 hurricane on October 1. Once over the Gulf of Mexico, Lili intensified reaching major hurricane status (Category 3) on the morning of October 2. It continued to intensify rapidly reaching maximum intensity of 125 knots and 938 mb central pressure later on October 2. Fortunately f, Lili suddenly weakened to an 85 knot Category 2 hurricane before making landfall near Pecan Island, Louisiana. The sudden weakening of the system is likely attributed to three factors: increased vertical wind shear, dry air entrainment from the western Gulf and cooler sea surface temperatures near the coast. After making landfall, Lili rapidly weakened and became embedded within a shortwave trough. Eight U.S. deaths were directly attributed to Lili, and 700 million dollars in damage was caused by the influence of the cyclone.

5 Special Characteristics of the 2002 Hurricane Season

The 2002 hurricane season had the following special characteristics.

- Another late-starting season. The first hurricane in 2002 (Gustav) did not form until September 11th. This is the latest date for the first hurricane to form since 1941 when the first hurricane did not develop until September 18th. This is the second year in a row with a late start for the hurricane season. The first hurricane in 2001 (Erin) did not form until September 8th.

- This season saw a very low number of hurricanes in relationship to the number of named storms. Although there were 12 named storms, only four hurricanes occurred during 2002 (a ratio of 3:1). No year since 1950 has had a ratio this large. The closest year to this ratio is 1957 which had 8 named storms and 3 hurricanes (a ratio of 2.67:1).

- Since 1950, only 1971, 1984 and 1990 have had as many as 12 named storms with as few as only two intense (or major) hurricanes.

- This season saw the first U.S. hurricane landfall (Lili) since Irene (15 October 1999). There were 21 consecutive hurricanes that formed in the Atlantic between Lili and Irene that did not make landfall along the U.S. coast. This shattered the old record of 17 consecutive Atlantic basin hurricanes without a U.S. landfall that occurred between Allen (1980) and Alicia (1983).

- Active year for U.S. landfalling tropical storms. Six non-hurricane tropical storms (Bertha, Edouard, Fay, Hanna, Isidore and Kyle) made U.S. landfall. Previously, since 1900, no more than five sub-hurricane intensity tropical storms had ever made U.S. landfall during any particular year. One hurricane made landfall (Lili) for a total of seven named storms. Since 1950, only the years 1953, 1959, 1985 and 1998 had seven or more U.S. landfalling named storms (including all intensities).

- Only two tropical-only hurricanes (Isidore and Lili) occurred this year. This is the fewest number of tropical-only hurricanes since 1997 when only Hurricane Erika formed from an easterly wave. This year (2002) had the highest ratio (9 to 3) of North (> 25°N) versus South (> 25°N) forming NS.

- This was the first year with below-average NTC (80) since 1997 (54).

- Lifetime of Hurricane Kyle (lasted from 9/20-10/12). This was the third longest tropical cyclone (15.25 days) on record behind only Ginger (21 days; 1971) and Inga (15.5 days; 1969). Kyle weakened to a tropical depression three times during its existence only to be upgraded to a tropical storm later in its lifetime.

- Despite the large number of named storms that formed during September (8), a new record for the month, there was relatively little hurricane activity during the month. The number of hurricane days, intense hurricanes and intense hurricane days were only 65, 77 and 58 percent respectively of the average September.

5.1 Things We Do Not Understand About the 2002 Season

- Why the Atlantic Thermohaline Circulation (ATC) weakened and the tropical Atlantic surface temperature cooled so rapidly during the early summer months and then rapidly warmed again in September and October. We attribute this to a short period multi-month weakening of the ATC and the associated development of positive NAO and AO values during the first seven months of this year.

- Why Kyle existed for such a long time with very marginal tropical cyclone conditions.

- Why western Atlantic basin conditions became so favorable in September when surface pressures decreased and vertical wind shear was reduced. Our best hypothesis is that a large-scale Madden-Julian or 40-50 day pressure wave moved through the western tropical Atlantic at the climatological peak of the hurricane season in September. Once the 20-25 day active portion of this wave passed by in early October, surface pressure and vertical wind shears again became unfavorable, and no additional cyclones formed.

6 Specifics Regarding Primary Forecast Parameters During 2002

Specific trends in the factors which we know to be associated with seasonal variation of hurricane activity during 2002 included the following:

a) ENSO Conditions. Equatorial Pacific SSTAs (expressed as °C) in Niño-1-2, 3, 3.4 and 4 (see Fig. 1 for locations) are shown in Table 4. A moderate El Niño was present through most of the hurricane season. The Tahiti minus Darwin surface pressure difference (the Southern Oscillation Index, SOI) was negative while equatorial Outgoing Longwave Radiation (OLR) values near the Dateline were below average, indicative of enhanced deep convection which attends El Niño events.

b) Stratospheric QBO Winds

Table 5 shows both the absolute and relative (i.e., anomaly) values of 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 12°N during March through October 2002.

Table 4: April through October 2002 Niño sea surface temperature anomaly indices (in °C) and Tahiti minus Darwin (SOI) surface pressure differences (in SD).

	April	May	June	July	August	September	October
Niño-1-2	1.1	0.5	–0.4	–0.8	–0.9	–0.6	0.2
Niño-3	0.2	0.2	0.7	0.5	0.5	0.7	0.9
Niño-3.4	0.3	0.4	0.9	0.9	1.1	1.2	1.5
Niño-4	0.7	0.8	0.2	1.0	0.9	1.0	1.1
Normalized SOI in S.D.	–0.4	–1.2	–0.7	–0.7	–1.6	–0.7	–0.7

We had projected both 30 and 50 mb QBO winds to be from a relative westerly direction and, therefore, would be an enhancing influence for this year's hurricane activity in the deep tropics. Both 30 and 50 mb QBO wind anomalies remained westerly throughout the 2002 season. Other negative influences such as a warm ENSO, high surface pressure, etc. acted to suppress deep tropical hurricane activity throughout the hurricane season.

Table 5: Observed March through October 2002 values of stratospheric QBO zonal winds (U) in latitude belts between 11-13°N, as obtained from Caribbean stations at Curacao (12°N), Barbados (13°N), and Trinidad (11°N). Values are in ms^{-1}.

OBSERVED WIND

Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	15	6	2	–2	–2	–2	–3	–1
50 mb (20 km)	0	3	1	–1	–5	–2	1	2

OBSERVED WIND ANOMALIES

Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	9	14	15	16	16	17	13	11
50 mb (20 km)	0	4	7	9	9	9	11	9

c) Sea-Level Pressure Anomaly (SLPA)

Table 6 gives information on regional Caribbean basin and Gulf of Mexico SLPA during this season. The high August SLPA values were a surprise. We had earlier projected below average August West Atlantic SLPA values. Pressure was substantially above average within the deep tropics except for September. High values of SLPA typically are associated with strong mass subsidence and tend to be an inhibiting influence on seasonal TC activity. It is surprising that NS activity in September was as high as it was given the generally high western Atlantic tropical SLPAs in July and August. The observed large amounts of NS activity were largely due to the exceptionally large number of cyclones that formed at sub-tropical latitudes. In general, when climate factors inhibit low latitude development, we see more high latitude cyclone activity. However, this year's high latitude activity was well above our expectations.

d) Zonal Wind Anomalies (ZWA)

Table 6: Lower Caribbean basin SLPA for 2002 in mb (for San Juan, Barbados, Trinidad, Curacao and Cayenne) - top row and for the Caribbean-Gulf of Mexico (for Brownsville, Miami, Merida (Mexico), San Juan, Curacao and Barbados) - bottom row. Values in millibars (mb). Note: We use a SLP mean from 1950–1990 which is lower than the mean SLP during the last three decades by about 0.5 mb.

