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

The recent upturn in Atlantic basin major hurricane activity which began in 1995 is expected to continue in 2004. We anticipate an above average probability for Atlantic basin major hurricanes and U.S. major hurricane landfall.

(as of 5 December 2003)

This forecast is based on new research by the authors,
along with current meteorological information through November 2003

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

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

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2004

Forecast Parameter and 1950–2000 Climatology (in parentheses)	5 December 2003 Forecast for 2004
Named Storms (NS) (9.6)	13
Named Storm Days (NSD) (49.1)	55
Hurricanes (H)(5.9)	7
Hurricane Days (HD)(24.5)	30
Intense Hurricanes (IH) (2.3)	3
Intense Hurricane Days (IHD)(5.0)	6
Hurricane Destruction Potential (HDP) (72.7)	85
Net Tropical Cyclone Activity (NTC)(100%)	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 Peninsula Florida – 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) Above-average major hurricane landfall risk in the Caribbean

DISTINCTION BETWEEN CSU SEASONAL HURRICANE FORECASTS AND THOSE ISSUED BY NOAA

Seasonal hurricane forecasts have now 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). The forecasts, which are issued in December of the prior year, and in April, June, and August of the current year, have steadily improved through continuing research. These forecasts now include predictions of Atlantic basin hurricane activity and 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.

Acknowledgement

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

DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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 November 2003 indicates that the 2004 Atlantic hurricane season will be an active one. 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). The probability of U.S. major hurricane landfall is estimated to be 30 percent above the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2004 to be about 125 percent of the long-term average. This forecast is based on our recently developed 6-11 month extended range statistical forecast procedure which utilizes 52 years of past data. Both statistical and analog predictors have been utilized. These include five selective measures of September-November North Atlantic and Pacific surface pressure and 500 mb height fields and a measure of the stratospheric QBO. The influence of El Niño conditions are implicit in these six predictor fields, and therefore we do not utilize a specific ENSO forecast as a predictor. Our predictors indicate that we will likely have weak warm ENSO conditions by next summer.

1 Introduction

This is the 21st year in which the first author has made forecasts of the upcoming 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. The forecasts are based on a statistical methodology derived from 52 years of past data and a separate study of analog years which have similar 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 December Forecast Methodology

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. Our initial 6-11 month early December seasonal hurricane forecast scheme (Gray et al. 1992) demonstrated hindcast skill for the period of 1950–1990. Our new, recently developed forecast scheme uses more hindcast years (1950–2001) and shows improved hindcast skill and better physical insights into why such precursor relationships have an extended period memory.

Through extensive analyses of NOAA-NCEP reanalysis products, Phil Klotzbach of our forecast team has developed a new set of 6-11 month extended range predictors which shows superior hindcast prediction skill over our previous 1 December forecast scheme. The location of each of these new predictors is shown in Fig. 1. The pool of six predictors for this new extended range forecast is given in Table 1. Strong statistical relationships can be extracted via combinations of these predictors (which are available by 1 December) and the Atlantic basin hurricane activity occurring the following year.

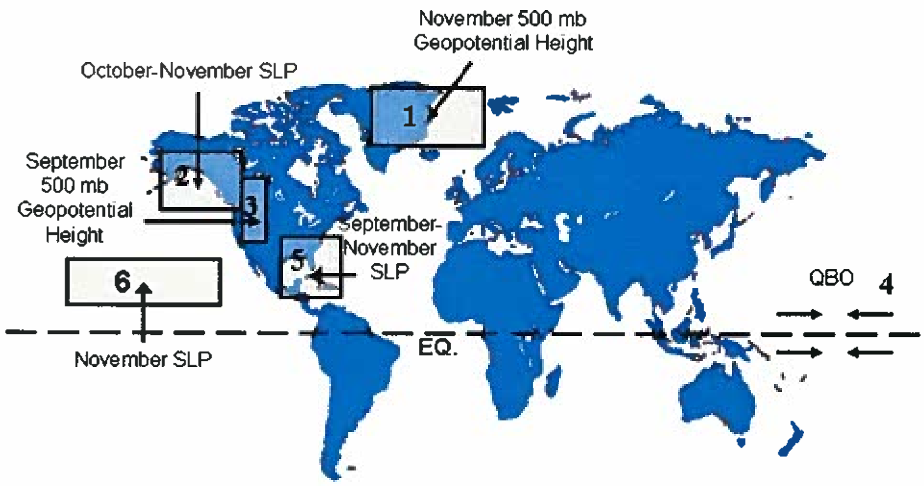

Figure 1: Location of the new predictors for our early December extended range prediction for the 2004 hurricane season.

