EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND US LANDFALL STRIKE PROBABILITY FOR 2004

The recent upturn in Atlantic basin hurricane activity which began in 1995 is expected to continue in 2004, although at a somewhat reduced rate from some of the very active years since 1995. We have adjusted our numbers downward slightly from our earlier 2004 forecasts.

(as of 6 August 2004)

This forecast is based on new research by the authors,
along with current meteorological information through July 2004

By

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with assistance from William Thorson[3]

This forecast as well as past forecasts and verifications are available via the World Wide Web: http://tropical.atmos.colostate.edu/Forecasts/ - also, consult our new United States landfall probability webpage for detailed landfall probabilities at the following URL: http://www.e-transit.org/hurricane

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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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2004

	Issue Date	Issue Date	Issue Date	Issue Date
Forecast Parameter and 1950-2000	5 December	2 April	28 May	6 August
Climatology (in parentheses)	2003	2004	2004	2004
Named Storms (NS) (9.6)	13	14	14	13
Named Storm Days (NSD) (49.1)	55	60	60	55
Hurricanes (H)(5.9)	7	8	8	7
Hurricane Days (HD)(24.5)	30	35	35	30
Intense Hurricanes (IH) (2.3)	3	3	3	3
Intense Hurricane Days (IHD)(5.0)	6	8	8	6
Hurricane Destruction Potential (HDP) (72.7)	85	100	100	85
Net Tropical Cyclone Activity (NTC)(100%)	125	145	145	125

PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING COASTAL AREAS:

1) Entire U.S. coastline - 68% (average for last century is 52%)

2) U.S. East Coast Including the Florida Peninsula - 48% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 38% (average for last century is 30%)

4) Expected above-average major hurricane landfall risk in the Caribbean

DISTINCTION BETWEEN CSU SEASONAL HURRICANE FORECASTS AND THOSE ISSUED BY NOAA

Seasonal hurricane forecasts have been issued for 21 years by the tropical meteorology research group of Prof. William Gray of the Department of Atmospheric Science, Colorado State University (CSU). These forecasts are now issued in early December of the prior year, and in early April, June, August, September and October of the current year. The predictions have shown steady improvement through continuing research. These forecasts now include U.S. hurricane landfall probabilities for seasonal as well as individual monthly periods.

The National Oceanic and Atmospheric Administration (NOAA) has also recently begun to issue Atlantic basin seasonal hurricane forecasts. The NOAA forecasts are independent of our CSU forecasts although they utilize prior CSU research augmented by their own insights. The NOAA and the 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.

Acknowledgment

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

ABSTRACT

Information obtained through July 2004 indicates that the 2004 Atlantic hurricane season will have above-average activity. We estimate that 2004 will have about 7 hurricanes (average is 5.9), 13 named storms (average is 9.6), 55 named storm days (average is 49), 30 hurricane days (average is 24.5), 3 intense (category 3-4-5) hurricanes (average is 2.3), 6 intense hurricane days (average is 5.0) and a Hurricane Destruction Potential (HDP) of 85 (average is 71). We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2004 to be about 125 percent of the long-term average. The probability of U.S. major hurricane landfall is estimated to be about 130 percent of the long-period average. This early August forecast is based on a newly-devised extended range statistical forecast procedure which utilizes 52 years of past global reanalysis data. Analog predictors are also utilized. The influence of El Niño conditions in our hurricane forecast are implicit in our predictor fields, and therefore we do not utilize a specific ENSO forecast. As of early August, it appears that warm neutral or weak warm ENSO conditions are likely for the remainder of the Atlantic hurricane season. These conditions are expected to bring about a small diminution of Atlantic hurricane activity from that predicted by our early April and late May forecasts.

1 Introduction

This is the 21st year in which the first author has made forecasts of the coming season's Atlantic basin hurricane activity. Our Colorado State University research project has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill significantly exceeding climatology. These forecasts are based on a statistical methodology derived from 52 years of past global reanalysis data and a separate study of prior analog years which have had similar global atmosphere and ocean precursor circulation features to this year. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic tropical cyclone activity and landfall probability.

2 Forecast Methodology

We believe that seasonal forecasts must be based on methods showing significant hindcast skill in application to long periods of prior years. Most atmosphere-ocean circulation and energy exchange processes are too complicated to allow for skillful deterministic initial value seasonal and yearly prediction. It is only through hindcast studies that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided the atmosphere continues to behave in the future as it has in the past. Unlike initial value deterministic prediction, it is not necessary to fully understand all relevant atmospheric and oceanic processes to issue a skillful statistical forecast. One can use prior empirical associations without understanding all of the physical linkages and processes which are involved.

The last few years have seen tremendous growth in the accessibility of global atmospheric data on the Internet. An example of this accessibility is the NOAA/NCEP reanalysis which archives historical atmospheric and ocean surface data and makes this data easily available. Other cooperative research groups are developing similar reanalysis products. Many of these reanalysis data sets are available from the late 1940s and offer exciting and unique opportunities for the development of new and skillful extended range empirical climate forecasts.

There is a great curiosity as to how active the coming hurricane season will be. Any forecast with reasonable physical linkages which has demonstrated hindcast skill above that of climatology is of interest to most residents of the southeast U.S. and the Caribbean. It is important that the public be informed as to what the current atmospheric and oceanic conditions suggest may occur in the coming hurricane season.

3 Earlier 1 August Statistical Hurricane Forecast Schemes

Our original early August seasonal hurricane forecast scheme was developed in the early 1990s (Gray et al. 1993) and demonstrated significant hindcast skill for the period of 1950-1991 (Gray et al. 1994). This scheme included measurements of West African rainfall as an important forecast input. A revised 1 August forecast scheme was developed in the mid-1990s. Both schemes did not have the advantage of the NOAA reanalysis products of the last 3-4 years.

Since the observed shift of Atlantic Ocean SST patterns in 1995 [and implied increase in the strength of the Atlantic Thermohaline Circulation (THC)], our earlier 1 August forecast schemes have consistently underpredicted Atlantic basin hurricane activity. The previously observed (1950-1994) strong association between West African rainfall and Atlantic hurricanes has not been reliable since 1994.

3.1 New 1 August Seasonal Forecast Scheme

Most reanalysis data sets are available from the late 1940s and offer exciting and unique opportunities for the development of new and more skillful extended range empirical climate forecasts. For example:

1. Our new scheme has been developed on 11 more years of hindcast data (1950-2001).

2. Our new scheme has been able to use the recently developed NOAA/NCEP reanalysis data that were not available to us at the time we developed our earlier scheme. The reanalysis has allowed us to more readily search for new forecast parameters.

Through extensive analyses of the recently available NOAA/NCEP reanalysis products, Phil Klotzbach of our forecast team has developed a new set of 1 August extended range predictors which shows superior hindcast skill over our previous 1 August forecast schemes. This new 1 August forecast scheme does not use West African rain as a predictor. No significant improvement in hindcast skill was achieved by adding June-July fields to the 1 June forecast, and therefore, the 1 August seasonal forecast uses the same predictors as the 1 June forecast.

