SUMMARY OF 2009 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND 15-DAY FORECASTS

The 2009 hurricane season had activity at below-average levels. Our June and August forecasts correctly predicted below-average hurricane activity due to the development of a moderate El Niño. We consider this season's forecasts to have been successful.

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

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

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

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

19 November 2009

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

ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2009

Forecast Parameter and 1950-2000 Climatology (in parentheses)	10 Dec 2008	Update 9 April 2009	Update 2 June 2009	Update 4 Aug 2009	Observed 2009 Total
Named Storms (NS) (9.6)	14	12	11	10	9
Named Storm Days (NSD) (49.1)	70	55	50	45	27.25
Hurricanes (H) (5.9)	7	6	5	4	3
Hurricane Days (HD) (24.5)	30	25	20	18	11.25
Major Hurricanes (MH) (2.3)	3	2	2	2	2
Major Hurricane Days (MHD) (5.0)	7	5	4	4	3.25
Accumulated Cyclone Energy (ACE) (96.2)	125	100	85	80	50
Net Tropical Cyclone Activity (NTC) (100%)	135	105	90	85	66

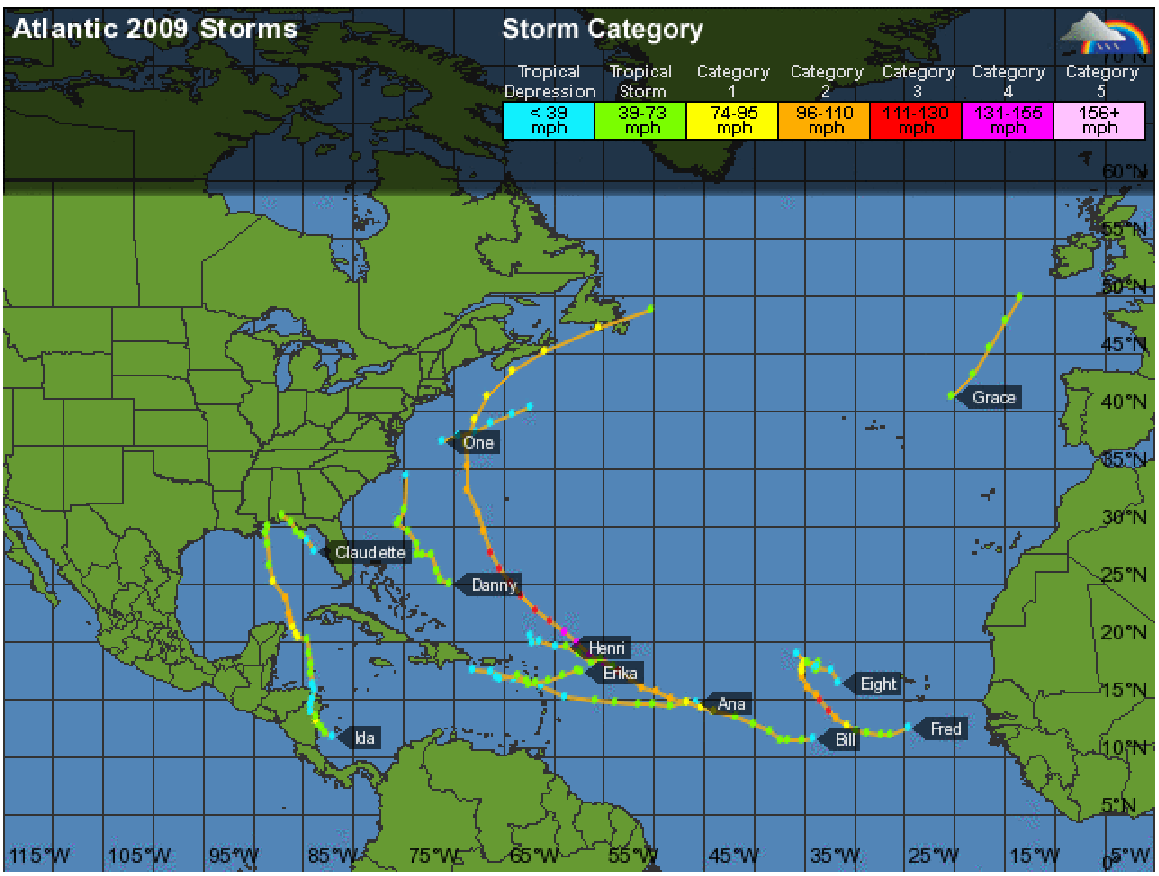

Figure courtesy of Weather Underground (http://www.wunderground.com)

ABSTRACT

This report summarizes tropical cyclone (TC) activity, which occurred in the Atlantic basin during 2009 and verifies the authors' seasonal and 15-day forecasts of this activity. A forecast was initially issued for the 2009 season on 10 December 2008 with updates on 9 April, 2 June, and 4 August of this year. These seasonal forecasts also contained estimates of the probability of U.S. hurricane landfall during 2009. For the first time this year, probabilities of hurricane landfall were also provided for the Caribbean and Central America. The skill of our early June and early August forecasts was reasonably good, while our earlier predictions of early December 2008 and early April of this year over-estimated this year's tropical cyclone activity because of our inability to judge the formation of the moderate El Niño event which began to develop late this spring.

During the August-October period, we also issued 15-day forecasts. These forecasts were primarily based on predicted activity by the global forecast models and the phase of the Madden-Julian Oscillation. These forecasts showed modest skill and will be refined and issued again during the 2010 hurricane season.