Month	Jun	Jul	Aug	Sep	Oct
5-station Lower Caribbean Average SLPA	1.0	1.1	0.9	0.3	0.6
6-station Caribbean plus Gulf of Mexico Average SLPA	0.6	–0.5	0.3	–0.1	0.3

Table 7 shows the average upper tropospheric (12 km or 200 mb) ZWA during the June through October 2002 period. Consistent with the prior ENSO discussion, all months except June and September had positive wind anomalies. These positive ZWA values enhanced regional tropospheric vertical wind shear and were a primary factor (along with positive SLPA) in suppressing July through August low latitude hurricane activity. It was only during September when lower latitude tropospheric wind conditions became favorable for TC formation. Positive ZWA conditions caused westward-moving easterly waves from Africa to experience increased tropospheric vertical wind shear and remained disorganized.

Table 7: 2002 Caribbean basin 200 mb (12 km) Zonal Wind Anomaly (ZWA) in ms^{-1} for the four stations including Kingston (18°N), Curacao (12°N), Barbados (13.5°N), and Trinidad (11°N).

	June	July	August	September	October
Average ZWA	–1.3	+3.2	+3.5	–1.1	+4.8

e) African Western Sahel Rainfall in 2002

Summer rainfall in the West Sahel region of Africa during 2002 was again (as last year) below average during June through September. Our best estimate of the June through September western Sahel average was about -1.0 S.D. below normal. The African rainfall-hurricane relationship has not held up well since 1995. This is clearly a topic needing further study.

f) Large-scale Atlantic Sea Surface Temperature and Surface Pressure Changes

Table 8 gives monthly average normalized SST and SLP anomalies over the broad Atlantic basin during 2002. Note how SSTA values cooled and SLPA values rose during much of 2002 and then there was an abrupt SSTA warming and a SLPA falling in September and October. Note that March 2002 surface pressure was not indicative of Atlantic pressure conditions in the later months of September and October. This also applied to October and November sub-tropical ridge pressure conditions of last year.

Table 8: Large area averaged Atlantic Ocean normalized SST and SLP anomalies from January through October 2002.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
SSTA (50-60°N,20-60°W)	.35	.27	0	-.66	-1.42	-1.75	-.98	.56	.47	1.05
SSTA (Eq-70°N,20-60°W)	1.44	-.03	.13	-.50	-.51	-1.23	-1.12	.35	1.13	1.30
SLPA (0-50°N,100°W to 30°E)	.72	.75	.93	.82	.99	1.18	.95	.60	-.56	-.55

7 Verification of Individual 2002 Lead Time Forecasts

Table 9 shows a comparison of our 2002 forecasts for five different lead times along with this year's observed numbers. Whereas our early December and early April forecasts were too high, our early August and early September forecasts were quite close for category 1-2 and category 3-4-5 hurricane activity and for the numbers of days of these intensities. By contrast, our forecast of named storms and named storm days was too low.

Table 9: Verification of our 2002 total seasonal hurricane predictions.

Tropical Cyclone Parameters and 1950-2000 Climatology (in parentheses)	7 Dec 2001	Updated 5 April 2002 Forecast	Updated 31 May 2002 Forecast	Updated 7 Aug 2002 Forecast	Updated 2 Sept Forecast	Observed 2 Sept 2002 Totals
Named Storms (NS) (9.6)	13	12	11	9	8	12
Named Storm Days (NSD) (49.1)	70	65	55	35	25	54
Hurricanes (H)(5.9)	8	7	6	4	3	4
Hurricane Days (HD)(24.5)	35	30	25	12	10	11
Intense Hurricanes (IH) (2.3)	4	3	2	1	1	2
Intense Hurricane Days (IHD)(5.0)	7	6	5	2	2	2.5
Hurricane Destruction Potential (HDP) (72.7)	90	85	75	35	25	31
Net Tropical Cyclone Activity (NTC)(100%)	140	125	100	60	45	80

Table 10 compares our forecast aids for our early August seasonal prediction. Column (1) gives the 1950-2000 climatology and Column (2) lists our statistical predictions. Column (3) presents our analog predictions based on our best analog years to 2002. Column (4) is our adjusted forecast, and column (5) is the 2002 verification. Our forecast of greatly reduced levels of hurricane activity with our two later predictions was quite successful. It must be remembered that in terms of normalized TC destruction, the sub-hurricane intensity cyclones typically cause less than ten percent of all cyclone-spawned damage. Most damage is caused by the intense cyclones.

7.1 Preface: Aggregate Verification of our Last Four Yearly Forecasts

We are making progress in better understanding and in improving seasonal prediction skill (as demonstrated by the last four 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 four years of seasonal forecasts have shown an improved level of forecast skill. We define forecast skill as the degree to which we

Table 10: Verification of our 7 August forecast techniques compared to the actual tropical cyclone activity that occurred.

Full Forecast Parameters	(1) 1950-2000 Climatology	(2) Statistical Prediction	(3) Analog Prediction	(4) Adjusted Actual Fcst	(5) Verification
Named Storms (NS)	9.6	5.9	6.3	9	12
Named Storm Days (NSD)	49.1	29.7	30.3	35	54
Hurricanes (H)	5.8	5.9	3.7	4	4
Hurricane Days (HD)	24.5	8.4	14.7	12	11
Intense Hurricanes (IH)	2.3	1.2	0.3	1	2
Intense Hurricane Days (IHD)	5.0	1.0	2.1	2	2.5
Hurricane Destruction Potential (HDP)	72.6	34.4	37.7	35	31
Net Tropical Cyclone Activity (NTC)	100%	69.9	52	60	80

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 (Table 11). By this measure, each of the eight parameters of our seasonal forecasts have shown some degree of forecast skill at all lead times except for hurricanes at the early December lead. Table 11 shows our average skill score for the last four years at different lead times for all parameters.

Table 11: Last four years (1999-2002) average percent of variation from climatology as a function of different forecast lead times (in percent).

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	19	34	49	27
NSD	18	26	87	69
H	-10	15	67	64
HD	5	25	35	69
IH	8	26	44	44
IHD	12	18	20	51
HDP	35	38	52	79
NTC	48	58	67	79

Each of our last four yearly forecasts have worked out very well. Figures 6 lists the percent variation from climatology of the average of these four yearly forecasts for NTC while Fig. 7 does the same for HDP.

Our average skill during the last four years has shown a steady increase as the lead time of the prediction 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 period (48% and 35%) and very high skill (79%) from the early August (Figs. 6 and 7) forecast of these two parameters.

