FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2009

We have reduced our forecast slightly from early June due largely to the development of an El Niño. We continue to call for a below-average Atlantic basin tropical cyclone season in 2009. We also anticipate a below-average probability of United States and Caribbean major hurricane landfall.

(as of 4 August 2009)

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

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

Emily Wilmsen, Colorado State University Media Representative, (970-491-6432) is available to answer various questions about this forecast

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Why issue forecasts for seasonal hurricane activity?

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

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early August. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as it regards to the probability of an active or inactive hurricane season. Our early August statistical forecast methodology shows strong evidence over more than 100 past years that significant improvement over climatology can be attained. The model correctly predicted an above-average season in 2008. We would never issue a seasonal hurricane forecast unless we had a statistical model developed over a long hindcast period which showed significant skill over climatology.

We issue these forecasts to satisfy the curiosity of the general public and to bring attention to the hurricane problem. There is a general interest in knowing what the odds are for an active or an inactive season. One must remember that our forecasts are based on the premise that those global oceanic and atmospheric conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about similar trends in future seasons. This is not always true for individual seasons. It is also important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. The probability of landfall for any one location along the coast is very low and reflects the fact that, in any one season, most U.S. coastal areas will not feel the effects of a hurricane no matter how active the individual season is. However, all coastal residents should prepare for the coming hurricane season every year, since landfalling tropical cyclones can devastate communities in inactive or active seasons. It only takes one landfalling system to make this a very active season for you.

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2009

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Issue Date 10 December 2008	Issue Date 9 April 2009	Issue Date 2 June 2009	Observed Activity Through July 2009	Forecast Activity After 1 August	Total Seasonal Forecast
Named Storms (NS) (9.6)	14	12	11	0	10	10
Named Storm Days (NSD) (49.1)	70	55	50	0	45	45
Hurricanes (H) (5.9)	7	6	5	0	4	4
Hurricane Days (HD) (24.5)	30	25	20	0	18	18
Major Hurricanes (MH) (2.3)	3	2	2	0	2	2
Major Hurricane Days (MHD) (5.0)	7	5	4	0	4	4
Accumulated Cyclone Energy (ACE) (96.1)	125	100	85	0	80	80
Net Tropical Cyclone Activity (NTC) (100%)	135	105	90	0	85	85

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

1) Entire U.S. coastline - 46% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 27% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 26% (average for last century is 30%)

POST 1-AUGUST PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE TRACKING INTO THE CARIBBEAN (10-20°N, 60-88°W)

1) 37% (average for last century is 42%)

ABSTRACT

Information obtained through July 2009 indicates that the 2009 Atlantic hurricane season will be less active than the average 1950-2000 season due largely to the development of an El Niño. We estimate that 2009 will have about 4 hurricanes (average is 5.9), 10 named storms (average is 9.6), 45 named storm days (average is 49.1), 18 hurricane days (average is 24.5), 2 major (Category 3-4-5) hurricanes (average is 2.3) and 4 major hurricane days (average is 5.0). The probability of U.S. major hurricane landfall and Caribbean major hurricane activity is estimated to be below the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2009 to be approximately 85 percent of the long-term average. We have decreased our seasonal forecast slightly from early June.

This forecast is based on an extended-range early August statistical prediction scheme that utilizes 106 years of past data. Analog predictors are also utilized.

We have witnessed the development of an El Niño event over the past couple of months. These conditions are expected to intensify to a moderate El Niño over the next few months. El Niño events tend to be associated with increased levels of vertical wind shear and decreased levels of Atlantic hurricane activity. Tropical Atlantic sea surface temperatures anomalies have warmed somewhat since our early June prediction and surface pressures have fallen somewhat. But, the negative influences of El Niño-induced strong Caribbean Basin and Main Development Region vertical wind shear typically dominate over surface pressure and sea surface temperature in the tropical Atlantic.

Although we have been in an active multi-decadal Atlantic Basin hurricane era since 1995, it is not unusual to have a few below-average years within an active multi-decadal period. Likewise, it is not unusual to have a few above-average years within an inactive multi-decadal period. We expect the active Atlantic hurricane era that we have been in since 1995 to continue for the next 10-15 years.

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 forecasts. Phil has been a member of my research project for the last nine 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. He is currently making new seasonal and 15-day forecast innovations that are improving our forecasts. The success of last year's seasonal forecasts is an example. Phil was awarded his Ph.D. degree in 2007. He is currently spending most of his time working towards better understanding and improving these Atlantic basin hurricane forecasts.

Acknowledgment

We are grateful to the National Science Foundation (NSF) 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 seasonal forecast 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.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of major hurricanes form, defined as 10-20°N, 70-20°W.

Major Hurricane - (MH) 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.

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

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

Named Storm Day – (NSD) As in HD but for four 6-hour periods during which a tropical or sub-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 North Atlantic (TNA) index – A measure of sea surface temperatures in the area from 5.5-23.5°N, 57.5-15°W.

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 26th 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 108 years of past data. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic basin tropical cyclone activity and landfall probability. We believe that seasonal forecasts must be based on methods that show significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided that the atmosphere continues to behave in the future as it has in the past.

The best predictors do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain the portion of the variance of seasonal hurricane activity that is not associated with the other forecast variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 2-3 other predictors.

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 2-3 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmosphere-ocean 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 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 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, 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 1. The location of each of these predictors is shown in Fig. 1. 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 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)

Table 1: Listing of 1 August 2009 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 below-average hurricane season.

Predictor	Values for 2009 Forecast	Effect on 2009 Hurricane Season
1) June-July SST (20-40°N, 15-35°W) (+)	+0.3 SD	**Slightly Enhance**
2) June-July SLP (10-25°N, 10-60°W) (-)	-0.3 SD	**Slightly Enhance**
3) June-July SST (5°S-5°N, 90-150°W) (-)	+1.2 SD	Strongly Suppress
4) Pre-1 August Named Storm Days – South of 23.5°N, East of 75°W	0 NSD	Suppress

Post-1 August Seasonal Forecast Predictors

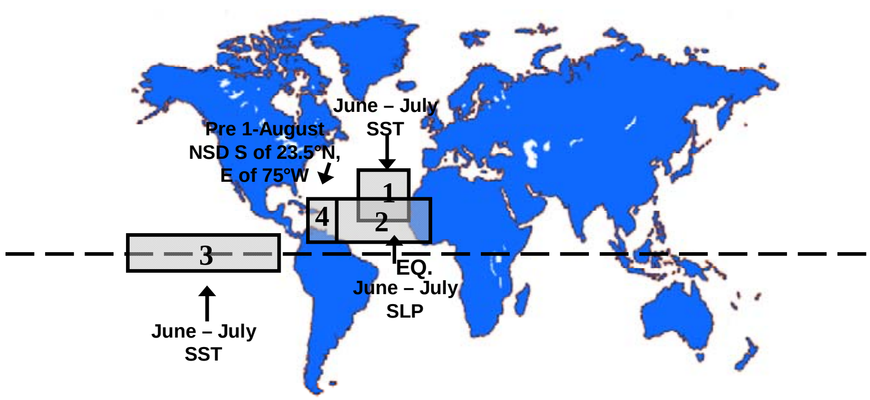

Figure 1: Location of predictors for the post-1 August forecast for the 2009 hurricane season.

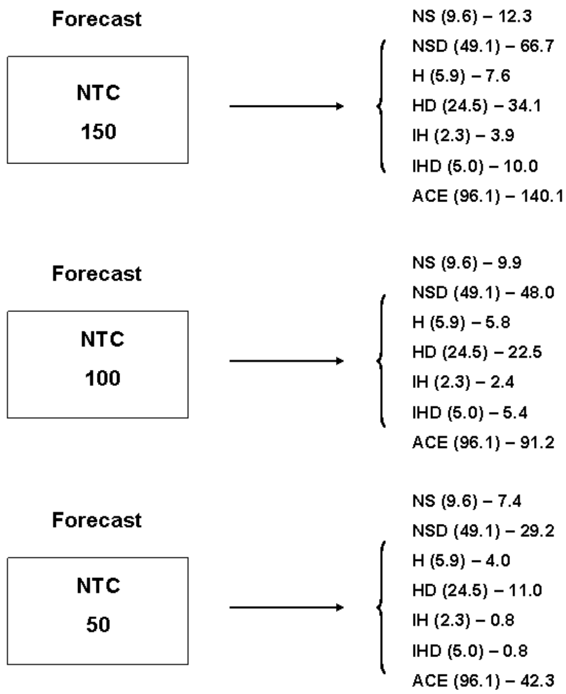

Figure 2: Schematic showing how predictions of 150, 100 and 50 NTC units, respectively, would be converted into predictions for other seasonal parameters. Numbers in parentheses are the climatological averages.