Activity in 2009 was reduced considerably due largely to the moderate El Niño event that developed. This event generated significantly stronger-than-average vertical wind shear, especially in the Caribbean and Gulf of Mexico. Consequently, only nine named storms, three hurricanes and two major hurricanes formed in 2009. This activity was 61%, 38%, and 51% of the 1995-2008 average activity for named storms, hurricanes and major hurricanes, respectively.

DEFINITIONS AND ACRONYMS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sea Surface Temperature – SST

Sea Surface Temperature Anomaly – SSTA

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

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

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

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

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

Notice of Author Changes

By William Gray

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

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

Phil Klotzbach is an outstanding young scientist with a superb academic record. I have been amazed at how far he has come in his knowledge of hurricane prediction since joining my project in 2000. I foresee an outstanding future for him in the hurricane field. He is currently making new seasonal and 15-day forecast innovations that are improving our forecasts. The success of the last two years of seasonal forecasts is an example. Phil was awarded his Ph.D. degree in 2007. He is currently spending most of his time working towards better understanding and improving these Atlantic basin hurricane forecasts.

Acknowledgment

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

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

1 Preliminary Discussion

1a. Introduction

The year-to-year variability of Atlantic basin hurricane activity is the largest of any of the globe's tropical cyclone basins. There has always been and will continue to be much interest in knowing if the coming Atlantic hurricane season is going to be unusually active, very quiet or just average. There was never a way of objectively determining much about how active the coming Atlantic hurricane season was going to be until the early to mid-1980s when global data sets became more accessible.

The global atmosphere and oceans in combination have stored memory buried within them that can provide clues as to how active the upcoming Atlantic basin hurricane season is likely to be. The benefit of such empirical investigation (or data mining) is such that any precursor relationship that might be found can immediately be utilized without having to have a complete understanding of the physics involved.

Analyzing the available data in the 1980s, we found that the coming Atlantic seasonal hurricane season did indeed have various precursor signals that extended backward in time from zero to 6-8 months before the start of the season. These precursor signals involved El Niño – Southern Oscillation (ENSO), Atlantic sea surface temperatures and pressures, West African rainfall, the Quasi-Biennial Oscillation (QBO) and a number of other global parameters. Much effort has since been expended by our project's current and former members (along with other research groups) to try to quantitatively maximize the best combination of hurricane precursor signals to give the highest amount of reliable seasonal hindcast skill. We have experimented with a large number of various combinations of precursor variables. We now find that our most reliable forecasts utilize a combination of three or four variables.

A cardinal rule we have always followed is to issue no forecast for which we do not have substantial hindcast skill extending back in time for at least 35-40 years. The NCEP/NCAR reanalysis data sets we now use are available back to 1948 which gives us more than 60 years of hindcast information.

The explorative process to skillful prediction should continue to develop as more data becomes available and as more robust relationships are found. There is no one best forecast scheme that we can always be confident in applying. We have learned that precursor relations can change with time and that one must be alert to these changing relationships. For instance, our early forecast schemes relied heavily on the stratospheric QBO and West African rainfall. These precursor signals have not worked in recent years. Because of this we have had to substitute other precursor signals in their place. All the prediction techniques that were used and discussed with our 2008 and 2009 forecasts have been revised and improved by the first author over the course of the past two years. As we gather new data and new insights in coming years, it is to be expected that our forecast schemes will in future years also need revision. Keeping up with the changing global climate system, using new data signals, and exploring new physical relationships is a full-time job. Success can never be measured by the success of a few real-time forecasts but only by long-period hindcast relationships and sustained demonstration of real-time forecast skill over a decade or more.

1b. Seasonal Forecast Theory

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 precursor 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 forecasts, unfortunately, must deal with the much more complicated interaction of the energy-moisture fields with the momentum fields.

We find that there is a rather high (50-60 percent) degree of year-to-year hurricane forecast potential if one combines 3-4 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 3-4) do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain a 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 3-4 other predictors.

In a four-predictor empirical forecast model, the contribution of each predictor to the net forecast skill can only be determined by the separate elimination of each parameter from the full four-predictor model while noting the hindcast skill degradation. When taken from the full set of predictors, one parameter may degrade the forecast skill by 25-30 percent, while another degrades the forecast skill by only 10-15 percent. An individual parameter that, through elimination from the forecast, degrades a forecast by as much as 25-30 percent may, in fact, by itself, show relatively 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 3-4 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. Despite the complicated relationships that are involved, all of our statistical models show considerable hindcast skill. We are confident that in applying these skillful hindcasts to future forecasts that appreciable real-time skill will result.

2 Tropical Cyclone Activity for 2009

Figure 1 and Table 1 summarize the Atlantic basin tropical cyclone activity which occurred in 2009. A below-average season was experienced for all tropical cyclone parameters. See page 4 for acronym definitions.

3 Individual 2009 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2009 season. Figure 1 shows the tracks of all of this season's tropical cyclones, and Table 1 gives statistics for each of these tropical cyclones. Online entries from Wikipedia (http://www.wikipedia.org) were very helpful in putting together these tropical cyclone summaries. One unusual characteristic of the 2009 hurricane season was that five of the nine tropical cyclones that formed this year died over tropical waters. This typically only happens in years characterized by strong vertical shear in the deep tropics, which was observed this year due largely to the moderate El Niño event that developed.

