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

We foresee a somewhat above-average Atlantic basin tropical cyclone season in 2009. We anticipate an above-average probability of United States major hurricane landfall.

(as of 10 December 2008)

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

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

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. The model correctly predicted an above-average hurricane season in 2008. We would never issue an early December forecast or any other forecast unless we had a statistical model developed over a long hindcast period which showed significant skill.

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 2009

Forecast Parameter and 1950-2000 Climatology (in parentheses)	10 December 2008 Forecast for 2009
Named Storms (NS) (9.6)	14
Named Storm Days (NSD) (49.1)	70
Hurricanes (H) (5.9)	7
Hurricane Days (HD) (24.5)	30
Intense Hurricanes (IH) (2.3)	3
Intense Hurricane Days (IHD) (5.0)	7
Accumulated Cyclone Energy (ACE) (96.1)	125
Net Tropical Cyclone Activity (NTC) (100%)	135

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

1) Entire U.S. coastline - 63% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 39% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 38% (average for last century is 30%)

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

ABSTRACT

Information obtained through November 2008 indicates that the 2009 Atlantic hurricane season will be somewhat more active than the average 1950-2000 season. We estimate that 2009 will have about 7 hurricanes (average is 5.9), 14 named storms (average is 9.6), 70 named storm days (average is 49.1), 30 hurricane days (average is 24.5), 3 intense (Category 3-4-5) hurricanes (average is 2.3) and 7 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 120 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2009 to be about 135 percent of the long-term 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 currently do not expect to see El Niño conditions during the 2009 Atlantic hurricane season.

Notice of Author Changes

By William Gray

The order of the authorship of these forecasts was reversed in 2006 from Gray and Klotzbach to Klotzbach and Gray. After 22 years (1984-2005) of making these forecasts, it was appropriate that I step back and have Phil Klotzbach assume the primary responsibility for our project's seasonal, monthly and landfall probability forecasts. Phil has been a member of my research project for the last eight years and was second author on these forecasts from 2001-2005. I have greatly profited and enjoyed our close personal and working relationships.

Phil is now devoting much more time to the improvement of these forecasts than I am. I am now giving more of my efforts to the global warming issue and in synthesizing my projects' many years of hurricane and typhoon studies.

Phil Klotzbach is an outstanding young scientist with a superb academic record. I have been amazed at how far he has come in his knowledge of hurricane prediction since joining my project in 2000. I foresee an outstanding future for him in the hurricane field. He is currently making many new seasonal and monthly forecast innovations that are improving our forecasts. The success of this year's seasonal forecasts is an example. Phil was awarded his Ph.D. degree in 2007. He is currently spending most of his time working towards better understanding and improving these Atlantic basin hurricane forecasts.

Acknowledgment

We are grateful to the National Science Foundation (NSF) and Lexington Insurance Company (a member of the American International Group (AIG)) for providing partial support for the research necessary to make these forecasts. We also thank the GeoGraphics Laboratory at Bridgewater State College (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

The second author gratefully acknowledges the valuable input to his CSU research project over many years by former project members and now colleagues Chris Landsea, John Knaff and Eric Blake. We also thank Professors Paul Mielke and Ken Berry of Colorado State University for much statistical analysis and advice over many years. We also thank Bill Thorson for technical advice and assistance.

DEFINITIONS

Accumulated Cyclone Energy – (ACE) A measure of a named storm's potential for wind and storm surge destruction defined as the sum of the square of a named storm's maximum wind speed (in 10^4 $knots^2$) for each 6-hour period of its existence. The 1950-2000 average value of this parameter is 96.

Atlantic Basin – The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño – (EN) A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years on average.

Hurricane – (H) A tropical cyclone with sustained low-level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day – (HD) A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

Intense Hurricane - (IH) A hurricane which reaches a sustained low-level wind of at least 111 mph (96 knots or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale (also termed a "major" hurricane).

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

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

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

Named Storm Day – (NSD) As in HD but for four 6-hour periods during which a tropical or sub-tropical cyclone is observed (or is estimated) to have attained tropical storm intensity winds.

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

QBO – Quasi-Biennial Oscillation – A stratospheric (16 to 35 km altitude) oscillation of equatorial east-west winds which vary with a period of about 26 to 30 months or roughly 2 years; typically blowing for 12-16 months from the east, then reversing and blowing 12-16 months from the west, then back to easterly again.

Saffir/Simpson (S-S) Category – A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge intensity. One is a weak hurricane; whereas, five is the most intense hurricane.

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

SST(s) – Sea Surface Temperature(s)

SSTA(s) – Sea Surface Temperature(s) Anomalies

Tropical Cyclone – (TC) A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms and other weaker rotating vortices.

Tropical North Atlantic (TNA) index – A measure of sea surface temperatures in the area from 5.5-23.5°N, 57.5-15°W.

Tropical Storm – (TS) A tropical cyclone with maximum sustained winds between 39 (18 ms^{-1} or 34 knots) and 73 (32 ms^{-1} or 63 knots) miles per hour.

ZWA – Zonal Wind Anomaly – A measure of the upper level (~200 mb) west to east wind strength. Positive anomaly values mean winds are stronger from the west or weaker from the east than normal.

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

1 Introduction

This is the 26th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. These forecasts are based on a statistical methodology derived from 58 years of past data. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic basin tropical cyclone activity and landfall probability. We believe that seasonal forecasts must be based on methods that show significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided that the atmosphere continues to behave in the future as it has in the past.

