EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITY FOR 2009

We foresee average activity for the 2009 Atlantic hurricane season. We have decreased our seasonal forecast from our initial early December prediction. We anticipate an average probability of United States major hurricane landfall.

(as of 7 April 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 extended-range 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 April. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming season. Our early April statistical forecast methodology shows strong evidence over 58 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 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.

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
Named Storms (NS) (9.6)	14	12
Named Storm Days (NSD) (49.1)	70	55
Hurricanes (H) (5.9)	7	6
Hurricane Days (HD) (24.5)	30	25
Intense Hurricanes (IH) (2.3)	3	2
Intense Hurricane Days (IHD) (5.0)	7	5
Accumulated Cyclone Energy (ACE) (96.1)	125	100
Net Tropical Cyclone Activity (NTC) (100%)	135	105

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

1) Entire U.S. coastline - 54% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 32% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 31% (average for last century is 30%)

4) Average major hurricane landfall risk in the Caribbean

ABSTRACT

Information obtained through March 2009 indicates that the 2009 Atlantic hurricane season will have about as much activity as the average 1950-2000 season. We estimate that 2009 will have about 6 hurricanes (average is 5.9), 12 named storms (average is 9.6), 55 named storm days (average is 49.1), 25 hurricane days (average is 24.5), 2 intense (Category 3-4-5) hurricanes (average is 2.3) and 5 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 105 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2009 to be approximately 105 percent of the long-term average. We have decreased our seasonal forecast from early December.

This forecast is based on an extended-range early April statistical prediction scheme that utilizes 58 years of past data. Analog predictors are also utilized. The influence of El Niño conditions is implicit in these predictor fields, and therefore we do not utilize a specific ENSO forecast as a predictor.

We expect current weak La Niña conditions to transition to neutral and perhaps weak El Niño conditions by this year's hurricane season. If El Niño conditions develop for this year's hurricane season, it would tend to increase levels of vertical wind shear and decrease levels of Atlantic hurricane activity. Another reason for our forecast reduction is due to anomalous cooling of sea surface temperatures in the tropical Atlantic. Cooler waters are associated with dynamic and thermodynamic factors that are less conducive for an active Atlantic hurricane season.

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 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 many new seasonal and monthly 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) 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.

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.

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 58 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 April Forecast Methodology

We developed a new April forecast scheme which was used for the first time last year. This scheme worked out quite well in predicting a very active season last year. Complete details on the earlier April forecast schemes used from 1995-2007 are available in our April 2008 forecast (Klotzbach and Gray 2008).

2.1 Current April Statistical Forecast Scheme

We have found that using two late-winter predictors and our early December hindcast, we can obtain early April hindcasts that show considerable skill over the period from 1950-2007. This new forecast model also provided a very accurate prediction for the 2008 hurricane season.

This new scheme was created by evaluating the two late-winter predictors using least-squared regression. The resulting hindcasts were then ranked in order from 1 (the highest value) to 58 (the lowest value). Then the resulting preliminary April NTC hindcast rank was adjusted to the final April NTC hindcast by using the following method. We ranked the December NTC hindcasts in a similar manner as was done with early April (i.e., from 1 to 58). Then the final April NTC hindcast rank was derived by computing the following equation:

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

The final NTC hindcast was obtained by taking the final April NTC hindcast rank and assigning the observed NTC value for that rank. For example, if the final April NTC hindcast rank was 10 (the 10^{th} highest rank), the NTC value assigned for the prediction would be the 10^{th} highest observed rank, which in this case would be 166 NTC units. Since there is considerable uncertainty at this extended lead time as to final forecast values, final hindcast values are constrained to be between 40 and 200 NTC units.

Using the ranking method to arrive at our final forecast values is a new statistical forecasting approach for us. We find that using this method improves the hindcast skill of our forecasts somewhat (approximately 4-10%) and also allows for improved predictability of outliers. For example, simply by ranking our December hindcasts and assigning observed NTC values to those ranks improves our hindcast skill (as measured by variance explained) in early December from 45% to 49%.

The new forecast scheme detailed below correlates with observations at 0.80 for the years from 1995-2007 and 0.85 for the years from 2002-2007. We believe that we have solid physical links between these predictors and the upcoming Atlantic basin hurricane season.

Table 1 displays hindcasts for 1950-2007 using the current scheme, while Figure 1 displays observations versus NTC hindcasts. We have correctly predicted above- or below-average seasons in 45 out of 58 hindcast years (78%). Our predictions have had a smaller error than climatology in 37 out of 58 years (64%). Our average hindcast error is 26 NTC units, compared with 44 NTC units for climatology. This scheme also shows considerable stability when broken in half, explaining 59 percent of the variance from 1950-1978 and 72 percent of the variance from 1979-2007. This new scheme is also well-tuned to the multi-decadal active hurricane periods from 1950-1969 and 1995-2007 versus the inactive hurricane period from 1970-1994 (Table 2). Figure 2 displays the locations of the two late-winter predictors used in this scheme in map form. Please refer to Figure 1 of our early December forecast for locations of predictors used in our early

December prediction scheme. Table 3 lists the three (two new late-winter predictors and our early December prediction) that are utilized for this year's April forecast. A more extensive discussion of current conditions in the Atlantic and Pacific Oceans is provided in Sections 5 and 6.

Table 1: Observed versus hindcast NTC for 1950-2007 using the current forecast 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 45 out of 58 years (78%), while hindcast improvement over climatology occurred in 37 out of 58 years (64%).

