EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITY FOR 2008

We foresee a somewhat above-average Atlantic basin tropical cyclone season in 2008. We anticipate an above-average probability of United States major hurricane landfall.

(as of 7 December 2007)

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

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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Why issue 6-11 month extended-range forecasts for next year's hurricane activity?

We are frequently asked this question. Our answer is that it is possible to say something about the probability of next year's hurricane activity which is superior to climatology. The Atlantic basin has the largest year-to-year variability of any of the global tropical cyclone basins. People are curious to know how active next year is likely to be, particularly if you can show hindcast skill improvement over climatology over many past years.

Everyone should realize that it is impossible to precisely predict next season's hurricane activity at such an extended range. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards the probability of an active or inactive hurricane season for next year. Our new early December statistical forecast methodology shows evidence over 58 past years that significant improvement over climatology can be attained. We would never have issued these early December forecasts or any other forecast unless we had a statistical model developed over a long hindcast period which showed significant skill.

We issue these forecasts to satisfy the curiosity of the general public and to bring attention to the hurricane problem. There is a curiosity in knowing what the odds are for an active or inactive season next year. One must remember that 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. This is not always true for individual seasons. It is also 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.

The methodology of this year's extended-range forecast is based on a new 1 December statistical technique developed on 58 years (1950-2007) of data. This forecast is expressed in units of Net Tropical Cyclone (NTC) activity as discussed in Table 11. Table 2 lists our 58 years of hindcasts compared with observations. We have gone the right way (correctly predicted an above- or below-average season) in 45 out of these 58 hindcast years. This new scheme has also shown 1 December hindcast skill over the last 16-year period where our real-time 1 December forecasts have not shown improvement over climatology. See Section 2 for a full explanation of this new forecast methodology.

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2008

Forecast Parameter and 1950-2000 Climatology (in parentheses)	7 December 2007 Forecast for 2008
Named Storms (NS) (9.6)	13
Named Storm Days (NSD) (49.1)	60
Hurricanes (H) (5.9)	7
Hurricane Days (HD) (24.5)	30
Intense Hurricanes (IH) (2.3)	3
Intense Hurricane Days (IHD) (5.0)	6
Accumulated Cyclone Energy (ACE) (96.1)	115
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 - 60% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 37% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 36% (average for last century is 30%)

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

ABSTRACT

Information obtained through November 2007 indicates that the 2008 Atlantic hurricane season will be somewhat more active than the average 1950-2000 season. We estimate that 2008 will have about 7 hurricanes (average is 5.9), 13 named storms (average is 9.6), 60 named storm days (average is 49.1), 30 hurricane days (average is 24.5), 3 intense (Category 3-4-5) hurricanes (average is 2.3) and 6 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 115 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2008 to be 125 percent of the long-term average. This forecast is based on a new extended-range early December statistical prediction scheme that utilizes 58 years of past data. Analog predictors are also utilized. The influences of El Niño conditions are implicit in these predictor fields, and therefore we do not utilize a specific ENSO forecast as a predictor. We expect current moderate La Niña conditions to weaken somewhat by the 2008 Atlantic basin hurricane season.

This forecast also contains an analysis of all of our extended-range forecasts that have been issued for the last 16 years (1992-2007). These real-time operational early December forecasts have not shown forecast skill over climatology during this 16-year period. This has occurred despite the fact that the skill over the hindcast period (varying from 40-55 years depending on the forecast scheme) showed appreciable skill (approximately 40-50% of the variance explained).

The current early December forecast consists of a new set of three predictors that has shown appreciable hindcast skill ($r^2 = 0.45$) over the last 58 years (1950-2007). It is surprising that the global atmosphere-ocean system has such a strong extended-range predictive signal. This scheme also shows appreciable hindcast skill over the more recent 16-year period from 1992-2007 ($r^2 = 0.52$) for which our previous early December schemes have not been able to show operational skill over climatology.

Notice of Author Changes

By William Gray

The order of the authorship of these forecasts was reversed in 2006 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 seven years and was second author on these forecasts from 2001-2005. 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 in 2000. 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. He was recently awarded his Ph.D. degree.

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 United States Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

The second author gratefully acknowledges valuable input to his CSU research project over many years by former project members 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.

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.

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.

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 25th 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 a statistical methodology derived from 58 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.

The best predictors 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 forecast 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 2-3 other predictors.

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 2-3 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. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme must show significant hindcast skill before it is used in real-time forecasts.

2 New Early December Forecast Methodology

Although our seasonal hurricane forecast scheme has shown significant real time skill for our early June and early August predictions, we have yet to demonstrate real-time forecast skill for our early December forecasts that have been issued for the last 16 years (1992-2007).

Our initial 6-11 month early December seasonal hurricane forecast scheme (Gray et al. 1992), although demonstrating appreciable hindcast skill for the period from 1950-1990, did not give skillful results when utilized for 10 real-time forecasts between 1992-2001. This was due to the discontinuation of the strong relationships we had earlier found between West African rainfall and the stratospheric quasi-biennial oscillation (QBO) with Atlantic basin major hurricane activity 6-11 months in the future. We did not expect these African rainfall and QBO predictive relationships that had worked so well for 41 years to stop working. We do not yet have a good explanation as to why these relationships have failed. We have discontinued this earlier 1 December forecast scheme and have developed several new 1 December forecast schemes since that time.

