EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITY FOR 2007

We have increased our forecast for the 2007 hurricane season, largely due to the rapid dissipation of El Niño conditions. We are now calling for a very active hurricane season. Landfall probabilities for the 2007 hurricane season are well above their long-period averages.

(as of 3 April 2007)

By Philip J. Klotzbach[1] and William M. Gray[2]

with special assistance from William Thorson[3]

This forecast as well as past forecasts and verifications are available via the World Wide Web at http://hurricane.atmos.colostate.edu/Forecasts

Emily Wilmsen, 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 2007

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Issue Date 8 December 2006	Issue Date 3 April 2007
Named Storms (NS) (9.6)	14	17
Named Storm Days (NSD) (49.1)	70	85
Hurricanes (H) (5.9)	7	9
Hurricane Days (HD) (24.5)	35	40
Intense Hurricanes (IH) (2.3)	3	5
Intense Hurricane Days (IHD) (5.0)	8	11
Accumulated Cyclone Energy (ACE) (96.2)	130	170
Net Tropical Cyclone Activity (NTC) (100%)	140	185

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

1) Entire U.S. coastline - 74% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 50% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 49% (average for last century is 30%)

4) Above-average major hurricane landfall risk in the Caribbean

ABSTRACT

Information obtained through March 2007 indicates that the 2007 Atlantic hurricane season will be much more active than the average 1950-2000 season. We estimate that 2007 will have about 9 hurricanes (average is 5.9), 17 named storms (average is 9.6), 85 named storm days (average is 49.1), 40 hurricane days (average is 24.5), 5 intense (Category 3-4-5) hurricanes (average is 2.3) and 11 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 140 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2007 to be about 185 percent of the long-term average.

This early April forecast is based on a newly devised extended range statistical forecast procedure which utilizes 40 years of past global reanalysis data and is then tested on an additional 15 years of global reanalysis data. Analog predictors are also utilized. We have increased our forecast from our early December prediction due largely to the rapid dissipation of El Niño which has occurred over the past couple of months. Currently, neutral ENSO conditions are observed. We expect either neutral or weak-to-moderate La Niña conditions to be present during the upcoming hurricane season. Tropical and North Atlantic sea surface temperatures remain well above their long-period averages.

Acknowledgment

We are grateful to the National Science Foundation (NSF) and Lexington Insurance Company (a member of the American International Group (AIG)) 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). We thank Jim Kossin and Dan Vimont of the University of Wisconsin-Madison for providing the data for the Atlantic Meridional Mode prediction used in this forecast.

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

Notice of Author Changes

By William Gray

The order of the authorship of these forecasts has been reversed from Gray and Klotzbach to Klotzbach and Gray. After 22 years (since 1984) of making these forecasts, it is appropriate that I step back and have Phil Klotzbach assume the primary responsibility for our project's seasonal, monthly and landfall probability forecasts. Phil has been a member of my research project for the last six years and has been second author on these forecasts for the last five years. I have greatly profited and enjoyed our close personal and working relationships.

Phil is now devoting more time to the improvement of these forecasts than I am. I am now giving more of my efforts to the global warming issue and in synthesizing my projects' many years of hurricane and typhoon studies.

Phil Klotzbach is an outstanding young scientist with a superb academic record. I have been amazed at how far he has come in his knowledge of hurricane prediction since joining my project six years ago. I foresee an outstanding future for him in the hurricane field. I expect he will make many new forecast innovations and skill improvements in the coming years. I plan to continue to be closely involved in the issuing of these forecasts for the next few years.

DEFINITIONS

Accumulated Cyclone Energy – (ACE) A measure of a named storm's potential for wind and storm surge destruction defined as the sum of the square of a named storm's maximum wind speed (in 10^4 knots^2) for each 6-hour period of its existence. The 1950-2000 average value of this parameter is 96.

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.

Intense Hurricane - (IH) A hurricane which reaches a sustained low-level wind of at least 111 mph (96 knots 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 an intensity of Saffir/Simpson category 3 or higher.

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.

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. The 1950-2000 average value of this parameter is 100.

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 reversing 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.

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

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

1 Introduction

This is the 24th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. These forecasts are based on statistical methodologies derived from 55 years of past data and a separate study of analog years which have similar precursor circulation features to the current season. 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 basin tropical cyclone activity and landfall probability. We believe that seasonal forecasts must be based on methods that show 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 that the atmosphere continues to behave in the future as it has in the past.

