EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2010

We foresee an above-average Atlantic basin tropical cyclone season in 2010 and anticipate an above-average probability of U.S. and Caribbean major hurricane landfall. Although these early December forecasts have not shown recent-year real-time forecast skill, we believe our new early December forecast scheme will begin to demonstrate forecast skill in the coming years.

(as of 9 December 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

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

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

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

Everyone should realize that it is impossible to precisely predict next season's hurricane activity at such an extended range. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards the probability of an active or inactive hurricane season for next year. Our early December statistical forecast methodology shows evidence over 58 past years that significant improvement over climatology can be attained. Because our December forecasts have yet to show real-time forecast skill, we will only be providing a range of numbers and an assessment of current conditions and how we think these conditions may impact next year's Atlantic basin tropical cyclone season. We will not be issuing specific numbers until our early April forecast.

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

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2010

Forecast Parameter and 1950-2000 Climatology (in parentheses)	9 December 2009 Forecast for 2010
Named Storms (NS) (9.6)	11-16
Named Storm Days (NSD) (49.1)	51-75
Hurricanes (H) (5.9)	6-8
Hurricane Days (HD) (24.5)	24-39
Major Hurricanes (MH) (2.3)	3-5
Major Hurricane Days (MHD) (5.0)	6-12
Accumulated Cyclone Energy (ACE) (96.1)	100-162
Net Tropical Cyclone Activity (NTC) (100%)	108-172

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

1) Entire U.S. coastline - 64% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 40% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 40% (average for last century is 30%)

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

1) 53% (average for last century is 42%)

*Landfall probabilities are calculated based on the midpoint of our predicted NTC range (e.g., NTC of 140)

ABSTRACT

Information obtained through November 2009 indicates that the 2010 Atlantic hurricane season will be somewhat more active than the average 1950-2000 season. We estimate that activity will return to levels more typical of years during an active era, such as what we have experienced since 1995. We expect to see approximately 11-16 named storms, 6-8 hurricanes and 3-5 major hurricanes occur during the 2010 hurricane season. These numbers are based on the average of our statistical model, our analog model and qualitative adjustments and insights. At this point, there is too much uncertainty in what large-scale parameters will be in August-October of next year to issue a forecast for specific numbers. However, we do feel that we are in a favorable position for issuing an early December forecast this year, since we believe the odds of a multi-year El Niño event are quite small. Because we are predicting an above-average hurricane season in 2010, the probability of U.S. and Caribbean major hurricane landfall is estimated to be above the long-period average. This forecast is based on a new extended-range early December statistical prediction scheme that utilizes 58 years of past data. The influences of El Niño conditions are implicit in these predictor fields, and therefore we do not utilize a specific ENSO forecast as a predictor. We expect to see the moderate to strong El Niño event that is currently in progress diminish by the 2010 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 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 relationship.

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 the last two years of 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 AND ACRONYMS

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 – 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-force winds.

Madden Julian Oscillation (MJO) – A globally propagating mode of tropical atmospheric intra-seasonal variability. The wave tends to propagate eastward at approximately 5 ms^{-1}, circling the globe in approximately 40-50 days.

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.

Multivariate ENSO Index (MEI) – An index defining ENSO that takes into account tropical Pacific sea surface temperatures, sea level pressures, zonal and meridional winds and cloudiness.

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-force winds.

Net Tropical Cyclone (NTC) Activity –Average seasonal percentage mean of NS, NSD, H, HD, MH, MHD. Gives overall indication of Atlantic basin seasonal hurricane activity. The 1950-2000 average value of this parameter is 100.

Quasi-Biennial Oscillation (QBO) – 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 Scale – 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.

Southern Oscillation Index (SOI) – A normalized measure of the surface pressure difference between Tahiti and Darwin.

Sea Surface Temperature – SST

Sea Surface Temperature Anomaly – SSTA

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.

Vertical Wind Shear – The difference in horizontal wind between 200 mb (approximately 40000 feet or 12 km) and 850 mb (approximately 5000 feet or 1.6 km).

1 knot = 1.15 miles per hour = 0.515 meters per second

1 Introduction

This is the 27th 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 atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme must show significant hindcast skill before it is used in real-time forecasts.

2 December Statistical Forecast Methodology

Although our seasonal hurricane forecast scheme has shown significant real-time skill for our early June and early August predictions, we have yet to demonstrate real-time forecast skill for our early December forecasts that have been issued for the last 18 years (1992-2009).

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

Beginning with the 2002 December forecast for the 2003 season, we relied on a new early December forecast scheme (Scheme B) (Klotzbach and Gray 2004) which did not utilize West African rainfall and gave less weight to the QBO. This newer statistical scheme, although showing improved hindcast skill, did not demonstrate real-time forecast skill for the four years from 2003-2006. A slightly modified scheme was used in 2007.

We developed a new statistical forecast methodology for our early December prediction in 2007 for the 2008 Atlantic hurricane season (Scheme C). We developed this forecast due to the fact that our real-time forecasts issued in early December from 1992-2007 did not show skill in real time. For full details on the new forecast methodology, please refer to the published paper (Klotzbach 2008). Table 1 summarizes the characteristics of our two most recent 1 December forecast schemes.

Table 1: Listing of our two most recent December extended-range prediction schemes.

	Scheme B Klotzbach and Gray (2004)	Scheme C Klotzbach (2008)
Years Used in Real-Time Forecasting	2003-2006 (4 Yrs.)	2008-2009 (2 Yrs.)
Number of Predictors	6	3
Hindcast Period	1950-2001 (52 Yrs.)	1950-2007 (57 Yrs.)
Hindcast Skill for NTC (r)	0.65	0.73
Real-Time Forecast Skill for NTC (r)	0.05 (2003-2006)	n/a – Only used for 2 years (2008-2009)
Hindcast/Forecast Skill for NTC (r) (1992-2009)	0.56	0.75
Reason for lack of Skill	Some physical relationships not well understood	n/a

While statistical prediction schemes A and B showed virtually no forecast correlation for the period from 2002-2009, the new scheme (Scheme C) detailed below correlated at 0.75 for the years from 1992-2009 and 0.78 for the years from 2002-2009.