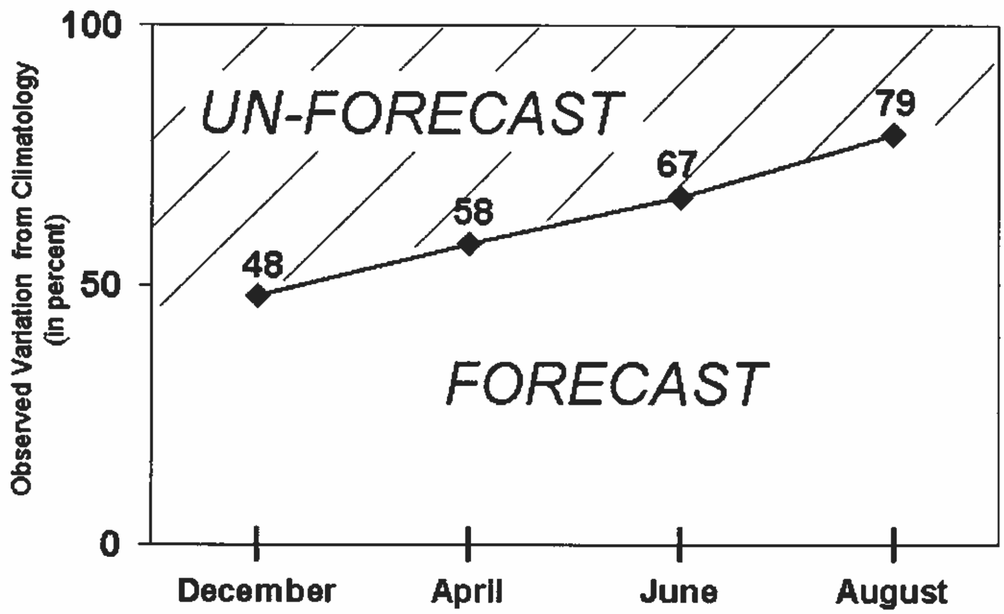

Figure 6: Last four-year average percent of Net Tropical Cyclone (NTC) activity which was forecast at the four individual lead times of early December, early April, early June and early August.

8 Prediction and Verification of Individual Monthly Forecasts for August and September 2002

8.1 Background

Periods within variously active or inactive Atlantic basin hurricane seasons do not necessarily conform to the overall trend of the season. For example, although 1961 was a very active hurricane season, there was no tropical cyclone activity during the month of August. In 1995, 19 named storms formed in the Atlantic, but only one new named storm developed during the 30-day period spanning the statistical peak of the hurricane season between 27 August and 26 September. Conversely, the inactive season of 1941 had only six named storms (average is 9.3), but four of these storms developed during September (average September activity is 3.4). During the inactive hurricane season of 1968, three of the eight named storms formed during June (average is 0.5).

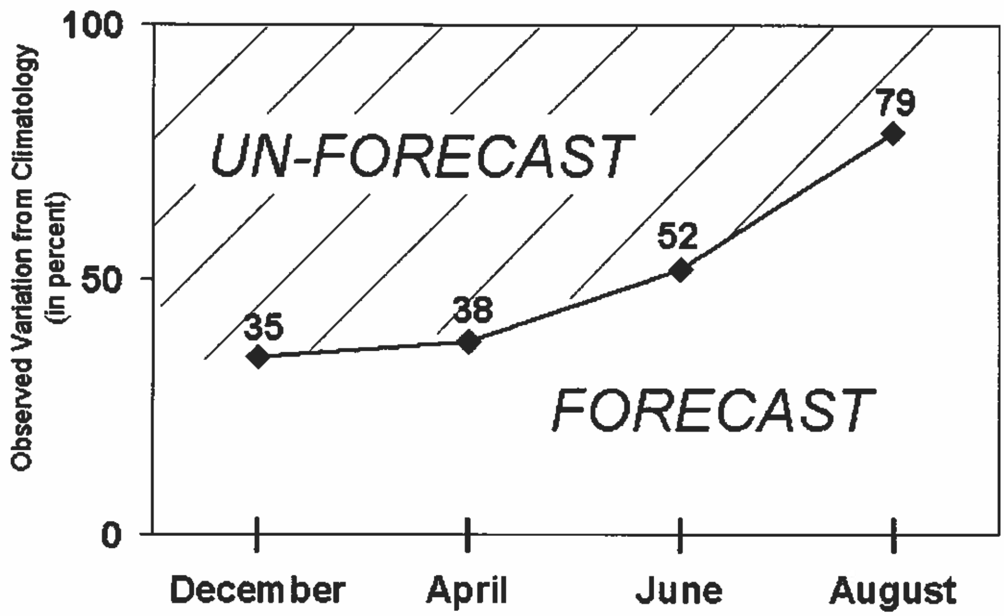

Figure 7: Last four-year average percent of Hurricane Destruction Potential (HDP) which was forecast at the four individual lead times of early December, early April, early June and early August.

In efforts being spearheaded by Eric Blake and Philip Klotzbach of our project, we are studying how well various sub-season and/or individual monthly trends can be forecast. It is, in general, more difficult to predict shorter periods of hurricane activity than to predict the entire seasonal activity. [Most predictive signals will vary more from climatology in relation to monthly than to seasonal trends.] Despite these inherent difficulties, we have devised skillful August-only and September-only forecast schemes (as determined by 51 years of hindcast testing using a seasonal independent jackknife approach). This technique involves searching global (mostly) summer data for potential predictors associated with active versus inactive August and September periods while predicting the same activity parameters (NS, NSD, H, HD, etc.) as in our seasonal scheme. We have made extensive use of the NCEP/NCAR reanalysis data. The methodology for the issuing of these August-only and September-only forecasts has been documented in project reports by Blake (2002) and Klotzbach (2002). We also plan to develop a monthly forecast for October. When August, September and October are considered in combination, they comprise approximately 90 percent of all tropical cyclone activity in the Atlantic.

After the August and September individual monthly forecasts are made they, together with our seasonal forecast, are adjusted for consistency. We find that by using these independent August-only and September-only forecasts, we are able to add improvement to our seasonal forecasts.

8.2 Verification

8.2.1 August

Table 12 summarizes our forecast of TC activity for August 2002, along with a jackknife estimate of hindcast skill for the 51-year period of 1949-1999, long period August mean values, and final adjusted August 2002 forecast numbers and verification.

Table 12: Prediction of August-only 2002 Atlantic basin seasonal hurricane activity, 51-year hindcast variance (r^2) explained (skill), August climatology and actual observed August 2002 activity.