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1950	230	200	30	130	100
1951	115	**97**	18	15	**-3**
1952	93	**150**	-57	-7	**-50**
1953	116	188	-72	16	**-56**
1954	124	**92**	32	24	**-8**
1955	188	166	22	88	66
1956	66	**129**	-63	-34	**-29**
1957	82	**109**	-27	-18	**-9**
1958	133	134	-1	33	32
1959	94	89	5	-6	1
1960	92	**133**	-41	-8	**-33**
1961	211	200	11	111	100
1962	32	**106**	-74	-68	**-6**
1963	111	**94**	17	11	**-6**
1964	160	116	44	60	16
1965	82	**115**	-33	-18	**-15**
1966	134	130	4	34	30
1967	93	82	11	-7	**-4**
1968	39	66	-27	-61	34
1969	150	200	-50	50	0
1970	62	52	10	-38	28
1971	91	85	6	-9	3
1972	27	40	-13	-73	60
1973	50	64	-14	-50	36
1974	72	50	22	-28	6
1975	89	74	15	-11	**-4**
1976	82	82	0	-18	18
1977	45	40	5	-55	50
1978	83	45	38	-17	**-21**
1979	92	40	52	-8	**-44**
1980	129	**57**	72	29	**-43**
1981	109	**93**	16	9	**-7**
1982	35	62	-27	-65	38
1983	31	40	-9	-69	60
1984	74	93	-19	-26	7
1985	106	111	-5	6	1
1986	37	40	-3	-63	60
1987	46	80	-34	-54	20
1988	118	**83**	35	18	**-17**
1989	130	129	1	30	29
1990	98	82	16	-2	**-14**
1991	57	40	17	-43	26
1992	64	40	24	-36	12
1993	52	72	-20	-48	28
1994	35	46	-11	-65	54
1995	222	160	62	122	60
1996	192	134	58	92	34
1997	51	51	0	-49	49
1998	166	200	-34	66	32
1999	185	192	-7	85	78
2000	134	118	16	34	18
2001	129	**98**	31	29	**-2**
2002	80	91	-11	-20	9
2003	173	185	-12	73	61
2004	228	200	28	128	100
2005	273	173	100	173	73
2006	85	124	-39	-15	**-24**
2007	97	92	5	-3	**-2**
Average	**106**	**104**	**26**	**44**	**+18**

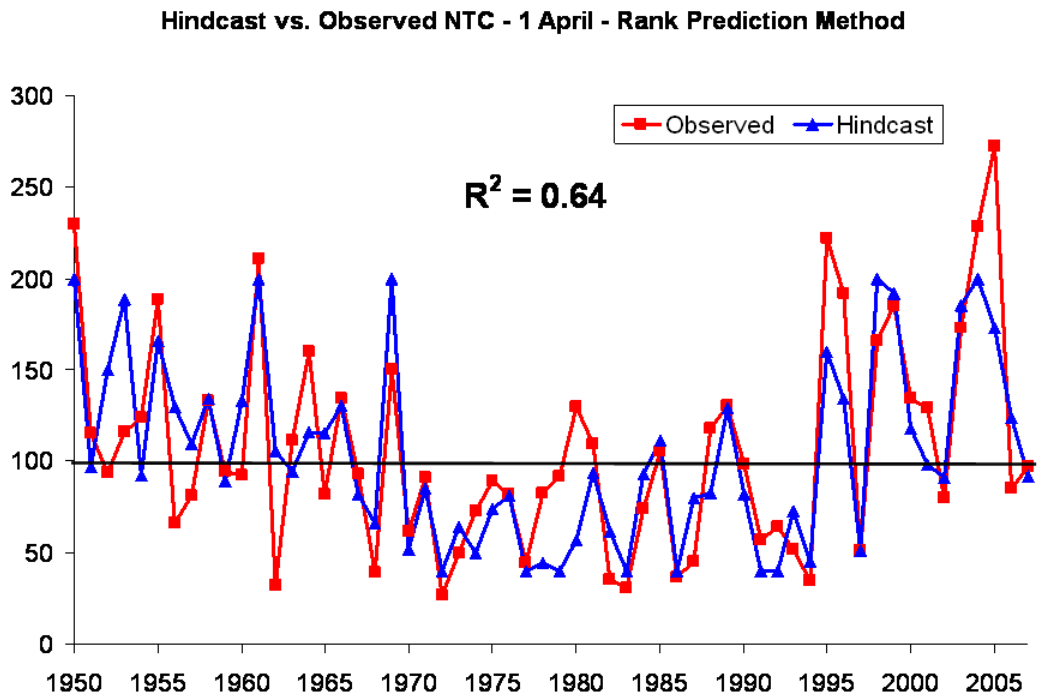

Figure 1: Observed versus hindcast values of NTC for 1950-2007.

Table 2: Hindcast versus observed average NTC for active vs. inactive multi-decadal periods in our developmental data set.