Table 2 shows our statistical forecast for the 2009 hurricane season and the comparison of this forecast with climatology (average season between 1950-2000). Our statistical forecast is calling for below average activity this year.

Table 2: Post-1 August statistical forecast for 2009.

Predictands and Climatology (1950-2000 Post-1 August Average)	Statistical Forecast
Named Storms (NS) – 8.4	9.5
Named Storm Days (NSD) – 44.9	44.6
Hurricanes (H) – 5.4	5.5
Hurricane Days (HD) – 23.4	20.4
Major Hurricanes (MH) – 2.1	2.1
Major Hurricane Days (MHD) – 4.9	4.6
Accumulated Cyclone Energy Index (ACE) – 90	82
Net Tropical Cyclone Activity (NTC) – 93	91

Figure 3 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.

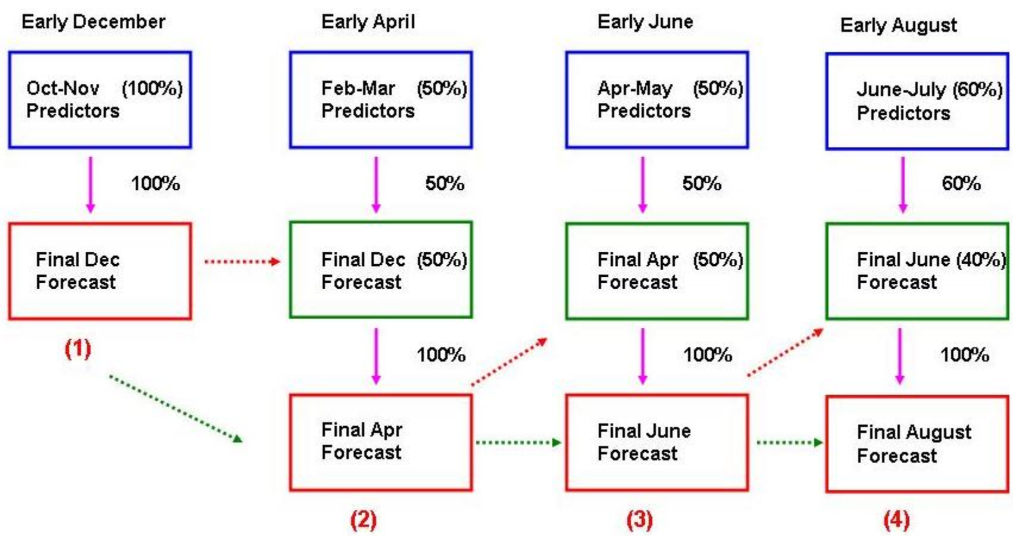

Figure 3: The new methodology utilized in calculating our statistical forecasts of seasonal NTC.

Table 3 displays our early August hindcasts for 1950-2007 using the new statistical scheme, while Figure 4 displays observations versus NTC hindcasts. The real-time forecast for 2008 is also listed. 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 4).

Table 3: 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%). The real-time forecast for 2008 is also provided.

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**
2008	**125**	**137**	**|12|**	**|27|**	**15**

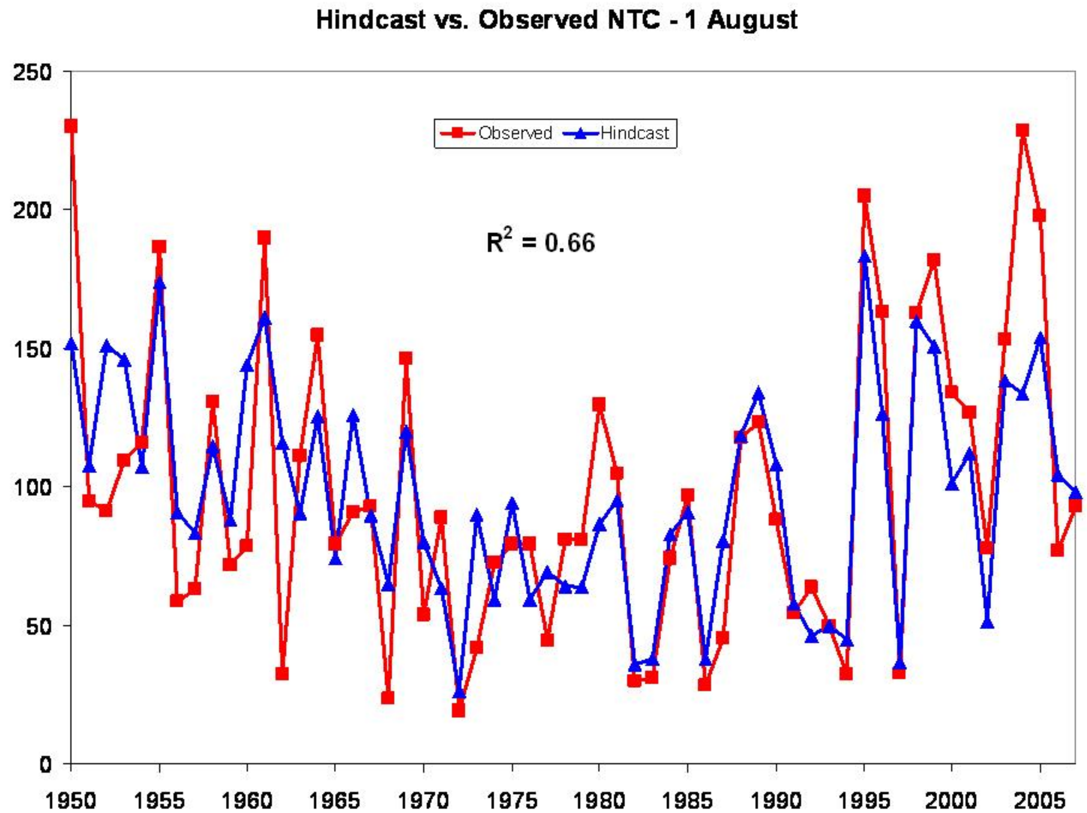

Figure 4: Observed versus hindcast values of post-1 August NTC for 1950-2007.

Table 4: 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

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 2009 forecast: http://tropical.atmos.colostate.edu/Forecasts/2009/june2009/jun2009.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 5). 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 6). 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 7). 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 (south of 23.5°N); however, if tropical formations do occur, it indicates that a very active hurricane season is likely. For example, the seven years with the most named storm days in the deep tropics in June and July (since 1949) are 1966, 1969, 1995, 1996, 1998, 2005, and 2008. All seven 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 8). 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.