Beginning with the 2002 December forecast for the 2003 season, we relied on a new early December forecast scheme (Scheme B) (Klotzbach and Gray 2004) which did not utilize West African rainfall and gave less weight to the QBO. This newer statistical scheme, although showing improved hindcast skill, has also not demonstrated real-time forecast skill for the four years from 2003-2006. See Tables 1 and 3 for information on all of our early December extended-range forecast schemes.

We recently developed an even simpler, three-predictor model that we used for our early December prediction for the 2007 season (Scheme C). This scheme showed comparable hindcast skill to the six-predictor scheme (Scheme B) that we used over the previous few years. The relationships between individual predictors and seasonal tropical cyclone activity occurring the following year were better understood using this new and simpler three-predictor scheme. Having only three predictors also eliminates over-fitting of the hindcast which can occur when the scheme uses 4-6 variables. Similar to the newly-developed August seasonal forecast scheme (Klotzbach 2007), this scheme only predicted Net Tropical Cyclone (NTC) activity, and the other predictors were then derived from this NTC prediction. For example, if a typical season predicted an NTC value of 120%, the predicted number of named storms for the season would be 1.2 times 10 (the 1950-2000 annual average for named storms) or 12. Table 1 summarizes the characteristics of each of our previous 1 December forecast schemes.

Table 1: Listing of all previous December extended-range prediction schemes.

	Scheme A Gray et al. (1992)	Scheme B Klotzbach and Gray (2004)	Scheme C Klotzbach and Gray (2006)	Scheme D Klotzbach and Gray (2007)
Years Used in Real-Time Forecasting	1992-2002 (11Yrs.)	2003-2006 (4 Yrs.)	2007 (1 Yr.)	2008 (1 Yr.)
Number of Predictors	3	6	3	3
Hindcast Period	1950-1990 (41 Yrs.)	1950-2001 (52 Yrs.)	1950-2005 (56 Yrs.)	1950-2006 (57 Yrs.)
Hindcast Skill for NTC (r)	0.69	0.65	0.70	0.66
Actual Skill for NTC (r)	0.05 (1992-2002)	0.05 (2003-2006)	n/a – Only used for 1 year	n/a – First year used
Hindcast/Forecast Skill for NTC (r) (1992-2007)	0.03	0.64	0.54	0.74
Reason for lack of Skill	QBO and West African rainfall stopped working	Some physical relationships not well understood	n/a – Only used for 1 year	n/a

2.1 December Statistical Forecast Scheme

Neither Scheme B nor Scheme C have shown real-time forecast skill for the last six years (2002-2007). We are working to try to better understand why schemes that have shown good hindcast skill over extended past periods should fail when being used in real-time. However, we have found that using a combination of only three predictors from a combination of previous 1 December forecasts by Klotzbach and Gray (2004) and Klotzbach and Gray (2006) (referred to in the remainder of the forecast as Scheme D) yielded the most reliable hindcast skill over the period from 1950-2007, while also retaining good skill over the recent period from 2002-2007.

While statistical prediction schemes A, B, and C showed virtually no forecast correlation for the period from 2002-2007, the new scheme (Scheme D) detailed below correlated at 0.74 for the years from 1992-2007 and 0.72 for the years from 2002-2007. This combination of predictors from schemes B and C will be utilized as this year's statistical forecast model. We believe that we have solid physical links between all three predictors and the upcoming Atlantic basin hurricane season.

Table 2 displays hindcasts for 1950-2007 using Scheme D. We have correctly predicted above- or below-average seasons in 45 out of 58 hindcast years (78%). Our predictions have had a smaller error than climatology in 40 out of 58 years (69%). Our average hindcast error is 32 NTC units, compared with 44 NTC units for climatology. This scheme also shows considerable stability when broken in half, explaining 44 percent of the variance from 1950-1978 and 49 percent of the variance from 1979-2007. This new scheme is also well-tuned to the multi-decadal active hurricane periods from 1950-1969 and 1995-2007 versus the inactive hurricane period from 1970-1994 (Table 3). Figure 1 displays the locations of the three predictors used in this scheme in map form, while Table 4 lists the three predictors that are utilized for this year's December forecast. Table 5 displays the forecasts from statistical models B, C, and D for 2002-2007 along with the correlations between each scheme and observations over this period.

Table 2: Observed versus hindcast NTC for 1950-2007 using Scheme D. Average errors for hindcast NTC and climatological NTC predictions are given without respect to sign. Bold-faced years in the "Hindcast NTC" column are years that we did not go the right way, while bold-faced years in the "Hindcast improvement over Climatology" column are years that we did not beat climatology. The hindcast went the right way with regards to an above- or below-average season in 45 out of 58 years (78%), while hindcast improvement over climatology occurred in 40 out of 58 years (69%).