Years	***Average Hindcast NTC***	***Average Observed NTC***
1950-1969 (Active)	130	117
1970-1994 (Inactive)	66	72
1995-2007 (Active)	140	155

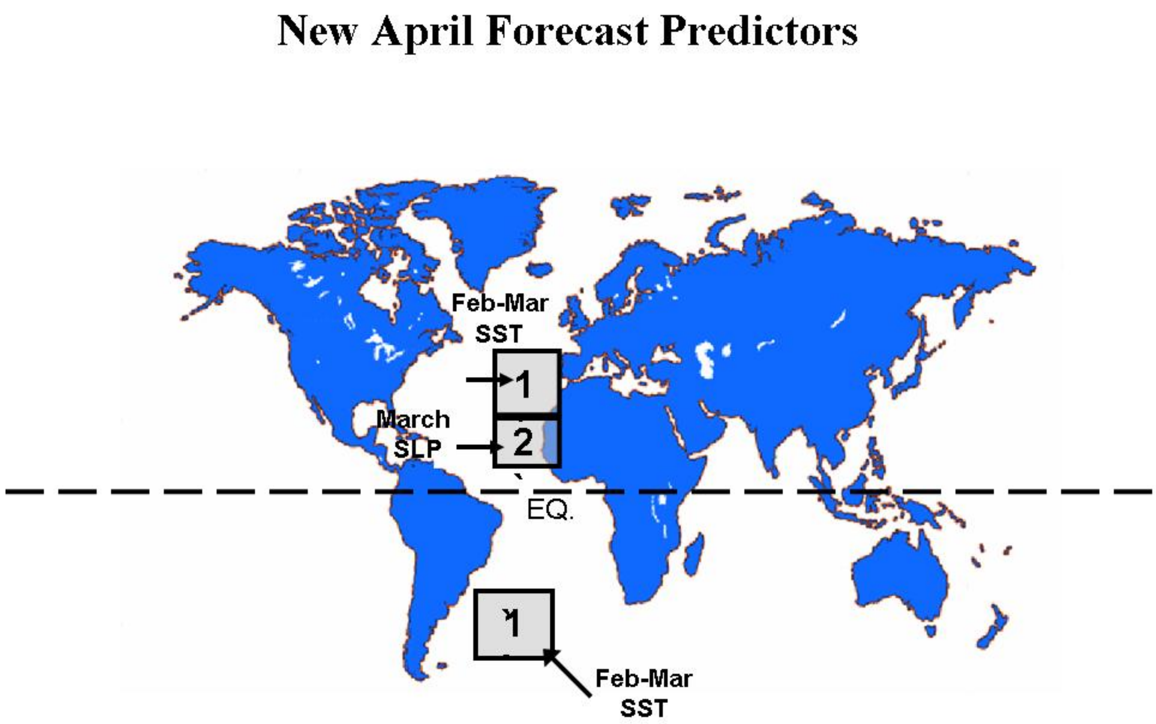

Figure 2: Location of late-winter predictors for our April extended-range statistical prediction for the 2009 hurricane season.

Table 3: Listing of 1 April 2009 predictors for the 2009 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2009 Forecast Values
1) February-March SST Gradient (30-45°N, 10-30°W) – (30-45°S, 20-45°W) (+)	-1.2 SD
2) March SLP (10-30°N, 10-30°W) (-)	-1.2 SD
3) Early December Hindcast (+)	135 NTC

There is also extended-range forecast skill from 1 April for United States hurricane landfall probabilities. In the 15 out of 58 years where our current hindcast scheme forecast NTC values above 133, we had more than twice as many hurricane (40 versus 17) and major hurricane (18 versus 7) landfalls along the U.S. coastline when compared with the 15 out of 58 years where our hindcast scheme gave NTC values below 64. For the Florida Peninsula and the U.S. East Coast, the ratio between NTC hindcast values greater than 133 and below 64 are 25 to 6 for hurricanes and 10 to 1 for major hurricanes.

2.2 Physical Associations among Predictors Listed in Table 3

The locations and brief descriptions of our two late-winter predictors for our early April statistical forecast are now discussed. It should be noted that both forecast parameters correlate significantly with physical features during August through October that are known to be favorable for elevated levels of hurricane activity. These factors are primarily related to August-October vertical wind shear in the Atlantic Main Development Region (MDR) from 10-20°N, 20-70°W as shown in Figure 3.