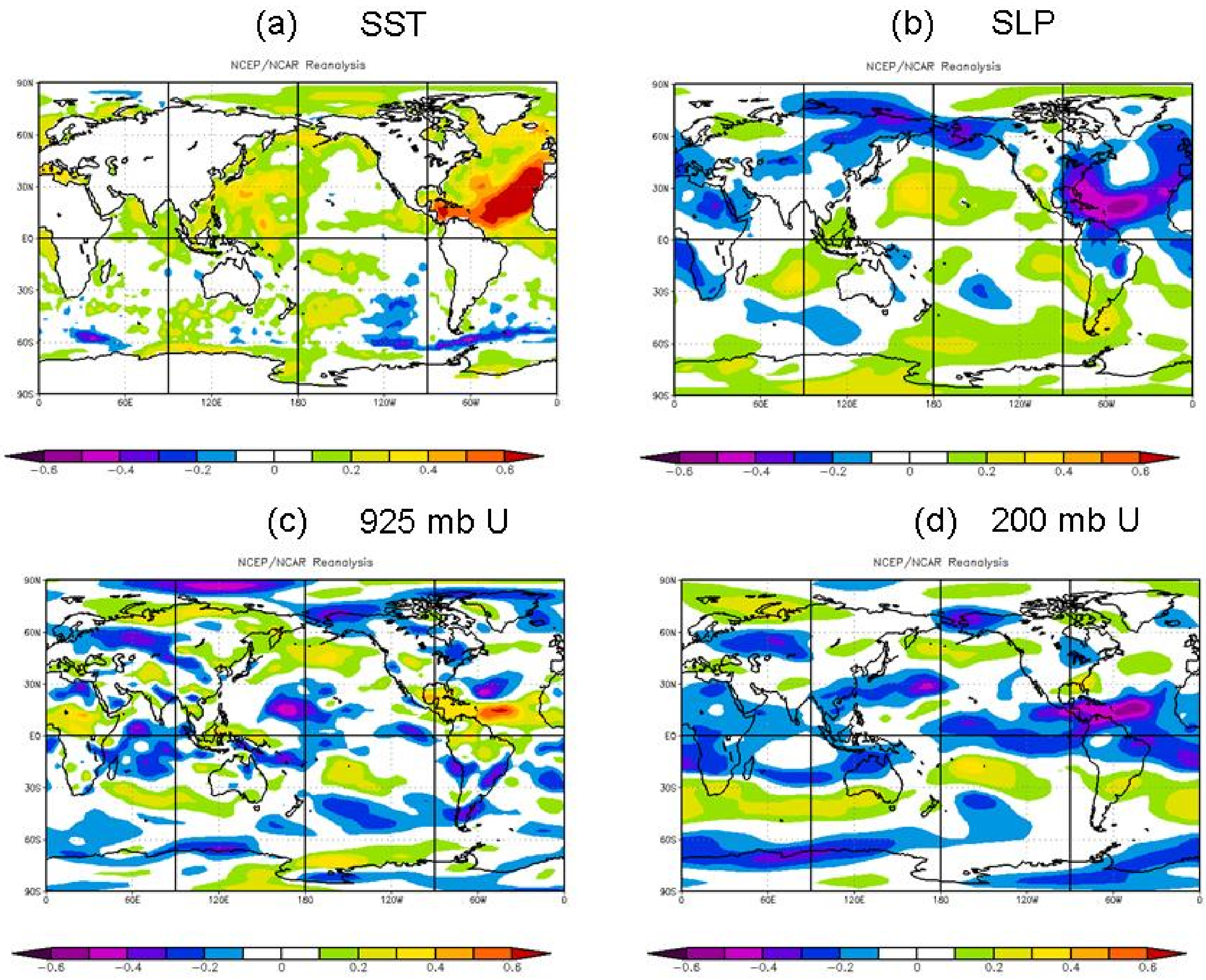

Figure 5: Linear correlations between June-July SST in the subtropical eastern Atlantic (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d).

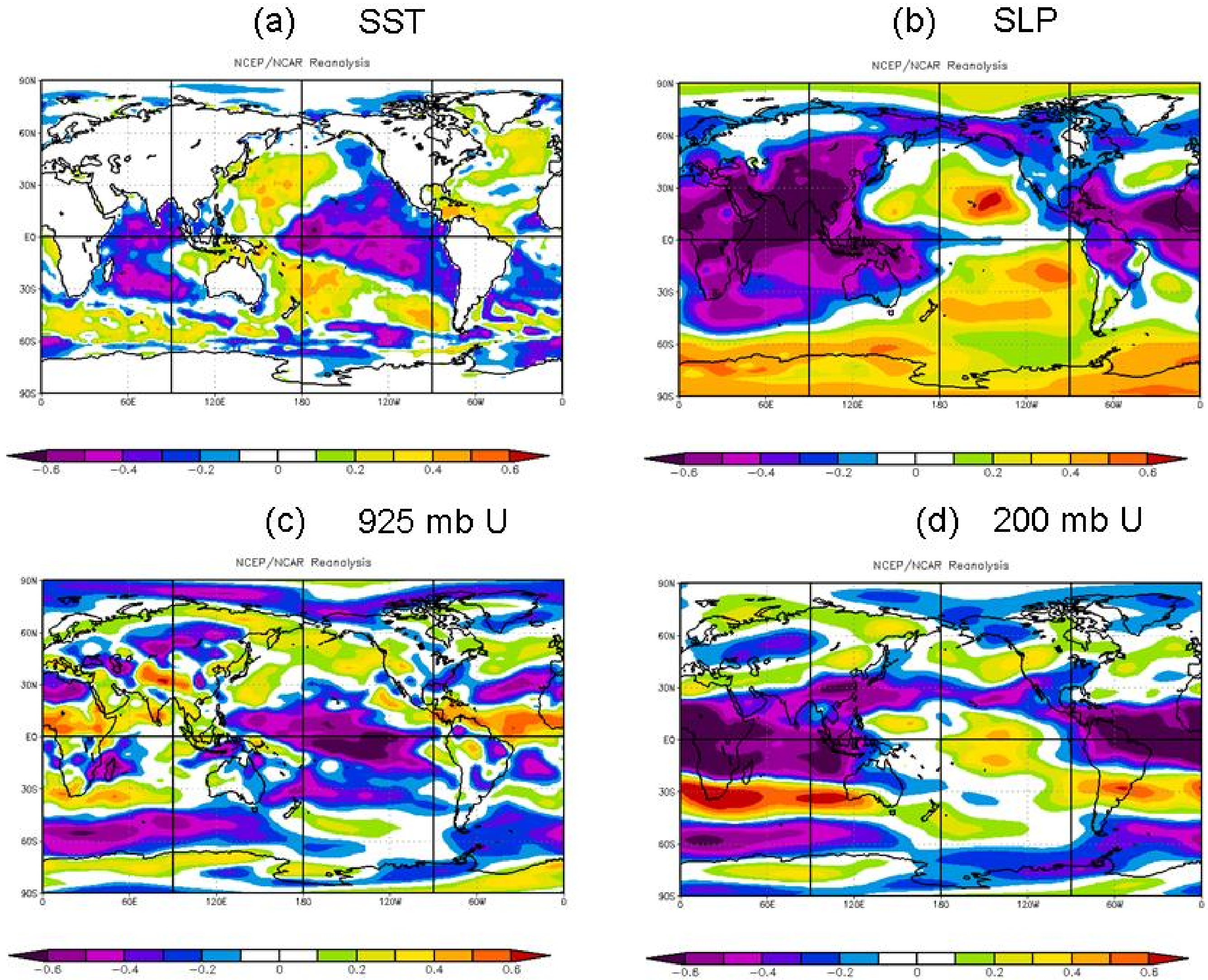

Figure 6: Linear correlations between June-July SLP in the tropical Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). Sea level pressure values have been multiplied by -1 to allow for easy comparison with Figure 5.

