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

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

(as of 3 June 2008)

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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Q: Why do you issue seasonal hurricane forecasts?

A: There is an inherent curiosity amongst the general public about how active or inactive the coming season is likely to be. Using historical data, there is considerable hindcast (using the past to predict the future) skill available for predicting the upcoming season. However, one must realize that these are statistical forecasts which will fail in some years. We find that we learn a lot from our forecast errors. Our end-of-the-season verifications give much information on explaining what the factors were that dictated the number and frequency of storms. Some of these factors may not have been considered in our forecasts for that particular year, and we often add new predictors in a quantitative or qualitative manner based on our end-of-the-season verifications.

There is also an educational component to these forecasts. For example, it was discovered about 25 years ago that El Niño reduced hurricane activity in the Atlantic. Through the issuing of these seasonal forecasts, this relationship has become well-known amongst the general public. Also, these seasonal hurricane forecasts have taught us many new relationships between climate features and Atlantic basin hurricanes such as sea surface temperatures, sea level pressures and levels of vertical wind shear in the tropical Atlantic. These relationships may have not been so readily elucidated had we not publicly made forecasts for which we are held accountable.

Q: Should coastal residents prepare differently if an active or inactive season is predicted?

A: Coastal residents need to prepare for every hurricane season, regardless of seasonal predictions. There is inherent uncertainty in seasonal predictions. Also, seasonal forecasts do not say anything about when or where storms are going to make landfall. We can only give probabilities of hurricane landfall. These probabilities are higher in active seasons than in inactive seasons.

Coastal residents also need to realize that the probability of landfall for any one point along the coastline is quite small in any year. However, one must also realize that it only takes one storm making landfall in your neighborhood to make it an active season for you. Major hurricanes have made U.S. landfall in inactive seasons (e.g., Hurricane Alicia - 1983 and Hurricane Andrew - 1992).

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2008

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Issue Date 7 December 2007	Issue Date 9 April 2008	Issue Date 3 June 2008
Named Storms (NS) (9.6)	13	15	15*
Named Storm Days (NSD) (49.1)	60	80	80
Hurricanes (H) (5.9)	7	8	8
Hurricane Days (HD) (24.5)	30	40	40
Intense Hurricanes (IH) (2.3)	3	4	4
Intense Hurricane Days (IHD) (5.0)	6	9	9
Accumulated Cyclone Energy (ACE) (96.1)	115	150	150
Net Tropical Cyclone Activity (NTC) (100%)	125	160	160

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

1) Entire U.S. coastline - 69% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 45% (average for last century is 31%)

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

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

Special Note

*Our early June forecast includes Tropical Storm Arthur which formed on May 31. Our prediction for the remainder of the season is for fourteen additional post-1 June named storms.

ABSTRACT

Information obtained through May 2008 indicates that the 2008 Atlantic hurricane season will be more active than the average 1950-2000 season. We estimate that 2008 will have about 8 hurricanes (average is 5.9), 15 named storms (average is 9.6), 80 named storm days (average is 49.1), 40 hurricane days (average is 24.5), 4 intense (Category 3-4-5) hurricanes (average is 2.3) and 9 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 135 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2008 to be approximately 160 percent of the long-term average. We have kept our seasonal forecast the same as it was in early April. The primary concern with our current seasonal forecast numbers is the continued ocean surface warming in the eastern and central tropical Pacific. Although it seems unlikely at this point, there is a possibility that an El Niño could develop this summer and fall.

This forecast is based on a new extended-range early June 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 neutral ENSO conditions to persist during the 2008 Atlantic basin hurricane season, although there is a possibility that a weak El Niño could develop.

This forecast also contains an analysis of all of our extended-range forecasts that have been issued for the last 13 years (1995-2007). These real-time operational early June forecasts have shown only marginal forecast skill over climatology during this 13-year period. This has occurred despite the fact that the skill over the hindcast period (varying from 40-55 years) showed appreciable skill (approximately 40-50% of the variance explained). Some of the relationships between individual predictors and the upcoming hurricane season that showed skill in earlier forecasts have not shown skill in recent forecasts. This has led to our development of a new, more skillful, 1 June hindcast scheme. Predictors in the new 1 June scheme show strong correlations with physical features known to impact hurricane activity during the August-October period.

The current early June forecast consists of a new set of two predictors along with an adjustment based on our early April forecast. This new forecast approach has shown appreciable hindcast skill ($r^2 = 0.66$) over the last 58 years (1950-2007). This scheme also shows remarkable hindcast skill over the more recent 13-year period from 1995-2007 ($r^2 = 0.79$) for which our previous early June scheme did not show significant real-time forecast 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 was 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 eight 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 awarded his Ph.D. degree in 2007. Klotzbach is currently spending most of his time working towards the improvement of these Atlantic basin seasonal hurricane forecasts.

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. We also thank Bill Thorson for technical advice and assistance.

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. 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 June Forecast Methodology

As was done with our early December and early April forecast schemes, we have developed a new 1 June prediction scheme this year. We have found that using two spring predictors and our early April hindcast, we can obtain early June hindcasts that show considerable skill over the period from 1950-2007. This new scheme also shows very good skill over the recent period from 1995-2007. Figure 1 illustrates the new forecast methodology that we are utilizing for all of our statistical forecasts this year. The basic methodology involves selecting two or three new predictors at each forecast lead time and combining these new predictors with the previous forecast. Our goal is to make the best possible prediction of Atlantic basin Net Tropical Cyclone (NTC) activity.

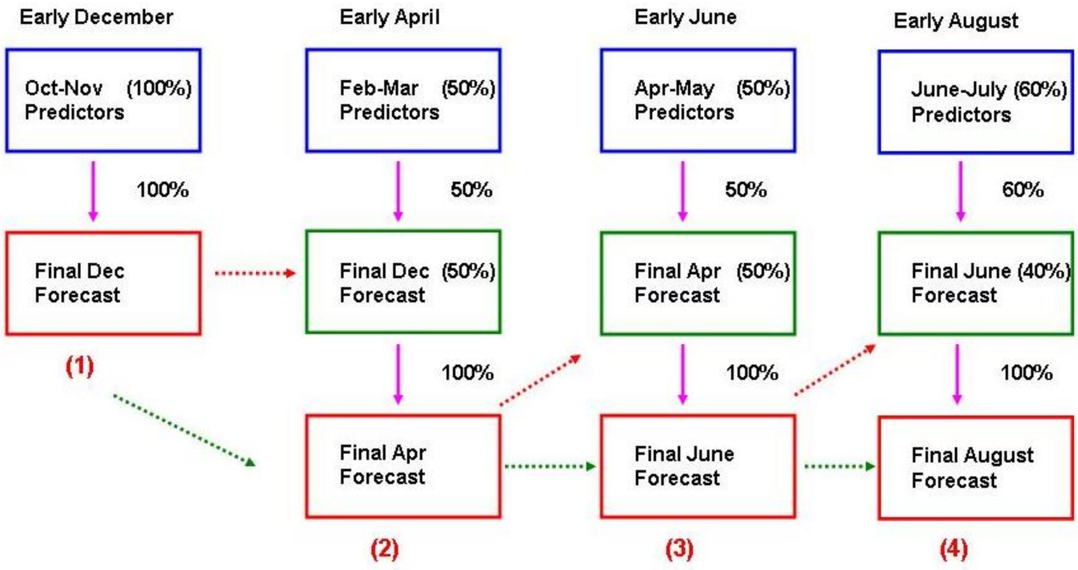

Figure 1: The new methodology utilized in calculating our statistical forecasts of seasonal NTC.

This new early June forecast scheme was created to overcome the lack of forecast skill that we have demonstrated over the last 13 years and especially the last four seasons of 2004-2007. This new early June scheme uses two new April-May predictors (weighted 50 percent) in combination with our early April prediction (weighted 50 percent) to predict seasonal NTC activity.

The forecast is created by combining the two April-May predictors using least-squared linear regression over the period from 1950-2007. The resulting hindcasts were then ranked in order from 1 (the highest value) to 58 (the lowest value). Table 1 displays hindcast NTC values from the combination of the two April-May predictors.

Table 1: Observed, hindcast and rank NTC hindcast values from the June NTC hindcast using the two spring predictors. Also displayed are the years in rank order.

