EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2011

We foresee an above-average Atlantic basin tropical cyclone season in 2011 and anticipate an above-average probability of U.S. and Caribbean major hurricane landfall. This early seasonal forecast has less skill than our forecasts issued closer to the start of the hurricane season.

(as of 8 December 2010)

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

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523
Email: amie@atmos.colostate.edu

Arago's Admonition:

> "Never, no matter what may be the progress of science, will honest scientific men who have regards for their reputations venture to predict the weather."

---

[1] Research Scientist
[2] Professor Emeritus of Atmospheric Science

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2011

Forecast Parameter and 1950-2000 Climatology (in parentheses)	8 December 2010 Forecast for 2011
Named Storms (NS) (9.6)	17
Named Storm Days (NSD) (49.1)	85
Hurricanes (H) (5.9)	9
Hurricane Days (HD) (24.5)	40
Major Hurricanes (MH) (2.3)	5
Major Hurricane Days (MHD) (5.0)	10
Accumulated Cyclone Energy (ACE) (96.1)	165
Net Tropical Cyclone Activity (NTC) (100%)	180

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

1) Entire U.S. coastline - 73% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 49% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 48% (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) 62% (average for last century is 42%)

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 likely 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. However, we have yet to show real-time forecast skill, and we advise the readers to use these forecasts with caution.

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.

ABSTRACT

Information obtained through November 2010 indicates that the 2011 Atlantic hurricane season has the potential to be quite active. We estimate that activity will remain well above average, approximately at levels that were experienced in the average of the years between 1995-2010 that did not have El Niño conditions. We expect to see approximately 17 named storms, 9 hurricanes and 5 major hurricanes occur during the 2011 hurricane season. These numbers are based on the average of our statistical model, our analog model and qualitative adjustments and insights. Although there is significant uncertainty at this long lead time, we believe that El Niño conditions are unlikely, given the current upper ocean heat content anomalies in the tropical Pacific. Because we are predicting an above-average hurricane season in 2011, the probability of U.S. and Caribbean major hurricane landfall is estimated to be above the long-period average. This forecast is based on an 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 do not expect to see El Niño conditions reemerge in 2011. At this point, we are uncertain whether La Niña conditions or neutral conditions are more likely for the 2011 hurricane season. Sea surface temperatures in the far North Atlantic remain at record warm levels, indicating that the active phase of the thermohaline circulation and positive phase of the Atlantic Multi-Decadal Oscillation is expected to continue.

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 ten 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. The success of the last three years of seasonal forecasts is an example. He is currently developing new seasonal and two-week forecast innovations that are improving our forecasts. 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

This year's forecasts are funded by private and personal funds. We 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 graduate students 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 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 Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in both sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the thermohaline circulation. Although several definitions of the AMO are currently used in the literature, we define the AMO based on North Atlantic sea surface temperatures from 50-60°N, 10-50°W.

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 is 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, 20-70°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.

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

Thermohaline Circulation (THC) – A large-scale circulation in the Atlantic Ocean that is driven by fluctuations in salinity and temperature. When the THC is stronger than normal, the AMO tends to be in its warm (or positive) phase.

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, 15-57.5°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 28th 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 TC 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 19 years (1992-2010).

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 (although four years is not long enough to adequately evaluate a hindcast scheme for real-time skill). A slightly modified scheme was used in 2007.

We spent much time in studying this extended-range forecast problem and have developed a new statistical forecast methodology for our early December prediction in 2007 for the 2008 Atlantic hurricane season (Scheme C). This scheme showed increased hindcast skill over Scheme B while also using fewer predictors. 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.)	2008-2010 (3 Yrs.)
Number of Predictors	6	3
Hindcast Period	1950-2001 (52 Yrs.)	1950-2007 (58 Yrs.)
Hindcast Skill for NTC (r)	0.65	0.73
Hindcast/Forecast Skill for NTC (r) (1992-2010)	0.57	0.71

Table 2 displays hindcasts for 1950-2007 and statistical model forecasts for 2008-2010 using Scheme C. We have correctly predicted above- or below-average seasons in 46 out of 61 years (75%). Our predictions have had a smaller error than climatology in 41 out of 61 years (67%). Our average error is 30 NTC units, compared with 45 NTC units for climatology. This scheme has shown remarkable hindcast skill over the last 30 years from 1981 to 2010. Our average error during the past 30 years has been 29 NTC units, compared with 53 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 that we were not able to forecast more than six months in advance. This new scheme is also well-tuned to the multi-decadal active hurricane periods from 1950-1969 and 1995-2010 versus the inactive hurricane period from 1970-1994 (Table 3).

Table 2: Observed versus hindcast NTC for 1950-2010 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 46 out of 61 years (75%), while hindcast improvement over climatology occurred in 41 out of 61 years (67%). The hindcast improved over climatology in 24 out of the last 30 years (80%).

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**
2010	195	103	92	95	3
Average (1950-2010)	**108**	**105**	**|30|**	**|45|**	**+15**
Average (1981-2010)	**114**	**110**	**|29|**	**|53|**	**+24**

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
1995-2010 (Active)	152	141

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 along with their standardized values for the 2011 forecast. Table 5 displays the statistical forecast model output for the 2011 hurricane season. The statistical model calls for a very active hurricane season in 2011. 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 (r = 0.73) 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 (jackknife) cross-validation technique is applied.

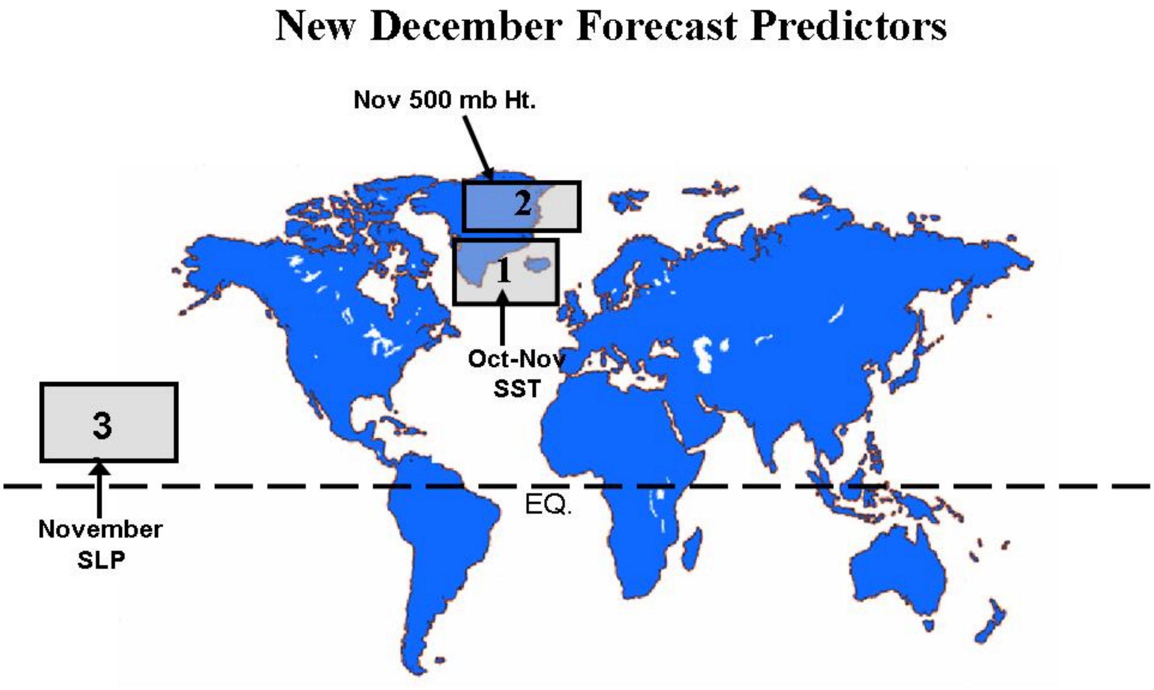

Figure 1: Location of predictors for our December extended-range statistical prediction for the 2011 hurricane season.