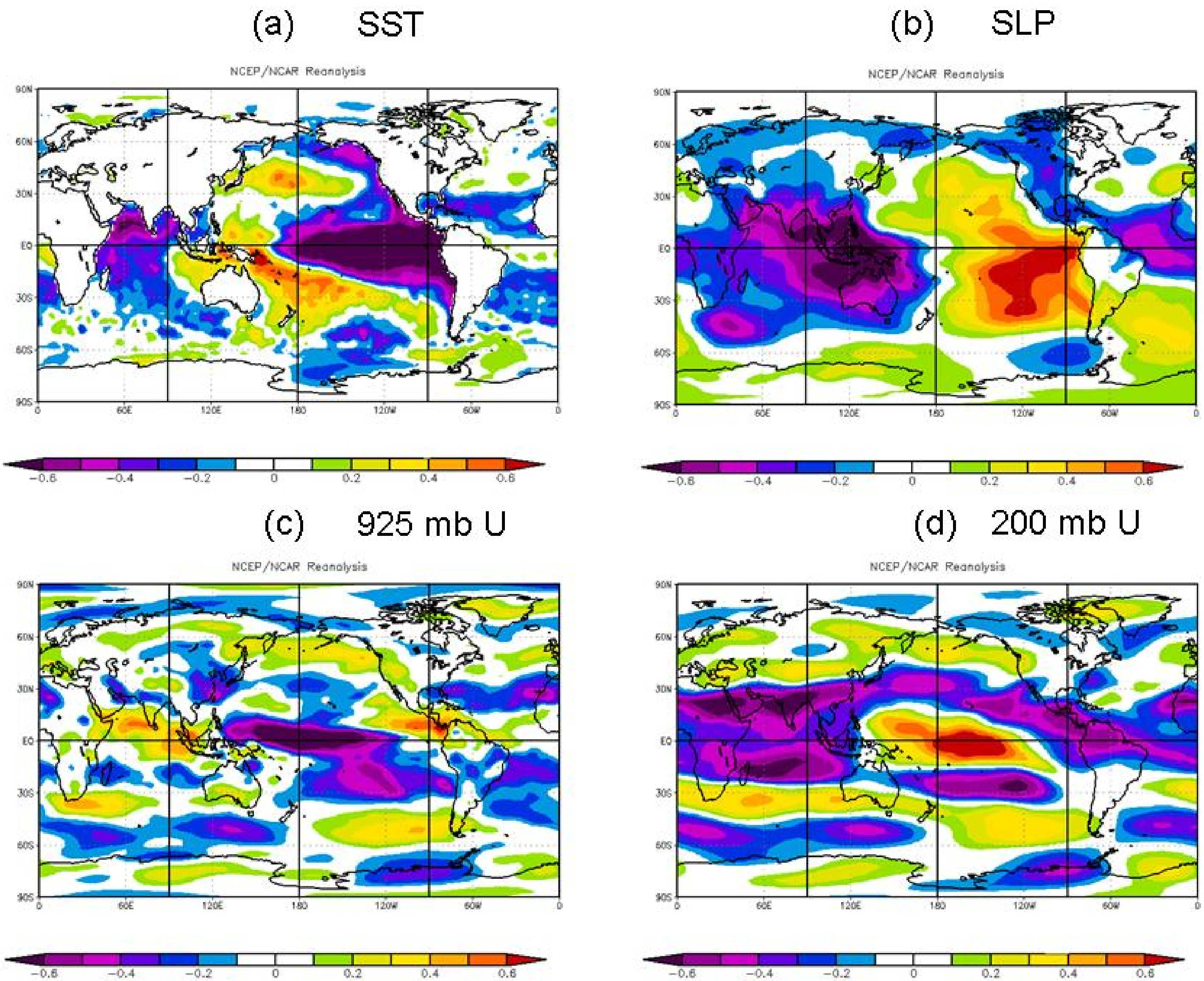

Figure 7: Linear correlations between June-July Nino 3 (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). Sea surface temperature values have been multiplied by -1 to allow for easy comparison with Figure 5.

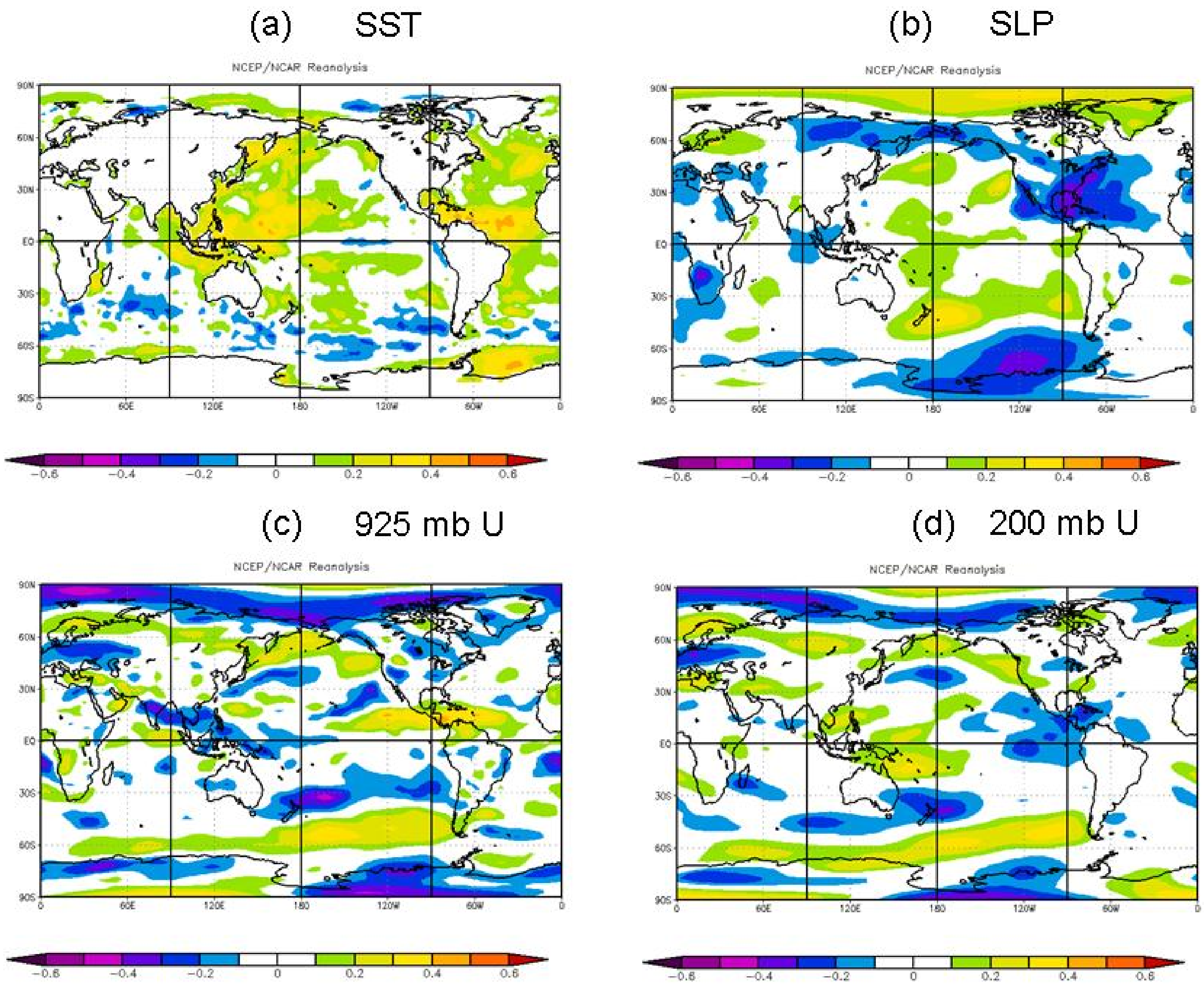

Figure 8: Linear correlations between June-July NSD in the tropics (Predictor 4) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d).

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 there is with all forecasts an uncertainty as to how well they will verify.

Table 5 provides our post-1 August forecast, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts over the 1990-2007 period, using equations developed over the 1950-1989 period. We typically expect to see 2/3 of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values.

Table 5: Model hindcast error and our 2009 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2009 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	3.3	10	6.7 – 13.3
Named Storm Days (NSD)	16.3	45	28.7 – 61.3
Hurricanes (H)	1.8	4	2.2 – 5.8
Hurricane Days (HD)	8.8	18	9.2 – 26.8
Major Hurricanes (MH)	1.2	2	0.8 – 3.2
Major Hurricane Days (MHD)	4.6	4	0.0 – 8.6
Accumulated Cyclone Energy (ACE)	37	80	43 – 117
Net Tropical Cyclone (NTC) Activity	33	85	52 – 118

4 Analog-Based Predictors for 2009 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2009. These years also provide useful clues as to likely trends in activity that the forthcoming 2009 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 2009 conditions. Table 6 lists the best analog selections from our historical database.

We select prior hurricane seasons since 1950 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that had the closest optimal combination of weak to moderate El Niño conditions and average tropical Atlantic and far North Atlantic sea surface temperatures.

There were four hurricane seasons with characteristics most similar to what we observed in June-July 2009. The best analog years that we could find for the 2009 hurricane season were 1957, 1963, 1965, and 2002. We anticipate that 2009 seasonal hurricane activity will have activity that is slightly less than what was experienced in the average of these four years due to expected continued intensification of El Niño. We believe that 2009 will have below-average activity in the Atlantic basin.

Table 6: Best analog years for 2009 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1957	8	38.00	3	21.00	2	6.50	84	86
1963	9	52.00	7	37.25	2	7.00	118	116
1965	6	39.50	4	27.25	1	7.50	84	86
2002	12	57.00	4	10.75	2	3.00	67	83
Mean	9.0	46.6	4.5	24.1	1.8	6.0	88	93
2009 Forecast	10	45	4	18	2	4	80	85

5 ENSO

Conditions in the tropical Pacific have transitioned to El Niño over the past couple of months. Sea surface temperature anomalies across the central and eastern tropical Pacific have now reached the 0.5°C anomaly threshold typically associated with El Niño events. Table 7 displays July and May SST anomalies for several Nino regions. Note that the entire central and eastern tropical Pacific has warmed by approximately 0.2 – 0.6°C during the past two months.

