SUMMARY OF 2006 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND MONTHLY FORECASTS

The 2006 Atlantic basin hurricane season had activity at slightly less than average (1950-2000) levels. This activity was much less than predicted in our seasonal forecasts.

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

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 verification.

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

Notice of Author Changes

By William Gray

The order of the authorship of these forecasts has been reversed 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 six years and has been second author on these forecasts for the last five years. 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 six years ago. 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. I plan to continue to be closely involved in the issuing of these forecasts for the next few years.

DEFINITIONS

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.

Hurricane Destruction Potential – (HDP) A measure of a hurricane's potential for wind and storm surge destruction defined as the sum of the square of a hurricane's maximum wind speed (in 10^4 $knots^2$) for each 6-hour period of its existence.

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.

MATL – Sea surface temperature anomaly in the Atlantic between 30-50°N, 10-30°W.

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.

NATL – Sea surface temperature anomaly in the Atlantic between 50-60°N, 10-50°W.

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.

ONR – Previous year October-November SLPA of subtropical Ridge in the eastern Atlantic between 20-30°W.

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.

SLPA – Sea Level Pressure Anomaly

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.

TATL – Sea surface temperature anomaly in the Atlantic between 8-22°N, 10-50°W.

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

ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2006

Forecast Parameter and 1950-2000 Climatology (in parentheses)	6 Dec 2005	Update 4 April 2006	Update 31 May 2006	Update 3 Aug 2006	Update 1 Sept 2006	Update 3 Oct 2005	Observed 2006 Total
Named Storms (NS) (9.6)	17	17	17	15	13	11	9
Named Storm Days (NSD) (49.1)	85	85	85	75	50	58	50
Hurricanes (H) (5.9)	9	9	9	7	5	6	5
Hurricane Days (HD) (24.5)	45	45	45	35	13	23	20
Intense Hurricanes (IH) (2.3)	5	5	5	3	2	2	2
Intense Hurricane Days (IHD) (5.0)	13	13	13	8	4	3	3
Net Tropical Cyclone Activity (NTC)* (100%)	195	195	195	140	90	95	85

*NTC is a combined measure of the yearly mean of six indices (NS, NSD, H, HD, IH, IHD) of hurricane activity as a percent deviation from the 1950-2000 annual average.

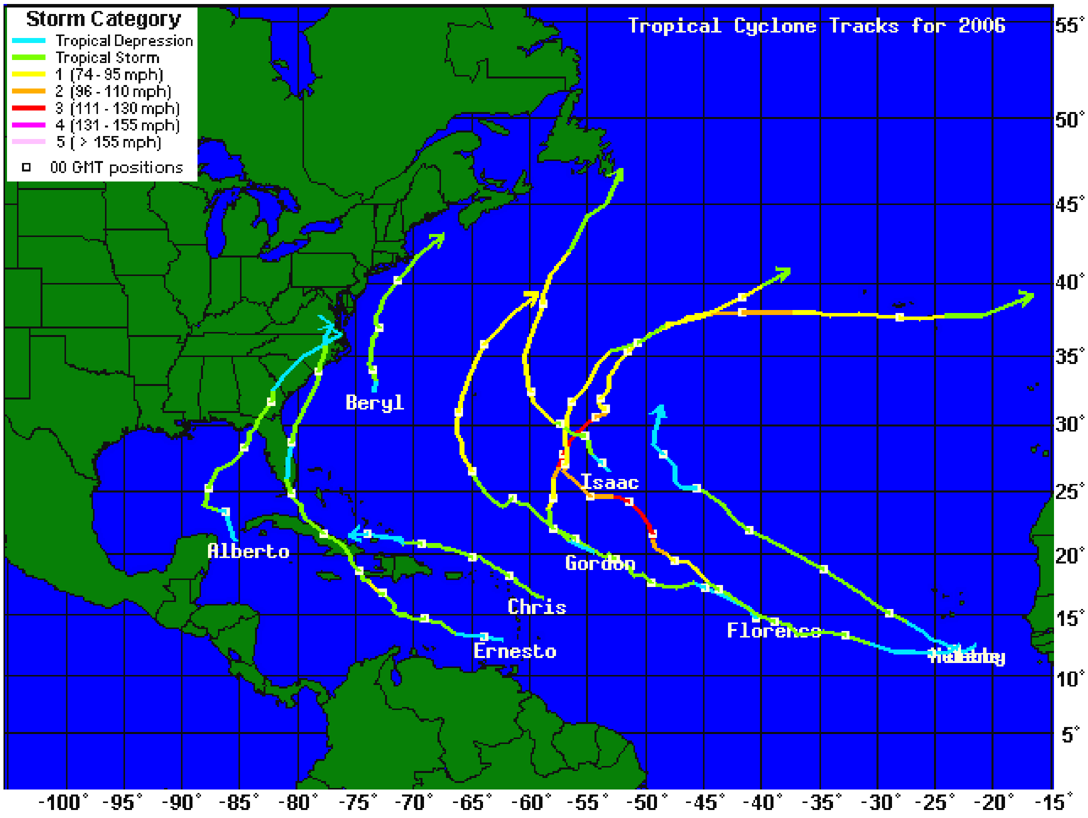

Figure courtesy of Weather Underground (http://www.weatherunderground.com)

ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2006 and verifies the authors' seasonal and monthly forecasts of this activity. A forecast was initially issued for the 2006 season on 6 December 2005 with updates on 4 April, 31 May, 3 August, 1 September and 3 October of this year. These forecasts also contained estimates of the probability of U.S. hurricane landfall during 2006. The 3 August forecast included forecasts of August-only, September-only and October-only tropical cyclone activity for 2006. Our 1 September forecast gave a seasonal summary to that date and included individual monthly predictions of September-only and October-only activity. Our 3 October forecast gave a seasonal summary to that date and included an October-November forecast. Our 2006 seasonal hurricane forecast was not successful. We anticipated a well above-average season, and the season had activity at slightly below-average levels. We did catch this downward trend beginning with our early August update We attribute a large portion of this forecast over-prediction to a late-developing El Niño and increased mid-level dryness in the tropical Atlantic.

Our August-only forecast was a bust. Our September-only forecast was quite successful, especially when evaluated against the Net Tropical Cyclone (NTC) activity metric. The October-only forecast also successfully called for activity at well below-average levels, and no tropical cyclone activity occurred after October 2. Our first forecast for the 2007 season will be issued on Friday, 8 December 2006.

1 Introduction

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 4-5 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 4-5) 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 4-5 other predictors.

In a five-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 five 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 little 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 4-5 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.

2 Tropical Cyclone Activity for 2006

Figure 1 and Table 1 summarize the Atlantic basin tropical cyclone activity which occurred in 2006. All the seasonal forecast parameters of NS, NSD, H, HD, IH, IHD and NTC were near their long-period averages. See page 4 for acronym definitions.

3 Individual 2006 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2006 season. See Fig. 1 for the tracks of these tropical cyclones, and see Table 1 for statistics of each of these tropical cyclones. Online entries from

Wikipedia (http://www.wikipedia.org) were very helpful in putting together this tropical cyclone summary.

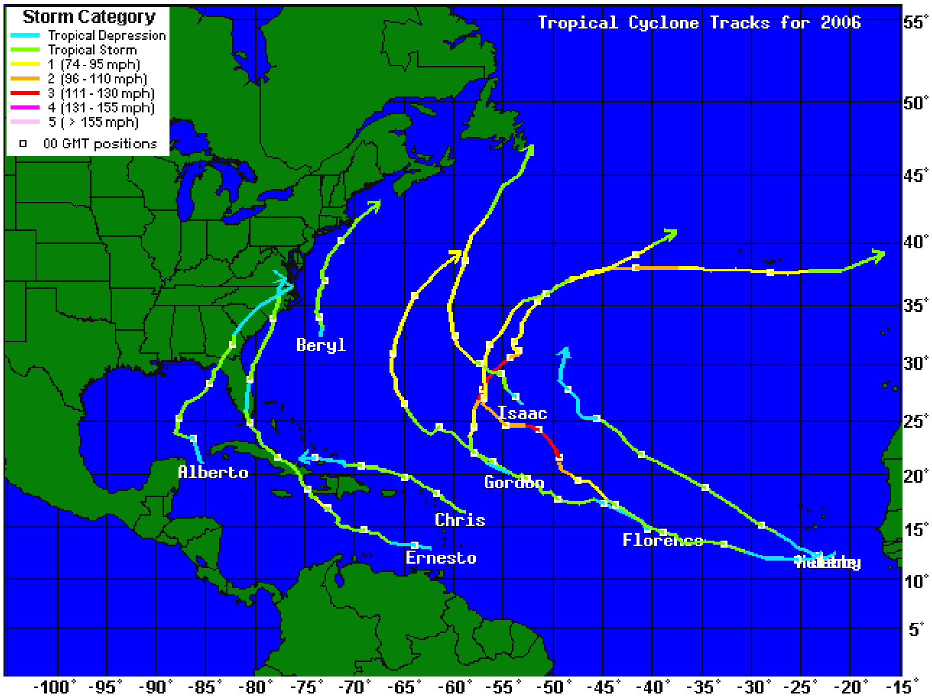

Figure 1: Tracks of 2006 Atlantic Basin tropical cyclones. Figure courtesy of Weather Underground (http://www.weatherunderground.com).

Table 1: Observed 2006 Atlantic basin tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	IHD	NTC
TS	Alberto	June 11-14	60 kt/995 mb	2.75			2.7
TS	Beryl	July 19-21	50 kt/1001 mb	2.75			2.7
TS	Chris	August 1-4	55 kt/1001 mb	3.25			2.8
TS	Debby	August 23-26	45 kt/1000 mb	3.25			2.8
H-1	Ernesto	August 25 – September 1	65 kt/988 mb	6.00	0.25		6.8
H-1	Florence	September 5-12	80 kt/972 mb	7.50	2.75		9.0
IH-3	Gordon	September 11-20	105 kt/955 mb	9.25	7.50	1.25	24.2
IH-3	Helene	September 14-24	110 kt/954 mb	10.75	7.50	1.75	26.4
H-1	Isaac	September 28-October 2	75 kt/985 mb	4.50	2.00		7.4
Totals	9			50.00	20.00	3.00	84.8

Tropical Storm Alberto: Alberto formed from an area of low pressure in the northwest Caribbean. It was upgraded to the first tropical storm of the 2006 season on June 11 based on aircraft reconnaissance measurements as well as a ship report. Alberto slowly intensified into a strong tropical storm reaching a maximum intensity of 60 knots on June 12. The system entrained dry air as it moved northeastward towards the Florida coastline and began to weaken. It weakened considerably before making landfall near Adams Beach, Florida on June 13 with maximum sustained winds at landfall estimated at 40 knots. Alberto became extratropical the following day. It was not responsible for any direct deaths, and property damage was reported to be minimal.

Tropical Storm Beryl: Beryl formed from an area of low pressure located about 250 miles southeast of the North Carolina coast on July 18. Beryl was upgraded to a tropical storm later on July 18 when aircraft reconnaissance measured 1000-foot flight level winds of 47 knots and a central pressure of 1007 mb. It tracked northward through a break in the sub-tropical ridge and intensified somewhat, reaching a maximum intensity of 50 knots on July 19. The system continued to track slowly northward and began to weaken as it moved over the cooler waters of the North Atlantic. A digging trough over the Great Lakes caused Beryl to accelerate northeastward, and it passed over Nantucket Island, MA early on July 21 with sustained winds at landfall estimated at 40 knots. It continued tracking northeastward and was declared extratropical later on July 21. Beryl was not responsible for any deaths, and it caused minimal damage.

Tropical Storm Chris: Chris formed from a tropical wave while near the Leeward Islands on July 31. It was upgraded to a tropical storm on August 1 due to its appearance in conventional and microwave satellite data. Chris tracked westward and gradually intensified due to favorable upper-tropospheric outflow channels. A ridge to the north of Chris continued to drive the system westward, and it reached its maximum intensity of 55 knots on August 2. It became rapidly disorganized early on August 3 as it encountered strong northerly shear and very dry air. It was downgraded to a tropical depression early on August 4, and it dissipated over Cuba on August 5.