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

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 2-3 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated 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 Forecast Methodology

We developed a new statistical forecast methodology for our early December prediction which we used for the first time last year. 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 our recently published paper (Klotzbach 2008). This forecast worked out quite well last year.

Figure 1 displays the locations of the three predictors used in this forecast scheme, while Table 1 lists the three predictors that are utilized for this year's December forecast. Table 2 displays the statistical forecast model output for the 2009 hurricane season. 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.

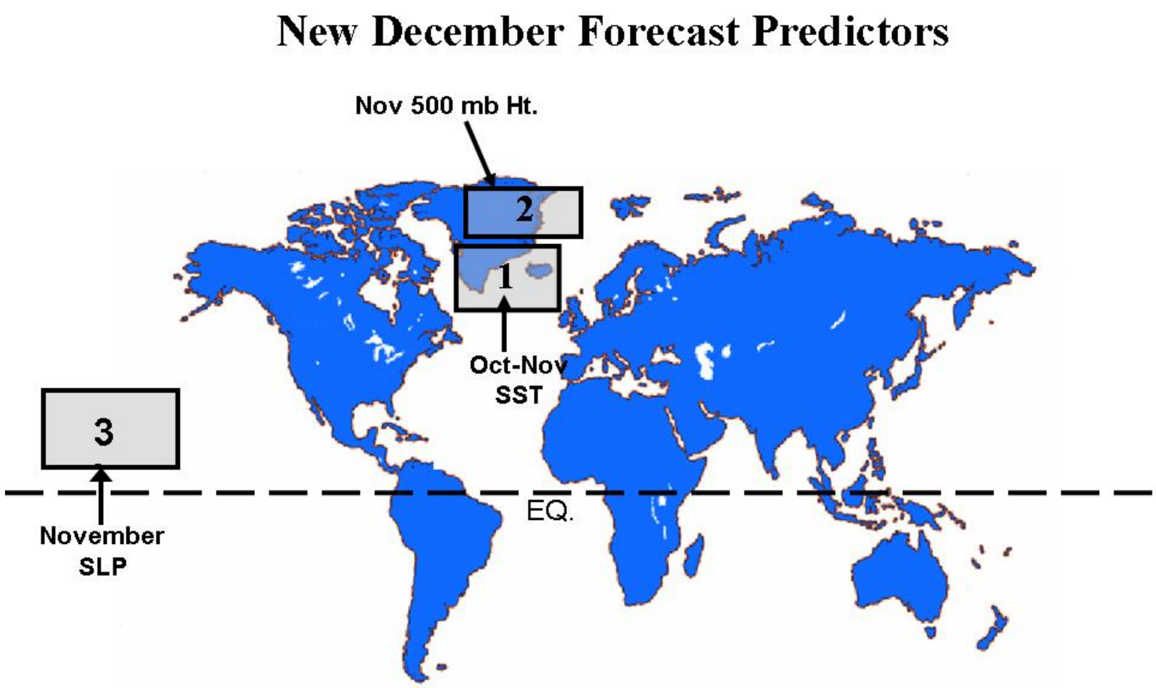

Figure 1: Location of predictors for our December extended-range statistical prediction for the 2009 hurricane season.

Table 1: Listing of 1 December 2008 predictors using the new statistical forecast for the 2009 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2008 Values for 2009 Forecast
1) October-November SST (55-65°N, 10-60°W) (+)	+0.7 SD
2) November 500 mb geopotential height (67.5-85°N, 10°E-50°W) (+)	-0.5 SD
3) November SLP (7.5-22.5°N, 125-175°W) (+)	+1.6 SD

Table 2: Statistical forecast model output for the 2009 Atlantic hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme
Named Storms (9.6)	11.5
Named Storm Days (49.1)	60.4
Hurricanes (5.9)	7.0
Hurricane Days (24.5)	30.2
Intense Hurricanes (2.3)	3.4
Intense Hurricane Days (5.0)	8.4
Accumulated Cyclone Energy Index (96.1)	124
Net Tropical Cyclone Activity (100%)	133