Table 2 displays hindcasts for 1950-2007 and forecasts for 2008-2009 using Scheme C. We have correctly predicted above- or below-average seasons in 45 out of 60 years (75%). Our predictions have had a smaller error than climatology in 40 out of 60 years (67%). Our average error is 29 NTC units, compared with 44 NTC units for climatology. This scheme has shown remarkable skill from 1981 to the present. Our average error during the past 29 years has been 27 NTC units, compared with 52 NTC units for climatology. Since 1981, our forecast has only had three significant busts in 1995, 2006 and 2009. The forecast bust in 1995 was due to the transition from the inactive to the active hurricane era and the concomitant warming of SSTs in the tropical Atlantic during the spring of that year. Both 2006 and 2009 were El Niño years. This new scheme is also well-tuned to the multi-decadal active hurricane periods from 1950-1969 and 1995-2009 versus the inactive hurricane period from 1970-1994 (Table 3).

Table 2: Observed versus hindcast NTC for 1950-2009 using Scheme C. Average errors for hindcast NTC and climatological NTC predictions are given without respect to sign. Bold-faced years in the "Hindcast NTC" column are years that we did not go the right way, while bold-faced years in the "Hindcast improvement over Climatology" column are years that we did not beat climatology. The hindcast went the right way with regards to an above- or below-average season in 45 out of 60 years (75%), while hindcast improvement over climatology occurred in 40 out of 60 years (67%).

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1950	230	192	38	130	92
1951	115	**82**	34	15	**-18**
1952	93	**124**	-31	-7	**-24**
1953	116	188	-73	16	**-57**
1954	124	111	13	24	11
1955	188	129	59	88	29
1956	66	**160**	-94	-34	**-60**
1957	82	**116**	-34	-18	**-16**
1958	133	**93**	40	33	**-7**
1959	94	**106**	-11	-6	**-6**
1960	92	**129**	-37	-8	**-29**
1961	211	200	11	111	100
1962	32	**118**	-86	-68	**-18**
1963	111	130	-19	11	**-8**
1964	160	**80**	80	60	**-20**
1965	82	85	-3	-18	15
1966	134	134	0	34	34
1967	93	51	42	-7	**-35**
1968	39	40	-1	-61	60
1969	150	166	-16	50	34
1970	62	40	22	-38	16
1971	91	89	2	-9	7
1972	27	46	-19	-73	54
1973	50	52	-2	-50	48
1974	72	82	-9	-28	18
1975	89	83	6	-11	5
1976	82	97	-15	-18	3
1977	45	50	-5	-55	50
1978	83	66	17	-17	1
1979	92	40	52	-8	**-43**
1980	129	**40**	89	29	**-60**
1981	109	109	0	9	9
1982	35	74	-39	-65	26
1983	31	40	-9	-69	60
1984	74	91	-17	-26	9
1985	106	**92**	14	6	**-8**
1986	37	64	-27	-63	36
1987	46	40	6	-54	49
1988	118	**92**	26	18	**-8**
1989	130	150	-20	30	10
1990	98	82	17	-2	**-15**
1991	57	72	-16	-43	28
1992	64	40	24	-36	12
1993	52	45	7	-48	41
1994	35	57	-22	-65	43
1995	222	**93**	129	122	**-7**
1996	192	173	19	92	73
1997	51	62	-11	-49	38
1998	166	200	-34	66	31
1999	185	200	-15	85	70
2000	134	115	19	34	15
2001	129	133	-4	29	25
2002	80	94	-14	-20	6
2003	173	200	-27	73	46
2004	228	200	28	128	100
2005	273	185	88	173	85
2006	85	**134**	-49	-15	**-34**
2007	99	98	1	-1	0
2008	162	127	35	62	27
2009	66	**133**	-67	-34	**-33**
Average (1950-2009)	**107**	**105**	**|32|**	**|44|**	**+12**
Average (1981-2009)	**112**	**110**	**|27|**	**|52|**	**+25**

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

Years	***Average Observed NTC***	***Average Hindcast NTC***
1950-1969 (Active)	117	122
1970-1994 (Inactive)	72	69
1995-2009 (Active)	150	143

Figure 1 displays the locations of the three predictors used in Scheme C, while Table 4 lists the three predictors that are utilized for this year's December forecast. Table 5 displays the statistical forecast model output for the 2010 hurricane season. The statistical model calls for an average hurricane season in 2010. Figure 2 presents the hindcast skill of the December forecast over the period from 1950-2007. The forecast scheme explains 54 percent of the variance when the linear regression equations are developed over the full time period. The forecast model explains approximately 40 percent of the variance when a drop-one cross-validation technique is applied.