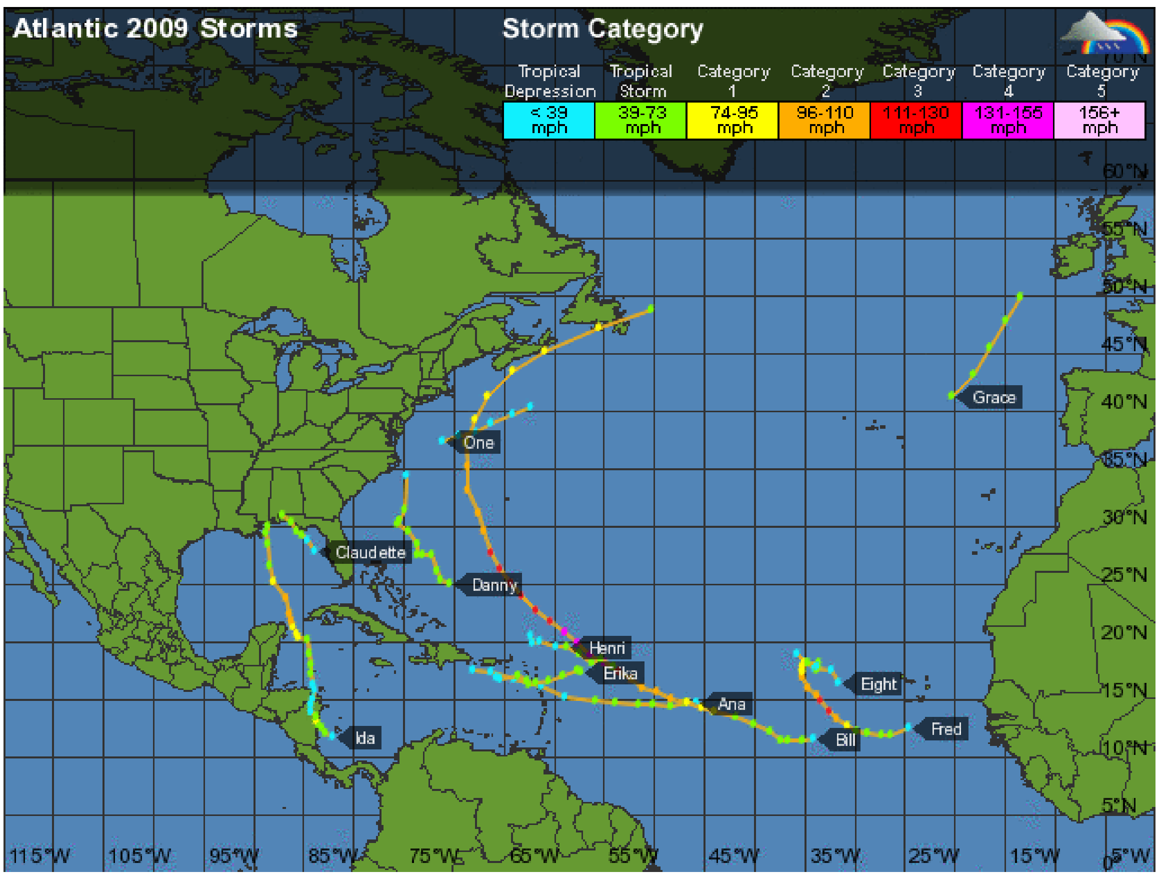

Figure 1: Tracks of 2009 Atlantic Basin tropical cyclones. Figure courtesy of Weather Underground (http://www.wunderground.com).

Table 1: Observed 2009 Atlantic basin tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	MHD	ACE	NTC
TS	Ana	August 15 – 16	35 kt/1004 mb	1.25			0.6	2.2
MH-4	Bill	August 15 – 24	115 kt/943 mb	8.75	7.00	2.75	26.1	28.7
TS	Claudette	August 16 – 17	45 kt/1006 mb	0.75			0.5	2.0
TS	Danny	August 26 – 29	5 0 kt/1006 mb	2.75			1.9	2.7
TS	Erika	September 1 – 3	50 kt/1004 mb	2.00			1.3	2.4
MH-3	Fred	September 8 – 12	105 kt/958 mb	4.75	2.75	0.50	9.8	17.0
TS	Grace	October 5 - 6	60 kt/989 mb	1.25			1.4	2.2
TS	Henri	October 6 – 7	45 kt/1005 mb	1.25			0.8	2.2
H-2	Ida	November 4 – 10	90 kt/979 mb	4.50	1.50		7.4	7.1
Totals				27.25	11.25	3.25	49.8	66.3

Tropical Storm Ana: Ana formed on August 11 from a tropical wave in the eastern tropical Atlantic (Figure 2). Strong easterly shear hindered the system's development for the next several days. After being briefly downgraded to an open wave, Ana strengthened into a tropical storm on August 15 as the vertical shear relaxed considerably. Ana moved very quickly across the tropical Atlantic as it was steered by strong trade wind flow. However, subsiding air and persistent vertical shear exposed the low-level circulation, and Ana was downgraded to a remnant low on August 16. Ana was not responsible for any deaths, and damage from the system was minimal.