Table 1: Listing of 1 December 2003 predictors for next year's hurricane activity. A plus (+) means that positive values of the parameter indicate increased hurricane activity the following year, and a minus (–) means that positive values of the parameter indicate decreased hurricane activity the following year.

	2003 Values for 2004 Forecast
(1) – November 500 mb geopotential height (67.5–85°N, 10E-50°W) (+)	+0.8SD
(2) – October-November SLP (45-65°N, 120-160°W) (–)	+0.9SD
(3) – September 500 mb geopotential height (35-55°N, 100-120°W) (+)	+0.4SD
(4) – July 50 mb U (5°S-5°N, 0-360) (–)	–0.4SD
(5) – September-November SLP (15-35°N, 75-95°W) (–)	–0.7SD
(6) – November SLP (7.5-22.5°N, 125-175°W) (+)	–2.6SD

2.1 Physical Associations among Predictors Listed in Table 1

The locations and brief descriptions of our 6-11 month predictors are as follows:

Predictor 1. November 500 MB Geopotential Height in the far North Atlantic (+)

(67.5-85°N, 10E-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 ridging 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 wind strength 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.

Predictor 2. October-November SLP in the Gulf of Alaska (-)

(45-65°N, 120-160°W)

Negative values of this predictor are strongly associated with a positive "Alaskan pattern" (Renwick and Wallace 1996) as well as a positive "Pacific North American Pattern" (PNA) which implies reduced blocking over the central Pacific with increased heights over the western United States. The negative mode of this predictor is typically associated with current warm eastern Pacific equatorial SST conditions which usually lead to cool ENSO conditions the following year. Low sea level pressure is observed to occur in the Gulf of Alaska with a decaying El Niño event, and anomalously high pressure is observed with a weakening La Niña event (Larkin and Harrison 2002). Negative values of this predictor indicate that La Niña conditions are likely the following year which tends to enhance Atlantic hurricane activity.

Predictor 3. September 500 MB Geopotential Height in Western North America (+)

(35-55°N, 100-120°W)

Positive values of this predictor correlate very strongly (r = 0.8) with positive values of the PNA. PNA values are usually positive in the final year of an El Niño event (Horel and Wallace 1981). Therefore, cooler ENSO conditions are likely during the following year. Significant lag correlations exist between this predictor and enhanced geopotential height anomalies in the subtropics during the following summer. High heights in the subtropics reduce the height gradient between the tropics and subtropics resulting in easterly anomalies at 200 mb throughout the tropics which favor hurricane development.

Predictor 4. July 50 MB Equatorial U (-)

(5°S-5°N, 0-360)

Easterly anomalies of the QBO during the previous July indicate that the QBO will likely be in the west phase during the following year's hurricane season. The west phase of the QBO has been shown to provide favorable conditions for development of tropical cyclones in the deep tropics according to Gray et al. (1992, 1993, 1994) and Shapiro (1989). Hypothetical mechanisms for how the QBO affects hurricanes are as follows: a) Atlantic TC activity is inhibited during easterly phases of the QBO due to enhanced lower stratospheric wind ventilation and increased upper-troposphere-lower-stratosphere wind shear, and b) for slow moving systems, the west phase of the QBO has a slower relative wind (advective wind relative to the moving system) than does the east phase. This allows for greater coupling between the lower stratosphere and the troposphere.

Predictor 5. September-November SLP in the Gulf - SE USA (-)

(15-35°N, 75-95°W)

This feature is strongly related to the following year's August-September sea level pressure in the tropical and subtropical Atlantic. August-September SLP in the tropical Atlantic is one of the most important predictors for seasonal activity, that is, lower-than-normal sea level pressure is favorable for more TC activity. Low pressure in this area during September-November correlates quite strongly with the positive phase of the PNA. In addition, easterlies at 200 mb throughout the tropical Atlantic are typical during the following year's August-September period with low values of this predictor.

Predictor 6. November SLP in the Subtropical NE Pacific (+)

(7.5-22.5°N, 125-175°W)

This feature is also strongly related to the following year's August-September sea level pressure in the tropical and subtropical Atlantic. High pressure in this area correlates with low sea level pressure in the tropical Atlantic and easterly anomalies at 200 mb during the following August through September period. According to Larkin and Harrison (2002), high pressure in this area appears during most winters preceding the development of a La Niña event. High pressure in this region forces stronger trade winds in the east Pacific which increases upwelling and helps initiate La Niña conditions which eventually enhance Atlantic hurricane activity during the following summer. In addition, this predictor correlates with low geopotential heights at 500 mb throughout the tropics the following year which is also favorable for more hurricane activity in the Atlantic.