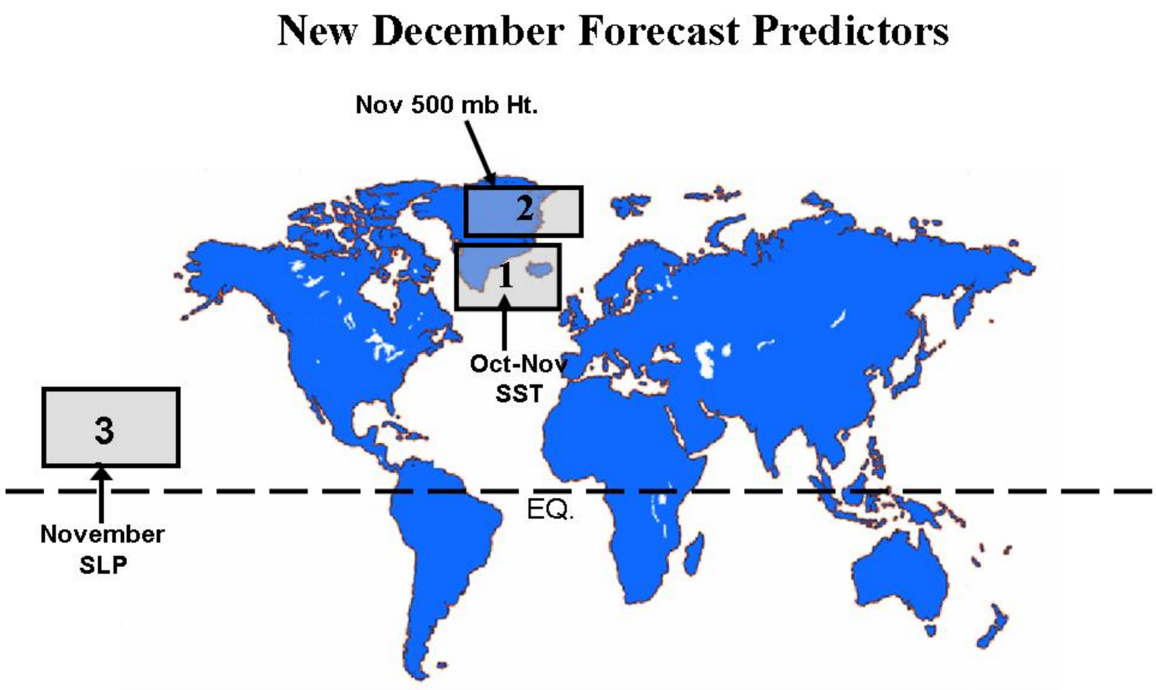

Figure 1: Location of predictors for our December extended-range statistical prediction for the 2010 hurricane season.

Table 4: Listing of 1 December 2009 predictors for the 2010 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2009 Values for 2010 Forecast
1) October-November SST (55-65°N, 10-60°W) (+)	+0.2 SD
2) November 500 mb geopotential height (67.5-85°N, 10°E-50°W) (+)	+0.3 SD
3) November SLP (7.5-22.5°N, 125-175°W) (+)	-0.9 SD

Table 5: Statistical forecast model output for the 2010 Atlantic hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme
Named Storms (9.6)	10.0
Named Storm Days (49.1)	49.1
Hurricanes (5.9)	5.9
Hurricane Days (24.5)	23.2
Major Hurricanes (2.3)	2.5
Major Hurricane Days (5.0)	5.7
Accumulated Cyclone Energy Index (96.1)	94
Net Tropical Cyclone Activity (100%)	103

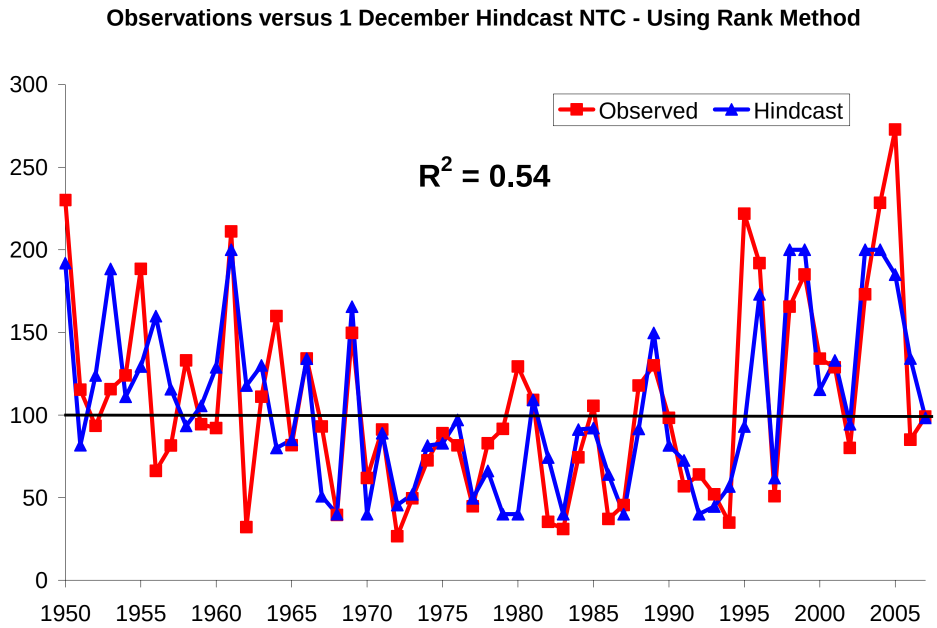

Figure 2: 1 December hindcast NTC versus observations using equations developed over the full period from 1950-2007. This hindcast scheme explains 54 percent of the variance (r = 0.73).

2.1 Physical Associations among Predictors Listed in Table 1

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

Predictor 1. October-November SST in the North Atlantic (+)

(55-65°N, 10-60°W)

Warm North Atlantic sea surface temperatures in the fall are indicative of an active phase of the Atlantic Multidecadal Oscillation (AMO) and a likely strong thermohaline circulation. An active AMO is associated with anomalously low vertical wind shear, warm tropical Atlantic sea surface temperatures and anomalously low sea level pressures during the hurricane season. All four of these factors are favorable for an active Atlantic basin hurricane season (Figure 3).

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

(67.5-85°N, 10°E-50°W)

Positive values of this predictor correlate very strongly (r = -0.7) with negative values of the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO). Negative AO and NAO values imply more ridging in the central Atlantic and a warm North Atlantic Ocean (50-60°N, 10-50°W) due to stronger southerly winds and more blocking action during this period. Also, on decadal timescales, weaker zonal winds in the subpolar areas (40-60°N, 0-60°W) across the Atlantic are indicative of a relatively strong thermohaline circulation. Positive values of this November index (higher heights, weaker mid-latitude zonal winds) are correlated with weaker tropical Atlantic 200 mb westerly winds and weaker trade winds during the following August-October. This brings about reduced tropospheric vertical wind shear which enhances TC development. Other following summer-early fall features that are directly correlated with this predictor are low sea level pressure in the Caribbean and a warm North and tropical Atlantic (Figure 4). Both of the latter are also hurricane-enhancing factors.

Predictor 3. November SLP in the Subtropical NE Pacific (+)

(7.5-22.5°N, 125-175°W)

According to Larkin and Harrison (2002), high pressure in the tropical NE Pacific appears during most winters preceding the development of a La Niña event. High pressure forces stronger trade winds in the East Pacific which increases upwelling and helps initiate La Niña conditions which eventually enhance Atlantic hurricane activity during the following summer. This predictor correlates with low geopotential heights at 500 mb throughout the tropics the following summer, indicative of a weaker Hadley circulation typical of La Niña conditions. Also, high pressure in November in the tropical NE Pacific correlates with low sea level pressure in the tropical Atlantic and easterly anomalies at 200 mb during the following August through October period (Figure 5).