Forecast Parameter	August Climatology	Statistical Forecast	Jackknife Hindcast Skill	August Adjusted Forecast To Agree With Seasonal Forecast	August 2002 Observed Number
NS	2.76	2.09	0.49	4.0	3.0
NSD	11.80	18.60	0.61	10.0	5.0
H	1.55	2.60	0.53	1.0	0.0
HD	5.67	7.11	0.62	4.0	0.0
IH	0.57	0.68	0.58	0.0	0.0
IHD	1.18	1.06	0.70	0.0	0.0
NTC	26.10	31.80	0.73	18.0	6.9

The final August adjusted forecast successfully predicted an inactive month. August was characterized by Caribbean basin ZWA and SLPA values which were quite unfavorable. The general circulation pattern was also quite unfavorable for TC development with warm ENSO conditions prevalent during the month along with a cool tropical Atlantic. Three named storms and no hurricanes formed during the month, and only one of the named storms formed from an easterly wave. Wind shear wreaked havoc on most of the waves moving off the coast of Africa and prohibited them from developing into storms. Bertha and Cristobal both formed from baroclinic systems in the subtropics and were very short-lived (<3 named storm days combined). Overall, August NTC activity was only about 25 percent of normal. This was the second year in a row that no hurricanes formed during the month of August which has not occurred during the past fifty years.

8.2.2 September

Table 13 summarizes our forecast of TC activity for September 2002 issued on 7 August and 2 September and final adjusted September 2002 forecast numbers.

Table 13: Independent September-only forecasts for 2002 including 7 August statistical forecast for September, 7 August adjusted forecast for September, 2 September statistical forecast, 2 September adjusted forecast and to adjusted forecast to fit the seasonal values.

Fcst. Variable	Sept. Clim.	7 Aug. Stat. Fcst. (for Sept.)	7 Aug. Fcst to fit Seasonal Fcst.	2 Sept. Stat. Fcst. (for Sept.)	2 Sept. Fcst. to Fit Seasonal Fcst.	Observed Sept. 2002 Activity
NS	3.4	2.5	3.0	1.6	3	8.0
NSD	21.7	15.0	18.0	13.5	13	36
H	2.4	2.1	2.0	1.5	2	4.0
HD	12.3	7.2	6.0	4.5	7	8.0
IH	1.3	0.7	1.0	0.3	1	1.0
IHD	3.0	2.3	2.0	2.3	2	1.75
NTC	48	32.5	30.0	24.8	26	55.9

The September 2002 forecast was quite accurate for the intense TC indices such as hurricanes days, intense hurricanes and intense hurricane days but was quite inaccurate for the weaker indices such as named storms and named storm days. Conditions rapidly became more favorable for TC development from August to September. Zonal wind shear was reduced considerably in the tropical Atlantic, and sea level pressure dropped precipitously in the western Caribbean. In addition, the tropical Atlantic which had cooled rapidly during the early part of the summer began a strong warming trend during September. Eight named storms formed during this month which was the most during the past 53 years (1950-2002). Only two of the eight named storms formed from easterly waves (Isidore and Lili). There was considerable activity in the Gulf of Mexico during September, and four named storms made landfall along the U.S. coast during the month (Edouard, Fay, Hanna and Isidore). Although named storm activity reached record values, hurricane days, intense hurricanes and intense hurricane days were below the climatological average likely due to the still unfavorable conditions over most of the tropical Atlantic. Overall, September NTC activity was about 10 percent above average.

The following statements are taken from our 7 August 2002 forecast and annotated with brief comments on what was actually observed.

- "We believe that the current strongly inhibiting values of Atlantic basin SLPA, SSTA, and upper and lower tropospheric zonal winds will 'trump' any of the pre-June monthly predictors in our seasonal and individual August and September forecasts and in most of our analog years." (Conditions remained unfavorable through August reducing activity considerably during that month; however, more favorable conditions became prevalent during September, and consequently TC activity increased considerably.)
- "The strongest predictor (for the September TC forecast), 1000 mb U (trade winds) in the Atlantic (5-15N, 30-50W) is running about +0.8 standard deviations stronger than

normal which indicates considerably less storm development owing to strong shear in the main development region." (No systems developed in the main tropical development region (5-15°N, 30-50°W). Conditions in the Western Caribbean however became quite favorable, and several storms developed in this area.)

The following statements are taken from our 2 September 2002 forecast and annotated with brief comments on what was actually observed.

- "We expect that these strong before-September inhibiting conditions will persist through September but be less restrictive than they have been in August." (Conditions were less restrictive in September for TC development, although the full extent to which conditions became more favorable was not predicted in the 2 September forecast.)
- "During El Niño years (as 2002 is) October and November hurricane activity is typically suppressed." (No tropical cyclones formed after September 21.)

See the CSU project reports of Blake (2002) and Klotzbach (2002) for more information on how these new individual monthly predictions are made.

9 Discussion

By measures of hurricane activity alone, 2002 was an inactive season. The first hurricane (Gustav - minimal category 1 hurricane) did not form until 11 September, when (climatologically) the season is half over. Gustav formed at a high latitude ($\approx$ 38°N) and had just marginal hurricane conditions for one day. Hurricane Kyle also never developed beyond a category 1 hurricane. Only two notable cyclones (Major Hurricanes Isidore and Lili) formed in the deep tropics ($<$ 25°N). The number of named storms existing in September (9) was a record, but most of these cyclones were weak and formed at high latitudes. This was a consequence of the unusual lower surface pressure and weakened tropospheric vertical wind shear which occurred in a broad area of the subtropics (latitude 25-40°N) during September. Seasonal forecast skill is highest in the tropics ($<$ 25°N) and is only marginal at sub-tropical latitudes. There is, in fact, an opposite relationship between tropical and subtropical activity. When tropical cyclone activity is suppressed (as in this year) there is typically a greater incidence of higher latitude storms. This was certainly the case this year. Our forecast worked well for TC activity in the tropics ($<$ 25°N) but greatly underestimated higher latitude activity. The ratio of the number of tropical storms (12) to hurricanes (4) or 3:1 was a record. The annual average of this ratio (9.6/5.9) is 1.6 or only one-half of what occurred this year.

The two primary factors in making the 2002 hurricane season a weak one with regards to hurricane activity were:

- The moderate El Niño which developed in the eastern tropical Pacific with its usual associated western tropical Atlantic strong upper-level westerly winds and enhanced Atlantic vertical wind shear. We underforecast the intensity of this El Niño in our early December 2001 and early April 2002 forecasts. As the El Niño progressed in the late spring and early summer we were obliged to selectively lower our 2002 forecast.

- Cooling of the Atlantic SSTs and rising Atlantic surface pressure up until August. We interpret these Atlantic changes as likely due to a weakening in the strength of the ATC which was inferred to take place during the months of the year leading up to August. It is not possible to directly measure the strength of the thermohaline circulation, but we can infer its strength from the proxy measurements of North Atlantic SSTA and Atlantic basin SLPA equatorward of 50°N and other atmospheric indices such as the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO). We did not foresee this 2002 ATC weakening when we issued our early December 2001 and early April 2002 forecasts. The progressive and broad spectrum of Atlantic changes that occurred through August (which we associate with a ATC weakening) were a primary reason (the other being the intensifying of the El Niño) that led us to progressively lower our seasonal forecast numbers with every new updated forecast from 5 April to 31 May to 7 August to 2 September 2002. This 6-7 month weakening of favorable Atlantic hurricane conditions was abruptly terminated between August and September. September Atlantic SSTs and SLPs showed an abrupt change to prior year conditions. North Atlantic SSTs rose, and SLPs fell in September. September became the most active September on record as regards to the number of named storms but still exhibited below-average HD, IH and IHD. There were 9 named storms which formed in the 24 days between 29 August and 21 September and 4 hurricanes. There was little tropical cyclone activity before and none after this period however. This is only the third year (1983, 1993) since 1972 that there has been no TC activity in October and November.