Year	Observed NTC	Hindcast NTC	Rank Hindcast NTC	Rank Hindcast NTC	Year	Hindcast NTC
1950	230	175	2	1	2005	179
1951	115	73	46	2	1950	175
1952	93	145	12	3	1999	169
1953	116	168	4	4	1953	168
1954	124	149	9	5	2000	163
1955	188	149	10	6	1996	160
1956	66	98	35	7	1989	156
1957	82	98	36	8	1961	156
1958	133	130	17	9	1954	149
1959	94	139	13	10	1955	149
1960	92	113	25	11	1995	146
1961	211	156	8	12	1952	145
1962	32	112	27	13	1959	139
1963	111	85	41	14	1984	135
1964	160	134	15	15	1964	134
1965	82	121	19	16	1990	134
1966	134	110	28	17	1958	130
1967	93	99	34	18	1973	127
1968	39	54	52	19	1965	121
1969	150	85	42	20	2001	121
1970	62	101	33	21	2004	119
1971	91	45	55	22	1987	117
1972	27	28	58	23	2006	116
1973	50	127	18	24	1988	116
1974	72	62	51	25	1960	113
1975	89	89	39	26	1993	113
1976	82	40	57	27	1962	112
1977	45	65	50	28	1966	110
1978	83	49	53	29	1998	106
1979	92	70	48	30	1980	105
1980	129	105	30	31	2007	103
1981	109	97	37	32	2003	103
1982	35	46	54	33	1970	101
1983	31	68	49	34	1967	99
1984	74	135	14	35	1956	98
1985	106	95	38	36	1957	98
1986	37	40	56	37	1981	97
1987	46	117	22	38	1985	95
1988	118	116	24	39	1975	89
1989	130	156	7	40	1997	86
1990	98	134	16	41	1963	85
1991	57	71	47	42	1969	85
1992	64	74	45	43	2002	85
1993	52	113	26	44	1994	83
1994	35	83	44	45	1992	74
1995	222	146	11	46	1951	73
1996	192	160	6	47	1991	71
1997	51	86	40	48	1979	70
1998	166	106	29	49	1983	68
1999	185	169	3	50	1977	65
2000	134	163	5	51	1974	62
2001	129	121	20	52	1968	54
2002	80	85	43	53	1978	49
2003	173	103	32	54	1982	46
2004	228	119	21	55	1971	45
2005	273	179	1	56	1986	40
2006	85	116	23	57	1976	40
2007	99	103	31	58	1972	28

As mentioned before, the resulting June NTC hindcast ranks are then adjusted to obtain the final June NTC hindcast by using the following method:

Final June NTC Hindcast Rank = 0.5 * (Preliminary June NTC Hindcast Rank) + 0.5 * (Final April NTC Hindcast Rank).

The final NTC hindcast value was obtained by taking the final June NTC hindcast rank and assigning the observed NTC value for that rank. For example, if the final June NTC hindcast rank was 10 (the 10^{th} highest rank), the NTC value assigned for the prediction would be the 10^{th} highest observed rank, which in this case would be 166 NTC units. Final hindcast values are constrained to be between 40 and 200 NTC units.

Using the ranking method to arrive at our final forecast values is a new statistical forecasting approach for us. We find that using this method improves the hindcast skill of our forecasts somewhat (approximately 4-10%) and also allows for improved predictability of outliers.

This scheme only predicts Net Tropical Cyclone (NTC) activity, and the other seasonal predictors are then derived from this NTC prediction. These other seasonal predictors are calculated by taking the observed historical relationship between themselves and NTC. Relationships between NTC and other seasonal metrics such as named storms, named storm days and hurricane days were derived by breaking up the observed hurricane statistics from 1950-2007 into six groups based on NTC ranking. Equations for converting NTC to other seasonal parameters were then calculated by fitting a least squared regression equation to the observed data. These equations are listed below. Figure 2 illustrates predictions for various seasonal parameters given NTC values of 150, 100 and 50, respectively. Utilizing this approach gives slightly lower root mean squared errors and seems more physically appropriate than simply adjusting each seasonal parameter by a uniform NTC factor.

Named Storms = 5.0 + (0.049 * NTC)
Named Storm Days = 10.5 + (0.375 * NTC)
Hurricanes = 2.2 + (0.036 * NTC)
Hurricane Days = -0.6 + (0.231 * NTC)
Intense Hurricanes = -0.7 + (0.031 * NTC)
Intense Hurricane Days = -3.8 + (0.092 * NTC)
Accumulated Cyclone Energy = -6.6 + (0.978 * NTC)

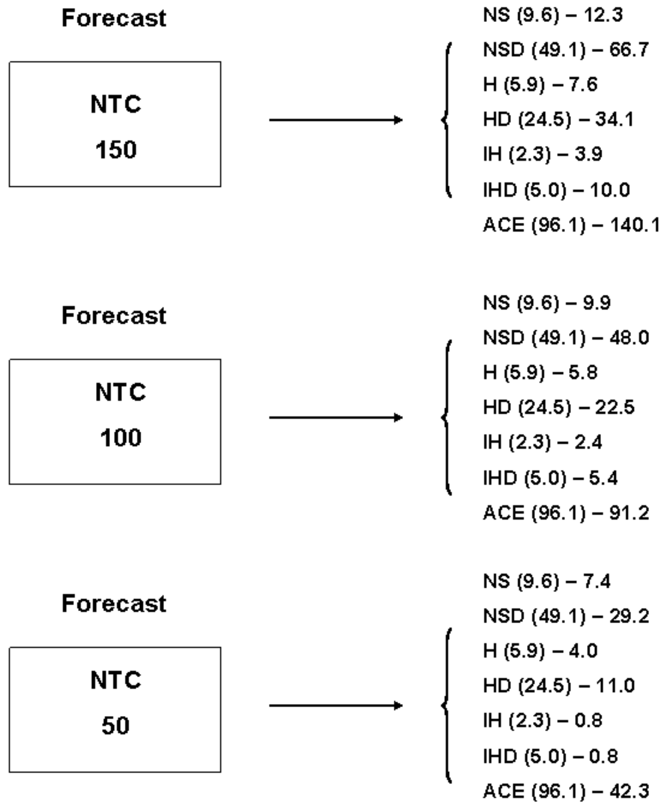

Figure 2: Schematic showing how predictions of 150, 100 and 50 NTC units, respectively, would be converted into predictions for other seasonal parameters. Numbers in parentheses are the climatological averages.

As mentioned before, our new statistical scheme shows enhanced levels of hindcast skill, explaining 66 percent of the variance from 1950-2007 and 79 percent of the variance from 1995-2007. We believe that we have solid physical links between these predictors and the upcoming Atlantic basin hurricane season.

Table 2 displays our early June hindcasts for 1950-2007 using the new statistical scheme, while Figure 3 displays observations versus NTC hindcasts. Our early June hindcasts have correctly predicted above- or below-average seasons in 46 out of 58 hindcast years (79%). These hindcasts have had a smaller error than climatology in 36 out of 58 years (62%). Our average hindcast error is 27 NTC units, compared with 44 NTC units for climatology. This scheme also shows considerable stability when broken in half, explaining 56 percent of the variance from 1950-1978 and 77 percent of the variance from 1979-2007. The scheme has shown remarkable skill over the past 28 years (since 1980). The model has had a smaller error than climatology in 20 out of the last 28 years (71%). 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 4 displays the locations of the two 1 June (using April-May data) predictors used in this scheme in map form. Please refer to Figure 2 of our early April forecast for locations of predictors used in our early April prediction scheme. Table 4 lists the three (two new spring predictors and our early April prediction) predictors that are utilized for this year's June forecast. A more extensive discussion of current conditions in the Atlantic and Pacific basins is provided in Sections 4 and 5.

Table 2: Observed versus hindcast NTC for 1950-2007 using the new statistical scheme. Average errors for hindcast NTC and climatological NTC predictions are given without respect to sign. Red bold-faced years in the "Hindcast NTC" column are years that we did not go the right way, while red 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 46 out of 58 years (79%), while hindcast improvement over climatology occurred in 36 out of 58 years (62%).