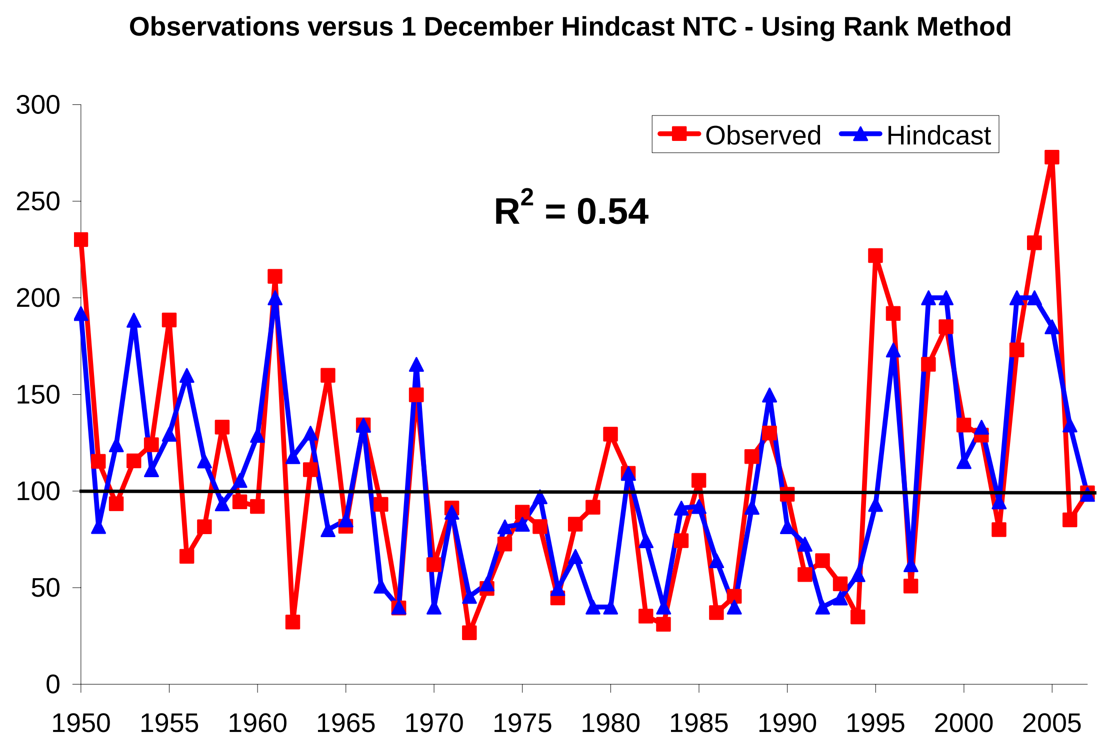

Figure 2: 1 December hindcast NTC versus observations using equations developed over the full period from 1950-2007. This hindcast scheme explains 54 percent of the variance (r = 0.73).

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).

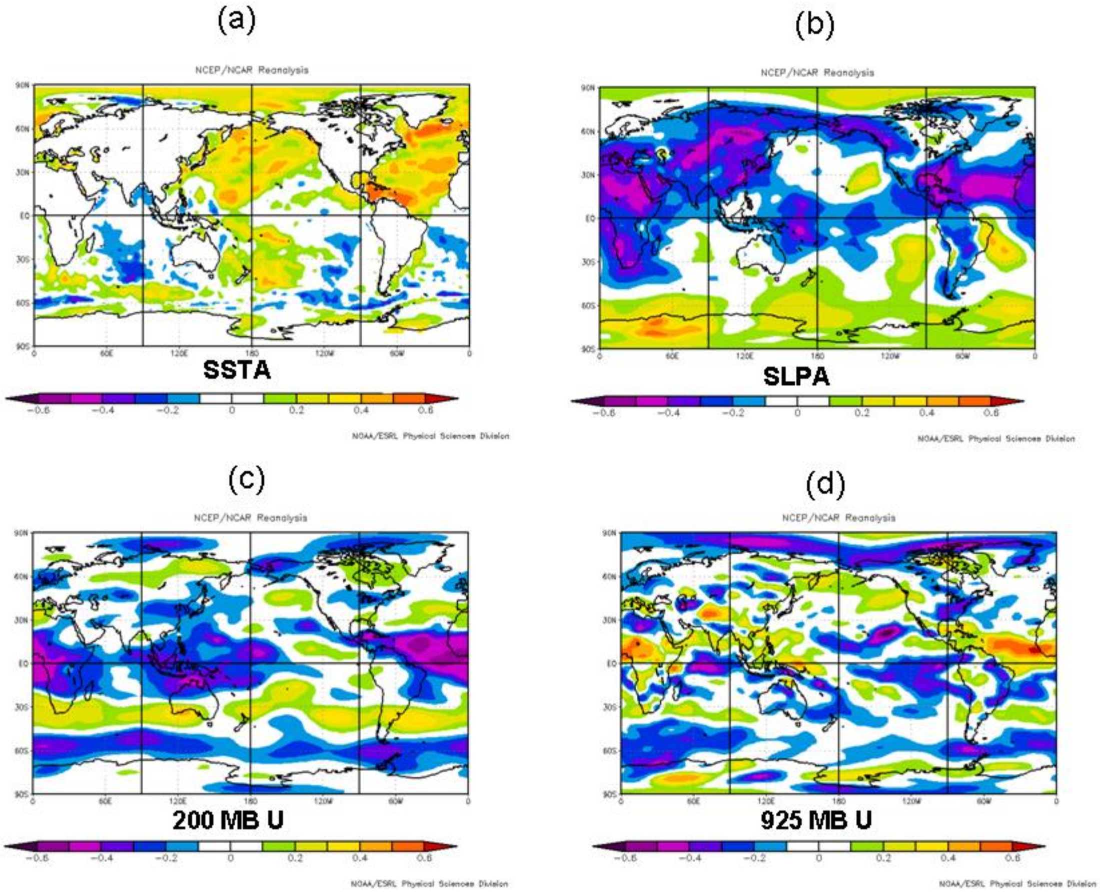

Figure 3: Linear correlations between October-November SST in the North Atlantic (Predictor 1) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 mb zonal wind (panel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