The pool of seven predictors for this new extended range forecast is given and defined in Table 1. The location of each of these new predictors is shown in Fig. 1. Strong statistical relationships can be extracted via combinations of these predictive parameters (which are available by the end of May), and quite skillful Atlantic basin hurricane forecasts for the following summer and fall can be made if the atmosphere and ocean continue to behave in the future as they have during the hindcast period of 1950-2001. Full documentation of the skill of this forecast can be found in our 28 May 2004 seasonal forecast.

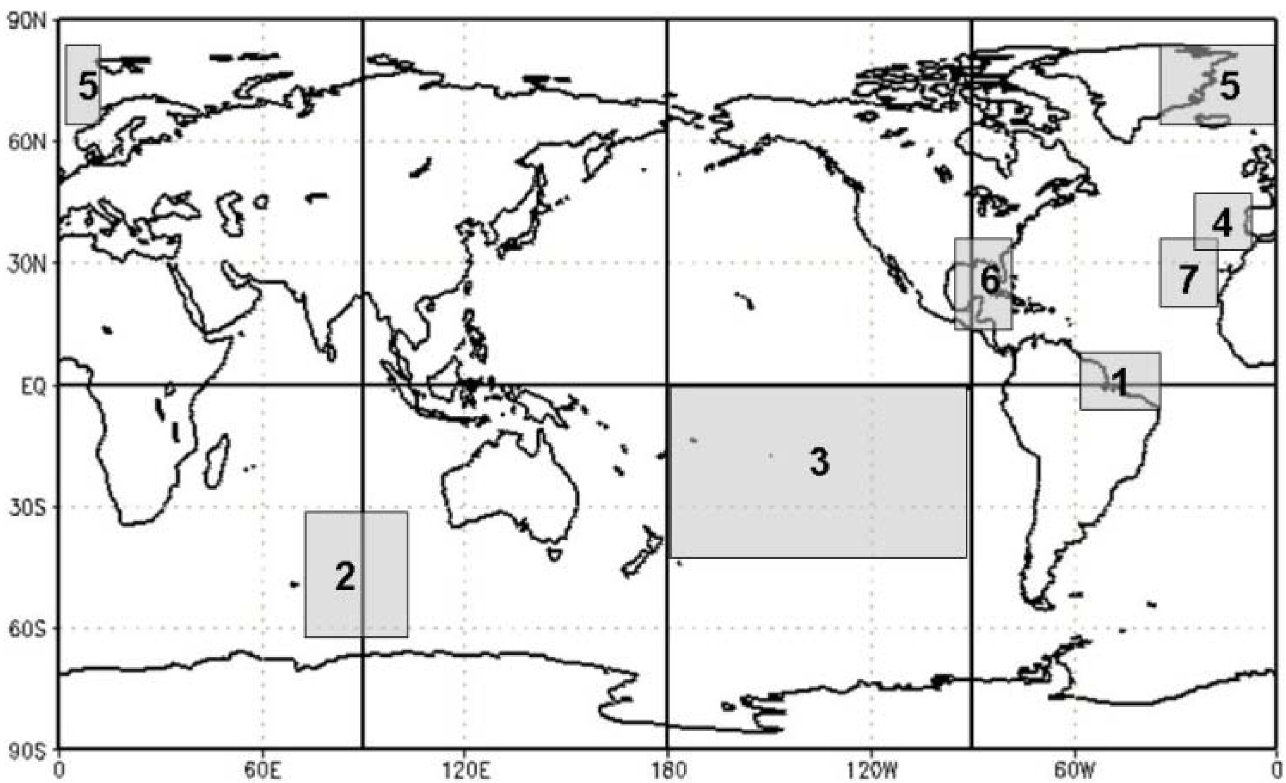

Figure 1: Location of predictors for our new 1 August forecast for the 2004 hurricane season.

Table 1: List of our new 1 August 2004 predictor set and their anomaly values for this year's hurricane activity. A plus (+) means that positive values of the parameter are associated with increased hurricane activity, and a minus (-) indicates that negative values of the parameter are associated with increased hurricane activity. Five of the seven values indicate increased hurricane activity for this year.

1 August Seasonal Predictors	2004 Observed Values	Effect on 2004 Hurricane Season
(1) - Feb. 200 mb U Anom. (5˙S-10˙N, 35-55˙W) (-)	-0.5 SD	**Enhance**
(2) - Feb.-Mar. 200 MB V Anom. (35-62.5˙S, 70-95˙E (-)	+0.3 SD	Suppress
(3) - Feb. SLPA (0-45˙S, 90-180˙W) (+)	-0.4 SD	Suppress
(4) - Feb. SSTA (35-50˙N, 10-30˙E) (+)	+1.8 SD	**Enhance**
(5) - Prev. Nov. 500 mb Ht. Anom. (67.5-85˙N, 10˙E-50˙W) (+)	+0.7 SD	**Enhance**
(6) - Prev. Sep.-Nov. SLP Anom. (15-35˙N, 75-95˙W) (-)	-0.8 SD	**Enhance**
(7) - May SSTA (20-40˙N, 15-30˙W) (+)	+0.5 SD	**Enhance**

Table 2 shows our statistical forecast for the 2004 hurricane season and the comparison of this forecast with climatology (average season between 1950-2000). All our forecast parameters are expected to be above average. Brief descriptions of our new early August seasonal predictors are contained in our 28 May 2004 seasonal forecast, which is listed on our Colorado State University hurricane forecast web site.

Table 2: New 1 August statistical seasonal forecast for 2004.

	Statistical
Predictands and Climatology	Forecast Numbers
Named Storms (NS) - 9.6	11.7
Named Storm Days (NSD) - 49.1	67.2
Hurricanes (H) - 5.9	6.4
Hurricane Days (HD) - 24.5	31.9
Intense Hurricanes (IH) - 2.3	2.5
Intense Hurricane Days (IHD) - 5.0	5.2
Hurricane Destruction Potential (HDP) - 72.7	99
Net Tropical Cyclone Activity (NTC) - 100	107

4 Recently Developed Predictions of Individual Monthly Atlantic TC Activity for August, September, and October

A new aspect of our climate research is the development of TC activity predictions for individual months. There are often monthly periods within active and inactive Atlantic basin hurricane seasons which do not conform to the overall season. For example, 1961 was an active hurricane season (NTC of 222), but there was no TC activity during August; 1995 had 19 named storms, but only one named storm developed during a 30-day period during the peak of the hurricane season between 29 August and 27 September. By contrast, the inactive season of 1941 had only six named storms (average 9.3), but four of them developed during September. During the inactive 1968 hurricane season, three of the eight named storms formed in June (June average is 0.5).

We have started new research to see how well various sub-season or individual monthly trends of TC activity can be forecast. This effort has recently been documented in papers by Blake and Gray (2004) for August and Klotzbach and Gray (2003) for September. These reports show that it is possible to develop a skillful prediction scheme for August-only and September-only Atlantic basin tropical cyclone activity. We are issuing our second October-only forecast this year. On average, August, September, and October have about 26%, 48%, and 17% of total NTC, respectively. Initial August-only forecasts have now been made by Blake for 2000-2003, and their verification looks promising.