Tropical Storm Debby: Debby formed from a very vigorous tropical wave that moved off the coast of Africa on August 20. It organized quite quickly and was upgraded to a tropical depression late on August 21 as it passed south of the Cape Verde Islands. Despite stable air, the system was upgraded to a tropical storm early on August 23 based on Dvorak satellite estimates as well as several Quikscat passes indicating winds of 30-35 knots near the center of the circulation. A mid-level high steered Debby towards the northwest, and it slowly intensified to its maximum intensity of 45 knots in an environment of light easterly shear. After undergoing a brief weakening trend likely due to dry air, it again strengthened to a 45-knot tropical storm. Southerly shear began to increase as the system moved northwestward, and it weakened to a minimal tropical storm on August 25 due to increasing shear as well as an environment of dry air. An upper-level low continued to impart southerly shear on Debby, and it was downgraded to a tropical depression on August 26. It dissipated later in the day on August 27.

Hurricane Ernesto: Ernesto formed from a tropical wave that was passing through the Windward Islands on August 24. It initially tracked westward due to a mid-level ridge of high pressure. Ernesto strengthened to a tropical storm the following day based on an aircraft reconnaissance report. An upper-level trough to the northwest of Ernesto imparted some southwesterly shear which prevented the system from intensify rapidly.

The shear began to weaken as the upper low moved westward, and Ernesto strengthened to a hurricane on August 27. Even though the synoptic environment became much more favorable for intensification at this time, Ernesto slowed over the southwestern part of Haiti, and this interaction with land rapidly took its toll. It was downgraded to a tropical storm later on August 27. It drifted northward towards Cuba and weakened further to a minimal tropical storm before making landfall near Playa Cazonal on August 28. Ernesto moved back over water early on August 29 and began to move northward towards the Florida Peninsula as a shortwave trough displaced the subtropical ridge that was previously positioned over the southeastern United States. Even though thermodynamics were favorable for strengthening of Ernesto over the Florida Straits, the system did not strengthen, likely due to some easterly shear. Ernesto made landfall near Plantation Key, FL early on August 30 as a minimal tropical storm. It weakened to a tropical depression while tracking northeastward over the Florida Peninsula. Once Ernesto emerged back over water off the Florida coastline, it began to intensify over the warm waters of the Gulf Stream. It reached its secondary maximum intensity of 60 knots before making its second United States landfall near Long Beach, North Carolina. Ernesto rapidly dissipated over land on September 1. Over $100 million dollars in total damage was attributed to Ernesto in the United States. Two people died in Florida in traffic accidents caused by heavy rains from Ernesto. Ernesto was also responsible for five deaths in Haiti.

Hurricane Florence: Florence formed from a tropical wave about midway between Africa and the Lesser Antilles on September 3. Southwesterly shear inhibited intensification early in Florence’s life cycle. It became the season’s sixth named tropical cyclone on September 5 due to tropical storm-strength classifications from microwave and conventional satellite imagery. It initially tracked northwestward under a subtropical ridge and strengthened slightly over the next couple of days as it continued to battle southerly shear. Florence was a rather large system and continued to fight against southerly shear as it tracked along the periphery of a subtropical ridge. This shear eventually began to relax, and Florence intensified into the second hurricane of the 2006 season on September 10. The system continued to intensify over warm sea surface temperatures as it tracked towards Bermuda. After passing by Bermuda on September 11, the system began to weaken as it encountered cooler sea surface temperatures and strong upper-level westerlies. It underwent extratropical transition on September 12. Although hurricane-force winds were felt on Bermuda from Florence, there was only minimal damage reported on the island, and no fatalities were reported.

Intense Hurricane Gordon: Gordon formed from a tropical wave early on September 11 while located northeast of the Lesser Antilles. The system was initially under significant northerly shear generated by the upper-level anticyclone surrounding Hurricane Florence. It was upgraded to the seventh tropical storm of the year later on September 11 and began to intensify further as it moved into an area of light shear and warm sea surface temperatures. It turned northward while moving through a break in the subtropical ridge and was classified as a hurricane early on September 13. The system continued to deepen on September 13 and became the first major hurricane of the year early on September 14. Gordon began to turn towards the northeast as it became embedded in the westerlies. It began to weaken later on September 14, and it was only a minimal hurricane with 65 knot winds early on September 16. At this point, steering currents collapsed, and Gordon drifted slowly northeastward across the open Atlantic. Gordon then began to defy the odds and strengthened while traveling over somewhat cooler waters. It reached a secondary peak with 90 knot winds on September 19. Gordon then turned eastward as it became completely embedded in the westerlies and tracked towards the Azores Islands. It passed over the Azores as a Category One hurricane and weakened to a tropical storm on September 20. The system became extratropical later that day. Damage in the Azores from Gordon was minimal.

Intense Hurricane Helene: Helene formed in the far eastern tropical Atlantic from a tropical wave on September 12. It initially tracked westward under the subtropical ridge. Initial intensification was inhibited by a strong mid-level jet; however, it was able to escape from the jet's influence and became classified as a tropical storm on September 14. Despite being in a low-shear environment, Helene struggled to develop further due to large amounts of dry air penetrating into the cyclonic circulation. It eventually began to enter a more favorable environment with more copious amounts of moisture. Helene became a hurricane on September 16. It began to move towards a break in the subtropical ridge and turned northwestward. At this point, Helene entered a very favorable environment for intensification with warm waters and low vertical wind shear, and it became the second major hurricane of the year on September 18. It maintained major hurricane status for the next couple of days while tracking more westward as a ridge temporarily built to the north of Helene. An upper-level trough soon broke down the ridge, and Helene began to track northward. Some dry air and increased levels of wind shear began to affect the cyclone, and it weakened to a Category 2 hurricane on September 19 and a Category 1 hurricane on September 21. By early on September 23, Helene was becoming less tropical in nature and was downgraded to a tropical storm. It was upgraded back to a hurricane later on September 23 due to satellite-measured hurricane-force winds. An upper-level trough was rapidly approaching Helene at this point, and it underwent extratropical transition on September 24.

Hurricane Isaac: Isaac developed from an area of low pressure in the central Atlantic on September 27. An upper-level low caused some southerly shear over Isaac which initially inhibited intensification. It was upgraded to a tropical storm on September 28 based on a Quikscat pass which indicated that the system had 35-knot winds. Isaac tracked northwestward as it interacted with the upper-level low and strengthened slowly while battling dry air entrainment and continued southerly shear. By later on September 29, the shear began to abate and the surrounding environment became moister, and Isaac strengthened. A strong trough began to curve Isaac more towards the north at this time. It became the fifth hurricane of the year on September 30 and reached its maximum intensity of 75 knots early on October 1. At this point, southwesterly shear and cooler sea surface temperatures began to impact Isaac, and it was downgraded to a tropical storm on October 2. Isaac began to accelerate towards the north and northeast, and it became extratropical later on October 2.

U.S. Landfall. Figure 2 shows the tracks of all 2006 tropical cyclones which impacted the United States. The U.S. was affected by three tropical storms this year: Tropical Storms Alberto, Beryl and Ernesto. Table 2 displays the estimated damage from these three storms. Alberto and Beryl did minimal damage, while Ernesto incurred approximately 100 million dollars in total damage in North Carolina and Virginia. Obviously, the damage in 2006 from tropical cyclones was very minor, especially when compared with the 50+ billion dollars in total damage incurred by the 2004 season and the 100+ billion dollars in total damage incurred by the 2005 season.

Figure 2: Tropical cyclones making U.S. landfall (TS Alberto, TS Beryl and TS Ernesto). Tropical depression strength is indicated by a dotted line while tropical storm strength is indicated by a dashed line.

Table 2: United States damage estimates for the three tropical storms that made U.S. landfall in 2006 (in millions of dollars). We assume that total damage is twice that of insured damage.

Storm Name	Insured Damage	Total Damage (Assumes Twice Insured Damage)
Alberto	Minimal	Minimal
Beryl	Minimal	Minimal
Ernesto	50	100
Total	50	100

4 Special Characteristics of the 2006 Hurricane Season

The 2006 hurricane season had the following special characteristics:

- Another early-starting season. Alberto formed on June 11. The climatological average date for the first named storm formation in the Atlantic, based on 1944-2005 data, is July 10.

- Nine named storms formed during the 2006 season. This is the fewest named storms to form in the Atlantic since 1997, when only seven named storms formed.

- Five hurricanes formed during the 2006 season. This is the fewest hurricanes to form in the Atlantic since 2002, when four hurricanes formed.

- Two major hurricanes formed during the 2006 season. 1997 was the most recent year to have fewer than two major hurricanes form (1 – Erika).

- 50 named storm days occurred in 2006. This is the lowest value of named storm days since 1997, when only 28.75 named storm days occurred.

- 20 hurricane days occurred in 2006. This is the lowest value of hurricane days since 2002, when 10.75 hurricane days were observed.

- 3 intense hurricane days occurred in 2006. This ties 2002 for the lowest value of intense hurricane days observed since 1997, when only 2.25 intense hurricane days occurred.

- Only one hurricane formed during August. This is the fewest hurricanes to form in August since 2002, when no hurricanes formed.

- September 2006’s NTC value was 66. This is the ninth straight September with NTC exceeding the climatological average of 48. The last September with below-average NTC was 1997, when only 28 NTC units were accrued.

- 18.25 hurricane days occurred in September 2006. This is more than were observed in September 2005 (16.75 hurricane days).

- No named storms formed in October. This is the first time that no named storms have formed in October since 2002. Prior to 2006, only eleven years since 1950 witnessed no named storm formations in October.

- Only two named storm days were observed in October (from Isaac which formed in late September). This is the fewest named storm days in October since 1994, when zero named storm days were observed.

- The season accumulated 85 NTC units. This is the lowest NTC value since the 2002 season which accrued 82 NTC units.

- No Category 4 or 5 hurricanes formed in the Atlantic basin this year. This is the first year with no Category 4-5 hurricanes in the Atlantic since 1997.

- Three named storms made United States landfall in 2006. This is the fewest number of named storms to make landfall in the United States since 2001 when three named storms (Allison, Barry and Gabrielle) made landfall.

- This is only the 11th year since 1945 that no hurricanes have made United States landfall.

- From Alberto-Helene, each tropical cyclone lasted as long or longer than the cyclone preceding it. For example, Alberto and Beryl lasted 2.75 named storm days, Chris and Debby lasted 3.25 named storm days, Ernesto lasted 6 named storm days, etc.

- Both Gordon and Helene accumulated 7.5 hurricane days. These two storms accrued as many hurricane days as Wilma, which was the longest-lived hurricane of the 2005 season.

5 Verification of Individual 2006 Lead Time Forecasts

Table 3 is a comparison of our 2006 forecasts for six different lead times along with this year's observations. Our seasonal forecasts for 2006 from early December 2005, early April 2006 and late May 2006 were a disappointment. We expected an active season, and the season actually had activity at slightly below-average levels. We did anticipate that these earlier seasonal forecasts were likely somewhat of an over-forecast in our early August and early September updates for the 2006 season. As we will discuss in detail later, we attribute this large over-forecast to a late-developing El Niño and copious amounts of dry air in the tropical Atlantic.