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1950	230	158	72	130	58
1951	115	**90**	25	15	**-10**
1952	93	**123**	-30	-7	**-23**
1953	116	157	-41	16	**-26**
1954	124	118	6	24	18
1955	188	137	52	88	37
1956	66	**148**	-82	-34	**-48**
1957	82	**119**	-37	-18	**-19**
1958	133	111	22	33	11
1959	94	**115**	-21	-6	**-15**
1960	92	**135**	-43	-8	**-35**
1961	211	193	19	111	93
1962	32	**120**	-88	-68	**-20**
1963	111	138	-27	11	**-16**
1964	160	**86**	74	60	**-14**
1965	82	92	-10	-18	8
1966	134	141	-7	34	27
1967	93	76	17	-7	**-10**
1968	39	57	-18	-61	43
1969	150	149	1	50	49
1970	62	55	7	-38	31
1971	91	96	-5	-9	4
1972	27	73	-46	-73	27
1973	50	79	-29	-50	21
1974	72	88	-16	-28	12
1975	89	92	-3	-11	8
1976	82	**115**	-34	-18	**-15**
1977	45	74	-29	-55	26
1978	83	84	-1	-17	16
1979	92	22	69	-8	**-61**
1980	129	**63**	66	29	**-37**
1981	109	118	-9	9	1
1982	35	86	-51	-65	14
1983	31	14	17	-69	52
1984	74	96	-22	-26	4
1985	106	110	-5	6	1
1986	37	84	-47	-63	16
1987	46	15	30	-54	24
1988	118	103	14	18	3
1989	130	148	-18	30	12
1990	98	89	9	-2	**-7**
1991	57	85	-28	-43	15
1992	64	56	8	-36	28
1993	52	66	-14	-48	34
1994	35	81	-46	-65	19
1995	222	110	112	122	10
1996	192	149	43	92	49
1997	51	83	-32	-49	17
1998	166	176	-10	66	56
1999	185	170	15	85	70
2000	134	107	27	34	7
2001	129	127	2	29	27
2002	80	**103**	-23	-20	**-3**
2003	173	150	23	73	50
2004	228	163	65	128	63
2005	273	138	134	173	38
2006	85	**133**	-48	-15	**-33**
2007	94	**104**	-10	-6	**-4**
Average	**106**	**106**	**32**	**44**	**+12**

Table 3: Hindcast versus observed average NTC for active vs. inactive multi-decadal periods.

Years	***Average Hindcast NTC***	***Average Observed NTC***
1950-1969 (Active)	123	117
1970-1994 (Inactive)	80	72
1995-2007 (Active)	132	155

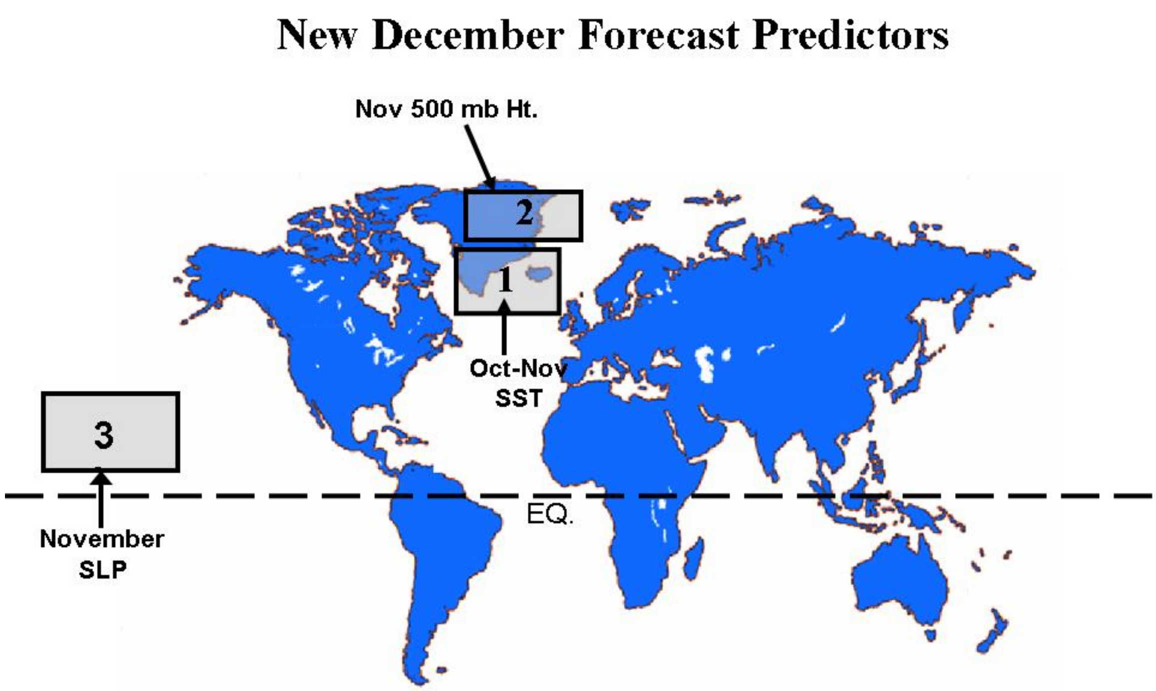

Figure 1: Location of predictors for our December extended-range statistical prediction for the 2008 hurricane season.

Table 4: Listing of 1 December 2007 predictors using the new statistical forecast for the 2008 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2007 Values for 2008 Forecast
1) October-November SST (55-65°N, 10-60°W) (+)	+1.1 SD
2) November 500 mb geopotential height (67.5-85°N, 10°E-50°W) (+)	0.0 SD
3) November SLP (7.5-22.5°N, 125-175°W) (+)	-0.7 SD

Table 5. Statistical forecasts from schemes B, C, and D along with observations of Net Tropical Cyclone Activity from 2002-2007. Note that scheme D does the best at predicting year-to-year variations in NTC activity. A value of 100 represents the average hurricane season.