It has been generally thought that it is more difficult to predict hurricane activity during shorter periods than to predict activity for the entire season. Despite the presumed inherent difficulties with these shorter period forecasts, Blake and Klotzbach have devised quite skillful August-only, September-only, and October-only prediction schemes based on 51 years (1950-2000) of hindcast testing using a statistically independent jackknife approach. Predictors are largely derived from June and July NCEP global reanalysis data but also include information from earlier in the year.

4.1 Independent August-Only Statistical Forecast

Figure 2 and Table 3 list the predictors used in the August-only hindcast (Blake and Gray 2004) for each of the nine different forecast parameters. The table also shows hindcast skill for the 51-year period 1950-2000, as well as the independent jackknife hindcast skill over this period. Table 4 gives the predictor values for August 2004. Table 5 gives our independent statistical prediction for August 2004. These predictors indicate slightly below-average activity for August 2004. However, due to the considerable amount of tropical cyclone activity that has already occurred during this August, we are forecasting a slightly above-average August.

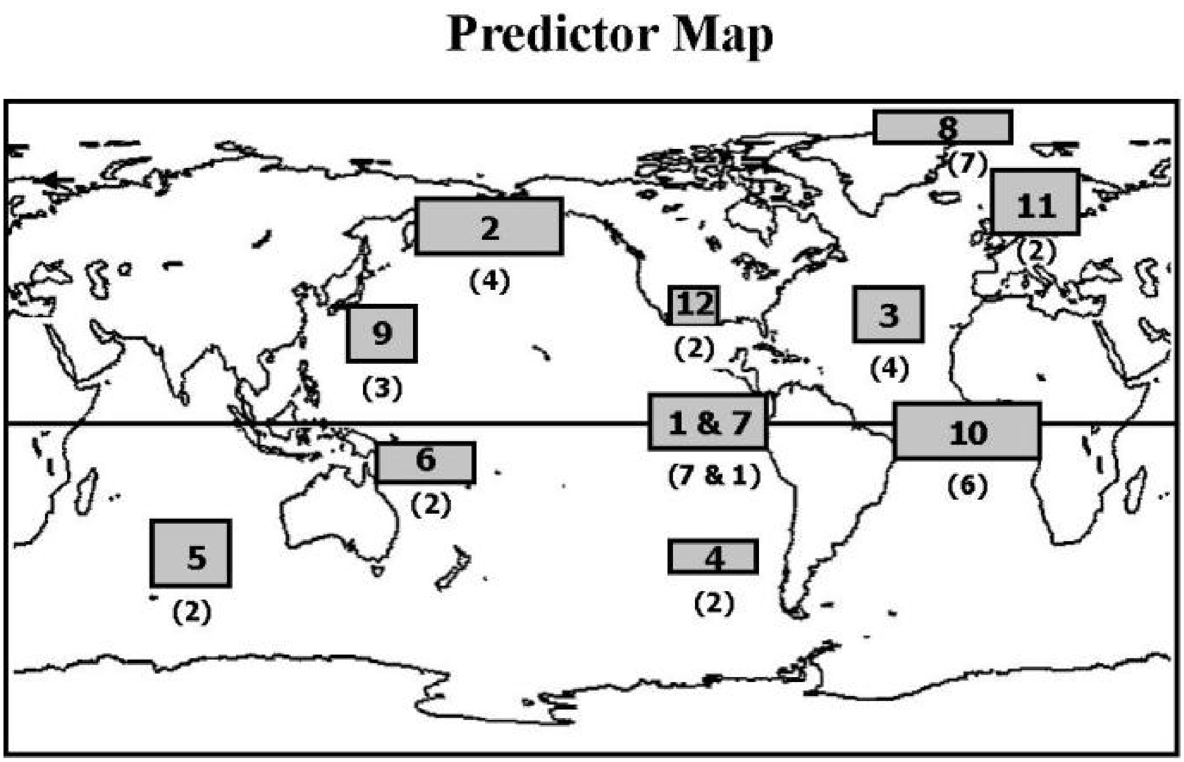

Figure 2: Global map showing locations of August-only TC predictors. Table 3 provides a listing and description of these predictors. The numbers in the boxes are keyed to descriptions in the bottom of Table 3. The numbers in parentheses beneath each box indicate how many predictive equations are used for each predictor.

Table 3: Listing of predictors chosen for each forecast parameter and the total hindcast variance explained by these predictors for the August-only forecast. The name and atmospheric parameter utilized in each predictor is given below - where the number for each is keyed to Fig. 2.

Forecast Parameter	No. of Predictors	Predictors Chosen from Table	Variability Explained by Hindcast (R^2) (1949-1999)	Likely Independent Forecast Skill (Jackknife)
NS	5	3, 6, 7, 9, 11	.55	.41

NSD	5	1, 2, 3, 8, 10	.71	.61
H	4	1, 2, 8, 10	.57	.47
HD	5	3, 4, 8, 9, 10	.69	.59
IH	5	1, 3, 5, 8, 12	.68	.59
IHD	5	1, 4, 5, 6, 9	.78	.72
NTC	5	1, 2, 8, 10, 12	.74	.66
TONS	4	1, 8, 10, 11	.68	.60
TOH	4	1, 2, 8, 10	.64	.56
1) Galapagos July 200 mb v, sign of correlation (-)				
2) Bering Sea July SLP, sign of correlation (-)				
3) Atlantic Ocean July SLP, sign of correlation (-)				
4) SE Pacific July 200 mb u, sign of correlation (-)				
5) S. Indian Ocean July 500 mb ht, sign of correlation (-)				
6) Coral Sea July 200 mb u, sign of correlation (+)				
7) Galapagos July 200 mb u, sign of correlation (-)				
8) North Greenland June 200 mb u, sign of correlation (+)				
9) Northwest Pacific June SLP, sign of correlation (+)				
10) S. Atlantic Ocean April SLP, sign of correlation (-)				
11) Scandinavia February SLP, sign of correlation (-)				
12) SW USA January SLP, sign of correlation (-)				

Table 4: August 2004 Predictor Values

		Effect on 2004
Predictors	2004 Observed Values	Hurricane Season
Galapagos July 200 mb v, sign of correlation (-)	-1.1 SD	**Enhance**
Bering Sea July SLP, sign of correlation (-)	-0.9 SD	**Enhance**
Atlantic Ocean July SLP, sign of correlation (-)	-0.8 SD	**Enhance**
SE Pacific July 200 mb u, sign of correlation (-)	+0.1 SD	Suppress
S. Indian Ocean July 500 mb ht, sign of correlation (-)	+2.5 SD	Suppress
Coral Sea July 200 mb u, sign of correlation (+)	+0.5 SD	**Enhance**
Galapagos July 200 mb u, sign of correlation (-)	-0.8 SD	**Enhance**
North Greenland June 200 mb u, sign of correlation (+)	-0.9 SD	Suppress
Northwest Pacific June SLP, sign of correlation (+)	-1.7 SD	Suppress
S. Atlantic Ocean April SLP, sign of correlation (-)	+1.4 SD	Suppress
Scandinavia February SLP, sign of correlation (-)	-0.2 SD	**Enhance**
SW USA January SLP, sign of correlation (-)	+0.1 SD	Suppress

Table 5: Independent August-only prediction of 2004 hurricane activity based on Blake and Gray (2004). August climatology is shown in parentheses.