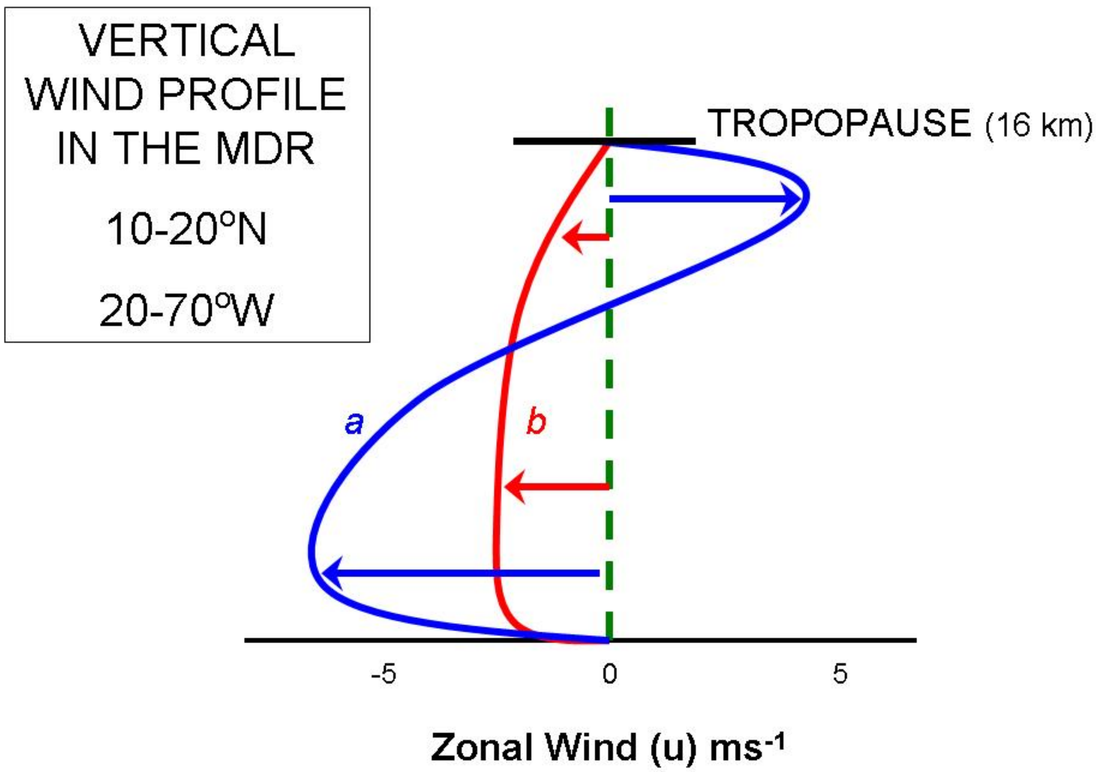

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

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, 200 mb zonal wind, and 925 mb zonal wind, respectively. In general, higher values of SSTA, lower values of SLPA, anomalous westerlies at 925 mb and anomalous easterlies at 200 mb are associated with active Atlantic basin hurricane seasons.

For more information about the predictors utilized in our early December statistical forecast (used as 50% of our early April forecast), please refer to our early December 2008 forecast:
http://tropical.atmos.colostate.edu/Forecasts/2008/dec2008/dec2008.pdf

Predictor 1. February-March SST Gradient between the Subtropical Eastern Atlantic and the South Atlantic (+)

(30-45°N, 10-30°W) - (30-45°S, 20-45°W)

A combination of above-normal sea surface temperatures (SSTs) in the eastern subtropical Atlantic and cooler-than-normal SSTs in the South Atlantic are associated with a weaker-than-normal Azores high and reduced trade wind strength during the boreal spring (Knaff 1997). This heightened SST gradient in February-March is strongly correlated with weaker trade winds and upper tropospheric westerly winds, lower-than-normal sea level pressures and above-normal SSTs in the tropical Atlantic during the following August-October period (Figure 4). All three of these August-October features are commonly associated with active Atlantic basin hurricane seasons, through reductions in vertical wind shear, increased vertical instability and increased mid-tropospheric moisture, respectively. A stronger-than-normal temperature gradient between the North Atlantic and South Atlantic correlates quite strongly (~0.6) with active Atlantic basin tropical cyclone seasons. Based on data from the NCEP reanalysis, SSTs in the South Atlantic have been warming faster than SSTs in the North Atlantic over the period from 1950-2007, and therefore, the SST gradient calculation for Predictor 1 has been de-trended. February-March values of this de-trended SST gradient correlate at 0.54 with August-October values of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) over the period from 1950-2007. The AMM has been shown to impact Atlantic hurricane activity through alterations in the position and intensity of the Atlantic Inter-Tropical Convergence Zone (ITCZ). Changes in the Atlantic ITCZ bring about changes in tropical Atlantic vertical and horizontal wind shear patterns and in tropical Atlantic sea surface temperature patterns.

Predictor 2. March SLP in the Subtropical Atlantic (-)

(10-30°N, 10-30°W)

Our April statistical scheme in the late 1990s used a similar predictor when evaluating the strength of the March Atlantic sub-tropical ridge (Azores High). If the pressure in this area is higher-than-normal, it correlates strongly with enhanced Atlantic trade winds. These stronger trades enhance mixing and upwelling, driving cooler tropical Atlantic sea surface temperatures. These cooler SSTs are associated with higher-than-normal sea level pressures which can create a self-enhancing feedback that relates to higher pressure, stronger trades and cooler SSTs during the hurricane season (Figure 5) (Knaff 1998). All three of these factors are associated with inactive hurricane seasons. Sea level pressure values in this region have been trending slightly upward since the 1950s. We have removed half of the trend in the SLP values for our predictor calculations to avoid a potentially non-physical lowering of forecast values.