5.1 Preface: Aggregate Verification of our Last Eight Yearly Forecasts

Despite this year's forecast bust, we are improving our skill in seasonal prediction with an improved level of understanding. This improved skill is demonstrated by the last eight years of our seasonal forecast verifications. Skillful extended range seasonal predictions are indeed possible. With more research, our understanding and skill should continue to improve. We define forecast skill as the degree to which we are able to improve the prediction of the variation of seasonal hurricane activity parameters above that specified by the long-term climatology. Forecast skill is expressed as the ratio of our forecast error to the observed difference from climatology or:

Forecast Error / Seasonal Difference From Climatology

Table 3: Verification of our 2006 seasonal hurricane predictions.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	6 Dec 2005	Update 4 April 2006	Update 31 May 2006	Update 3 Aug 2006	Update 1 Sept 2006	Update 3 Oct 2005	Observed 2006 Total
Named Storms (NS) (9.6)	17	17	17	15	13	11	9
Named Storm Days (NSD) (49.1)	85	85	85	75	50	58	50
Hurricanes (H) (5.9)	9	9	9	7	5	6	5
Hurricane Days (HD) (24.5)	45	45	45	35	13	23	20
Intense Hurricanes (IH) (2.3)	5	5	5	3	2	2	2
Intense Hurricane Days (IHD) (5.0)	13	13	13	8	4	3	3
Net Tropical Cyclone Activity (NTC)* (100%)	195	195	195	140	90	95	85

For example, if there were a year with five more tropical storms than average and we had predicted two more storms than average, we would give ourselves a skill score of 2 over 5 or 40 percent. All predictands show skill in hindcast testing. Table 4 shows our average skill score based on 52 years of hindcasts from 1950-2001.

Table 4: Average variance explained by our hindcasts above that specified by climatology as a function of different forecast lead times (in percent) for the 52-year period of 1950-2001.

Tropical Cyclone Parameter	Early December	Early April	Early June And August
NS	31	31	31
NSD	29	38	39
H	35	36	36
HD	37	40	39
IH	41	40	36
IHD	29	34	35
NTC	44	47	41

Our early December forecasts of the last eight years have had only marginal skill. However, our hindcast skill is quite significant when evaluated over the 1950-2001 period (Table 4).

Another way to consider the skill of our forecasts is to evaluate whether the forecast for each parameter successfully forecast above- or below-average activity. Table 5 displays how frequently our forecasts have been on the right side of climatology for the past eight years. In general, our forecasts are successful at forecasting whether the season will be more or less active than normal by as early as December of the previous year with improving skill as the hurricane season approaches.

Table 5: The number of years that our tropical cyclone forecasts issued at various lead times have correctly predicted above- or below-average activity for each predictand over the past eight years (1999-2006)

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	6/8	7/8	7/8	6/8
NSD	7/8	8/8	8/8	7/8
H	5/8	6/8	6/8	6/8
HD	5/8	6/8	6/8	7/8
IH	5/8	5/8	7/8	7/8
IHD	5/8	5/8	7/8	7/8
NTC	5/8	6/8	6/8	7/8
Total	**38/56 (68%)**	**43/56 (77%)**	**47/56 (84%)**	**48/56 (86%)**

Of course, there are significant amounts of unexplained variance in a number of the individual parameter forecasts. Even though the skill for some of these parameter forecasts is somewhat low, especially for the early December lead time, there is a great curiosity in having some objective measure as to how active the coming hurricane season is likely to be. Therefore, even a forecast that is only modestly skillful is likely of interest.

5.2 Predictions of Individual Monthly TC Activity

A new aspect of our climate research is the development of TC activity predictions for individual months. On average, August, September and October have about 26%, 48%, and 17% or 91% of the total Atlantic basin NTC activity. August-only monthly forecasts have now been made for the past seven seasons, and September-only forecasts have been made for the last five seasons. This is the fourth year that we have issued an October-only forecast. For the first time this year, we attempted to predict November activity and issued a joint October-November forecast with our 3 October update.

There are often monthly periods within active and inactive hurricane seasons which do not conform to the overall season. To this end, we have recently developed new schemes to forecast August-only, September-only and October-only Atlantic basin TC activity by the beginning of each of these three months. These efforts have been documented by Blake and Gray (2004) for the August-only forecast and Klotzbach and Gray (2003) for the September-only forecast – see citations and additional reading section.

Quite skillful August-only, September-only and October-only prediction schemes have been developed based on 51 years (1950-2000) of hindcast testing using a statistically independent jackknife approach. Predictors are derived from prior months, usually June and July (NCEP global reanalysis) data for all three (August-only, September-only and October-only) individual monthly forecasts and include August's data for the early September forecast of September-only and October-only forecasts. We include data through September for our early October forecast. Table 6 gives an outline and timetable of the different forecasts and verifications we issue in early August, early September and early October.

Table 6: Timetable of the issuing of our after-July monthly forecasts (in early August, in early September, and early October), the times of their verification, and the dates of seasonal updates. Note that we make three separate October-only forecasts; two separate September-only forecasts, and one separate August-only forecast. Seasonal updates are issued in early September and early October.

Times of Forecast and Verification	Based on Data Through		**Forecasts**		
Early August	July	August Forecast	September Forecast	October Forecast	Full Season Forecast
Early September	August	August Verification	September Forecast	October Forecast	Remainder of Season Forecast
Early October	September		September Verification	October Forecast	Remainder of Season Forecast

5.3 August-only 2006 Forecast

Our August 2006 forecast was a bust (see Table 7) and was not typical of our previous six August-only forecasts for 2000-2005 or our hindcasts of August-only activity as contained in our original developmental datasets over the period 1949-1999. Our developmental data sets showed considerable skill. Table 8 shows the skill of our prior six August-only forecasts for Net Tropical Cyclone (NTC) activity over the 2000-2005 period. Note that we have correctly predicted above- or below-average activity in five out of the prior six years.

Table 7: CSU forecast and verification of August-only hurricane activity made in early August.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	August 2006 Statistical Forecast	Adjusted August 2006 Forecast	August 2006 Verification
Named Storms (NS) (2.8)	3.3	4	3
Named Storm Days (NSD) (11.8)	21.1	22	12
Hurricanes (H) (1.6)	2.9	3	1
Hurricane Days (HD) (5.7)	8.1	11	0.25
Intense Hurricanes (IH) (0.6)	0.7	1	0
Intense Hurricane Days (IHD) (1.2)	2.0	3	0
Net Tropical Cyclone Activity (NTC) (26.4)	53.6	50	12

Table 8: Predicted, observed, August-only 2006 forecast (bottom line) and climatological NTC for our six August-only forecasts of 2000-2005. Evaluation of skill with respect to average error and mean square error are also shown.

Year	Observed NTC	Predicted NTC	Climatological NTC
2000	42	33	26
2001	9	22	26
2002	7	18	26
2003	26	22	26
2004	89	35	26
2005	41	50	26
Average Error (2000-2005)		16.7	21.7
Mean Square Error (MSE) (2000-2005)		569	851
Skill of Prediction (relative to MSE)			**0.33**
2006	**12**	**50**	**26**

August 2006 had about average named storm activity, but the amount of hurricane and intense hurricane activity was well below average. Only one hurricane formed during August (Ernesto), and it lasted less than one day due to interaction with land. On average, about six hurricane days occur during August. Several features likely contributed to an inactive month.

There was considerable subsidence, dry air and dust (A. Evan 2006, personal communication) across the tropical Atlantic during the month of August. Subsidence inhibits the development and maintenance of strong thunderstorms which are necessary for the intensification of easterly waves into tropical cyclones. Two of the three storms that formed during August (Chris and Debby) never reached hurricane strength due partially to very dry air being ingested into their respective circulations. Figure 3 displays a measure of brightness temperature across the tropical Atlantic. Brightness temperatures can be considered a measure of mid-level moisture, with colder temperatures indicating more moisture. Note that brightness temperatures were well above average (i.e. less moisture) throughout most of the month of August.

Another factor that may have played a role in reducing Atlantic basin hurricane activity during August was the development of El Niño conditions in the tropical Pacific. Conditions rapidly trended towards El Niño during August. In general, associated with El Niño conditions, is a drier Caribbean and western tropical Atlantic and increased vertical wind shear across the entire tropical Atlantic/Caribbean area. See Section 7.1 for a more in-depth discussion of ENSO.

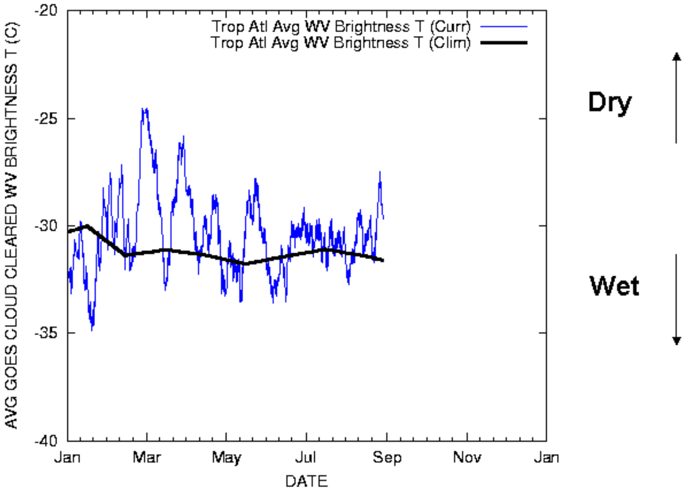

Figure 3: Water vapor brightness temperature across the tropical Atlantic from January-August. Note that brightness temperatures were warmer than average for most of August. Brightness temperatures are a proxy for mid-level moisture, with cooler temperatures indicating more moisture. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA).

5.4 September-only 2006 Forecast

Our September 2006 forecast verified quite well (see Table 9). Even though conditions in August were not favorable for Atlantic basin tropical cyclone activity, we predicted that they would likely become more favorable for hurricane development in September, and this prediction verified very well. Dry air and African dust intrusions (A. Evan 2006, personal communication) continued to predominate across the tropical Atlantic in September; however, vertical wind shear was below average for most of the month. Four named storms (Florence, Gordon, Helene and Isaac) formed during September, and all four of these storms became hurricanes. Gordon and Helene became major hurricanes.

Table 9: Independent September-only forecasts for 2006 including the 3 August statistical forecast for September, the 3 August adjusted forecast for September, the 1 September statistical forecast for September and the 1 September adjusted forecast for September. Observed activity is in the far right-hand column.

Tropical Cyclone Parameters and 1950-2000 September Average (in parentheses)	3 Aug. Stat. Fcst. (for Sep.)	3 Aug. Adjusted Forecast	1 Sep. Stat. Fcst. (for Sep.)	1 Sep. Adjusted Forecast	Observed Sep. 2006 Activity
Named Storms (NS) (3.4)	4.1	5	3.4	5	4
Named Storm Days (NSD) (21.7)	20.8	25	17.2	20	30.50
Hurricanes (H) (2.4)	2.2	3	3.2	3	4
Hurricane Days (HD) (12.3)	7.2	12	5.5	10	18.25
Intense Hurricanes (IH) (1.3)	1.8	2	1.7	2	2
Intense Hurricane Days (IHD) (3.0)	1.5	5	2.5	4	3
Net Tropical Cyclone Activity (NTC) (48%)	48	60	45	59	66

September had above-average activity when evaluated by the NTC metric. This represents the ninth consecutive September that has had above normal NTC activity. September 2006 accrued 66 NTC units, which is somewhat more than the 1950-2000 average of 48. Although El Niño conditions continued to develop in the central and eastern Pacific, vertical wind shear in the tropical Atlantic was actually somewhat below average. Figure 4 shows vertical wind shear across the tropical Atlantic (0-20ºN, 20-60ºW) for 2006 in the tropical Atlantic from June-September. Note that values in September 2006 were generally below the long-term average. Atlantic basin sea surface temperatures also remained above average throughout the month. We think that the likely inhibiting factor that kept September from being a very active month was the continued predominance of dry air in the tropical Atlantic. Figure 5 displays water vapor brightness temperatures across the tropical Atlantic (0-20ºN, 20-60ºW). Note that brightness temperatures remained above average (i.e. less moisture) throughout most of the month of September, as they had in August. The continued dominance of subsidence across the tropical Atlantic may in part have been due to a shift in the Walker Circulation associated with the developing El Niño.

We consider our September monthly forecast to have been a success. We predicted that despite an inactive early season, we would see above-average activity in September, and this is what occurred. Our forecast predicted that three hurricanes and two major hurricanes would develop during September, and four hurricanes and two major hurricanes formed.