	Statistical Model	Qualitative Adjustment
NS	3.63 (2.76)	4
NSD	14.30 (11.80)	20
H	1.64 (1.55)	3
HD	2.29 (5.67)	8
IH	0.30 (0.57)	1

IHD	-2.03 (1.18)	1
NTC	20.10 (26.1)	35

4.2 Independent September-Only Statistical Forecast

Figure 3 and Table 6 portray and list our 1 August predictors for September-only activity for this year. The number of predictors used and individual parameter hindcast skill are given in Table 7. Table 8 gives the predictor values for September 2004. Table 9 gives our independent September statistical forecast and our adjusted final forecast.

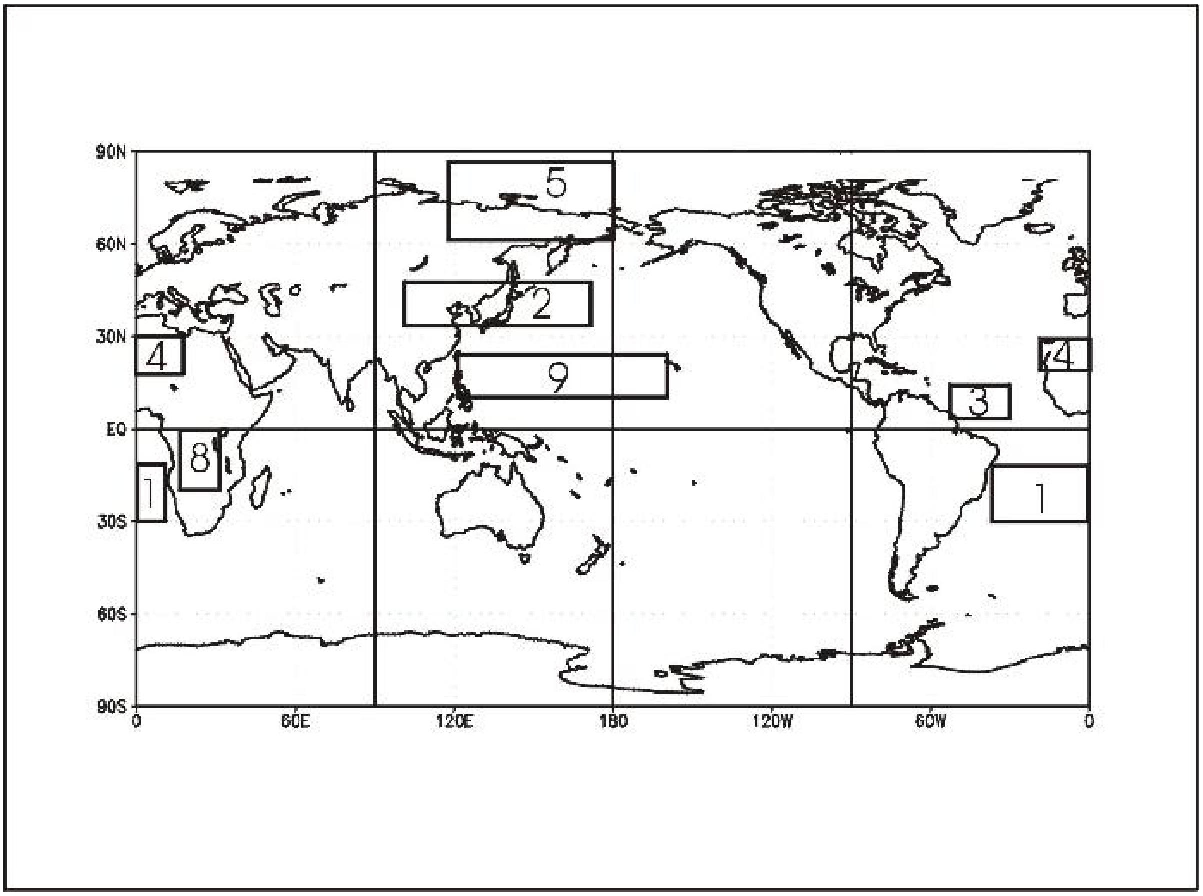

Figure 3: Predictors selected for the end of July forecast of September tropical cyclone activity. The numbers in each area are keyed to the description given in Table 6.

Table 6: Predictors selected for the end of July forecast of September tropical cyclone activity. The sign of the predictor associated with increased tropical cyclone activity is in parentheses. Note that predictors 6 and 7 are not used since they require August data.

Name of Predictor	Location	Equations Used
1) April 1000 mb U (-)	(12.5-30°S, 40°W-10°E)	IH
2) July 200 mb Geo Ht. (+)	(32-42°N, 100-160°E)	NS, NSD, H, HD, IH, TONS, TOH, NTC
3) July 1000 mb U (+)	(5-15°N, 30-50°W)	NS, NSD, H, HD, IH, IHD, TONS, TOH, NTC
4) Feb. 1000 mb U (-)	(20-30°N, 15°W-15°E)	NSD, HD, IHD, NTC

5) April 200 mb U (-)	(67.5-85˚N, 110-180˚E)	NS, NSD, HD, IH, IHD, TONS, TOH, NTC
8) May 200 mb V (+)	(0-20˚S, 15-30˚E)	NSD, H, HD
9) Jan-Feb 200 mb U (-)	(15-25˚N, 120˚E-160˚W)	IH, IHD, TONS, TOH, NTC

Table 7: Variance (r^2) explained for each of the nine TC activity indices and aggregate NTC based on the 1 August hindcast of September tropical cyclone activity from 1950-2000.

Parameter	Number of Predictors	Variance Explained	Jackknife Variance Explained
NS	3	0.29	0.19
NSD	5	0.54	0.44
H	3	0.38	0.28
HD	5	0.60	0.51
IH	5	0.63	0.53
IHD	4	0.63	0.54
TONS	4	0.50	0.40
TOH	4	0.63	0.55
NTC	5	0.75	0.68
Aggregate NTC		0.80	

Table 8: September 2004 predictor values - the sign of the predictor associated with increased tropical cyclone activity is in parentheses.

Predictor	2004 Observed Values	Effect on 2004 Hurricane Season
1) April 1000 mb U (12.5-30S, 40W-10E) (-):	-0.3 SD	**Enhance**
2) July 200 mb Geopotential Height (32-42N,100-160E) (+):	-0.7 SD	Suppress
3) July 1000 mb U (5-15N,30-50W) (+):	-0.5 SD	Suppress
4) February 1000 mb U (20-30N, 15W-15E) (-):	-0.3 SD	**Enhance**
5) April 200 mb U (67.5-85N, 110-180E) (-):	-1.5 SD	**Enhance**
8) May 200 mb V (0-20S, 15-30E) (+):	-0.6 SD	Suppress
9) January-February 200 mb U (15-25N, 120E-160W) (-):	+1.0 SD	Suppress

Table 9: Independent 2004 September statistical forecast based on data through July 2004.