Figure 8 shows the monthly averages of the Atlantic deviations from average of SSTA minus SLPA. Values are plotted from January 2001 through October 2002. Positive deviations are favorable for enhancing Atlantic basin hurricane activity and negative values for inhibiting Atlantic basin hurricane activity. Note the steady lowering (or increasingly negative values of this quantity) from late 2001 to July 2002. This was the major factor in the continuous lowering of our seasonal prediction. The other important factor was the rise of Niño 3.4 SSTA values from June onward as shown in Fig. 9.

9.1 Theory

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 scale changes. We hypothesize that these changes in North Atlantic SSTAs are to a substantial degree a result of variations in the 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,

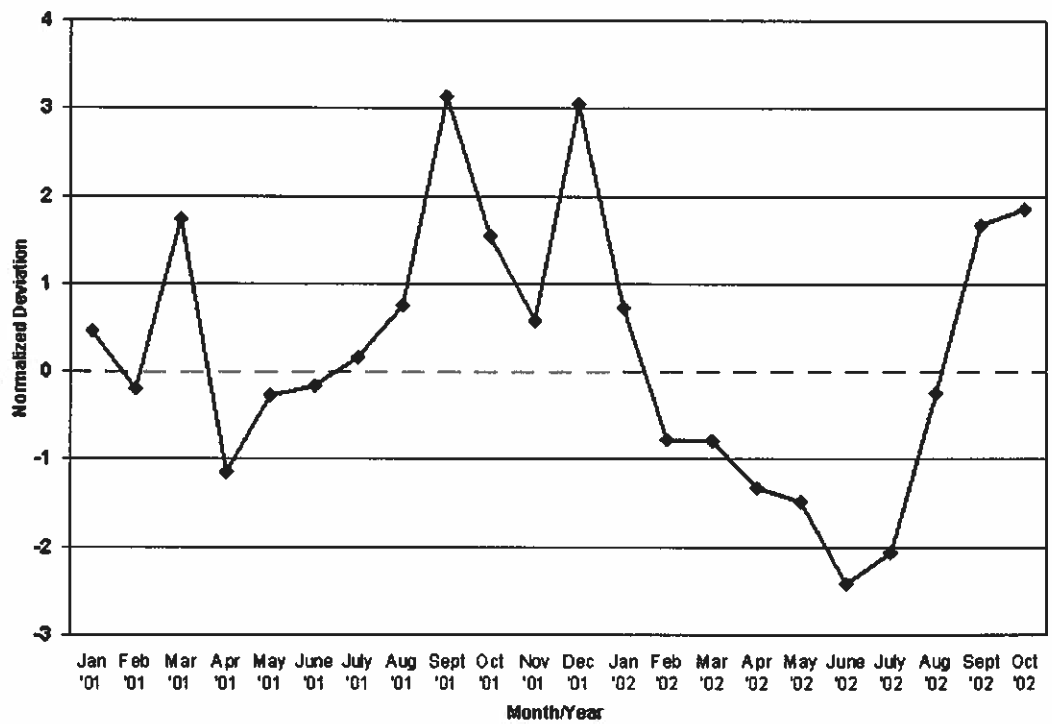

Figure 8: Normalized values of Atlantic SSTA minus SLPA monthly averages from January 2001 through October 2002. SSTA has been averaged from the Equator to 70°N, 20-60°W and SLPA from the Equator to 50°N, 30°E to 100°W. Positive values are more favorable for hurricane activity. Data obtained from the NOAA reanalysis products.

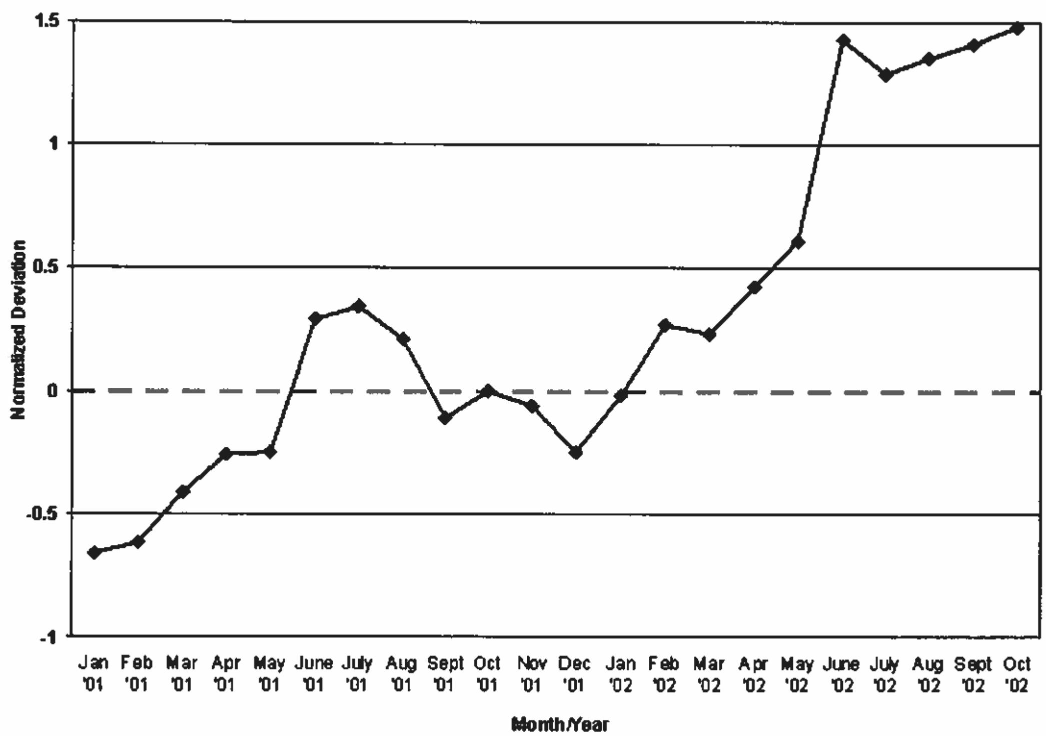

Figure 9: Normalized monthly average values of equatorial Pacific Niño 3.4 SSTA from January 2001 through October 2002. See Fig. 3 for the location of Niño 3.4.

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. It is likely that the salt content of the North Atlantic plays the dominant role in ATC changes.

By making a parameter which combines a number of the above features we can, we believe, diagnose the strength of the ATC and have a general explanation for most of the Atlantic basin long period general circulation features. The ATC is hypothesized to be the primary driver of changes on time scales of a season and longer. We thus attribute the change to unfavorable Atlantic basin hurricane enhancing conditions this year, after six of the prior seven seasons have seen a great increase in hurricane activity, to be a result of a 6-8 month weakening in the strength of the ATC circulation which has been strong in most months since mid-1995. Historical records have shown that it is not uncommon to have 6 to 24 month alterations in the ATC from its multi-decadal long strong and/or weak values. For example, we have previously judged the thermohaline circulation to have been weak for most of the period between 1970-1994 except for the break in this pattern in 1988 and 1989 - two seasons of above normal hurricane activity where Atlantic conditions were more typical of the above listed conditions.