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

We find that there is a rather high (50-60 percent) degree of year-to-year hurricane forecast potential if one combines 4-5 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 4-5) do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain the portion of the variance of seasonal hurricane activity that is not associated with the other variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 4-5 other predictors.

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

2 Early April Forecast Methodology

Our initial early April seasonal hurricane forecast scheme demonstrated hindcast skill for the period of 1950-1995. We developed a new early April forecast scheme that used more hindcast years (1950-2001) and showed improved hindcast skill and better physical insights into why such precursor relationships have an extended period memory.

This year, we have focused on revamping our statistical prediction techniques. We debuted a new early December statistical prediction technique that used fewer predictors and only used data for the two months prior to the forecast issuance date. In addition, the scheme was developed on dependent data from 1950-1989 and then tested on "independent" data from 1990-2004. Predictors were only included in the forecast if they added skill in both the dependent dataset and the independent dataset. We also attempted to only predict the NTC index with our new statistical technique, instead of attempting to predict a multitude of predictands including named storms, named storm days, etc. See our early December 2006 forecast for more information on this new technique.

Our new early April forecast scheme that we are using for the first time this year utilizes a similar technique to what was used in developing our new early December forecast scheme. We only attempt to predict the NTC index and only use predictors from the two months prior to the forecast issuance date (i.e. February-March data). This scheme then derives predictions for our other predictands from this NTC prediction. For example, if a typical season has 10 named storms and the predicted NTC value is 120%, the predicted number of named storms for the season would be 12 (10 * 120%).

Our new early April forecast uses three predictors derived from the NOAA-NCEP reanalysis products. A combination of these three predictors, using data over the complete 1950-2004 period, is able to hindcast 55% of the variance in NTC activity. The location of each of these new predictors is shown in Fig. 1. The pool of three predictors for this extended range forecast is given in Table 1. Strong statistical relationships can be extracted via combinations of these predictors (which are available by the end of March) and the amount of Atlantic basin hurricane activity occurring later in the year. The combination of these three predictors is calling for an active season this year.

New April Forecast Predictors

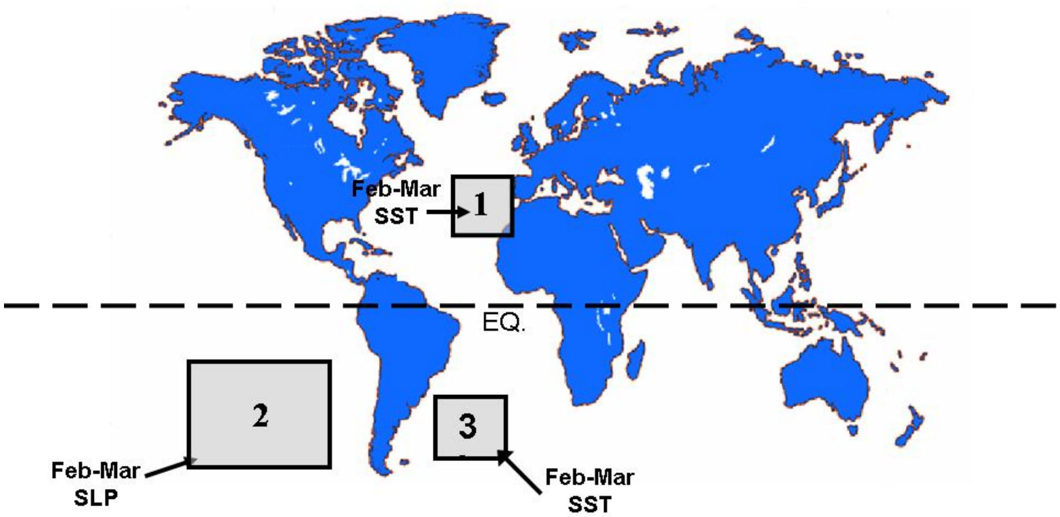

Figure 1: Location of predictors for the early April forecast for the 2007 hurricane season.

Table 1: Listing of 1 April 2007 predictors for this year's hurricane activity. A plus (+) means that positive values of the parameter indicate increased hurricane activity this year, and a minus (-) means that positive values of the parameter indicate decreased hurricane activity this year. The combination of these three predictors calls for an active hurricane season this year.