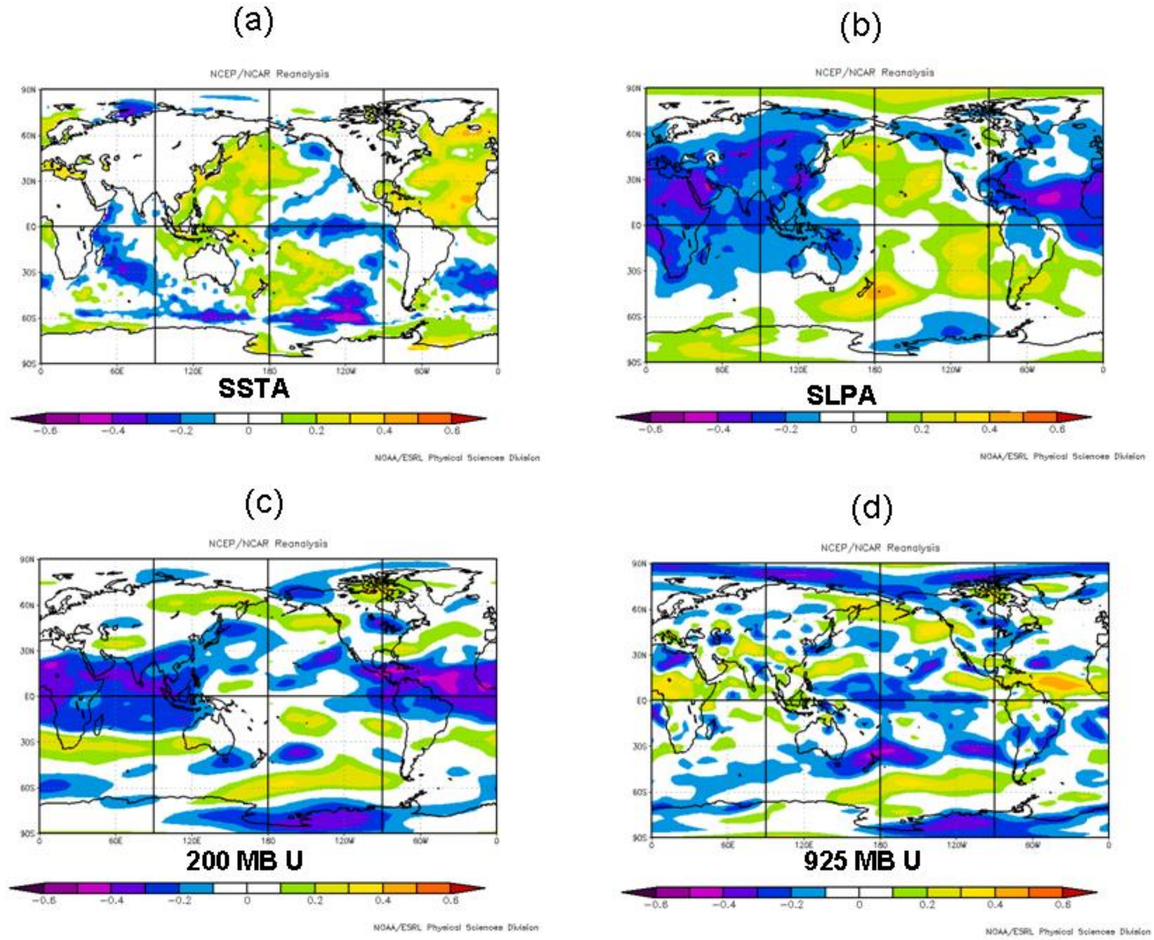

Figure 4: Linear correlations between November 500 mb geopotential heights in the far North Atlantic (Predictor 2) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925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