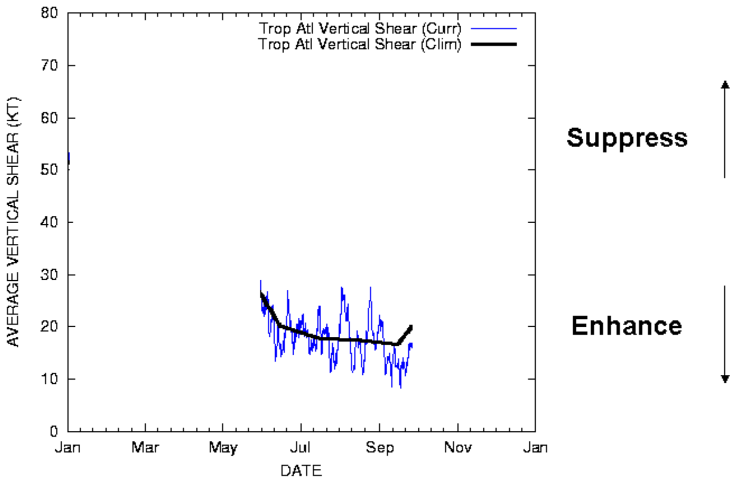

Figure 4: Vertical wind shear (850-200 mb) across the tropical Atlantic (0-20ºN, 20-60ºW) from June-September. Note that vertical wind shear values in September have generally been below the long-period average. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA) from the Tropical Cyclone Formation Probability Product (DeMaria et al. 2001).

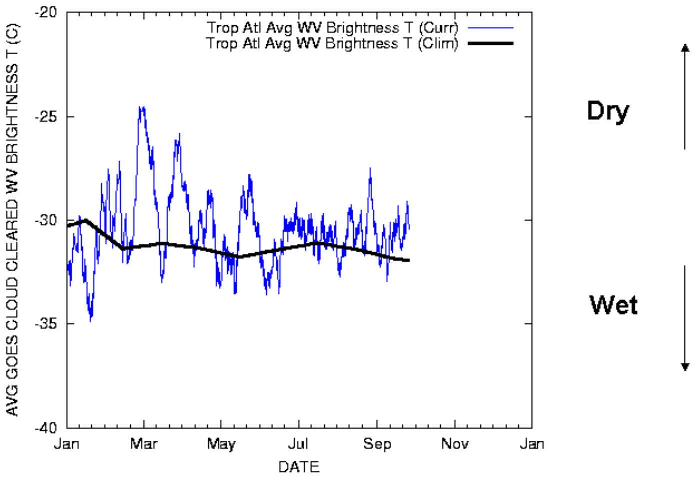

Figure 5: Water vapor brightness temperature across the tropical Atlantic (0-20ºN, 20-60ºW) from January-September. Note that brightness temperatures remained above average for most of September. Brightness temperatures are a proxy for mid-level moisture, with cooler temperatures indicating more moisture. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA) from the Tropical Cyclone Formation Probability Product (DeMaria et al. 2001).

5.5 October-only 2006 Forecast

The October-only forecast successfully called for an inactive month; however, we did not expect it to be as inactive as it turned out to be. No named storms formed in the Atlantic after Isaac developed on September 28. The only activity that occurred during the month was early in October as Isaac dissipated over the open Atlantic. Since vertical wind shear tends to be heightened in El Niño years, and this year has seen a rapid transition towards El Niño in August-October, we expected to see a large amount of vertical wind shear across the tropical Atlantic this October (see Figure 6). Anomalously strong vertical wind shear tends to bring an early-season end to tropical cyclone activity in the tropical Atlantic, and this is what occurred this year. No new named storms formed in the Atlantic in October. In our early October update for the remainder of the season, we also added November to our October forecast, since tropical cyclone development in November in El Niño years is very rare. We have not seen any development of tropical cyclones in November. Table 10 displays the statistical and adjusted October-only forecasts issued on 3 August, 1 September, and 3 October respectively as well as the observed activity that occurred in October 2006. We are planning to revise our future October-only statistical forecasts to include a more explicit treatment of El Niño.

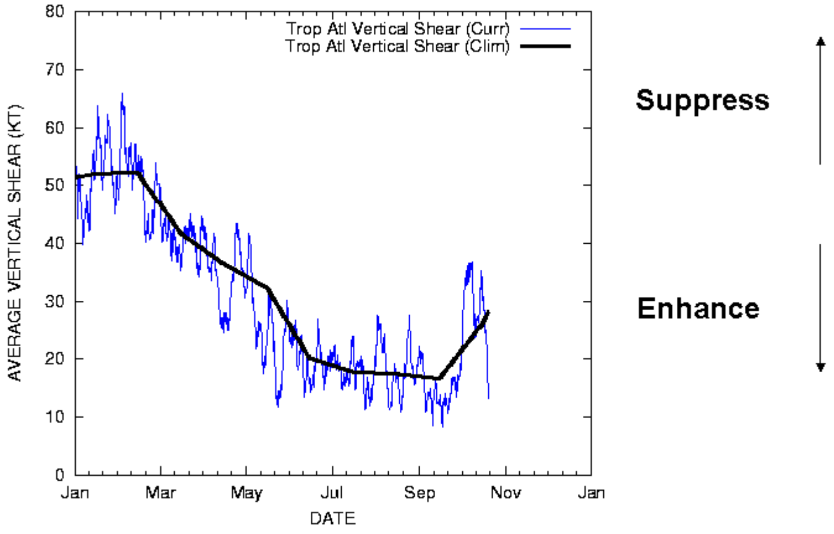

Figure 6: Vertical wind shear (850-200 mb) across the tropical Atlantic (0-20ºN, 20-60ºW) from January-October. Note that vertical wind shear values in October have generally been above the long-period average. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA) from the Tropical Cyclone Formation Probability Product (DeMaria et al. 2001).

Table 10: Independent October-only forecasts for 2006 including the 3 August statistical forecast for October, the 3 August adjusted forecast for October, the 1 September statistical forecast for October, the 1 September adjusted forecast for September, the 3 October statistical forecast for October and the 3 October adjusted forecast for October-November. Observed activity is in the far right-hand column.

TC Parameters and 1950-2000 Oct. Clim. (in parentheses)	3 Aug. Stat. Fcst. (for Oct.)	3 Aug. Adjusted Forecast	1 Sep. Stat. Fcst. (for Oct.)	1 Sep. Adjusted Forecast	3 Oct. Stat. Fcst. (for Oct.)	3 Oct. Adjusted Forecast for Oct-Nov	Observed Oct-Nov 2006 Activity
NS (1.7)	1.4	2	2.6	2	3.2	2	0
NSD (9.0)	7.3	11	13.5	10	16.9	10	2
H (1.1)	0.9	1	1.7	1	2.1	1	0
HD (4.4)	3.6	4	6.6	3	8.3	4	1.5
IH (0.3)	0.2	0	0.5	0	0.6	0	0
IHD (0.8)	0.6	0	1.2	0	1.5	0	0
NTC (17%)	15	15	27	12	32	12	2

6 Verification of 2006 U.S. Landfall Probabilities

A new initiative in our research involves efforts to develop forecasts of the seasonal probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events cannot be accurately forecast, the net seasonal probability of landfall (relative to climatology) can be forecast with statistical skill. With the premise that landfall is a function of varying climate conditions, a probability specification has been accomplished through a statistical analysis of all U.S. hurricane and named storm landfalls during a 100-year period (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 statistically related to the overall Atlantic basin Net Tropical Cyclone (NTC) activity and to climate trends linked to multi-decadal variations of the Atlantic Ocean thermohaline circulation (as measured by North Atlantic SSTA). Table 11 gives verifications of our landfall probability estimates for 2006.

Landfall probabilities for the 2006 hurricane season were estimated to be well above their climatological averages; however the season actually recorded below-average landfall activity. Three tropical storms made landfall this year (Alberto, Beryl and Ernesto). Fortunately, no hurricanes made landfall along the United States coastline this year. This is only the 11th year since 1945 that no hurricanes made landfall along the U.S. coastline.

This is the first year that we have attempted to analyze landfall steering current patterns in an attempt to determine whether the Gulf Coast or East Coast was more likely to be targeted by tropical cyclones this year. Our analysis of steering current patterns correctly predicted that the Gulf Coast would likely not be targeted by many storms this year; however, we thought that the East Coast would be a likely target for tropical cyclone activity. We believed that there would tend to be a ridge along the East Coast this summer/fall, as there tends to be a moderate positive correlation between ridging in the northeast United States/eastern Canada in April-May and East Coast ridging in

August-October. However, this relationship did not hold for this year. Ridging in the northeast United States and Canada in April-May of 2006 was replaced by a mid-level trough along the East Coast for most of the Atlantic basin hurricane season, and most storms recurved. Figure 7 displays mid-level (500 mb) height anomalies in April-May in the northeast United States and eastern Canada, while Figure 8 displays mid-level (500 mb) height anomalies in August-September 2006 along the East Coast of the United States from North Carolina northward. Note that the ridging along the East Coast in Figure 7 was displaced by a trough in Figure 8.

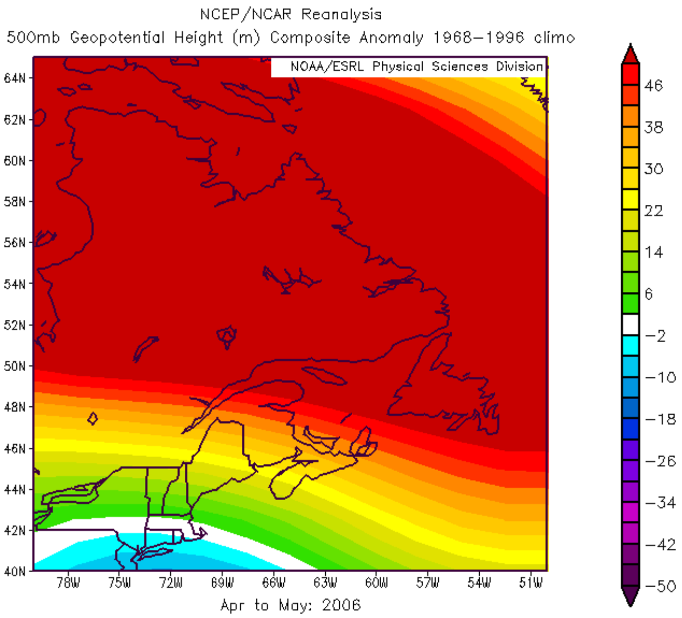

Figure 7: 500 mb geopotential height anomaly field for April-May in the northeast United States and eastern Canada.

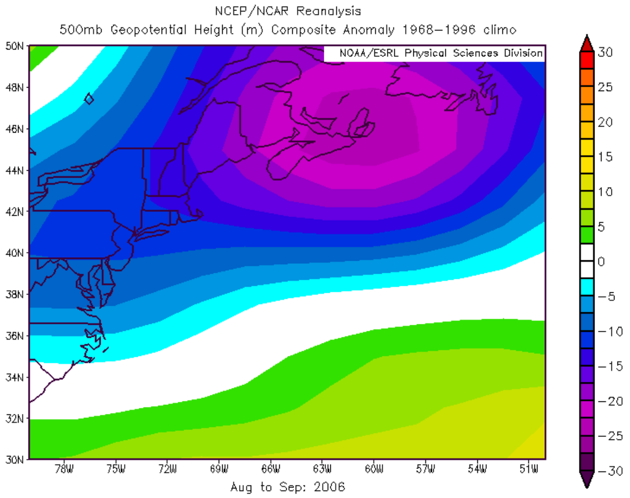

Figure 8: 500 mb geopotential height field anomaly for August-September along the East Coast of the United States from North Carolina northward.

Active research continues on our landfall probability technique, and full documentation of the methodology for estimating hurricane landfall probability is being prepared. Landfall probabilities include specific forecasts of the probability of landfalling tropical storms (TS) and hurricanes of category 1-2 and 3-4-5 intensity for each of 11 units of the U.S. coastline (Figure 9). These 11 units are further subdivided into 55 subregions based on coastal population density, and these subregions are further subdivided into 205 coastal and near-coastal counties. The climatological and current-year probabilities are now available online via the United States Landfalling Hurricane Probability Webpage at http://www.e-transit.org/hurricane. Since the website went live on June 1, 2004, the webpage has received over half-a-million hits.