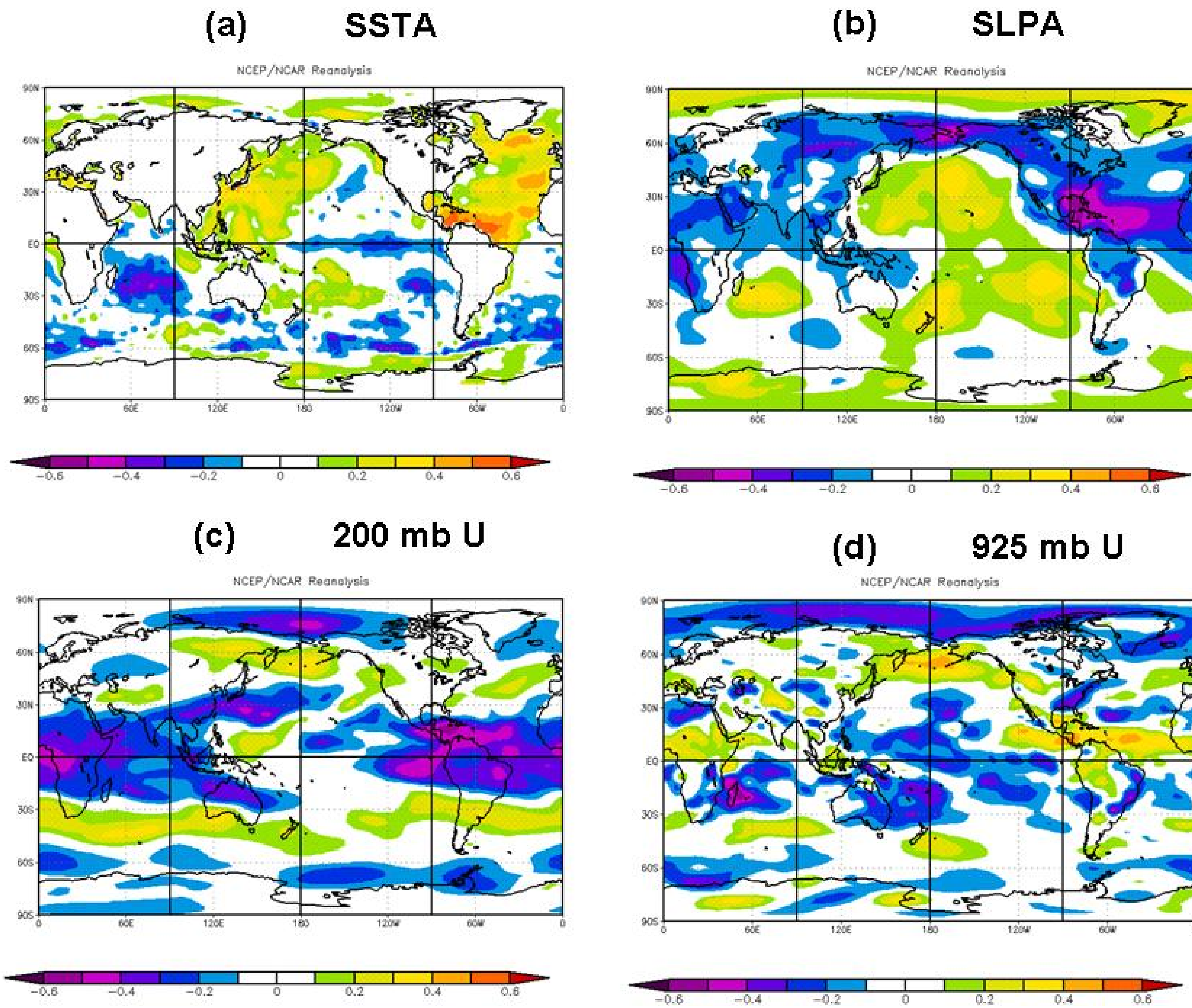

Figure 4: Linear correlations between the February-March SST gradient between the subtropical eastern Atlantic and the South Atlantic (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