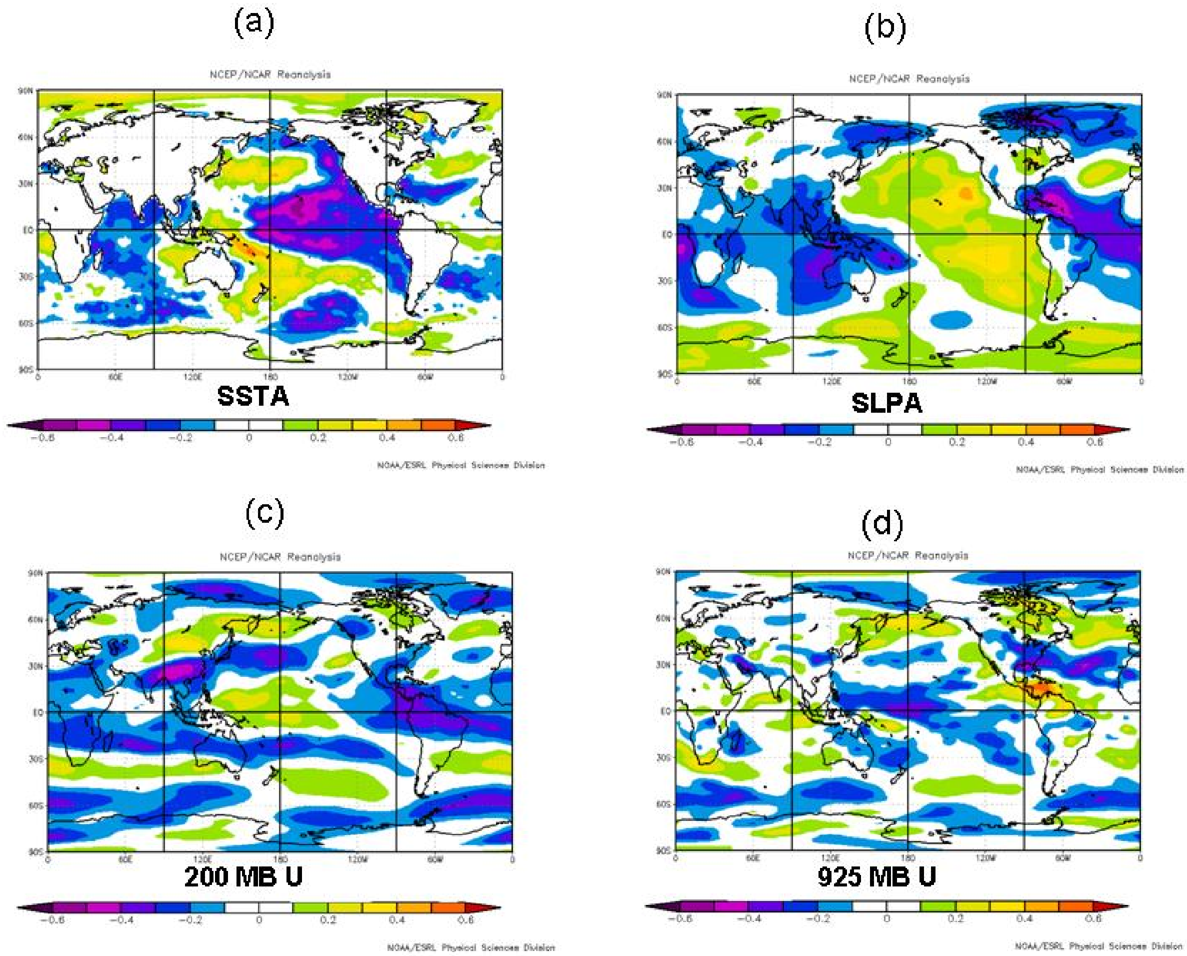

Figure 5: Linear correlations between November sea level pressure in the subtropical Northeast Pacific (Predictor 3) and the following year's August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 200 mb zonal wind (panel c) and August-October 925 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 fairly frequently regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. Obviously, our predictions are our best estimate, but certainly, there is with all forecasts an uncertainty as to how well they will verify. 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 3 provides our early December forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts over the 1990-2007 period, using equations developed over the 1950-1989 period. We typically expect to see

2/3 of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values. Note that there is a large degree of uncertainty with our early December prediction.

Table 3: Model hindcast error and our 2009 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2009 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	4.4	14	9.6 – 18.4
Named Storm Days (NSD)	23.9	70	46.1 – 93.9
Hurricanes (H)	2.5	7	4.5 – 9.5
Hurricane Days (HD)	12.4	30	17.6 – 42.4
Intense Hurricanes (IH)	1.5	3	1.5 – 4.5
Intense Hurricane Days (IHD)	4.7	7	2.3 – 11.7
Accumulated Cyclone Energy (ACE)	50	125	75 – 175
Net Tropical Cyclone (NTC) Activity	49	135	86 - 184

4 ENSO

We currently have cool neutral ENSO conditions in the tropical Pacific. Observed sea surface temperatures anomalies in the eastern and central Pacific are approximately 0.4 – 0.9°C below the long-period average. One of the important questions for the upcoming hurricane season is what ENSO will look like during the 2009 Atlantic hurricane season. Following last winter’s La Niña event, ENSO conditions transitioned to neutral during the 2008 hurricane season. Associated with this warming was a depletion of the anomalous warm pool that built up in the western Pacific during the early months of this year. Table 4 displays equatorial upper ocean heat content for three areas in November 2007, June 2008 and November 2008. Note how there was a considerable buildup in upper ocean heat content from November 2007 to June 2008, and since that time period, there has been considerable cooling. At this time, conditions favor additional cooling, with anomalously strong trade winds and a positive Southern Oscillation Index.

There is obviously a considerable amount of uncertainty as to whether these cooling trends in the Pacific will continue. Most statistical and dynamical forecast models indicate that neutral or cool ENSO conditions will continue for the next few months (Figure 6). We will certainly be closely monitoring ENSO conditions over the winter months and will have a lot more to say with our early April update.

Table 4: Equatorial upper-ocean (top 300 meters) heat content anomalies in November 2007, June 2008 and November 2008, respectively for 130°E-80°W, 160°E-80°W and 180°-100°W, respectively.

Year	130°E-80°W	160°E-80°W	180°-100°W
November 2007 Anomaly (°C)	-0.5	-1.0	-1.2
June 2008 Anomaly (°C)	+0.7	+0.6	+0.4
November 2008 Anomaly (°C)	-0.4	-0.6	-0.8

