FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY, AUGUST MONTHLY ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITY FOR 2008

We foresee a very active Atlantic basin tropical cyclone season in 2008. We have raised our forecast from our early June prediction. We anticipate an above-average probability of United States major hurricane landfall.

(as of 5 August 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 hurricane season is likely to be. Using historical data, there is considerable hindcast (using the past to predict the future) skill available for predicting the hurricane 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 tropical cyclones. Some of these factors may not have been considered in our forecasts for that particular year, and we sometimes add new predictors for future forecasts 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	Observed Activity Through July 2008	Forecast Activity After 1 August	Total Seasonal Forecast
Named Storms (NS) (9.6)	13	15	15	4	13	17
Named Storm Days (NSD) (49.1)	60	80	80	26	64	90
Hurricanes (H) (5.9)	7	8	8	2	7	9
Hurricane Days (HD) (24.5)	30	40	40	8.75	36.25	45
Intense Hurricanes (IH) (2.3)	3	4	4	1	4	5
Intense Hurricane Days (IHD) (5.0)	6	9	9	0.75	10.25	11
Accumulated Cyclone Energy (ACE) (96.1)	115	150	150	37	138	175
Net Tropical Cyclone Activity (NTC) (100%)	125	160	160	37	153	190

POST 1-AUGUST PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING COASTAL AREAS:

1) Entire U.S. coastline - 67% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 43% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 42% (average for last century is 30%)

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

ABSTRACT

Information obtained through July 2008 indicates that the 2008 Atlantic hurricane season will be much more active than the average of the 1950-2000 seasons. We estimate that the full 2008 Atlantic basin hurricane season will have about 9 hurricanes (average is 5.9), 17 named storms (average is 9.6), 90 named storm days (average is 49.1), 45 hurricane days (average is 24.5), 5 intense (Category 3-4-5) hurricanes (average is 2.3) and 11 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall for the remainder of the hurricane season is estimated to be about 130 percent of the long-period average. We expect full-season Atlantic basin Net Tropical Cyclone (NTC) activity in 2008 to be approximately 190 percent of the long-term average. We have raised our seasonal forecast from what was predicted in early April and early June. This is due to a combination of a very active early tropical cyclone season in the deep tropics and more favorable hurricane-enhancing sea surface temperature and sea level pressure patterns in the tropical Atlantic. The primary concern with our current very active 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 fall.

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 (1984-2005) 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 much 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 seasonal and monthly 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 the 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. This early August forecast is based on a statistical methodology derived from 106 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 season's observations. 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. There are no solid reasons for thinking that it will not.

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.

1.1 2008 Atlantic Basin Activity through July

The 2008 Atlantic basin hurricane season has gotten off to a very fast start. Four named storms have already formed this year, including Hurricane Bertha, which was the longest-lived tropical cyclone that has ever formed during the month of July. Hurricane Dolly made landfall as a Category 2 hurricane in south Texas on July 23. The 2008 Atlantic basin hurricane season has already accrued 37 ACE units as well as 37 NTC units. Since 1851, only 2005, 1933, and 1916 have accrued more ACE units prior to 1 August and only 2005, 1916, and 1966 have accrued more NTC units prior to 1 August than 2008, respectively. Table 1 records observed Atlantic basin tropical cyclone activity through 1 August, while tracks through 1 August are displayed in Figure 1.

Table 1: Observed 2008 Atlantic basin tropical cyclone activity through July.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	IHD	ACE	NTC
TS	Arthur	May 31–June 1	35 kt/1005 nb	0.75			0.4	2.0
IH-3	Bertha	July 3-20	105 kt/948 mb	17.25	7.50	0.75	28.4	25.3
TS	Cristobal	July 19-23	55 kt/1000 mb	3.75			3.2	3.0
H-2	Dolly	July 20-24	85 kt/964 mb	4.25	1.25		5.5	6.9
Totals	4			26.00	8.75	0.75	37.4	37.1

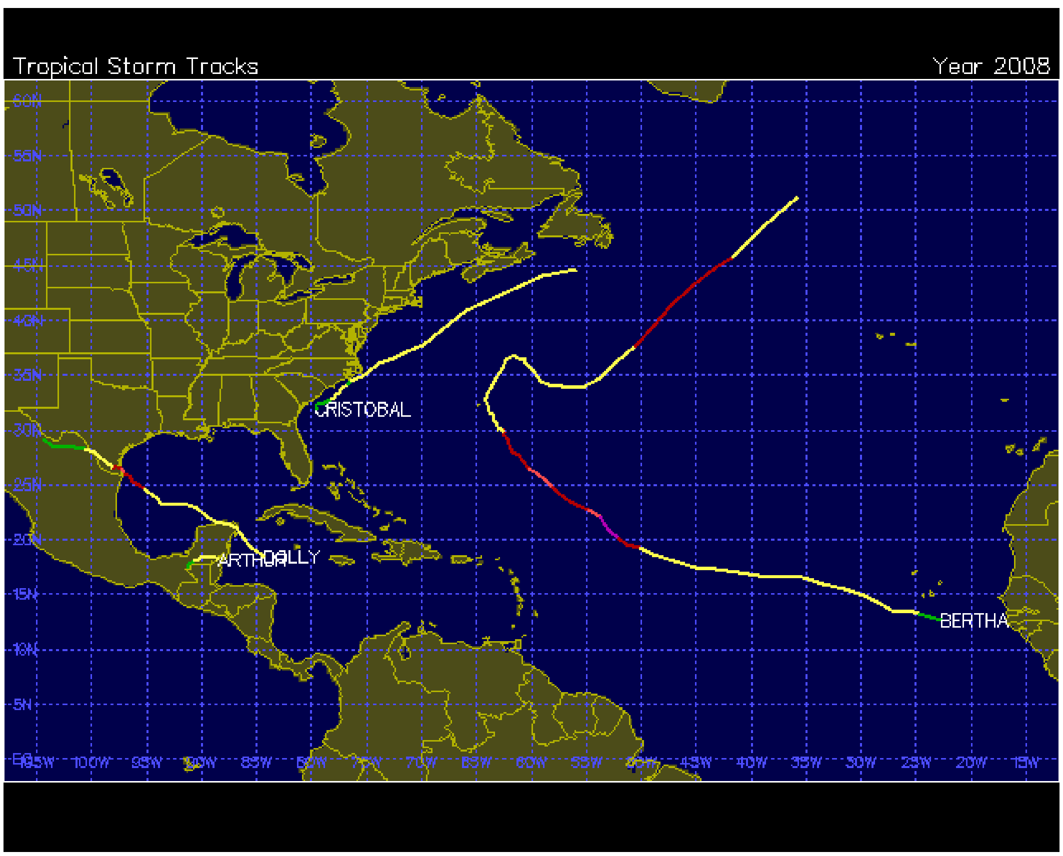

Figure 1: 2008 Atlantic basin hurricane tracks through July. Figure courtesy of Unisys Weather (http://weather.unisys.com).

2 Newly-Developed 1 August Forecast Scheme

We have recently developed a new 1 August statistical seasonal forecast scheme for the prediction of Net Tropical Cyclone (NTC) activity. This scheme was developed on NCEP/NCAR reanalysis data from 1949-1989. It was then tested on independent data from 1990-2005 to insure that the forecast showed similar skill in this later period. As a rule, predictors were only added to the scheme if they explained an additional three percent of the variance of NTC in both the dependent period (1949-1989) and the independent period (1990-2005). The forecast scheme was also tested on independent data from 1900-1948. It also showed comparable skill during this time period. Over the 1900-1948 period, the scheme explained 51% of the variance in NTC activity, and over the more recent period from 1949-2005, the scheme explained 52% of the variance.

With the development of the new 1 June forecast scheme this year, we have found that we can significantly improve the variance explained of our 1 August scheme. First, we subtract observed June-July NTC activity from our 1 June prediction. Then, we multiply the 1 June prediction by 0.4 and the 1 August prediction by 0.6 and add the two together to arrive at a final 1 August statistical prediction of post-1 August NTC. This methodology explains 66% of the variance in post-1 August NTC activity over the period of 1950-2007. Using the early August statistical scheme alone explained 52% of the variance in post-1 August NTC over the same time period.

The pool of four June-July predictors for the early August forecast is given and defined in Table 2. The location of each of these predictors is shown in Fig. 2. Strong statistical relationships can be extracted via combinations of these predictive parameters (which are available by the end of July), and quite skillful Atlantic basin forecasts of NTC activity for the season can be made if the atmosphere and ocean continue to behave in the future as they have in the recent past.

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 relationships 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 3 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)

Table 2: Listing of 1 August 2008 predictors for this year's hurricane activity. A plus (+) means that positive deviations of the parameter indicate increased hurricane activity this year, and a minus (-) means that positive deviations of the parameter indicate decreased hurricane activity this year. The combination of these four predictors calls for a well above-average hurricane season.

