EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY, INDIVIDUAL MONTHLY ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITY FOR 2007

We have lowered our seasonal forecast slightly; however, we continue to call for a very active Atlantic basin hurricane season in 2007. Landfall probabilities for the United States coastline remain above their long-period averages.

(as of 3 August 2007)

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with special assistance from William Thorson[3]

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

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

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2007

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Issue Date 8 December 2006	Issue Date 3 April 2007	Issue Date 31 May 2007	Observed* Activity Through July 2007	Forecast Activity After 1 August	Total Seasonal Forecast
Named Storms (NS) (9.6)	14	17	17	2	13	15
Named Storm Days (NSD) (49.1)	70	85	85	1.25	73.75	75
Hurricanes (H) (5.9)	7	9	9	0	8	8
Hurricane Days (HD) (24.5)	35	40	40	0	35	35
Intense Hurricanes (IH) (2.3)	3	5	5	0	4	4
Intense Hurricane Days (IHD) (5.0)	8	11	11	0	10	10
Accumulated Cyclone Energy (ACE) (96.2)	130	170	170	1	149	150
Net Tropical Cyclone Activity (NTC) (100%)	140	185	185	4	156	160

*Sub-tropical storm Andrea formed off the southeast coast of the United States on May 9. Since Andrea was never classified as a tropical storm by the National Hurricane Center, it will not be counted as a named storm in our seasonal statistics.

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

1) Entire U.S. coastline - 68% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 43% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 44% (average for last century is 30%)

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

ABSTRACT

Information obtained through July 2007 continues to indicate that the 2007 Atlantic hurricane season will be more active than the average 1950-2000 season. We have reduced our forecast slightly from our early April and late May predictions. We now estimate that 2007 will have about 8 hurricanes (average is 5.9), 15 named storms (average is 9.6), 75 named storm days (average is 49.1), 35 hurricane days (average is 24.5), 4 intense (Category 3-4-5) hurricanes (average is 2.3) and 10 intense hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 130 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2007 to be about 160 percent of the long-term average.

This early August forecast is based on a newly devised extended range statistical forecast procedure which was developed on 40 years of past global reanalysis data and is then tested on an additional 15 years of global reanalysis data. In addition, this new statistical forecast procedure has shown comparable skill during the first half of the 20th century. Overall, the scheme explains over 50 percent of the variance in Net Tropical Cyclone activity from 1900-2005.

We have lowered our forecast from our early April and late May predictions due to slightly less favorable conditions in the tropical Atlantic. Sea surface temperature anomalies have cooled across the tropical Atlantic in recent weeks, and there have been several significant dust outbreaks from Africa, signifying a generally stable air mass over the tropical Atlantic. ENSO conditions have trended slightly cooler over the past few weeks. We expect either cool neutral or weak La Niña conditions to be present during the upcoming hurricane season. Our final forecast is a combination of our statistical forecast, an analog forecast technique and qualitative adjustments based upon other atmospheric and oceanic patterns that are not implicitly considered in our quantitative approaches.

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The second author gratefully acknowledges 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.

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 (since 1984) of making these forecasts, it is 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 seven 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 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. I expect he will make many new forecast innovations and skill improvements in the coming years. He was recently awarded his Ph.D. degree.

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.

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

Named Storm Day – (NSD) As in HD but for four 6-hour periods during which a 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 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 24th 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 statistical methodologies derived from over 100 years of past data and a separate study of analog years which have similar precursor circulation features to the current season. 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.

A variety of atmosphere-ocean conditions interact with each other to cause year-to-year and month-to-month hurricane variability. The interactive physical linkages between these many physical parameters and hurricane variability are complicated and cannot be well elucidated to the satisfaction of the typical forecaster making short range (1-5 days) predictions where changes in the momentum fields are the crucial factors. Seasonal and monthly forecasts, unfortunately, must deal with the much more complicated interaction of the energy-moisture fields with the momentum fields.

We find that there is a rather high (50-60 percent) degree of year-to-year hurricane forecast potential if one combines 3-4 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 3-4) 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 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.

In a four-predictor empirical forecast model, the contribution of each predictor to the net forecast skill can only be determined by the separate elimination of each parameter from the full four predictor model while noting the hindcast skill degradation. When taken from the full set of predictors, one parameter may degrade the forecast skill by 25-30 percent, while another degrades the forecast skill by only 10-15 percent. An individual parameter that, through elimination from the forecast, degrades a forecast by as much as 25-30 percent may, in fact, by itself, show much less direct correlation with the predictand. A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 3-4 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. It follows that any seasonal or climate forecast scheme showing significant hindcast skill must be empirically derived. No one can completely understand the full complexity of the atmosphere-ocean system or develop a reliable scheme for forecasting the myriad non-linear interactions in the full-ocean-atmosphere system.

