EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND US LANDFALL STRIKE PROBABILITY FOR 2005

We foresee a well above-average hurricane season for the Atlantic basin in 2005. Also, an above-average probability of U.S. major hurricane landfall is anticipated. We have adjusted our forecast upward from our early April forecast as it now appears unlikely that El Niño conditions will develop this summer.

(as of 31 May 2005)

This forecast is based on new research by the authors,
along with current meteorological information through late May 2005

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://hurricane.atmos.colostate.edu/Forecasts/] — also,

Brad Bohlander, Colorado State University Media Representative, (970-491-6432) is available to answer various questions about this forecast.

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2005

Forecast Parameter and 1950–2000 Climatology (in parentheses)	Issue Date 3 December 2004	Issue Date 1 April 2005	Issue Date 31 May 2005
Named Storms (NS) (9.6)	11	13	15
Named Storm Days (NSD) (49.1)	55	65	75
Hurricanes (H)(5.9)	6	7	8
Hurricane Days (HD)(24.5)	25	35	45
Intense Hurricanes (IH) (2.3)	3	3	4
Intense Hurricane Days (IHD)(5.0)	6	7	11
Net Tropical Cyclone Activity (NTC)(100%)	115	135	170

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

1) Entire U.S. coastline – 77% (average for last century is 52%)

2) U.S. East Coast Including the Florida Peninsula – 59% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville – 44% (average for last century is 30%)

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

Acknowledgment

We are grateful to NSF and AIG - Lexington Insurance Company (a member of the American International Group) for providing partial support for the research necessary to make these forecasts. We also thank the GeoGraphics Laboratory at Bridgewater State College (MA) for their assistance in developing the Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

The first author gratefully acknowledges valuable input to his CSU project research over many years by former graduate students and now colleagues Chris Landsea, John Knaff and Eric Blake. We thank Professors Paul Mielke and Ken Berry for much statistical analysis and advice over many years.

DEFINITIONS

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

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

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

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

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

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

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

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

Madden Julian Oscillation - (MJO) A broad area of equatorial convection that propagates eastward from the Indian Ocean. It is frequently associated with the development of El Niño events.

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 five is the most intense hurricane.

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

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

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

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

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

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

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

U - West to east zonal wind component.

V - South to north meridional wind component.

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

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

ABSTRACT

Information obtained through late May 2005 indicates that the 2005 Atlantic hurricane season will be a very active one. We estimate that 2005 will have about 15 named storms (average is 9.6), 8 hurricanes (average is 5.9), 75 named storm days (average is 49.1), 45 hurricane days (average is 24.5), 4 intense (category 3-4-5) hurricanes (average is 2.3) and 11 intense hurricane days (average is 5.0). We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2005 to be about 170 percent of the long-term average. The probability of U.S. major hurricane landfall is estimated to be 150 percent of the long-period average. We expect this year to continue the past-decade trend of above-average hurricane seasons.

This late May forecast is based on a newly devised extended range statistical forecast procedure which utilizes 55 years of past global reanalysis data. Analog predictors are also utilized. We have increased our forecast from our early April prediction due to continued Atlantic Ocean warming and a decreased likelihood of the development of an El Niño this summer/fall. Conditions in the Atlantic are very favorable for an active hurricane season.

1 Introduction

This is the 22nd 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 55 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 associated with the forthcoming seasonal Atlantic tropical cyclone activity and landfall probability. We believe that seasonal forecasts must be based on methods showing significant hindcast skill in application to long periods of prior data. It is only through hindcast skill 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. We have no reason for thinking that it will not.

2 Earlier 1 June Statistical Hurricane Forecast Scheme

Our original early June seasonal hurricane forecast scheme was developed in the early 1990s 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.

Since the observed shift of Atlantic Ocean SST patterns in 1995 [and the implied increase in the strength of the Atlantic Thermohaline Circulation (THC)], our original 1 June forecast scheme (1994) has consistently underpredicted Atlantic basin hurricane activity. Our earlier 1 June statistical scheme used West African rainfall data as an important predictor. We do not understand why, but the previously observed (1950-1994) strong association between West Africa rainfall and Atlantic hurricanes has not been reliable since 1994. We have lost confidence in the previous 1 June statistical forecast scheme compared to our newly developed one. We have thus decided to discontinue our earliest 1 June forecast scheme.