10 Landfall Probabilities for 2002

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 14 gives verifications of our landfall probability estimates for 2002.

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 for each of 11 units of the U.S. coastline (Fig. 10). 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 11 offers a summary and a general outline of the landfall probability estimate methodology. These landfall forecast probabilities will be supplemented with additional probability values for each 100 km coastal segment receiving tropical storm force winds ($\geq$ 40 mph), sustained hurricane force winds ($\geq$ 75 mph), and major hurricane (category 3-4-5) force winds ($\geq$ 115 mph). Discussions of potential tropical cyclone-spawned hurricane destruction within each of the 96 different U.S. coastal regions are also in preparation.

Table 14: 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 and the East Coast (Regions 5-11) for 2002 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 right column. The actual landfall numbers for 2002 follow the dash "–" symbol. Table (a) is for the entire U.S. , 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			
	7 Dec.	5 Apr.	31 May	7 Aug.
TS	91%	88%	83%	78% (80) -7
HUR (Cat 1-2)	96%	84%	75%	66% (68) -1
HUR (Cat 3-4-5)	86%	75%	64%	49% (52) -0
All HUR	96%	96%	91%	82% (84) -1
Named Storms	99%	99%	98%	96% (97) -7

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

	Forecast Date			
	7 Dec.	5 Apr.	31 May	7 Aug.
TS	78%	70%	64%	57% (59) -6
HUR (Cat 1-2)	57%	56%	48%	41% (42) -1
HUR (Cat 3-4-5)	43%	43%	35%	29% (30) -0
All HUR	76%	75%	67%	58% (61) -1
Named Storms	94%	93%	88%	82% (83) -6

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

	Forecast Date			
	7 Dec.	5 Apr.	31 May	7 Aug.
TS	60%	60%	54%	49% (51) -1
HUR (Cat 1-2)	66%	63%	52%	42% (45) -0
HUR (Cat 3-4-5)	58%	56%	42%	28% (31) -0
All HUR	86%	84%	73%	58% (62) -0
Named Storms	95%	94%	88%	79% (81) -1

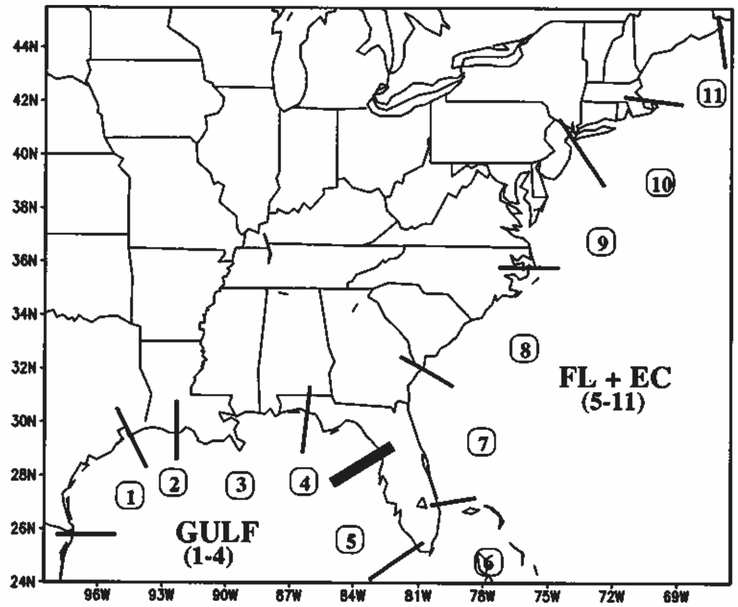

Figure 10: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

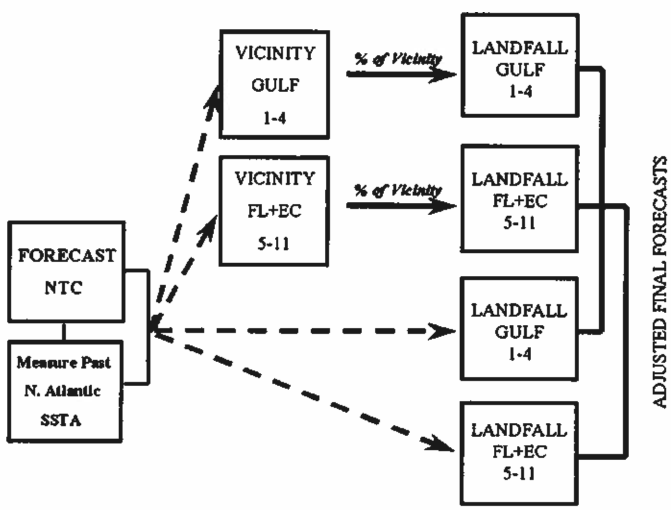

Figure 11: General flow diagram illustrating how forecasts of U.S. hurricane landfall probability are made. We forecast NTC and use an observed measure of the last few years of North Atlantic (50-60°N, 10-50°W) SSTA*. Regression equations are then developed from the combination of forecast NTC and measured 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).

11 Increased Level of Atlantic Basin Hurricane Activity During Six of the Last Eight Years - But Decreased U.S. Landfall

11.1 Increased Activity

A major reconfiguration of the distribution of Atlantic SST anomalies began in mid-1995 and has largely persisted through the present except for the 6-month dip earlier this year. North Atlantic SSTs have become about 0.4 to 0.6°C warmer than normal since 1995. This trend is well associated with increased major hurricane activity in the Atlantic basin during six of the last eight 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 eight years which conform to a prominent shift into hurricane-enhancing Atlantic circulation patterns. 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 8-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.

Despite El Niño-linked reduction of hurricane activity during 1997 and 2002, the last eight years (1995-2002) constitute the most active eight consecutive years on record. Table 15 provides a summary of the total number of named storms (87), named storm days (496), hurricanes (55), hurricane days (256), major hurricanes (26), major hurricane days (59) and Net Tropical Cyclone activity (1054) that occurred during the recent six years of 1995-1996 and 1998-2001. The six-year annual average of NS, NSD, H, HD, IH, IHD and NTC during these years was 145, 211, 151, 254, 273, 368 and 237 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. Note that NTC activity during these recent six active years averaged 237 percent of the level of NTC activity observed during the 1970-1994 period.