2 Newly-Developed 1 August Forecast Scheme

We have recently developed a new 1 August statistical seasonal forecast scheme for the prediction of Net Tropical Cyclone (NTC) activity. This scheme was developed on NCEP/NCAR reanalysis data from 1949-1989. It was then tested on independent data from 1990-2005 to insure that the forecast showed similar skill in this later period. As a rule, predictors were only added to the scheme if they explained an additional three percent of the variance of NTC in both the dependent period (1949-1989) and the independent period (1990-2005). The forecast scheme was also tested on independent data from 1900-1948. It also showed comparable skill during this time period. Over the 1900-1948 period, the scheme explained 51% of the variance in NTC activity, and over the more recent period from 1949-2005, the scheme explained 52% of the variance.

The pool of four predictors for this new seasonal forecast is given and defined in Table 1. The location of each of these new predictors is shown in Fig. 1. Strong statistical relationships can be extracted via combinations of these predictive parameters (which are available by the end of July), and quite skillful Atlantic basin forecasts of NTC activity for the season can be made if the atmosphere and ocean continue to behave in the future as they have during the 20th century.

Our statistical forecast for the other predictors (i.e., named storms, hurricanes) is then adjusted by the predicted statistical value of NTC. For example, if a typical season has 10 named storms and the predicted NTC value is 120%, the predicted number of named storms for the season would be 12 (10 * 120%).

August Seasonal Forecast Predictors

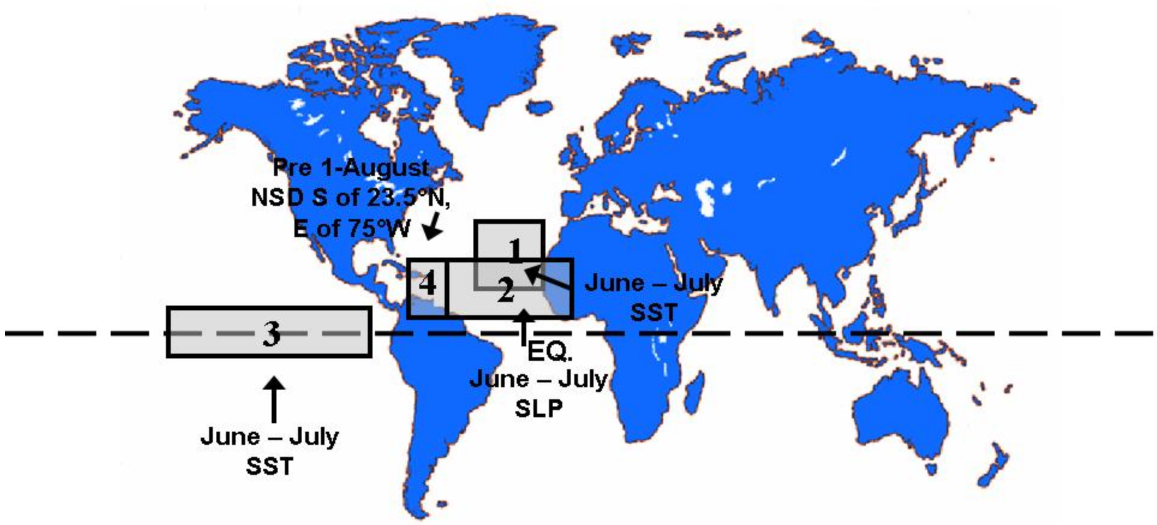

Figure 1: Location of predictors for the 1 August forecast for the 2007 hurricane season.

Table 1: Listing of 1 August 2007 predictors for this year's hurricane activity. A plus (+) means that positive deviations of the parameter indicate increased hurricane activity this year, and a minus (-) means that positive deviations of the parameter indicate decreased hurricane activity this year. The combination of these four predictors calls for about an average hurricane season.

Predictor	Values for 2007 Forecast	Effect on 2007 Hurricane Season
1) June-July SST (20-40°N, 15-35°W) (+)	-0.4 SD	Suppress
2) June-July SLP (10-25°N, 10-60°W) (-)	-0.5 SD	**Enhance**
3) June-July SST (5°S-5°N, 90-150°W) (-)	-0.8 SD	**Enhance**
4) Pre-1 August Named Storm Days – South of 23.5°N, East of 75°W	0	Suppress

Table 2 shows our statistical forecast for the 2007 hurricane season and the comparison of this forecast with climatology (average season between 1950-2000). Our statistical forecast is calling for about average activity this year, which adds additional support for the reduction of our forecast from our early April and late May predictions. However, we still believe that the 2007 season will be much more active than the average 1950-2000 season.

Table 2: Post-1 August statistical forecast for 2007.