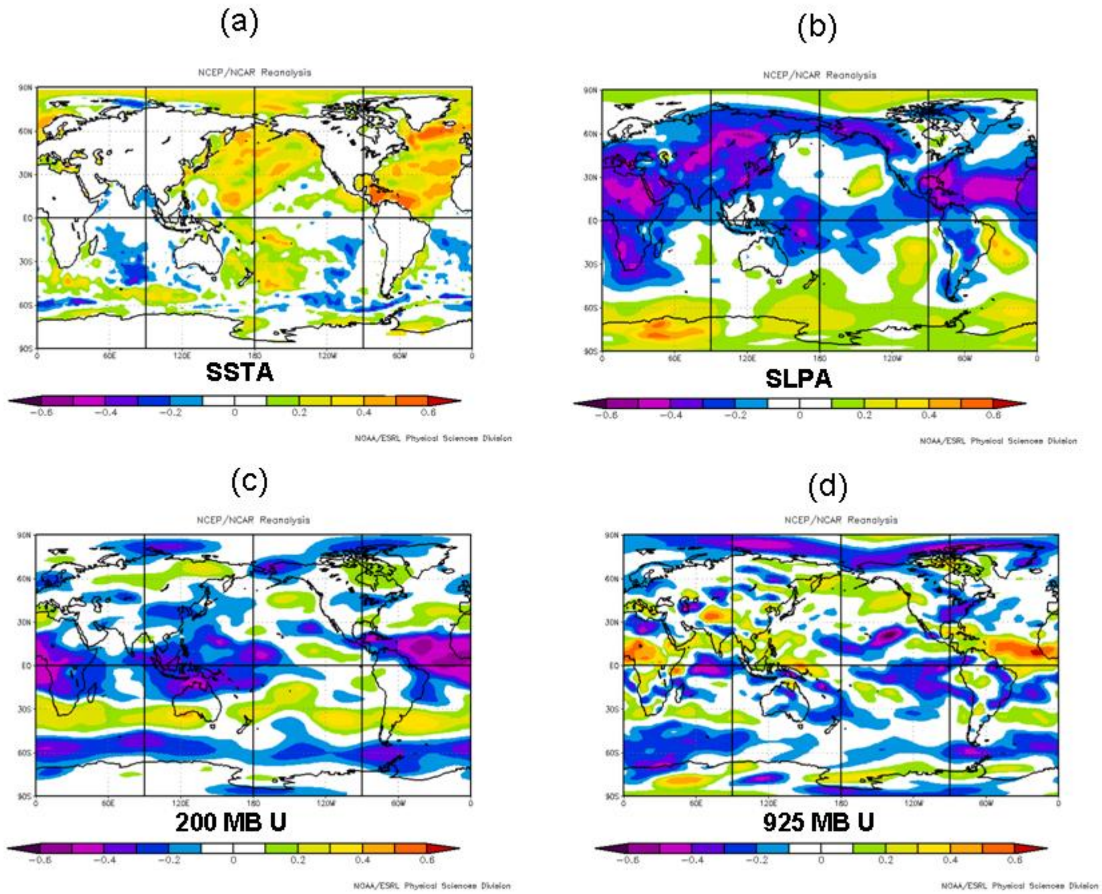

Figure 3: Linear correlations between October-November SST in the North Atlantic (55-65°N, 10-60°W) (Predictor 1) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

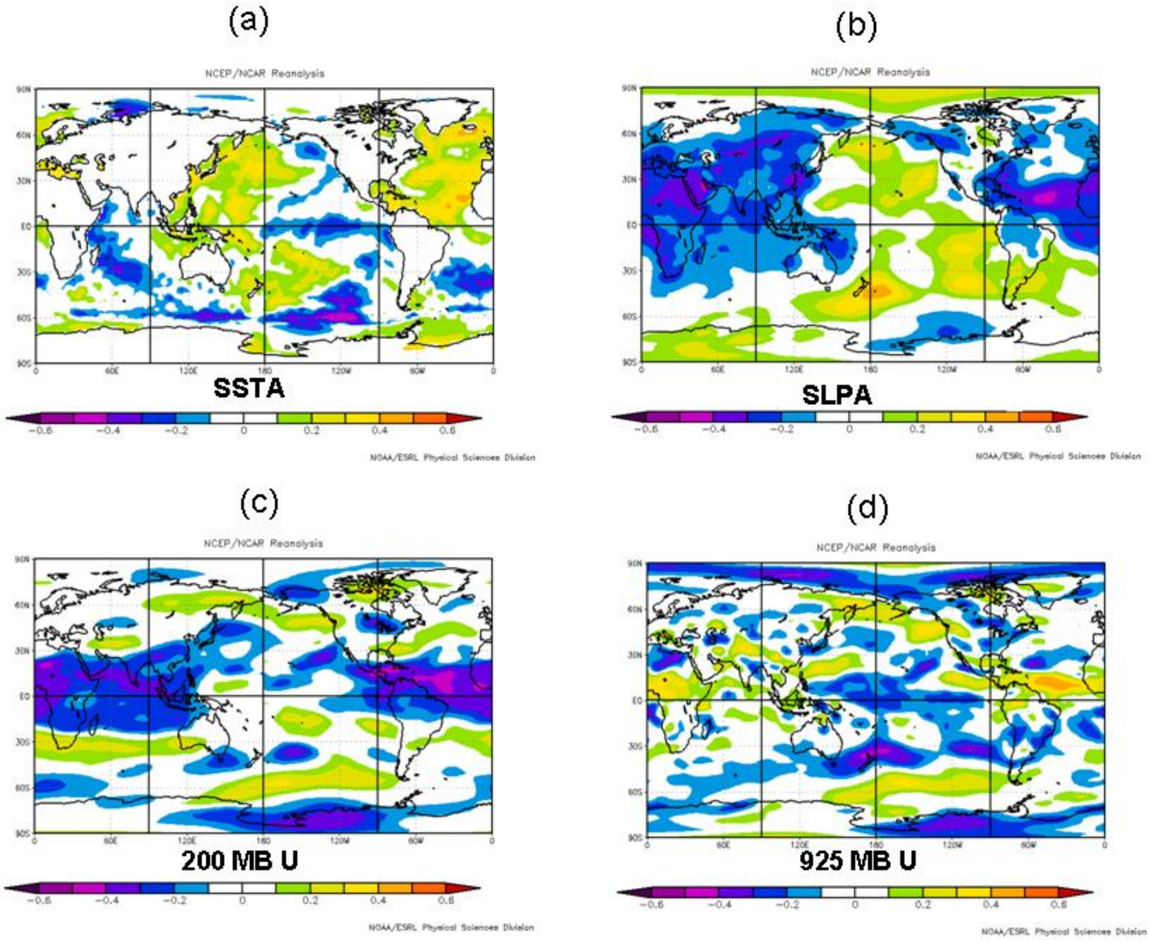

Figure 4: Linear correlations between November 500 mb geopotential heights in the far North Atlantic (67.5-85°N, 50°W-10°E) (Predictor 2) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