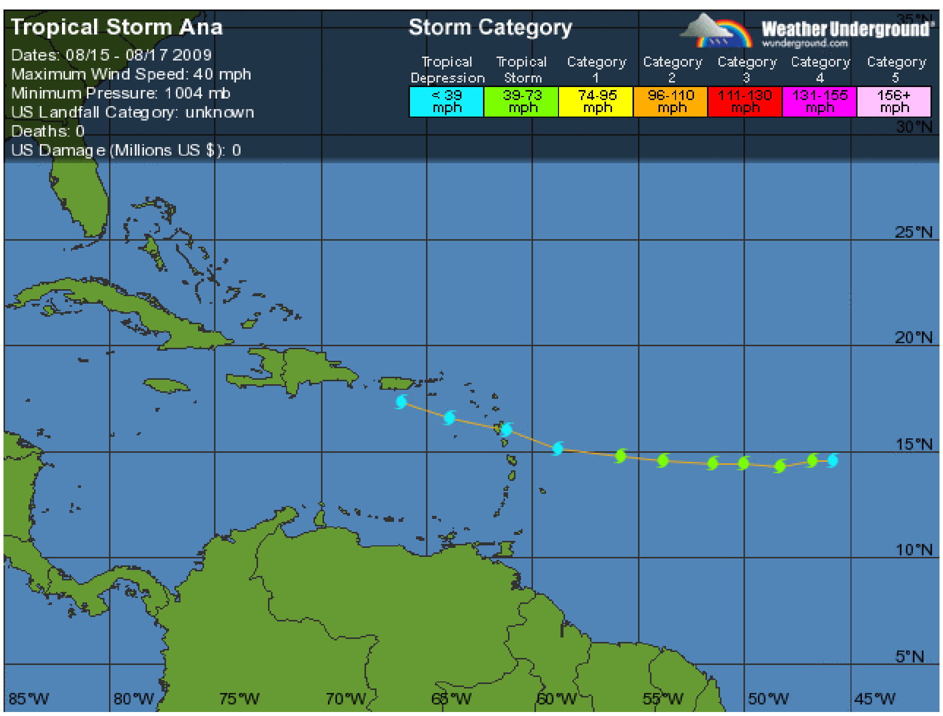

Figure 2: Track of Tropical Storm Ana. Figure courtesy of Weather Underground.

Major Hurricane Bill: Bill formed from an area of low pressure in the eastern tropical Atlantic on August 15 and intensified into a tropical storm later that day (Figure

3). It tracked west-northwestward while gradually strengthening in a favorable environment of low shear and warm sea surface temperatures. Bill became the first hurricane of the 2009 season on August 17. Bill rapidly intensified on August 18 and became a major hurricane that evening. It continued to track northwestward around the western periphery of the Bermuda/Azores High and briefly reached Category Four intensity on the Saffir-Simpson scale. Some fluctuations in intensity occurred over the next couple of days, but Bill remained a major hurricane until August 21 when it weakened, largely due to an eyewall replacement cycle. A trough along the eastern United States steered Bill northward and then northeastward. Bill began to weaken as it encountered stronger vertical shear and cooler SSTs. It began to undergo extra-tropical transition as it brushed by the eastern part of Nova Scotia and was classified as extra-tropical on August 24 just after traversing eastern Newfoundland. Bill was responsible for two direct fatalities, while damage from the system was minimal.