Predictor	Values for 2008 Forecast	Effect on 2008 Hurricane Season
1) June-July SST (20-40°N, 15-35°W) (+)	+1.3 SD	**Enhance**
2) June-July SLP (10-25°N, 10-60°W) (-)	-1.1 SD	**Enhance**
3) June-July SST (5°S-5°N, 90-150°W) (-)	+0.5 SD	Suppress
4) Pre-1 August Named Storm Days – South of 23.5°N, East of 75°W	5.75 NSD	**Enhance**

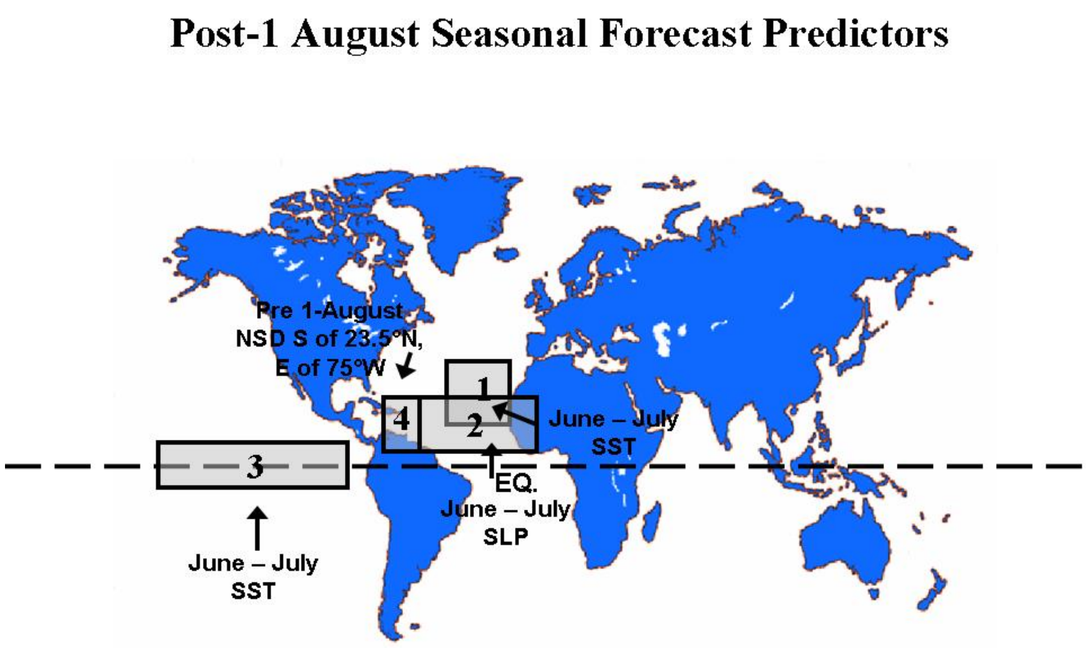

Figure 2: Location of predictors for the post-1 August forecast for the 2008 hurricane season.

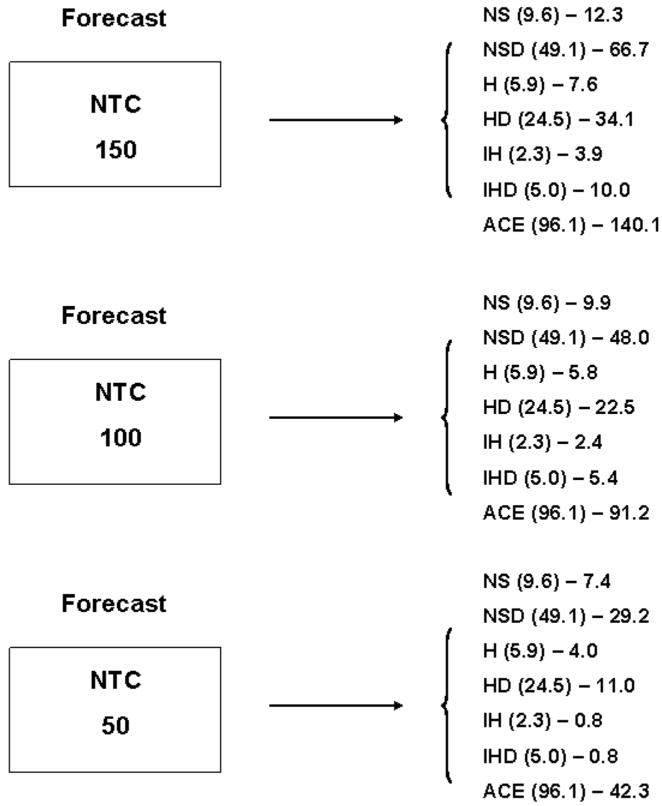

Figure 3: Schematic showing how predictions of 150, 100 and 50 NTC units, respectively, would be converted into predictions for other seasonal parameters. Numbers in parentheses are the climatological averages.

Table 3 shows our statistical forecast for the 2008 hurricane season and the comparison of this forecast with climatology (average season between 1950-2000). Our statistical forecast is calling for well above average activity this year, which adds additional support for raising our forecast from our early April and early June predictions. We believe that the 2008 season will be much more active than the average 1950-2000 season. Our 2008 forecast is calling for somewhat more activity than is being predicted by our statistical model due to our early August predictors being extraordinary favorable for an active season. Also, our analog years all point to a very active season (see Section 4).

Table 3: Post-1 August statistical forecast for 2008.

Predictands and Climatology (1950-2000 Post-1 August Average)	Statistical Forecast	Percent of Average
Named Storms (NS) – 8.4	11.7	139%
Named Storm Days (NSD) – 44.9	62.2	139%
Hurricanes (H) – 5.4	7.2	133%
Hurricane Days (HD) – 23.4	31.3	134%
Intense Hurricanes (IH) – 2.1	3.5	167%
Intense Hurricane Days (IHD) – 4.9	8.9	182%
Accumulated Cyclone Energy Index (ACE) – 90	128	142%
Net Tropical Cyclone Activity (NTC) – 93	138	148%

Figure 4 illustrates the new forecast methodology that we are utilizing for all of our statistical forecasts for this year. The basic methodology involves selecting two to four 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.

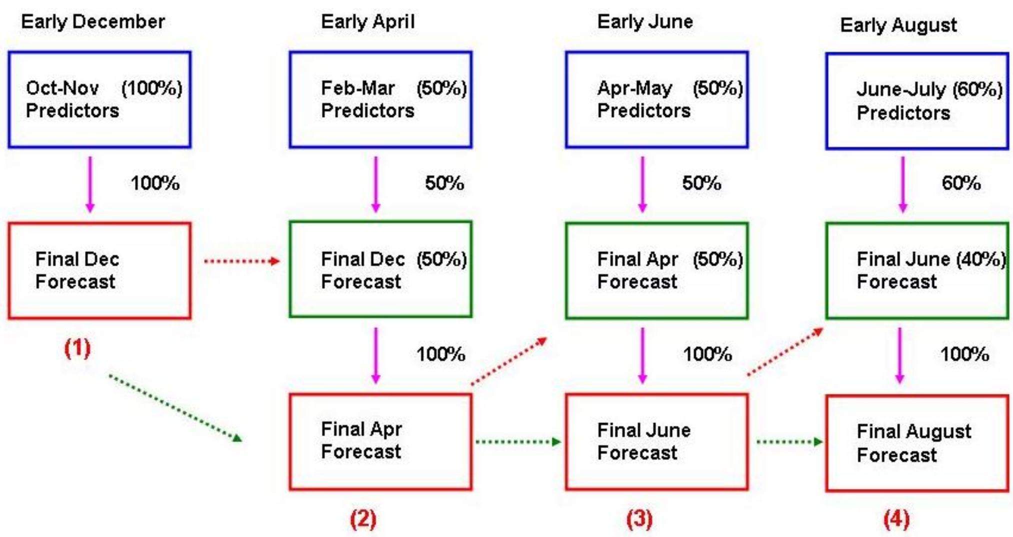

Figure 4: The new methodology utilized in calculating our statistical forecasts of seasonal NTC.

Table 4 displays our early August hindcasts for 1950-2007 using the new statistical scheme, while Figure 5 displays observations versus NTC hindcasts. Our early August hindcasts have correctly predicted above- or below-average post-1 August NTC in 47 out of 58 hindcast years (81%). These hindcasts have had a smaller error than climatology in 39 out of 58 years (67%). Our average hindcast errors have been 24 NTC units, compared with 41 NTC units had we used only climatology. 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 5).

Table 4: Observed versus hindcast post-1 August 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 47 out of 58 years (79%), while hindcast improvement over climatology occurred in 39 out of 58 years (67%).

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1950	230	152	78	137	59
1951	95	108	-13	2	**-11**
1952	91	**151**	-60	-2	**-58**
1953	110	146	-36	17	**-19**
1954	116	107	9	23	14
1955	187	174	13	94	81
1956	58	91	-33	-35	2
1957	63	83	-20	-30	10
1958	131	115	16	38	22
1959	72	88	-16	-21	5
1960	79	**144**	-65	-14	**-51**
1961	190	161	29	97	68
1962	32	**116**	-84	-61	**-23**
1963	111	**91**	21	18	**-2**
1964	155	126	29	62	33
1965	79	74	5	-14	9
1966	91	**126**	-35	-2	**-33**
1967	93	**90**	3	0	**-3**
1968	23	65	-42	-70	28
1969	146	120	26	53	27
1970	54	80	-26	-39	13
1971	89	64	25	-4	**-21**
1972	19	26	-7	-74	67
1973	42	90	-48	-51	3
1974	72	59	13	-21	7
1975	79	**94**	-15	-14	**-1**
1976	79	60	20	-14	**-6**
1977	45	69	-25	-48	24
1978	81	64	17	-12	**-4**
1979	81	64	17	-12	**-5**
1980	129	**86**	43	36	**-7**
1981	105	95	10	12	2
1982	30	36	-6	-63	57
1983	31	38	-7	-62	55
1984	74	83	-9	-19	10
1985	97	**91**	6	4	**-2**
1986	28	38	-10	-65	55
1987	46	81	-35	-47	12
1988	118	118	-1	25	24
1989	123	134	-11	30	19
1990	88	**108**	-20	-5	**-15**
1991	54	58	-3	-39	35
1992	64	46	18	-29	12
1993	50	50	0	-43	43
1994	32	45	-13	-61	48
1995	205	183	22	112	90
1996	163	126	37	70	33
1997	33	37	-4	-60	56
1998	163	160	3	70	67
1999	182	151	31	89	58
2000	134	101	33	41	8
2001	127	112	15	34	19
2002	78	51	26	-15	**-11**
2003	153	138	15	60	45
2004	228	134	95	135	41
2005	198	154	44	105	61
2006	77	**105**	-28	-16	**-12**
2007	93	98	-5	0	**-5**
Average	**98**	**98**	**|24|**	**|41|**	**+17**