Years	***Scheme B Forecast***	***Scheme C Forecast***	***Scheme D Forecast***	***Observation***
2002	90	124	103	80
2003	132	149	150	173
2004	107	158	163	228
2005	92	126	138	273
2006	142	139	133	85
2007	72	149	104	94
Correlation (2002-2007)	**-0.03**	**0.11**	**0.72**	
Hindcast Correlation	1950-2001 0.65	1950-2006 0.68	1950-2007 0.67	

There is also extended-range forecast skill from 1 December for United States hurricane landfall probabilities. In the 15 out of 58 years where our newest hindcast scheme (Scheme D) forecast NTC values above 135, we had approximately twice as many hurricane (39 versus 19) and major hurricane (16 versus 8) landfalls along the U.S. coastline when compared with the 15 out of 58 years where our newest hindcast scheme gave NTC values below 85. For the Florida peninsula and the U.S. East Coast, the ratio between NTC hindcast values greater than 135 and below 85 are 22 to 8 for hurricanes and 9 to 2 for major hurricanes.

There have been several hindcast years which were very successful. Table 6 displays the 10 years that our extended-range hindcasts were closest to actual observations. The average hindcast minus observed NTC difference in these years was 4. The average difference between the observed NTC and climatological NTC of 100 in these 10 years was 25.

Table 6: The 10 years that our hindcasts were closest to observations.

Years	***Hindcast NTC***	***Observed NTC***
1954	118	124
1966	141	134
1969	149	150
1970	55	62
1971	96	91
1975	92	89
1978	84	83
1985	110	106
1992	56	64
2001	127	129

There have also been several years where the hindcast was a failure. Table 7 displays the 10 years that our extended-range hindcasts deviated the most from actual observations. For our 10 worst hindcast years, our average NTC error was 81, while the error using climatology was 84. For the 38 of 58 intermediate years between our 10 best and 10 worst NTC forecasts, our average NTC error was 26 while the average NTC error using climatology was 39. The average hindcast error we would have had using climatology for all forecasts was 44.

In general, our worst hindcasts mirror the hindcast errors using climatology, while our best forecasts significantly improve upon climatology.

Table 7: The 10 years that our hindcasts deviated the most from observations.

Years	***Hindcast NTC***	***Observed NTC***
1950	158	230
1955	137	188
1956	66	148
1962	120	32
1964	86	160
1979	22	92
1980	63	129
1995	110	222
2004	163	228
2005	138	273

2.2 Physical Associations among Predictors Listed in Table 4

The locations and brief descriptions of our 6-11 month predictors for our statistical forecast are now discussed. It should be noted that all three forecast parameters correlate significantly with physical features of next year's August to October period that are known to be favorable for elevated levels of hurricane activity. For each of the three predictors, we display a four-panel figure showing linear correlations between this year's value of each predictor and next year's August-October values of sea surface temperature, sea level pressure, 200 mb zonal wind and 925 mb zonal wind, respectively.

<u>Predictor 1. October-November SST in the North Atlantic (+)</u>

(55-65°N, 10-60°W)

Warm North Atlantic sea surface temperatures in the fall are indicative of an active phase of the Atlantic Multidecadal Oscillation (AMO) and a likely strong thermohaline circulation. An active AMO is associated with anomalously low vertical wind shear, warm tropical Atlantic sea surface temperatures and anomalously low sea level pressures during the hurricane season. All four of these factors are favorable for an active Atlantic basin hurricane season (Figure 2). Values of this predictor from 1998-2007 have been subjectively reduced by 0.25°C, as values during the last decade have been much higher than observed during the previous 60 years.

<u>Predictor 2. November 500 mb Geopotential Height in the far North Atlantic (+)</u>

(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 ridging in the central Atlantic and a warm North Atlantic Ocean (50-60°N, 10-50°W) due to stronger southerly winds and more blocking action during this period. Also, on decadal timescales, weaker zonal winds in the subpolar areas (40-60°N, 0-60°W) across the Atlantic are indicative of a relatively strong thermohaline circulation. Positive values of this November index (higher heights, weaker mid-latitude zonal winds) are correlated with weaker tropical Atlantic 200 mb westerly winds and weaker trade winds the following August-October. This brings about reduced tropospheric vertical wind shear which enhances TC development. Other following summer-early fall features that are directly correlated with this predictor are low sea level pressure in the Caribbean and a warm North and tropical Atlantic (Figure 3). Both of the latter are also hurricane-enhancing factors.

<u>Predictor 3. November SLP in the Subtropical NE Pacific (+)</u>

(7.5-22.5°N, 125-175°W)

According to Larkin and Harrison (2002), high pressure in the tropical NE Pacific appears during most winters preceding the development of a La Niña event. High pressure 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. This predictor correlates with low geopotential heights at 500 mb throughout the tropics the following summer, indicative of a weaker Hadley circulation typical of La Niña conditions. Also, high pressure in November in the tropical NE Pacific correlates with low sea level pressure in the tropical Atlantic and easterly anomalies at 200 mb during the following August through October period (Figure 4).