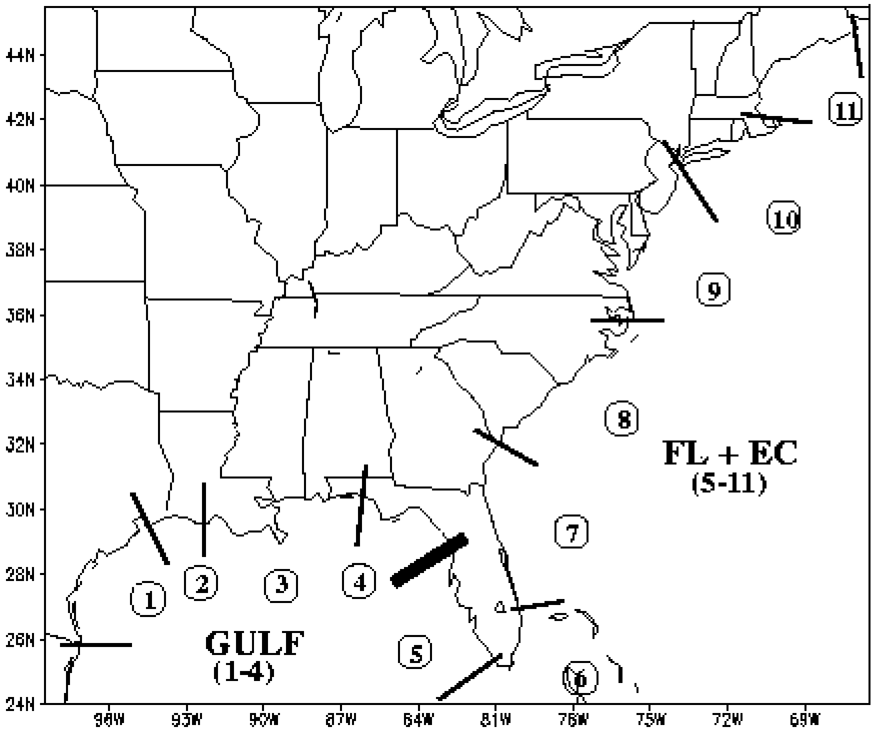

Figure 9: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

Table 11: Estimated forecast probability (percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes, and 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 2006 at various lead times. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 3 August forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast, and Table (c) is for the Florida Peninsula and the East Coast.

(a) The entire U.S. (Regions 1-11)

	Forecast Date				
	6 Dec.	4 Apr.	31 May	3 Aug.	Observed Number
TS	91%	91%	94%	85% (80%)	3
HUR (Cat 1-2)	88%	88%	90%	67% (68%)	0
HUR (Cat 3-4-5)	81%	81%	82%	73% (52%)	0
All HUR	98%	98%	95%	91% (84%)	0
Named Storms	99%	99%	99%	99% (97%)	3

(b) The Gulf Coast (Regions 1-4)

	Forecast Date				
	6 Dec.	4 Apr.	31 May	3 Aug.	Observed Number
TS	74%	74%	66%	57% (59%)	1
HUR (Cat 1-2)	61%	61%	44%	33% (42%)	0
HUR (Cat 3-4-5)	47%	47%	38%	26% (30%)	0
All HUR	79%	79%	62%	51% (61%)	0
Named Storms	95%	95%	86%	79% (83%)	1

(c) Florida Peninsula Plus the East Coast (Regions 5-11)

	Forecast Date				
	6 Dec.	4 Apr.	31 May	3 Aug.	Observed Number
TS	64%	64%	85%	64% (51%)	2
HUR (Cat 1-2)	69%	69%	83%	47% (45%)	0
HUR (Cat 3-4-5)	64%	64%	69%	64% (31%)	0
All HUR	89%	89%	87%	81% (62%)	0
Named Storms	96%	96%	94%	93% (81%)	2

7 Why Was the 2006 Atlantic Basin Season Over-Forecast?

As can be seen from the table outlining our predictions on page 5, we considerably over-forecast activity that occurred in the 2006 Atlantic basin hurricane season. We thought that the season would be very active, approximately in line with the average activity that we have experienced since the start of the most recent positive phase of the Atlantic Multi-decadal Oscillation (AMO) (1995-2005). Instead, this season ended up with activity at slightly below the 1950-2000 mean, with only nine named storms, five hurricanes and two major hurricanes forming. In the next few pages, we discuss some of the features that developed during the Atlantic basin season that likely caused the season to be much less active than we anticipated.

7.1 ENSO

One of the extraordinary features of the 2006 Atlantic basin hurricane season has been the rapid onset of El Niño conditions in the tropical Pacific. The warming of the eastern and central Pacific during August through October 2006 has been truly remarkable. Only 1997 witnessed a larger temperature increase in Nino 3 anomalies from June-July to August-September than did the 2006 season. But, in 1997, June-July Nino 3 anomalies (2.1ºC) were already well above average while 2006 June-July anomalies (0.1ºC) were not. This was by far the largest percentage warming of SST anomalies between June-July and August-September in the tropical Pacific for a year that had El Niño conditions in August-September. For this comparison, we define El Niño years as those with Nino 3 temperatures that averaged greater than or equal to 0.5ºC from August-September.

In 2006 sea surface temperatures in Nino 3 warmed by approximately 0.6ºC from their June-July values to their August-September values. This is the largest percentage increase in anomalies (700%) from June-July values to August-September values. The second largest percentage increase (500%) in SST anomalies in Nino 3 during this same time period was in 1979. Table 12 displays June-July and August-September Nino 3 values for the fifteen years with the warmest readings in Nino 3 during August-September.

Table 12: June-July Nino 3 temperatures, August-September Nino 3 temperatures and the percentage change of anomalies from June-July to August-September for the fifteen years that were classified as El Niño based on August-September Nino 3 anomalies >= 0.5ºC.

Year	June-July (JJ) Nino 3 (ºC)	Aug-Sep (AS) Nino 3 (ºC)	Anomaly Percentage Change (AS/JJ)
1997	2.1	3.0	143%
1972	1.3	1.7	131%
1987	1.4	1.7	121%
1982	1.0	1.5	150%
1965	1.0	1.2	120%
1957	0.9	0.9	100%
1976	0.6	0.9	150%
1951	0.5	0.8	160%
1963	0.6	0.8	133%
1983	1.4	0.7	50%
2002	0.6	0.6	100%
1969	0.5	0.6	120%
1979	0.1	0.5	500%
1953	0.5	0.5	100%
2006	**0.1**	**0.7**	**700%**

The rapid warming of SSTs in the eastern and central Pacific was not forecast well by the statistical and dynamical ENSO models. Using ENSO prediction information obtained from the monthly technical ENSO updates provided by the International Research Institute for Climate and Society (IRI) shows that an average of the 12 dynamical and 8 statistical models did not predict this year's rapid warming between June-July and August-September. These models predict sea surface temperatures in Nino 3.4 for three month increments (e.g. July-August-September). Observed Nino 3.4 anomalies for July-August-September (JAS) of 2006 were 0.5ºC. Table 13 displays the statistical model consensus, the dynamical model consensus, and the combined model consensus for predicted Nino 3.4 temperatures for July-August-September 2006 for various lead times from January-July. Note that the rapid warming was not predicted by the model consensus. The inability to predict this fast-developing ENSO event certainly made our forecast of the 2006 Atlantic basin hurricane season more difficult.

Table 13: Predicted July-August-September (JAS) 2006 Nino 3.4 values for the consensus of dynamical models, statistical models and all models from various lead times. Model output information was obtained from IRI.

Date	Dynamical Model JAS Nino 3.4 Prediction (ºC)	Statistical Model JAS Nino 3.4 Prediction (ºC)	All Model Nino 3.4 JAS Prediction (ºC)
19 January	0.2	0.1	0.1
15 February	0.1	-0.1	0.0
15 March	0.1	0.0	0.1
18 April	0.1	0.1	0.1
17 May	0.1	0.1	0.1
13 June	0.2	0.1	0.2
19 July	0.4	0.2	0.3
Observed			**0.5**

By 1 August, one can usually make a good extrapolated El Niño forecast for the August-October period. However, this was not the case this year. The onset of east Pacific warm SST anomalies associated with El Niño conditions typically occurs between spring and early summer. The usual El Niño can be detected by June-July. However, this year's July Nino 3 SST anomaly was only 0.22ºC and showed little increase from May and June. But, there was an unexpected and surprisingly strong Nino 3 warming during August-September of approximately 0.6ºC. There is now (mid-November) a moderate El Niño event in place in the tropical Pacific. This year's late El Niño event is similar to the late onset of 1986, but this year's warming from July to September was stronger than the 1986 warming. Looking back at the historical records of El Niño onset events for the 20th century, this season appears to be about the strongest two-month warming from July to September. It is difficult to attribute this sudden warming to one particular cause, but there were persistent westerly wind bursts along the equatorial Pacific for most of August and September. Associated with these westerly wind bursts was the development of intense, long-lived, low-latitude Hurricane Ioke which developed in the central Pacific on August 20. Ioke moved across the eastern and central Pacific and helped prolong and intensify these westerly wind bursts while moving slowly westward. Westerly wind bursts are important in that they touch off Kelvin waves which transport warm anomalies eastward. Figure 10 displays low-level wind anomalies across the equatorial Pacific from April-October. Note the predominance of westerly wind anomalies across the central and western equatorial Pacific from August-October.

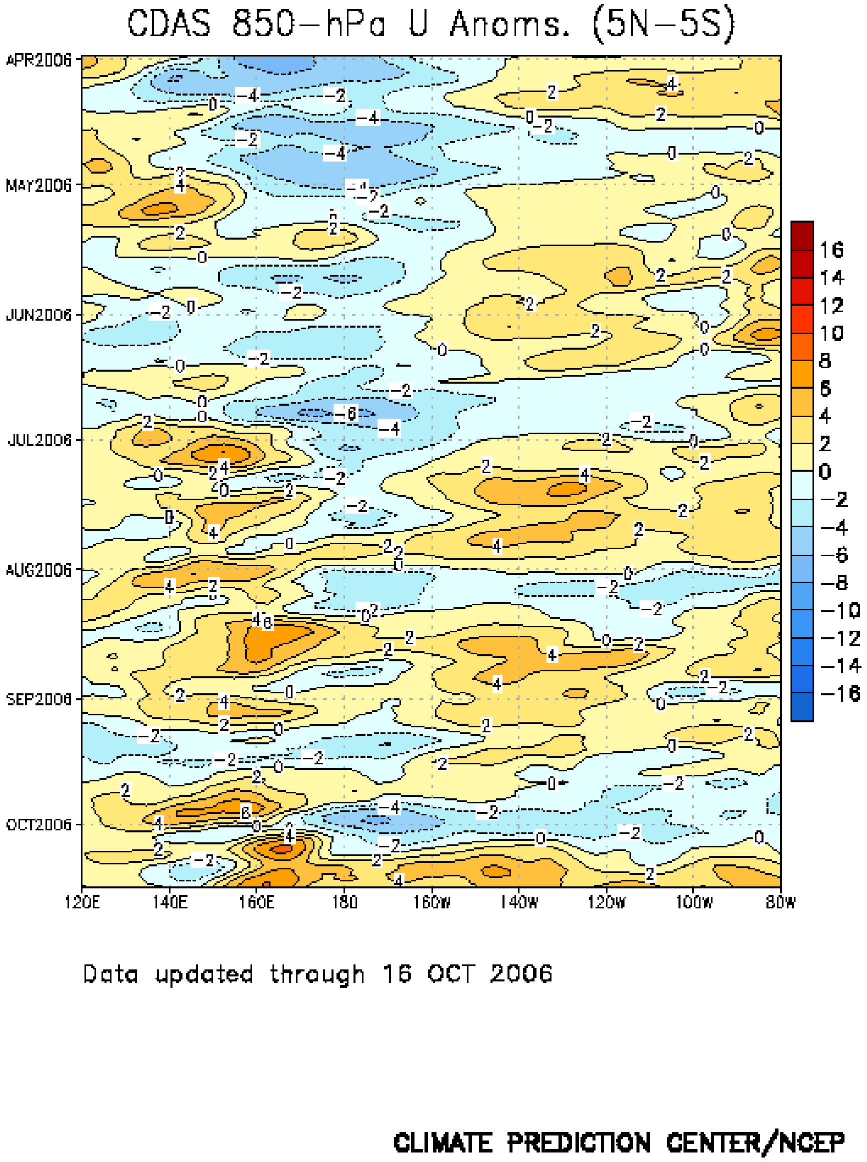

Figure 10: 850 mb zonal wind anomalies across the equatorial Pacific from April-October 2006. Brown values indicate westerly anomalies, while blue values indicate easterly anomalies.