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1950	230	200	30	130	100
1951	115	**82**	34	15	**-18**
1952	93	**173**	-80	-7	**-73**
1953	116	200	-84	16	**-69**
1954	124	130	-6	24	18
1955	188	188	0	88	88
1956	66	98	-32	-34	2
1957	82	93	-12	-18	7
1958	133	134	-1	33	32
1959	94	**109**	-15	-6	**-9**
1960	92	**129**	-37	-8	**-29**
1961	211	200	11	111	100
1962	32	97	-65	-68	3
1963	111	**82**	29	11	**-18**
1964	160	133	27	60	33
1965	82	**124**	-42	-18	**-24**
1966	134	116	19	34	16
1967	93	82	11	-7	**-5**
1968	39	52	-13	-61	48
1969	150	106	44	50	6
1970	62	72	-11	-38	28
1971	91	62	29	-9	**-21**
1972	27	40	-13	-73	60
1973	50	92	-42	-50	8
1974	72	45	28	-28	0
1975	89	66	23	-11	**-12**
1976	82	51	31	-18	**-12**
1977	45	40	5	-55	51
1978	83	40	43	-17	**-26**
1979	92	40	52	-8	**-43**
1980	129	**80**	49	29	**-20**
1981	109	**85**	24	9	**-15**
1982	35	50	-14	-65	50
1983	31	40	-9	-69	60
1984	74	**115**	-41	-26	**-15**
1985	106	**92**	14	6	**-8**
1986	37	40	-3	-63	60
1987	46	91	-46	-54	9
1988	118	**93**	25	18	**-7**
1989	130	160	-30	30	0
1990	98	94	4	-2	**-2**
1991	57	46	11	-43	32
1992	64	40	24	-36	12
1993	52	83	-31	-48	17
1994	35	57	-22	-65	43
1995	222	185	37	122	85
1996	192	192	0	92	92
1997	51	64	-13	-49	36
1998	166	134	31	66	34
1999	185	200	-15	85	70
2000	134	150	-16	34	18
2001	129	111	18	29	11
2002	80	74	6	-20	14
2003	173	129	44	73	29
2004	228	166	63	128	66
2005	273	200	73	173	100
2006	85	**118**	-33	-15	**-18**
2007	99	89	10	-1	**-9**
Average	**106**	**104**	**27**	**44**	**+17**

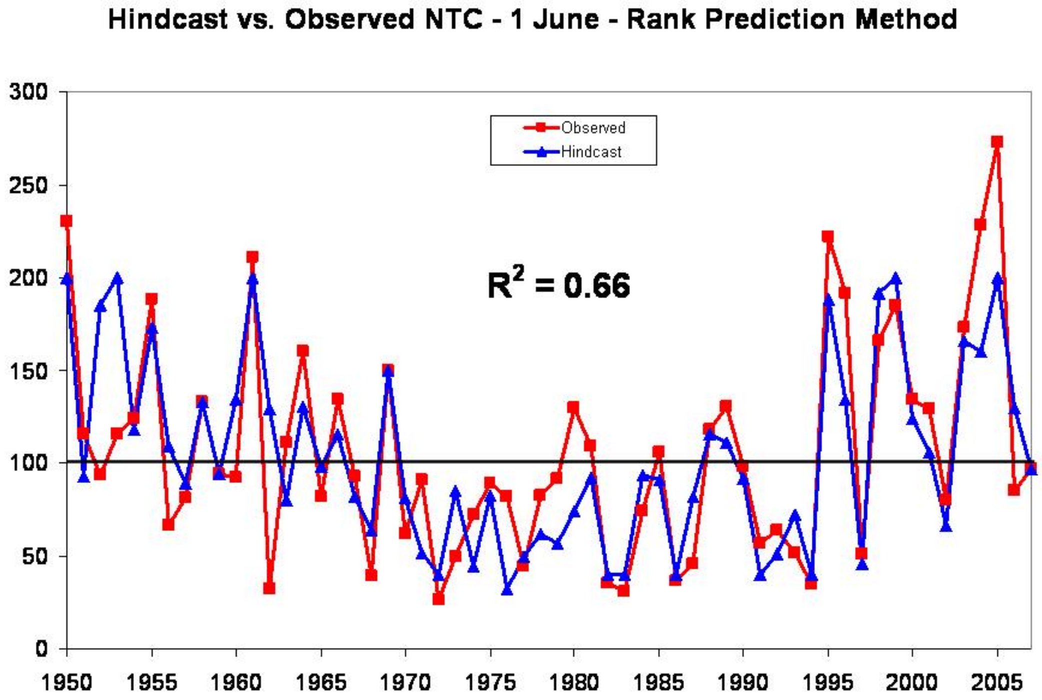

Figure 3: Observed versus hindcast values of NTC for 1950-2007.

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

Years	*Average Hindcast NTC*	*Average Observed NTC*
1950-1969 (Active)	126	117
1970-1994 (Inactive)	69	72
1995-2007 (Active)	139	155

New June Forecast Predictors

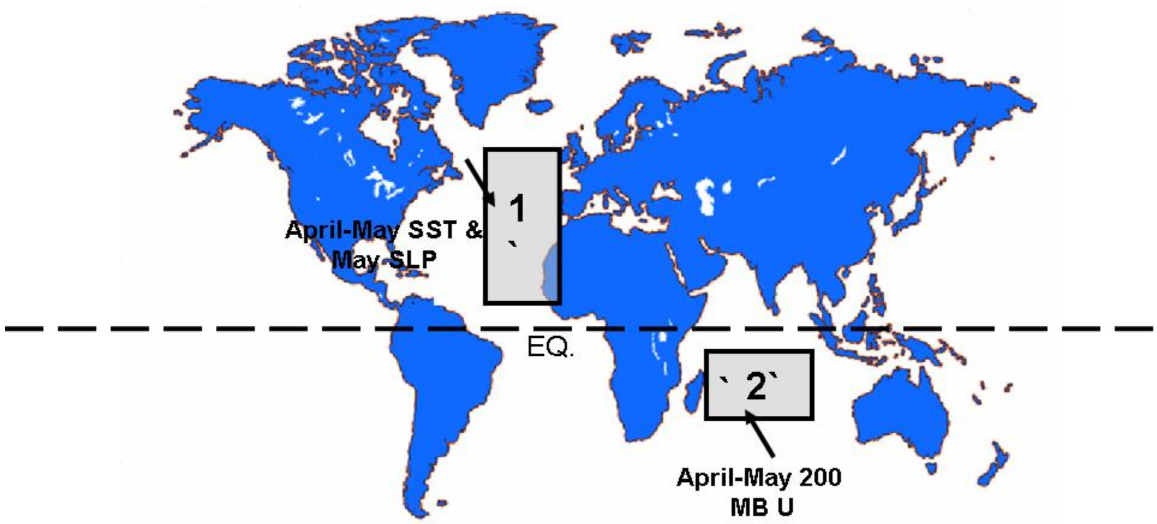

Figure 4: Location of new spring predictors for our June extended-range statistical prediction for the 2008 hurricane season.

Table 4: Listing of 1 June 2008 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	2008 Forecast Values
1) Subtropical Atlantic Index (+): April-May SST (20-50°N, 15-30°W) (+) & May SLP (10-35°N, 10-40°W) (-)	+1.6 SD
2) April-May 200 MB U (5-25°S, 50-90°E) (-)	+1.2 SD
3) Early April Hindcast (+)	186 NTC

There have been several early June hindcast years which were very successful. Table 5 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 45.

Table 5: The 10 years that our hindcasts were closest to observations.

Years	***Observed NTC***	***Hindcast NTC***
1954	124	130
1955	188	188
1958	133	134
1977	45	40
1983	31	40
1986	37	40
1990	98	94
1996	192	192
2002	80	74
2007	99	89

There have also been several years where the early June hindcast was a failure. Table 6 displays 10 of the 58 years that our extended-range hindcasts deviated the most from actual observations. For our 10 worst hindcast years, our average NTC error was 60, while the error using climatology was 61. For the 38 of 58 intermediate years between our 10 best and 10 worst early June NTC hindcasts, our average NTC error was 24 while the average NTC error using climatology was 40. The average hindcast error we would have had using climatology for all hindcasts was 44.

Over the entire 58-year period, our average hindcast error is 27 NTC units, compared with 44 NTC units using climatology. Our average early June hindcast error is approximately 40% less than the climatological error.