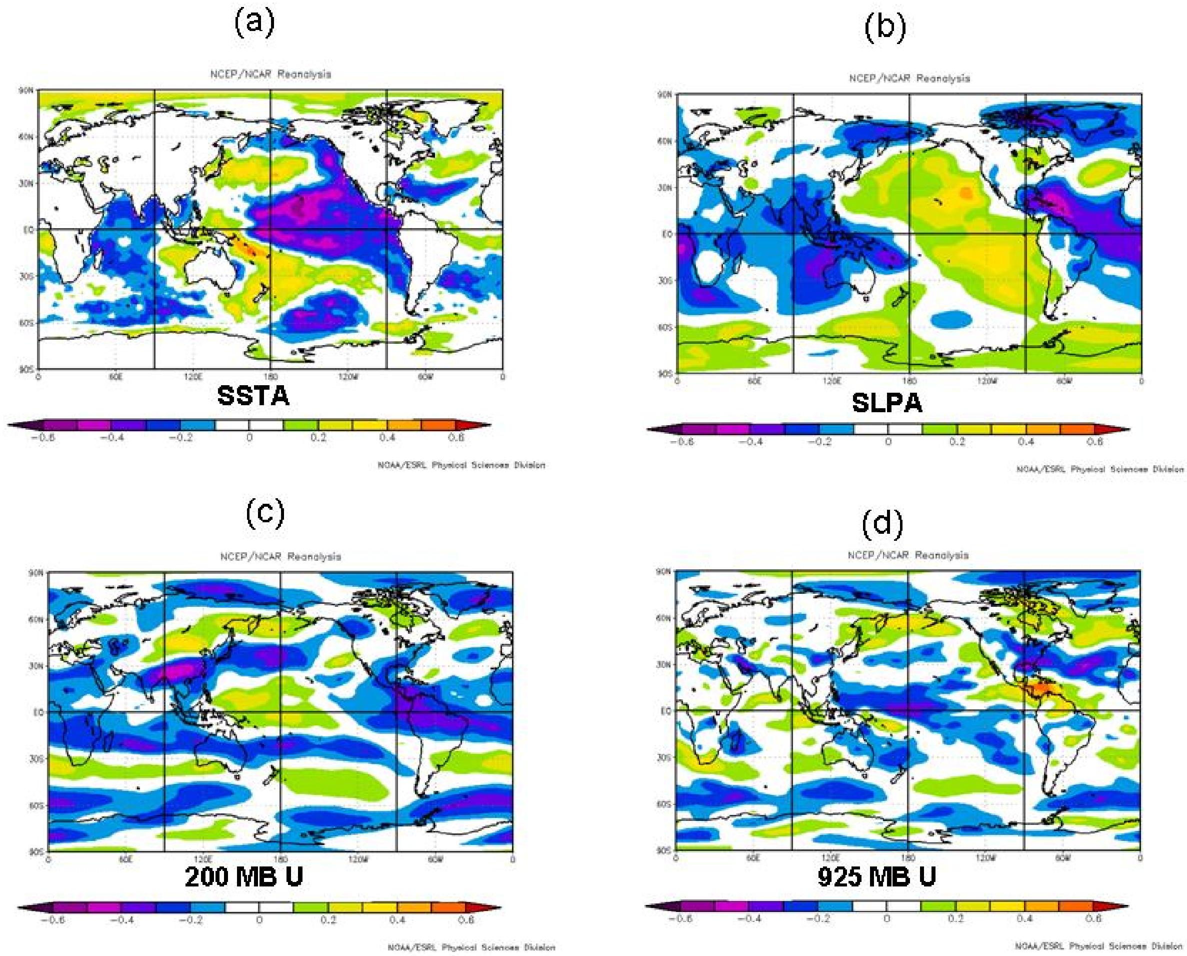

Figure 5: Linear correlations between November sea level pressure in the subtropical Northeast Pacific (7.5-22.5°N, 125-175°W) (Predictor 3) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

3 Forecast Uncertainty

One of the questions that we are asked 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. There is a large amount of uncertainty, especially with our early December prediction, issued seven months prior to the start of the hurricane season.

Table 6 provides our early December forecast 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. Note that there is a large degree of uncertainty with the early December prediction from our statistical model.

Table 6: Model hindcast error. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)
Named Storms (NS)	±4.4
Named Storm Days (NSD)	±23.9
Hurricanes (H)	±2.5
Hurricane Days (HD)	±12.4
Intense Hurricanes (IH)	±1.5
Intense Hurricane Days (IHD)	±4.7
Accumulated Cyclone Energy (ACE)	±50
Net Tropical Cyclone (NTC) Activity	±49

4 ENSO

We currently have a moderate to strong El Niño event in place over the tropical Pacific. Observed sea surface temperatures anomalies in the eastern and central Pacific are approximately 0.5 – 2.0°C above the long-period average while the September-October-averaged Multivariate Enso Index (MEI) (Wolter and Timlin 1998) is currently one standard deviation above average. We find that the MEI is a more robust index of ENSO conditions than simply using a particular SST index, as the MEI also takes into account sea level pressure, zonal and meridional winds and cloudiness. By doing this, it provides a more robust measure of what is actually going on in the atmosphere/ocean system. The MEI is defined by a bi-monthly average (e.g., August-September).