Predictor	Values for 2007 Forecast
1) February-March SST (30-45°N, 10-30°W) (+)	+1.7 SD
2) February-March SLP (20-45°S, 100-160°W) (+)	0.0 SD
3) February-March SST (30-45°S, 20-45°W) (-)	+1.1 SD

2.1 Physical Associations among Predictors Listed in Table 1

Brief descriptions of our early April predictors follow:

Predictor 1. February-March SST in the Subtropical Eastern Atlantic (+)

(30-45°N, 10-30°W)

Above-normal sea surface temperatures (SSTs) in the eastern subtropical Atlantic are associated with a weaker-than-normal Azores high and reduced trade wind strength during the boreal spring (Knaff 1997). These above-average SSTs in February-March are strongly correlated with weaker trade winds, lower-than-normal sea level pressures and above-average SSTs in the tropical Atlantic during the following August-October period. All three of these August-October features are commonly associated with active Atlantic basin hurricane seasons, through reductions in vertical wind shear, increased vertical instability and increased surface latent and sensible heat fluxes, respectively.

Predictor 2. February-March SLP in the Subtropical Southeastern Pacific (+)

(20-45°S, 100-160°W)

Anomalously high sea level pressures in this portion of the subtropical southeastern Pacific during February-March are associated with a positive Southern Oscillation Index and stronger trade winds across the tropical Pacific. Anomalously strong trade winds drive increased upwelling in the eastern tropical Pacific and are typically associated with cool ENSO conditions. Lag correlations for the August-October period indicate that La Niña conditions are much more likely with positive values of this predictor. Cool ENSO conditions are typically associated with more active Atlantic basin hurricane seasons through a reduction of vertical wind shear across the Caribbean and tropical Atlantic (e.g. Gray 1984a, Goldenberg and Shapiro 1996).

Predictor 3. February-March SST in the South Atlantic (-)

(30-45°S, 20-45°W)

Above-average SSTs in February-March in the South Atlantic are associated with higher sea level pressures throughout the tropical Atlantic during the same time period. These higher pressures in the tropical Atlantic feed back and drive stronger trade winds across the tropical Atlantic during the August-October period. Warm ENSO conditions and above-average vertical wind shear across the tropical Atlantic are typically experienced during August-October with above-average SSTs in the South Atlantic in the February-March timeframe. More research is being conducted to tie down the physical linkage between this predictor and Atlantic basin TC activity.

3 Analog-Based Predictors for 2007 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2007. These years also provide useful clues as to likely trends in activity that the forthcoming 2007 hurricane season may bring. For this early April extended range forecast, we project atmospheric and oceanic conditions for August through October 2007 and determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current February-March 2007 conditions. Table 2 lists our analog selections.

We select prior hurricane seasons since 1949 which have similar atmospheric-oceanic conditions to those currently being experienced. For 2007, we searched for years that had transitioning warm to neutral or cool ENSO conditions and warm North Atlantic sea surface temperatures.

There were five hurricane seasons since 1949 with characteristics most similar to what we observe in February-March 2007 and characteristics that we expect to see in August-October 2007. The best analog years that we could find for the 2007 hurricane season are 1952, 1964, 1966, 1995 and 2003. We anticipate that 2007 seasonal hurricane activity will have activity slightly more than what was experienced in the average of these five years. We expect the 2007 hurricane season to be very active.

Table 2: Best analog years for 2007 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1952	7	39.75	6	22.75	3	7.00	87	103
1964	12	71.25	6	43.00	6	14.75	170	184
1966	11	64.00	7	41.75	3	7.75	145	137
1995	19	121.25	11	61.75	5	11.50	227	222
2003	16	79.25	7	32.75	3	16.75	175	174
Mean	13.0	75.1	7.4	40.4	4.0	11.80	161	179
2007 Forecast	17	85	9	40	5	11	170	185

4 ENSO

The weak to moderate El Niño event that rapidly developed during August to October 2006 has now dissipated. Current observed SST anomalies in the various regions range from approximately +0.5°C in the Nino 4 region (5°S-5°N, 160°E-150°W) to approximately -0.5°C in the Nino 1+2 regions (10°S-0°, 80-90°W), indicating that we currently have neutral conditions in the tropical Pacific. The likelihood of redevelopment of warm ENSO conditions this summer/fall is quite unlikely, as the western Pacific warm pool has been largely depleted, and enhanced trade winds have been blowing across the eastern and central Pacific for the past couple of months. In addition, it is very rare to have warm ENSO conditions, followed by dissipation of the event, and then by redevelopment of another warm event within a one-year period.