Predictands and Climatology (1950-2000 Post-1 August Average)	Statistical Forecast Numbers
Named Storms (NS) – 8.4	9.6
Named Storm Days (NSD) – 44.9	49.1
Hurricanes (H) – 5.4	5.9
Hurricane Days (HD) – 23.4	24.5
Intense Hurricanes (IH) – 2.1	2.3
Intense Hurricane Days (IHD) – 4.9	5.0
Net Tropical Cyclone Activity (NTC) – 93	100

2.1 Physical Associations among Predictors Listed in Table 1

Brief descriptions of our 1 August predictors follow:

<u>Predictor 1. June-July SST in the Northeastern Subtropical Atlantic (+)</u>

(20°-40°N, 15-35°W)

Warm sea surface temperatures in this area in June-July correlate very strongly with anomalously warm sea surface temperatures in the tropical Atlantic throughout the upcoming hurricane season. Anomalously warm sea surface temperatures are important for development and intensification of tropical cyclones by infusing more latent heat into the system (Goldenberg and Shapiro 1998). In addition, associated with anomalously warm June-July SSTS are weaker trade winds. Weaker trade winds cause less evaporation and upwelling of the sea surface which therefore feeds back into keeping the tropical Atlantic warm. In addition, weaker trade winds imply that there is less vertical wind shear across the tropical Atlantic. Weak wind shear is favorable for tropical cyclone development and intensification (Gray 1968, Gray 1984a, Goldenberg and Shapiro 1996, Knaff et al. 2004). Lastly, there is a strong positive correlation (~0.5) between anomalously warm June-July SSTs in the subtropical northeastern Atlantic and low sea level pressures in the tropical Atlantic and Caribbean during the heart of the hurricane season. Low sea level pressures imply decreased subsidence and enhanced mid-level moisture. Both of these conditions are favorable for tropical cyclogenesis and intensification (Knaff 1997).

<u>Predictor 2. June-July SLP in the Tropical Atlantic (-)</u>

(10-25°N, 10-60°W)

Low sea level pressure in the tropical Atlantic in June-July implies that early summer conditions in the tropical Atlantic are favorable for an active tropical cyclone season with increased vertical motion, decreased stability and enhanced mid-level moisture. There is a strong auto-correlation ($r > 0.5$) between June-July sea level pressure anomalies and August-October sea level pressure anomalies in the tropical Atlantic. Low sea level pressure in the tropical Atlantic also correlates quite strongly ($r > 0.5$) with reduced trade winds (weaker easterlies) and anomalous easterly upper-level winds (weaker westerlies). The combination of these two features implies weaker vertical wind shear and therefore more favorable conditions for tropical cyclone development in the Atlantic (Gray 1968, Gray 1984a, Goldenberg and Shapiro 1996).

Predictor 3. June-July Nino3 Index (-)

(5°S-5°N, 90-150°W)

Cool sea surface temperatures in the Nino3 region during June-July imply that a La Niña event is currently present. In general, positive or negative anomalies in the Nino3 region during the early summer persist throughout the remainder of the summer and fall. El Niño conditions shift the center of the Walker Circulation eastward which causes increased convection over the central and eastern tropical Pacific. This increased convection in the central and eastern Pacific manifests itself in anomalous upper-level westerlies across the Caribbean and tropical Atlantic, thereby increasing vertical wind shear and reducing Atlantic basin hurricane activity. The relationship between ENSO and Atlantic hurricane activity has been well-documented in the literature (e.g., Gray 1984a, Goldenberg and Shapiro 1996, Elsner 2003, Bell and Chelliah 2006).

Predictor 4. Named Storm Days South of 23.5°N, East of 75°W (+)

Most years do not have named storm formations in June and July in the tropical Atlantic; however, if deep tropical formations do occur, it indicates that a very active hurricane season is likely. For example, the six years with the most named storm days in the deep tropics in June and July (since 1949) are 1966, 1969, 1995, 1996, 1998 and 2005. All six of these seasons were very active. When storms form in the deep tropics in the early part of the hurricane season, it indicates that conditions are already very favorable for TC development. In general, the start of the hurricane season is restricted by thermodynamics (warm SSTs, unstable lapse rates), and therefore deep tropical activity early in the hurricane season implies that the thermodynamics are already quite favorable for TC development. Also, this predictor's correlation with seasonal NTC is 0.53 over the 1949-2005 period, and when tested on independent data (1900-1948), the correlation actually improves to 0.63, which gives us increased confidence in its use as a seasonal predictor.

2.2 Hindcast Skill

Table 3 shows the degree of hindcast variance (r^2) explained by our new 1 August forecast scheme based on our 41-year developmental dataset (1949-1989), our skill on the independent dataset (1990-2005), and our skill over the full 1949-2005 period. Note that the scheme generally showed improved skill in the independent dataset, which lends increased confidence in its use.

Table 3: Variance (r^2) explained for our new 1 August forecast scheme for NTC in the developmental dataset (1949-1989), in the independent dataset (1990-2005), and over the entire dataset (1949-2005).

Variable	Variance (r^2) Explained Developmental Dataset (1949-1989)	Variance (r^2) Explained Independent Dataset (1990-2005)	Variance (r^2) Explained Entire Dataset (1949-2005)
NTC	0.45	0.71	0.52

3 Predictions of Individual Monthly Atlantic TC Activity for August, September and October

A new aspect of our climate research is the development of TC activity predictions for individual months. There are often monthly periods within active and inactive Atlantic basin hurricane seasons which do not conform to the overall season. For example, 1961 was an active hurricane season (NTC of 222), but there was no TC activity during August; 1995 had 19 named storms, but only one named storm developed during a 30-day period during the peak of the hurricane season between 29 August and 27 September. By contrast, the inactive season of 1941 had only six named storms (average 9.3), but four of them developed during September. During the inactive 1968 hurricane season, three of the eight named storms formed in June (June average is 0.5).