2.2 Hindcast Skill

Table 2 shows the degree of hindcast variance explained by our new 1 December forecast scheme based on a 52-year developmental dataset.

To reduce overfitting, the 1 December forecast picks the best combination of five predictors from a pool of six predictors or until the jackknife variance explained no longer increases.

3 Analog Based Predictors for 2004 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2003/2004. These years also provide useful clues as to likely trends in activity that the forthcoming 2004 hurricane season may bring. For this (1 December) extended range forecast, we project atmospheric and oceanic conditions for August through October 2004 and determine which of the prior years in our database have distinct

Table 2: Variance explained based upon 52 years (1950-2001) of hindcasting.

Variables Selected	Variance (r^2) Explained	Jackknife (r^2)
NS – 1,2,3	0.40	0.29
NSD – 1, 3, 4, 5, 6	0.45	0.28
H – 1, 2, 3, 4, 5	0.53	0.38
HD – 1, 2, 3, 4, 5	0.53	0.35
IH – 1, 2, 3, 4, 5	0.69	0.57
IHD – 1, 3, 4, 5, 6	0.51	0.41
HDP – 1, 3, 4, 5, 6	0.57	0.37
NTC – 1, 3, 4, 5, 6	0.62	0.46

trends in key environmental conditions which are similar to current October-November 2003 conditions. Table 3 lists our analog selections.

Analog Years. We have found four prior hurricane seasons since 1949 which appear to be similar to current November 2003 conditions and projected 2004 August-October conditions. Specifically, we expect the North Atlantic (50-60°N, 10-50°W) warm SST anomalies to remain warm for the 2004 hurricane season due to current negative AO and NAO values and hence that the strong Atlantic thermohaline circulation will persist through the next hurricane season. Also, it is assumed that the conditions of the Northern Hemisphere NAO, PNA, PDO, and AO of seven of the last nine years will persist through 2004. The latter assumptions carry the implication that the recent global atmosphere and ocean circulation regimes which have been present in all but two of the last nine years will continue to be present in 2004.

There were four hurricane seasons since 1949 with characteristics similar to what we observe in November 2003 and what we anticipate for the summer/fall 2004 period. These best analog years are 1953, 1960, 1967, and 1969 (Table 3). We anticipate that 2004 seasonal hurricane activity will be somewhat above the average values for these four analog years due to an anticipated active thermohaline circulation. Thus, based on this analysis, we expect 2004 to be an active hurricane season and in line with the average of seven of the last nine years (1995-1996; 1998-2001; 2003). We anticipate 2004 to be considerably more active than the average season during the inactive 1970–1994 period.

Table 3: Best analog years for 2004 with the associated hurricane activity listed for each year.

	NS	NSD	H	HD	IH	IHD	HDP	NTC
1953	14	65	6	18	3	5.50	59	116
1960	7	30	4	18	2	9.50	72	92
1967	8	58	6	36	1	3.25	98	93
1969	17	83	12	40	3	2.75	110	150
Mean	11.5	59.0	7.0	28.0	2.3	5.3	84.8	112.8
2004 Forecast	13	55	7	30	3	6	85	125

Table 4 shows our final adjusted 1 December forecast for the 2004 season which is a combination of our derived full 52-year statistical forecast and our four analog year forecast. We foresee an active 2004 hurricane season.

Table 4: Summary of our new 1 December statistical forecast, our analog forecast, and our adjusted final forecast for this year.

Forecast Parameter and 1950–2000 Climatology (in parentheses)	New Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	10.4	11.5	13
Named Storm Days (49.1)	44.3	59.0	55
Hurricanes (5.9)	6.5	7.0	7
Hurricane Days (24.5)	30.5	28.0	30
Intense Hurricanes (2.3)	2.7	2.3	3
Intense Hurricane Days (5.1)	4.8	5.3	6
Hurricane Destruction Potential (72.7)	78.0	84.8	85
Net Tropical Cyclone Activity (100%)	107.4	112.8	125

4 Discussion

Our analysis of the current and projected global atmospheric and oceanic circulation patterns indicates that Atlantic tropical cyclone activity should be above average during the 2004 Atlantic basin hurricane season. We anticipate that ENSO conditions will remain neutral to slightly warm and that the warm sea surface temperatures in the North and tropical Atlantic that have been prevalent in most years since 1995 will continue.

5 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 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 5) 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 (November 2003) 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.