Table 4: Listing of 1 December 2010 predictors for the 2011 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2010 Values for 2011 Forecast
1) October-November SST (55-65°N, 10-60°W) (+)	+3.0 SD
2) November 500 mb geopotential height (67.5-85°N, 10°E-50°W) (+)	+1.1 SD
3) November SLP (7.5-22.5°N, 125-175°W) (+)	+1.6 SD

Table 5: Statistical forecast model output for the 2011 Atlantic hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme
Named Storms (9.6)	14.8
Named Storm Days (49.1)	85.5
Hurricanes (5.9)	9.4
Hurricane Days (24.5)	45.6
Major Hurricanes (2.3)	5.5
Major Hurricane Days (5.0)	14.6
Accumulated Cyclone Energy Index (96.1)	189
Net Tropical Cyclone Activity (100%)	200

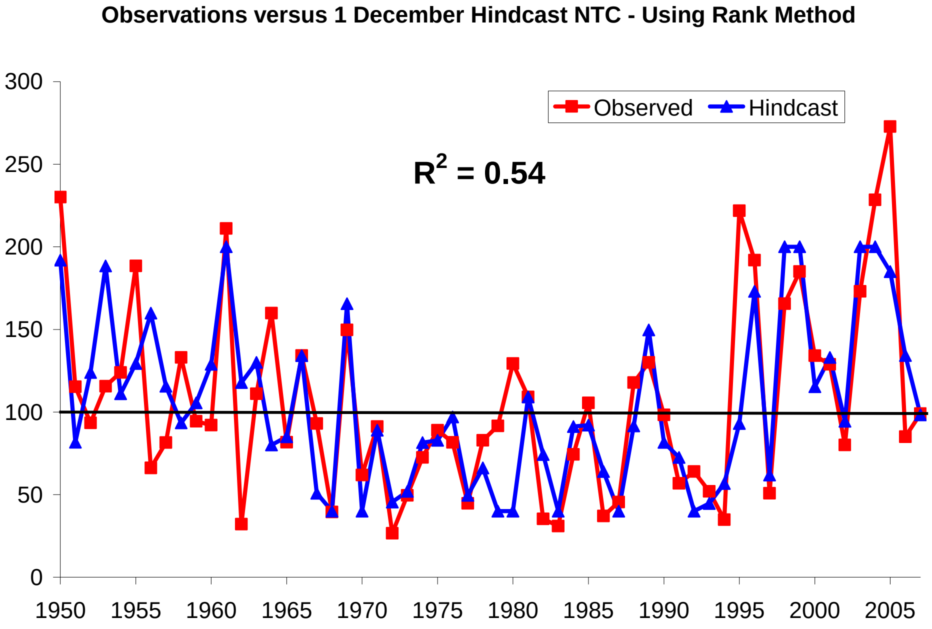

Figure 2: 1 December hindcast NTC versus observations using equations developed over the full period from 1950-2007. This hindcast scheme explains 54 percent of the variance (r = 0.73).

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 three 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. 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).

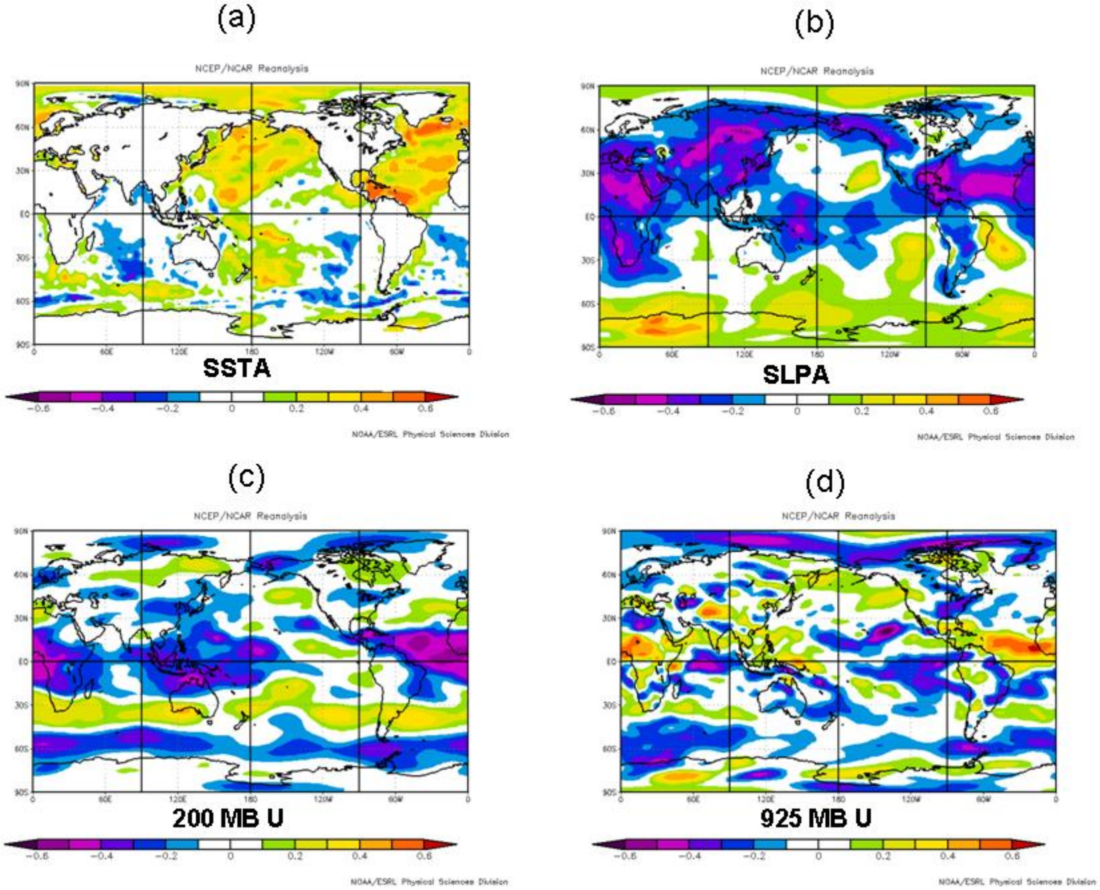

Figure 3: Linear correlations between October-November SST in the North Atlantic (55-65°N, 10-60°W) (Predictor 1) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb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