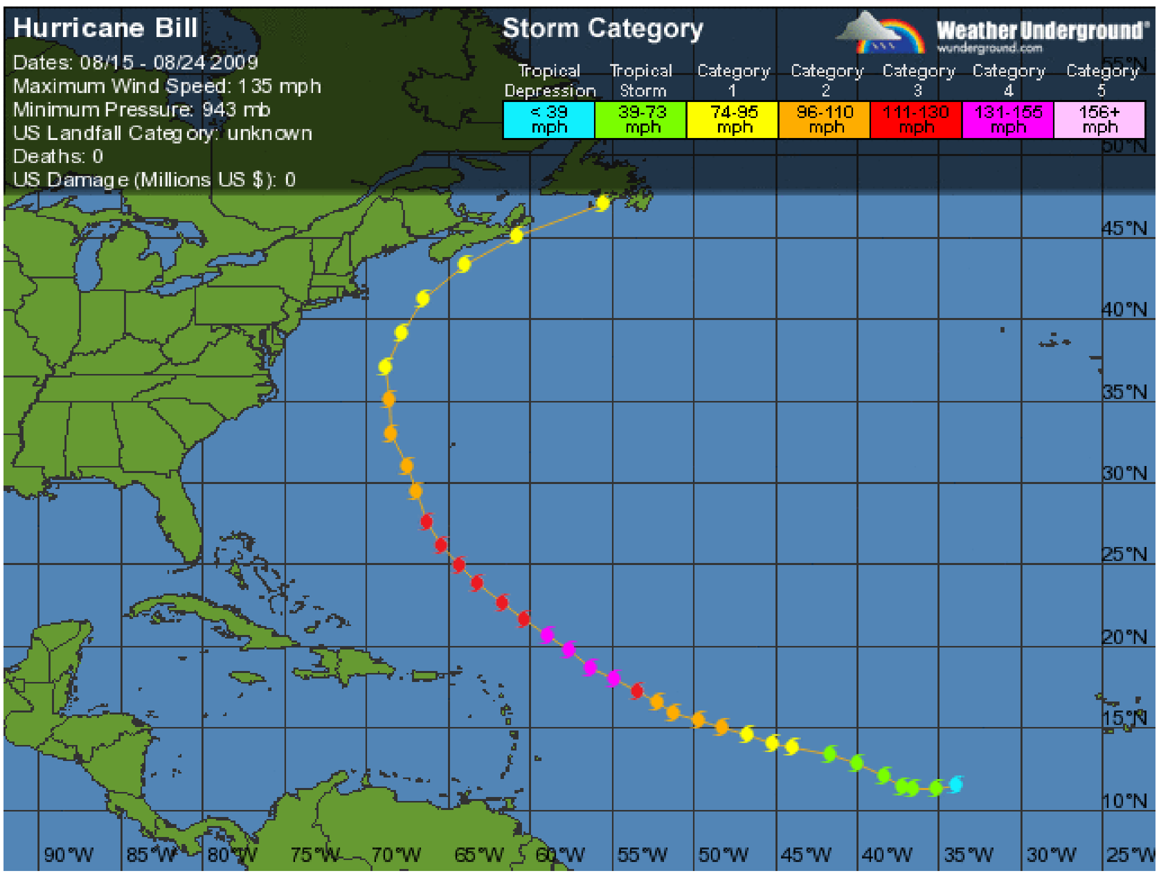

Figure 3: Track of Hurricane Bill. Figure courtesy of Weather Underground.

<u>Tropical Storm Claudette</u>: Claudette formed from an area of low pressure in the eastern Gulf of Mexico on August 16 (Figure 4). It was upgraded to a tropical storm later that day as it approached the Florida Panhandle. The system made landfall near Fort Walton Beach early on August 17 with maximum sustained winds estimated at 45 knots. It rapidly weakened over land and was downgraded to a tropical depression while located over southern Alabama. Claudette was responsible for two deaths, while damage from

the system was minimal. Claudette was one of two systems to make U.S. landfall this year.

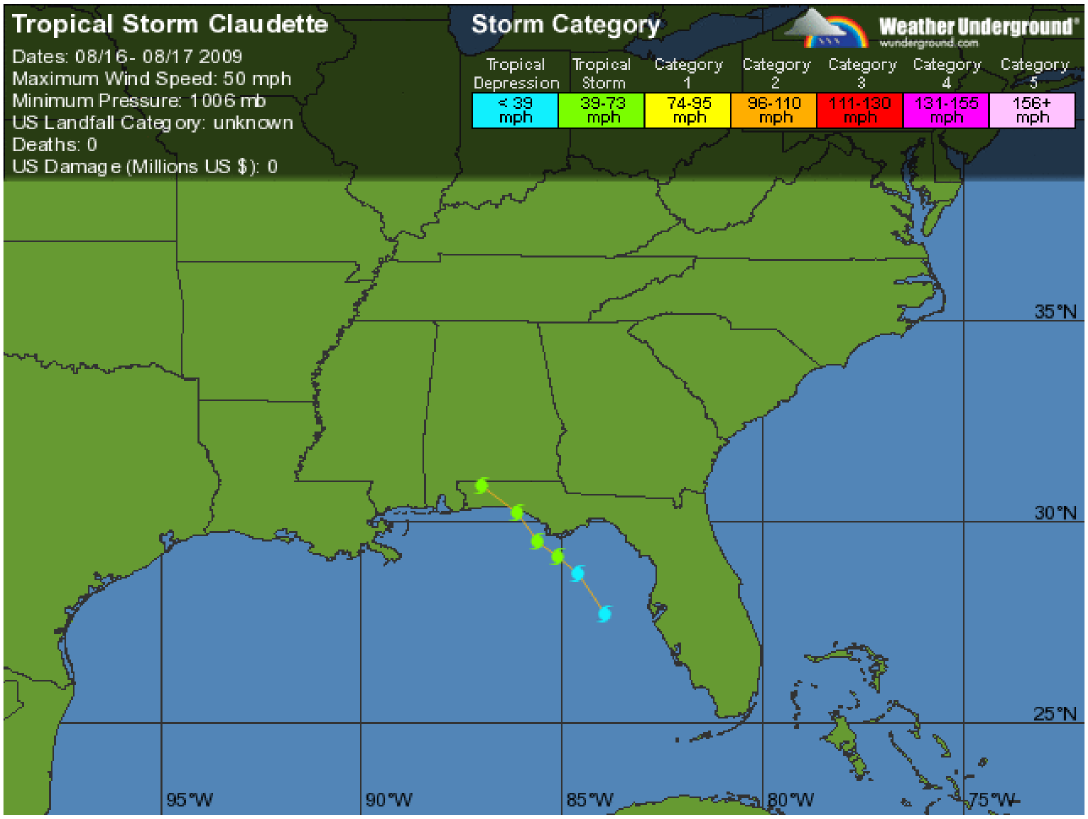

Figure 4: Track of Tropical Storm Claudette. Figure courtesy of Weather Underground.

<u>Tropical Storm Danny</u>: Danny formed from an area of disturbed weather east of the Bahamas on August 26 (Figure 5). It generally tracked northwestward over the next day as it was steered between a subtropical ridge and a mid-level low along the northern Gulf Coast. The system was quite disorganized with the deep convection often removed considerably from the center of the circulation. It reached its maximum intensity of 50 knots on August 27. An upper-level trough caused strong southwesterly vertical shear, and Danny weakened to a minimal tropical storm by August 28. By August 29, Danny was absorbed by a frontal low developing off of the North Carolina coast. It was responsible for one fatality.