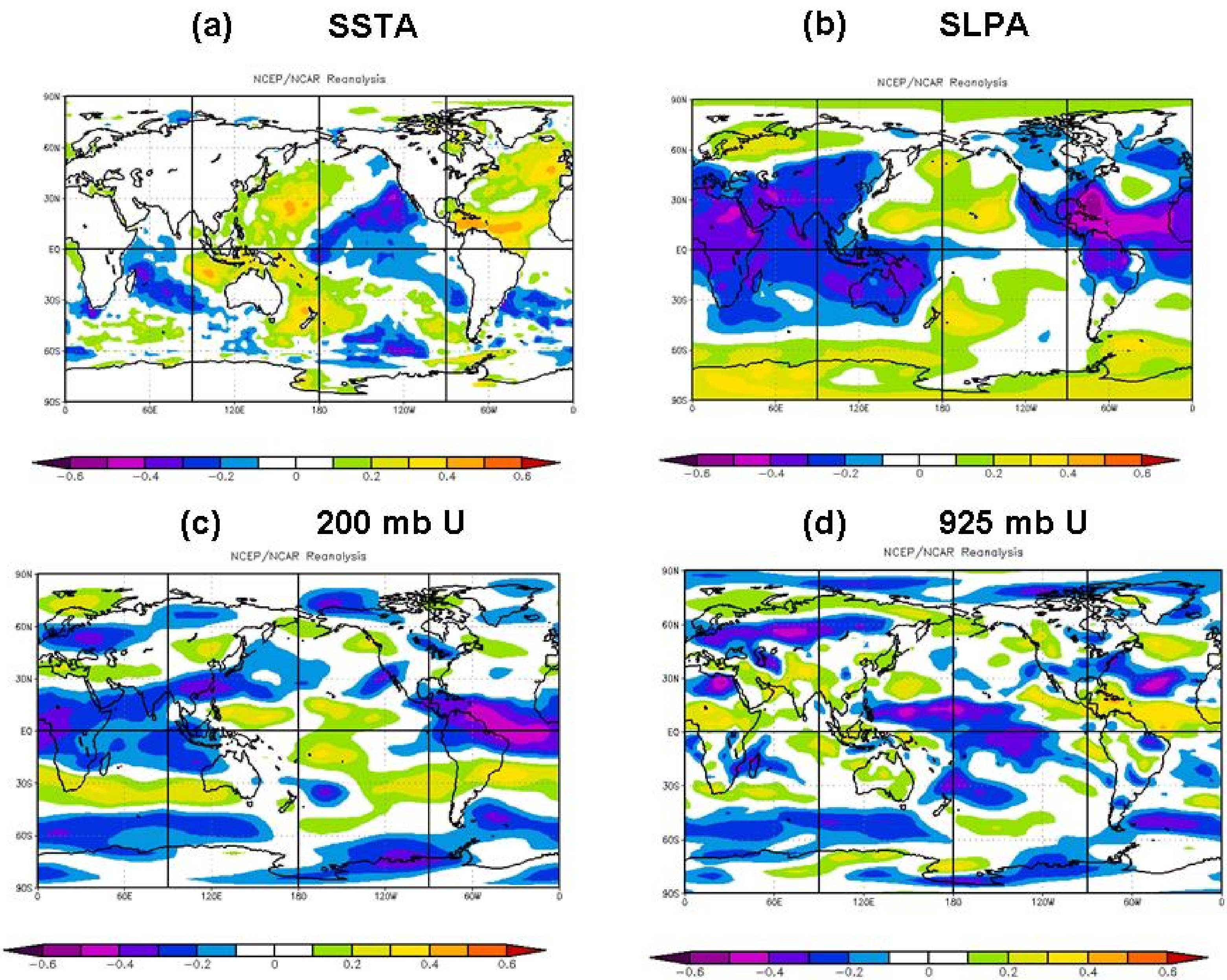

Figure 5: Linear correlations between March SLP in the subtropical Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity. All values have been multiplied by -1 to allow for easy comparison with Figure 4.

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.

Table 4 provides our early April forecasts, 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 4: 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)	4.0	12	8.0 – 16.0
Named Storm Days (NSD)	19.4	55	35.6 – 74.4
Hurricanes (H)	2.2	6	3.8 – 8.2
Hurricane Days (HD)	9.5	25	15.5 – 34.5
Intense Hurricanes (IH)	1.4	2	0.6 – 3.4
Intense Hurricane Days (IHD)	4.4	5	0.6 – 9.4
Accumulated Cyclone Energy (ACE)	39	100	61 – 139
Net Tropical Cyclone (NTC) Activity	41	105	64 – 146

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 April extended range forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current February-March 2009 conditions. Table 5 lists our analog selections.

We select prior hurricane seasons since 1949 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that were generally characterized by weak La Niña conditions, near-average tropical Atlantic SSTs and above-average far North Atlantic SSTs during February-March.

There were five hurricane seasons since 1949 with characteristics most similar to what we observed in February-March 2009. The best analog years that we could find for the 2009 hurricane season were 1951, 1968, 1976, 1985 and 2001. We anticipate that 2009 seasonal hurricane activity will have activity in line with what was experienced in the average of these five years. We believe that 2009 will have about average activity in the Atlantic basin.

Table 5: Best analog years for 2009 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1951	10	57.75	8	36.25	5	8.25	137	148
1968	8	33.75	5	11.75	0	0.00	45	47
1976	10	49.50	6	25.50	2	1.00	84	86
1985	11	51.25	7	21.25	3	4.00	88	106
2001	15	68.75	9	25.50	4	4.25	110	135
Mean	10.8	52.2	7.0	24.1	2.8	3.5	93	105
2009 Forecast	12	55	6	25	2	5	100	105

5 ENSO

Weak La Niña conditions occurred during the winter of 2008-2009. This event has weakened somewhat over the past few weeks. SSTs are generally slightly below average across the eastern and central tropical Pacific. Table 6 displays January and March SST anomalies for several Nino regions. Note that all four regions have experienced warming since January, with more warming occurring in the central Pacific. This anomalous warming is unlike the warming that occurred last year in that the early springtime warming that occurred last year was concentrated in the eastern Pacific.

Table 6: January and March SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. March-January SST anomaly differences are also provided.

Region	January SST Anomaly (°C)	March SST Anomaly (°C)	March – January SST Anomaly (°C)
Nino 1+2	-0.1	0.0	+0.1
Nino 3	-0.6	-0.5	+0.1
Nino 3.4	-1.0	-0.5	+0.5
Nino 4	-0.7	-0.4	+0.3

As was the situation last year, the big question is whether this current observed warming will continue through this year's hurricane season. The spring months are known as the ENSO predictability barrier time period, as this is when both statistical and dynamical models show their least amount of skill. This is likely due to the fact that from a climatological perspective, trade winds across the Pacific are weakest during the late spring and early summer, and therefore, changes in phase of ENSO are often observed to occur during the April-June period. Unlike March 2008 when none of the available statistical or dynamical models called for a warm ENSO event during August-October, several models are predicting a warm ENSO event this year (Figure 6). The dynamical model consensus calls for a weak El Niño event this August-October (August-October averaged Nino 3.4 anomaly of +0.6°C). By contrast, the statistical models tend to predict less warming.