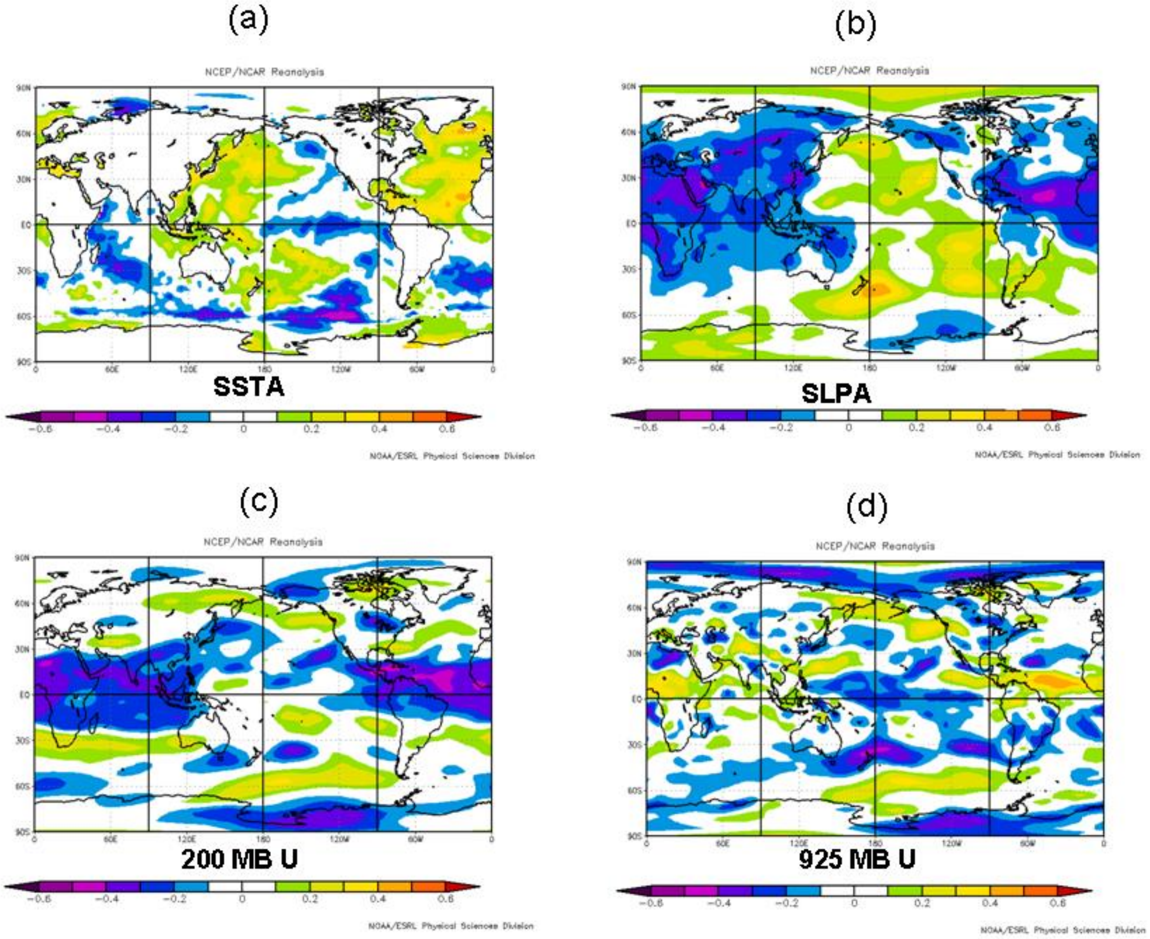

Figure 4: Linear correlations between November 500 mb geopotential heights in the far North Atlantic (67.5-85°N, 50°W-10°E) (Predictor 2) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c)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

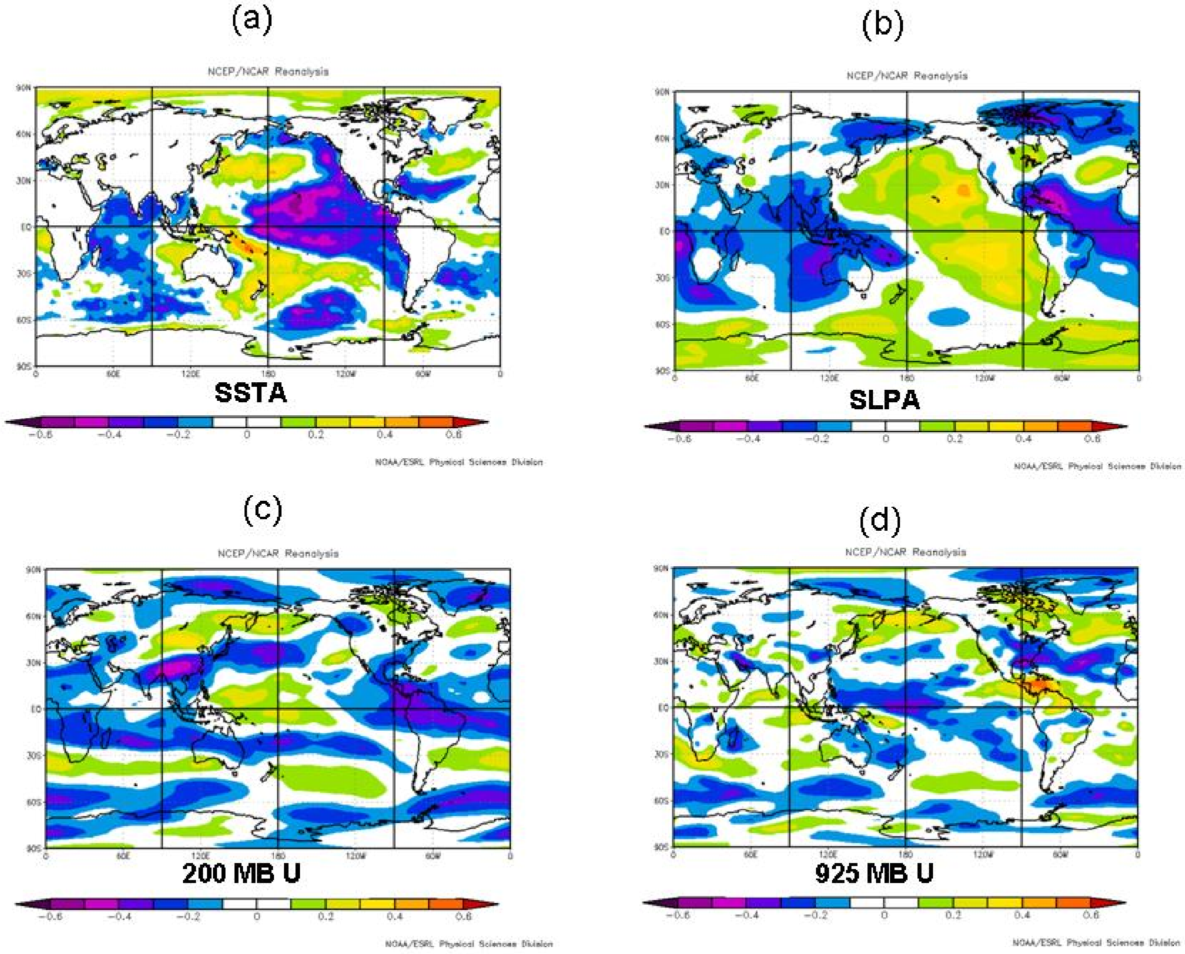

Figure 5: Linear correlations between November sea level pressure in the subtropical Northeast Pacific (7.5-22.5°N, 125-175°W) (Predictor 3) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel 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 eight months prior to the start of the active part of the hurricane season in early August.

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. Climatological average values from 1950-2000 are in parentheses in the right hand column.

Parameter	Hindcast Error (SD)	2011 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	±4.4	17	12.6 – 21.6 (9.6)
Named Storm Days (NSD)	±23.9	85	61.1 – 108.9 (49.1)
Hurricanes (H)	±2.5	9	6.5 – 11.5 (5.9)
Hurricane Days (HD)	±12.4	40	27.6 – 52.4 (24.5)
Major Hurricanes (MH)	±1.5	5	3.5 – 6.5 (2.3)
Major Hurricane Days (MHD)	±4.7	10	5.3 – 14.7 (5.0)
Accumulated Cyclone Energy (ACE)	±50	165	115 – 215 (96.1)
Net Tropical Cyclone (NTC) Activity	±49	180	131 – 229 (100)

4 ENSO

We currently have a strong La Niña event in place over the tropical Pacific. Observed sea surface temperatures anomalies in the eastern and central Pacific are approximately 1.0 – 2.0°C below the long-period average while the September-October-averaged Multivariate Enso Index (MEI) (Wolter and Timlin 1998) is currently 1.9 standard deviations below 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) and extends back to 1950. Only 1975 had a lower September-October-averaged MEI than 2010.

One of the important questions for the upcoming hurricane season is whether El Niño will re-develop for the 2011 hurricane season. At this point, we think that this is a very unlikely scenario, given the current upper ocean heat content structure across the tropical Pacific. El Niño events occur when there is an anomalous buildup of warm water in the western tropical Pacific, which then is transferred to the eastern and central Pacific. The current anomalies of upper ocean heat content across the tropical Pacific indicate that more time is needed for a buildup of the warm pool in the western tropical Pacific before another El Niño event will occur. According to the Climate Prediction Center (CPC), the

November 2010 anomalous upper ocean heat content averaged from 0-300 meters from 130°E-80°W was approximately -0.8°C. Eight years since the CPC's upper ocean heat content data began in 1979 have had upper ocean heat content anomalies of -0.4°C or less during the month of November. Table 7 displays the November upper ocean heat content anomalies for these years, along with the following year's August-October averaged Nino 3.4 index. None of the following years had El Niño conditions (defined as an August-October-averaged Nino 3.4 anomaly greater than 0.5°C), with only one of these years having above-average SSTs in the Nino 3.4 region.

There is significant uncertainty in exactly what ENSO conditions will look like next year. Most statistical and dynamical forecast models indicate that La Niña will persist through the winter (Figure 6), with some moderation 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: Years with November equatorial upper ocean heat content anomalies averaged from 130°E-80°W less than -0.4°C and the following August-October-averaged Nino 3.4 index.