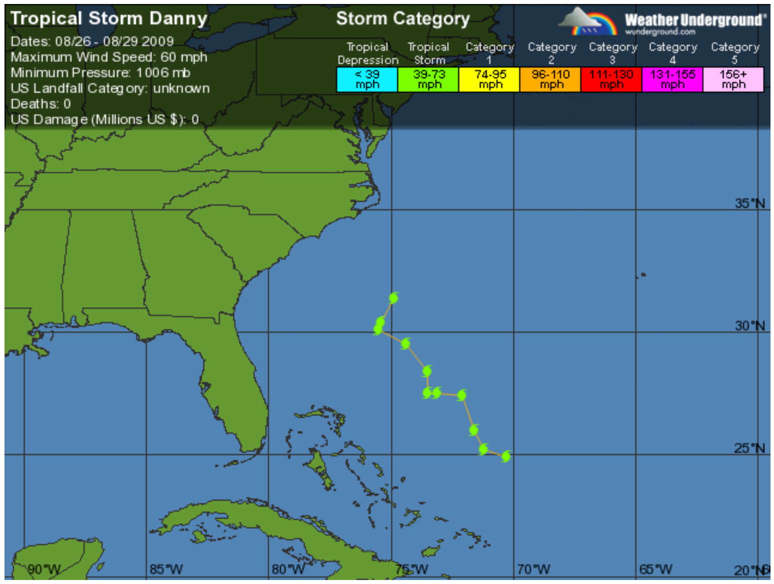

Figure 5: Track of Tropical Storm Danny. Figure courtesy of Weather Underground.

Tropical Storm Erika: Erika formed from an area of low pressure east of the Leeward Islands on September 1 (Figure 6). It reached its maximum intensity of 50 knots later that day. Moderate westerly vertical shear disrupted deep convection near the center of Erika, and by September 2, the system had weakened considerably. Erika passed over Guadeloupe and entered the Caribbean Sea later that day. The center of the circulation became exposed on September 3, and Erika was downgraded to a tropical depression at this point. No fatalities were reported from the storm, and damage was minimal.

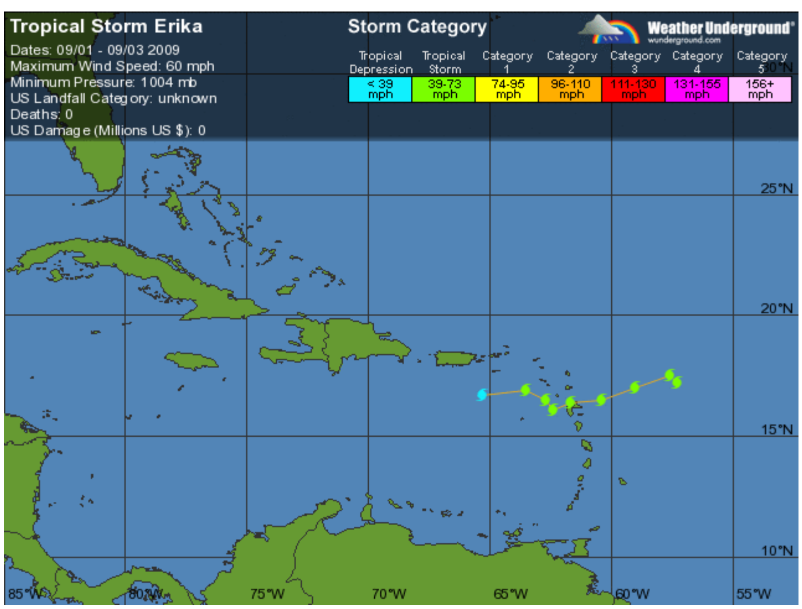

Figure 6: Track of Tropical Storm Erika. Figure courtesy of Weather Underground.

Major Hurricane Fred: Fred developed from a tropical wave while located south of the Cape Verde Islands (Figure 7). It was upgraded to the sixth tropical storm of the year early on September 8. The system strengthened into a hurricane by early on September 9 while located in a favorable environment of low vertical shear and warm waters. It rapidly intensified into a major hurricane later that day while tracking northwestward due to a mid-level ridge to its north. By late on September 9, the system began to weaken as it ingested dry air and encountered stronger southwesterly shear. A strong upper-level trough to the west of Fred pummeled the system with continuous strong vertical shear for the next couple of days. By late on September 11, it was downgraded to a tropical storm while drifting in an area of very weak steering currents. Persistent shear and dry air at mid-levels caused the system to weaken to a tropical depression on September 12. Fred was the third storm in recorded history to reach major hurricane status east of 35°W. No fatalities or damage were reported from Fred.