Table 7: May and July 2009 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	0.5	0.7	+0.2
Nino 3	0.4	1.0	+0.6
Nino 3.4	0.3	0.9	+0.6
Nino 4	0.3	0.6	+0.3

El Niño has continued to progress towards a moderate event. Table 8 displays 13 years since 1950 that have experienced significant warming from the previous winter through the May-July period. Nearly all of these years continued to anomalously warm over the August-October period.

Table 8: May-July Nino 3.4 anomalies and August-October Nino 3.4 anomalies for 13 years that experienced significant warming from the previous winter. Note that most of these years continued to warm from the May-July to the August-October period.

Year	May-July Nino 3.4 SST Anomaly (°C)	August-October Nino 3.4 SST Anomaly (°C)	August-October minus May-July (°C)
1951	0.2	0.7	+0.5
1957	0.9	0.9	0.0
1963	0.3	0.9	+0.6
1965	0.6	1.4	+0.8
1972	0.8	1.5	+0.7
1976	-0.2	0.5	+0.7
1982	0.7	1.5	+0.8
1986	0.0	0.7	+0.7
1991	0.8	0.9	+0.1
1994	0.5	0.7	+0.2
1997	1.3	2.2	+0.9
2002	0.8	1.1	+0.3
2004	0.5	0.9	+0.4
Average	0.6	1.0	+0.4

El Niño events almost always reduce Atlantic basin hurricane activity, especially in the deep tropics and the Caribbean. Figure 9 displays hurricane tracks south of 23.5°N for the six warmest versus the six coldest ENSO years as defined by the August-October Nino 3.4 index. This dramatic reduction in tropical activity in El Niño years is largely due to increased upper-level westerly winds associated with the weaker and eastward shifted Walker Circulation. Also, enhanced subsidence and higher sea level pressures in the tropical Atlantic are typically associated with El Niño years.

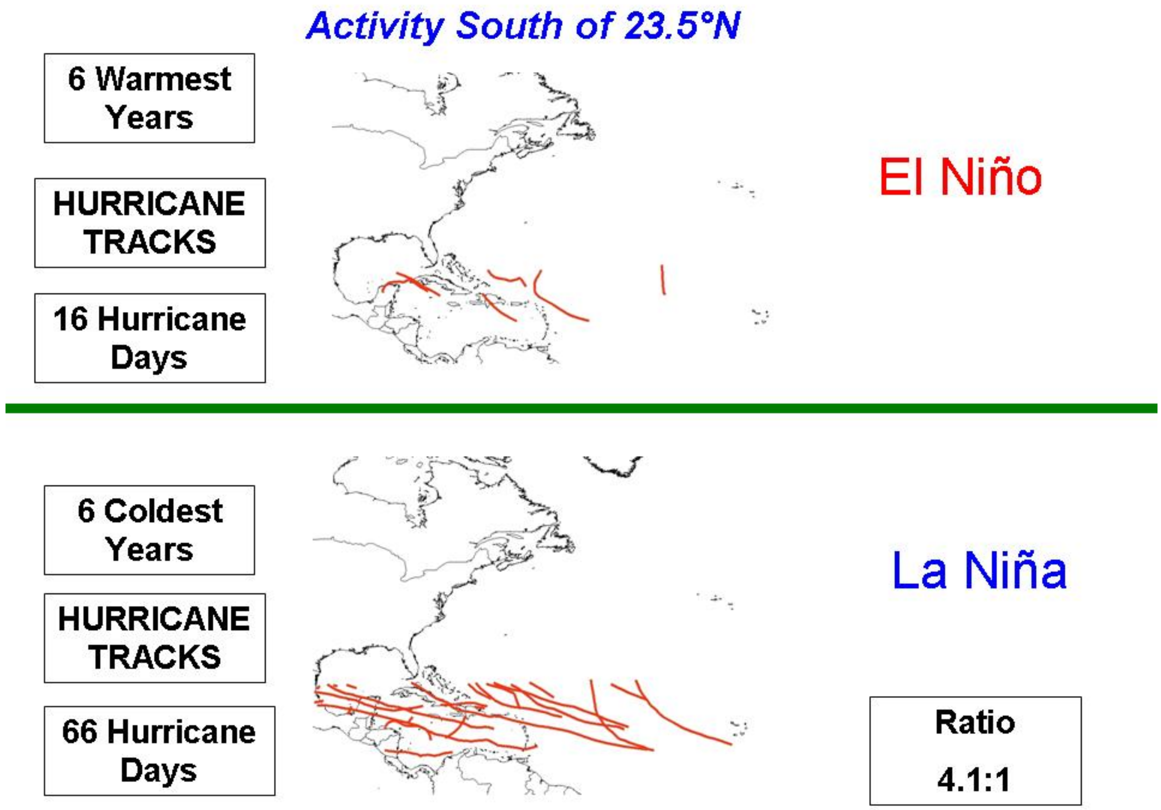

Figure 9: Tracks for all hurricanes occurring in the six warmest versus the six coldest ENSO years over the period from 1950-2008. ENSO years are classified based on the August-October Nino 3.4 index.

El Niño events, while reducing activity in the deep tropics, do not tend to have a similar impact on systems forming north of 25°N. While pre-existing cyclonic vorticity is typically reduced in El Niño years in the deep tropics, vorticity is actually enhanced in the sub-tropics. The ratio of named storms forming south of 23.5°N and east of 75°W with storms forming north of 25°N changes considerably from neutral and La Niña years to El Niño years. Based on data from 1950-2008, approximately 45% of all storms form north of 25°N in a La Niña year or neutral year, while approximately 60% of all storms form north of 25°N in El Niño years.

One of the big questions with this forecast is how much warming will be experienced across the tropical Pacific over the next few months. Figure 10 displays the latest suite of model forecasts. Most models indicate continued warming, with about half of the models calling for a moderate El Niño event (>1.0°C) developing in the next couple of months. Given the current setup of the tropical Pacific along with model forecasts, we anticipate that a moderate event will be in progress during the most active portion of the hurricane season (from mid-August to mid-October).