Over the past couple of years, we have been using an updated statistical scheme that utilized NOAA/NCEP reanalysis data. However, this scheme used mostly data from the previous fall and winter, and therefore we have recently developed a new early June scheme that makes use of mostly spring data.

2.1 Newly Developed 1 June Forecast Scheme

Our newly-developed early June forecast scheme also utilizes NOAA/NCEP reanalysis data and was developed on data from 1949-1989. It was then tested on independent data from 1990-2004 to insure that the forecast shows similar skill in this later forecast period.

The pool of four 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 1949-2004.

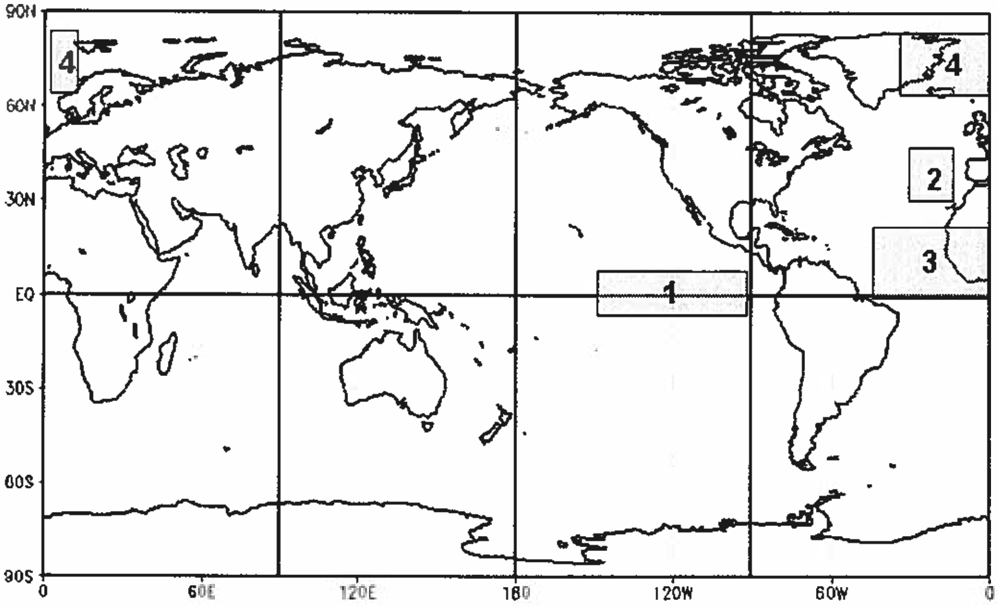


Figure 1: Location of predictors for our new 1 June forecast for the 2005 hurricane season.

Table 2 shows our statistical forecast for the 2005 hurricane season and the comparison of this forecast with climatology (average season between 1950-2000). Our statistical forecast is calling for about average activity this year.

2.2 Physical Associations of Predictors With Hurricane Activity

Brief descriptions of our new late May predictors follow:

Predictor 1. May SST in the Eastern Equatorial Pacific (-)

Table 1: List of our new 1 June 2005 predictors and their anomalous 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.

	2005 Observed Values
(1) – May SST (5°S-5°N, 90-150°W (–)	+0.8 SD
(2) – April-May SST (30-45°N, 10-30°W) (+)	+0.7 SD
(3) – March-April SLPA (0-20°N, 0-40°W) (–)	+0.7 SD
(4) – Previous November 500 mb Height Anomaly (67.5-85°N, 10°E-50°W) (+)	– 0.2 SD

Table 2: New late May statistical forecast for 2005.

Predictands and Climatology	Statistical Forecast Numbers
Named Storms (NS) – 9.6	9.8
Named Storm Days (NSD) – 49.1	49.3
Hurricanes (H) – 5.9	5.7
Hurricane Days (HD) – 24.5	22.7
Intense Hurricanes (IH) – 2.3	2.3
Intense Hurricane Days (IHD) – 5.0	6.0
Net Tropical Cyclone Activity (NTC) – 100	101

(5°S-5°N, 90-150°W)

Sea surface temperatures in this area are taken to be a measure of ENSO conditions. When sea surface temperatures are much cooler than normal, La Niña conditions are present, and when sea surface temperatures are much warmer than normal, El Niño conditions are occurring. Although there is some change over during the summer and fall, in general, anomalies in this area tend to persist from the late spring through the summer and fall. El Niño conditions during the summer and fall tend to decrease Atlantic hurricane activity by increasing westerlies at upper levels across the Atlantic (Gray 1984a, Goldenberg and Shapiro 1996). These increased westerlies increase vertical wind shear across the area where Atlantic tropical cyclones develop.