11.2 Downturn in U.S. Hurricane Landfall

During the 102 years between 1900 and 2001, 112 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 37 year period (1966–2002). 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 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 37 years since 1965 only 8 landfalling major hurricanes (an average of 0.22 per year) struck the Florida Peninsula and U.S. East Coast. However, between 1900–1965 there

Table 15: Comparison of recent six of the last eight years (1995-1996, 1998-2001) hurricane activity with climatology and 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
TOTAL	87	496	55	256	26	59.00	1064
Six-year Ave. 1995-96,98-01	14.5	83	9.2	43	4.33	9.83	177
Ratio 6 active yr/climatology in percent	151	169	153	173	188	197	178
Ratio Above 6 active yr/1970–94 in percent	145	211	151	254	273	368	237

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 strong 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 hurricane activity during six of the last eight years (1995–2002) has been attended by a reduction in landfall events which is even more pronounced than what occurred in the 1970-94 period. The portion of developing hurricanes making U.S. landfall during the last eight years has been only one-third as great as the percentage expected to make landfall based on long-term Atlantic basin hurricane climatology. Specifically, of the 29 major hurricanes that developed in the Atlantic basin during the last eight years, only three (Opal, 1995; Fran, 1996; and Bret, 1999) have made landfall on the U.S. coastline. Average data for the Atlantic basin over the last century indicates that one in three (73 of 218) intense Atlantic basin storms come inland. Based on these data we should have expected about 9 to 10 major hurricane landfalls where only 3 occurred. Similarly, there have been a total of 61 Atlantic basin hurricanes (all intensities) since 1995 with only 9 coming ashore. Climatology specifies that 20 U.S. hurricane landfall events should have taken place.

The last 37 years have also seen a great increase in U.S. southeast coastal 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.

12 The 1995–2002 Upswing in Atlantic Hurricanes and Global Warming

In contrast with the large increase in Atlantic basin major hurricane activity during six of the last eight years, total global hurricane and typhoon activity during the period 1995–2002 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 man-made 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 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 1994. 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 1995–2002 period. There were 86 Atlantic basin hurricanes during the 27 years of 1950–1969, 1995–2002 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 relate such small global temperature changes to this high level of hurricane activity.

13 Forthcoming Early December Forecasts of 2003 Hurricane Activity

We will be issuing a seasonal forecast of 2003 Atlantic basin hurricane activity on Friday 6 December 2003. This forecast will be based on data available to us through November 2002. As in the past, updates to the 2003 seasonal forecast will be issued in early April, early June, early August and early September 2003. The early August forecast will include separate forecasts for August-only and September-only activity during 2003. All of these forecasts will be available at our Web address given on the front cover (http://tropical.atmos.colostate.edu/forecasts/index.html).

14 Acknowledgments

Eric Blake and John Knaff have made many important contributions to the conceptual and scientific background for these forecasts. The authors are indebted to a number of meteorological experts who have furnished us with the data necessary to make this forecast or who have given us valuable assessments of the current state of global atmospheric and oceanic conditions. We are particularly grateful to Arthur Douglas, Richard Larsen, Ray Zehr and Mark DeMaria for very valuable climate discussions and input data. We thank Colin McAdie and Jiann-Gwo Jiing who have furnished us with data. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical, and data analysis assistance. We have profited over the years from many indepth discussions with most of the current NHC hurricane forecasters. These include Lixion Avila, Miles Lawrence, Richard Pasch, Jack Beven, James Franklin and Stacy Stewart. The first author would further like to acknowledge the encouragement he has received for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, former directors of the National Hurricane Center (NHC), and from the current director, Max Mayfield. We also thank Bill Bailey of the Insurance Information Institute for his sage advice and encouragement.

The financial backing for the issuing and verification of these forecasts has in part been supported by the National Science Foundation, but this NSF support is insufficient. We are very grateful to the Research Foundation of the United Services Automobile Association (USAA) and to the American International Group (AIG) - Lexington Branch) for providing support to the first author's research project. It is this support which is allowing our seasonal predictions to continue and be expanded.

15 Citations and Additional Reading

Blake, E. S., 2002: Prediction of August Atlantic basin hurricane activity. Dept. of Atmos. Sci. Paper No. 719, Colo. State Univ., Ft. Collins, CO, 80 pp.

DeMaria, M., J. A. Knaff and B. H. Connell, 2001: A tropical cyclone genesis parameter for the tropical Atlantic. *Wea. Forecasting*, 16(2), 219–233.

Elsner, J. B., G. S. Lemiller, and T. B. Kimberlain, 1996: Objective classification of Atlantic hurricanes. *J. Climate*, 9, 2880-2889.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and Implications. *Science*, 293, 474–479.

Goldenberg, S. B. and L. J. Shapiro, 1996: Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate*, 1169-1187.

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency: Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, 112, 1649-1668.

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. *Mon. Wea. Rev.*, 112, 1669-1683.

Gray, W. M., 1990: Strong association between West African rainfall and US landfall of intense hurricanes. *Science*, 249, 1251–1256.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1992: Predicting Atlantic seasonal hurricane activity 6–11 months in advance. *Wea. Forecasting*, 7, 440-455.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. *Wea. Forecasting*, 8, 73-86.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1994a: Predicting Atlantic basin seasonal tropical cyclone activity by 1 June. *Wea. Forecasting*, 9, 103-115.

Gray, W. M., J. D. Sheaffer and C. W. Landsea, 1996: Climate trends associated with multi-decadal variability of intense Atlantic hurricane activity. Chapter 2 in "Hurricanes, Climatic Change and Socioeconomic Impacts: A Current Perspective", H. F. Diaz and R. S. Pulwarty, Eds., Westview Press, 49 pp.

Gray, W. M., 1998: Atlantic ocean influences on multi-decadal variations in El Niño frequency and intensity. Ninth Conference on Interaction of the Sea and Atmosphere, 78th AMS Annual Meeting, 11-16 January, Phoenix, AZ, 5 pp.

Henderson-Sellers, A., H. Zhang, G. Berz, K. Emanuel, W. Gray, C. Landsea, G. Holland, J. Lighthill, S-L. Shieh, P. Webster, K. McGuffie, 1998: Tropical cyclones and global climate change: A post-IPCC assessment. *Bull. Amer. Meteor. Soc.*, 79, 19-38.

Klotzbach, P. J., 2002: Forecasting September Atlantic basin tropical cyclone activity at zero and one-month lead times. Dept. of Atmos. Sci. Paper No. 723, Colo. State Univ., Ft. Collins, CO, 91 pp.

Knaff, J. A., 1997: Implications of summertime sea level pressure anomalies. *J. Climate*, 10, 789-804.

Knaff, J. A., 1998: Predicting summertime Caribbean sea level pressure. *Weather and Forecasting*, 13, 740–752.

Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO, 272 pp.

Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.*, 121, 1703-1713.

Landsea, C. W. and W. M. Gray, 1992: The strong association between Western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate*, 5, 435–453.

Landsea, C. W., W. M. Gray, P. W. Mielke, Jr., and K. J. Berry, 1992: Long-term variations of Western Sahelian monsoon rainfall and intense U.S. landfalling hurricanes. *J. Climate*, 5, 1528–1534.

Landsea, C. W., W. M. Gray, K. J. Berry and P. W. Mielke, Jr., 1997: Revised Atlantic basin seasonal tropical cyclone prediction methods for 1 June and 1 August forecast dates. To be submitted to *Wea. Forecasting.*

Landsea, C. W., W. M. Gray, K. J. Berry and P. W. Mielke, Jr., 1996: June to September rainfall in the African Sahel: A seasonal forecast for 1996. 4 pp.

Landsea, C. W., N. Nicholls, W.M. Gray, and L.A. Avila, 1996: Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geo. Res. Letters*, **23**, 1697-1700.