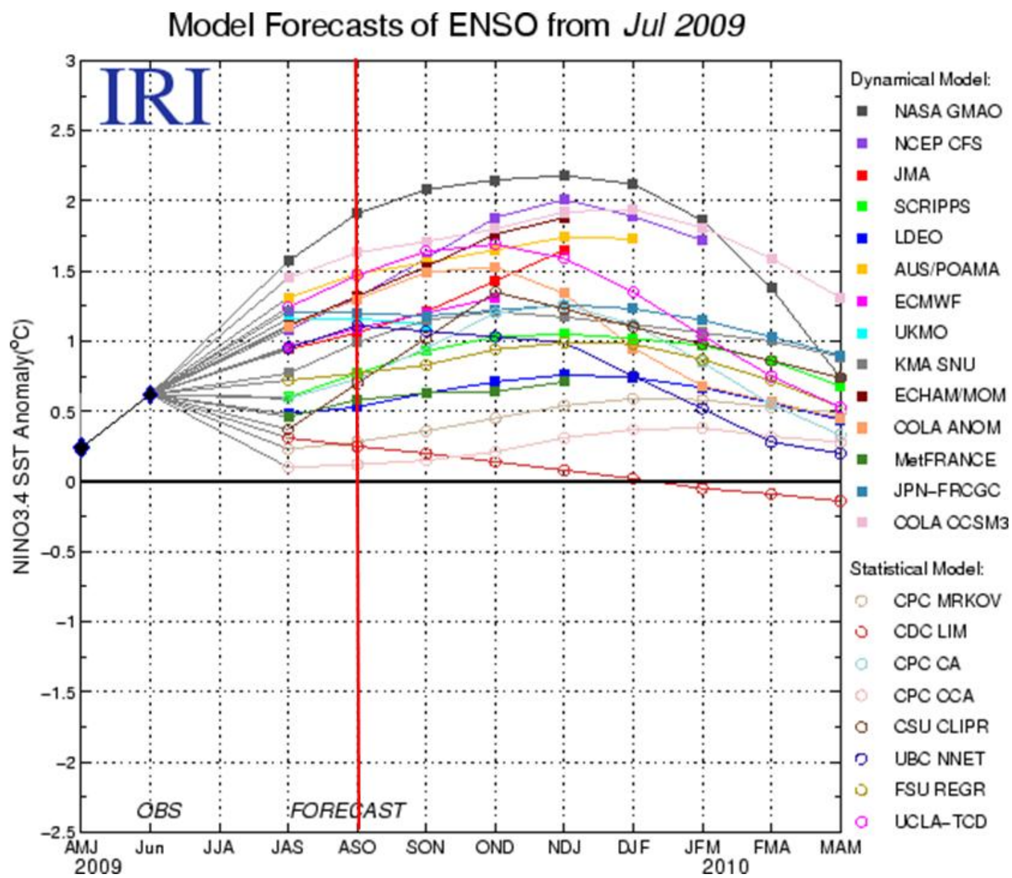

Figure 10: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

6 Current Atlantic Basin Conditions

Conditions in the Atlantic have become more favorable for Atlantic hurricanes since May. SST anomalies across the MDR have warmed considerably from May to July (Figure 11). The tropical Atlantic has warmed approximately 0.25-0.5°C during the two-month period. July sea level pressure anomalies have been somewhat below average (Figure 12), driving weaker trades during the month. Despite this warming, the Atlantic remains slightly cooler than the 1995-2008 average. Current Tropical North Atlantic index (defined as 5.5-23.5°N, 57.5-15°W) SST anomaly values have increased to slightly above 0°C after dipping to approximately -0.4°C during May. We believe that the neutral tropical Atlantic combined with a weak/moderate El Niño event will likely lead to a fairly quiet hurricane season.

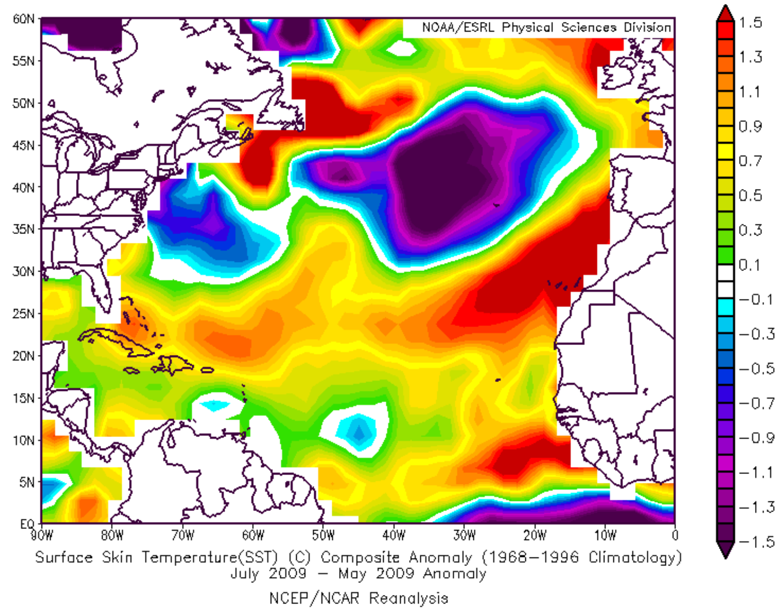

Figure 11: July 2009 – May 2009 SST anomaly difference across the Atlantic. The tropical Atlantic has warmed considerably over the past two months.

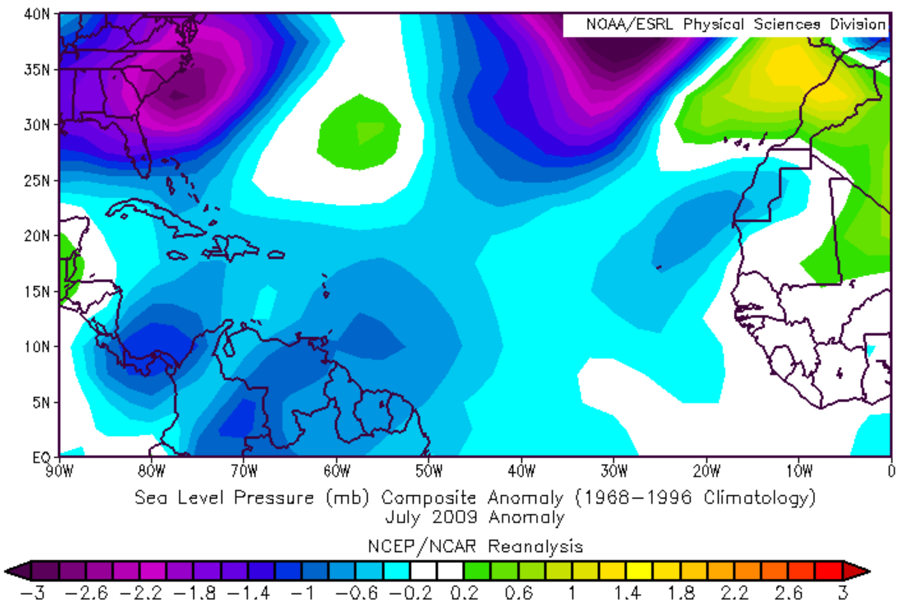

Figure 12: July 2009 Atlantic SLP anomaly.

7 Adjusted 2009 Forecast

Table 9 shows our final adjusted early August forecast for the 2009 season which is a combination of our statistical scheme, our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. Our statistical forecast and our analog forecast indicate activity at below-average levels. We foresee a below-average Atlantic basin hurricane season due to the development of El Niño.

Table 9: Summary of our early August statistical forecast, our analog forecast and our adjusted final forecast for the 2009 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	9.5	9.0	10
Named Storm Days (49.1)	44.6	46.6	45
Hurricanes (5.9)	5.5	4.5	4
Hurricane Days (24.5)	20.4	24.1	18
Intense Hurricanes (2.3)	2.1	1.8	2
Intense Hurricane Days (5.0)	4.6	6.0	4
Accumulated Cyclone Energy Index (96.1)	82	88	80
Net Tropical Cyclone Activity (100%)	91	93	85

8 Landfall Probabilities for 2009

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events cannot be accurately forecast months in advance, the total seasonal probability of landfall can be forecast with statistical skill. With the observation that, statistically, landfall is a function of varying climate conditions, a probability specification has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the 20th century (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions.

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 10). 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 10: 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 MH, and 5 MHD 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)	Major Hurricanes (MH)	2.3
6)	Major Hurricane Days (MHD)	5.0

Table 11 lists strike probabilities for the 2009 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. In our early June forecast, we debuted probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2009 is expected to be below its long-term average of 100, and therefore, landfall probabilities are below their long-term average.

Please visit the 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. The probability of each U.S. coastal state being impacted by hurricanes and major hurricanes is also included. In addition, we now include probabilities of named storms, hurricanes and major hurricanes tracking within 50 and 100 miles of various islands and landmasses in the Caribbean and Central America.

Table 11: Estimated probability (expressed in percent) of one or more 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 (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2009. Probabilities of a tropical storm, hurricane and major hurricane tracking into the Caribbean are also provided. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	74% (79%)	62% (68%)	46% (52%)	79% (84%)	95% (97%)
Gulf Coast (Regions 1-4)	53% (59%)	37% (42%)	26% (30%)	54% (60%)	78% (83%)
Florida plus East Coast (Regions 5-11)	45% (50%)	39% (44%)	27% (31%)	55% (61%)	75% (81%)
Caribbean (10-20°N, 60-88°W)	77% (82%)	51% (57%)	37% (42%)	69% (75%)	93% (96%)

We are debuting state hurricane impact probabilities with this forecast. We have utilized the Atlantic basin hurricane impact dataset created by the National Hurricane

Center available here: http://www.aoml.noaa.gov/hrd/hurdat/ushurrlist18512008_jun09.txt. This dataset calculates which states were impacted by all hurricanes making U.S. landfall. We have calculated probabilities of each state being impacted by a hurricane and major hurricane using data from 1856-2008. Several states can be impacted by the same tropical cyclone, for example, Hurricane Katrina impacted Louisiana and Mississippi as a Category 3 hurricane while impacting Florida and Alabama as a Category 1 hurricane. Current-year and climatological probabilities of hurricane impact by state are now available on our Landfalling Probability Webpage (http://www.e-transit.org/hurricane). Table 12 displays climatological and current-year probabilities for each state being impacted by a hurricane and major hurricane.