Year	November Upper Ocean Heat Content Anomaly	Following Year's August-October Nino 3.4
1983	-1.36	-0.42
1987	-0.51	-1.55
1988	-0.99	-0.37
1992	-0.42	0.25
1995	-0.44	-0.27
1998	-1.53	-1.01
1999	-0.72	-0.44
2007	-0.54	-0.11
Average	**-0.81**	**-0.49**
2010	-0.77	

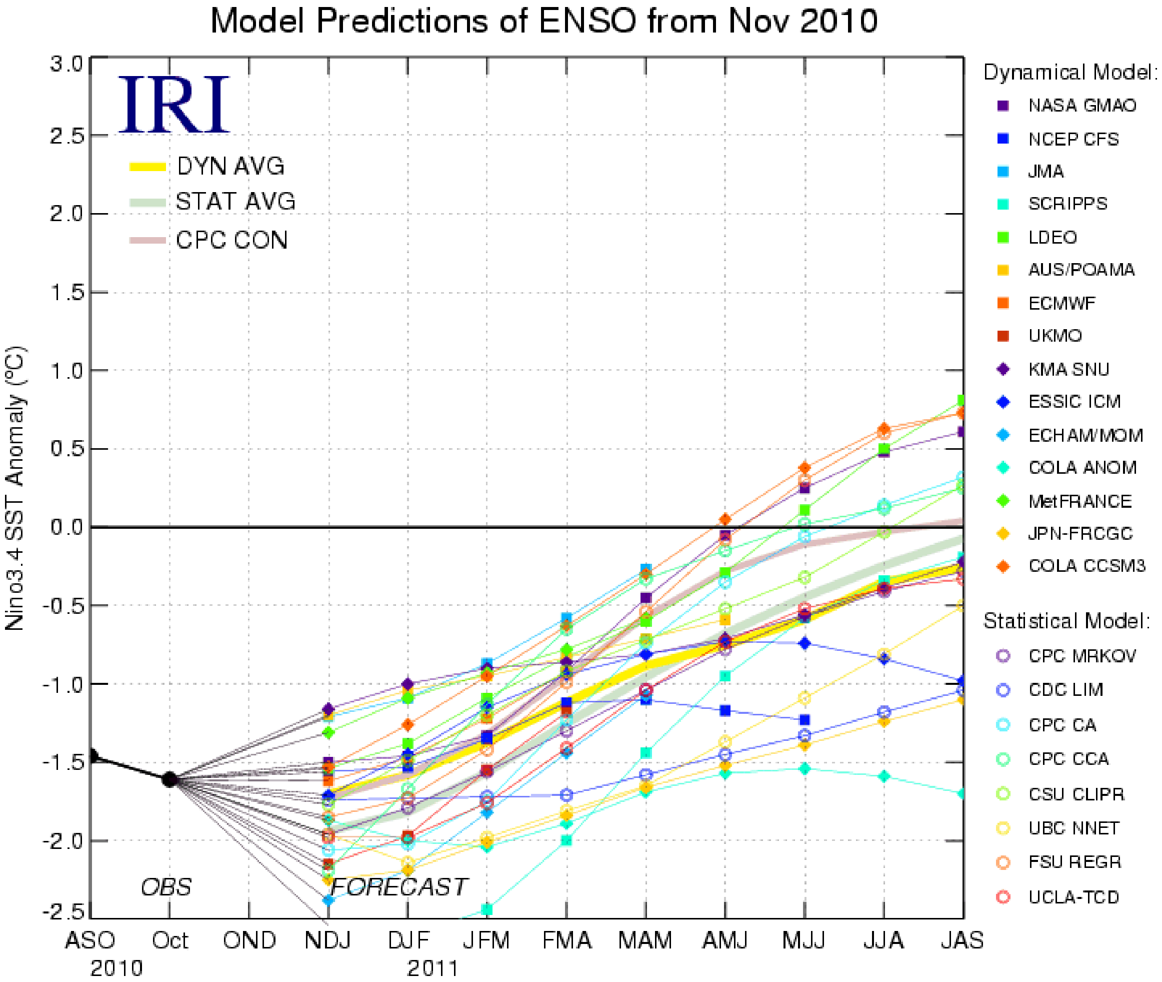

Figure 6: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

5 Analog Forecast

Table 8 displays our analog year selection for the 2011 hurricane season. We selected years with similar September-October-averaged MEI indices along with anomalously warm October-November-averaged far North Atlantic sea surface temperatures.

Table 8: Analog years for 2011 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1956	8	30.00	4	12.75	2	2.75	54	68
1961	11	70.75	8	47.50	7	24.50	205	230
1989	11	66.00	7	31.75	2	9.75	135	130
1999	12	78.50	8	41.00	5	14.25	177	182
2008	16	88.25	8	30.50	5	7.50	146	162
Mean	11.6	66.7	7.0	32.7	4.2	11.8	143	154
2011 Fcst.	**17**	**85**	**9**	**40**	**5**	**10**	**165**	**180**

6 Adjusted 2011 Forecast

Table 9 shows our final adjusted early December forecast for the 2011 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. We foresee a very active Atlantic basin hurricane season, given that we feel that El Niño's reappearance in 2011 seems unlikely.

Warm sea surface temperatures are likely to continue being present in the tropical and North Atlantic during 2011, 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 9: Summary of our early December statistical forecast, our analog forecast and our adjusted final forecast for the 2011 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	14.8	11.6	17
Named Storm Days (49.1)	85.5	66.7	85
Hurricanes (5.9)	9.4	7.0	9
Hurricane Days (24.5)	45.6	32.7	40
Major Hurricanes (2.3)	5.5	4.2	5
Major Hurricane Days (5.0)	14.6	11.8	10
Accumulated Cyclone Energy Index (96.1)	189	143	165
Net Tropical Cyclone Activity (100%)	200	154	180

7 Landfall Probabilities for 2011

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

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 10). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall.

Table 10: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 MH, and 5 MHD would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

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

Table 11 lists strike probabilities for the 2011 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula along with probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2011 is expected to be above its long-term average of 100, and therefore, landfall probabilities are above their long-term average.

Some have questioned the use of the relationship between NTC and U.S. landfall, especially given the fact that 2010, despite having twelve hurricanes in the Atlantic basin, had no U.S. hurricane landfalls. This was an especially unusual event. Generally, active hurricane seasons have many more U.S. landfalls than do inactive seasons. Table 12 displays the number of named storm, hurricane and major hurricane landfalls for the 10 highest observed NTC years since 1950 compared with the 10 lowest observed NTC years since 1950. Note the large ratios that exist, especially for major hurricanes.

Please visit the Landfalling Probability Webpage at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine. The probability of each U.S. coastal state being impacted by hurricanes and major hurricanes is also included. In addition, we now include probabilities of named storms, hurricanes and major hurricanes tracking within 50 and 100 miles of various islands and landmasses in the Caribbean and Central America.

Table 11: Estimated probability (expressed in percent) of one or more landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2011. 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)	94% (79%)	87% (68%)	73% (52%)	96% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	79% (59%)	63% (42%)	48% (30%)	81% (60%)	96% (83%)
Florida plus East Coast (Regions 5-11)	72% (50%)	65% (44%)	49% (31%)	82% (61%)	95% (81%)
Caribbean (10-20°N, 60-88°W)	95% (82%)	78% (57%)	62% (42%)	92% (75%)	99% (96%)

Table 12: The number of named storms, hurricanes and major hurricanes making U.S. landfall in the top 10 observed NTC and bottom 10 observed NTC years since 1950. The top 10/bottom 10 ratio is also provided.

	Named Storms	Hurricanes	Major Hurricanes	Average NTC
Top 10	47	30	16	217
Bottom 10	22	9	2	41
Ratio	**2.1**	**3.3**	**8.0**	**5.3**

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

A. BACKGROUND

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 those two unusually destructive seasons. In addition, three category 2 hurricanes (Dolly, Gustav and Ike) pummeled the Gulf Coast in 2008 causing considerable devastation. Some researchers have tried to link the rising CO_2 levels with SST increases during the late 20th century and say that this has brought on higher levels of hurricane intensity.

These speculations that hurricane intensity has increased have been given much media attention; however, we believe that they are not valid, given current observational data.