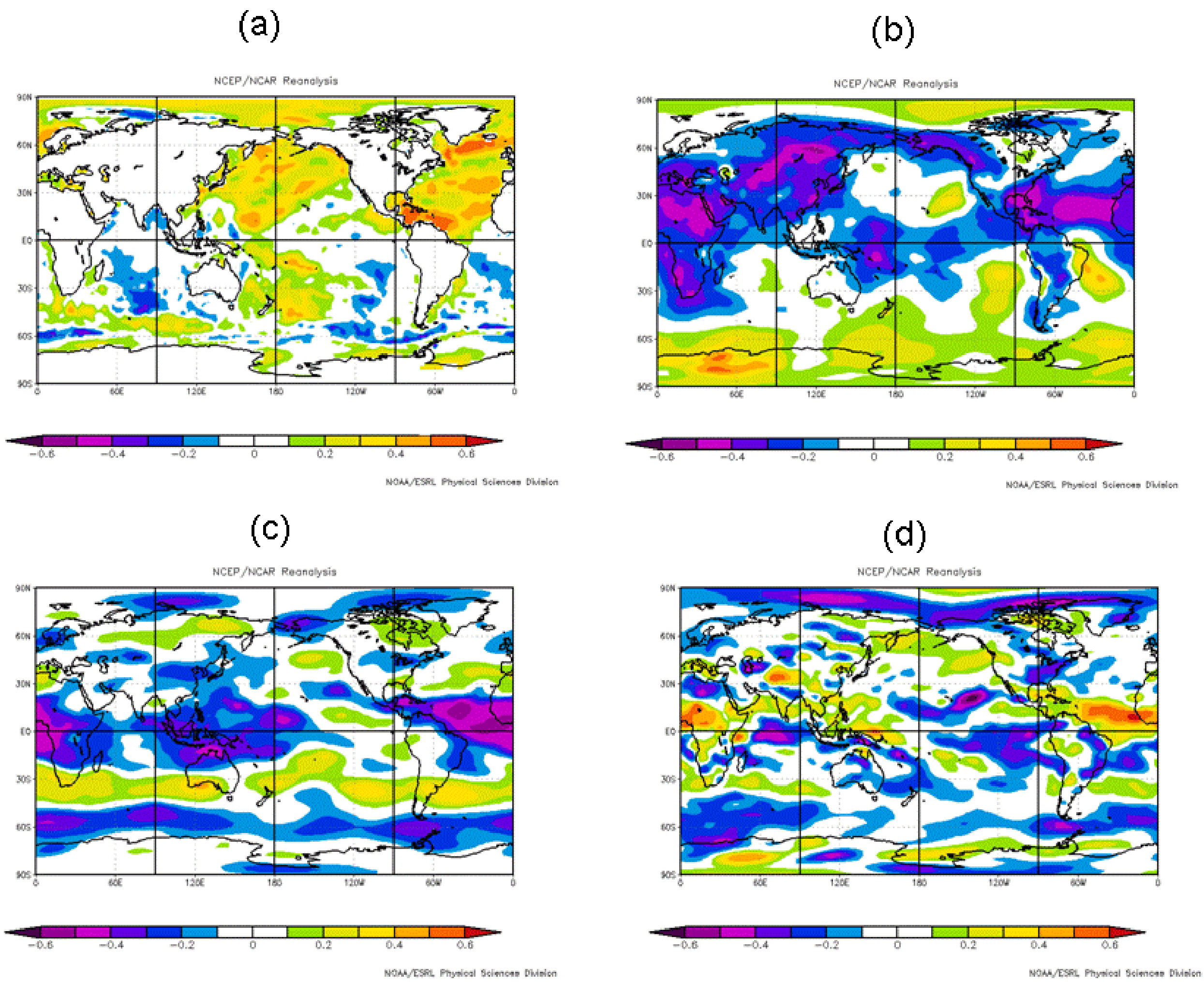

Figure 2: Linear correlations between October-November SST in the North Atlantic (Predictor 1) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