Predictor 2. April-May SST off the Northwestern European Coast (+)

(30-45°N, 10-30°W)

Warm sea surface temperatures in this area indicate that the Atlantic subtropical ridge is weaker than normal, and therefore trade winds across the Atlantic are also weaker than normal. These anomalies in April-May correlate strongly with a generally warm Atlantic Ocean as well as with low sea level pressure throughout the tropical Atlantic during the heart of the hurricane season from August-October. Weaker trade winds and easterly anomalies at upper levels during the summer throughout the tropical Atlantic are also associated with this feature.

Predictor 3. March-April SLP in the Tropical Atlantic (-)

(0-20°N, 0-40°W)

Low sea level pressure in the tropical Atlantic during March-April implies increased instability, reduced trade wind strength and warm sea surface temperatures during the spring.

In general, these favorable conditions for tropical cyclone activity tend to persist through the summer and fall, as evidenced by strong lag correlations ($r > 0.4$) between this feature and warm sea surface temperatures in the tropical Atlantic during the late summer/early fall. Also, reduced vertical wind shear and continued low sea level pressure during the late summer/early fall are associated with low values of this feature in March-April.

Predictor 4. November 500 mb Geopotential Height in the far North Atlantic (+)

(67.5-85°N, 10°E-50°W)

Positive values of this predictor correlate very strongly ($r = -0.7$) with negative values of the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO). Negative AO and NAO values imply more blocking in the central Atlantic and a likely warm north Atlantic Ocean (50-60°N, 10-50°W). Also, on decadal timescales, weaker zonal winds in the subpolar areas are indicative of a relatively strong thermohaline circulation which is favorable for hurricane activity. Positive values of this November index are negatively correlated with both 200 mb zonal winds and trade winds the following September in the tropical Atlantic. The associated reduced tropospheric vertical wind shear enhances conditions for TC development. Other features that are directly correlated with this predictor are low sea-level pressure in the Caribbean and a warm North and tropical Atlantic. Both of the latter are also hurricane-enhancing factors.

2.3 Hindcast Skill of New 1 June Scheme

Table 3 shows the degree of hindcast variance (r^2) explained by our new 1 June forecast scheme based on our 41-year developmental dataset (1949-1989), our skill on the independent dataset (1990-2004), and our skill over the entire dataset (1949-2004). Note that the scheme generally shows comparable or improved skill in the independent dataset, which lends us increased confidence in its use.

Table 3: Variance (r^2) explained for our new 1 June forecast scheme in the developmental dataset (1949-1989), in the independent dataset (1990-2004), and over the entire dataset (1949-2004).

Variable	Variance (r^2) Explained Developmental Dataset (1949-1989)	Variance (r^2) Explained Independent Dataset (1990-2004)	Variance (r^2) Explained Entire Dataset (1949-2004)
NS	0.27	0.49	0.29
NSD	0.40	0.65	0.37
H	0.31	0.67	0.36
HD	0.51	0.63	0.49
IH	0.45	0.67	0.49
IHD	0.54	0.38	0.48
NTC	0.54	0.70	0.52

3 Analog-Based Predictors for 2005 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2005. These years also provide useful clues as to likely trends in activity that the forthcoming 2005 hurricane season may bring. For this 31 May forecast, we project atmospheric and oceanic conditions for August through October 2005 and determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current late May 2005 conditions. Table 4 lists our analog selections.

Analog Years. We have found five prior hurricane seasons (since 1949) which appear to be similar to current late May 2005 conditions and projected August-October 2005 conditions. Specifically, we expect the North Atlantic (50-60°N, 10-50°W) warm SST anomalies to remain warm for the 2005 hurricane season. An unusually warm north Atlantic is indicative of a strong Atlantic thermohaline circulation. The tropical equatorial Quasi-Biennial Oscillation (QBO) is projected to be from an easterly direction. Easterly QBO conditions typically act to slightly reduce Atlantic major hurricane activity. We anticipate that the recent global atmosphere and ocean circulation regimes which have been present in all but two of the last ten years (the El Niño years of 1997 and 2002) will continue to be present in 2005. In addition, we looked for years that had weak El Niño conditions the previous fall and winter with neutral ENSO conditions in the eastern and central Pacific observed during the summer of the year being selected.