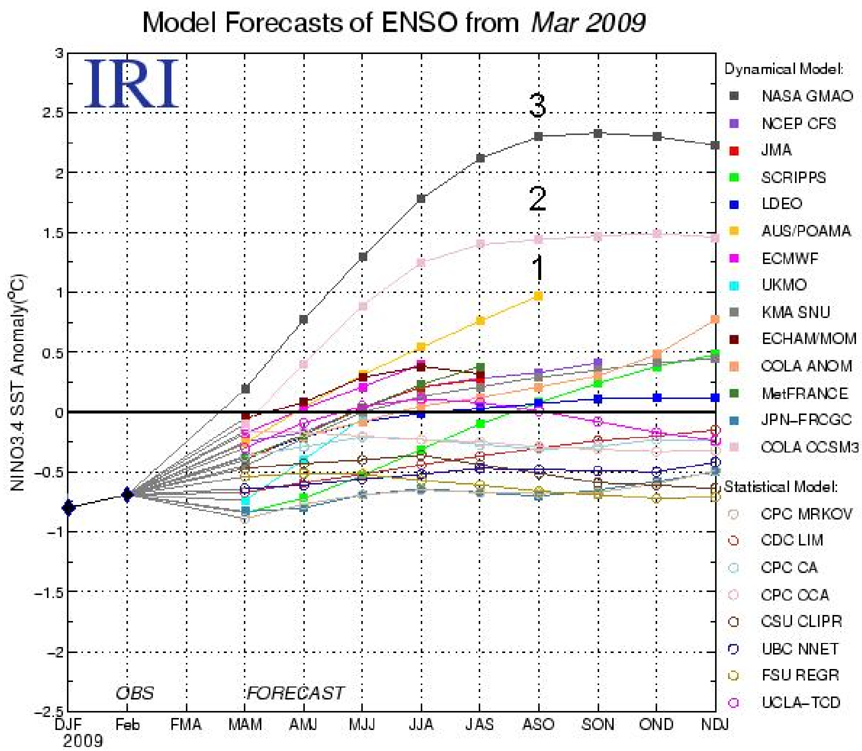

Figure 6: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). Currently, three dynamical models (1) POAMA, (2) COLA CCSM3, and (3) NASA GMAO are calling for a significant warm ENSO event. All other models call for neutral or cool conditions for the August-October period.

Based on this information, we believe that the current weak La Niña will likely continue to moderate over the next couple of months. At this point, we believe there is an approximately 50% chance of a weak El Niño developing during this summer/fall. The potential for a weak El Niño is one of the reasons that we have reduced our forecast from early December. El Niños typically increase levels of vertical wind shear in the tropical Atlantic, causing detrimental conditions for Atlantic tropical cyclone formation and intensification. We should know more about the potential for an El Niño by the time of our next forecast on June 2.

6 Current Atlantic Basin Conditions

Conditions in the Atlantic are less favorable for an active season than they were in November 2008. Figure 7 displays the SST anomaly difference between March 2009 and November 2008. Note the strong anomalous cooling that has occurred across the Main Development Region. Current Tropical North Atlantic index (defined as 5.5-23.5°N, 57.5-15°W) SST anomaly values of approximately -0.4°C are the lowest that have been observed since June-July 1994. This strong anomalous cooling is another reason for the reduction in our Atlantic basin hurricane forecast. Cooler-than-normal waters provide less latent and sensible heat flux for developing tropical cyclones. In addition, an anomalously cool tropical Atlantic is typically associated with higher sea level pressure values and stronger-than-normal trade winds, indicating a more stable atmosphere with increased levels of vertical wind shear.

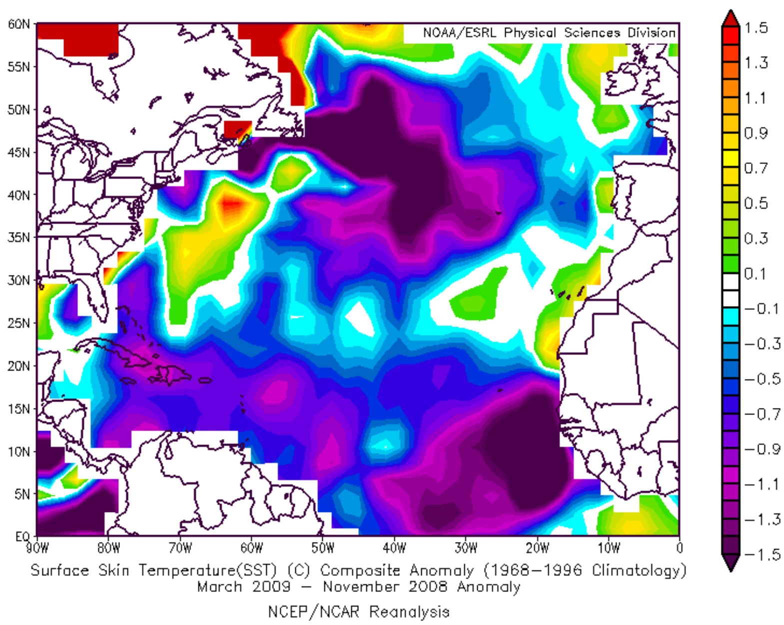

Figure 7: March 2009 – November 2008 SST anomaly difference across the Atlantic. In general, the Atlantic has cooled considerably over the past four months.

The question that remains to be answered is whether or not this anomalous cooling will continue. The Azores High has been somewhat weaker than average during March 2009, implying weaker trades which should lead to some anomalous warming in the Main Development Region. We will certainly be monitoring trends in Atlantic SSTs in the weeks leading up to our next forecast.

7 Adjusted 2009 Forecast

Table 7 shows our final adjusted early April 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 near-average levels. We foresee an average Atlantic basin hurricane season.

We have reduced our early April forecast from our forecast of early December due to the possibility of the development of an El Niño as well as a strong anomalous cooling of SSTs in the tropical Atlantic.