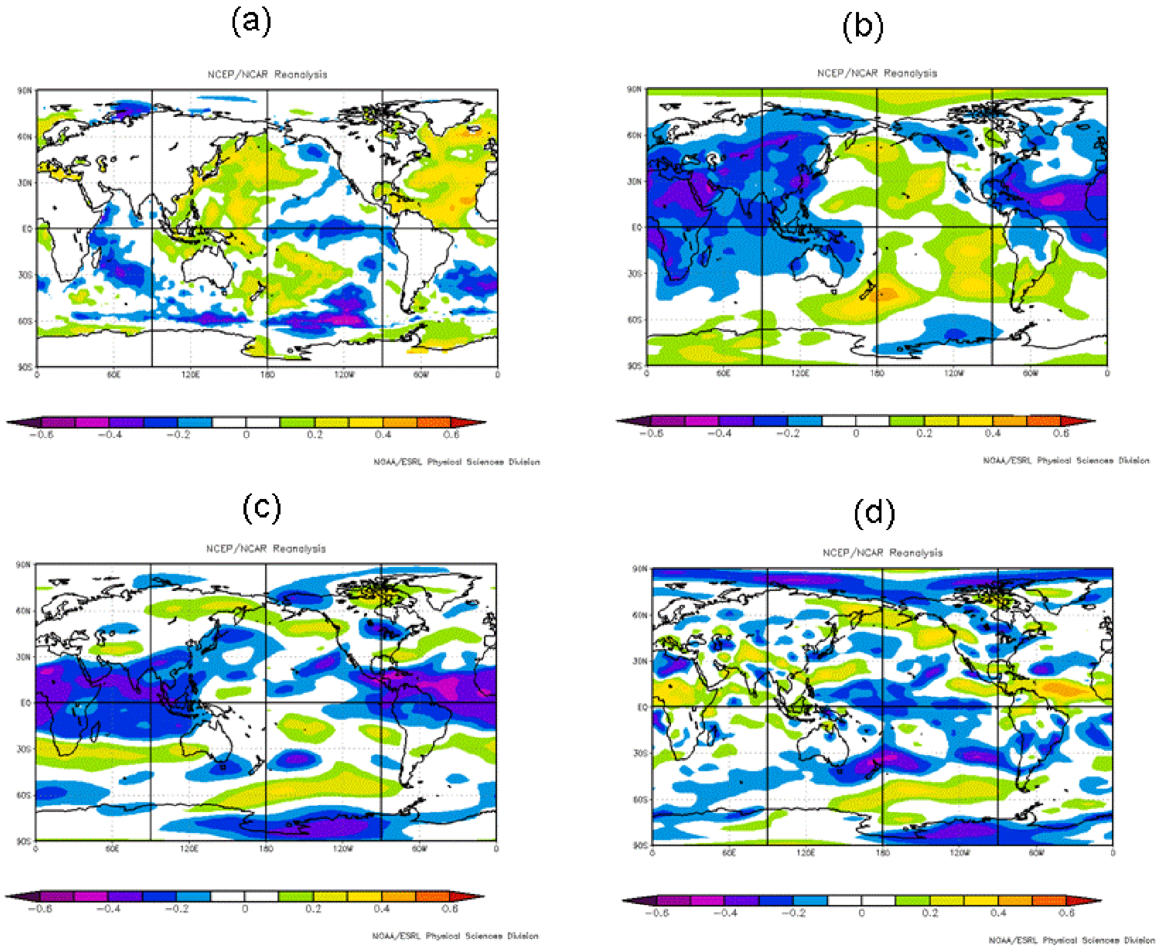

Figure 3: Linear correlations between November 500 mb geopotential heights in the far North Atlantic (Predictor 2) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

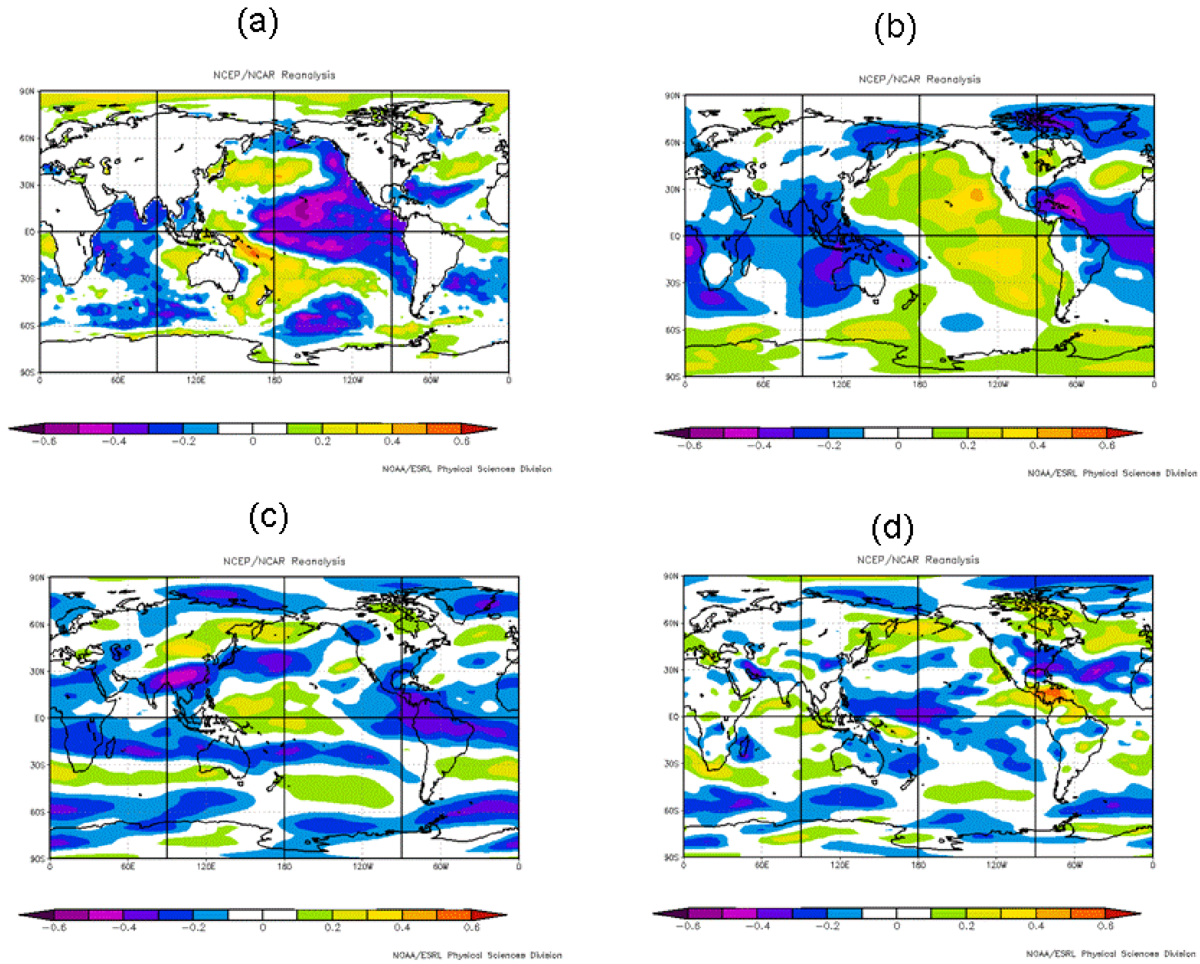

Figure 4: Linear correlations between November sea level pressure in the subtropical Northeast Pacific (Predictor 3) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

3 Analog-Based Predictors for 2008 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2007/2008. These years also provide useful clues as to likely trends in activity that the forthcoming 2008 hurricane season may bring. For this early December extended range forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current October-November 2007 conditions. Table 8 lists our analog selections.