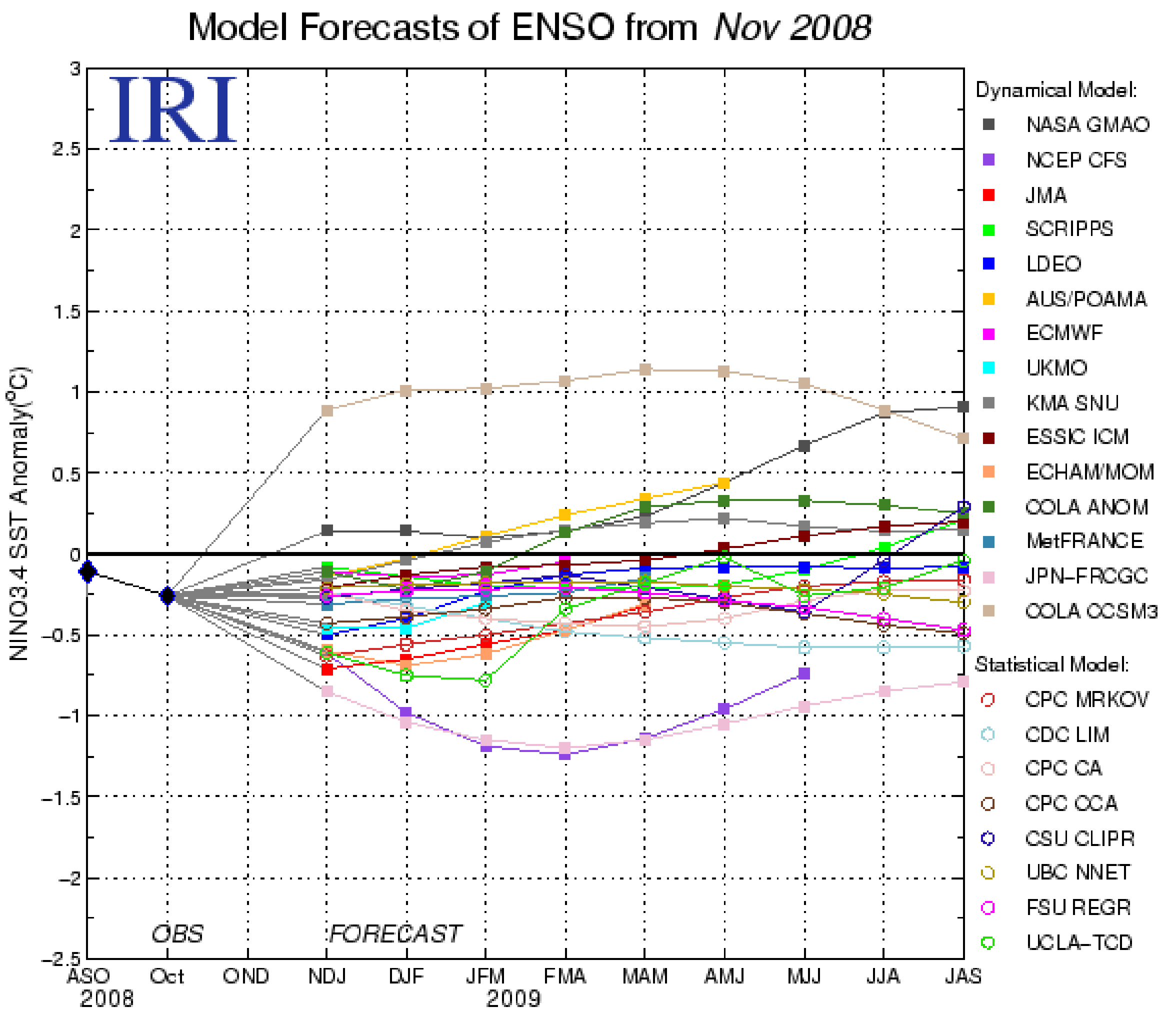

Figure 6: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

5 Adjusted 2009 Forecast

Table 5 shows our final adjusted early December forecast for the 2009 season which is a combination of our statistical scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. We foresee a somewhat above-average Atlantic basin hurricane season. We do not anticipate an El Niño event for the 2009 hurricane season. We are not including an analogue section process for the early December forecast this year, as we are not convinced of the utility of selecting analogues for the hurricane season this far in advance. We will be including analogues with our April forecast.

Warm sea surface temperatures are likely to continue being present in the tropical and North Atlantic during 2009, 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 5: Summary of our early December statistical forecast and our adjusted final forecast for the 2009 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Adjusted Final Forecast
Named Storms (9.6)	11.5	14
Named Storm Days (49.1)	60.4	70
Hurricanes (5.9)	7.0	7
Hurricane Days (24.5)	30.2	30
Intense Hurricanes (2.3)	3.4	3
Intense Hurricane Days (5.0)	8.4	7
Accumulated Cyclone Energy Index (96.1)	124	125
Net Tropical Cyclone Activity (100%)	133	135

6 Landfall Probabilities for 2009

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

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 6). 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 6: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 IH, and 5 IHD would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

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

Table 7 lists strike probabilities for the 2009 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. The mean annual probability of one or more landfalling systems is given in parentheses. Note that Atlantic basin NTC activity in 2009 is expected to be above its long-term average of 100, and therefore, United States landfall probabilities are above average.

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

Table 7: Estimated probability (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (region 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2009. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Coastal Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	88% (79%)	78% (68%)	63% (52%)	92% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	70% (59%)	52% (42%)	38% (30%)	71% (60%)	91% (83%)
Florida plus East Coast (Regions 5-11)	61% (50%)	54% (44%)	39% (31%)	72% (61%)	89% (81%)

7 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 this year.

The global warming arguments have been given much attention by many media references to recent papers claiming to show such a linkage. Despite the global warming of the sea surface that has taken place over the last three decades, the global numbers of hurricanes and their intensity have not shown increases in recent years except for the Atlantic (Klotzbach 2006).

The Atlantic has seen a very large increase in major hurricanes during the 14-year period of 1995-2008 (average 3.9 per year) in comparison to the prior 25-year period of 1970-1994 (average 1.5 per year). This large increase in Atlantic major hurricanes is primarily a result of the multi-decadal increase in the Atlantic Ocean thermohaline circulation (THC) that is not directly related to global sea surface temperatures or CO_2 increases. Changes in ocean salinity are believed to be the driving mechanism. These multi-decadal changes have also been termed the Atlantic Multidecadal Oscillation (AMO).