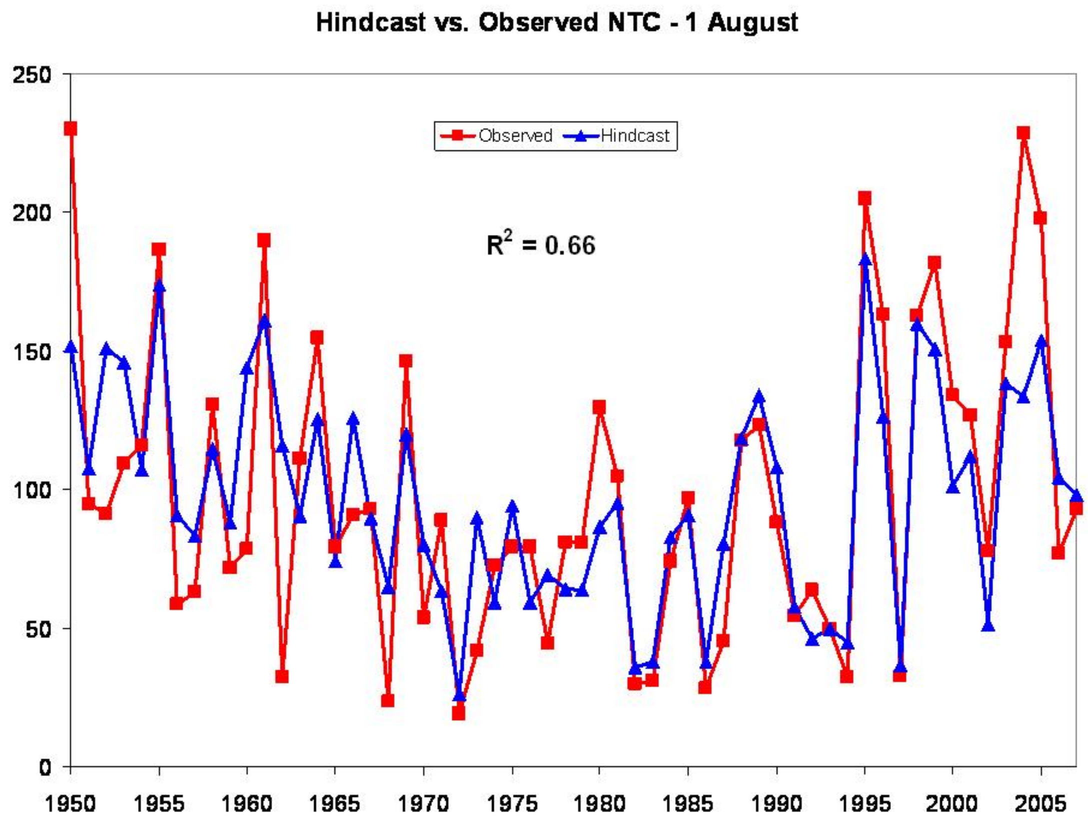

Figure 5: Observed versus hindcast values of post-1 August NTC for 1950-2007.

Table 5: Observed versus hindcast average post-1 August NTC for active vs. inactive multi-decadal periods.

Years	*Average Observed NTC*	*Average Hindcast NTC*
1950-1969 (Active)	108	116
1970-1994 (Inactive)	68	71
1995-2007 (Active)	141	119

There have been several early August 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 post-1 August NTC of 93 in these 10 years was 32.

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

Years	***Observed NTC***	***Hindcast NTC***
1965	79	74
1967	93	90
1982	30	36
1985	97	91
1988	118	118
1991	54	58
1993	50	50
1997	33	37
1998	163	160
2007	93	98

There have also been several years where the early August hindcast was a failure. Table 7 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 would have been 68. For the 38 of 58 intermediate years between our 10 best and 10 worst early August NTC hindcasts, our average NTC error was 20 while the average NTC error using climatology was 37.

Over the entire 58-year period, our average hindcast error is 24 NTC units, compared with 41 NTC units using climatology. Our average early August hindcast error is approximately 40% less than the climatological error.

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

Years	***Observed NTC***	***Hindcast NTC***
1950	230	152
1952	91	151
1960	79	144
1962	32	116
1968	23	65
1973	42	90
1980	129	86
1996	163	126
2004	228	134
2005	198	154

Table 8 displays how forecasts issued with our new hindcast scheme would have compared with our actual real-time forecasts issued in early August since 1995. Our more recent early 1 August real-time forecasts from 1995-2007 have not been particularly successful. The last 13 years of forecasts have correlated at 0.41 with observations from 1995-2007. In contrast, our new 1 August hindcast scheme that we are using for this year correlates at 0.87 with the last 13 years of observations.

Another way of evaluating model skill is examining errors compared with climatology. Our real-time August NTC predictions have had an error of 45 NTC units over the period from 1995-2007, while a climatological prediction has an error of 62 NTC units. Our new August hindcast has an average error of 27 NTC units over the past thirteen years, an improvement of approximately 40% when compared with our real-time early August forecasts. This is an improvement of approximately 55% 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 as well as climatology was 64 NTC units and 43 NTC units using our new model. The new hindcast model improves upon our real-time forecasts or on climatology by approximately 35% over the last four years of 2004-2007.

Our new hindcast scheme had a smaller NTC error than our real-time August NTC prediction in 8 out of the last 13 years. This scheme also had a smaller NTC error than a climatological prediction in 10 out of the last 13 years.

Table 8: Real-time early August forecasts, hindcasts based on our new August scheme and observed NTC since 1995.

Years	***Real-Time August NTC Forecasts***	***New August NTC Hindcasts***	***Observed NTC***
1995	130	183	205
1996	105	126	163
1997	100	37	33
1998	110	160	163
1999	160	151	182
2000	130	101	134
2001	120	112	127
2002	60	51	78
2003	120	138	153
2004	125	134	228
2005	167	154	198
2006	134	105	77
2007	156	98	93
Verification Correlation	**0.41**	**0.87**	

2.1 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of our four predictors for our August statistical forecast are now discussed. It should be noted that all 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 June statistical forecast (used as 40% of our early August forecast), please refer to our early June 2008 forecast:
http://tropical.atmos.colostate.edu/Forecasts/2008/june2008/jun2008.pdf

Predictor 1. June-July SST in the Northeastern Subtropical Atlantic (+)

(20°-40°N, 15-35°W)

Warm sea surface temperatures in this area in June-July correlate very strongly with anomalously warm sea surface temperatures in the tropical Atlantic throughout the upcoming hurricane season (Figure 6). Anomalously warm sea surface temperatures are important for development and intensification of tropical cyclones by infusing more latent heat into the system (Goldenberg and Shapiro 1998). In addition, associated with anomalously warm June-July SSTS are weaker trade winds. Weaker trade winds cause less evaporation and upwelling of cooler sub-surface water which feeds back into keeping the tropical Atlantic warm. In addition, weaker trade winds imply that there is less vertical wind shear across the tropical Atlantic. Weak wind shear is favorable for tropical cyclone development and intensification (Gray 1968, Gray 1984a, Goldenberg and Shapiro 1996, Knaff et al. 2004). Lastly, there is a strong positive correlation (~0.5) between anomalously warm June-July SSTs in the subtropical northeastern Atlantic and low sea level pressures in the tropical Atlantic and Caribbean during August-October. Low sea level pressures imply decreased subsidence and enhanced mid-level moisture. Both of these conditions are favorable for tropical cyclogenesis and intensification (Knaff 1997).

Predictor 2. June-July SLP in the Tropical Atlantic (-)

(10-25°N, 10-60°W)

Low sea level pressure in the tropical Atlantic in June-July implies that early summer conditions in the tropical Atlantic are favorable for an active tropical cyclone season with increased vertical motion, decreased stability and enhanced mid-level moisture. There is a strong auto-correlation ($r > 0.5$) between June-July sea level pressure anomalies and August-October sea level pressure anomalies in the tropical Atlantic (Figure 7). Low sea level pressure in the tropical Atlantic also correlates quite strongly ($r > 0.5$) with reduced trade winds (weaker easterlies) and anomalous easterly upper-level winds (weaker westerlies). The combination of these two features implies weaker vertical wind shear and therefore more favorable conditions for tropical cyclone development in the Atlantic (Gray 1968, Gray 1984a, Goldenberg and Shapiro 1996).

Predictor 3. June-July Nino3 Index (-)

(5°S-5°N, 90-150°W)

Cool sea surface temperatures in the Nino3 region during June-July imply that a La Niña event is currently present. In general, positive or negative anomalies in the Nino3 region during the early summer persist throughout the remainder of the summer and fall (Figure 8). El Niño conditions shift the center of the Walker Circulation eastward which causes increased convection over the central and eastern tropical Pacific. This increased convection in the central and eastern Pacific manifests itself in anomalous upper-level westerlies across the Caribbean and tropical Atlantic, thereby increasing vertical wind shear and reducing Atlantic basin hurricane activity. The relationship between ENSO and Atlantic hurricane activity has been well-documented in the literature (e.g., Gray 1984a, Goldenberg and Shapiro 1996, Elsner 2003, Bell and Chelliah 2006).

Predictor 4. Named Storm Days South of 23.5°N, East of 75°W (+)

Most years do not have named storm formations in June and July in the tropical Atlantic; however, if tropical formations do occur, it indicates that a very active hurricane season is likely. For example, the six years with the most named storm days in the deep tropics in June and July (since 1949) are 1966, 1969, 1995, 1996, 1998 and 2005. All six of these seasons were very active. When storms form in the deep tropics in the early part of the hurricane season, it indicates that conditions are already very favorable for TC development. In general, the start of the hurricane season is restricted by thermodynamics (warm SSTs, unstable lapse rates), and therefore deep tropical activity early in the hurricane season implies that the thermodynamics are already quite favorable for TC development (Figure 9). Also, this predictor's correlation with seasonal NTC is 0.52 over the 1950-2007 period, and when tested on independent data (1900-1948), the correlation actually improves to 0.63, which gives us increased confidence in its use as a seasonal predictor.