There has, however, been a large increase in Atlantic basin major hurricane activity since 1995 in comparison with the prior 16-year period of 1979-1994 (Figure 7) as well as the prior quarter-century period of 1970-1994. It has been tempting for many who do not have a strong background of hurricane information to jump on this recent increase in major hurricane activity as strong evidence of a human influence on hurricanes. It should be noted, however, that the last 16-year active major hurricane period of 1995-2010 has, however, not been more active than the earlier 16-year period of 1949-1964 when the Atlantic Ocean circulation conditions were similar to what has been observed in the last 16 years. These earlier active conditions occurred even though atmospheric CO_2 amounts were lower during the earlier period.

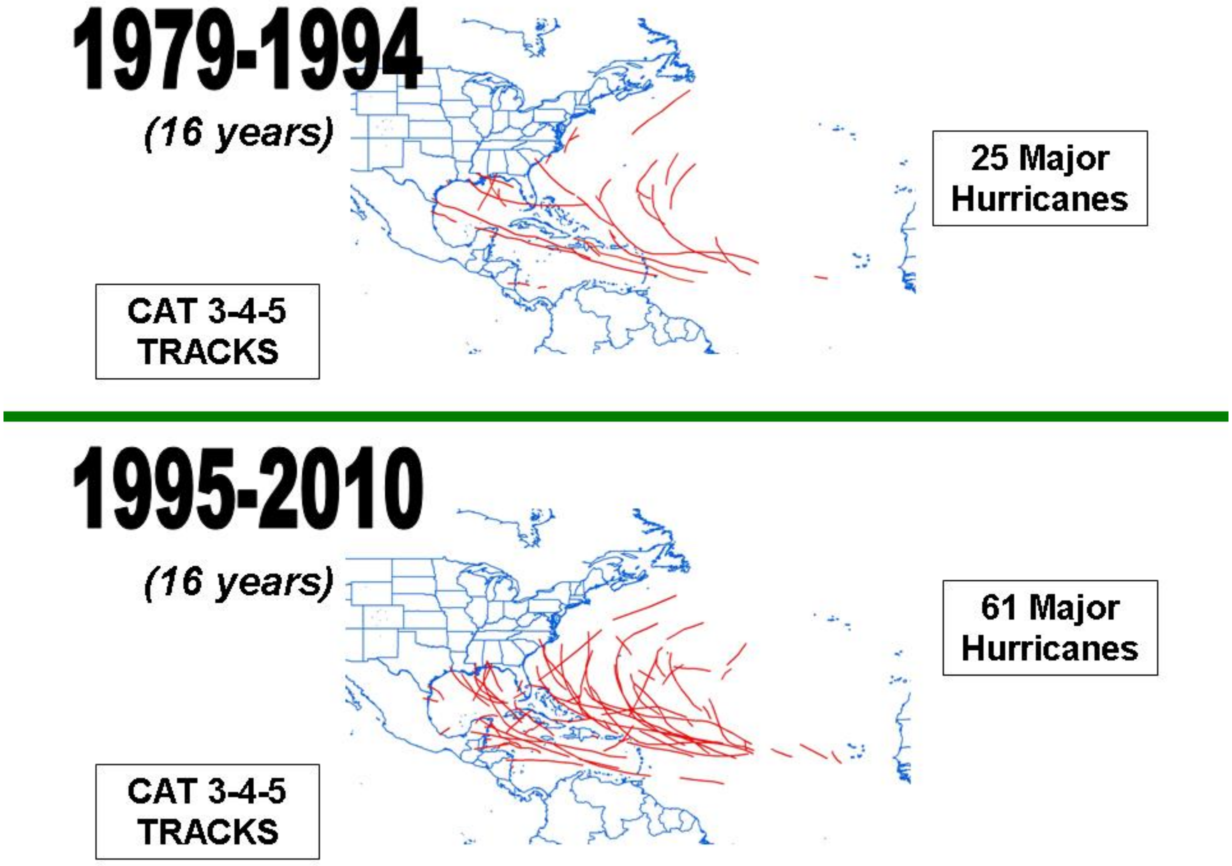

Figure 7: The tracks of major (Category 3-4-5) hurricanes during the 16-year period of 1995-2010 when the Atlantic thermohaline circulation (THC) was strong versus the prior 16-year period of 1979-1994 when the THC was weak. Note that there were approximately 2.5 times as many major hurricanes when the THC was strong as when it was weak.

Table 13 shows how large Atlantic basin hurricane variations are between strong and weak THC periods. Note especially how large the ratio is for major hurricane days (3.7) during strong vs. weak THC periods. Normalized U.S. hurricane damage studies by Pielke and Landsea (1998) and Pielke et al. (2008) show that landfalling major hurricanes account on average for about 80-85 percent of all hurricane-related destruction even though these major hurricanes make up only 20-25 percent of named storms.

Although global surface temperatures increased during the late 20th century, there is no reliable data to indicate increased hurricane frequency or intensity in any of the globe's other tropical cyclone basins since 1979. Global Accumulated Cyclone Energy (ACE) shows significant year-to-year and decadal variability over the past thirty years but no increasing trend (Figure 8). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005.

Table 13: Comparison of Atlantic annual basin hurricane activity in two 16-year periods when the Atlantic Ocean THC (or AMO) was strong versus an intermediate period (1970-1994) when the THC was weak.

	THC	SST (10-15°N; 70-40°W)	Avg. CO_2 ppm	NS	NSD	H	HD	MH	MHD	ACE	NTC
1949-1964 (16 years)	Strong	27.93	319	10.1	54.1	6.5	29.9	3.8	9.5	121	133
1970-1994 (25 years)	Weak	27.60	345	9.3	41.9	5.0	16.0	1.5	2.5	68	75
1995-2010 (16 years)	Strong	28.02	373	14.6	74.1	7.8	32.0	3.8	9.4	140	153
Annual Ratio Strong/Weak THC		Δ 0.35°C	~ 0	1.3	1.5	1.4	1.9	2.5	3.7	1.9	1.9

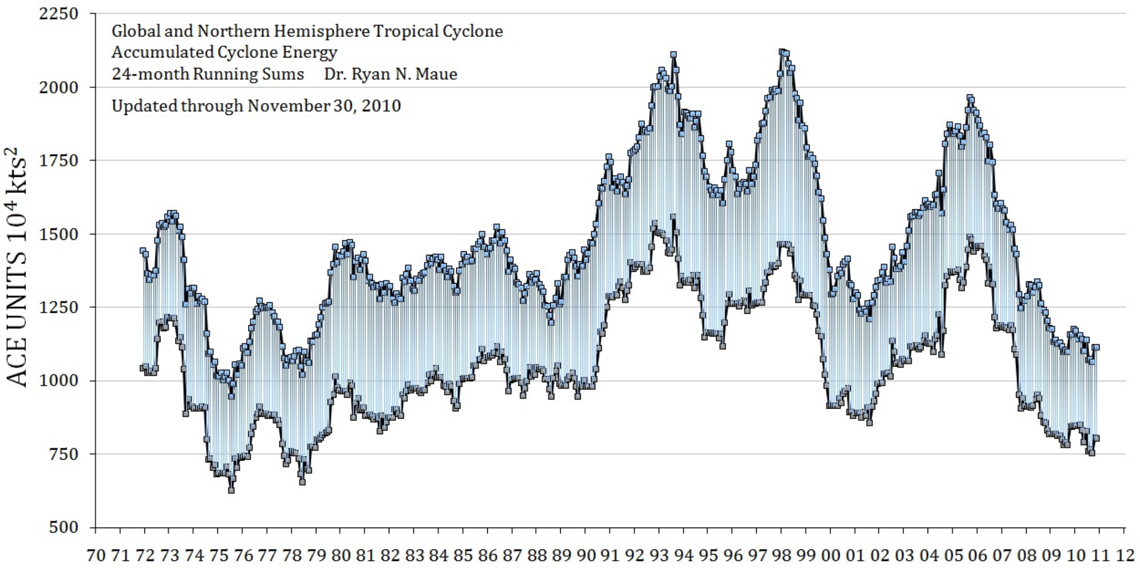

Figure 8: Northern Hemisphere and global Accumulated Cyclone Energy (ACE) over the period from 1979-November 2010. Figure has been adapted from Ryan Maue, Center for Ocean-Atmospheric Prediction Studies, Florida State University.