There have been five hurricane seasons since 1949 with characteristics similar to what we observe in late May 2005 and what we anticipate for the summer/fall 2005 period. These best analog years are 1958, 1966, 1995, 2003 and 2004 (Table 4). Thus, based on this analysis, we expect 2005 to be an active hurricane season and in line with the average of eight of the last ten years (1995, 1996; 1998-2001; 2003, 2004).

Table 4: Best analog years for 2005 with the associated hurricane activity listed for each year.

	NS	NSD	H	HD	IH	IHD	NTC
1958	10	56	7	30	4	8.25	133
1966	11	64	7	42	3	7.00	134
1995	19	121	11	62	5	11.50	222
2003	16	75	7	33	3	16.75	173
2004	14	90	9	46	6	22.00	229
Mean	14.0	81.2	8.2	42.6	4.2	13.1	176
2005 Forecast	15	75	8	45	4	11	170

4 Comparison of Forecast Techniques

Table 5 provides a comparison of our statistical and analog forecast techniques along with the final adjusted forecast and climatology. Column 1 is our 1 June statistical scheme, column 2 is our analog scheme, column 3 is our adjusted final forecast, and column 4 is the 1950-2000 climatology. We have chosen to give more weight to our analog prediction and foresee a very active 2005 season.

5 Discussion

We watched closely as a series of eastward-propagating Kelvin waves, triggered by strong MJO events, transported anomalously warm water eastward to the west coast of South America. These Kelvin waves caused considerable warming in the eastern and central Pacific during the latter part of April and the early part of May; however, the trade winds in the east Pacific have been fairly strong over the past few weeks, and there does not appear to be much forcing for additional warming in the coming weeks. Sea surface temperatures have

Table 5: Comparison of our 2005 statistical and analog forecast techniques along with our final adjusted forecast and the 1950-2000 climatology.

Forecast Parameter	(1) Statistical Forecast	(2) Analog Forecast	(3) 31 May 2005 Final Fcst	(4) 1950-2000 Climatology
Named Storms (NS)	9.8	14.0	15	9.6
Named Storm Days (NSD)	49.3	81.2	75	49.1
Hurricanes (H)	5.7	8.2	8	5.9
Hurricane Days (HD)	22.7	42.6	45	24.5
Intense Hurricanes (IH)	2.3	4.2	4	2.3
Intense Hurricane Days (IHD)	6.0	13.1	11	5.0
Net Tropical Cyclone Activity (NTC)	101	176	170	100

cooled in all Nino regions over the past two weeks, and we expect neutral ENSO conditions to persist throughout this upcoming summer and fall.

This will be an easterly Quasi-Biennial Oscillation (QBO) year. Low-latitude Atlantic hurricane activity is typically reduced in these seasons. But, this association has not worked well since we have entered this new era of enhanced activity that began in 1995. We do not anticipate the QBO exerting a large reducing influence on this year's activity.

The reader will note that we have raised our forecast considerably from what the statistics would indicate. This is due to the fact that we are in a new active era for Atlantic major hurricane activity, and Atlantic SST conditions are close to being the highest on record. We believe these unusually warm Atlantic SST conditions are high enough this year that they will trump most of our usual seasonal statistical predictors shown in Table 1.

We believe that the current active period is quite similar to the 1930s, where we had many active hurricane seasons, even though other features typically associated with active seasons in the 1950s and 1960s were not present. The 1930s were also a period of strong global warming similar to the global warming of the last decade. From the limited data available during the 1930s and 1940s, we deduce that the Atlantic was quite warm, similar to conditions that we are presently experiencing. However, other features, such as strong easterly anomalies at upper levels in the tropical Atlantic which were present in the 1950s and 1960s, do not appear to have been present in the earlier period of the 1930s. We have seen a slight increase in tropical Atlantic easterly anomalies since 1995 but have yet to see the easterlies that were present in the earlier decades of the 1950s and 1960s. In addition, the westerlies in the Southern Hemisphere have not yet weakened, even though, a weaker midlatitude circulation in the Southern Hemisphere is typically associated with active Atlantic hurricane seasons. We have therefore raised our forecast to be in more line with our analog years.