Statistical Forecast	Adjusted Forecast	September Climatology
NS: 3.5	NS: 5.0	NS: 3.4
H: 1.6	H: 3.0	H: 2.4
IH: 1.0	IH: 1.0	IH: 1.3
NSD: 22.31	NSD: 28.0	NSD: 21.7

HD: 13.00	HD: 15.0	HD: 12.3
IHD: 2.36	IHD: 3.0	IHD: 3.0
NTC: 43.3	NTC: 55	NTC: 48

Data available through the end of July indicates that September 2004 will have about average activity. The most significant predictor, 1000 mb trade winds in the Atlantic (5-15˚N, 30-50˚W), is running slightly below normal. The other six predictors are mixed: three call for above-average activity while three call for below-average activity. We believe that September will have slightly more activity than forecast by our statistical forecast based on the continuation of positive sea surface temperature anomalies in the tropical Atlantic and the continuation of an active thermohaline circulation. An updated September-only statistical forecast will be issued on 3 September. This early September forecast will have the advantage of August data.

4.3 Independent October-only Statistical Forecast

Through examination of the NCEP/NCAR reanalysis, we have discovered four predictors that in combination explain about 50 percent of the October cross-validated variance in Net Tropical Cyclone activity for the hindcast period of 1950-2001. We are currently unable to find combinations of predictors that explain large amounts of variance for the individual tropical cyclone parameters (i.e., named storms, hurricane days, etc.). Therefore, our October forecast consists of predicting NTC and consequently increasing or decreasing October's values for the other parameters accordingly. For example, if October NTC was 150 percent of normal and a typical October had two named storms, we would forecast three named storms for October. The predictors utilized in our initial October prediction are displayed graphically in Figure 4, and their 2004 values are displayed in Table 10. All four predictors are negative for storms. Therefore, we are calling for a below-average October with an NTC of about 50 percent of the climatological average. In round numbers, we are forecasting 2 named storms, 1 hurricane, 0 intense hurricanes and an NTC of 10 for October. This low forecast is primarily a consequence of the moderately positive sea surface temperature anomalies in the Nino 4 and Nino 3.4 regions. Warmth in these regions has been shown to reduce late-season tropical cyclone activity in the Atlantic. Table 11 displays our initial statistical forecast and our adjusted forecast for October tropical cyclone activity. Additional updates for the October-only forecast will be issued in early September and in early October. Physical links between the predictors and October tropical cyclone activity follow:

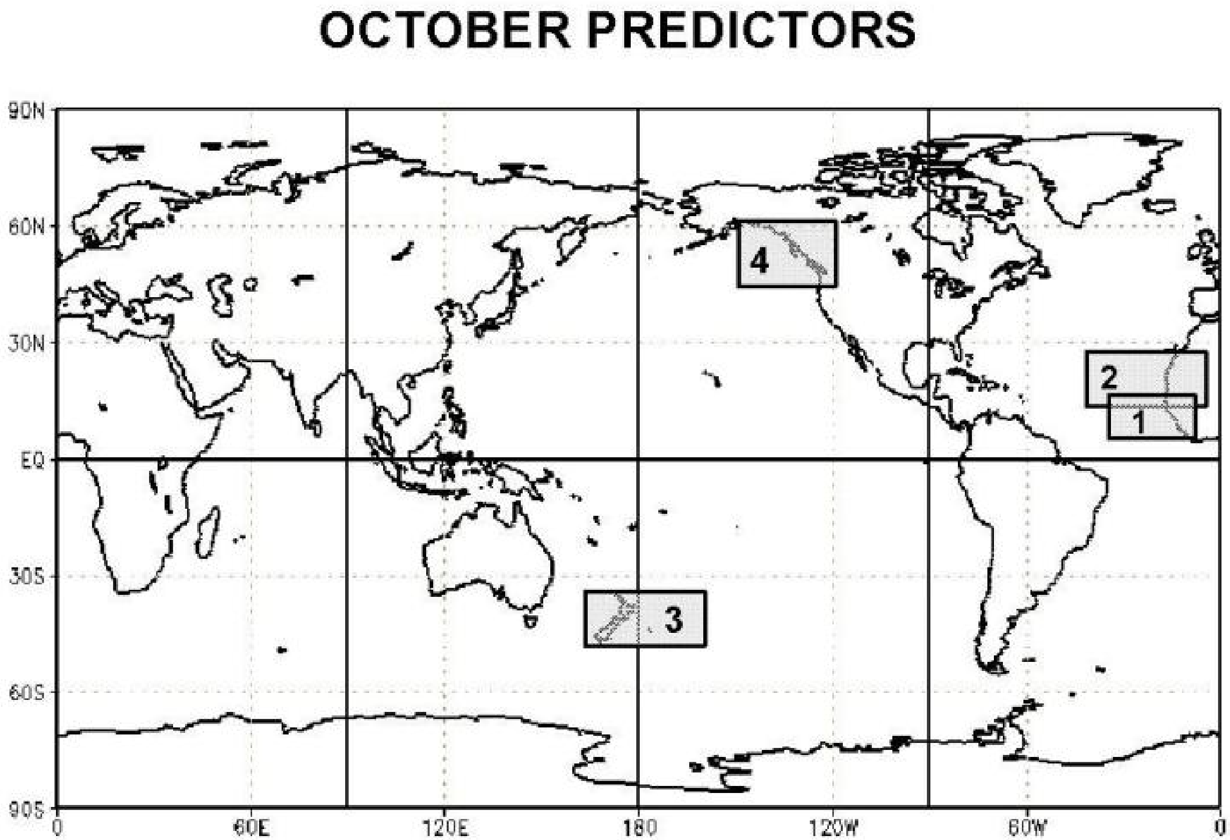

Figure 4: Location of 1 August predictors for October tropical cyclone activity.

Table 10: Predictors selected for the 1 August forecast of October tropical cyclone activity. The sign of the predictor associated with increased tropical cyclone activity is in parentheses.

Predictor	2004 Observed Values	Effect on 2004 Hurricane Season
1) June-July (10-25˚N, 10-40˚W) (-):	+1.0 SD	Suppress
2) July 200 mb Geopotential Height (20-35˚N,5-45˚W) (+):	-0.3 SD	Suppress
3) July 200 mb U (35-47.5˚S,160˚E-160˚W) (+):	-0.5 SD	Suppress
4) Previous November SLP (45-65˚N, 115-145˚W) (-):	+0.4 SD	Suppress

Table 11: Independent 2004 October statistical forecast based on data through July 2004.