Landsea, C. W., R. A. Pielke, Jr., A. M. Mestas-Nunez, and J. A. Knaff, 1999: Atlantic basin hurricanes: Indices of climatic changes. *Climatic Changes*, 42, 89-129.

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1996: Artificial skill and validation in meteorological forecasting. *Wea. Forecasting*, 11, 153-169.

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1997: A single-sample estimate of shrinkage in meteorological forecasting. Submitted to *Wea. Forecasting.*

Pielke, Jr. R. A., and C. W. Landsea, 1998: Normalized Atlantic hurricane damage, 1925–1995. *Wea. Forecasting*, **13**, 621–631.

Rasmusson, E. M. and T. H. Carpenter, 1982: Variations in tropical sea-surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.*, **110**, 354-384.

Sheaffer, J. D., 1995: Associations between anomalous lower stratospheric thickness and upper ocean heat content in the West Pacific warm pool. Presentation at the 21st AMS Conference on Hurricanes and Tropical Meteorology, Miami, FL, April 22-28.

Sheaffer, J. D. and W. M. Gray, 1994: Associations between Singapore 100 mb temperatures and the intensity of subsequent El Niño events. Proceedings, 18th Climate Diagnostics Workshop, 1-5 November, 1993, Boulder, CO.

16 Verification of Previous Forecasts

Table 16: Summary verifications of the author's prior seasonal forecasts of Atlantic TC activity between 1984-2001.

	Prediction Dates		
1984	24 May and 30 July Update		Observed
No. of Hurricanes	7		5
No. of Named Storms	10		12
No. of Hurricane Days	30		18
No. of Named Storm Days	45		51
1985	of 28 May	Update 27 July	Observed
No. of Hurricanes	8	7	7
No. of Named Storms	11	10	11
No. of Hurricane Days	35	30	21
No. of Named Storm Days	55	50	51
1986	29 May	Update 28 July	Observed
No. of Hurricanes	4	4	4
No. of Named Storms	8	7	6
No. of Hurricane Days	15	10	11
No. of Named Storm Days	35	25	23
1987	26 May	Update 28 July	Observed
No. of Hurricanes	5	4	3
No. of Named Storms	8	7	7
No. of Hurricane Days	20	15	5
No. of Named Storm Days	40	35	37
1988	26 May and 28 July Update		Observed
No. of Hurricanes	7		5
No. of Named Storms	11		12
No. of Hurricane Days	30		21
No. of Named Storm Days	50		47
Hurr. Destruction Potential(HDP)	75		81
1989	26 May	Update 27 July	Observed
No. of Hurricanes	4	4	7
No. of Named Storms	7	9	11
No. of Hurricane Days	15	15	32
No. of Named Storm Days	30	35	66
Hurr. Destruction Potential(HDP)	40	40	108
1990	5 June	Update 3 August	Observed
No. of Hurricanes	7	6	8
No. of Named Storms	11	11	14
No. of Hurricane Days	30	25	27
No. of Named Storm Days	55	50	66
Hurr. Destruction Potential(HDP)	90	75	57
Major Hurricanes (Cat. 3-4-5)	3	2	1
Major Hurr. Days	Not Fcst.	5	1.00
1991	5 June	Update 2 August	Observed
No. of Hurricanes	4	3	4
No. of Named Storms	8	7	8
No. of Hurricane Days	15	10	8
No. of Named Storm Days	35	30	22
Hurr. Destruction Potential(HDP)	40	25	22
Major Hurricanes (Cat. 3-4-5)	1	0	2
Major Hurr. Days	2	0	1.25

1992	26 Nov 1991	Update 5 June	Update 5 August	Observed
No. of Hurricanes	4	4	4	4
No. of Named Storms	8	8	8	6
No. of Hurricane Days	15	15	15	16
No. of Named Storm Days	35	35	35	39
Hurr. Destruction Potential(HDP)	35	35	35	51
Major Hurricanes (Cat. 3-4-5)	1	1	1	1
Major Hurr. Days	2	2	2	3.25

1993	24 Nov 1992	Update 4 June	Update 5 August	Observed
No. of Hurricanes	6	7	6	4
No. of Named Storms	11	11	10	8
No. of Hurricane Days	25	25	25	10
No. of Named Storm Days	55	55	50	30
Hurr. Destruction Potential(HDP)	75	65	55	23
Major Hurricanes (Cat. 3-4-5)	3	2	2	1
Major Hurr. Days	7	3	2	0.75

1994	19 Nov 1993	Update 5 June	Update 4 August	Observed
No. of Hurricanes	6	5	4	3
No. of Named Storms	10	9	7	7
No. of Hurricane Days	25	15	12	7
No. of Named Storm Days	60	35	30	28
Hurr. Destruction Potential(HDP)	85	40	35	15
Major Hurricanes (Cat. 3-4-5)	2	1	1	0
Major Hurr. Days	7	1	1	0
Net Trop. Cyclone (NTC) Activity	110	70	55	36

1995	30 Nov 1994	Update 14 April	Update 7 June	Update 4 August	Obs.
No. of Hurricanes	8	6	8	9	11
No. of Named Storms	12	10	12	16	19
No. of Hurricane Days	35	25	35	30	62
No. of Named Storm Days	65	50	65	65	121
Hurr. Destruction Potential(HDP)	100	75	110	90	173
Major Hurricanes (Cat. 3-4-5)	3	2	3	3	5
Major Hurr. Days	8	5	6	5	11.5
Net Trop. Cyclone (NTC) Activity	140	100	140	130	229

1996	30 Nov 1995	Update 4 April	Update 7 June	Update 4 August	Obs.
No. of Hurricanes	5	7	6	7	9
No. of Named Storms	8	11	10	11	13
No. of Hurricane Days	20	25	20	25	45
No. of Named Storm Days	40	55	45	50	78
Hurr. Destruction Potential(HDP)	50	75	60	70	135
Major Hurricanes (Cat. 3-4-5)	2	2	2	3	6
Major Hurr. Days	5	5	5	4	13
Net Trop. Cyclone (NTC) Activity	85	105	95	105	198

1997	30 Nov 1996	Update 4 April	Update 6 June	Update 5 August	Obs.
No. of Hurricanes	7	7	7	6	3
No. of Named Storms	11	11	11	11	7
No. of Hurricane Days	25	25	25	20	10
No. of Named Storm Days	55	55	55	45	28
Hurr. Destruction Potential(HDP)	75	75	75	60	26
Major Hurricanes (Cat. 3-4-5)	3	3	3	2	1
Major Hurr. Days	5	5	5	4	2.2
Net Trop. Cyclone (NTC) Activity	110	110	110	100	54

1998	6 Dec 1997	Update 7 April	Update 5 June	Update 6 August	Obs.
No. of Hurricanes	5	6	6	6	10
No. of Named Storms	9	10	10	10	14
No. of Hurricane Days	20	20	25	25	49
No. of Named Storm Days	40	50	50	50	80
Hurr. Destruction Potential(HDP)	50	65	70	75	145
Major Hurricanes (Cat. 3-4-5)	2	2	2	2	3
Major Hurr. Days	4	4	5	5	9.2
Net Trop. Cyclone (NTC) Activity	90	95	100	110	173

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