Most of the ENSO forecast models indicate that neutral or cool ENSO conditions are likely for this upcoming summer/fall. Based on the latest prediction plume figure from the International Research Institute (IRI) (Figure 2), only one of 16 models is calling for El Niño conditions (SST anomaly greater than 0.5°C) in the Nino 3.4 region (5°S-5°N, 120-170°W) during the August-October period. Ten models are calling for neutral conditions, while the remaining five models are calling for La Niña conditions (SST anomaly less than -0.5°C).

Based on the latest ENSO predictions as well as currently observed conditions in the tropical Pacific, we expect either neutral or cool ENSO conditions to be in place in the tropical Pacific during the upcoming hurricane season. Since SSTs in the tropical and northern Atlantic continue to be well above average, we expect a very active hurricane season in 2007.

The rapid dissipation of the weak to moderate El Niño event during the latter part of this winter has been quite impressive. Table 3 displays the five most significant cooling episodes of SST anomalies in the Nino 3.4 region from October-November to the following year's February-March time period. Based on this metric, using data since 1950, the observed cooling during this time period in 2006-2007 is the strongest cooling on record.

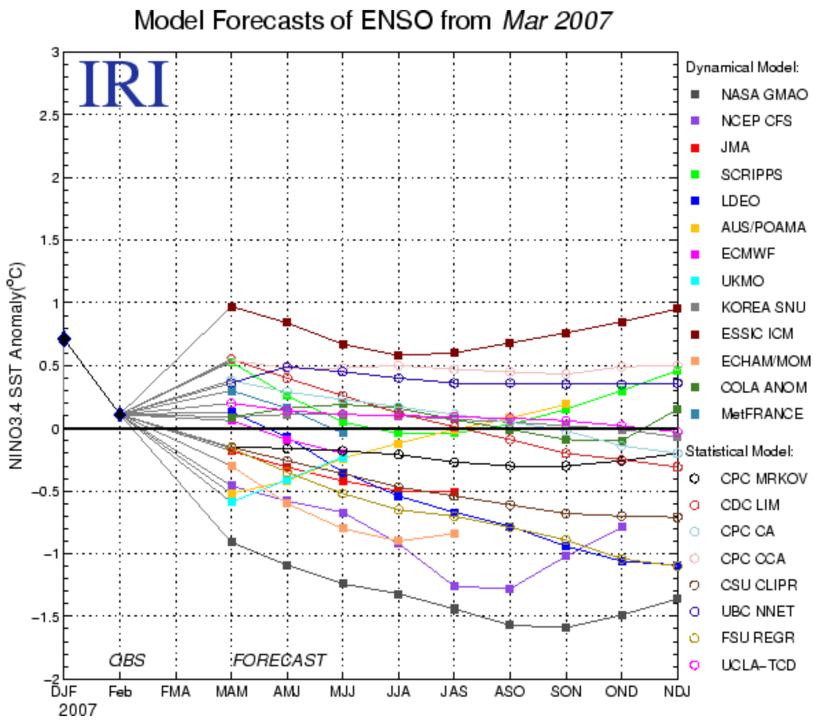

Figure 2: Latest prediction of Nino 3.4 anomalies from a variety of dynamical and statistical ENSO prediction models. Figure courtesy of the International Research Institute (IRI).

Table 3: Largest observed cooling anomalies in the Nino 3.4 region between November-December of the previous year and the current year's February-March period. The cooling observed in the 2006-2007 winter period is also provided.