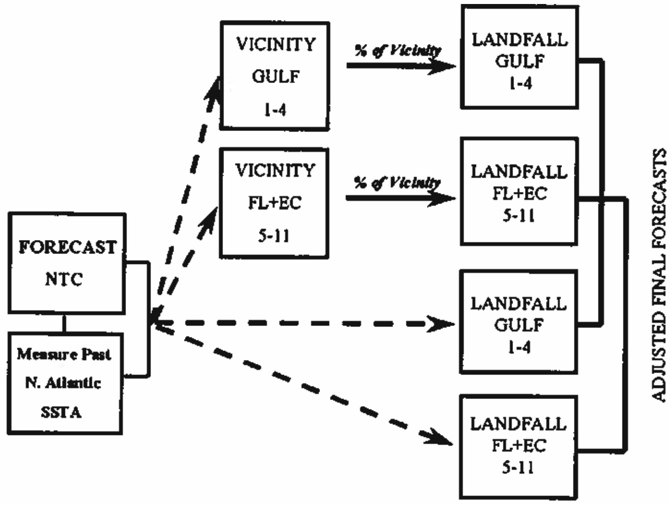

Figure 2: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60°N, 10-50°W) SSTA* are used to develop regression equations from U.S. hurricane landfall measurements of the last 100 years. Separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

As shown in Table 5, 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 5: 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 6 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 of 100, 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 6: 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	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	85% (80)	79% (68)	68% (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)	48% (31)	77% (62)	90% (81)

6 Increased Major Hurricane Activity Since 1995

A major reconfiguration of the distribution of Atlantic SST anomalies began in mid-1995 and has largely persisted through the present. North Atlantic SSTs have become about 0.4 to 0.6°C warmer than normal since 1995, and tropical Atlantic August-October upper tropospheric 200 mb winds have increased from the east, bringing about a significant decrease in tropospheric vertical wind shear. We hypothesize that these strong broadscale SST changes are associated with basic changes in the strength of the Atlantic Ocean thermohaline circulation (ATC). This interpretation is consistent with changes in a long list of global atmospheric circulation features during the last nine years which conform to a prominent shift into hurricane-enhancing Atlantic circulation patterns, particularly the enhancement of major hurricane activity. Historical and geographic evidence going back thousands of years indicates that shifts in the Atlantic multi-decadal thermohaline circulation tend to occur on periods of about 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. We expect that the hurricane season of 2004 will follow this recent upswing in hurricane activity. Our recent verification paper has more discussion on this issue and is available on our website:

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

7 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 recent 21 November 2003 verification report for more discussion on this subject.
[http://tropical.atmos.colostate.edu/forecasts/index.html]

8 Forecast Theory and Cautionary Note

Our forecasts are based on the premise that those global oceanic and atmospheric conditions which preceded 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.

9 Forthcoming Update Forecasts of 2004 Hurricane Activity

We will be issuing seasonal updates of our 2004 Atlantic basin hurricane activity forecast on Friday 2 April, Friday 28 May (to coincide with the official start of the 2004 hurricane season on 1 June), Friday 6 August, Friday 3 September and Friday 1 October 2004. The 6 August, 3 September and 1 October forecasts will include separate forecasts of August-only, September-only and October-only Atlantic basin tropical cyclone activity. A verification and discussion of all 2004 forecasts will be issued in late 2004. All these forecasts will be available at our web address given on the front cover
(http://tropical.atmos.colostate.edu/forecasts/index.html).

10 Acknowledgments

The first author gratefully acknowledges valuable input to our project research by former graduate students and colleagues Chris Landsea, John Knaff and Eric Blake. A number of other meteorologists have furnished us with data and given valuable assessments of the current state of global atmospheric and oceanic conditions. This includes Arthur

Douglas, Richard Larsen, Todd Kimberlain, Ray Zehr and Mark DeMaria. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical, and data analysis assistance over a number of years. We have profited over the years from many indepth discussions with most of the current and past NHC hurricane forecasters. The first author would further like to acknowledge the encouragement he has received for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, former directors of the National Hurricane Center (NHC), and from the current director, Max Mayfield. We also thank Bill Bailey of the Insurance Information Institute for his sage advice and encouragement.

The financial backing for the issuing and verification of these forecasts has in part been supported by the National Science Foundation, but this NSF support is insufficient. We appreciate the financial support of the Research Foundation of AIG - Lexington Insurance Company (a member of the American International Group) for the last two years. We are also grateful to the Research Foundations of the United Services Automobile Association (USAA) and to State Farm Insurance for prior support.

11 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., 2004: Prediction of August Atlantic basin hurricane activity. In press *Wea. Forecasting.*

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

Elsner, J. B., G. S. 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 Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate*, 1169-1187.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

12 Verification of Previous Forecasts

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

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

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

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

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

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