El Niño conditions have continued to develop across the tropical Atlantic. Table 14 displays sea surface temperature anomalies in four Nino regions (Nino 1+2, Nino 3, Nino 3.4, and Nino 4) for April-May, June-July, August-September and October-November 15, respectively. Note the general warming in all regions from April-May until the present.

Table 14: Sea surface temperature anomalies in four Nino regions (Nino 1+2, Nino 3, Nino 3.4, and Nino 4) for April-May, June-July, August-September and October-November 15, respectively.

Region	April-May	June-July	August-September	October-November 15
Nino 1+2	-0.9	0.1	0.9	1.2
Nino 3	-0.1	0.1	0.7	1.0
Nino 3.4	0.0	0.3	0.6	0.9
Nino 4	0.1	0.5	0.8	1.1

7.2 Dry Tropical Atlantic

The tropical Atlantic was quite dry through most of the 2006 hurricane season. Figure 11 shows water vapor brightness temperatures, a measure of deep convection, across the tropical Atlantic during 2006. The tropical Atlantic (0-20ºN, 20-60ºW) has generally been much drier than average, as evidenced by the warmer-than-normal brightness temperatures that have been measured across the region throughout the year.

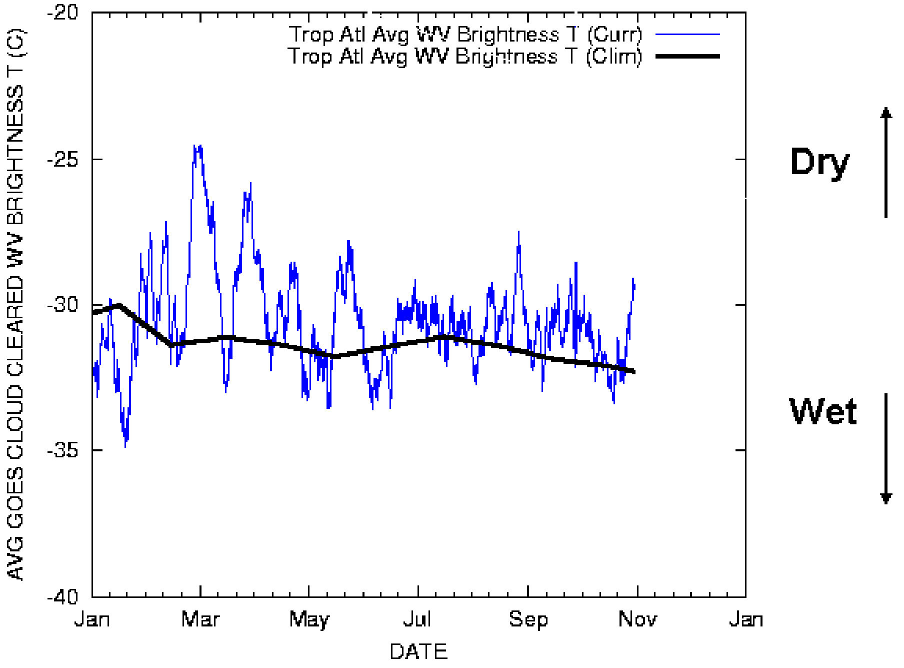

Figure 11: Water vapor brightness temperature across the tropical Atlantic (0-20ºN, 20-60ºW) from January-early November. Note that brightness temperatures have been above average for most of the year. Brightness temperatures are a proxy for mid-level moisture, with cooler temperatures indicating more moisture. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA) from the Tropical Cyclone Formation Probability Product (DeMaria et al. 2001).

One of the challenges from this year's hurricane season is trying to figure out what was the likely cause of the dry air and subsidence that was observed in the tropical Atlantic throughout the season but especially in August. Changes in large-scale tropical atmospheric circulations associated with the development of warm ENSO conditions tend to favor subsidence over the western Caribbean, although they show very little signature over the tropical Atlantic (Bell and Chelliah 2006). Therefore, we are inclined to believe that a large part of this mid-tropospheric dryness in August was due to frequent outbreaks of African dust associated with more frequent incursions of the Saharan Air Layer (SAL) (Evan et al. 2006). The Saharan Air Layer is detrimental to hurricane activity for several reasons, including entrainment of dry air into tropical waves which weakens updrafts and inhibits intensification. In addition, the SAL is associated with strong low-level jets which increase vertical wind shear (Dunion and Velden 2004). Also, there tends to be a stronger temperature inversion associated with the SAL which inhibits the formation of deep convection.

A further question then becomes: why were there more dust outbreaks associated with the Saharan Air Layer this year? There was a considerable amount of dust observed on satellite imagery, especially in August 2006, and we suggest that an anomalously dry early rainy season in the southern part of the Sahel may be partially responsible. Rainfall in the northern part of the Sahel does not reach its maximum until August-September, when the ITCZ makes its furthest northward excursion. We analyzed below-average rainfall in the southern Sahel during the May-July period, and the rainfall that did occur had difficulty moving northward in August. The northern part of the Sahel remained dry during August. Precipitation in the northern Sahel in May-July is quite small in any year, and therefore above-normal values during the May-July period are too low to be meaningful.

During the early part of this year's rainy season in the southern Sahel (May – July), the amount of precipitation was somewhat below average in the early season (Figure 12). In addition, rainfall in the Sahel during 2005 tended to be somewhat below average as well, and perhaps a combination of these two factors led to increased dust loading that was ingested into the Saharan Air Layer during August.

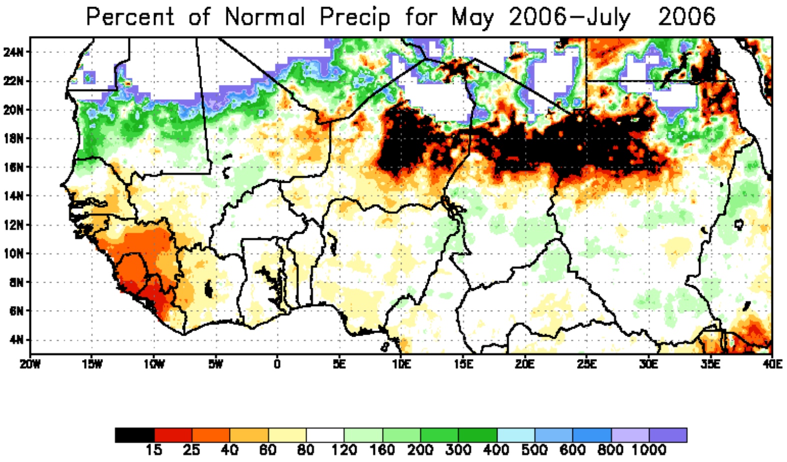

Figure 12: Percent of normal precipitation in West Africa during May-June-July 2006. Note that precipitation tended to be below normal in the southern Sahel region (approximately 10-15ºN, 0-15ºW).

8 Discussion of Differences between the 2006 Average Hurricane Season and the Very Active Seasons of 2004 and 2005

8.1 Introduction

The 2006 Atlantic basin hurricane season ended up with about average activity when compared with the 1950-2000 average. A total of nine named storms, five hurricanes and two major hurricanes formed during 2006. This is to be contrasted with the extremely active hurricane seasons of 2004 and 2005. Both 2004 and 2005 recorded NTC values in excess of 200%, while 2006's value was only 85% of the average 1950-2000 season. Table 15 compares the 2006 season with the 2004-2005 average. In addition, the 1995-2003 average values as well as the climatological average (1950-2000) values are presented for reference. The 2006 season was much less active (approximately only 1/3 as active when compared with NTC) than the 2004-2005 seasons, and it had less than 60% as much activity as was experienced during the very active 1995-2003 period. However, when compared with the long-period average from 1950-2000, 2006 was only slightly less active than the average season.

Table 15: Atlantic basin tropical cyclone activity in 2006 compared with the 2004-2005 average, the 1995-2003 active period and the 1950-2000 climatological average. The ratio of 2006's value with the other time periods is provided in parentheses.

TC Parameter	2006	2004-2005	1995-2003	1950-2000
Named Storms	9	20.5 (44%)	13.6 (66%)	9.6 (94%)
Named Storm Days	50	109.4 (46%)	73.3 (68%)	49.1 (102%)
Hurricanes	5	12.0 (42%)	7.7 (65%)	5.9 (85%)
Hurricane Days	20	47.6 (42%)	34.2 (58%)	24.5 (82%)
Intense Hurricanes	2	6.5 (31%)	3.6 (56%)	2.3 (87%)
Intense Hurricane Days	3	20.0 (15%)	8.8 (34%)	5.0 (60%)
Net Tropical Cyclone Activity	85	252.8 (34%)	148.5 (57%)	100 (85%)

Both thermodynamic (i.e., sea surface temperatures, mid-level moisture) and dynamic factors (i.e., vertical wind shear, pre-existing vorticity) were less favorable for tropical cyclone formation and intensification in 2006 than they were over the past two very active seasons of 2004-2005. The 2006 season was characterized by about average activity in June-July, below-average activity in August, above-average activity in September and below-average activity in October-November. In the next few pages, we attempt to explain why these various sub-seasonal periods likely had above- or below-average activity, respectively.

8.2 June-July Discussion

The early part of the 2006 hurricane season was characterized by about average activity with two named storms and no hurricanes forming during June-July. June-July 2006 had more activity than 2004 when no named storms formed; however, it is in sharp contrast with the June-July period in 2005 which witnessed the development of seven named storms, three hurricanes and two major hurricanes. The average June-July from 1950-2000 had 1.3 named storm formations, 0.5 hurricane formations and 0.1 major hurricane formations.

The start of the Atlantic basin hurricane season is usually restricted by thermodynamic factors (i.e., sea surface temperatures, mid-level moisture, upper-level temperatures, etc.) (DeMaria et al. 2001). In 2005, the thermodynamics became favorable quite early in the season, and two major hurricanes formed before the 1st of August (Dennis and Emily). In 2006, conditions were much less favorable than they were in 2005, and no formations were observed in the deep tropics in June and July. Figure 13 shows Atlantic basin sea surface temperatures in June-July of 2006 differenced from Atlantic basin sea surface temperatures in June-July 2005. SSTs in the tropical Atlantic averaged about 0.5ºC-1.0ºC cooler in June-July 2006 than they did in June-July 2005.

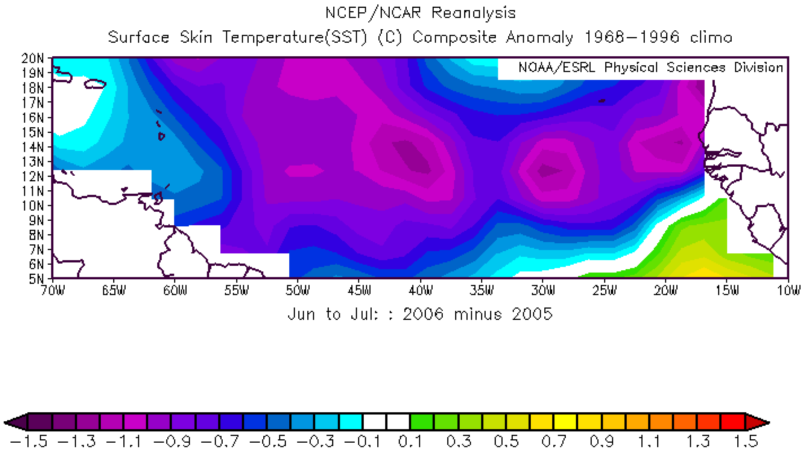

Figure 13: June-July sea surface temperatures in the tropical Atlantic in 2006 minus June-July sea surface temperatures in the tropical Atlantic in 2005.