Year	Previous Year's Nov-Dec Nino 3.4 Anomaly (°C)	Following Year's Feb-Mar Nino 3.4 Anomaly (°C)	(Feb-Mar) – (Nov-Dec)
1972-1973	2.1	1.0	-1.1
2002-2003	1.7	0.7	-1.0
1987-1988	1.7	0.7	-1.0
1997-1998	2.8	1.9	-0.9
1963-1964	1.0	0.1	-0.9
2006-2007	**1.3**	**0.1**	**-1.2**

5 Atlantic Meridional Mode

A new predictor that we are evaluating for the first time this year is a prediction of the July-November Atlantic Meridional Mode (AMM), calculated by Dan Vimont and Jim Kossin at the University of Wisconsin-Madison. The Atlantic meridional mode evaluates the strength of the SST gradient between the northern tropical and southern tropical Atlantic, spanning from 21°S-32°N and the South American coastline to the West African coastline. A positive AMM is in place when the meridional gradient of SST between the northern tropical Atlantic and southern tropical Atlantic is greater than the long-period average. When the AMM is positive, the Intertropical Convergence Zone (ITCZ) shifts northward. Consequently, convergence is enhanced in the northern tropical Atlantic, while trade wind strength and vertical wind shear in the tropical Atlantic are reduced. Also associated with a northward-shifted ITCZ are enhanced low-level vorticity and below-normal sea level pressures (Knaff 1997). When all these conditions occur, more active Atlantic basin tropical cyclone seasons are typically observed (Chiang and Vimont 2004, Klotzbach and Gray 2006). This AMM prediction, issued in early December of the previous year, explains approximately 40% of the variance of the observed AMM during the following year's July-November period. This year's AMM prediction is for a positive AMM index of 1.9 standard deviations above the long-period average, giving us increased confidence in predicting a very active hurricane season for 2007.

6 Adjusted 2007 Forecast

Table 4 shows our final adjusted early April forecast for the 2007 season which is a combination of our new statistical forecast, our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. Both our statistical forecast and our analog forecast indicate activity at well above-average levels. We anticipate that the current neutral ENSO conditions will either remain neutral or will transition to cool ENSO conditions by this summer/fall. Warm sea surface temperatures are likely to continue being present in the tropical and North Atlantic during 2007, due to the fact that we are in a positive phase of the Atlantic Multidecadal Oscillation (AMO) (e.g., a strong phase of the Atlantic thermohaline circulation).

Table 4: Summary of our early April statistical forecast, our analog forecast and our adjusted final forecast for the 2007 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	13.6	13.0	17
Named Storm Days (49.1)	69.7	75.1	85
Hurricanes (5.9)	8.4	7.4	9
Hurricane Days (24.5)	34.8	40.4	40
Intense Hurricanes (2.3)	3.3	4.0	5
Intense Hurricane Days (5.0)	7.1	11.8	11
Accumulated Cyclone Energy Index (96.2)	134	161	170
Net Tropical Cyclone Activity (100%)	142	179	185

7 Landfall Probabilities for 2007

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 20th century (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions.

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 5). Upon further study, as first mentioned in our early August forecast of 2006, SSTA* does not appear to add additional skill to landfall probabilities beyond that provided by NTC, and therefore, we are now basing our landfall probabilities on predicted NTC only.

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. 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.

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 the 2007 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. The mean annual probability of one or more landfalling systems is given in parentheses. Note that Atlantic basin NTC activity in 2007 is expected to be well above its long-term average of 100, and therefore, United States landfall probabilities are well above average.

Please visit our website at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions, 55 subregions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine.

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 Peninsula and the East Coast (Regions 5-11) for 2007. The long-term mean annual probability of one or more landfalling systems during the 20th century 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)	95% (79%)	88% (68%)	74% (52%)	97% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	80% (59%)	64% (42%)	49% (30%)	81% (60%)	96% (83%)
Florida plus East Coast (Regions 5-11)	73% (50%)	66% (44%)	50% (31%)	83% (61%)	95% (81%)

We were quite fortunate last year in that we had no hurricane landfalls. The 2006 season was only the 12th year since 1945 that we have witnessed no hurricane landfalls along the United States coastline. Since 1945, we have had only two consecutive-year periods where there were no hurricane landfalls. The two consecutive seasons of 1981-1982 and 2000-2001 had no hurricane landfalls. The dearth of landfalls in 2000 and 2001 was especially impressive considering that both of these seasons had above-average hurricane activity. From Hurricane Irene in 1999 to Hurricane Lili in 2002, 21 consecutive hurricanes developed in the Atlantic basin without a single U.S. landfall.