Statistical Forecast	Adjusted Forecast	October Climatology
NS: 0.4	NS: 2.0	NS: 1.7
H: 0.3	H: 1.0	H: 1.1
IH: 0.1	IH: 0.0	IH: 0.3
NSD: 2.25	NSD: 5.0	NSD: 9.0

HD: 1.10	HD: 3.0	HD: 4.4
IHD: 0.20	IHD: 0.0	IHD: 0.8
NTC: 5	NTC: 10	NTC: 18

4.4 Physical Association of October Forecast Parameters

1. June-July Sea Level Pressure (10-25˙N, 10-40˙W) (-)

   Low sea level pressure in June-July in this part of the subtropical Atlantic is the most important predictor for October tropical cyclone activity. Low pressure indicates that a weak subtropical ridge is present, trade winds are weaker, and consequently, due to an evaporation decrease, the tropical Atlantic is warmer than normal. On a climatological average, tropospheric vertical wind shear and sea level pressure are directly related. Lower than normal sea level pressure indicates that late-season tropical cyclones are more likely to occur due to a combination of reduced wind shear and a warm tropical Atlantic.

2. July 200 mb Geopotential Height (20-35˙N, 5-45˙W) (+)

   High heights in the northern subtropical Atlantic indicate that there is an increased height gradient between the tropical and subtropical Atlantic which decreases the area and strength of upper-level westerly winds. Stronger easterlies tend to persist throughout the remainder of the hurricane season thereby reducing vertical wind shear and providing more favorable conditions for October tropical cyclone development.

3. July 200 mb U (35-47.5˙S, 160˙E-160˙W) (+)

   Increased upper-level westerlies near New Zealand indicate increased Southern Hemisphere winter baroclinicity which is typically associated with favorable conditions for tropical cyclones in the Atlantic. These conditions tend to persist through October, increasing the likelihood of late-season tropical cyclones.

4. Previous November SLP (45-65˙N, 115-145˙W) (-)

   Low sea level pressure in this area during November of the previous year implies a deeper and eastward-shifted Aleutian Low which is typical of a positive Pacific North American Pattern (PNA). A positive PNA is frequently associated with the final year of warm ENSO conditions (Horel and Wallace 1981) and therefore, a return to cooler conditions in the eastern tropical Pacific during the following year. Cool ENSO conditions provide a favorable environment for the development of October tropical cyclones.

4.5 Monthly Prediction Summary

Tables 12 summarizes our individual monthly predictions and our monthly adjustments to these predictions. Based on jackknifed hindcast data from 1950-2000, the sum of the August, September, and October forecasts explains 79% of the variance in seasonal TC activity. Note that the sum of these three monthly predictions gives lower values of tropical cyclone activity than our full seasonal statistical forecast.

Table 12: August, September and October 2004 individual statistical model predictions and qualitative adjustments. The monthly climatology is given in parentheses.

	August	August	September	September	October	October	3 Month	3 Month
	Model	Adjustment	Model	Adjustment	Model	Adjustment	Sum	Sum of Adjusted

	Prediction	to	Prediction	to	Prediction	to	Statistics	Monthly Fcsts.
NS	3.6(2.76)	4	3.6 (3.4)	5	0.4 (1.7)	2	7.6	11
NSD	14.3 (11.80)	20	24.0 (21.7)	28	2.3 (9.0)	5	40.6	53
H	1.6 (1.55)	3	2.0 (2.4)	3	0.3 (1.1)	1	3.9	7
HD	2.3 (5.67)	8	13.0 (12.3)	15	1.1 (4.4)	3	16.4	26
IH	0.3 (0.57)	1	1.0 (1.3)	1	0.1 (0.3)	0	1.4	2
IHD	-2.0 (1.18)	1	2.5 (3.0)	3	0.2 (0.8)	0	0.7	4
NTC	20.1 (26.1)	35	45.3 (48)	55	5.0 (18)	10	70.4	100

4.6 Seasonal Analogs for 2004

Table 13 lists our best seasonal analogs for 2004. We selected years with warm anomalies in the tropical and north Atlantic Ocean. In addition, the years selected had warm anomalies in the central Pacific and cool anomalies in the east Pacific. Our seasonal analogs continue to point toward an active season.

Table 13: Best analog years for 2004 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	HDP	NTC
1953	14	65	6	18	3	5.50	59	116
1966	11	64	7	42	3	7.00	121	134
2001	15	63	9	27	4	5.00	65	137
2003	16	75	7	33	3	16.75	131	173
Mean	14.0	66.8	7.3	30.0	3.3	8.6	94	140
2004 Forecast	**13**	**55**	**7**	**30**	**3**	**6**	**85**	**125**

5 Forecast Adjustments

Table 14 provides a comparison of all of our forecast techniques along with the final full season adjusted forecast. Given the current (July) global conditions and other information we have, we anticipate somewhat greater activity than indicated by the sum of our individual monthly predictions. Although we give great credence to the sum of our individual monthly predictors and consider this our most skillful forecast, we feel we cannot totally disregard our prior seasonal forecasts of 6 December, 4 April, and 30 May which indicate a more active season. In addition, our full-season analogs also call for an active year. We are thus making only a slight downward adjustment of our earlier seasonal forecasts.

Table 14: Summary of all forecasts for activity after 1 August. Our entire seasonal forecast is given in the far right column.

			Sum of	Sum of	
	Seasonal	Seasonal	3-month	Adjusted	Final
	Statistical	Analog	Statistical	3-month	Seasonal
	Forecast	Forecast	Forecasts	Forecasts	Forecast

NS	11.7	14.0	7.6	11	13
NSD	67.2	66.8	40.6	53	55
H	6.4	7.3	3.9	6	7
HD	31.9	30.0	16.4	26	30
IH	2.5	3.3	1.4	2	3
IHD	5.2	8.6	0.7	4	6
NTC	107	140	70.4	100	125

6 Discussion

This is a difficult forecast. There are currently mixed climate signals which cause our full-season 2004 forecast to indicate above-average activity, while the sum of our three monthly forecasts indicates below-average activity. The Atlantic Ocean signals look very favorable for an active year; whereas, the Pacific Ocean signals indicate a suppressed season.

June and July changes in a number of climate signals and their influence on our individual monthly forecasts have led us to make a downward revision of our 2 April and 28 May forecasts by one storm number for named storms and hurricanes. We have also reduced our forecasts of the number of days that tropical cyclones will exist in the Atlantic, and we have consequently reduced our NTC value 20 points from 145 to 125. Several of the factors currently observed that lead us to believe that there will be enhanced hurricane activity in 2004 are as follows:

- Warm Atlantic SSTAs
- Below average SLPA in the Tropical Atlantic
- West-phase QBO
- Low equatorial 200 mb Geopotential Heights
- Persistence of favorable conditions associated with the active Atlantic Multidecadal Mode and a strong Atlantic thermohaline circulation

Factors currently observed that lead us to believe that Atlantic hurricane activity in 2004 will be reduced are as follows:

- Enhancement of warm ENSO conditions - especially in the Nino 4 and Nino 3.4 regions
- Stronger-than-average trade winds across the equatorial Atlantic - resulting in generally increased wind shear across the main development region
- Strong 200 mb easterly anomalies in the eastern equatorial Pacific - typically associated with warm ENSO conditions and reduced Atlantic seasonal activity

Consequently, based on these mixed climate signals, we are reducing our forecast somewhat from our early April and late May updates; however, we are not reducing the forecasts as much as suggested by the sum of our monthly forecasts.