We have conducted new research to see how well various sub-season or individual monthly trends of TC activity can be forecast. This effort has recently been documented in papers by Blake and Gray (2004) for August and Klotzbach and Gray (2003) for September. We have shown moderate skill with our final qualitative adjustments to our monthly forecasts; however, our statistical forecasts have not shown skill in real-time forecasting. We believe this is due to the schemes being considerably over-fit to the data. Because of this, we are currently in the process of redesigning our monthly statistical forecasts. Therefore, our monthly forecasts for this year are based on a combination of some new research material that we are gathering along with qualitative reasoning.

3.1 August-Only Forecast

This year's hurricane season has gotten off to a fairly slow start, due primarily to unfavorable thermodynamic conditions. Since the start of the active part of the hurricane season is governed primarily by thermodynamics, we believe that August will have activity at slightly above-average levels. Table 4 lists our prediction for activity during the month of August.

Table 4: August-only prediction of 2007 hurricane activity. August climatology is shown in parentheses.

Parameter	Qualitative Adjustment
NS (2.8)	3
NSD (11.8)	14
H (1.6)	2
HD (5.7)	6
IH (0.6)	1
IHD (1.2)	1.5
NTC (26.1)	32

3.2 September-Only Forecast

Climatologically, September is the most active month of the hurricane season. We expect to see fairly low values of vertical wind shear during September, due to the potential development of a weak La Niña event. In addition, sea surface temperatures in the tropical Atlantic reach their maximum values, and surface pressures attain their lower values during September. Even if these SST values are only near normal, it is typically found that near-normal SSTs and low values of vertical wind shear lead to active Septembers. Table 5 gives our prediction for September 2007. We are forecasting an active month for September.

Table 5: September-only prediction of 2007 hurricane activity. September climatology is shown in parentheses.

Parameter	Qualitative Adjustment
NS (3.4)	5
NSD (21.7)	35
H (2.4)	4
HD (12.3)	20
IH (1.3)	2
IHD (3.0)	6.5
NTC (48.0)	80

3.3 October-November Forecast

Typically, the end of the Atlantic basin hurricane season is governed by rising values of vertical wind shear. Since we expect either cool neutral or weak La Niña conditions this year, the end of the Atlantic basin hurricane will likely be extended this year.

Therefore, we are forecasting a very active October-November compared with climatology (Table 6).

Table 6: October-November prediction of 2007 hurricane activity. October-November climatology is shown in parentheses.

Parameter	Qualitative Adjustment
NS (2.2)	5
NSD (11.5)	24.75
H (1.4)	2
HD (5.2)	9
IH (0.4)	1
IHD (0.9)	2
NTC (22.0)	42

3.4 Monthly Prediction Summary

Table 7 summarizes our individual monthly predictions. The summation of our forecasts for August, September, and October-November add up to our rest-of-the-season prediction.

Table 7: August, September and October-November 2007 individual predictions.

Forecast Parameter	Observed June-July Activity	August Forecast	September Forecast	October-November Forecast	Aug-Sep-Oct-Nov Forecast Sum	Total Season Forecast
NS	2	3	5	5	13	15
NSD	1.25	14	35	24.75	73.75	75
H	0	2	4	2	8	8
HD	0	6	20	9	35	35
IH	0	1	2	1	4	4
IHD	0	1.5	6.5	2	10	10
NTC	4	32	82	42	156	160

4 Analog-Based Predictors for 2007 Hurricane Activity

4.1 Analog Years

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2007. These years also provide useful clues as to trends in activity that the upcoming 2007 hurricane season may bring. For this early August forecast, we project atmospheric and oceanic conditions for August through October 2007 and determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current June-July 2007 conditions. Table 8 lists our analog selections.

We select prior hurricane seasons since 1949 which have similar atmospheric-oceanic conditions to those currently being experienced. Analog years for 2007 were selected primarily on how similar they are to conditions that are currently observed such as slightly above-average tropical and North Atlantic sea surface temperatures and cool ENSO conditions.

There were five hurricane seasons since 1949 with characteristics similar to what we observed in June-July and what we project for August-October. The best analog years that we could find for the 2007 hurricane season are 1954, 1961, 1964, 1967 and 1996. We anticipate that 2007 will have comparable seasonal hurricane activity to what was experienced in the average of these five years. We believe that the 2007 Atlantic basin hurricane season will be somewhat above average.