Table 6: The 10 years that our hindcasts deviated the most from observations.

Years	***Observed NTC***	***Hindcast NTC***
1952	93	173
1953	116	200
1962	32	97
1969	150	106
1979	92	40
1980	129	80
1987	46	91
2003	173	129
2004	228	166
2005	273	200

Table 7 displays how forecasts issued with our new hindcast scheme would have compared with our actual real-time forecasts issued in early June since 1995. Our more recent early 1 June real-time forecasts from 1995-2007 have not been particularly successful. The last 13 years of forecasts have correlated at 0.09 with observations from

1995-2007. In contrast, the new hindcast scheme we are using for this year correlates at 0.89 with the last 13 years of observations.

Another way of evaluating model skill is examining errors compared with climatology. Our real-time June NTC predictions have an error of 61 NTC units over the period from 1995-2007, while a climatological prediction has an error of 69 NTC units. Our new June hindcast has an average error of 28 NTC units over the past thirteen years, an improvement of approximately 55% when compared with our real-time early June forecasts. This is an improvement of approximately 60% when compared with a climatological NTC forecast.

Over the last four years (2004-2007), the improvement of our new model over our real-time forecasts and climatology is also considerable. The average error of our real-time forecasts was 96 NTC units, compared with 79 NTC units for climatology and 45 NTC units using our new model. The new hindcast model improves upon our real-time forecasts by approximately 60% and upon climatology by approximately 40% over the period from 2004-2007.

Our new hindcast scheme had a smaller NTC error than our real-time June NTC prediction in 11 out of the past 13 years and in each of the last four years. Our new hindcast scheme has also had a smaller NTC error than a climatological prediction in 11 out of 13 years and in 3 of the last 4 years.

Table 7: Real-time early June forecasts, hindcasts based on our new early June scheme and observed NTC since 1995.

Years	***Real-Time June NTC Forecasts***	***New June NTC Hindcasts***	***Observed NTC***
1995	140	185	222
1996	95	192	192
1997	110	64	51
1998	100	134	166
1999	160	200	185
2000	160	150	134
2001	120	111	129
2002	100	74	80
2003	145	129	173
2004	145	166	228
2005	170	200	273
2006	195	118	85
2007	185	89	99
Verification Correlation	**0.09**	**0.89**	

2.1 Physical Associations among Predictors Listed in Table 4

The locations and brief descriptions of our two new spring predictors for our June statistical forecast are now discussed. It should be noted that both forecast parameters correlate significantly with physical features during August through October that are known to be favorable for elevated levels of hurricane activity. For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August-October values of sea surface temperature, sea level pressure, 925 mb zonal wind, and 200 mb zonal wind, respectively. For more information about the predictors utilized in our early April statistical forecast (used as 50% of our early June forecast), please refer to our early April 2008 forecast:
http://tropical.atmos.colostate.edu/Forecasts/2008/apr2008/apr2008.pdf

1. Subtropical Atlantic Index (+): April-May SST (20-50°N, 15-30°W) (+) & May SLP (10-35°N, 10-40°W) (-)

A combination of above-normal sea surface temperatures (SSTs) in the eastern subtropical Atlantic and lower-than-normal sea level pressures in the subtropical Atlantic is associated with a weakened Azores high and reduced trade wind strength during the late spring (Knaff 1997). This combined index in April-May is strongly correlated with weaker trade winds, lower-than-normal sea level pressures and above-normal SSTs in the tropical Atlantic during the following August-October period (Figure 5). 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. Stronger-than-normal values of this index correlate quite strongly (~0.5) with active Atlantic basin tropical cyclone seasons.

Predictor 2. April-May 200 MB U in the South Indian Ocean (-)

(5-25°S, 50-90°E)

Upper-level easterly wind anomalies in the South Indian Ocean during April-May are associated with anomalously low sea level pressure and anomalous upper-level divergence in the western tropical Pacific and anomalously high sea level pressure and anomalous upper-level convergence in the eastern tropical Pacific. These features are associated with an active Walker Circulation, which is typically observed in cool ENSO years. Figure 6 displays the significant correlations that are achieved between values of this predictor in April-May and August-October sea surface temperatures, sea level pressure and 925 and 200 mb zonal wind anomalies, respectively. Note the anomalous easterly winds that are typically observed at upper levels over the tropical Atlantic and Caribbean in August-October when upper-level easterlies exist in the South Indian Ocean in April-May. These anomalous easterlies, combined with anomalous westerlies at 925 mb, reduce vertical wind shear across the tropical Atlantic providing a more favorable environment for tropical cyclone formation and intensification. Predictor values have been trending slightly more positive in this region since the 1950s. We have removed the trend in zonal wind anomalies from our predictor calculations to avoid a potentially nonphysical lowering of forecast values, as there is some uncertainty as to the quality of the NCEP/NCAR reanalysis data for upper-level winds in the 1950s.

This predictor is located in an area that has not been considered in our previous early June forecasts. Since this predictor is new, we have gone through extensive testing to make sure that the predictor is valid. The predictor shows considerable stability when evaluated over both the 1950-1989 period and the 1990-2007 period. It correlates with NTC at -0.57 over the period from 1950-1989 and correlates with NTC at -0.60 over the period from 1990-2007. The correlation with NTC over the full time period from 1950-2007 is -0.59 (Figure 7).

When we examined the top 10 years when the predictor had its highest values and compared them with the bottom 10 years when the predictor had its lowest values, considerable differences were evident. In the 10 years when the zonal winds had their largest easterly anomalies, an average of 140 NTC units were observed, compared with an average of only 60 NTC units in the 10 years when the zonal winds had their largest westerly anomalies (Figure 8).