Also, the eastern tropical Atlantic tended to be significantly drier at low levels in June-July 2006 than it was in 2005. Figure 14 shows the difference in 850 mb relative humidity between June-July 2006 and June-July 2005. Relative humidity values were approximately 5-15% lower in 2006 than in 2005 across the eastern part of the tropical Atlantic with smaller dry deviations in the western part of the basin.

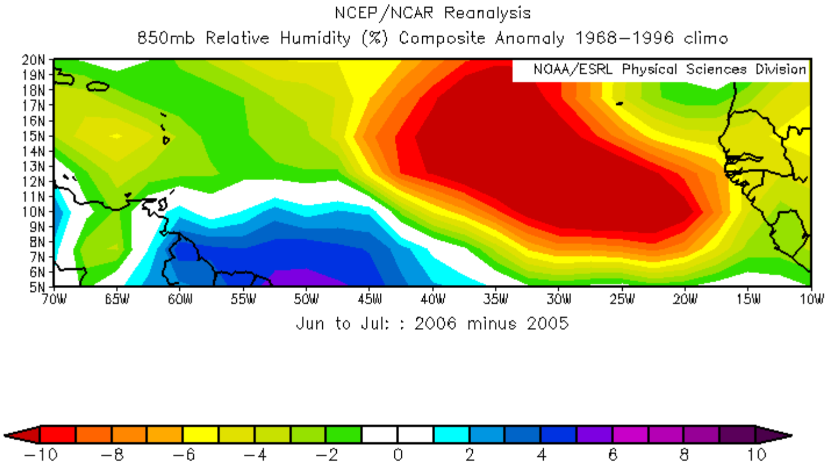

Figure 14: June-July 850 mb relative humidity in the tropical Atlantic in 2006 minus June-July 850 mb relative humidity in the tropical Atlantic in 2005.

Clearly, conditions in the early part of the 2006 hurricane season were not as favorable as they were in 2005, when activity was observed at record levels.

8.3 August Discussion

One of the biggest surprises for us during the 2006 hurricane season was the inactive August 2006 that was observed, as evidenced by our August-only forecast bust. August 2005 had well above-average activity, while activity in August 2004 reached near-record levels. Table 16 compares observed August 2006 activity with activity that occurred in August 2005 and August 2004 as well as the long-period average August from 1950-2000.

Table 16: Atlantic basin tropical cyclone activity in August 2006 compared with August 2005, August 2004 and the 1950-2000 August average.

TC Parameter	August 2006	August 2005	August 2004	Average August 1950-2000
Named Storms	3	5	8	2.8
Named Storm Days	12	21.75	32	11.8
Hurricanes	1	2	5	1.6
Hurricane Days	0.25	7	15.25	5.7
Intense Hurricanes	0	1	3	0.6
Intense Hurricane Days	0	2.25	5.5	1.2
Net Tropical Cyclone Activity	11.9	41.2	89.3	26.4

Based on the large drop-off in activity in August 2006 compared with the previous two years, we observe that certain climate conditions were not as favorable for hurricane development and intensification as they were in 2004 and 2005. As was mentioned earlier in our discussion of African dust and Saharan Air Layer outbreaks, we believe that dry mid levels was one of two important causes for the unusually inactive August 2006. Figure 15 shows 400 mb relative humidity differences in August 2006 from August 2004 and August 2005. Note that the tropical Atlantic was in general drier in 2006, especially in the southern part of the tropical Atlantic where many tropical waves struggled to form during August 2006.

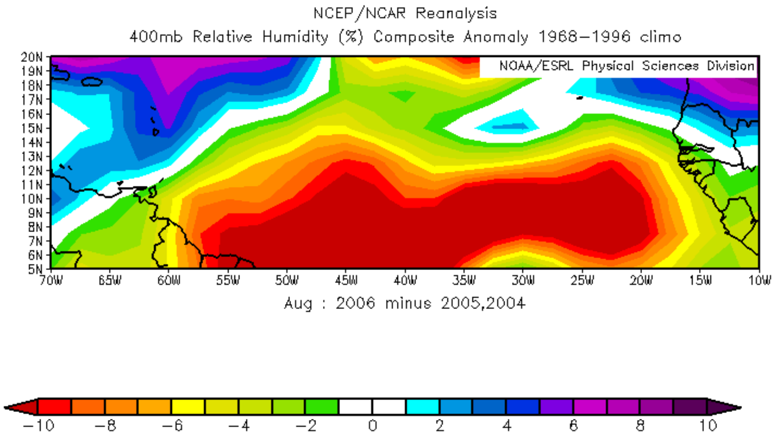

Figure 15: August 400 mb relative humidity in the tropical Atlantic in 2006 minus August 400 mb relative humidity in the tropical Atlantic in August 2005 and August 2004.

Vertical wind shear in August 2006 also tended to be above average. Figure 16 displays vertical wind shear over the tropical Atlantic during August 2006 compared with the long-period average. Note that values in August tended to be above their long period averages, indicating stronger than normal vertical wind shear which inhibits development and intensification of tropical waves into tropical cyclones.

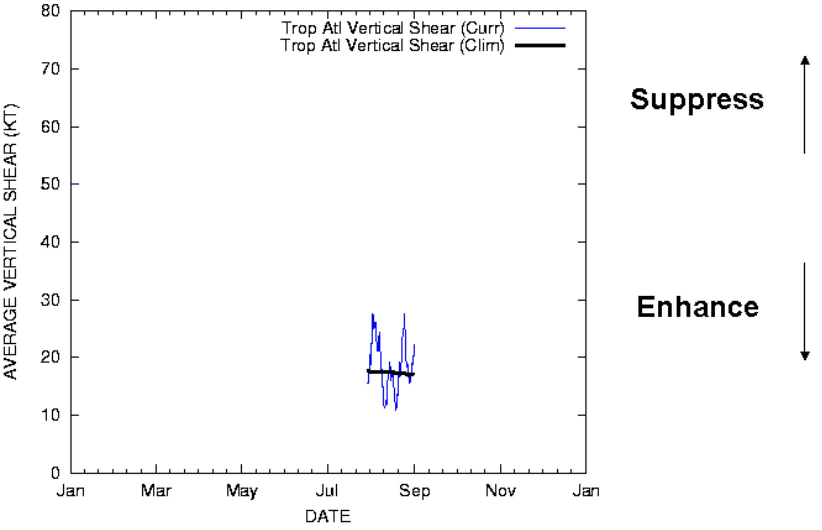

Figure 16: Vertical wind shear (200-850 mb) across the tropical Atlantic (0-20ºN, 20-60ºW) during August. The black line indicates the long-period average. Note that vertical wind shear was above average for most of the month. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA) from the Tropical Cyclone Formation Probability Product (DeMaria et al. 2001).

8.4 September Discussion

Despite the relatively quiet season that was observed in 2006, September 2006 had activity at well above-average levels. Table 17 compares observed September 2006 activity with activity that occurred in September 2005, September 2004 as well as the long-period average September from 1950-2000. Based on NTC, September 2006 was only slightly less active than September 2005, while September 2004 was the second most active September on record, trailing only 1961 which witnessed the development of four major hurricanes.

Table 17: Atlantic basin tropical cyclone activity in September 2006 compared with September 2005, September 2004 and the 1950-2000 September average.

TC Parameter	September 2006	September 2005	September 2004	Average September 1950-2000
Named Storms	4	5	4	3.4
Named Storm Days	30.50	35.75	52.25	21.7
Hurricanes	4	5	3	2.4
Hurricane Days	18.25	16.75	29.75	12.3
Intense Hurricanes	2	2	3	1.3
Intense Hurricane Days	3	3.5	16.75	3.0
Net Tropical Cyclone Activity	65.5	72.5	131.0	48.0

Although the tropical Atlantic remained rather dry through most of September, sea surface temperature anomalies became more positive during September, indicating slightly more favorable thermodynamic conditions during the month (Figure 17). Sea surface temperature anomalies increased by approximately 0.1ºC-0.3ºC throughout most of the basin.

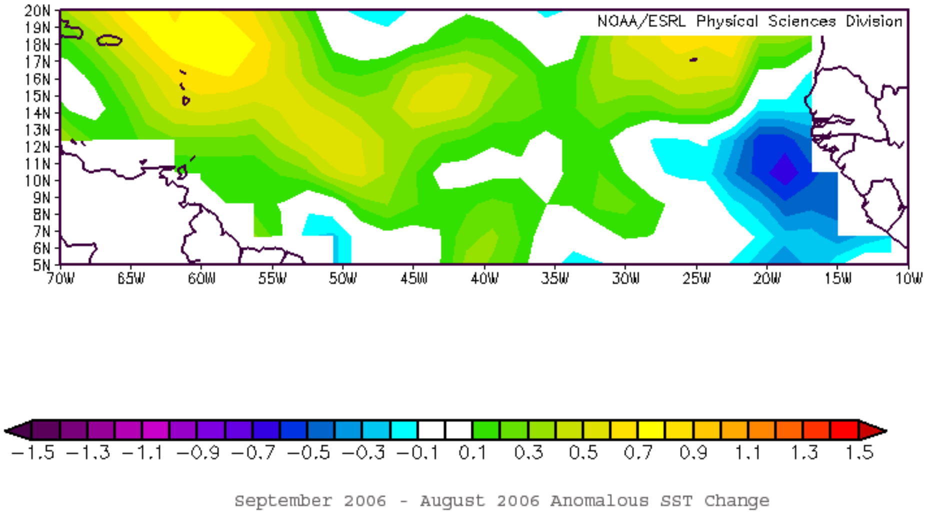

Figure 17: September 2006 – August 2006 anomalous sea surface temperature change in the tropical Atlantic.

Although thermodynamically conditions were only slightly more favorable for tropical cyclone activity in September, vertical wind shear was reduced considerably during September when compared with August values. On average, vertical wind shear reaches its lowest values (most favorable values for TC development) in September, and anomalies became more negative (less wind shear) during September 2006 than they were in August 2006. Figure 18 displays 200 mb zonal wind anomalies in September 2006 differenced from 200 mb zonal wind anomalies in August 2006. Note that easterly anomalies were present across most of the tropical Atlantic in September 2006 compared with August 2006. On average, winds across the tropical Atlantic blow out of the west at upper levels, and therefore, easterly anomalies at 200 mb indicate weaker westerlies.

Since the trade winds at low levels in the tropical Atlantic always blow out of the east, weaker upper level winds typically act to reduce the amount of vertical wind shear. We believe that this weaker vertical wind shear was an important ingredient in explaining the heightened activity that was observed in September 2006.

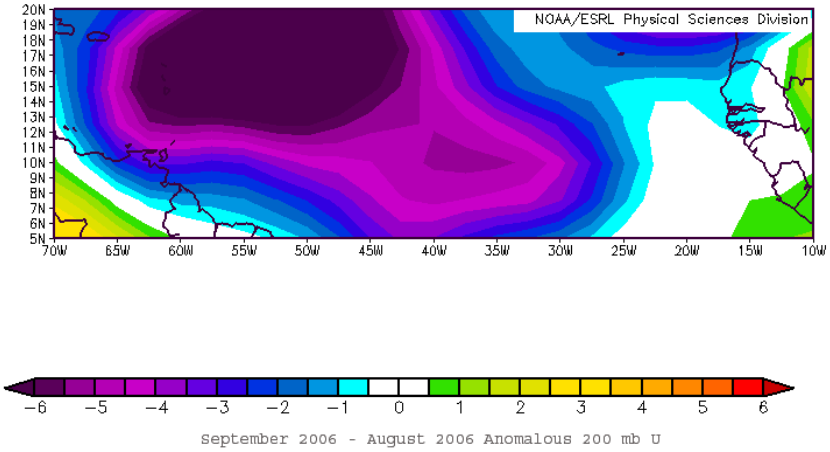

Figure 18: September 2006 – August 2006 anomalous 200 mb zonal wind change in the tropical Atlantic.