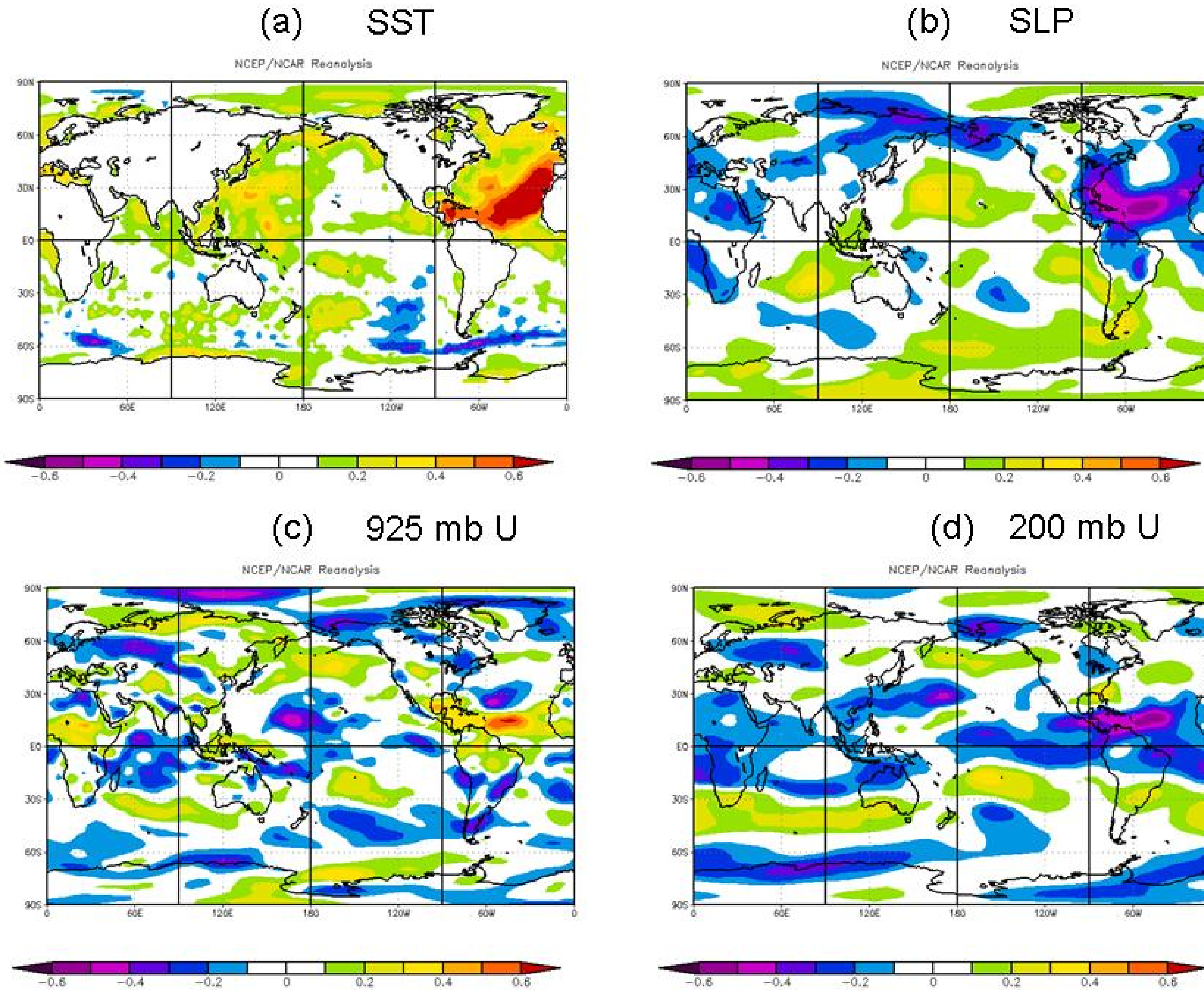

Figure 6: Linear correlations between <u>June-July SST</u> in the subtropical eastern Atlantic (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d).

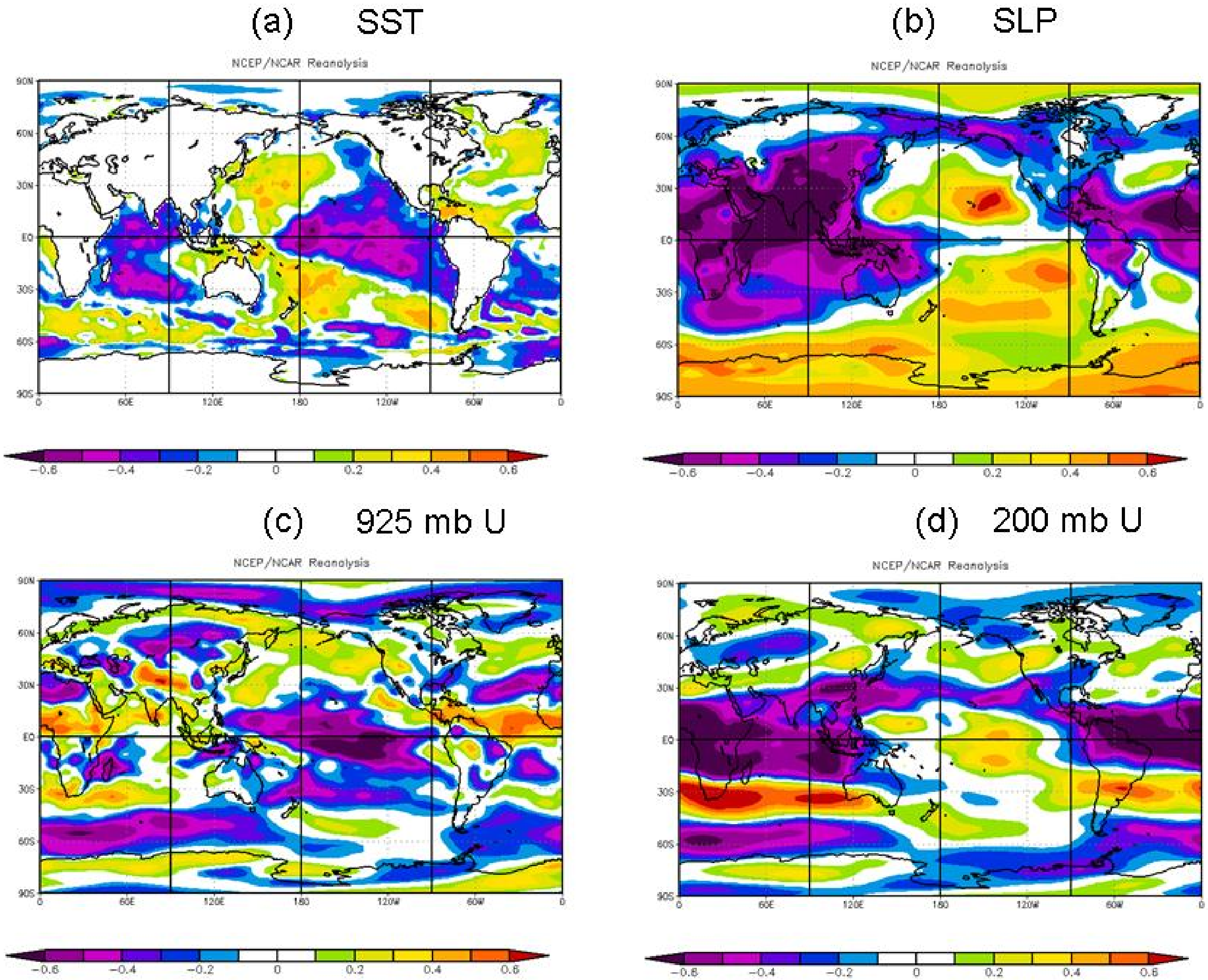

Figure 7: Linear correlations between June-July SLP in the tropical Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). Sea level pressure values have been multiplied by -1 to allow for easy comparison with Figure 6.