7 Is Global Warming Responsible for the Large Upswing in 2004-2005 U.S. Hurricane Landfalls?

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Florida landfalling hurricanes of 2004 (Charley, Frances, Ivan and Jeanne) raised questions about the possible role that global warming played in these two unusually destructive seasons.

The global warming arguments have been given much attention by many media references to recent papers claiming to show such a linkage. Despite the global warming of the sea surface that has taken place over the last 3 decades, the global numbers of hurricanes and their intensity have not shown increases in recent years except for the Atlantic (Klotzbach 2006), where recent hurricane increases are likely a result of naturally occurring multi-decadal Atlantic Ocean circulation variations.

The Atlantic has seen a very large increase in major hurricanes during the 12-year period of 1995-2006 (average 3.9 per year) in comparison to the prior 25-year period of 1970-1994 (average 1.5 per year). This large increase in Atlantic major hurricanes is primarily a result of the multi-decadal increase in the Atlantic Ocean thermohaline circulation (THC) that is not directly related to global temperature increase or to human-induced greenhouse gas increases. Changes in ocean salinity are believed to be the driving mechanism. These multi-decadal changes have also been termed the Atlantic Multidecadal Oscillation (AMO).

There have been similar past periods (1940s-1950s) when the Atlantic was just as active as in recent years. For instance, when we compare Atlantic basin hurricane numbers over the 15-year period (1990-2004) with an earlier 15-year period (1950-1964), we see no difference in hurricane frequency or intensity even though the global surface temperatures were cooler and there was a general global cooling during 1950-1964 as compared with global warming during 1990-2004.

Although global surface temperatures have increased over the last century and over the last 30 years, there is no reliable data available to indicate increased hurricane frequency or intensity in any of the globe's seven tropical cyclone basins, except for the Atlantic over the past twelve years. Meteorologists who study tropical cyclones have no valid physical theory as to why hurricane frequency or intensity would necessarily be altered significantly by small amounts ($< \pm 0.5^{o}C$) of global mean temperature change.

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the sea surface temperatures. Vertical lapse-rates will not be significantly altered. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will change significantly if global ocean temperatures continue to rise. For instance, in the quarter-century period from 1945-1969 when the globe was undergoing a weak cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period of 1970-1994 when the globe was undergoing a general warming trend, there were only 38 major hurricanes (48% as many) and 63 major hurricane days (31% as many) in the Atlantic basin. Atlantic sea-surface temperatures and hurricane activity do not necessarily follow global mean temperature trends.

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 7). Although global mean ocean and Atlantic surface temperatures have increased by about $0.4^{o}C$ between these two 50-year periods (1900-1949 compared with 1956-2005), the frequency of US landfall numbers actually shows a slight downward trend for the later period. If we chose to make a similar comparison between US landfall from the earlier 30-year period of 1900-1929 when global mean surface temperatures were estimated to be about $0.5^{o}C$ colder than they were during the 30-year period from 1976-2005, we find exactly the same US hurricane landfall numbers (54 to 54) and major hurricane landfall numbers (21 to 21).

We should not read too much into the two hurricane seasons of 2004-2005. The activity of these two years was unusual but well within natural bounds of hurricane variation. In addition, following the two very active seasons of 2004 and 2005, 2006 had slightly below-average activity, and no hurricanes made landfall in the United States.

Between 1966 and 2003, US major hurricane landfall numbers were below the long-term average. Of the 79 major hurricanes which formed in the Atlantic basin from

1966-2003, only 19 (24 percent) of them made US landfall. During the two seasons of 2004-2005, seven of 13 (54 percent) came ashore. None of the two major hurricanes that formed in 2006 made US landfall. This is how nature sometimes works.

What made the 2004-2005 seasons so unusually destructive was not the high frequency of major hurricanes but the high percentage of major hurricanes which were steered over the US coastline. The major US hurricane landfall events of 2004-2005 were primarily a result of the favorable, upper-air steering currents present during these two years.

Table 7: U.S. landfalling tropical cyclones by intensity during two 50-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Intense Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1900-1949 (50 years)	189	101	39	
1956-2005 (50 years)	165	83	34	+0.4°C

Although 2005 had a record number of tropical cyclones (27 named storms, 15 hurricanes and 7 major hurricanes), this should not be taken as an indication of something beyond natural processes. There have been several other years with comparable hurricane activity to 2005. For instance, 1933 had 21 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 named storm had tracks west of 60°W where surface observations were more plentiful. If we eliminate all the named storms of 2005 whose tracks were entirely east of 60°W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storms by seven (to 20) – about the same number as was observed to occur in 1933.