7 Landfall Probabilities for 2004

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events cannot be accurately forecast months in advance, the total seasonal probability of landfall can be forecast with statistical skill. With the observation that, statistically, landfall is a function of varying climate conditions, a probability specification has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the last 100 years (1900-1999). Specific landfall probabilities can be given for all cyclone intensity classes for a set of distinct U.S. coastal regions.

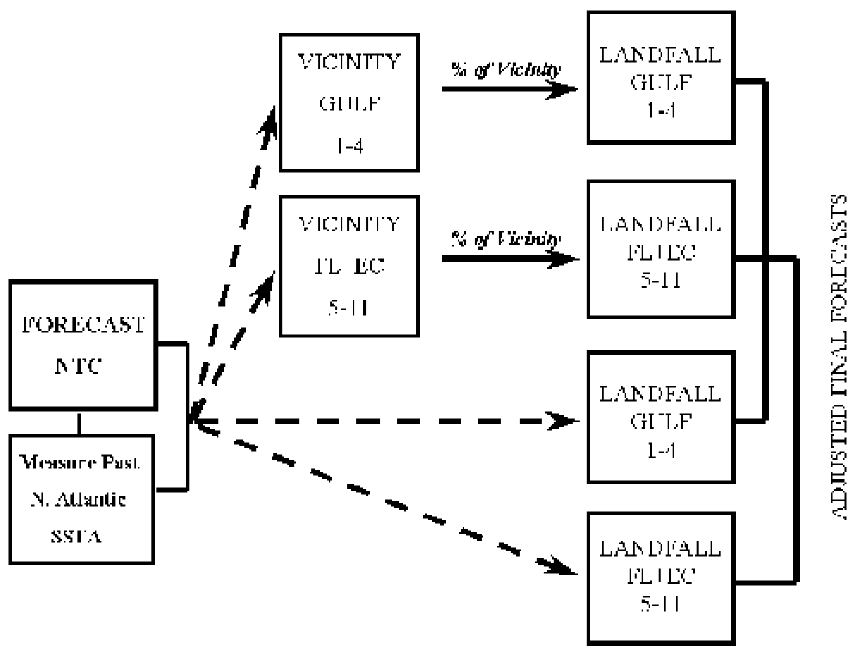

Figure 5: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60˚N, 10-50˚W) SSTA* are used to develop regression equations for U.S. hurricane landfall. Separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

Figure 5 provides a flow diagram showing how these forecasts are made. Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 16) and to climate trends linked to multi-decadal variations of the Atlantic Ocean thermohaline circulation as inferred from recent past years of North Atlantic SSTA* in the region of 50-60˚N, 10-50˚W.

Higher values of SSTA* generally indicate greater Atlantic hurricane activity, especially for intense or major hurricanes. Atlantic basin NTC can be skillfully hindcast, and the strength of the Atlantic Ocean thermohaline circulation can be inferred as SSTA* from North Atlantic SST anomalies in the current and prior years. These relationships are then utilized to make probability estimates for U.S. landfall. The current (July 2004) value of SSTA* is 44. Hence, in combination with a prediction of NTC of 125 for 2004, a combination of NTC + SSTA* of (125 + 44) yields a value of 169.

As shown in Table 15, NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. Whereas many active Atlantic hurricane seasons feature no landfalling hurricanes, some inactive years have experienced one or more landfalling hurricanes. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall. For example, landfall observations during the last 100 years show that a greater number of intense (Saffir-Simpson category 3-4-5) hurricanes strike the Florida and U.S. East Coast during years of (1) increased NTC and (2) above-average North Atlantic SSTA* conditions.

Table 15: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 IH, and 5 IHD, would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

	1950-2000 Average	
1)	Named Storms (NS)	9.6
2)	Named Storm Days (NSD)	49.1
3)	Hurricanes (H)	5.9
4)	Hurricane Days (HD)	24.5
5)	Intense Hurricanes (IH)	2.3
6)	Intense Hurricane Days (IHD)	5.0

Table 16 lists strike probabilities for different TC categories for the entire U.S. coastline, the Gulf Coast and Florida, and the East Coast for 2004. The mean annual probability of one or more landfalling systems is given in parentheses. Note that Atlantic basin NTC activity in 2004 is expected to be greater than the long-term average (125), and North Atlantic SSTA* values are measured to be above average (44 units). U.S. hurricane landfall probability is thus expected to be above average owing to both a higher NTC and above-average North Atlantic SSTAs. During periods of positive North Atlantic SSTA*, a higher percentage of Atlantic basin major hurricanes cross the Florida and eastern U.S. coastline for a given level of NTC.

Table 16: Estimated probability (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1 -2 hurricanes (HUR), 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 coastline (Regions 5-11) for 2004. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Coastal Region	TS	Cat. 1 & 2 HUR	Cat. 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	85% (80)	79% (68)	67% (52)	93% (84)	99% (97)
Gulf Coast (Regions 1-4)	66% (59)	51% (42)	38% (30)	70% (61)	90% (83)
Florida plus East Coast (5-11)	56% (51)	56% (45)	47% (31)	77% (62)	90% (81)

8 United States Landfalling Hurricane Webpage Application

Over the past four years, we have been compiling and synthesizing our landfalling hurricane data and have been developing a webpage application with extensive landfalling probabilities for the Gulf and East Coasts of the United States. In partnership with the GeoGraphics Laboratory at Bridgewater State College, a web application has been created that displays landfall probabilities for eleven regions, 55 subregions and 205 individual counties of the United States coast extending from Brownsville, Texas to Eastport, Maine. Individual probabilities of sustained winds of tropical storm force (40-75 mph), hurricane force (A 75 mph) and intense or major hurricane force (A 115 mph) are also given. These probabilities are based on the current forecast of NTC activity and on current values of SSTA*.