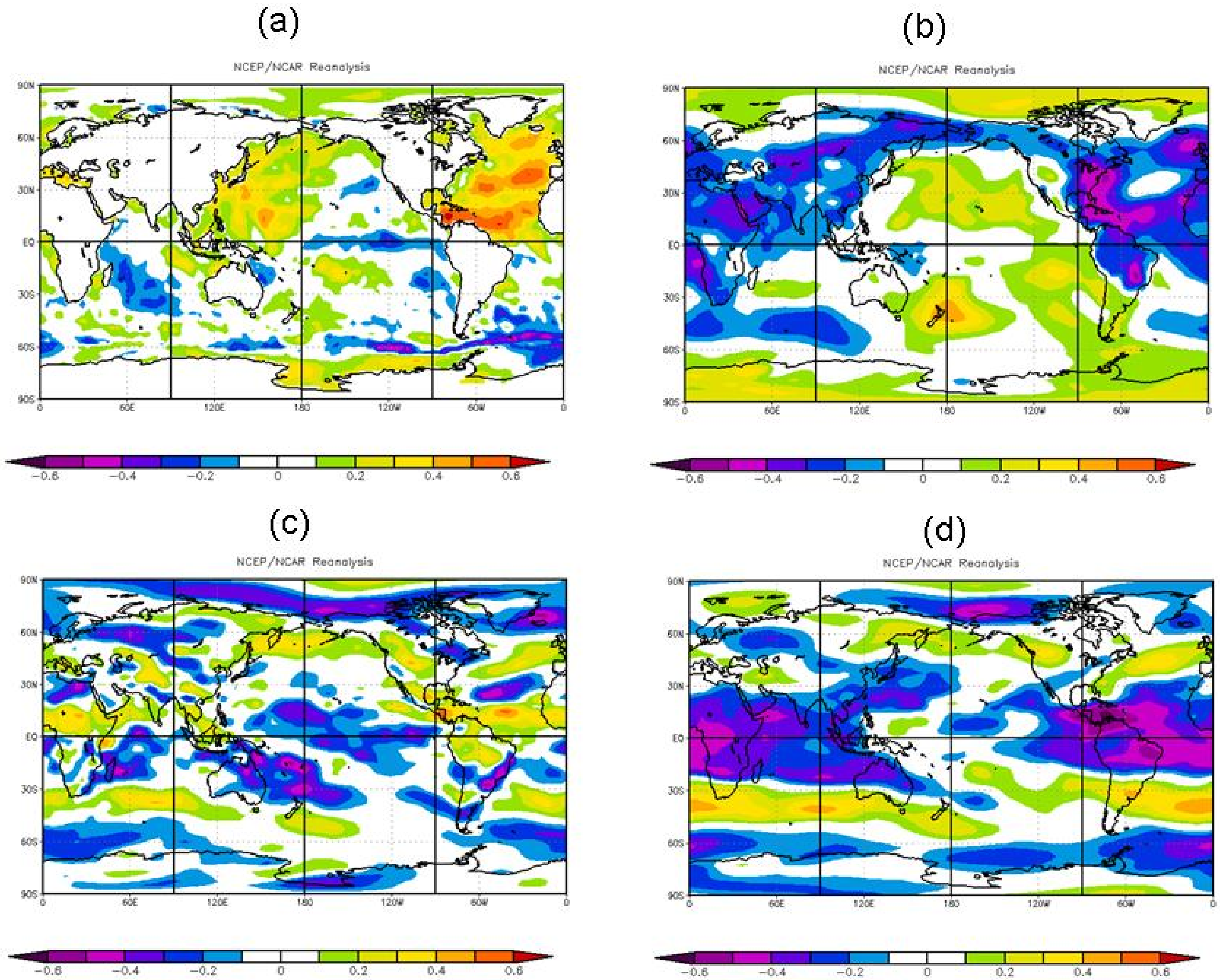

Figure 5: Linear correlations between the subtropical Atlantic index (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

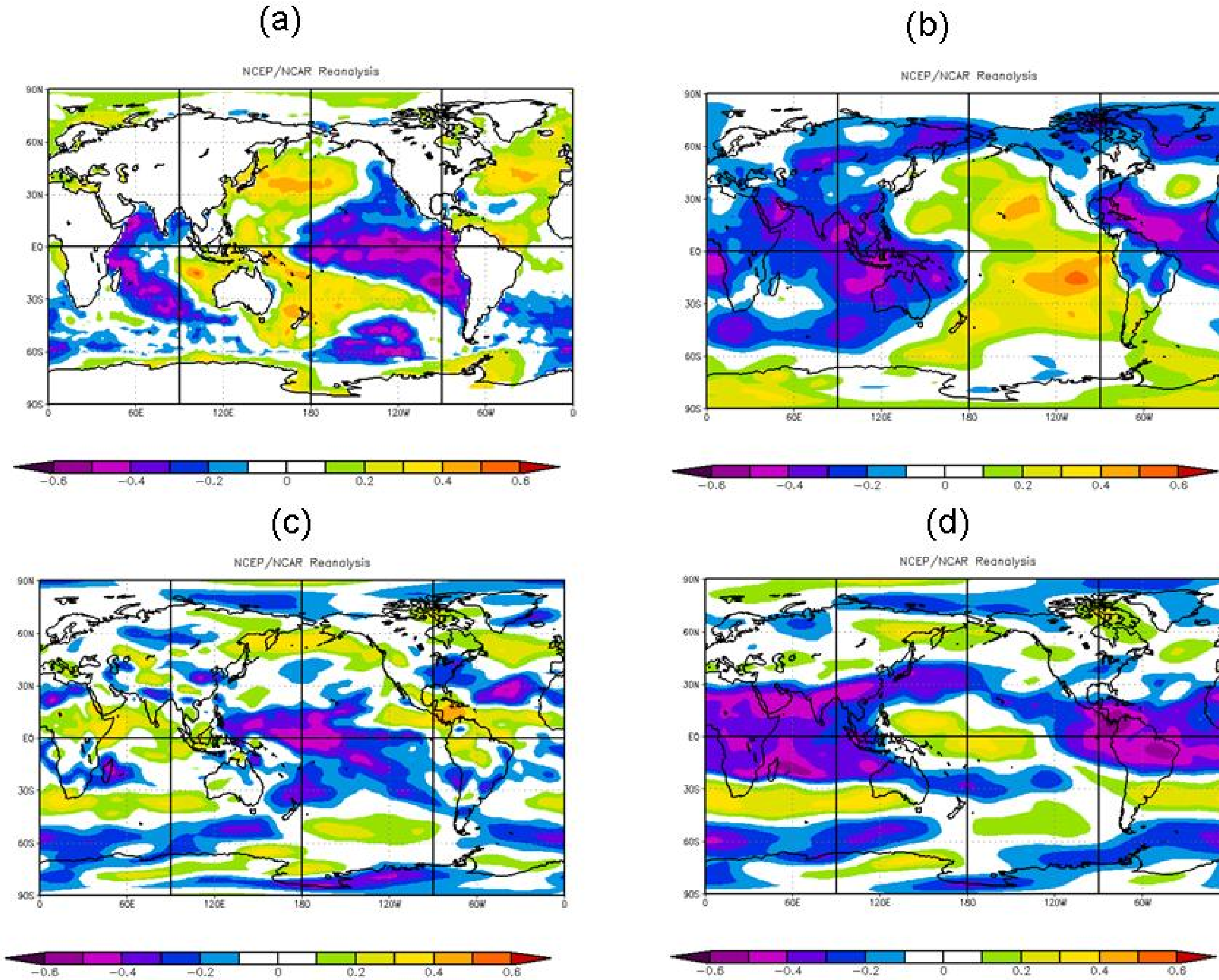

Figure 6: Linear correlations between April-May 200 mb U in the South Indian Ocean (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity. Zonal wind values have been multiplied by -1 to allow for easy comparison with Figure 5.

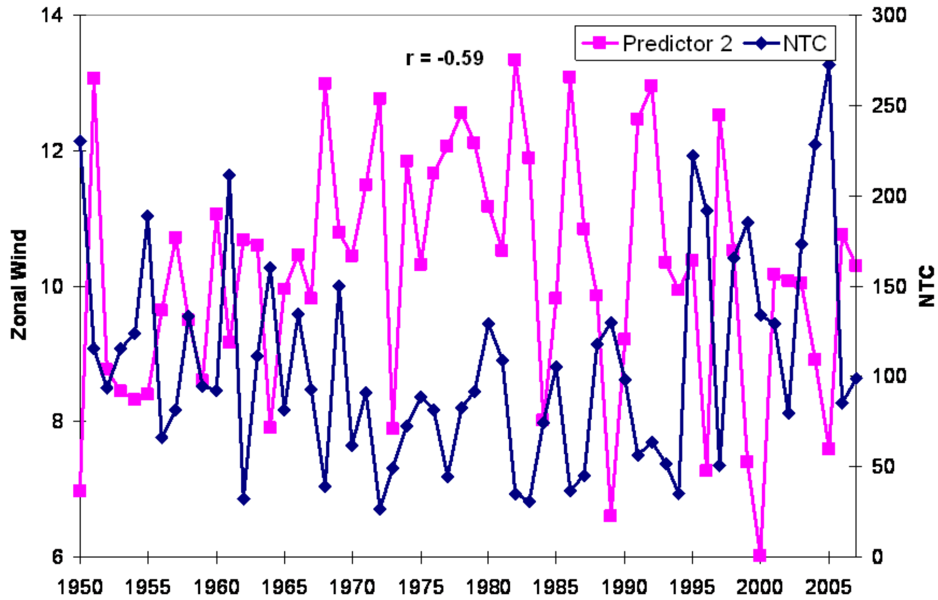

Figure 7: April-May values of Predictor 2 (pink line) and Atlantic basin NTC activity (blue line). Note the strong negative correlation between the two curves.

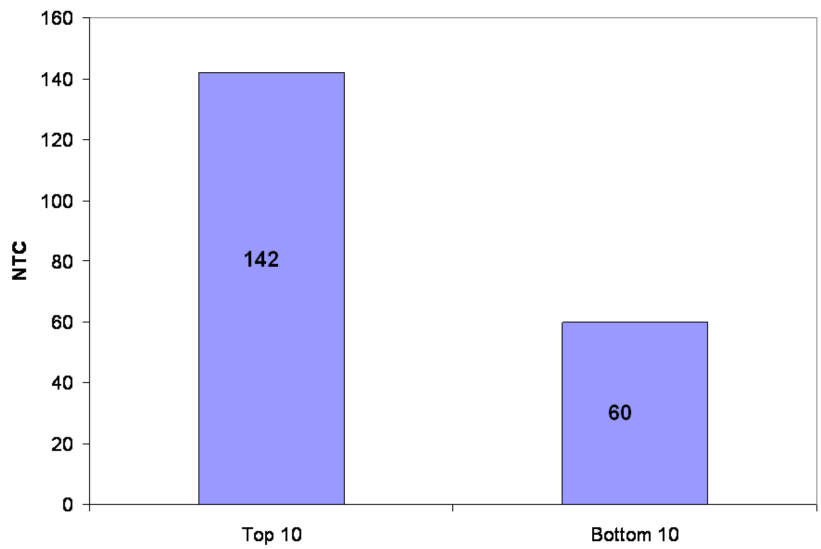

Figure 8: Top 10/bottom 10 ratios for Predictor 2. Note that much larger values of NTC were observed when Predictor 2 had anomalous easterly winds.