Although global surface temperatures have increased over the last century and over the last 30 years, there is no reliable data available to indicate increased hurricane frequency or intensity in any of the globe's other tropical cyclone basins.

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the sea surface temperatures. Vertical lapse rates will not be significantly altered. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will change significantly if global ocean temperatures were to continue to rise. For instance, in the quarter-century period from 1945-1969 when the globe was undergoing a weak cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period from 1970-1994 when the globe was undergoing a general warming trend, there were only 38 major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 7). Atlantic sea surface temperatures and hurricane activity do not necessarily follow global mean temperature trends.

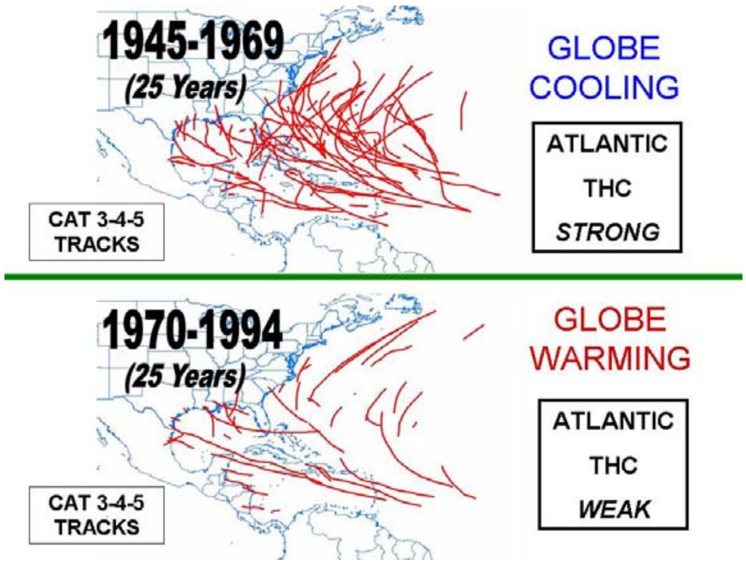

Figure 7: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was only about one-third as frequent during the latter period despite warmer global temperatures.

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 8). Although global mean ocean and Atlantic sea surface temperatures have increased by about 0.4^{o}C between these two 50-year periods (1900-1949 compared with 1959-2008), the frequency of US landfall numbers actually shows a slight downward trend for the later period. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 43-year period of 1923-1965 (24 landfall events) and the 43-year period of 1966-2008 (7 landfall events) was especially large (Figure 8). For the entire United States coastline, 38 major hurricanes made landfall during the earlier 43-year period (1923-1965) compared with only 26 for the latter 43-year period (1966-2008). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period (Figure 9). This figure illustrates that caution must be used when extrapolating trends into the future. Obviously, U.S. major hurricane landfalls will continue after 2050.

Table 8: U.S. landfalling tropical cyclones by intensity during two 50-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Intense Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1900-1949 (50 years)	189	101	39	+0.4°C
1959-2008 (50 years)	169	85	33	

We should not read too much into the two hurricane seasons of 2004-2005. The activity of these two years was unusual but well within natural bounds of hurricane variation.

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

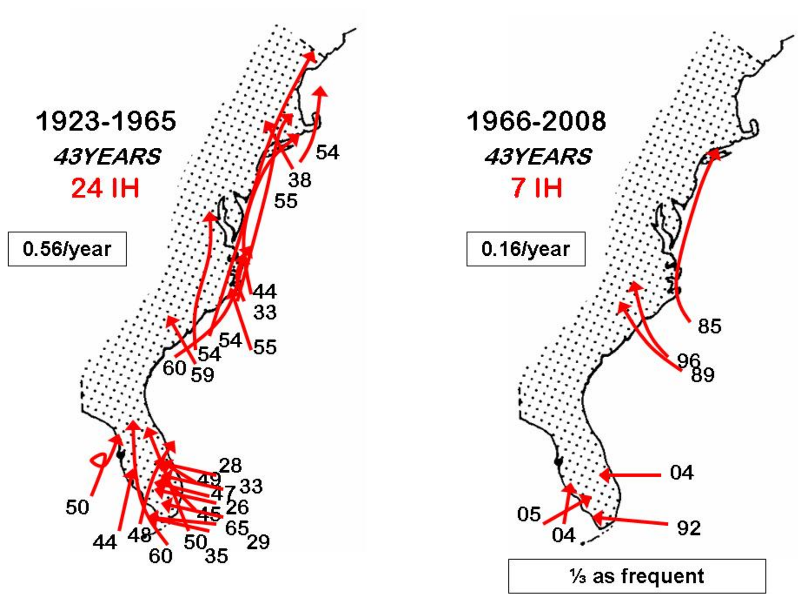

Figure 8: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 43-year period of 1923-1965 versus the most recent 43-year period of 1966-2008.