Table 8: Best analog years for 2007 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1954	11	51.75	8	31.50	2	9.50	95	127
1961	11	70.75	8	47.50	7	24.50	205	230
1964	12	71.25	6	43.00	6	14.75	170	184
1967	8	58.00	6	36.25	1	5.75	121	102
1996	13	79.00	9	45.00	6	13.00	166	192
Mean	11.0	66.20	7.4	40.7	4.4	13.50	151	167
2007 Forecast	15	75	8	35	4	10	150	160

4.2 Analog Period

After extensive evaluation of the data, we believe that the 2007 season will have activity very similar to what was experienced during the average of six years from the 1995-2006 period. The 2007 season is likely not going to be a hyper-active hurricane season, so when computing our average for the period, we leave out the hyper-active years of 1995, 2004 and 2005. Also, since 2007 is not going to be an El Niño year, we have left out the 1997, 2002 and 2006 seasons. Therefore we believe that 2007 will have activity similar to what was experienced over the average of the recent six seasons of 1996, 1998-2001, and 2003. Table 9 displays the activity for these six years compared with our prediction for the 2007 hurricane season.

Table 9: Best analog period for 2007 compared with the 2007 seasonal forecast.

Years	NS	NSD	H	HD	IH	IHD	ACE	NTC
1996	13	79.00	9	45.00	6	13.00	166	192
1998	14	88.00	10	48.50	3	9.50	182	169
1999	12	78.50	8	41.00	5	14.25	177	182
2000	14	67.00	8	32.75	3	5.00	116	130
2001	15	64.25	9	25.50	4	4.25	106	134
2003	16	79.25	7	32.75	3	16.75	175	174
Mean	14.0	76.0	8.5	37.6	4.0	10.5	154	164
2007 Forecast	15	75	8	35	4	10	150	160

5 Comparison of Forecast Techniques

Table 10 provides a comparison of our statistical and analog forecast techniques along with the final adjusted forecast and climatology. Column 1 gives activity prior to 1 August. Column 2 gives the analog forecast based on annual analogs. Column 3 is our analog forecast based on the six years selected from the 1995-2006 period. Column 4 is our final after-1 August forecast, column 5 is the total season adjusted forecast, and column 6 is the 1950-2000 climatology.

Table 10: Comparison of our post-1 August 2007 statistical and analog forecast techniques along with our final adjusted forecast and the 1950-2000 climatology.

Forecast Parameter	(1) Pre-1 Aug Activity	(2) Total Season Analog Year Forecast	(3) Total Recent Seasons Analog Period Forecast	(4) After-1 Aug Adjusted Final Forecast	(5) Total Season Adjusted Forecast	(6) 1950-2000 Climatology
NS	2	11.0	14	13	15	9.6
NSD	1.25	66.2	76.0	73.75	75	49.1
H	0	7.4	8.5	8	8	5.9
HD	0	40.7	37.6	35	35	24.5
IH	0	4.4	4.0	4	4	2.3
IHD	0	13.5	10.5	10	10	5.0
NTC	4	167	164	156	160	100

6 Discussion

6.1 West Africa Conditions

After putting less emphasis on conditions in West Africa over the past few years due to a failure of the African rainfall/Atlantic hurricane relationship, we have decided to take a further look at conditions over West Africa this year. We believe that a portion of the recent failure of this relationship is due to measurement quality and other errors over this portion of the globe. With the development of various satellite data products, we can now obtain more accurate and consistent measurements of currently-observed conditions.

There were considerable excursions of dry air/dust over the tropical Atlantic during August of last year, and these conditions may have been partly responsible for the inactive early portion of last season's hurricane activity. Amato Evan and colleagues at the University of Wisconsin-Madison/Cooperative Institute for Meteorological Satellite Studies (CIMSS) have developed a dataset of Saharan dust loadings from 1982-present (Evan et al. 2006). When dust loadings are greater than normal, it results in cooler tropical Atlantic sea surface temperatures due to less solar radiation reaching the surface. In addition, heightened Saharan dust concentrations imply increased stability and higher surface pressures, both of which are unfavorable for tropical cyclogenesis and intensification. Cooler SSTs associated with enhanced June-July Saharan dust loadings tend to persist for the following few months and appear to cause a damping influence on the season's hurricane activity.

Over the time period from 1982-2006, June-July Saharan dust loadings correlate at approximately 0.8 with dust loadings during August-September, implying a strong persistence between conditions during both time periods. June-July dust also correlates at -0.49 with Net Tropical Cyclone (NTC) activity during the upcoming hurricane season, implying that June-July dust is an additional factor that should be considered when issuing seasonal hurricane forecasts.

A preliminary estimate of June-July 2007 Saharan dust loadings, provided by Amato Evan and colleagues from CIMSS, calculates that fairly high levels of dust have been present over the tropical Atlantic during these two months. As previously discussed, higher concentrations of Saharan dust tend to imply drier air masses and cooler sea surface temperatures in the tropical Atlantic. Both of these conditions have been observed over the past two months. The less favorable thermodynamic conditions observed over the tropical Atlantic in June-July is the primary reason why we are slightly lowering our forecast for the 2007 season.