Causes of the Upswing in Atlantic Major Hurricane Activity since 1995. The Atlantic Ocean has a strong multi-decadal signal in its hurricane activity which is likely due to multi-decadal variations in the strength of the THC (Figure 9). The oceanic and atmospheric response to the THC is often referred to as the Atlantic Multi-decadal Oscillation (AMO). We use the THC and AMO interchangeably throughout the remainder of this discussion. The strength of the THC can never be directly measured, but it can be diagnosed, as we have done, from the magnitude of the sea surface temperature anomaly (SSTA) in the North Atlantic (Figure 10) combined with the sea level pressure anomaly (SLPA) in the Atlantic between the latitude of the equator and 50°N (Klotzbach and Gray 2008).

The THC (or AMO) is strong when there is an above-average poleward advection of warm low-latitude waters to the high latitudes of the North Atlantic. This water can then sink to deep levels when it reaches the far North Atlantic in a process known as deep water formation. The water then moves southward at deep levels in the ocean. The amount of North Atlantic water that sinks is proportional to the water's density which is determined by its salinity content as well as its temperature. Salty water is denser than fresh water especially at water temperatures near freezing. There is a strong association between North Atlantic SSTA and North Atlantic salinity (Figure 11). High salinity implies higher rates of North Atlantic deep water formation (or subsidence) and thus a stronger flow of upper level warm water from lower latitudes as replacement. See the papers by Gray et al. (1999), Goldenberg et al. (2001), and Grossman and Klotzbach (2009) for more discussion.

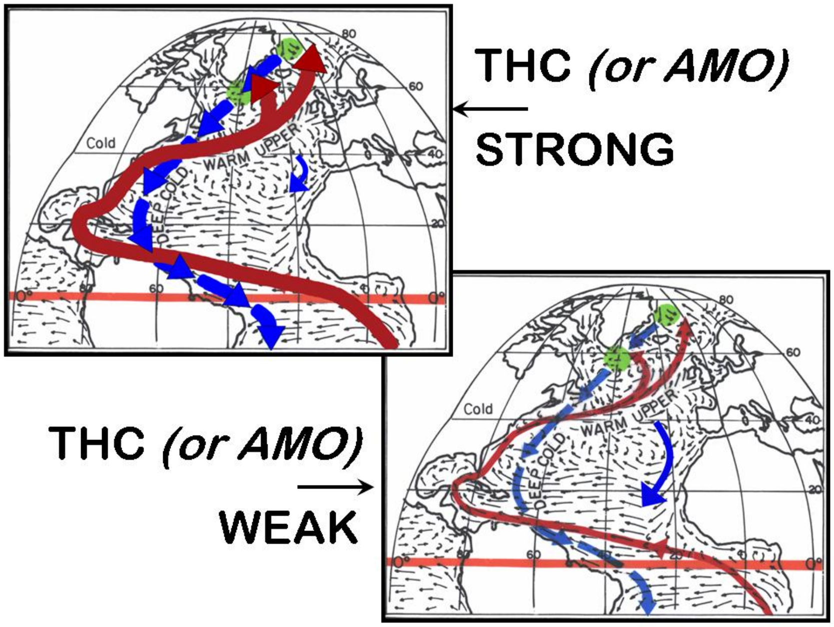

Figure 9: Illustration of strong (top) and weak (bottom) phases of the THC or AMO.

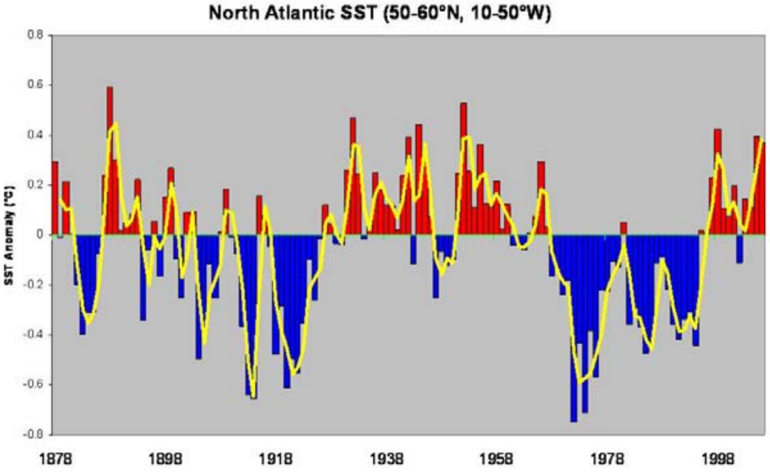

Figure 10: Long-period portrayal (1878-2006) of North Atlantic sea surface temperature anomalies (SSTA). The red (warm) periods are when the THC (or AMO) is stronger than average and the blue periods are when the THC (or AMO) is weaker than average.

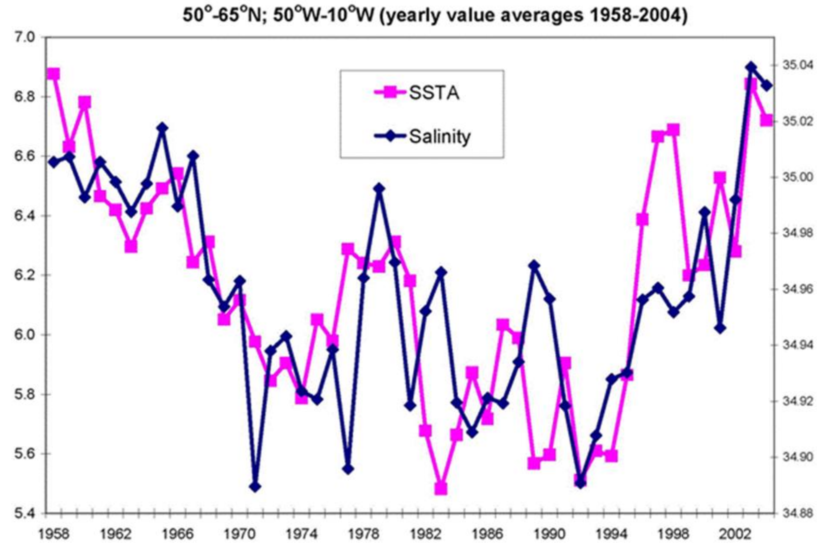

Figure 11: Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.

B. WHY CO_2 INCREASES ARE NOT RESPONSIBLE FOR ATLANTIC SST AND HURRICANE ACTIVITY INCREASES

Theoretical considerations do not support a close relationship between SSTs and hurricane intensity. In a global warming world, the atmosphere's upper air temperatures will warm or cool in unison with longer-period SST changes. Vertical lapse rates will thus not be significantly altered in a somewhat warmer or somewhat cooler tropical oceanic environment. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will significantly change if global or Atlantic Ocean temperatures were to rise by 1-2°C. Without corresponding changes in many other basic features, such as vertical wind shear or mid-level moisture, little or no additional TC activity should occur with SST increases.

Confusing Time Scales of SST Influences. A hurricane passing over a warmer body of water, such as the Gulf Stream, will often undergo some intensification. This is due to the sudden lapse rate increase which the hurricane's inner core experiences when it passes over warmer water. The warmer SSTs cause the hurricane's lower boundary layer temperature and moisture content to rise. While these low level changes are occurring, upper tropospheric conditions are often not altered significantly. These rapidly occurring lower- and upper-level temperature differences cause the inner-core hurricane lapse rates to increase and produce more intense inner-core deep cumulus convection. This typically causes a rapid increase in hurricane intensity. Such observations have led many observers to directly associate SST increases with greater hurricane potential intensity. This is valid reasoning for day-to-day hurricane intensity change associated with hurricanes moving over warmer or colder patches of SST. But such direct reasoning does not hold for conditions occurring in an overall climatologically warmer (or cooler) tropical oceanic environment where broad-scale global and tropical rainfall conditions are not expected to significantly vary. During long-period climate change, temperature and moisture conditions rise at both lower and upper levels. Lapse rates are little affected.