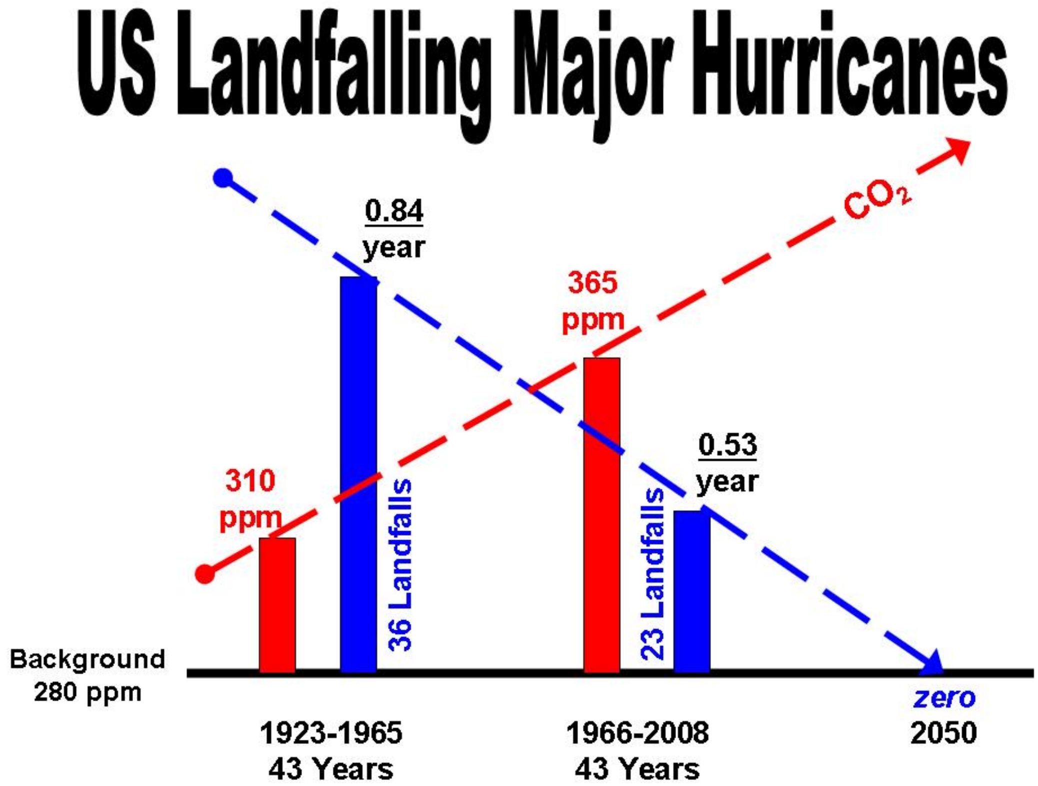

Figure 9: Portrayal of decreasing US total major hurricane landfalls over the last 43 years despite a mean rise in atmospheric CO_2. This figure illustrates that caution must be used when extrapolating trends into the future. Obviously, U.S. major hurricane landfalls will continue after 2050.

Although 2005 had a record number of tropical cyclones (28 named storms), this should not be taken as an indication of something beyond natural processes. There have been several other years with comparable hurricane activity to 2005. For instance, 1933 had 21 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 named storm had tracks west of 60°W where surface observations were more plentiful. If we eliminate all the named storms of 2005 whose tracks were entirely east of 60°W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storm total by seven (to 21) – the same number as was observed to occur in 1933.

Utilizing the National Hurricanes Center's best track database of hurricane records back to 1875, six previous seasons had more hurricane days than the 2005 season. These years were 1878, 1893, 1926, 1933, 1950 and 1995. Also, five prior seasons (1893, 1926, 1950, 1961 and 2004) had more major hurricane days. Although the 2005 hurricane season was certainly one of the most active on record, it was not as much of an outlier as many have indicated.

The active hurricane season in 2008 lends further support to the belief that the Atlantic basin remains in an active hurricane cycle associated with a strong thermohaline circulation and an active phase of the Atlantic Multidecadal Oscillation (AMO). This active cycle is expected to continue for another decade or two at which time we should enter a quieter Atlantic major hurricane period like we experienced during the quarter-century periods of 1970-1994 and 1901-1925. Atlantic hurricanes go through multi-decadal cycles. Cycles in Atlantic major hurricanes have been observationally traced back to the mid-19th century, and changes in the AMO have been inferred from Greenland paleo ice-core temperature measurements going back thousand of years.

8 Forthcoming Updated Forecasts of 2009 Hurricane Activity

We will be issuing seasonal updates of our 2009 Atlantic basin hurricane forecasts on **Tuesday April 7**, **Tuesday 2 June**, **Tuesday 4 August**, **Wednesday 2 September** and **Thursday 1 October 2009**. The 4 August, 2 September and 1 October forecasts will include separate forecasts of August-only, September-only and October-only Atlantic basin tropical cyclone activity. A verification and discussion of all 2009 forecasts will be issued in late November 2009. Our first seasonal hurricane forecast for the 2010 hurricane season will be issued in early December 2009. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

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11 Verification of Previous Forecasts

Table 9: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2003-2008.

2003	6 Dec. 2002	Update 4 April	Update 30 May	Update 6 August	Obs.
Hurricanes	8	8	8	8	7
Named Storms	12	12	14	14	14
Hurricane Days	35	35	35	25	32
Named Storm Days	65	65	70	60	71
Hurr. Destruction Potential	100	100	100	80	129
Intense Hurricanes	3	3	3	3	3
Intense Hurricane Days	8	8	8	5	17
Net Tropical Cyclone Activity	140	140	145	120	173

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

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

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

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

2008	7 Dec. 2007	Update 9 April	Update 3 June	Update 5 August	Obs.
Hurricanes	7	8	8	9	8
Named Storms	13	15	15	17	16
Hurricane Days	30	40	40	45	29.50
Named Storm Days	60	80	80	90	84.75
Intense Hurricanes	3	4	4	5	5
Intense Hurricane Days	6	9	9	11	8.50
Net Tropical Cyclone Activity	125	160	160	190	164