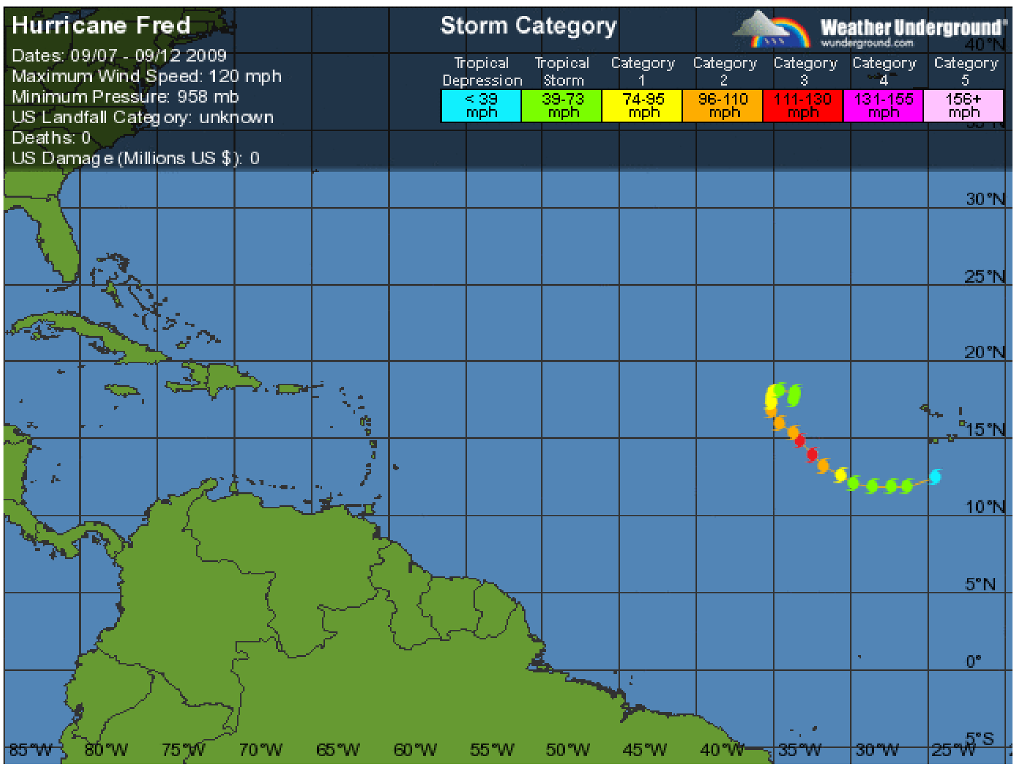

Figure 7: Track of Hurricane Fred. Figure courtesy of Weather Underground.

Tropical Storm Grace: Grace formed from a non-tropical area of low pressure northeast of the Azores Islands, a very atypical location for tropical cyclone development (Figure 8). The low was originally associated with an occluded front but gradually lost its frontal structure and was therefore characterized as a tropical storm on October 4. It tracked northeastward while embedded in southwesterly flow over the next 24 hours. It reached its maximum intensity of 60 knots early on October 5. By early on October 6, it merged with a frontal boundary while located over the far northeastern Atlantic. Grace was not responsible for any fatalities, and damage from the system was minimal.

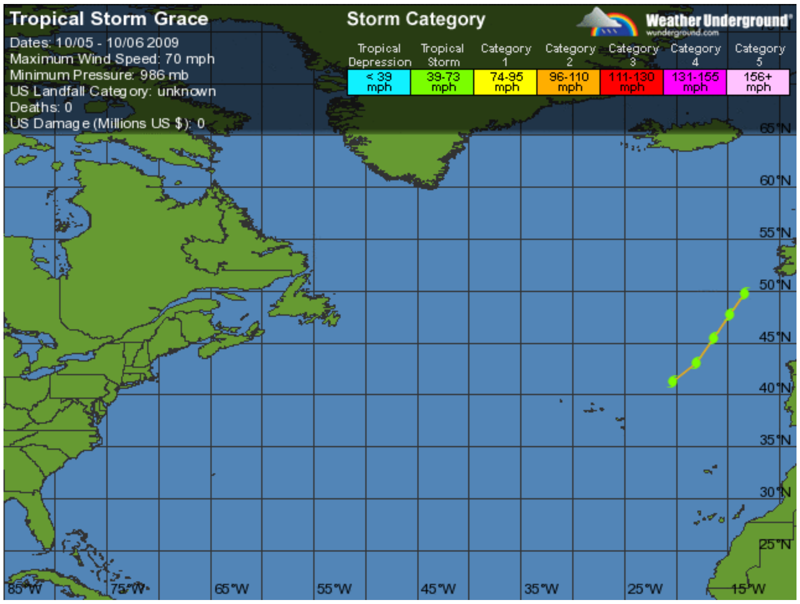

Figure 8: Track of Tropical Storm Grace. Figure courtesy of Weather Underground.

Tropical Storm Henri: Henri formed from an area of low pressure while located east of the Leeward Islands on October 6 (Figure 9). The system developed despite very strong southwesterly vertical shear Henri intensified into a 45-knot tropical storm on October 7 while traveling westward underneath a sub-tropical ridge. However, the persistent strong vertical shear eventually weakened the system to a tropical depression early on October 8. No damage or deaths were reported from Henri.

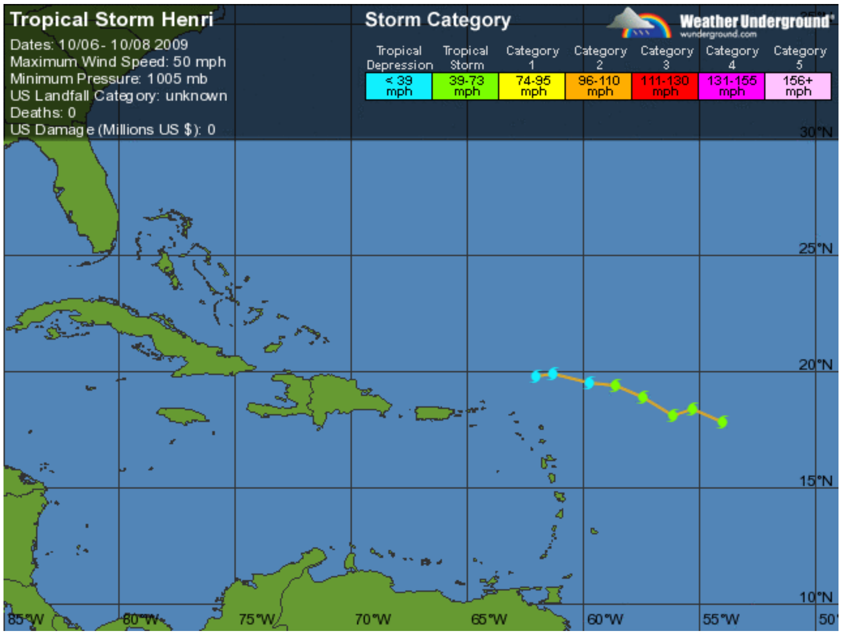

Figure 9: Track of Tropical Storm Henri. Figure courtesy of Weather Underground.