Table 12: Current-year and climatological (in parentheses) probabilities for each coastal state being impacted by a hurricane and major hurricane based on data from 1856-2008.

Coastal State	Hurricane Probability	Major Hurricane Probability
Alabama	13% (16%)	2% (3%)
Connecticut	6% (7%)	2% (2%)
Delaware	1% (1%)	<1% (<1%)
Florida	45% (51%)	18% (21%)
Georgia	10% (11%)	1% (1%)
Louisiana	26% (30%)	10% (12%)
Maine	3% (4%)	<1% (<1%)
Maryland	1% (1%)	<1% (<1%)
Massachusetts	6% (7%)	2% (2%)
Mississippi	9% (11%)	4% (4%)
New Hampshire	1% (1%)	<1% (<1%)
New Jersey	1% (1%)	<1% (<1%)
New York	6% (8%)	3% (3%)
North Carolina	25% (28%)	6% (8%)
Rhode Island	5% (6%)	2% (3%)
South Carolina	15% (17%)	3% (4%)
Texas	29% (33%)	10% (12%)
Virginia	5% (6%)	1% (1%)
Mid-Atlantic (VA, MD, DE, NJ)	6% (8%)	1% (1%)
Northeast U.S. (NY, CT, RI, MA, NH, ME)	10% (11%)	4% (4%)

Figures 13 and 14 display the climatological probability along with the El Niño-year (ASO Nino 3.4 >0.5°C) probability of various states being impacted by a hurricane and major hurricane, respectively. In general, the probabilities of being impacted by a hurricane and major hurricane are reduced slightly in El Niño years.

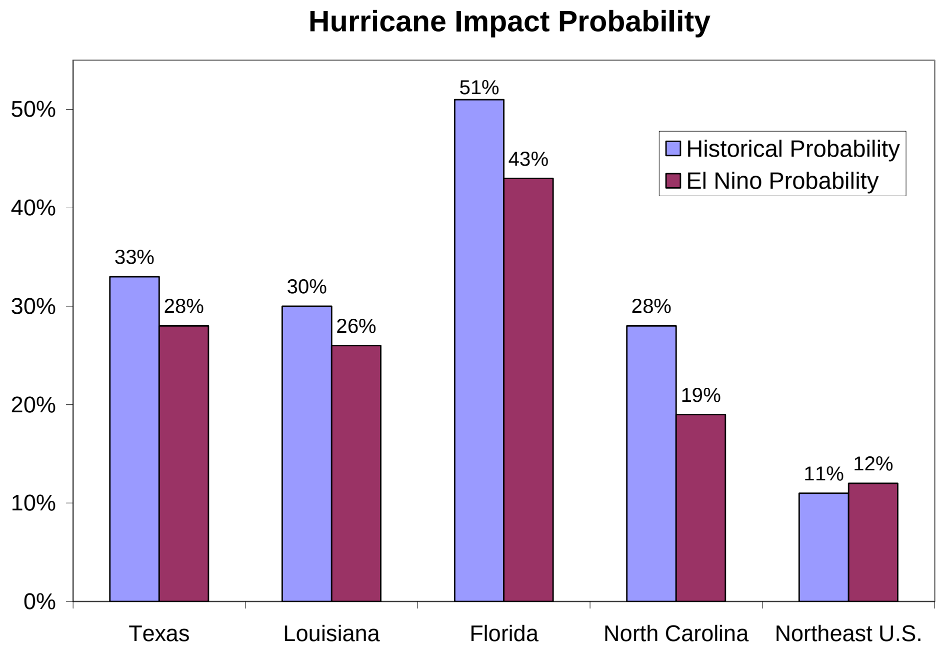

Figure 13: Probability of several areas along the U.S. coastline being impacted by a hurricane in all years compared with El Niño years. Probabilities are calculated based on the 1856-2008 period.

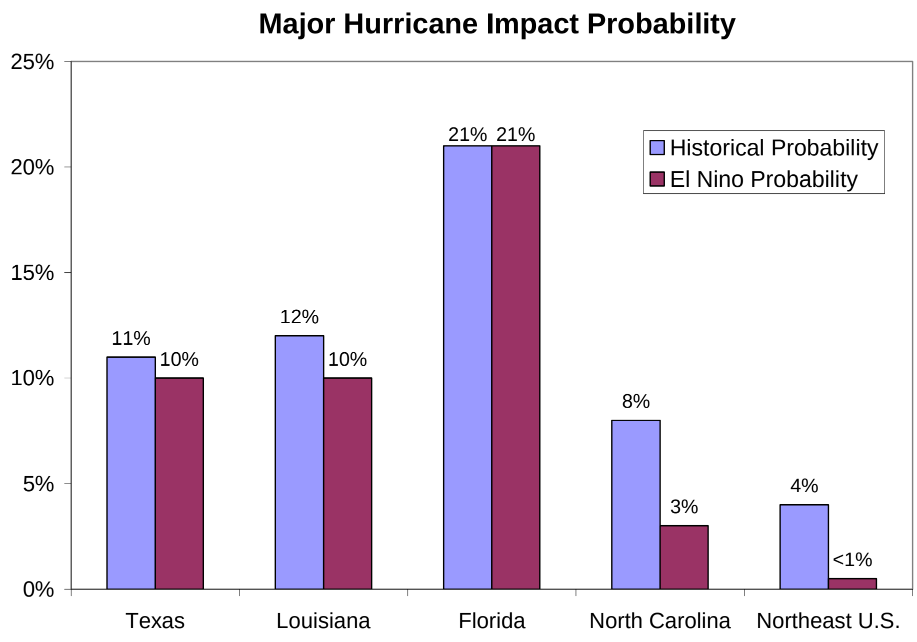

Figure 14: Probability of several areas along the U.S. coastline being impacted by a major hurricane in all years compared with El Niño years. Probabilities are calculated based on the 1856-2008 period.

9 Has Global Warming Been Responsible for the Recent Large Upswing (Since 1995) in Atlantic Basin Major Hurricanes and U.S. Landfall?

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. In addition, three Category 2 hurricanes (Dolly, Gustav and Ike) pummeled the Gulf Coast last year causing considerable devastation.

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 three 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 14-year period of 1995-2008 (average 3.9 per year) in comparison to the prior 25-year period of 1970-1994 (average 1.5 per year). This large increase in Atlantic major hurricanes is primarily a result of the multi-decadal increase in the Atlantic Ocean thermohaline circulation (THC) that is not directly related to global sea surface temperatures or CO_2 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). The AMO is the Atlantic component of the global ocean Meridional Overturning Circulation (MOC).

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.

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.

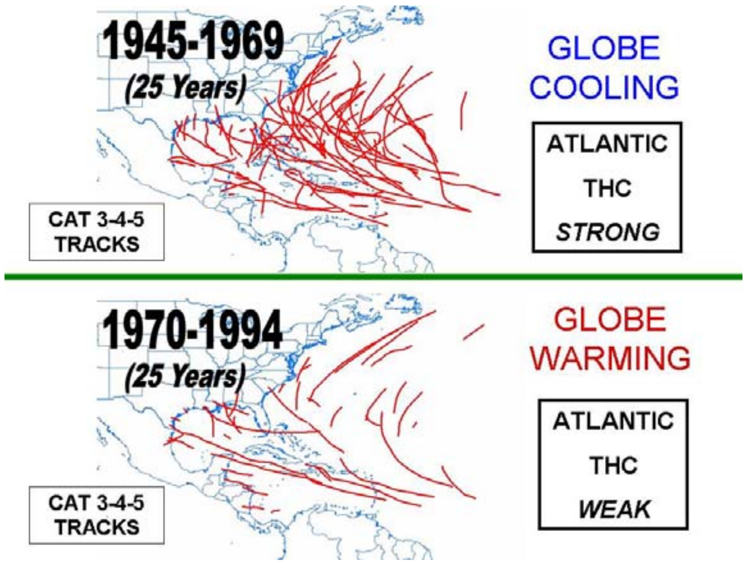

Figure 15: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than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

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1899 (Table 13). Although global mean ocean and Atlantic sea surface temperatures have increased by about 0.4^{o}C between these two 55-year periods (1899-1953 compared with 1954-2008), 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 43-year period of 1923-1965 (24 landfall events) and the 43-year period of 1966-2008 (7 landfall events) was especially large (Figure 16). For the entire United States coastline, 38 major hurricanes made landfall during the earlier 43-year period (1923-1965) compared with only 26 for the latter 43-year period (1966-2008). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period.