6 Landfall Probabilities for 2005

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 century (1900–1999). Specific landfall probabilities can be given for all cyclone intensity classes for a set of distinct U.S. coastal regions.

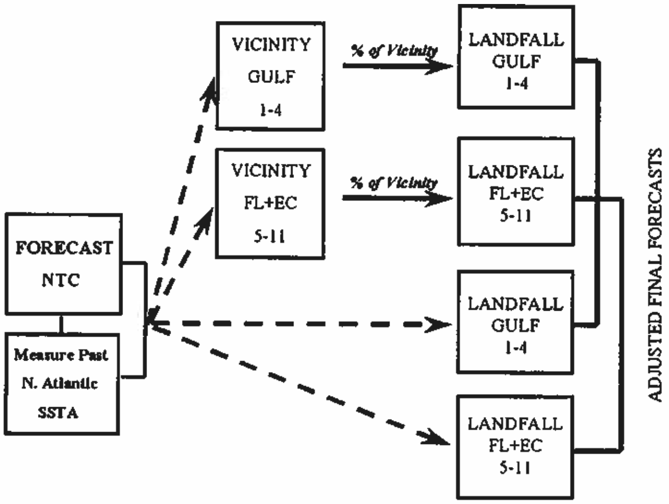


Figure 2: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60°N, 10-50°W) SSTA* are used to develop regression equations for U.S. hurricane landfall. Separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

Figure 2 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 6) 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*.

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 (May 2005) value of SSTA* is 62. Hence, in combination with a prediction of NTC of 170 for 2005, a combination of NTC + SSTA* of (170 + 62) yields a value of 232.

As shown in Table 6, 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. Although many active Atlantic hurricane seasons feature no landfalling hurricanes, and some inactive years experience one or more landfalling hurricanes, it is found 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 Florida and the U.S. East Coast during years of (1) increased NTC and (2) above-average North Atlantic SSTA* conditions.

Table 7 lists strike probabilities for different TC categories for the entire U.S. coastline, the Gulf Coast, and Florida and the East Coast for 2005. The mean annual probability of one or more landfalling systems is given in parentheses. Note that Atlantic basin NTC activity in 2005 is expected to be greater than the long-term average (170), and North Atlantic SSTA* values are measured to be above average (62 units). U.S. hurricane landfall probability is thus expected to be well 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

Table 6: 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

Atlantic basin major hurricanes cross the Florida and eastern U.S. coastline for a given level of NTC.

Table 7: 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 2005. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Coastal Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	89% (80)	85% (68)	77% (52)	97% (84)	99% (97)
Gulf Coast (Regions 1-4)	72% (59)	58% (42)	44% (30)	77% (61)	94% (83)
Florida plus East Coast (5-11)	61% (51)	65% (45)	59% (31)	86% (62)	95% (81)

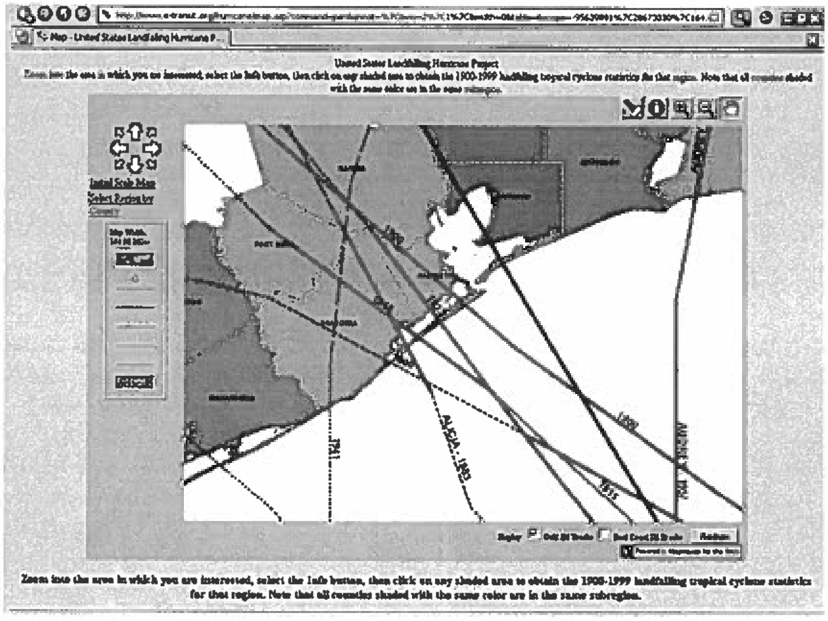
7 United States Landfalling Hurricane Webpage Application