We select prior hurricane seasons since 1949 which have similar atmospheric-oceanic conditions to those currently being experienced. Analog years for 2008 were selected primarily on how similar they are to conditions that are currently observed. We searched for years that had La Niña conditions, near-average tropical Atlantic sea surface temperatures and warm far North Atlantic sea surface temperatures.

There were five hurricane seasons since 1949 with characteristics most similar to what we observe in October-November 2007. The best analog years that we could find for the 2008 hurricane season are 1953, 1956, 1989, 1999, and 2000. We anticipate that 2008 seasonal hurricane activity will have activity in line with what was experienced in the average of these five years. We believe that 2008 will have somewhat above-average activity in the Atlantic basin.

Table 8: Best analog years for 2008 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1953	14	64.50	6	18.00	4	6.75	104	127
1956	8	30.00	4	12.75	2	2.75	54	68
1989	11	66.00	7	31.75	2	9.75	135	130
1999	12	78.50	8	41.00	5	14.25	177	182
2000	14	67.00	8	32.75	3	5.00	116	130
Mean	11.8	61.2	6.6	27.3	3.2	7.5	117	127
2008 Forecast	13	60	7	30	3	6	115	125

4 ENSO

We are currently in the middle of a moderate La Niña event which developed during the summer of 2007. Currently, observed sea surface temperatures anomalies in the eastern and central Pacific are approximately 1.0 – 2.0°C below the long-period average. One of the important questions for the upcoming hurricane season is whether or not the current La Niña event will continue through the 2008 Atlantic basin hurricane season. Table 9 shows the eight coldest observed October-November Nino 3.4 anomalies in active multi-decadal periods (1950-1969, 1995-present) and evaluates the following year's August-September-October Nino 3.4 anomalies. The final column in Table 9 displays the NTC that was observed the following year in the Atlantic basin.

Six out of the eight seasons following La Niña years were active Atlantic hurricane seasons, and seven out of the eight seasons witnessed either neutral conditions or a continuation of La Niña conditions. From this analysis, we believe that we will likely see moderating ENSO conditions next spring/summer; however, a transition to El Niño conditions seems unlikely.

Table 9: Observed October-November Nino 3.4 conditions for the eight coldest observed October-November periods in an active Atlantic multi-decadal period, observed August-September-October Nino 3.4 anomalies the following year and observed NTC the following year in the Atlantic basin.

Year	First Year Oct-Nov Nino 3.4 Anomaly (°C)	Second Year Aug-Sep-Oct Nino 3.4 Anomaly (°C)	Second Year Atlantic Basin NTC
1955-1956	-2.0	-0.6	68
1998-1999	-1.3	-1.0	182
1999-2000	-1.2	-0.4	130
1964-1965	-1.0	1.4	86
1995-1996	-0.9	-0.3	192
1954-1955	-0.8	-1.4	207
1950-1951	-0.8	-1.4	148
2000-2001	-0.7	0.0	134
Mean	-1.1	-0.5	143
2007-2008	**-1.4**	**-0.6 (Prediction)**	**125 (Prediction)**

5 Adjusted 2008 Forecast

Table 10 shows our final adjusted early December forecast for the 2008 season which is a combination of our statistical scheme, our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. Our statistical forecast and our analog forecast indicate activity at above-average levels. We foresee a somewhat above-average Atlantic basin hurricane season. We anticipate that current cool ENSO conditions will moderate somewhat by next summer, but a transition to El Niño seems unlikely.

Warm sea surface temperatures are likely to continue being present in the tropical and North Atlantic during 2008, 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 10: Summary of our early December statistical forecast, our analog forecast and our adjusted final forecast for the 2008 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	11.3	11.8	13
Named Storm Days (49.1)	57.9	61.2	60
Hurricanes (5.9)	7.0	6.6	7
Hurricane Days (24.5)	28.9	27.3	30
Intense Hurricanes (2.3)	2.7	3.2	3
Intense Hurricane Days (5.0)	6.0	7.5	6
Accumulated Cyclone Energy Index (96.1)	113	117	115
Net Tropical Cyclone Activity (100%)	118	127	125

6 Discussion of 2008 Forecast

In the 25 years since our CSU forecast team began issuing seasonal hurricane forecasts, we have always tried to make our forecasts as transparent as possible. We have attempted to fully explain just how we make these forecasts and the physical reasons for why we proceeded as we did. When the season was over, we have gone through considerable effort to fully document all the tropical cyclones that occurred and to explain the broader-scale climate features with which they were associated. We have tried to be as honest as we could in discussing our forecast successes and our inevitable forecast failures. We have not been ashamed of our forecast failures. It is the nature of seasonal forecasting to sometimes be wrong. Our only regret would be if we had not given our best effort and turned over every stone in the quest for the best possible forecast. Anyone who wants to duplicate this early December forecast for the 2008 season or the hindcast statistics for the 1950-2007 seasons can do so through using the NCEP/NCAR reanalysis data which are readily available on the web.