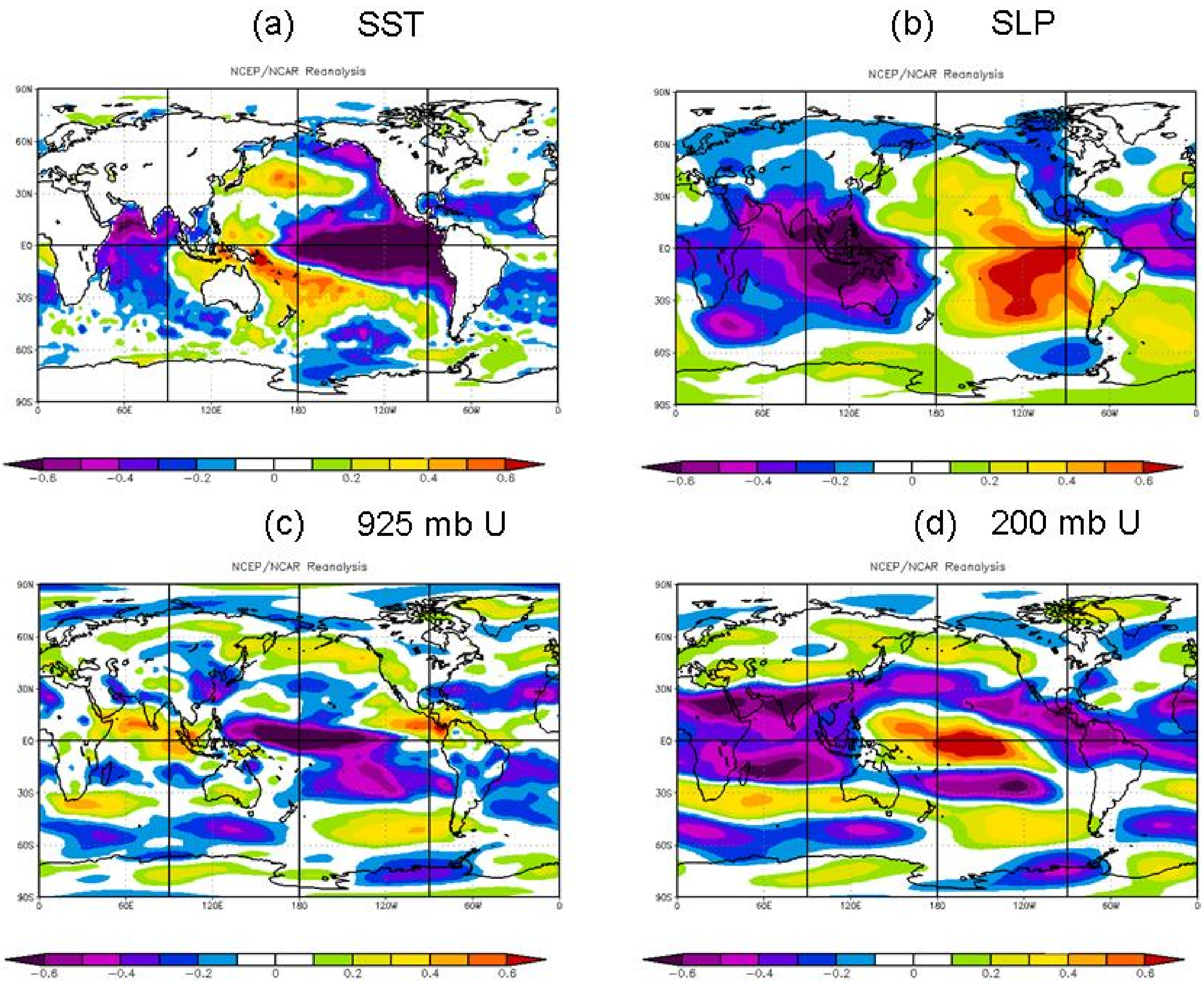

Figure 8: Linear correlations between June-July Nino 3 (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). Sea surface temperature values have been multiplied by -1 to allow for easy comparison with Figure 6.

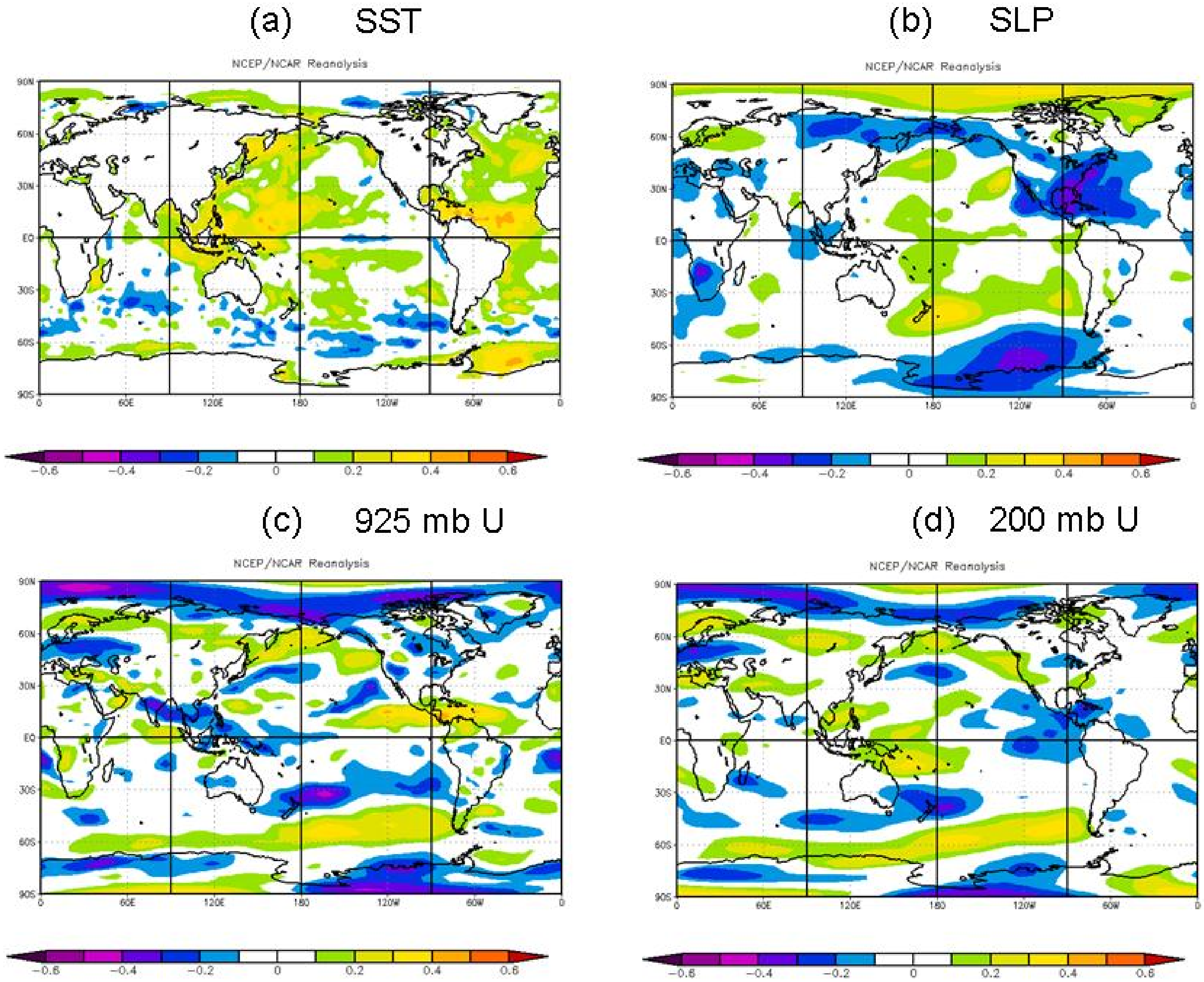

Figure 9: Linear correlations between June-July NSD in the tropics (Predictor 4) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d).

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.

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 August prediction. Assuming the future behaves similarly to the way that the past has behaved, 67% of predictions should lie within about one standard deviation of the forecast (as listed in Table 9), while 95% of predictions should lie within about 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)	2.0	17	15.0 – 19.0	13.0 – 21.0
Named Storm Days (NSD)	10.0	90	80.0 – 100.0	70.0 – 110.0
Hurricanes (H)	1.2	9	7.8 – 10.2	6.6 – 11.4
Hurricane Days (HD)	6.2	45	38.8 – 51.2	32.6 – 57.4
Intense Hurricanes (IH)	0.8	5	4.2 – 5.8	3.4 – 6.6
Intense Hurricane Days (IHD)	2.6	11	8.4 – 13.6	5.8 – 16.2
Accumulated Cyclone Energy (ACE)	22.3	175	152.7 – 197.3	130.4 – 219.6
Net Tropical Cyclone (NTC) Activity	20.5	190	169.5 – 210.5	149.0 – 231.0

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

We select prior hurricane seasons since 1900 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that had the closest optimal combination of near-neutral ENSO conditions, above-average tropical Atlantic and far North Atlantic sea surface temperatures and active seasons in the deep tropics in June-July.

There were five hurricane seasons with characteristics most similar to what we observed in June-July 2008. The best analog years that we could find for the 2008 hurricane season were 1926, 1961, 1996, 1998 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 well 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
1926	11	86.75	8	55.00	6	23.00	222	229
1961	11	70.75	8	47.50	7	24.50	205	230
1996	13	79.00	9	45.00	6	13.00	166	192
1998	14	88.00	10	48.50	3	9.50	182	169
2000	15	71.50	8	32.75	3	5.00	119	134
Mean	12.8	79.2	8.6	45.8	5	15.0	179	181
2008 Forecast	17	90	9	45	5	11	175	190

5 ENSO

Conditions in the tropical Pacific have continued to moderate over the past couple of months. Sea surface temperature anomalies have become positive in the eastern Pacific while returning to near average values in the central tropical Pacific. Table 11 displays May and July SST anomalies for several Nino regions. Note that the entire central and eastern tropical Pacific has warmed by approximately 0.5°C during the past two months.

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

Region	May SST Anomaly (°C)	July SST Anomaly (°C)	July minus May SST Warming (°C)
Nino 1+2	0.1	0.6	0.5
Nino 3	0.0	0.5	0.5
Nino 3.4	-0.6	0.1	0.7
Nino 4	-0.8	-0.3	0.5

The big question is whether this current observed warming will impact this season's Atlantic basin hurricane activity. Even though water temperatures have continued to warm, the atmosphere is still responding as if it were a weak La Niña situation with continued anomalously strong low-level trades and anomalous upper-level westerlies near the International Date Line. At this time, it appears unlikely that ENSO will transition to warm conditions by the August-October (ASO) period. Only two of the 23 statistical dynamical and statistical models predict an El Niño event over the ASO period (El Niño is defined as > 0.5°C anomaly) (Figure 10). The average of all statistical and dynamical models calls for a Nino 3.4 SST anomaly of 0.1°C over the August-October period.