One of the important questions for the upcoming hurricane season is whether El Niño will persist through the 2010 hurricane season. We think that the persistence of warm ENSO conditions through next year's hurricane season are quite unlikely. Table 7 displays standardized MEI anomalies and observed Atlantic NTC activity in El Niño years (defined as a July-August (JA) – September-October (SO) MEI anomaly of at least 0.6 standard deviations) and in the following year, given that both years are in an active era for Atlantic basin hurricanes, and the North Atlantic is warmer than average (e.g., 1950-1969, 1995-present). Seven out of the last thirty-five years in an active era (20%) were classified as warm ENSO events. None of the past seven events had El Niño conditions persist through the second year, and every event except for 1951-1952 had an increase in TC activity during the second year. It should be noted that an active era and the absence of El Niño does not guarantee an active season, as both 1952 and 2007 experienced near-average NTC activity.

When one examines the inactive era when the North Atlantic is cooler than average (1970-1994), several multi-year El Niño events are evident. Table 8 displays the years classified as ENSO events based on the JA-SO MEI index of greater than 0.6 standard deviations. Several events have persisted from one year to the next, including the 1976-1977 event, the 1982-1983 event, the 1986-1987 event as well as a prolonged event in the early 1990s. Ten out of the twenty-five years (40%) during the inactive era were classified as El Niño years. Since we are currently in an active Atlantic era for tropical cyclones and the North Atlantic is warm, we expect El Niño to dissipate by next year's hurricane season.

There is obviously a considerable amount of uncertainty as to what ENSO conditions will look like next year. Most statistical and dynamical forecast models indicate that warm ENSO conditions will continue for the next few months (Figure 6), with some cooling during the upcoming spring. However, there is very little forecast skill in ENSO model predictions from the late fall for the following summer/fall. We will be closely monitoring ENSO conditions over the next few months and will have more to say with our early April update.

Table 7: El Niño years during positive AMO eras (1950-1969, 1995-present), JA - SO Multivariate Enso Index (MEI) anomalies and observed NTC in these years. Also shown are the following year's JA – SO MEI anomalies and observed NTC. Note that none of the following years had a JA – SO MEI anomaly greater than 0.5 standard deviations.

Year	JA – SO MEI	NTC		Following Year	JA – SO MEI	NTC
1951	0.81	148		1952	0.15	103
1957	1.13	86		1958	0.27	144
1963	0.72	116		1964	-1.34	184
1965	1.37	86		1966	-0.01	140
1997	2.63	54		1998	-0.52	169
2002	0.86	83		2003	0.44	175
2006	0.88	85		2007	-0.88	99
Average	**1.20**	**94**			**-0.27**	**145**
				(Δ) Year 2 – Year 1	**-1.47**	**+51**
2009	0.99	66		2010	???	???

Table 8: El Niño years during the negative AMO era from 1970-1994, JA - SO Multivariate Enso Index (MEI) anomalies and observed NTC in these years. Also shown are the following year's JA – SO MEI anomalies and observed NTC. Several multi-year ENSO events are evident.

Year	JA – SO MEI	NTC		Following Year	JA – SO MEI	NTC
1972	1.65	35		1973	-1.56	53
1976	0.89	86		1977	0.83	37
1977	0.82	37		1978	-0.22	82
1979	0.69	97		1980	0.29	130
1982	1.86	38		1983	0.60	31
1983	0.60	31		1984	-0.09	80
1986	0.95	37		1987	1.85	46
1987	1.85	46		1988	-1.38	117
1991	0.92	58		1992	0.57	67
1993	1.05	52		1994	0.88	35
Average	**1.13**	**52**			**0.18**	**68**
				(Δ) **Year 2 – Year 1**	**-0.95**	**+16**

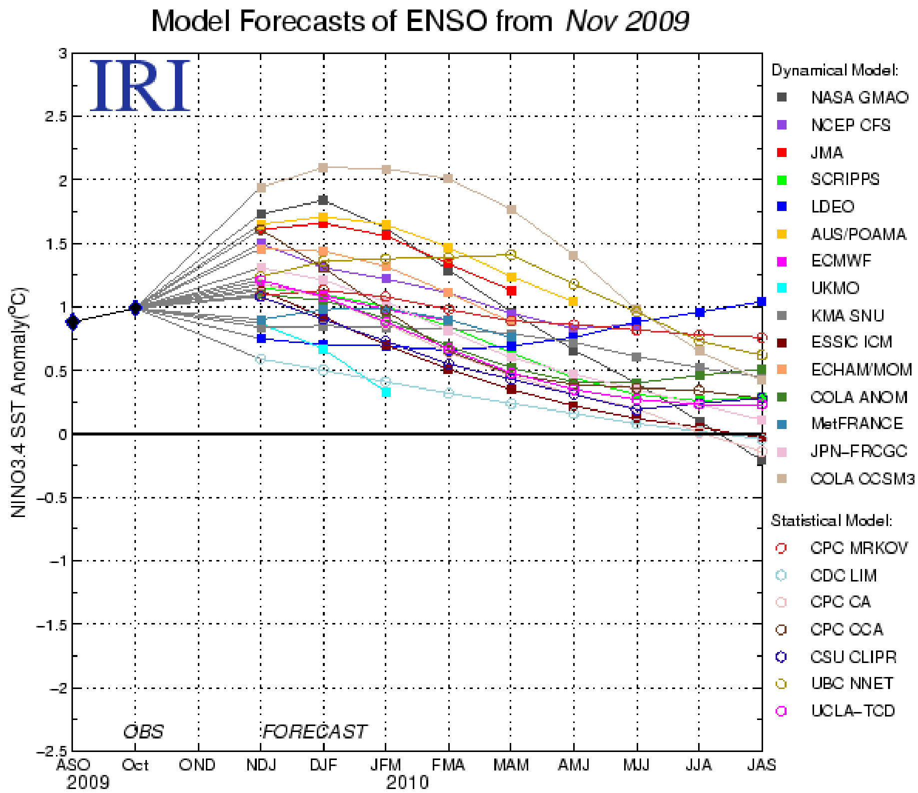

Figure 6: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

5 Analog Forecast

Table 9 displays our analog year selection for the 2010 hurricane season. We are using the average of the seven years following El Niño years during the active era (1950-1969, 1995-2009) as our analogs for this year. Note that the average of these seven analogs is close to the midpoint of our final forecast for 2010.