It is surprising that such extended-range 6-11 month hindcasts are able to show statistical skill over long periods. This suggests that there are long-period memory signals within the global climate system. These long-period signals are certainly worthy of much further study. There are likely many new future extended-range forecast signals yet to be uncovered.

One learns more about how the global climate system functions by making real-time public forecasts that have your name on them. This demonstrates your personal commitment to your seasonal forecast methodology and your belief that your current forecast is able to beat climatology. You always learn more when your seasonal forecast busts than when it verifies. Busted forecasts drive us to explain the reasons for the failure and likely lead to enhanced skill in future years.

7 Landfall Probabilities for 2008

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 11). 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 11: 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 12 lists strike probabilities for the 2008 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 2008 is expected to be above its long-term average of 100, and therefore, United States landfall probabilities are above average.

Please visit the United States Landfalling Probability Webpage 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. Work is underway to improve the webpage interface and add additional functionality. More information will be available in the next couple of months.

Table 12: 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 2008. 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)	86% (79%)	76% (68%)	60% (52%)	90% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	67% (59%)	50% (42%)	36% (30%)	68% (60%)	89% (83%)
Florida plus East Coast (Regions 5-11)	58% (50%)	52% (44%)	37% (31%)	70% (61%)	87% (81%)

8 Was Global Warming Responsible for the Large Upswing in 2004-2005 US Hurricane Landfalls?

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Southeast 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).

The Atlantic has seen a very large increase in major hurricanes during the 13-year period of 1995-2007 (average 3.8 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. 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 from 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 other tropical cyclone basins besides the

Atlantic. 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 (< ±1^{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 from 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). 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 13). Although global mean ocean and Atlantic sea surface temperatures have increased by about 0.4^{o}C between these two 50-year periods (1900-1949 compared with 1958-2007), 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°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, both 2006 and 2007 had slightly below-average and average activity, respectively, and only one Category 1 hurricane made United States landfall.

Between 1966 and 2003, US major hurricane landfall numbers were below the long-term average. Of the 79 major hurricanes that formed in the Atlantic basin from 1966-2003, only 19 (24 percent) made US landfall. During the two seasons of 2004-2005, seven of 13 (54 percent) came ashore. Zero of the four major hurricanes that formed in 2006 and 2007 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 that 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 13: 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	$+0.4^{o}C$
1958-2007 (50 years)	165	82	33	

Although 2005 had a record number of tropical cyclones (28 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 $60^{o}W$ where surface observations were more plentiful. If we eliminate all the named storms of 2005 whose tracks were entirely east of $60^{o}W$ and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storms by seven (to 21) – 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 slightly below-average season in 2006 and average activity in 2007, 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 thousand of years.

9 Forthcoming Updated Forecasts of 2008 Hurricane Activity

We will be issuing seasonal updates of our 2008 Atlantic basin hurricane forecasts on **Tuesday April 8**, **Tuesday 3 June**, **Tuesday 5 August**, **Tuesday 2 September** and **Thursday 2 October 2008**. The 5 August, 2 September and 2 October forecasts will include separate forecasts of August-only, September-only and October-November Atlantic basin tropical cyclone activity. A verification and discussion of all 2008 forecasts will be issued in late November 2008. Our first seasonal hurricane forecast for the 2009 hurricane season will be issued in early December 2008. 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 14: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2002-2007.

2002	7 Dec. 2001	Update 5 April	Update 31 May	Update 7 August	Update 2 Sept.	Obs.
Hurricanes	8	7	6	4	3	4
Named Storms	13	12	11	9	8	12
Hurricane Days	35	30	25	12	10	11
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.
Hurricanes	8	8	8	8	7	8	7
Named Storms	12	12	14	14	14	14	14
Hurricane Days	35	35	35	25	25	35	32
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.
Hurricanes	7	8	8	7	8	9	9
Named Storms	13	14	14	13	16	15	14
Hurricane Days	30	35	35	30	40	52	46
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.
Hurricanes	6	7	8	10	10	11	14
Named Storms	11	13	15	20	20	20	26
Hurricane Days	25	35	45	55	45	40	48
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.
Hurricanes	9	9	9	7	5	6	5
Named Storms	17	17	17	15	13	11	9
Hurricane Days	45	45	45	35	13	23	20
Named Storm Days	85	85	85	75	50	58	50
Intense Hurricanes	5	5	5	3	2	2	2
Intense Hurricane Days	13	13	13	8	4	3	3
Net Tropical Cyclone Activity	195	195	195	140	90	95	85

2007	8 Dec. 2006	Update 3 April	Update 31 May	Update 3 Aug	Update 4 Sep	Update 2 Oct	Obs.
Hurricanes	7	9	9	8	7	7	6
Named Storms	14	17	17	15	15	17	14
Hurricane Days	35	40	40	35	35.50	20	11.25
Named Storm Days	70	85	85	75	71.75	53	33.50
Intense Hurricanes	3	5	5	4	4	3	2
Intense Hurricane Days	8	11	11	10	12.25	8	5.75
Accumulated Cyclone Energy	130	170	170	150	148	100	68
Net Tropical Cyclone Activity	140	185	185	160	162	127	94