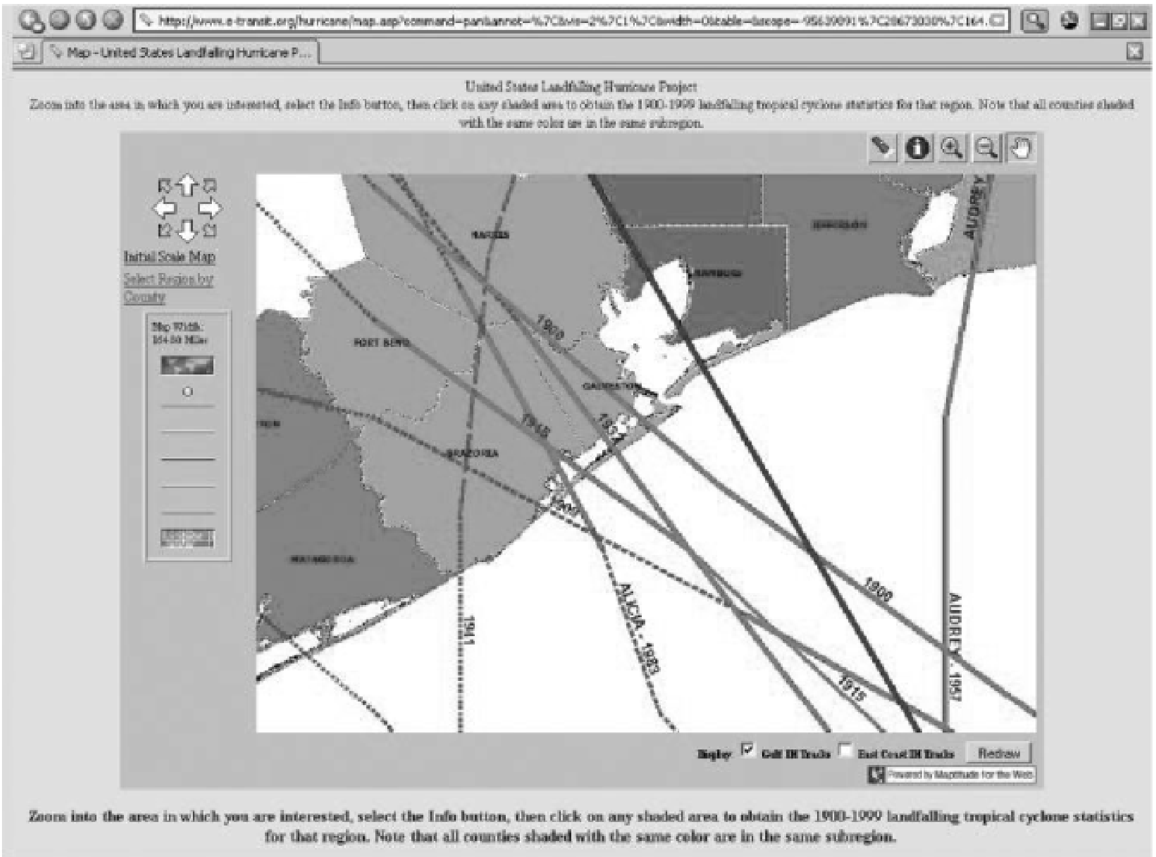

Figure 6: View of landfalling hurricane webpage centered on Subregion 1E - the Houston/Galveston metropolitan area.

County (High) Information	
Name	Miami-Dade FL
Region	6
Region - Coastline Distance	483
Region - 2000 Population	5,213,884
Region - Named Storms (1900-1999)	47
Region - Prob. 1 or More NS	54.4% (37.5%)
Region - Prob. 2 or More NS	11.8% (8.1%)
Region - Hurricanes (1900-1999)	34
Region - Prob. 1 or More H	41.8% (28.8%)
Region - Prob. 2 or More H	6.7% (4.6%)
Region - Intense Hurricanes (1900-1999)	16
Region - Prob. 1 or More IH	21.4% (14.8%)
Region - Prob. 2 or More IH	1.7% (1.2%)
Region - Prob. TS Force	44.3% (30.5%)
Region - 50 Year TS Prob.	100.0%
Region - NS Vicinity Prob.	98.1% (93.6%)
Region - Prob. H Force	13.5% (9.3%)
Region - 50 Year H Prob.	99.3%
Region - H Vicinity Prob.	70.4% (56.9%)
Region - Prob. IH Force	4.3% (3.0%)
Region - 50 Year IH Prob.	78.1%
Region - IH Vicinity Prob.	32.3% (23.6%)

Subregion:1	6b
Subregion - Coastline Distance (km)	89
Subregion - 2000 Population	2,253,362
Subregion - Prob. TS Force	8.2% (5.6%)
Subregion - Prob. TS Vicinity	52.0% (39.7%)
Subregion - 50 Year TS Prob.	94.5%
Subregion - Prob. H Force	2.5% (1.7%)
Subregion - Prob. H Vicinity	20.1% (14.3%)
Subregion - 50 Year H Prob.	58.0%
Subregion - Prob. IH Force	0.8% (0.6%)
Subregion - Prob. IH Vicinity	6.9% (4.8%)
Subregion - 50 Year IH Prob.	24.1%
County - Coastline Distance (km)	89
County - Inland Border Width (km)	--
County - 2000 Population	2,253,362
County - Prob. TS Force	8.2% (5.6%)
County - Prob. TS Vicinity	52.0% (39.7%)
County - 50 Year TS Prob.	94.5%
County - Prob. H Force	2.5% (1.7%)
County - Prob. H Vicinity	20.1% (14.3%)
County - 50 Year H Prob.	58.0%
County - Prob. IH Force	0.8% (0.6%)
County - Prob. IH Vicinity	6.9% (4.8%)
County - 50 Year IH Prob.	24.1%

Figure 7: Example of data available from the United States landfalling hurricane webpage.

Figures 6 and 7 display example screens of data that is available on this website. The user can select tracks of all intense hurricanes that have made landfall in a given area over the last 100 years. This webpage is currently available at http://www.e-transit.org/hurricane. One can also reach this webpage from a link off the CSU Tropical Meteorology Project homepage: http://tropical.atmos.colostate.edu.

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

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. There have been large changes in SSTA and 200 mb zonal wind anomaly (ZWA) during 1995-2003 as compared to conditions 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 (THC). 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.

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 17 provides a summary of the total number of named storms (103), named storm days (567), hurricanes (62), hurricane days (288), major hurricanes (29), major hurricane days (75.25) and Net Tropical Cyclone activity (1230) 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.

Table 17: 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	16	71	7	32	3	17.00	168
TOTAL	103	567	62	288	29	75.25	1230
Seven-year Ave. 1995-96,98-01, 03	14.5	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

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

Various groups and individuals have suggested that the recent 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. Please see our 21 November 2003 verification report for more discussion on this subject: http://tropical.atmos.colostate.edu/Forecasts/2003/nov2003

11 Forecast Theory and Cautionary Note

Our forecasts are based on the premise that those global oceanic and atmospheric conditions which precede comparatively active or inactive hurricane seasons in the past provide meaningful information about similar trends in future seasons. It is important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. The probability of landfall for any one location along the coast is very low and reflects the fact that, in any one season, most US coastal areas will not feel the effects of a hurricane no matter how active the individual season is. However, it must also be emphasized that a low landfall probability does not insure that hurricanes will not come ashore. Regardless of how active the 2004 hurricane season is, a finite probability always exists that one or more hurricanes may strike along the US coastline or the Caribbean Basin and do much damage.

12 Forthcoming Update Forecasts of 2004 Hurricane Activity

We will be issuing seasonal updates of our 2004 Atlantic basin hurricane activity forecast on Friday 3 September and Friday 1 October 2004. These updates will include separate forecasts for 2004 September-only activity and October-only Atlantic basin TC activity. A verification and discussion of all 2004 hurricane activity and forecasts will be issued in late November 2004. All of these forecasts will be available at our web address given on the front cover: http://tropical.atmos.colostate.edu/forecasts/index.html.

13 Acknowledgments

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14 Citations and Additional Reading

15 Verification of Previous Forecasts

Table 18: Summary verifications of the authors' five previous years of seasonal forecasts of Atlantic TC activity between 1999-2003.

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	17
No. of Hurricane Days	35	35	35	25	25	35	33
No. of Named Storm Days	65	65	70	60	55	70	75

Hurr. Destruction Potential(HDP)	100	100	100	80	80	125	131
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	173

Footnotes:

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