Table 9: Analog years for 2010 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1952	7	39.75	6	22.75	3	7.00	87	103
1958	10	55.50	7	30.25	5	9.50	121	144
1964	12	71.25	6	43.00	6	14.75	170	184
1966	11	64.00	7	41.75	3	8.75	145	140
1998	14	88.00	10	48.50	3	9.50	182	169
2003	16	81.50	7	32.75	3	16.75	176	175
2007	15	37.75	6	12.25	2	6.00	74	99
Mean	12.1	62.5	7.0	33.0	3.6	10.3	136	145
2010 Fcst.	**11-16**	**51-75**	**6-8**	**24-39**	**3-5**	**6-12**	**100-162**	**108-172**

6 Adjusted 2010 Forecast

Table 10 shows our final adjusted early December forecast for the 2010 season which is a combination of our statistical scheme, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. The final forecast is a range of numbers based upon one-half of one standard deviation of observed NTC activity during the 1995-2009 period (32 NTC units). We foresee a somewhat above-average Atlantic basin hurricane season. We anticipate the current El Niño event to dissipate by the 2010 hurricane season

Warm sea surface temperatures are likely to continue being present in the tropical and North Atlantic during 2010, due to the fact that we are in a positive phase of the Atlantic Multidecadal Oscillation (AMO) (e.g., a strong phase of the Atlantic thermohaline circulation).

Table 10: Summary of our early December statistical forecast, our analog forecast and our adjusted final forecast for the 2010 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	10.0	12.1	11-16
Named Storm Days (49.1)	49.1	62.5	51-75
Hurricanes (5.9)	5.9	7.0	6-8
Hurricane Days (24.5)	23.2	33.0	24-39
Major Hurricanes (2.3)	2.5	3.6	3-5
Major Hurricane Days (5.0)	5.7	10.3	6-12
Accumulated Cyclone Energy Index (96.1)	94	136	100-162
Net Tropical Cyclone Activity (100%)	103	145	108-172

7 Landfall Probabilities for 2010

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

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 11). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall.

Table 11: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 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 12 lists strike probabilities for the 2010 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 of 2009, we debuted probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2010 is expected to be above its long-term average of 100, and therefore, landfall probabilities are above 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 12: 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 2010. 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)	89% (79%)	79% (68%)	64% (52%)	93% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	71% (59%)	54% (42%)	40% (30%)	72% (60%)	92% (83%)
Florida plus East Coast (Regions 5-11)	62% (50%)	56% (44%)	40% (31%)	74% (61%)	90% (81%)
Caribbean (10-20°N, 60-88°W)	91% (82%)	69% (57%)	54% (42%)	86% (75%)	99% (96%)

8 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 between the mid 1970s to late 1990s and the general warming of the last century, the global numbers of hurricanes and their intensity have not shown increases in recent years except for the Atlantic since 1995 (Klotzbach 2006).

The Atlantic has seen a very large increase in major hurricanes during the 15-year period of 1995-2009 (average 3.7 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 THC is the Atlantic component of the global ocean Meridional Overturning Circulation (MOC). We have seen similar active periods to the 1995-2009 period in the past. For example, the 1945-1969 period experienced similar levels of major hurricane activity, and activity during this earlier period may have been underestimated somewhat due to lack of satellite data prior to the mid 1960s. Table 13 displays the average number of named storms, hurricanes, major hurricanes, ACE and NTC generated by all tropical cyclones during the active period from 1945-1969, the inactive period from 1970-1994 and the active period from 1995-2009.

Table 13: Average annual number of named storms, hurricanes, major hurricanes, ACE and NTC generated by tropical cyclones over an active period (1945-1969), an inactive period (1970-1994) and an active period (1995-2009)

Period	NS	H	MH	ACE	NTC
1945 – 1969 (Active)	9.9	6.3	3.2	112	122
1970 – 1994 (Inactive)	9.3	5.0	1.5	67	75
1995 – 2009 (Active)	14.5	7.7	3.7	139	151

As mentioned previously, Atlantic TC activity is directly related to tropical and North Atlantic SSTs. We have recently created an index of the AMO utilizing North Atlantic SSTs and tropical and sub-tropical Atlantic sea level pressures (Klotzbach and Gray 2008). Levels of tropical cyclone activity closely match positive and negative values of this AMO index (Figure 7).

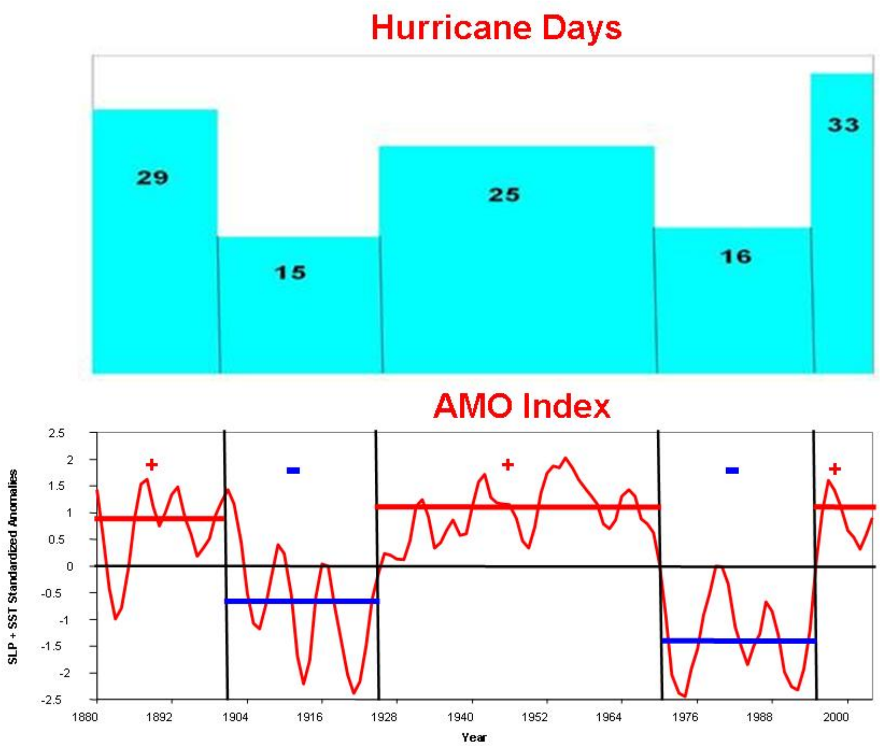

Figure 7: Average number of hurricane days for active and inactive periods and the corresponding AMO index, as calculated by Klotzbach and Gray (2008).