Over the past four years, we have been compiling and synthesizing our landfalling hurricane data and have developed a webpage application with extensive landfall 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 all 205 U.S. coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine. Individual probabilities of sustained winds of tropical storm force (40-75 mph), hurricane force ($\geq$ 75 mph) and intense or major hurricane force ($\geq$ 115 mph) are also given. These probabilities are based on the current forecast of NTC activity and on current values of SSTA*. Probabilities of winds in the vicinity of a subregion and county as well as 50-year probabilities for winds of tropical storm force, hurricane force, and intense hurricane force are also provided. Table 8 summarizes the data currently available on the webpage.

Figures 3 and 4 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://hurricane.atmos.colostate.edu.

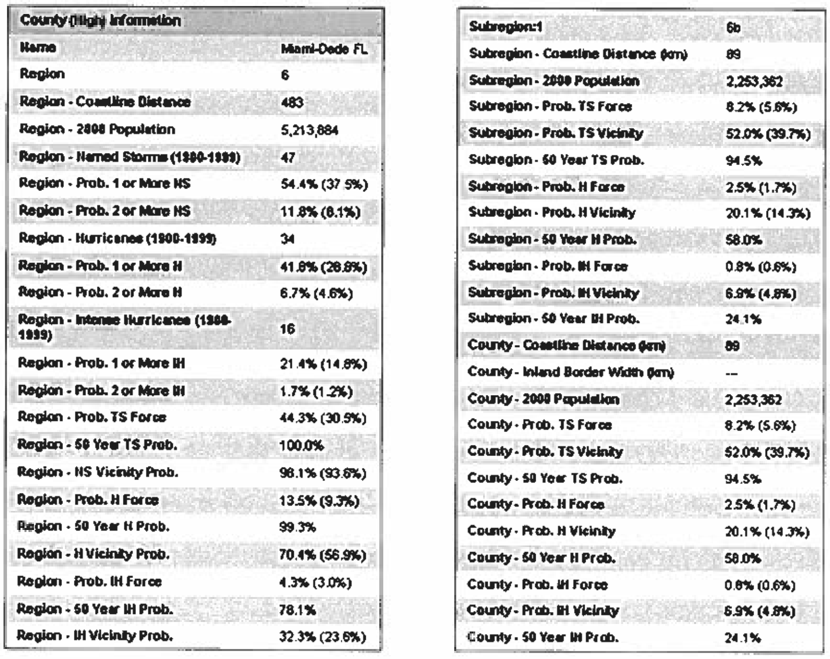
Table 8: Data currently available on our CSU landfalling hurricane probability webpage.

	Annual Landfall Probability	Annual Vicinity Probability	50-Year Probability
NS	X	X	X
H	X	X	X
IH	X	X	X



Zoom into the area in which you are interested, select the Info button, then click on any shaded area to obtain the 1900-1999 landfalling tropical cyclone statistics for that region. Note that all counties shaded with the same color are in the same subregion.

Figure 3: 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 4: Example of data available from the United States landfalling hurricane webpage.

8 The 1995-2004 Upswing in Atlantic Hurricanes and Global Warming

Many individuals have queried whether the unprecedented landfall of four destructive hurricanes in a seven-week period during August-September 2004 is related in any way to human-induced climate changes. There is no evidence that this is the case. If global warming were the cause of the increase in United States hurricane landfalls in 2004 and the overall increase in Atlantic basin major hurricane activity of the past ten years (1995-2004), one would expect to see an increase in tropical cyclone activity in the other storm basins as well (ie., West Pacific, East Pacific, Indian Ocean, etc.). This has not occurred. When tropical cyclones worldwide are summed, there has actually been a slight decrease since 1995. In addition, it has been well-documented that the measured global warming during the 25-year period of 1970-1994 was accompanied by a downturn in Atlantic basin hurricane activity over what was experienced during the 1930s through the 1960s.