3 Forecast Uncertainty

One of the questions that we are asked fairly frequently regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. Obviously, our predictions are our best estimate, but certainly, there is with all forecasts an uncertainty as to how well they will verify. In the case of this early June prediction, our primary uncertainty is the future state of ENSO.

We have calculated our uncertainty estimates based upon our statistical hindcast data. What we have done is to generate hindcast predictions for each individual index back to 1950. Then, standard deviations of the absolute value of hindcast errors are computed. Assuming a normalized error distribution, 2/3 of hindcasts will fall within one standard deviation of the absolute value of hindcast errors. For example, if there were 60 years of hindcast data, 40 of these years would have had hindcasts within one standard deviation of the model hindcast value. Table 9 provides the standard deviation of errors for each individual forecast parameter, along with our 1 and 2 standard deviation error estimate for each seasonal parameter for this early June prediction. Assuming the future behaves similarly to the way that the past has behaved, 67% of predictions should lie within one standard deviation of the forecast (as listed in Table 9), while 95% of predictions should lie within two standard deviations of the forecast.

Table 9: Model hindcast error over the 1950-2007 period and our 2008 hurricane forecast. Uncertainty ranges are also given in one and two standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2008 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)	Uncertainty Range – 2 SD (95% of Forecasts Likely in this Range)
Named Storms (NS)	2.2	15	12.8 – 17.2	10.6 – 19.4
Named Storm Days (NSD)	9.9	80	70.1 – 89.9	60.2 – 99.8
Hurricanes (H)	1.2	8	6.8 – 9.2	5.6 – 10.4
Hurricane Days (HD)	6.6	40	33.4 – 46.6	26.8 – 53.2
Intense Hurricanes (IH)	0.7	4	3.3 – 4.7	2.6 – 5.4
Intense Hurricane Days (IHD)	2.5	9	6.5 – 11.5	4.0 – 14.0
Accumulated Cyclone Energy (ACE)	22.2	150	127.8 – 172.2	105.6 – 194.4
Net Tropical Cyclone (NTC) Activity	19.8	160	140.2 – 179.8	120.4 – 199.6

4 Analog-Based Predictors for 2008 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2008. These years also provide useful clues as to likely trends in activity that the forthcoming 2008 hurricane season may bring. For this early

June forecast we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current April-May 2008 conditions. Table 10 lists our analog selections.

We select prior hurricane seasons since 1949 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that had near-neutral ENSO conditions and above-average tropical Atlantic and far North Atlantic sea surface temperatures during April-May.

There were four hurricane seasons since 1949 with characteristics most similar to what we observed in April-May 2008. The best analog years that we could find for the 2008 hurricane season were 1951, 1961, 2000, and 2001. We anticipate that 2008 seasonal hurricane activity will have activity in line with what was experienced in the average of these four years. We believe that 2008 will have above-average activity in the Atlantic basin.

Table 10: Best analog years for 2008 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1951	10	57.75	8	36.25	5	8.25	137	148
1961	11	70.75	8	47.50	7	24.50	205	230
2000	14	67.00	8	32.75	3	5.00	116	130
2001	15	64.25	9	25.50	4	4.25	106	134
Mean	12.5	64.9	8.3	35.5	4.8	10.5	141	161
2008 Forecast	15	80	8	40	4	9	150	160

5 ENSO

The moderate to strong La Niña event that occurred during the winter of 2007-2008 has mostly dissipated. Sea surface temperature anomalies are about average in the eastern Pacific while remaining below average in the central tropical Pacific. Table 11 displays March and May SST anomalies for several Nino regions. Note that the central Pacific has continued to warm over the past couple of months, while temperatures in the eastern Pacific have cooled.

Table 11: March and May 2008 SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. May-March SST anomaly differences are also provided.

Region	March SST Anomaly (°C)	May SST Anomaly (°C)	May - March SST Anomaly (°C)
Nino 1+2	0.8	0.1	-0.7
Nino 3	-0.5	0.1	0.6
Nino 3.4	-1.1	-0.5	0.6
Nino 4	-1.3	-0.6	0.5

The big question is whether this current observed warming will continue through this year's hurricane season. At this time, it appears unlikely that ENSO will transition to warm conditions by the August-October (ASO) period. None of the statistical models and only one of the dynamical models currently predicts an El Niño event over the ASO period (El Niño is defined as > 0.5°C anomaly) (Figure 9). The average of all statistical and dynamical models calls for a Nino 3.4 SST anomaly of -0.2°C over the August-October period.

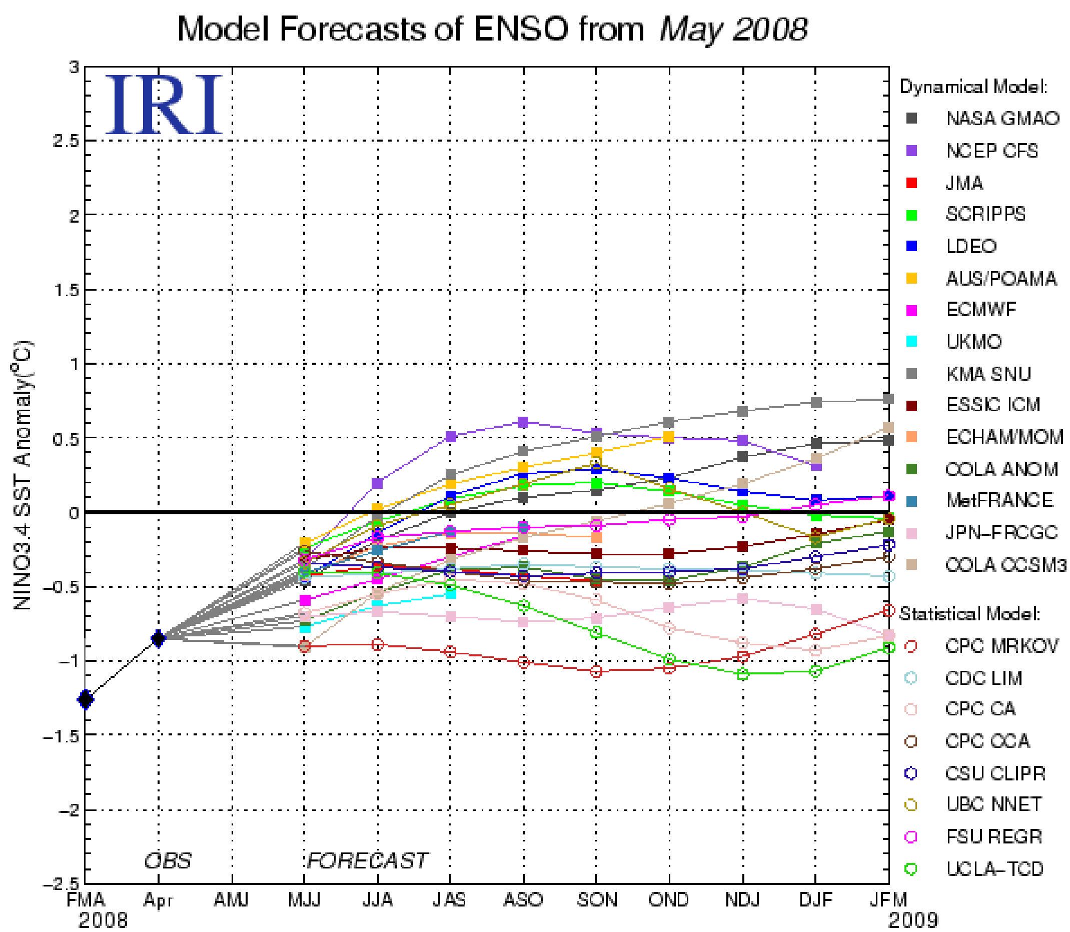

Figure 9: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

Based on this information, we believe that current cool neutral ENSO conditions will likely continue to moderate over the next couple of months. We do not foresee a transition to El Niño conditions during the 2008 hurricane season at this time, although this is certainly a possibility. Despite the fact that upper ocean heat content values have been increasing in the eastern and central tropical Pacific, we are not prepared to forecast an El Niño event. Due to the increasingly favorable conditions in the tropical Atlantic (see Section 6), we believe that even a weak El Niño event could certainly lead to an active hurricane season. Table 12 displays several active Atlantic hurricane seasons that took place despite warm El Niño conditions.