6.2 ENSO

ENSO conditions have cooled slightly over the past two months. SST anomalies moderated somewhat during June, likely associated with a slackening of equatorial Pacific trade winds. Over the past few weeks, SST anomalies have begun decreasing again. It now appears that cool neutral or weak La Niña conditions will be present during the August-October period. Currently observed SST anomalies in the various Nino regions range from approximately +0.4°C in the Nino 4 region (5°S-5°N, 160°E-150°W) to approximately -1.2°C in the Nino 1+2 regions (10°S-0°, 80-90°W), indicating that we currently have ENSO-neutral conditions in the tropical Pacific. Table 11 shows the June-July SST anomalies compared with the April-May SST anomalies in various Nino regions.

Table 11: June-July SST anomaly compared with April-May SST anomaly in various Nino regions.

Year	April-May Anomaly (°C)	June-July Anomaly (°C)	(June-July) – (Apr-May)
Nino 1+2	-1.2	-1.5	-0.3
Nino 3	-0.4	-0.7	-0.3
Nino 3.4	-0.1	-0.1	0.0
Nino 4	0.2	0.3	+0.1

All ENSO forecast models indicate that neutral or cool ENSO conditions are likely for this upcoming summer/fall. Based on the latest prediction plume figure from the International Research Institute (IRI) (Figure 2), no models are calling for El Niño conditions (SST anomaly greater than 0.5°C) in the Nino 3.4 region (5°S-5°N, 120-170°W) during the August-October period. The forecast models are basically split between weakly cool and La Niña conditions (SST anomaly less than -0.5°C).

Based on the latest ENSO predictions, as well as currently observed conditions in the tropical Pacific, we expect cool neutral or weak La Niña conditions to be in place in the tropical Pacific during the upcoming hurricane season.

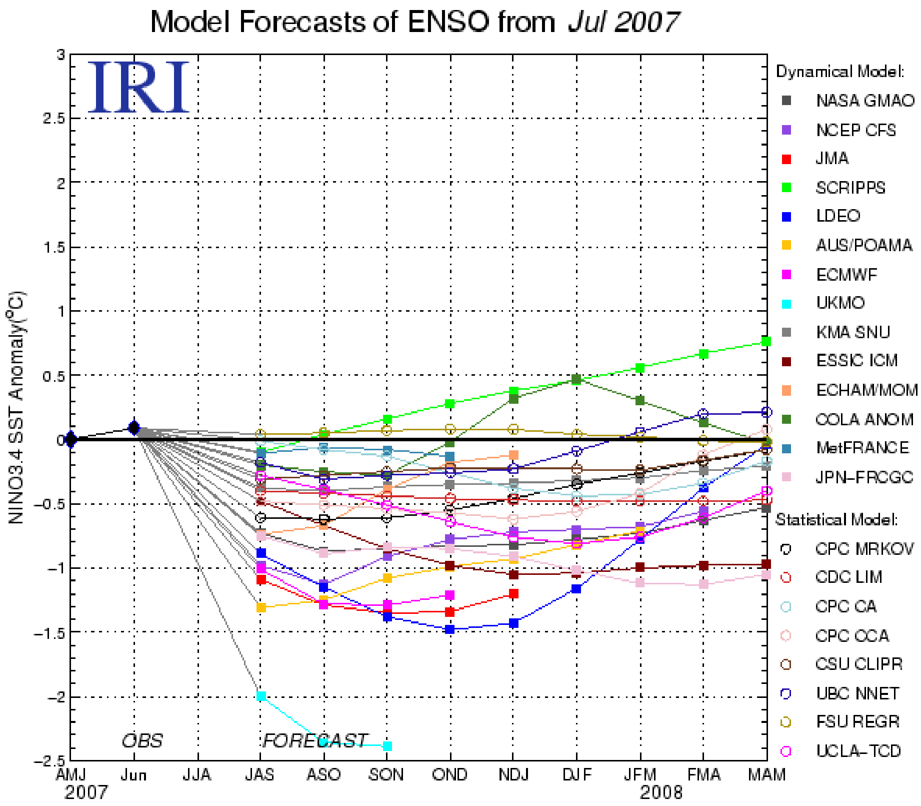

Figure 2: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

7 Post 1-August Landfall Probabilities for 2007

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 12). Upon further study, as first mentioned in our early August forecast in 2006, SSTA* does not appear to add additional skill to landfall probabilities beyond that provided by NTC, and therefore, we are now basing our landfall probabilities on predicted NTC only.

In our early August prediction that we issued last year, we attempted to make some analysis of steering current patterns to determine which portions of the United States coastline were more likely to be affected by tropical cyclones. However, we believe that much further analysis is needed to better understand these steering current patterns, and therefore, our probabilities this year will simply be adjusted based upon our latest NTC prediction.

As shown in Table 12, 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 12: 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 13 lists strike probabilities for the 2007 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 2007 is expected to be well above its long-term average of 100, and therefore, United States landfall probabilities are well above average.

Please visit our website at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions, 55 subregions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine.