Utilizing the National Hurricanes Center's best track database of hurricane records back to 1875, six previous seasons had more hurricane days than the 2005 season. These years were 1878, 1893, 1926, 1933, 1950 and 1995. Also five prior seasons (1893, 1926, 1950, 1961 and 2004) had more major hurricane days. Finally, five previous seasons (1893, 1926, 1950, 1961 and 2004) had greater Hurricane Destruction Potential (HDP) values than 2005. HDP is the sum of the squares of all hurricane-force maximum winds and provides a cumulative measure of the net wind force generated by a season's hurricanes. Although the 2005 hurricane season was certainly one of the most active on record, it is not as much of an outlier as many have indicated.

Despite a fairly inactive 2006 hurricane season, we believe that the Atlantic basin is currently in an active hurricane cycle associated with a strong thermohaline circulation and an active phase of the Atlantic Multidecadal Oscillation (AMO). This active cycle is expected to continue for another decade or two at which time we should enter a quieter Atlantic major hurricane period like we experienced during the quarter century periods of 1970-1994 and 1901-1925. Atlantic hurricanes go through multi-decadal cycles. Cycles in Atlantic major hurricanes have been observationally traced back to the mid-19th century, and changes in the AMO have been inferred from Greenland paleo ice-core temperature measurements going back at least one thousand years.

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 U.S. 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 2007 hurricane season is, a finite probability always exists that one or more hurricanes may strike along the U.S. coastline or in the Caribbean Basin and do much damage.

9 Forthcoming Updated Forecasts of 2007 Hurricane Activity

We will be issuing seasonal updates of our 2007 Atlantic basin hurricane forecasts on **Thursday 31 May** (to coincide with the official start of the 2007 hurricane season on 1 June), **Friday 3 August**, **Tuesday 4 September** and **Tuesday 2 October 2007**. The 3 August, 4 September and 2 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 2007 forecasts will be issued in late November 2007. Our first seasonal hurricane forecast for the 2008 hurricane season will be issued in early December 2007. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

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12 Verification of Previous Forecasts

Table 8: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2001-2006.

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	65	65	75	75	71
Intense Hurricanes	2	2	3	3	4
Intense Hurricane Days	4	4	5	5	5
Net Tropical Cyclone 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	90	85	75	35	25	31
Intense Hurricanes	4	3	2	1	1	2
Intense Hurricane Days	7	6	5	2	2	2.5
Net Tropical Cyclone 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	16
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	100	100	100	80	80	125	129
Intense Hurricanes	3	3	3	3	3	2	3
Intense Hurricane Days	8	8	8	5	9	15	17
Net Tropical Cyclone Activity	140	140	145	120	130	155	173

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
Intense Hurricanes	3	3	3	3	5	6	6
Intense Hurricane Days	6	8	8	6	15	23	22
Net Tropical Cyclone Activity	125	145	145	125	185	240	229

2005	3 Dec. 2004	Update 1 April	Update 31 May	Update 5 August	Update 2 Sept.	Update 3 Oct.	Obs.
No. of Hurricanes	6	7	8	10	10	11	14
No. of Named Storms	11	13	15	20	20	20	26
No. of Hurricane Days	25	35	45	55	45	40	48
No. of Named Storm Days	55	65	75	95	95	100	116
Intense Hurricanes	3	3	4	6	6	6	7
Intense Hurricane Days	6	7	11	18	15	13	16.75
Net Tropical Cyclone Activity	115	135	170	235	220	215	263

2006	6 Dec. 2005	Update 4 April	Update 31 May	Update 3 August	Update 1 Sept.	Update 3 Oct.	Obs.
No. of Hurricanes	9	9	9	7	5	6	5
No. of Named Storms	17	17	17	15	13	11	10
No. of Hurricane Days	45	45	45	35	13	23	21
No. of Named Storm Days	85	85	85	75	50	58	53
Intense Hurricanes	5	5	5	3	2	2	2
Intense Hurricane Days	13	13	13	8	4	3	2
Net Tropical Cyclone Activity	195	195	195	140	90	95	85