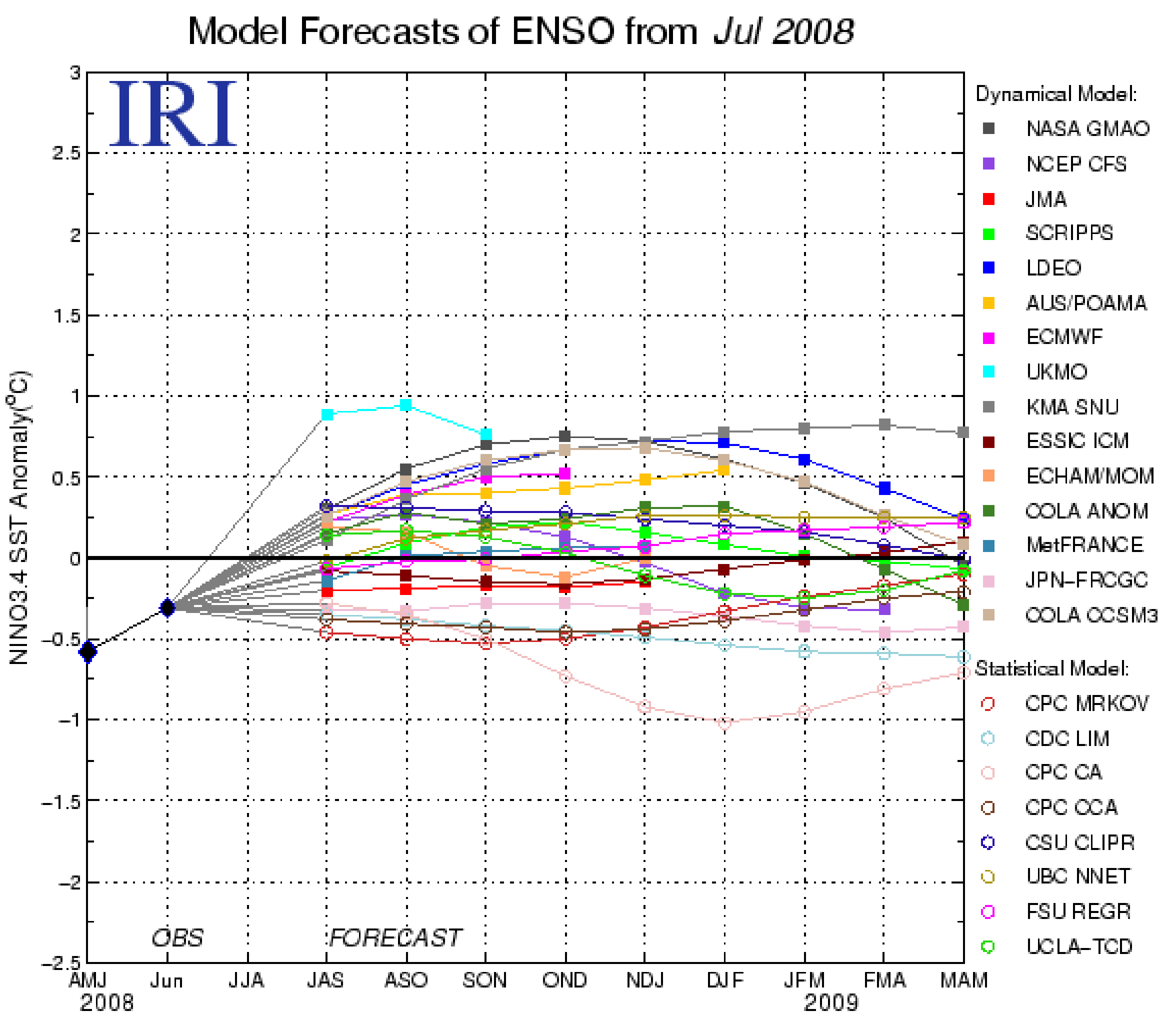

Figure 10: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

Based on this information, we believe that neutral ENSO conditions will persist through the remainder of this year's hurricane season. We do not foresee a transition to El Niño conditions during the 2008 hurricane season at this time, although this is certainly still a possibility. Despite the fact that upper ocean heat content values have continued to increase slightly in the eastern and central tropical Pacific, we are not prepared to forecast an El Niño event. We believe that the very favorable conditions in the tropical Atlantic (see Section 6) will likely overwhelm any detrimental impacts from anomalous warming in the tropical Pacific.

6 Current Atlantic Basin Conditions

Current conditions in the Atlantic basin are quite favorable for an active hurricane season. These conditions have remained quite favorable over the past couple of months. Both our June-July sub-tropical Atlantic SST predictor (Predictor 1) and our June-July tropical Atlantic SLP predictor (Predictor 2) indicate conditions that are quite favorable for an active season. The current sea surface temperature pattern in the Atlantic is typically observed during active hurricane seasons, with anomalously warm water throughout most of the tropical and sub-tropical Atlantic (Figure 11). Sea level pressures have been below average throughout most of the tropical Atlantic during the past two months (Figure 12). Based on satellite appearances and tropical Atlantic sea level pressure anomalies, our best estimate is that African dust outbreaks over the tropical Atlantic have been somewhat below-average during the June-July timeframe.

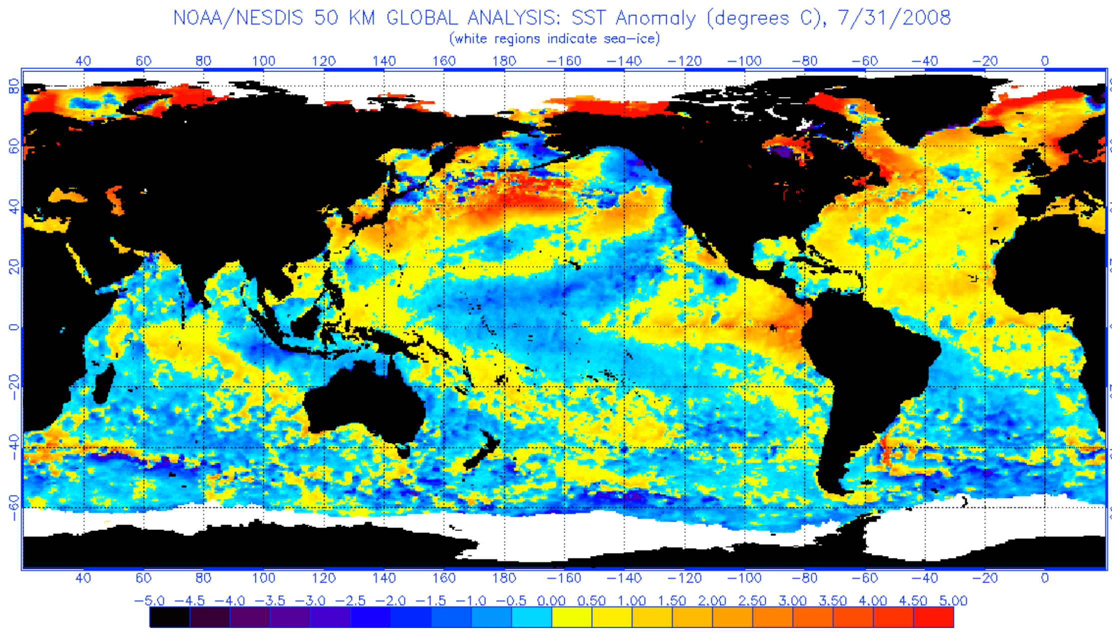

Figure 11: Current SST anomaly pattern as estimated from satellite. Note the wide expanse of anomalously warm waters in the tropical and sub-tropical Atlantic. Figure courtesy of NOAA/NESDIS.

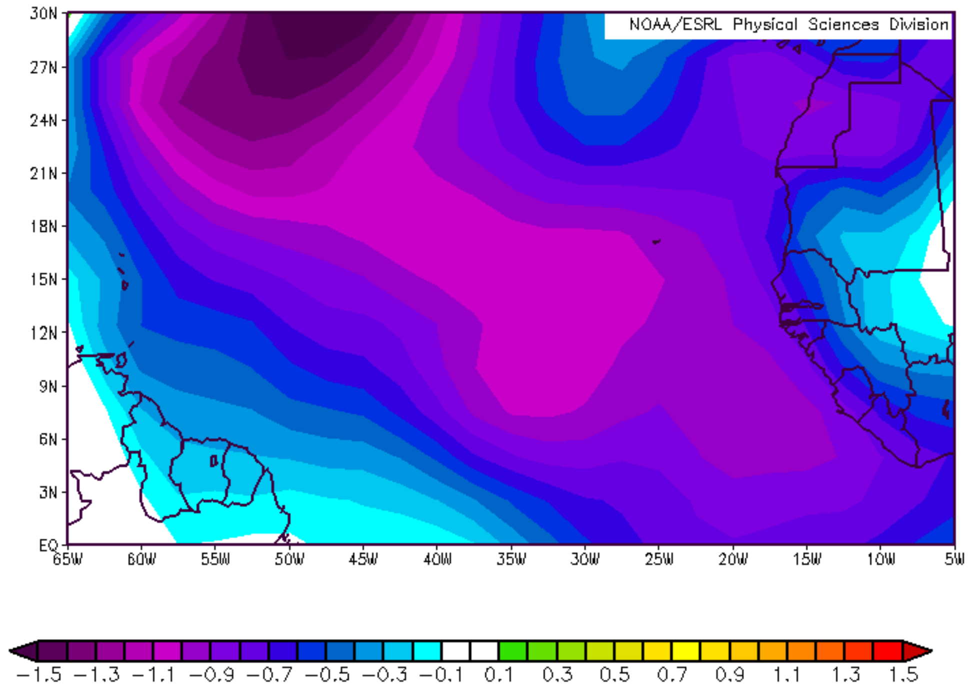

Figure 12: June-July SLP anomalies (in mb) in the tropical and subtropical Atlantic. Anomalies are calculated with respect to the 1968-1996 period.