Any warming-induced increase in boundary layer temperature and moisture will be (to prevent significant global rainfall alteration) largely offset by a similar but weaker change through the deep troposphere up to about 10 km height. Upper-tropospheric changes are weaker than boundary layer changes, but they occur through a much deeper layer. These weaker and deeper compensating increases in upper-level temperature and moisture are necessary to balance out the larger increases in temperature and moisture which occur in the boundary layer. Global and tropical rainfall would be altered significantly only if broad-scale lapse rates were ever altered to an appreciable degree.

Thus, we cannot automatically assume that with warmer global SSTs that we will necessarily have more intense hurricanes due to lapse-rate alterations. We should not expect that the frequency and/or intensity of major hurricanes will necessarily change as a result of changes in global or individual storm basin SSTs. Historical evidence does not support hurricanes being less intense during the late 19th century and the early part of the 20th century when SSTs were slightly lower.

CO_2 Influence on Hurricane Activity. We have been performing research with the International Satellite Cloud Climatology Project (ISCCP) and the NOAA National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis data sets. We have used this data to make an annual average of the global tropical (30°N-30°S; 0-360°) energy budget (Figure 12) for the years from 1984-2004. Note that the various surface and top of the atmosphere energy fluxes are very large. For the tropical surface, for instance, there are 637 Wm^{-2} units of downward incoming solar and infrared (IR) energy. This downward energy flux is largely balanced by an upward surface energy flux of 615 Wm^{-2} which is due to upward fluxes from IR radiation, evaporated liquid water, and sensible heat. Similar large energy fluxes are present at the top of the atmosphere and within the troposphere.

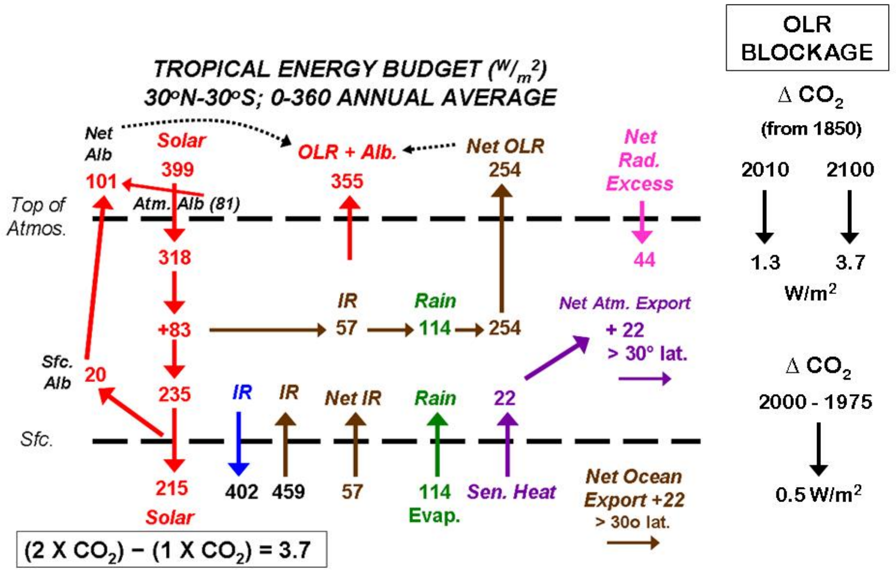

Figure 12: Vertical cross-section of the annual tropical energy budget as determined from a combination of ISCCP and NCEP/NCAR Reanalysis data over the period from 1984-2004. Abbreviations are **IR** for longwave infrared radiation, **Alb** for albedo and **OLR** for outgoing longwave radiation. The tropics receive an excess of about 44 Wm^{-2} radiation energy which is convected and exported as sensible heat to latitudes poleward of 30°. Estimates are about half (22 Wm^{-2}) of this excess is transported by the atmosphere and the other half is transported by the oceans. Note, on the right, how small an OLR blockage has occurred up to now due to CO_2 increases (~ 1.3 Wm^{-2}) and a continued small blockage of 3.7 Wm^{-2} that will occur from a doubling of CO_2 by the end of this century.

It has been estimated that a doubling of CO_2 (from the pre-industrial period) without any feedback influences would result in a blockage of OLR to space of about 3.7 Wm^{-2}. The currently-measured value of CO_2 in the atmosphere is 385 parts per million by volume (ppmv). If we take the background pre-industrial value of CO_2 to be 285 ppmv, then by theory we should currently be having (from CO_2 increases alone) about (100/285)*3.7 = 1.3 Wm^{-2} less OLR energy flux to space than was occurring in the mid-19th century.

This reduced OLR of 1.3 Wm^{-2} is very small in comparison with most of the other tropical energy budget exchanges. Slight changes in any of these other larger tropical energy budget components could easily negate or reverse this small CO_2-induced OLR blockage. For instance, an upper tropospheric warming of about 1°C with no change in moisture would enhance OLR sufficiently that it would balance the reduced OLR influence from a doubling of CO_2. Similarly, if there were a reduction of upper level water vapor such that the long wave radiation emission level to space were lowered by about 7 mb (~ 140 m), there would be an enhancement of OLR (with no change of temperature) sufficient to balance the suppression of OLR from a doubling of CO_2. The 1.3 Wm^{-2} reduction in OLR we have experienced since the mid-19th century (about one-third of the way to a doubling of CO_2) is very small compared with the overall 399 Wm^{-2} of solar energy impinging on the top of the tropical atmosphere and the mostly compensating 356 Wm^{-2} of OLR and albedo energy going back to space. This 1.3 Wm^{-2} energy gain is much too small to ever allow a determination of its possible influence on TC activity. Any such potential CO_2 influence on TC activity is deeply buried as turbulence within the tropical atmospheres' many other energy components. It is possible that future higher atmospheric CO_2 levels may cause a small influence on global TC activity. But any such potential influence would likely never be able to be detected, given that our current measurement capabilities only allow us to assess TC intensity to within about 5 mph.

C. DISCUSSION

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the SSTs. 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 Atlantic major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 13). Atlantic SSTs and hurricane activity do not follow global mean temperature trends.