We attribute the heightened Atlantic major hurricane activity of the 2004 season as well as the increased Atlantic major hurricane activity of the previous nine years to be a consequence of the multidecadal fluctuations in the Atlantic Ocean thermohaline circulation (THC) as we have been discussing in our Atlantic basin seasonal hurricane forecasts for several years. Major hurricane activity in the Atlantic has been shown to undergo marked multidecadal fluctuations that are directly related to North Atlantic sea surface temperature anomalies. When the Atlantic Ocean thermohaline circulation is running strong, the central Atlantic equatorial trough (ITCZ) becomes stronger. The stronger the Atlantic equatorial trough becomes, the more favorable are conditions for the development of major hurricanes in the central Atlantic. Since 1995, the THC has been flowing more strongly, and there has been a concomitant increase in major hurricanes in the tropical Atlantic. Even though the 2004 hurricane season was quite active, it was only somewhat more active than seven of the past nine hurricane seasons (1995-1996, 1998-2001, 2003). It was the environmental steering currents that drove four of the six major hurricanes of 2004 on such long, low-latitude westerly tracks that made the 2004 Atlantic basin hurricane season so special. The very damaging 2004 hurricane season was simply a low probability event resulting from unusual natural variability in the ocean-atmosphere system.

Similarly, the ten typhoons that struck Japan in 2004 were also a rare statistical event that was in part a consequence of the anomalously warm tropical central Pacific sea surface temperatures and a weaker-than-normal West Pacific subtropical anticyclone. This caused a high percentage of West Pacific typhoons that formed in the central Pacific to be steered toward the Japanese Islands. Such high U.S. and Japan landfalls events of last year should in no way be associated with the human-induced global warming hypothesis.

9 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 2005 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.

10 Forthcoming Update Forecasts of 2005 Hurricane Activity

We will be issuing seasonal updates of our 2005 Atlantic basin hurricane activity forecast on Friday 5 August, Friday 2 September and Monday 3 October 2005. These 5 August, 2 September and 3 October forecasts will include separate forecasts of August-only, September-only and October-only Atlantic basin tropical cyclone activity. Table 9 displays our upcoming forecasts in a tabular format. A verification and discussion of all 2005 forecasts will be issued in late November 2005. Our first seasonal hurricane forecast for the 2006 hurricane season will be issued in early December 2005. All these forecasts will be available at our web address given on the front cover
(http://hurricane.atmos.colostate.edu/Forecasts).

Table 9: Upcoming 2005 Atlantic Basin tropical cyclone forecasts and seasonal updates.

Date	5 Aug.	3 Sep.	2 Oct.
Seasonal Forecast	X	X	X
Monthly Forecast	X	X	X

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12 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.

Blake, E. S. and W. M. Gray, 2004: Prediction of August Atlantic basin hurricane activity. *Wea. Forecasting*, 19, 1044-1060.

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

Elsner, J. B., G. S. Lehmiller, 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 Nino 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., and P. J. Klotzbach, 2003 and 2004: Forecasts of Atlantic seasonal and monthly hurricane activity and US landfall strike probability. Available online at http://hurricane.atmos.colostate.edu.

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.

Klotzbach, P. J. and W. M. Gray, 2003: Forecasting September Atlantic basin tropical cyclone activity. *Wea. and Forecasting*, 18, 1109-1128.

Klotzbach, P. J. and W. M. Gray, 2004: Updated 6-11 month prediction of Atlantic basin seasonal hurricane activity. *Wea. and Forecasting*, 19, 917-934.

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., 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. *Weather and Forecasting*, 12, 847-858.

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.

Seseske, S. A., 2004: Forecasting summer/fall El Niño-Southern Oscillation events at 6-11 month lead times. Dept. of Atmos. Sci. Paper No. 749, Colo. State Univ., Ft. Collins, CO, 104 pp.

13 Verification of Previous Forecasts

Table 9: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 1999-2004. Verification of our earlier year forecasts for the years 1984-1998 are given in our late November seasonal verifications (on this Web location).

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

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

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

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

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

2004	5 Dec 2003	Update 2 April	Update 28 May	Update 6 August	Update 3 Sept	Update 1 Oct	Obs.
No. of Hurricanes	7	8	8	7	8	9	9
No. of Named Storms	13	14	14	13	16	15	14
No. of Hurricane Days	30	35	35	30	40	52	46
No. of Named Storm Days	55	60	60	55	70	96	90
Major Hurricanes (Cat. 3-4-5)	3	3	3	3	5	6	6
Major Hurr. Days	6	8	8	6	15	23	22
Net Trop. Cyclone (NTC) Activity	125	145	145	125	185	240	229