7 August Monthly Forecast

We have extensively revised our monthly forecasts this year. We are now issuing individual monthly predictions for the months of August, September and October during the early part of the month being predicted. That is, our August monthly forecast is released with this update (5 August), our early September forecast will be released on 2 September, and our early October forecast will be released on 1 October. Our statistical model for August monthly activity utilizes a much smaller predictor pool than was used in the original forecast scheme, and, as is done with our seasonal predictions, we only attempt to hindcast NTC. We have utilized three of the same predictors as outlined in the original August monthly forecast model for this August's NTC prediction (Blake and Gray 2004). Table 12 and Figure 13 discuss and display the predictors utilized in this year's August monthly forecast.

Table 12: Listing of predictors for August's hurricane activity. A plus (+) means that positive deviations of the parameter indicate increased hurricane activity for August, and a minus (-) means that positive deviations of the parameter indicate decreased hurricane activity for August.

Predictor	Values for 2008 Forecast	Effect on 2008 Hurricane Season
1) July 200 mb V (7.5°S-7.5°N, 75-105°W) (-)	-1.2 SD	**Enhance**
2) July SLP (20-40°N, 25-55°W) (-)	-0.5 SD	**Enhance**
3) July SLP (47.5-62.5°N, 155°E-165°W) (-)	-0.4 SD	**Enhance**

New August Monthly Forecast Predictors

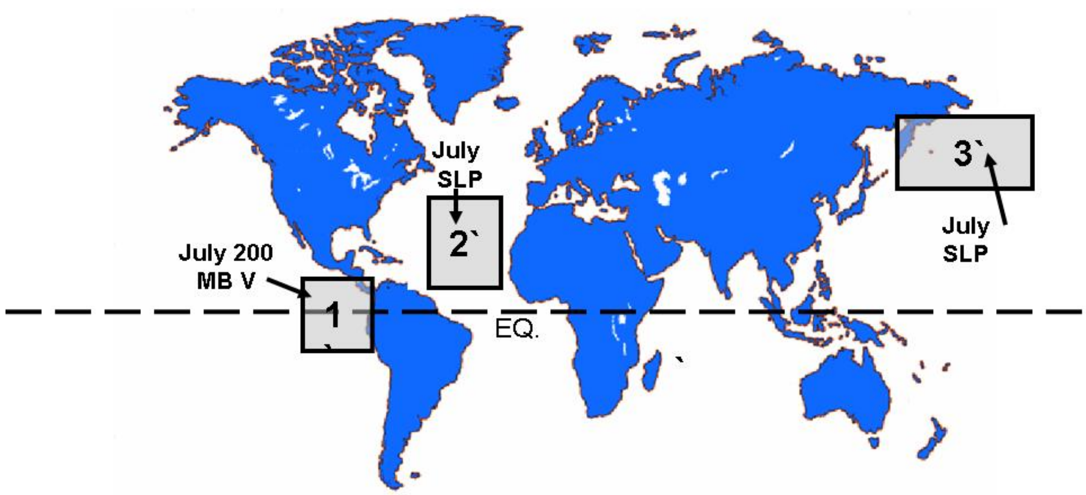

Figure 13: Global map showing locations of August-only TC predictors. Table 12 provides a listing and description of these predictors. The numbers in the boxes are keyed to the descriptions given in Table 12.

This new August statistical forecast model has shown considerable skill at hindcasting NTC over the period from 1948-2007. Using a linear regression model and the same ranking technique that was used in our seasonal forecast schemes from December, April, and June, we were able to hindcast 52 percent of the variance over the 1948-2007 period. Each predictor had to explain an additional 5 percent in variance explained over the period from 1948-1987, 1988-2007, and over the full 1948-2007 period to be included the model. Figure 14 shows hindcasts of August NTC along with observations over the past sixty years. Table 13 displays our August monthly forecast for this year. All other parameters are calculated from the statistical model's NTC prediction using a similar methodology as was used for the seasonal forecast calculations. Final equations are below:

Named Storms = 1.5 + (0.05 * NTC)
Named Storm Days = 2.3 + (0.37 * NTC)
Hurricanes = 0.3 + (0.05 * NTC)
Hurricane Days = -0.6 + (0.23 * NTC)
Intense Hurricanes = -0.2 + (0.03 * NTC)
Intense Hurricane Days = -0.9 + (0.09 * NTC)
Accumulated Cyclone Energy = -2.1 + (0.96 * NTC)

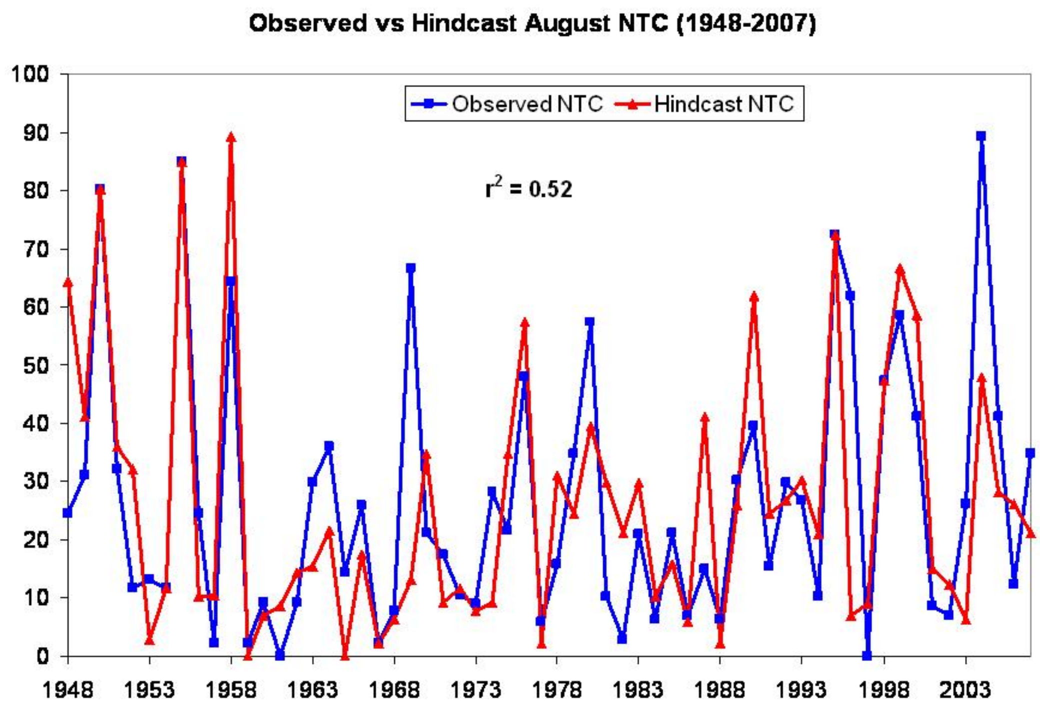

Figure 14: Observed versus hindcast August NTC over the period from 1948-2007.

Table 13: Independent August-only prediction of 2008 hurricane activity. August climatology is shown in parentheses.

Parameter	Statistical Model	Qualitative Adjustment
NS	3.9 (2.8)	4
NSD	19.7 (11.8)	20
H	2.7 (1.6)	3
HD	10.2 (5.7)	10
IH	1.3 (0.6)	1
IHD	3.4 (1.2)	3
ACE	43.1 24.2)	40
NTC	47.0 (26.1)	45

Individual monthly predictions for September and October will be issued on 2 September and 1 October, respectively.

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 August 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 August forecasts for post-1 August named storms have correlated with observations at 0.61 (Table 14).

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

Year	Predicted Named Storms	Observed Named Storms
1984	10	12
1985	10	9
1986	7	4
1987	7	7
1988	11	12
1989	9	8
1990	11	12
1991	7	7
1992	8	6
1993	10	7
1994	7	6
1995	16	14
1996	11	10
1997	11	3
1998	10	13
1999	14	11
2000	11	14
2001	12	14
2002	9	11
2003	14	12
2004	13	14
2005	13	20
2006	13	7
2007	13	12
Correlation		**0.61**

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 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 to be 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 remainder of 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 well above its long-term average of 100, and therefore, United States landfall probabilities are well above average. It should be noted that we already have had one hurricane make landfall in south Texas (Dolly as a Category 2 on South Padre Island).

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 post-1 August 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). 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)	91% (79%)	82% (68%)	67% (52%)	94% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	74% (59%)	57% (42%)	42% (30%)	75% (60%)	94% (83%)
Florida plus East Coast (Regions 5-11)	66% (50%)	59% (44%)	43% (31%)	77% (61%)	92% (81%)

10 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 or CO_2 gas increases. Changes in ocean salinity are believed to be the driving mechanism. These multi-decadal changes have also been termed the Atlantic Multidecadal Oscillation (AMO).

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.

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 were to 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) (Figure 15). Atlantic sea surface temperatures and hurricane activity do not necessarily follow global mean temperature trends.