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.

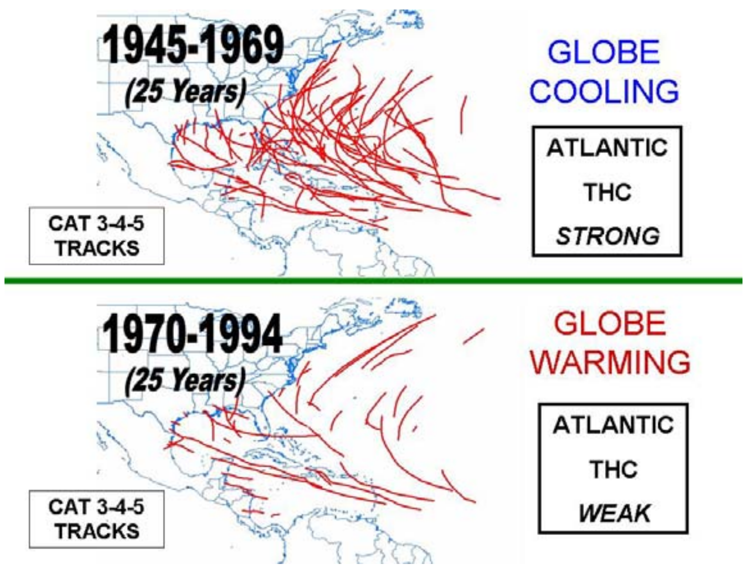

Figure 8: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in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

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 14). Although global mean ocean and Atlantic sea surface temperatures have increased by about 0.4^{o}C between these two 55-year periods (1900-1954 compared with 1955-2009), 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 44-year period of 1922-1965 (24 landfall events) and the 44-year period of 1966-2009 (7 landfall events) was especially large (Figure 9). For the entire United States coastline, 38 major hurricanes made landfall during the earlier 44-year period (1922-1965) compared with only 26 for the latter 44-year period (1966-2009). This occurred despite the fact that CO_2 averaged approximately 365 parts per million (ppm) during the latter period compared with 310 ppm during the earlier period.

Table 14: 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***
1900-1954 (55 years)	208	113	44	$+0.4^{o}C$
1955-2009 (55 years)	184	90	36	

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 so much the high frequency of 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.

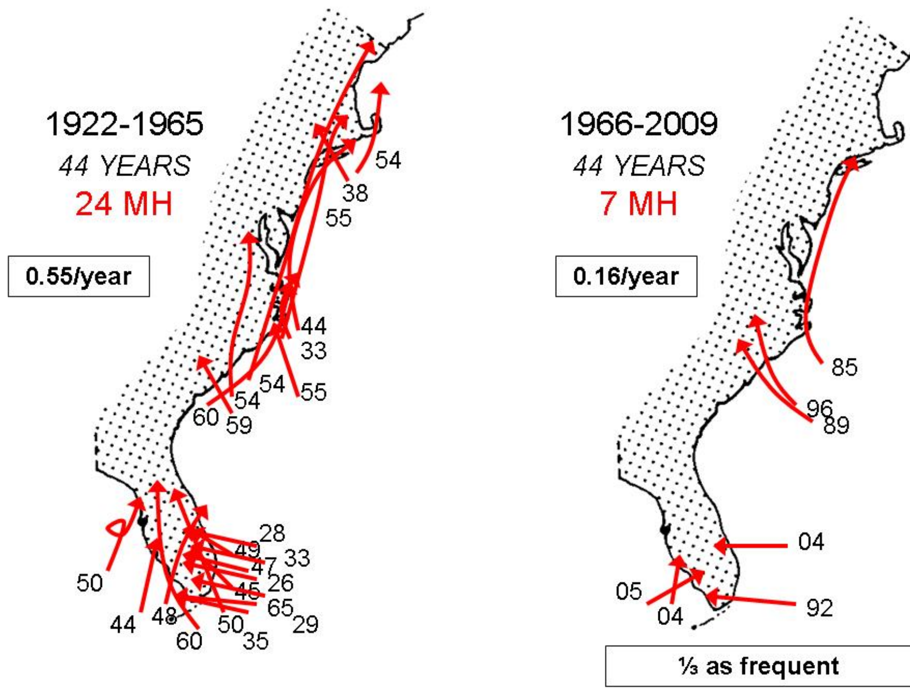

Figure 9: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 44-year period of 1922-1965 versus the most recent 44-year period of 1966-2009.

9 Forthcoming Updated Forecasts of 2010 Hurricane Activity

We will be issuing seasonal updates of our 2010 Atlantic basin hurricane forecasts on **Wednesday April 7**, **Wednesday 2 June**, **and Wednesday 4 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2010 forecasts will be issued in late November 2010. Our first seasonal hurricane forecast for the 2011 hurricane season will be issued in early December 2010. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

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12 Verification of Previous Forecasts

Table 15: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2004-2009.

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
Major Hurricanes	3	3	3	3	6
Major 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
Major Hurricanes	3	3	4	6	7
Major 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
Major Hurricanes	5	5	5	3	2
Major 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
Major Hurricanes	3	5	5	4	2
Major 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	29.50
Named Storm Days	60	80	80	90	84.75
Major Hurricanes	3	4	4	5	5
Major Hurricane Days	6	9	9	11	8.50
Accumulated Cyclone Energy	115	150	150	175	146
Net Tropical Cyclone Activity	125	160	160	190	164

2009	10 Dec. 2008	Update 9 April	Update 2 June	Update 4 August	Obs.
Hurricanes	7	6	5	4	3
Named Storms	14	12	11	10	9
Hurricane Days	30	25	20	18	11.25
Named Storm Days	70	55	50	45	27.25
Major Hurricanes	3	2	2	2	2
Major Hurricane Days	7	5	4	4	3.25
Accumulated Cyclone Energy	125	100	85	80	50
Net Tropical Cyclone Activity	135	105	90	85	66