Table 13: Estimated probability (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2007. The long-term mean annual probability of one or more landfalling systems during the 20th century 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)	92% (79%)	83% (68%)	68% (52%)	95% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	75% (59%)	58% (42%)	43% (30%)	76% (60%)	94% (83%)
Florida plus East Coast (Regions 5-11)	67% (50%)	60% (44%)	44% (31%)	78% (61%)	93% (81%)

We were quite fortunate last year in that we had no hurricane landfalls. The 2006 season was only the 12th year since 1945 that we had witnessed no hurricane landfalls along the United States coastline. Since 1945, we have had only two consecutive-year periods when there were no hurricane landfalls. The two consecutive seasons of 1981-1982 and 2000-2001 had no hurricane landfalls. The dearth of landfalls in 2000 and 2001 was especially impressive considering that both of these seasons had above-average hurricane activity. From Hurricane Irene in October 1999 to Hurricane Lili in September 2002, 21 consecutive hurricanes developed in the Atlantic basin without a single U.S. landfall.

8 Is Global Warming Responsible for the Large Upswing in 2004-2005 U.S. Hurricane Landfalls?

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Florida 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.

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 3 decades, the global numbers of hurricanes and their intensity have not shown increases in recent years except for the Atlantic (Klotzbach 2006), where recent hurricane increases are likely a result of naturally occurring multi-decadal Atlantic Ocean circulation variations.

The Atlantic has seen a very large increase in major hurricanes during the 12-year period of 1995-2006 (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 temperature increase or to human-induced greenhouse gas 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).

There have been similar past periods (1940s-1950s) when the Atlantic was just as active as in recent years. For instance, when we compare Atlantic basin hurricane numbers over the 15-year period (1990-2004) with an earlier 15-year period (1950-1964), we see no difference in hurricane frequency or intensity even though the global surface temperatures were cooler and there was a general global cooling during 1950-1964 as compared with global warming during 1990-2004.

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 seven tropical cyclone basins, except for the Atlantic over the past twelve years. Meteorologists who study tropical cyclones have no valid physical theory as to why hurricane frequency or intensity would necessarily be altered significantly by small amounts ($< \pm 0.5^{o}C$) of global mean temperature change.

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 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 of 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) in the Atlantic basin. Atlantic sea-surface temperatures and hurricane activity do not necessarily follow global mean temperature trends.

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 14). Although global mean ocean and Atlantic surface temperatures have increased by about $0.4^{o}C$ between these two 50-year periods (1900-1949 compared with 1957-2006), the frequency of US landfall numbers actually shows a slight downward trend for the later period. If we chose to make a similar comparison between US landfall from the earlier 30-year period of 1900-1929 when global mean surface temperatures were estimated to be about $0.5^{o}C$ colder than they were during the 30-year period from 1976-2005, we find exactly the same US hurricane landfall numbers (54 to 54) and major hurricane landfall numbers (21 to 21).

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

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

Table 14: U.S. landfalling tropical cyclones by intensity during two 50-year periods.

<table>
<tr><th>YEARS</th><th>Named Storms</th><th>Hurricanes</th><th>Intense Hurricanes (Cat 3-4-5)</th><th>Global Temperature Increase</th></tr>
<tr><td>1900-1949
(50 years)</td><td>189</td><td>101</td><td>39</td><td rowspan="2">0.4°C</td></tr>
<tr><td>1956-2005
(50 years)</td><td>165</td><td>83</td><td>34</td></tr>
</table>

Although 2005 had a record number of tropical cyclones (27 named storms, 15 hurricanes and 7 major hurricanes), this should not be taken as an indication of something beyond natural processes. There have been several other years with comparable hurricane activity to 2005. For instance, 1933 had 21 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 named storm had tracks west of 60^{o}W where surface observations were more plentiful. If we eliminate all the named storms of 2005 whose tracks were entirely east of 60^{o}W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storms by seven (to 20) – about 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. Finally, five previous seasons (1893, 1926, 1950, 1961 and 2004) had greater Hurricane Destruction Potential (HDP) values than 2005. HDP is the sum of the squares of all hurricane-force maximum winds and provides a cumulative measure of the net wind force generated by a season's hurricanes. Although the 2005 hurricane season was certainly one of the most active on record, it is not as much of an outlier as many have indicated.

Despite a fairly inactive 2006 hurricane season, we believe that the Atlantic basin is currently 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 thousands of years.

9 Forecast Theory and Cautionary Note

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. It is important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. The probability of landfall for any one location along the coast is very low and reflects the fact that, in any one season, most U.S. coastal areas will not feel the effects of a hurricane no matter how active the individual season is. However, it must also be emphasized that a low landfall probability does not insure that hurricanes will not come ashore. Regardless of how active the 2007 hurricane season is, a finite probability always exists that one or more hurricanes may strike along the U.S. coastline or in the Caribbean Basin and do much damage.

10 Forthcoming Updated Forecasts of 2007 Hurricane Activity

We will be issuing updates of our 2007 Atlantic basin hurricane forecasts on **Tuesday 4 September** and **Tuesday 2 October 2007**. The 4 September and 2 October forecasts will include separate forecasts of September-only and October-only Atlantic basin tropical cyclone activity. A verification and discussion of all 2007 forecasts will be issued in late November 2007. Our first seasonal hurricane forecast for the 2008 hurricane season will be issued in early December 2007. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/.