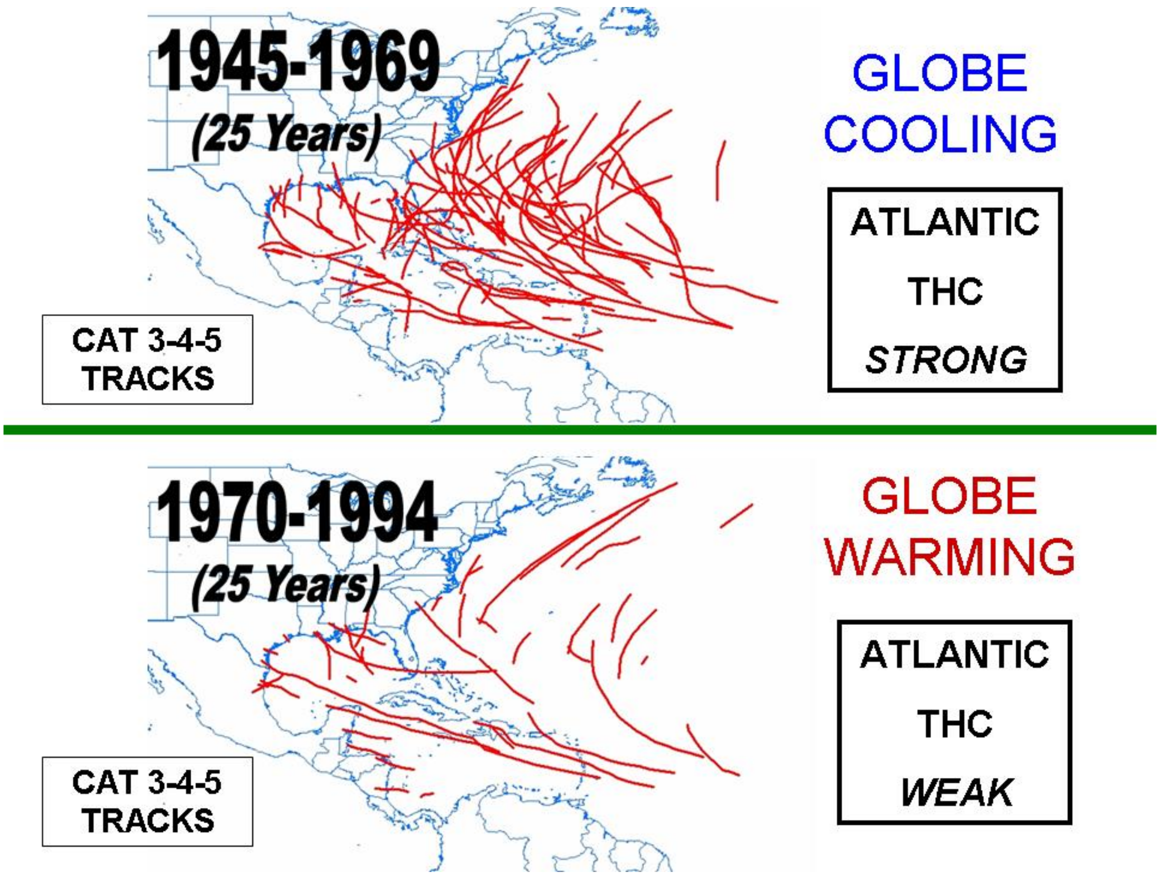

Figure 15: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was less than 1/2 as frequent during the latter period despite warmer global temperatures.

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 17). 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. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 42-year period of

1924-1965 (24 landfall events) and the 42-year period of 1966-2007 (7 landfall events) was especially large (Figure 16). For the entire United States coastline, 39 major hurricanes made landfall during the earlier 42-year period (1924-1965) compared with only 22 for the latter 42-year period (1966-2007). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period (Figure 17). This figure illustrates that caution must be used when extrapolating trends into the future. Obviously, U.S. major hurricane landfalls will continue.

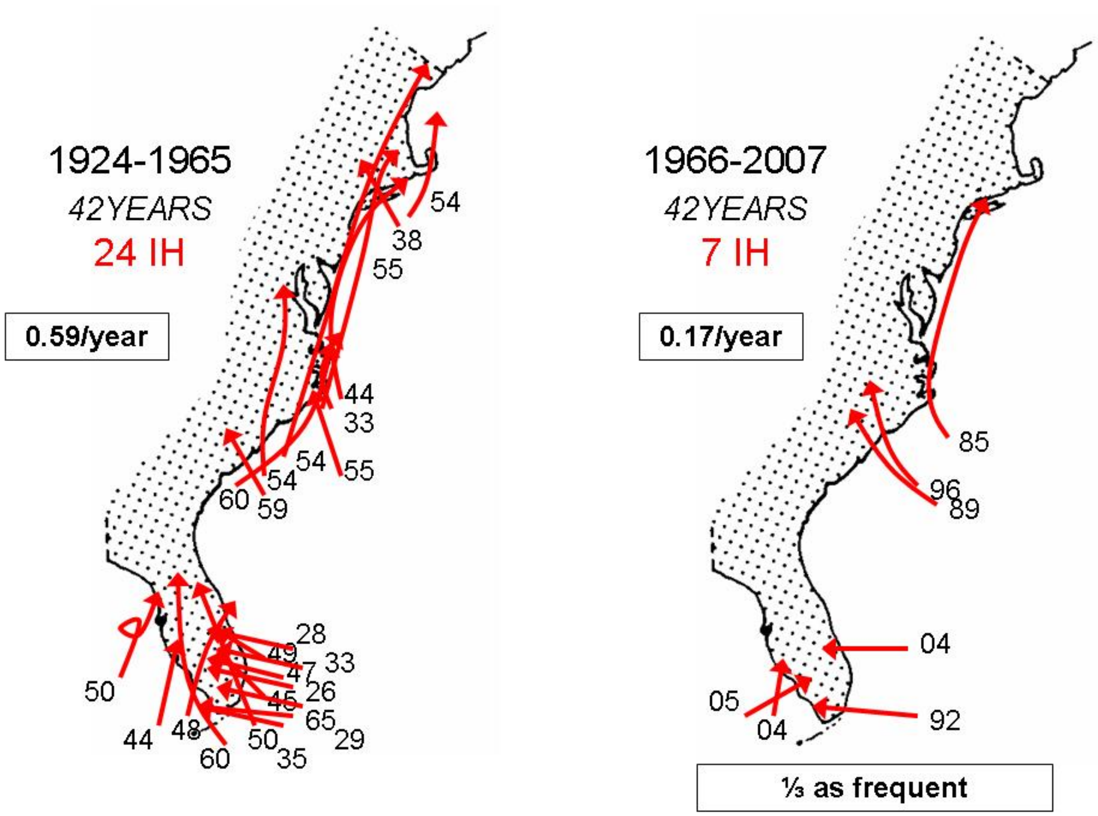

Figure 16: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 42-year period of 1924-1965 versus the most recent 42-year period of 1966-2007.

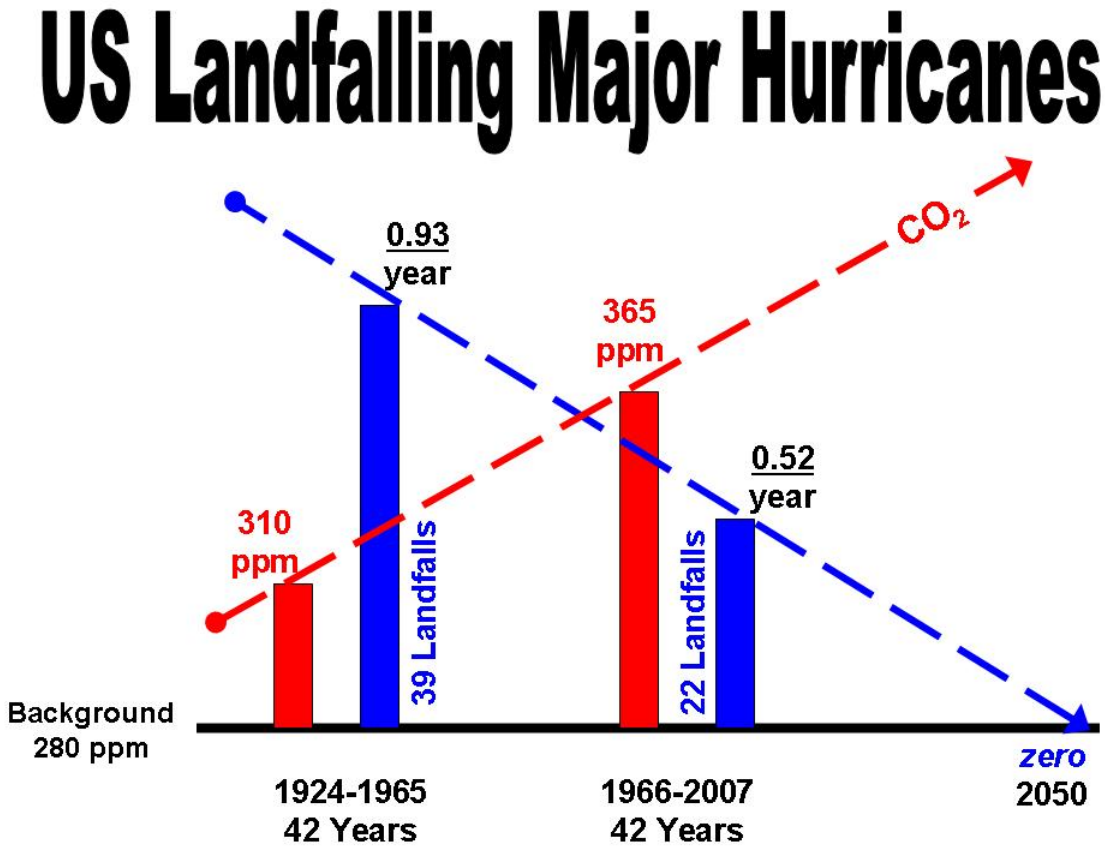

Figure 17: Portrayal of decreasing US total major hurricane landfalls over the last 42 years despite a mean rise in atmospheric CO_2. This figure illustrates that caution must be used when extrapolating trends into the future. Obviously, U.S. major hurricane landfalls will continue.

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.

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 17: 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) – 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. 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-19^{th} century, and changes in the AMO have been inferred from Greenland paleo ice-core temperature measurements going back thousand of years.

11 Forthcoming Updated Forecasts of 2008 Hurricane Activity

We will be issuing monthly forecasts for September activity on **Tuesday 2 September** and for October activity on **Wednesday 1 October 2008**. These monthly forecasts will also include seasonal updates up to that point in the season. A verification and discussion of all 2008 Atlantic basin TC activity 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 Verification of Previous Forecasts

Table 18: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2003-2007. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

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