Table 7: Summary of our early April 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)	10.2	10.8	12
Named Storm Days (49.1)	50.2	52.2	55
Hurricanes (5.9)	6.0	7.0	6
Hurricane Days (24.5)	23.9	24.1	25
Intense Hurricanes (2.3)	2.6	2.8	2
Intense Hurricane Days (5.0)	5.9	3.5	5
Accumulated Cyclone Energy Index (96.1)	97	93	100
Net Tropical Cyclone Activity (100%)	106	105	105

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 8). 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 8: 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 9 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. The mean annual probability of one or more landfalling systems is given in parentheses. Note that Atlantic basin NTC activity in 2009 is expected to be near its long-term average of 100, and therefore, United States landfall probabilities are near average.

Please visit the United States Landfalling Probability Webpage at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine. A new webpage interface has recently been uploaded to the website.

We are currently working on calculating probabilities for several islands in the Caribbean, and we intend to have these probabilities available for our early June forecast.

Table 9: Estimated probability (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2009. 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)	81% (79%)	69% (68%)	54% (52%)	86% (84%)	97% (97%)
Gulf Coast (Regions 1-4)	60% (59%)	44% (42%)	31% (30%)	62% (60%)	85% (83%)
Florida plus East Coast (Regions 5-11)	52% (50%)	46% (44%)	32% (31%)	63% (61%)	82% (81%)

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).

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 8). Atlantic sea surface temperatures and hurricane activity do not necessarily follow global mean temperature trends.

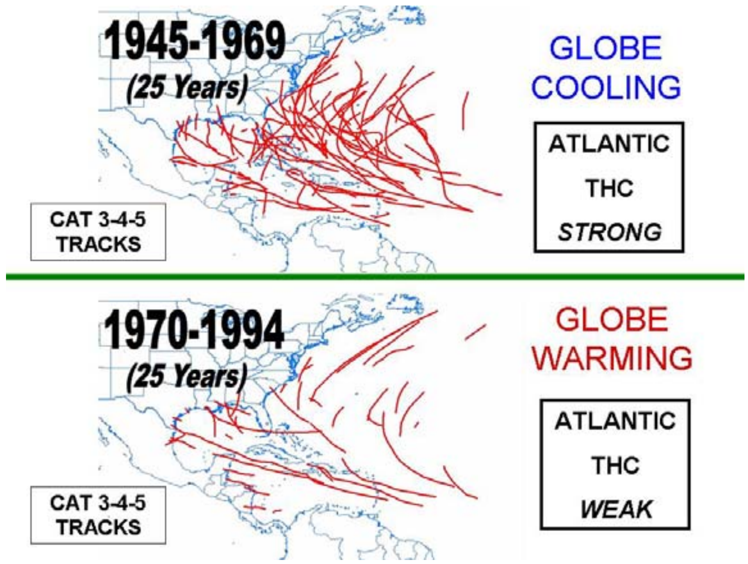

Figure 8: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was only about one-third as frequent during the latter period despite warmer global temperatures.

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1899 (Table 10). 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 9). 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 10: 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 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.

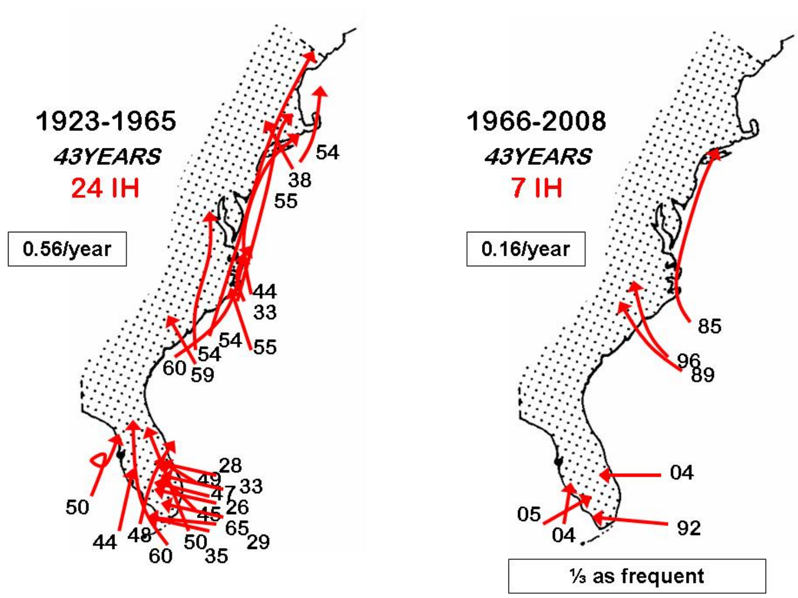

Figure 9: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 43-year period of 1923-1965 versus the most recent 43-year period of 1966-2008.

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^{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 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 about 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 will be issuing seasonal updates of our 2009 Atlantic basin hurricane forecasts on **Tuesday 2 June**, **Tuesday 4 August**, **Wednesday 2 September** and **Thursday 1 October 2009**. The 4 August, 2 September and 1 October forecasts will include separate forecasts of August-only, September-only and October-only Atlantic basin tropical cyclone activity. A verification and discussion of all 2009 forecasts will be issued in late November 2009. Our first seasonal hurricane forecast for the 2010 hurricane season will be issued in early December 2009. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

12 Acknowledgments

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14 Verification of Previous Forecasts

Table 11: 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