11 Acknowledgments

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13 Verification of Previous Forecasts

Table 15: Verification of the authors' early August forecasts of Atlantic named storms and hurricanes between 1984-2006. Observations only include storms that formed after 1 August. Note that these early August forecasts have either exactly verified or forecasted the correct deviation from climatology in 21 of 23 years for named storms and 17 of 23 years for hurricanes. If we predict an above- or below-average season, it tends to be above or below average, even if our exact forecast numbers did not verify.

Year	Predicted NS	Observed NS	Predicted H	Observed H
1984	10	12	7	5
1985	10	9	7	6
1986	7	4	4	3
1987	7	7	4	3
1988	11	12	7	5
1989	9	8	4	7
1990	11	12	6	7
1991	7	7	3	4
1992	8	6	4	4
1993	10	7	6	4
1994	7	6	4	3
1995	16	14	9	10
1996	11	10	7	7
1997	11	3	6	1
1998	10	13	6	10
1999	14	11	9	8
2000	11	14	7	8
2001	12	14	7	9
2002	9	11	4	4
2003	14	12	8	5
2004	13	14	7	9
2005	13	20	8	12
2006	13	7	7	5
Average	**10.6**	**10.1**	**6.1**	**6.0**
1984-2006 Correlation		**0.61**		**0.60**

Table 16: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2001-2006.

2001	7 Dec. 2000	Update 6 April	Update 7 June	Update 7 August	Obs.
No. of Hurricanes	5	6	7	7	9
No. of Named Storms	9	10	12	12	15
No. of Hurricane Days	20	25	30	30	26
No. of Named Storm Days	45	50	60	60	64
Hurr. Destruction Potential	65	65	75	75	71
Intense Hurricanes	2	2	3	3	4
Intense Hurricane Days	4	4	5	5	4.25
Net Tropical Cyclone Activity	90	100	120	120	134

2002	7 Dec. 2001	Update 5 April	Update 31 May	Update 7 August	Update 2 Sept.	Obs.
No. of Hurricanes	8	7	6	4	3	4
No. of Named Storms	13	12	11	9	8	12
No. of Hurricane Days	35	30	25	12	10	11
No. of Named Storm Days	70	65	55	35	25	54
Hurr. Destruction Potential	90	85	75	35	25	31
Intense Hurricanes	4	3	2	1	1	2
Intense Hurricane Days	7	6	5	2	2	3
Net Tropical Cyclone Activity	140	125	100	60	45	82

2003	6 Dec. 2002	Update 4 April	Update 30 May	Update 6 August	Update 3 Sept.	Update 2 Oct.	Obs.
No. of Hurricanes	8	8	8	8	7	8	7
No. of Named Storms	12	12	14	14	14	14	16
No. of Hurricane Days	35	35	35	25	25	35	32
No. of Named Storm Days	65	65	70	60	55	70	79
Intense Hurricanes	3	3	3	3	3	2	3
Intense Hurricane Days	8	8	8	5	9	15	16.75
Net Tropical Cyclone Activity	140	140	145	120	130	155	174

2004	5 Dec. 2003	Update 2 April	Update 28 May	Update 6 August	Update 3 Sept.	Update 1 Oct.	Obs.
No. of Hurricanes	7	8	8	7	8	9	9
No. of Named Storms	13	14	14	13	16	15	14
No. of Hurricane Days	30	35	35	30	40	52	46
No. of Named Storm Days	55	60	60	55	70	96	90
Intense Hurricanes	3	3	3	3	5	6	6
Intense Hurricane Days	6	8	8	6	15	23	22.25
Net Tropical Cyclone Activity	125	145	145	125	185	240	229

2005	3 Dec. 2004	Update 1 April	Update 31 May	Update 5 August	Update 2 Sept.	Update 3 Oct.	Obs.
No. of Hurricanes	6	7	8	10	10	11	15
No. of Named Storms	11	13	15	20	20	20	27
No. of Hurricane Days	25	35	45	55	45	40	50
No. of Named Storm Days	55	65	75	95	95	100	129
Intense Hurricanes	3	3	4	6	6	6	7
Intense Hurricane Days	6	7	11	18	15	13	17.75
Net Tropical Cyclone Activity	115	135	170	235	220	215	277

2006	6 Dec. 2005	Update 4 April	Update 31 May	Update 3 August	Update 1 Sept.	Update 3 Oct.	Obs.
No. of Hurricanes	9	9	9	7	5	6	5
No. of Named Storms	17	17	17	15	13	11	10
No. of Hurricane Days	45	45	45	35	13	23	21
No. of Named Storm Days	85	85	85	75	50	58	53
Intense Hurricanes	5	5	5	3	2	2	2
Intense Hurricane Days	13	13	13	8	4	3	2
Net Tropical Cyclone Activity	195	195	195	140	90	95	85