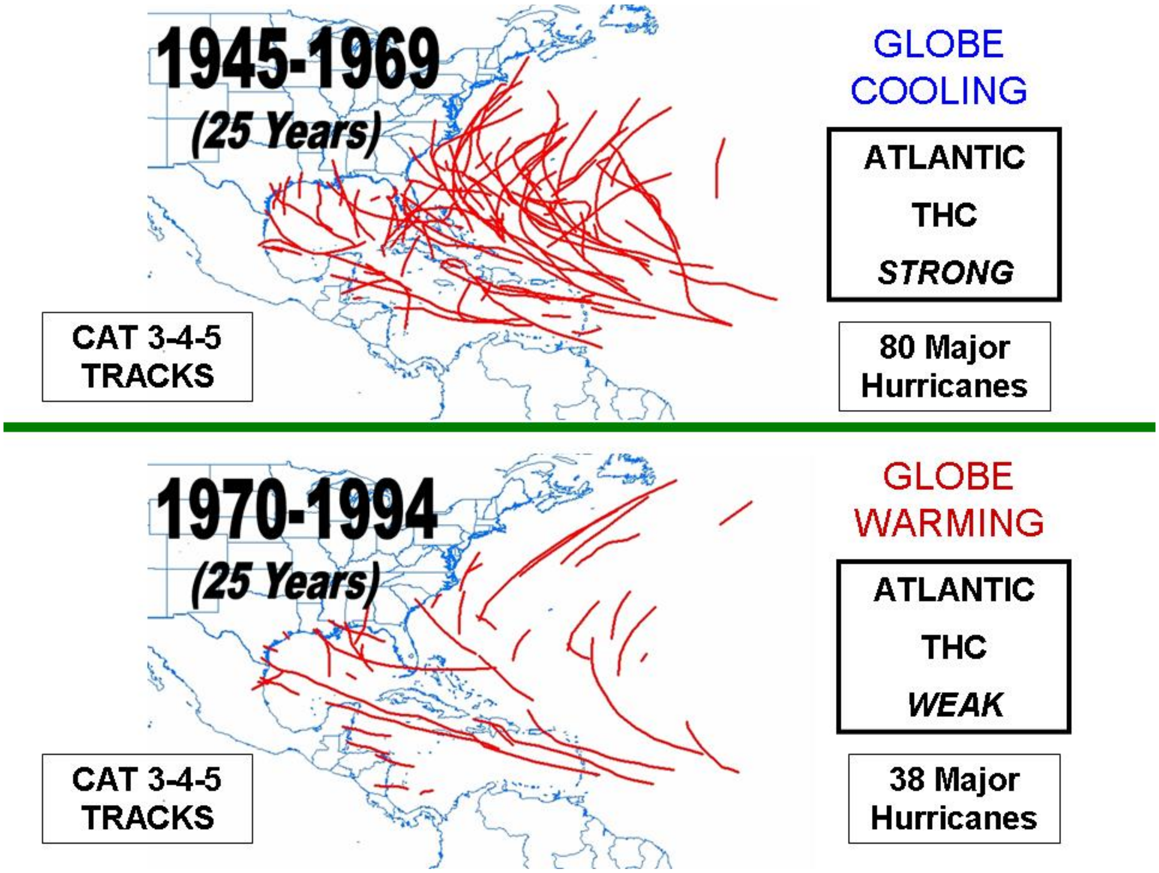

Figure 13: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than 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 TCs since 1900 (Table 14). Although global mean ocean and Atlantic SSTs have increased by about 0.4°C between two 55-year periods (1901-1955 compared with 1956-2010), 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 45-year period of 1921-1965 (24 landfall events) and the 45-year period of 1966-2010 (7 landfall events) was especially large (Figure 14). For the entire United States coastline, 39 major hurricanes made landfall during the earlier 45-year period (1921-1965) compared with only 26 major hurricanes for the latter 45-year period (1966-2010). 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 14: U.S. landfalling tropical cyclones by intensity during two 55-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Major Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1901-1955 (55 years)	210	115	44	+0.4°C
1956-2010 (55 years)	180	87	34	

We should not read too much into the four very active hurricane seasons of 2004, 2005, 2008 and 2010. The activity of these 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.

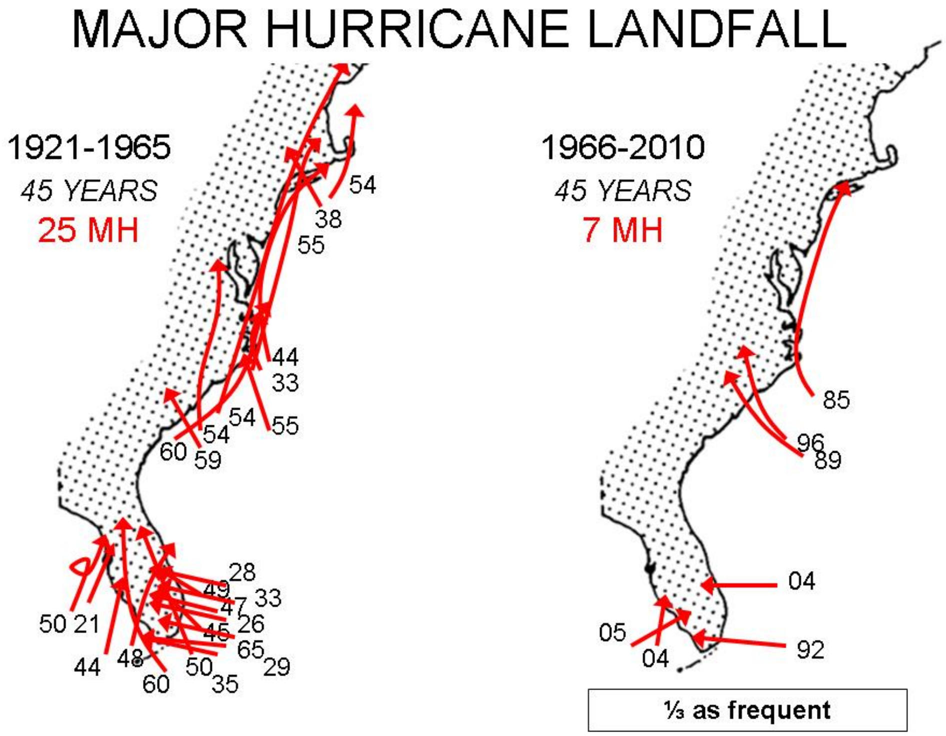

Figure 14: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 45-year period of 1921-1965 versus the most recent 45-year period of 1966-2010.

Although 2005 had a record number of TCs (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 storms had tracks west of 60°W where surface observations were more plentiful. If we eliminate all of the named storms of 2005 whose tracks were entirely east of 60°W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storm total by seven (to 21) – the same number as was observed to occur in 1933.

Utilizing the National Hurricane 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.

We believe that the Atlantic basin remains in an active hurricane cycle associated with a strong THC. 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. Changes in the THC (or AMO) have been inferred from Greenland paleo ice-core temperature measurements going back thousand of years. These changes are natural and have nothing to do with human activity.

9 Forthcoming Updated Forecasts of 2011 Hurricane Activity

We will be issuing seasonal updates of our 2011 Atlantic basin hurricane forecasts on **Wednesday April 6**, **Wednesday 1 June**, **and Wednesday 3 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 2011 forecasts will be issued in late November 2011. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

10 Acknowledgments

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

11 Citations and Additional Reading

Alexander, M. A., I. Blade, M. Newman, J. R. Lanzante, N.-C. Lau, and J. D. Scott, 2002: The atmospheric bridge: The influence of ENSO teleconnections on air-sea interaction over the global oceans. *J. Climate,* 15, 2205-2231.

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

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

Chiang, J. C. H. and D. J. Vimont, 2004: Analogous Pacific and Atlantic meridional modes of tropical atmosphere-ocean variability. *J. Climate,* 17, 4143-4158.

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

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

Evan, A. T., J. Dunion, J. A. Foley, A. K. Heidinger, and C. S. Velden, 2006: New evidence for a relationship between Atlantic tropical cyclone activity and African dust outbreaks, *Geophys. Res. Lett,* 33, doi:10.1029/2006GL026408.

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

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

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

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

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

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

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

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

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

Gray, W. M., J. D. Sheaffer and C. W. Landsea, 1996: Climate trends associated with multi-decadal variability of intense Atlantic hurricane activity. Chapter 2 in “Hurricanes, Climatic Change and

Socioeconomic Impacts: A Current Perspective", H. F. Diaz and R. S. Pulwarty, Eds., Westview Press, 49 pp.

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

Grossmann, I. and P. J. Klotzbach, 2009: A review of North Atlantic modes of natural variability and their driving mechanisms. *J. Geophys. Res.*, 114, D24107, doi:10.1029/2009JD012728.

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

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

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

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

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

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

Klotzbach, P. J. and W. M. Gray, 2006: Causes of the unusually destructive 2004 Atlantic basin hurricane season. *Bull. Amer. Meteor. Soc.,* 87, 1325-1333.

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

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

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

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

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

Landsea, C. W., 2007: Counting Atlantic tropical cyclones back to 1900. *EOS,* 88, 197, 202.

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

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

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

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

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

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

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

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

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

Pielke, Jr. R. A., and J. Gratz, C. W. Landsea, D. Collins, and R. Masulin, 2008: Normalized hurricane damage in the United States: 1900-2005. *Nat. Haz. Rev.,* 9, 29-42, doi:10.1061/(ASCE)1527-6988(2008)9:1(29).

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

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

Vimont, D. J., and J. P. Kossin, 2007: The Atlantic meridional mode and hurricane activity. *Geophys. Res. Lett.,* 34, L07709, doi:10.1029/2007GL029683.

Wheeler, M. C., and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.,* 132, 1917-1932.

12 Verification of Previous Forecasts

Table 15: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2005-2010.

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

2010	9 Dec. 2009	Update 7 April	Update 2 June	Update 4 August	Obs.
Hurricanes	6-8	8	10	10	12
Named Storms	11-16	15	18	18	19
Hurricane Days	24-39	35	40	40	37.50
Named Storm Days	51-75	75	90	90	88.25
Major Hurricanes	3-5	4	5	5	5
Major Hurricane Days	6-12	10	13	13	11
Accumulated Cyclone Energy	100-162	150	185	185	163
Net Tropical Cyclone Activity	108-172	160	195	195	195