8.5 October Discussion

We believe that the rapid development of El Niño conditions during the late summer/early fall of 2006 was likely responsible for the rapid end to the 2006 hurricane season. Although magnitudes were somewhat less in 2004, we saw a similar trend towards El Niño conditions that year, and both years came to an early end, due in large part to an increase in vertical wind shear across the tropical Atlantic and Caribbean. In the climatological average sense, the end of the Atlantic basin hurricane season is usually dictated by shear (DeMaria et al. 2001), and El Niño is known to increase vertical shear in the tropical Atlantic and especially the Caribbean. In general, most hurricanes and intense hurricanes that develop in October form in the Caribbean, and therefore El Niño has a greater impact on October activity than it does during August-September, where more storms form in the tropical Atlantic.

October 2004 and 2006 are to be contrasted with October 2005, which was the most active October on record since 1950. Table 18 displays observed October 2006 activity with activity that occurred in October 2005, October 2004 as well as the long-period average October from 1950-2000. Note that both October 2004 and October 2006 were characterized by well below-average activity.

Table 18: Atlantic basin tropical cyclone activity in October 2006 compared with October 2005, October 2004 and the 1950-2000 October average.

TC Parameter	October 2006	October 2005	October 2004	Average October 1950-2000
Named Storms	0	6	1	1.7
Named Storm Days	2	18.75	4	9.0
Hurricanes	0	4	1	1.1
Hurricane Days	1.5	9.75	0.5	4.4
Intense Hurricanes	0	2	0	0
Intense Hurricane Days	0	5.25	0	0.8
Net Tropical Cyclone Activity	1.7	66.7	6.3	18

As mentioned briefly in the preceding paragraph, there was a marked trend toward El Niño conditions during both October 2004 and 2006. However, in October 2005, ENSO was in its neutral phase and trending towards La Niña conditions, and wind shear in the Caribbean was quite low. Table 19 displays temperatures in the Nino 3 region (5ºS-5ºN, 150º-90ºW) in October 2004, October 2005, and October 2006, respectively. Note the warm temperatures in October 2004 and October 2006 compared to the anomalously cool conditions that were observed last year.

Table 19: Observed sea surface temperature anomalies in the Nino 3 region (5ºS-5ºN, 150º-90ºW) during October 2004, October 2005, and October 2006, respectively.

Month	Nino 3 Anomaly
October 2004	+0.4ºC
October 2005	-0.2ºC
October 2006	+1.1ºC

The primary influence that El Niño has on wind shear is through a strengthening of upper-level westerly winds. Figure 19 displays zonal winds across the Caribbean in October 2006 differenced from zonal winds across the Caribbean in October 2005. Winds averaged approximately 3-6 ms^{-1} stronger out of the west across the Caribbean in October 2006 than they were in October 2005, indicating more vertical wind shear and more inhibition of tropical cyclone development in this region.

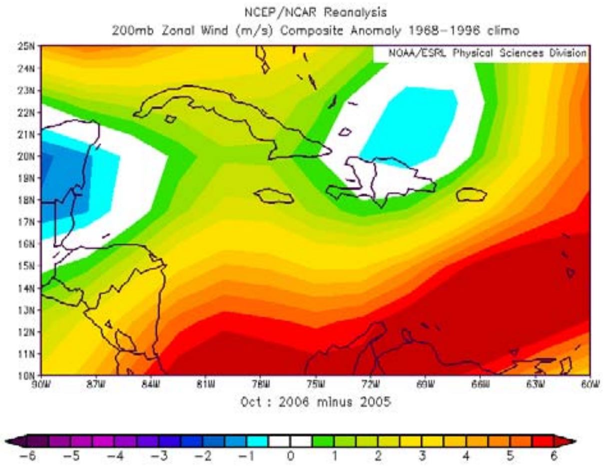

Figure 19: October 2006 – October 2005 200 mb zonal wind anomalies across the Caribbean.

8.6 Track Differences

The 2006 Atlantic basin hurricane season was much less active than the 2004 and 2005 seasons; however, an area in which 2006 was a-typical was the fact that there were no landfalling hurricanes along the United States coastline this year. This is the first year that there have been no landfalling hurricanes along the U.S. coastline since 2001, and this is only the 11th year since 1945 that there have been no U.S. landfalling hurricanes. There tended to be a ridge of high pressure over the northeast U.S. during the heart of the hurricane season in 2004 and 2005 which pushed storms further westward and caused many hurricane landfalls during these two very active seasons. This year, there tended to be an anomalous trough of low pressure along the East Coast, which is more typical of what occurred during 1995-2003 when only three of 32 major hurricanes made U.S. landfall (compared with the long-period average of approximately 30% of major hurricanes making U.S. landfall). Figure 20 displays the difference in the 500 mb geopotential height field from August-September 2006 with the average of the height fields of August-September of 2004 and August-September of 2005. Heights were much lower in August-September 2006, indicating anomalous troughing and deeper penetration of mid-latitude westerly wind currents into the sub-tropical western Atlantic. This caused storms to recurve out to sea before making United States landfall. Figure 1 clearly shows the recurving paths that most of this year's tropical cyclones took.

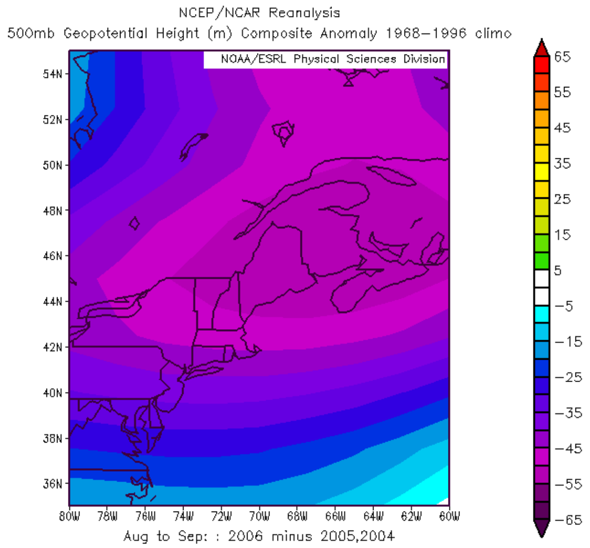

Figure 20: August-September 2006 500 mb geopotential height differenced from August-September 2005 and August-September 2004 500 mb geopotential heights. The anomalous trough during the 2006 season caused more cyclones to recurve in the open Atlantic well east of the United States mainland.

Recently, Klotzbach and Gray (2006) have postulated a steering current parameter to help diagnose likelihood of landfall during a particular season. Figure 21 shows the anomalous wavetrain pattern setup that tends to favor landfall in the United States. A favorable pattern for U.S. landfall includes an anomalous ridge along the East Coast of the United States with anomalous troughs to the east and west that help to reinforce the stationarity of the wave pattern.

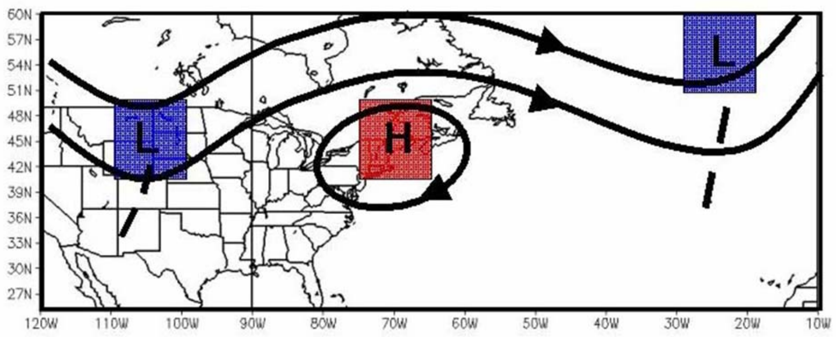

Figure 21: Anomalous 500 mb wave train pattern setup that indicates increased likelihood of United States landfall and Western Atlantic-Gulf formations. Taken from Klotzbach and Gray (2006).

This steering current parameter was very favorable for landfall in the 2004 hurricane season (with an August-September 500 mb geopotential height value of 1.3 standard deviations above normal) while the 2005 hurricane season also had above-average values of this height parameter. However, in 2006 this steering current parameter was below normal (with an August-September 500 mb geopotential height value of 0.5 standard deviations below normal) indicating an increasing chance for recurvature and a decreasing likelihood of U.S. landfall. It is believed that a combination of less favorable conditions for genesis and intensification along with less favorable westerly steering currents caused more easterly storm recurvature and was a major factor in helping prevent the U.S. from being devastated by hurricane landfall during the 2006 season.

9 Was Global Warming Responsible for the Large Upswing in 2004-2005 US 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).

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. 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. 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 ($< \pm 1^{o}$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). 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 20). 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 1956-2005), 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 well within natural bounds of hurricane variation. In addition, following the two very active seasons of 2004 and 2005, 2006 had slightly below-average activity, and no hurricanes made landfall in the United States.

Between 1966 and 2003, US major hurricane landfall numbers were below the long-term average. Of the 79 major hurricanes which formed in the Atlantic basin from 1966-2003 only 19 (24 percent) of them made US landfall. During the two seasons of 2004-2005, seven of 13 (54 percent) came ashore. Zero of the two major hurricanes that formed in 2006 made US landfall. This is how nature sometimes works.

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 20: 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
1956-2005 (50 years)	165	83	34	

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°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 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 thousand of years.

10 Forecasts of 2007 Hurricane Activity

We will be issuing our first forecast for the 2007 hurricane season on Friday, 8 December 2006. This 8 December forecast will include the dates of all of our updated 2007 forecasts. All of these forecasts will be made available at our web address given on the front cover: http://hurricane.atmos.colostate.edu/Forecasts.

11 Acknowledgments

Besides the individuals named on page 2, there have been a number of other meteorologists that have furnished us with data and given valuable assessments of the current state of global atmospheric and oceanic conditions. These include Brian McNoldy, Arthur Douglas, Richard Larsen, Todd Kimberlain, Ray Zehr, and Mark DeMaria. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical and data analysis and assistance over a number of years. We have profited over the years from many in-depth discussions with most of the current and past NHC hurricane forecasters. The second author would further like to acknowledge the encouragement he has received for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, former directors of the National Hurricane Center (NHC), and from the current director, Max Mayfield and their forecast staffs. Uma Shama and Larry Harman of Bridgewater State College, MA have provided assistance and technical support in the development of our Landfalling Hurricane Probability Webpage. We also thank Bill Bailey of the Insurance Information Institute for his sage advice and encouragement.

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13 Verification of Previous Forecasts

Table 21: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2000-2005.

2000	8 Dec. 1999	Update 7 April	Update 7 June	Update 4 August	Obs.
No. of Hurricanes	7	7	8	7	8
No. of Named Storms	11	11	12	11	14
No. of Hurricane Days	25	25	35	30	32
No. of Named Storm Days	55	55	65	55	66
Hurr. Destruction Potential	85	85	100	90	85
Intense Hurricanes	3	3	4	3	3
Intense Hurricane Days	6	6	8	6	5.25
Net Tropical Cyclone Activity	125	125	160	130	134

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	27
No. of Named Storm Days	45	50	60	60	63
Hurr. Destruction Potential	65	65	75	75	71
Intense Hurricanes	2	2	3	3	4
Intense Hurricane Days	4	4	5	5	5
Net Tropical Cyclone Activity	90	100	120	120	142

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	2.5
Net Tropical Cyclone Activity	140	125	100	60	45	80

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	14
No. of Hurricane Days	35	35	35	25	25	35	32
No. of Named Storm Days	65	65	70	60	55	70	71
Hurr. Destruction Potential	100	100	100	80	80	125	129
Intense Hurricanes	3	3	3	3	3	2	3
Intense Hurricane Days	8	8	8	5	9	15	17
Net Tropical Cyclone Activity	140	140	145	120	130	155	173

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
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	18
Net Tropical Cyclone Activity	115	135	170	235	220	215	277