Table 12: Active Atlantic basin hurricane seasons with weak El Niño (0.4 – 0.8°C) conditions.

Year	ASO Nino 3.4 SST Anomaly (°C)	Atlantic Basin NTC
1951	0.6	148
1953	0.4	127
1969	0.7	178
2004	0.8	229

6 Current Atlantic Basin Conditions

Current conditions in the Atlantic basin are quite favorable for an active hurricane season. These conditions have trended even more favorable than were observed in early April. Our early June Atlantic predictor (Predictor 1) calls for a very active hurricane season in 2008. The current sea surface temperature pattern in the Atlantic is a pattern typically observed before very active seasons. Waters off the coast of Iberia as well as the eastern tropical Atlantic are very warm right now (Figure 10). In addition, cool SST anomalies in the central tropical Atlantic have moderated considerably over the past month (Figure 11). Sea level pressures have been below average throughout most of the eastern Atlantic during the month of May (Figure 12).

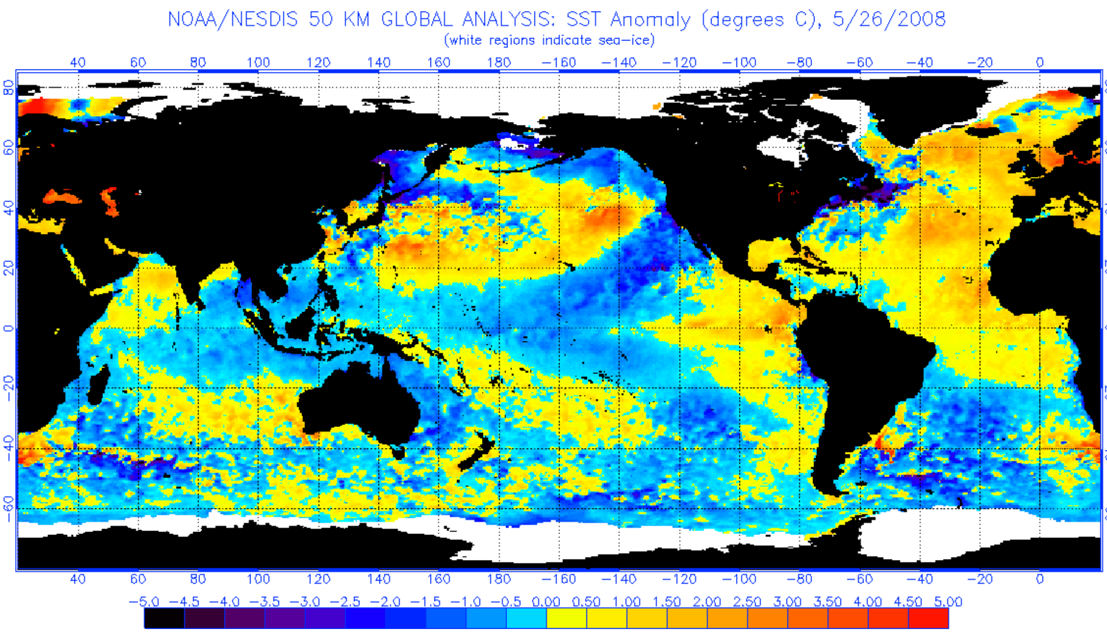

Figure 10: Current SST anomaly pattern as estimated from satellite. Note the warm anomalies in the eastern tropical and subtropical Atlantic. Figure courtesy of NOAA/NESDIS.

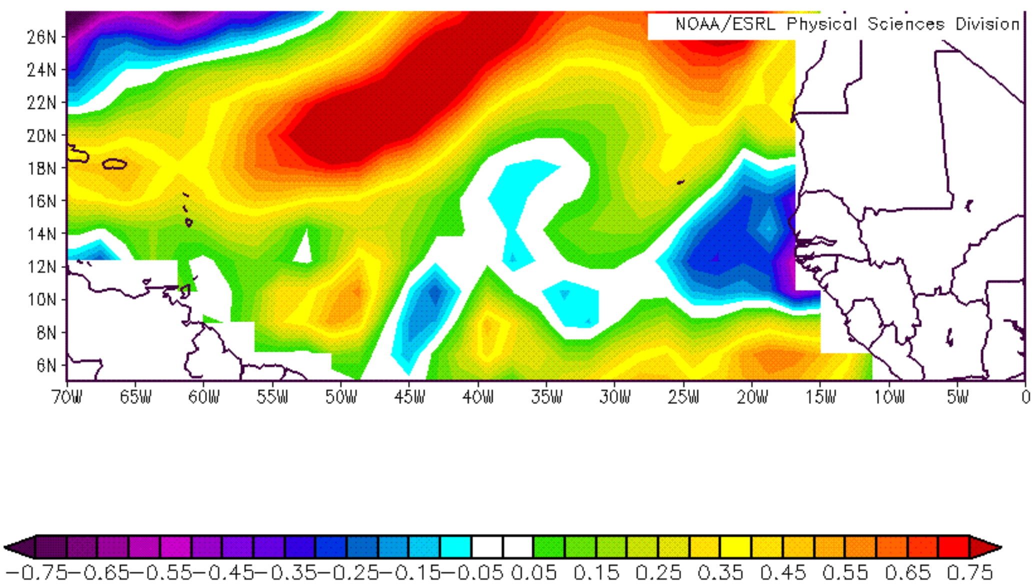

Figure 11: May minus April 2008 SST anomaly change (°C). Note the anomalous warming that has taken place throughout most of the tropical and subtropical Atlantic.

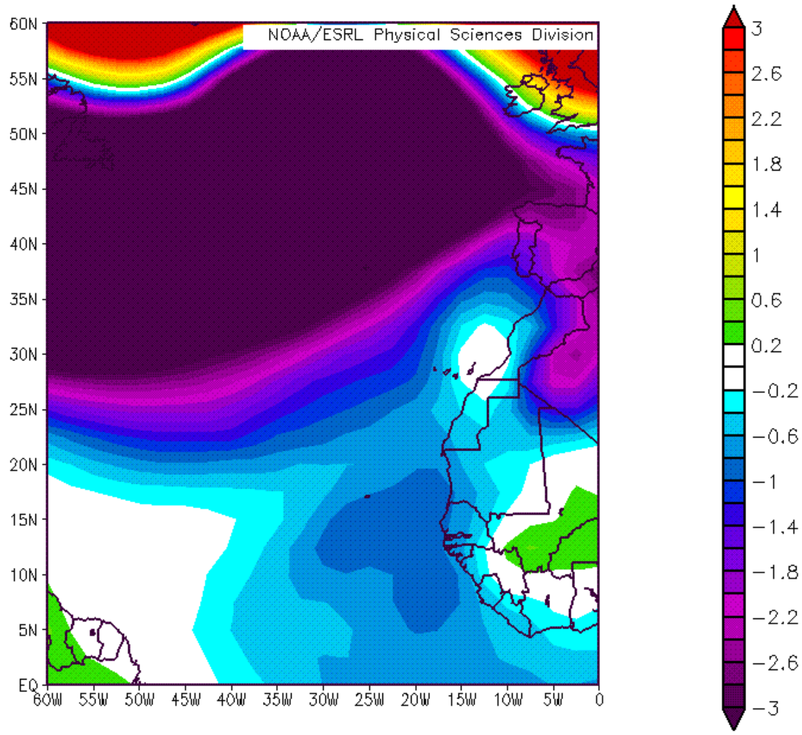

Figure 12: Observed May 2008 sea level pressure anomalies in the eastern Atlantic.