Table 13: U.S. landfalling tropical cyclones by intensity during two 55-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Intense Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1899-1953 (55 years)	207	111	42	+0.4°C
1954-2008 (55 years)	188	95	39	

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 the natural bounds of hurricane variation.

What made the 2004-2005 and 2008 seasons so destructive was not the high frequency of major hurricanes but the high percentage of hurricanes that were steered over the US coastline. The US hurricane landfall events of these years were primarily a result of the favorable upper-air steering currents present during these years.

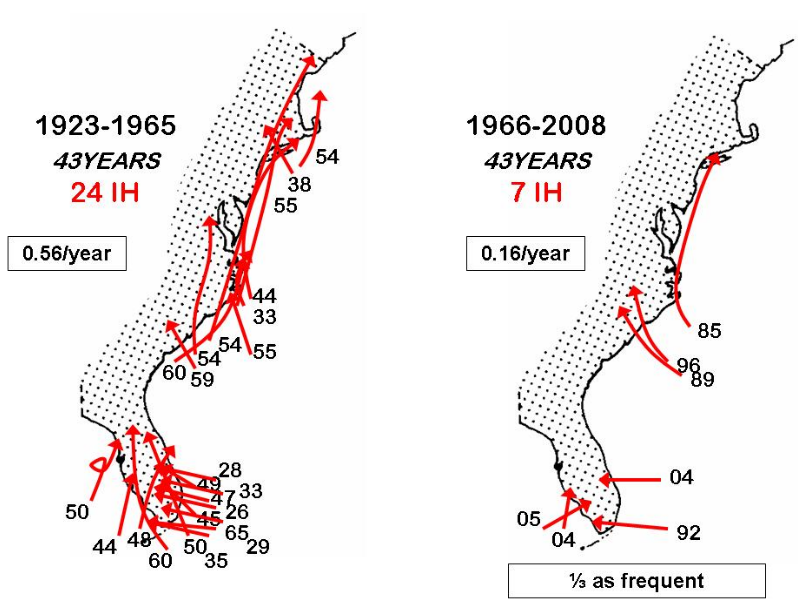

Figure 16: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 43-year period of 1923-1965 versus the most recent 43-year period of 1966-2008.

Although 2005 had a record number of tropical cyclones (28 named storms), 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 storm total 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 was not as much of an outlier as many have indicated.

The active hurricane season in 2008 lends further support to the belief that the Atlantic basin remains 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.

10 Anticipated Large Increase in US Hurricane Destruction

The large increase in the hurricane-spawned destruction that occurred in 2004, 2005 and 2008 has not surprised us. We have been anticipating a great upsurge in hurricane destruction for many years as illustrated by the statements we have made in previous seasonal forecast reports such as:

"…major increases in hurricane-spawned coastal destruction are inevitable." (April 1989)

"A new era of major hurricane activity appears to have begun…. As a consequence of the exploding U.S. and Caribbean coastal populations during the last 25-30 years, we will begin to see a large upturn in hurricane-spawned destruction – likely higher than anything previous experienced." (June 1997)

"We must expect a great increase in landfalling major hurricanes in the coming decades. With exploding southeast coastal populations, we must also prepare for levels of hurricane damage never before experienced." (April 2001)

"If the future is like the past, it is highly likely that very active hurricane seasons will again emerge during the next few years, and the prospects for very large U.S. and Caribbean increases in hurricane damage over the next few decades remains high. We should indeed see future hurricane damage much greater than anything in the past." (May 2002)

"Regardless of whether a major hurricane makes landfall this year, it is inevitable that we will see hurricane-spawned destruction in coming years on a scale many, many times greater than what we have seen in the past." (May 2003)

These projections of increased U.S. hurricane destruction were made with our anticipation that the Atlantic thermohaline circulation (THC) (which had been very weak from the late-1960s to the mid-1990s) would be changing to a stronger mode making for a large increase in Atlantic basin major hurricane activity. The THC has become much stronger since 1995. **These projections were made with no consideration given to rising levels of atmospheric CO_2.**

We were very fortunate during the early part of this strong THC period in that only 3 of 32 major hurricanes that formed in the Atlantic between 1995-2003 made U.S. landfall. The long-term average is that approximately 1 in 3.5 major hurricanes that forms in the Atlantic makes U.S. landfall. This luck failed to hold beginning with the 2004 hurricane season.

11 Forthcoming Updated Forecasts of 2009 Hurricane Activity

We are planning on issuing experimental 15-day forecasts approximately every two weeks during the August-October period. These 15-day forecasts will supersede the August, September and October monthly forecasts. The first two-week forecast will be issued on Wednesday, August 5. A verification and discussion of all 2009 forecasts will be issued in late November 2009. A qualitative discussion (not a specific numbers forecast) for 2010 will be issued in early December. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

12 Acknowledgments

Besides the individuals named on page 5, there have been a number of other meteorologists that have furnished us with data and given valuable assessments of the current state of global atmospheric and oceanic conditions. These include Brian McNoldy, Arthur Douglas, Ray Zehr, Mark DeMaria, Todd Kimberlain, Paul Roundy and Amato Evan. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical and data analysis and assistance over a number of years. We have profited over the years from many in-depth discussions with most of the current and past NHC hurricane forecasters. The second author would further like to acknowledge the encouragement he has received for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, and Max Mayfield, former directors of the National Hurricane Center (NHC). Uma Shama, Larry Harman and Daniel Fitch of Bridgewater State College, MA have provided assistance and technical support in the development of our Landfalling Hurricane Probability

Webpage. We also thank Bill Bailey of the Insurance Information Institute for his sage advice and encouragement.

The financial backing for the issuing and verification of these forecasts has been supported in part by the National Science Foundation. We also thank the GeoGraphics Laboratory at Bridgewater State College for their assistance in developing the Landfalling Hurricane Probability Webpage.

13 Citations and Additional Reading

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14 Verification of Previous Forecasts

Table 14: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2004-2008.

2004	5 Dec. 2003	Update 2 April	Update 28 May	Update 6 August	Obs.
Hurricanes	7	8	8	7	9
Named Storms	13	14	14	13	14
Hurricane Days	30	35	35	30	46
Named Storm Days	55	60	60	55	90
Intense Hurricanes	3	3	3	3	6
Intense Hurricane Days	6	8	8	6	22
Net Tropical Cyclone Activity	125	145	145	125	229

2005	3 Dec. 2004	Update 1 April	Update 31 May	Update 5 August	Obs.
Hurricanes	6	7	8	10	14
Named Storms	11	13	15	20	26
Hurricane Days	25	35	45	55	48
Named Storm Days	55	65	75	95	116
Intense Hurricanes	3	3	4	6	7
Intense Hurricane Days	6	7	11	18	16.75
Net Tropical Cyclone Activity	115	135	170	235	263

2006	6 Dec. 2005	Update 4 April	Update 31 May	Update 3 August	Obs.
Hurricanes	9	9	9	7	5
Named Storms	17	17	17	15	10
Hurricane Days	45	45	45	35	20
Named Storm Days	85	85	85	75	50
Intense Hurricanes	5	5	5	3	2
Intense Hurricane Days	13	13	13	8	3
Net Tropical Cyclone Activity	195	195	195	140	85

2007	8 Dec. 2006	Update 3 April	Update 31 May	Update 3 August	Obs.
Hurricanes	7	9	9	8	6
Named Storms	14	17	17	15	15
Hurricane Days	35	40	40	35	11.25
Named Storm Days	70	85	85	75	34.50
Intense Hurricanes	3	5	5	4	2
Intense Hurricane Days	8	11	11	10	5.75
Net Tropical Cyclone Activity	140	185	185	160	97

2008	7 Dec. 2007	Update 9 April	Update 3 June	Update 5 August	Obs.
Hurricanes	7	8	8	9	8
Named Storms	13	15	15	17	16
Hurricane Days	30	40	40	45	30.50
Named Storm Days	60	80	80	90	88.25
Intense Hurricanes	3	4	4	5	5
Intense Hurricane Days	6	9	9	11	7.50
Net Tropical Cyclone Activity	125	160	160	190	162