7 Adjusted 2008 Forecast

Table 13 shows our final adjusted early June 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 either of these schemes. Both our statistical and our analog forecast schemes indicate activity at above-average levels. We foresee an active Atlantic basin hurricane season.

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). Also, the Azores High remains weak and is expected to promote weaker-than-normal trade winds over the next few months enhancing warm SST anomalies in the tropical and subtropical Atlantic – all factors that enhance hurricane activity.

Table 13: Summary of our early June 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)	11.5	12.5	15
Named Storm Days (49.1)	60.4	64.9	80
Hurricanes (5.9)	7.0	8.3	8
Hurricane Days (24.5)	30.2	35.5	40
Intense Hurricanes (2.3)	3.4	4.8	4
Intense Hurricane Days (5.0)	8.4	10.5	9
Accumulated Cyclone Energy Index (96.1)	123	141	150
Net Tropical Cyclone Activity (100%)	133	161	160

8 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 made 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 did not turn over every stone in the quest for the best possible forecast. In addition, forecast failures drive us to improve our statistical forecast models by accounting for our errors. Our forecast failures of 2006 and 2007 were the impetus to drive us to develop new and improved forecast schemes. All of our statistical models for the 2008 hurricane season are new and contain what we believe to be improved model physics. Anyone who wants to duplicate this early June 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 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 often lead to enhanced forecast skill in future years. Our past 24 years (1984-2007) of June forecasts for named storms have correlated with observations at 0.57 (Table 14).

Table 14: Predicted versus observed named storms from 1 June over the period from 1984-2007.

Year	Predicted Named Storms	Observed Named Storms
1984	10	12
1985	11	11
1986	8	6
1987	8	7
1988	11	12
1989	7	11
1990	11	14
1991	8	8
1992	8	6
1993	11	8
1994	9	7
1995	12	19
1996	10	13
1997	11	7
1998	10	14
1999	14	12
2000	12	14
2001	12	15
2002	11	12
2003	14	16
2004	14	14
2005	15	27
2006	17	10
2007	17	15
Correlation		**0.57**

9 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 20^{th} 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 (NTC) activity (Table 15). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. 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 15: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 IH, and 5 IHD would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

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

Table 16 lists strike probabilities for 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 and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine. A new webpage interface has recently been uploaded to the website. Additional functionality will be added in the next couple of months.

Table 16: Estimated probability (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (region 1-4), and along the Florida 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)	92% (79%)	84% (68%)	69% (52%)	95% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	76% (59%)	59% (42%)	44% (30%)	77% (60%)	94% (83%)
Florida plus East Coast (Regions 5-11)	67% (50%)	60% (44%)	45% (31%)	78% (61%)	93% (81%)

10 Observed and Hindcast Early June US Tropical Cyclone Landfall Frequency as Related to NTC

Table 17 shows the number of tropical cyclones making US landfall for the 15 of the last 58 years (1950-2007) when observed values of NTC activity were 130 or greater compared with the 15 out of the last 58 years when observed values of NTC activity were less than 65. Note the large differences in landfall frequency. There is no question but that, based on long-period statistical averages, heightened levels of Atlantic basin tropical cyclone activity lead to more frequent US landfall events. This association may not hold for individual years or for a small sample of years, but certainly, in a long-term average sense, more active seasons have more landfalling hurricanes.

Table 17: Comparison of US tropical cyclone landfall frequency for the 15 years between 1950-2007 when NTC activity was 130 or higher versus the 15 years when NTC was observed to be lower than 65.

	Named Storm Landfalls	Hurricane Landfalls	Major Hurricane Landfalls
15 Years When NTC >130	66	41	18
15 Years When NTC < 65	32	14	5
Ratio	**2.1**	**2.9**	**3.6**

Table 18 illustrates how well hindcast NTC values of our new 1 June forecast scheme are related to various categories of US tropical cyclone landfall.

Table 18: U.S. tropical cyclone landfalls which occurred in our highest 5, 10, 15 and 25 1 June hindcast years of NTC versus the lowest 5, 10, 15, and 25 1 June hindcast years over the period from 1950-2007.

	Named Storm Landfalls	Hurricane Landfalls	Major Hurricane Landfalls
Top 5 Years (NTC >160)	25	15	7
Bottom 5 Years (NTC < 50)	13	8	0
Top 10 Years (NTC > 146)	52	31	15
Bottom 10 Years (NTC < 70)	23	14	5
Top 15 Years (NTC > 133)	70	41	17
Bottom 15 Years (NTC < 85)	39	20	5
Top 25 Years (NTC > 112)	103	54	24
Bottom 25 Years (NTC < 90)	64	33	10

Note that our new early June hindcast scheme is especially skillful at distinguishing the probability of US major (Category 3-4-5) hurricane landfall frequency. On a long-period normalized basis, major hurricanes cause approximately 80-85 percent of US tropical cyclone-related destruction. Note that our 5, 10, 15 and 25 highest NTC hindcast years experienced 7, 15, 17, and 24 major hurricane landfalls, respectively. This contrasts with our 5, 10, 15, and 25 lowest NTC hindcast values which experienced 0, 5, 5, and 10 major hurricane landfall events.

There should be no question that higher values of our early June hindcast of NTC give a significantly higher probability of US landfall events, especially for major hurricane landfalls. However, one should also realize that this strong long-period statistical relationship may not work in individual years.

11 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 19). 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 (Humberto) 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 19: 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°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°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 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.

12 Forthcoming Updated Forecasts of 2008 Hurricane Activity

We will be issuing updates of our 2008 Atlantic basin hurricane forecasts on **Tuesday 5 August**, **Tuesday 2 September** and **Wednesday 1 October 2008 –** note date change for October update. The 5 August, 2 September and 1 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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14 Citations and Additional Reading

Blake, E. S., 2002: Prediction of August Atlantic basin hurricane activity. Dept. of Atmos. Sci. Paper No. 719, Colo. State Univ., Ft. Collins, CO, 80 pp.

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

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

Elsner, J. B., G. S. Lehmiller, and T. B. Kimberlain, 1996: Objective classification of Atlantic hurricanes. *J. Climate,* 9, 2880-2889.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and Implications. *Science*, 293, 474-479.

Goldenberg, S. B. and L. J. Shapiro, 1996: Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate*, 1169-1187.

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

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

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

Gray, W. M., and P. J. Klotzbach, 2003 and 2004: Forecasts of Atlantic seasonal and monthly hurricane activity and US landfall strike probability. Available online at http://hurricane.atmos.colostate.edu

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

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

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

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

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

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

Klein, S. A., B. J. Soden, and N-C Lau, 1999: Remote sea surface temperature variations during ENSO: Evidence for a tropical atmospheric bridge. *J. Climate*, 12, 917-932.

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

Klotzbach, P. J., 2006: Trends in global tropical cyclone activity over the past twenty years (1986-2005). *Geophys. Res. Lett.*, 33, doi:10.1029/2006GL025881.

Klotzbach, P. J., 2007: Revised prediction of seasonal Atlantic basin tropical cyclone activity from 1 August. *Wea. and Forecasting*, 22, 937-949.

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

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

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

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

Kossin, J. P., and D. J. Vimont, 2007: A more general framework for understand Atlantic hurricane variability and trends. *Bull. Amer. Meteor. Soc.*, 88, 1767-1781.

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

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

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

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

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

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

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

Landsea, C.W. et al., 2005: Atlantic hurricane database re-analysis project. Available online at http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html

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

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1997: A single sample estimate of shrinkage in meteorological forecasting. *Wea. Forecasting*, 12, 847-858.

Pielke, Jr. R. A., and C. W. Landsea, 1998: Normalized Atlantic hurricane damage, 1925-1995. *Wea. Forecasting*, 13, 621-631.

Rasmusson, E. M. and T. H. Carpenter, 1982: Variations in tropical sea-surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.*, 110, 354-384.

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

15 Verification of Previous Forecasts

Table 20: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2002-2007. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

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	15
Hurricane Days	35	40	40	35	35.50	20	11.25
Named Storm Days	70	85	85	75	71.75	53	34.50
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	97