<u>Hurricane Ida</u>: Ida formed from an area of low pressure in the southwest Caribbean on November 4 (Figure 10). The system strengthened quickly into a tropical storm later in the day as it headed northwest towards Nicaragua. It briefly reached hurricane status before making landfall on November 5. Ida dropped copious amounts of rain on Honduras and Nicaragua. It weakened to a tropical depression while drifting northward over Nicaragua on November 6. A deep trough over Mexico steered Ida northward over Honduras and into the northwest Caribbean Sea. Once over the warm waters of the Caribbean, Ida re-strengthened into a tropical storm on November 7 and into a hurricane on November 8. The system briefly reached its maximum intensity of 90 knots before strong southwesterly shear began to displace the low level-circulation. By November 9, Ida weakened back to a tropical storm as it moved northward towards the Gulf Coast. Ida slowed as it approached the coastline and weakened to a minimal tropical storm before making landfall near Dauphin Island, Alabama with maximum sustained winds near 40 knots. It underwent extra-tropical transition later that day. Ida is the second latest tropical cyclone to make Gulf Coast landfall, trailing only Hurricane Kate in 1985 which made landfall on November 21.

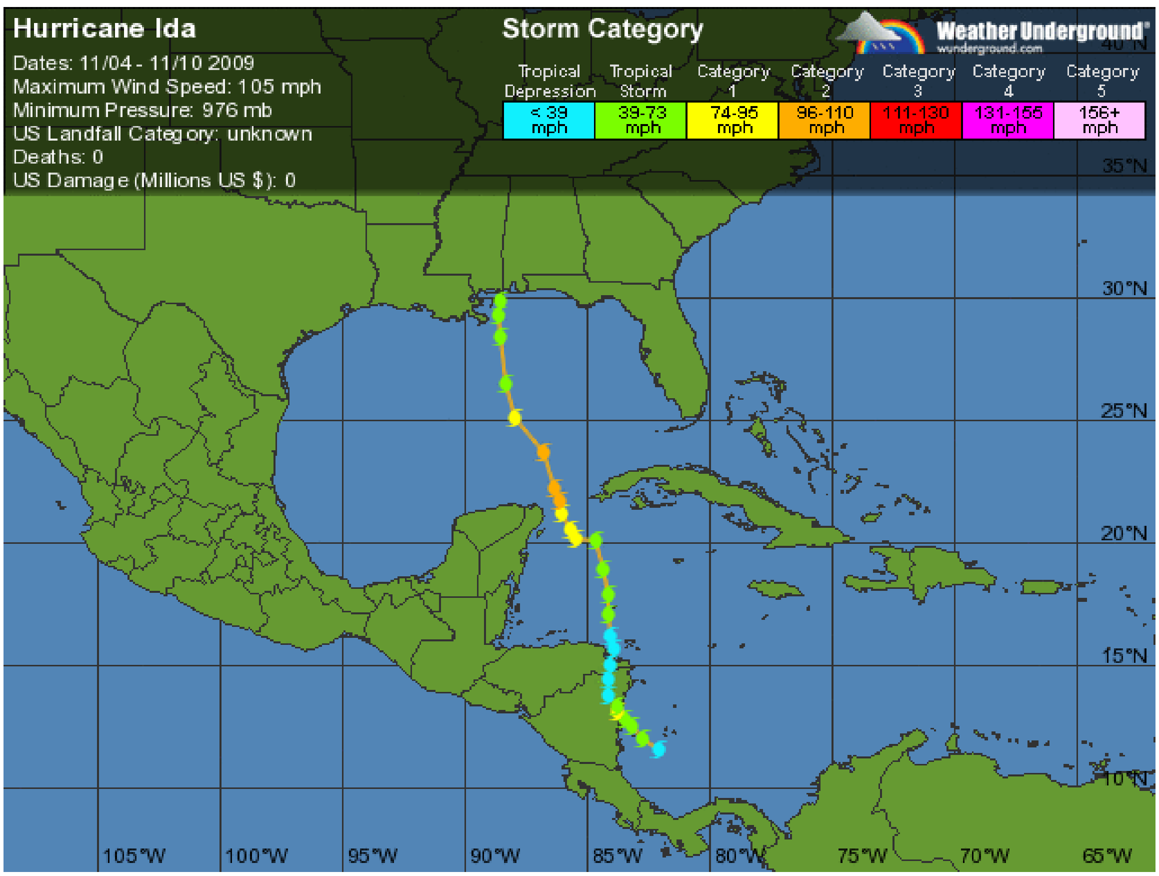

Figure 10: Track of Hurricane Ida. Figure courtesy of Weather Underground.

U.S. Landfall. Figure 11 shows the tracks of Claudette and Ida, the two tropical cyclones that made U.S. landfall this year. Only minimal damage was reported from both Claudette and Ida.

Figure 11: Tropical cyclones making U.S. landfall (Tropical Storm Claudette and Tropical Storm Ida).

4 Special Characteristics of the 2009 Hurricane Season

The 2009 hurricane season had the following special characteristics:

- A late-starting season. Ana did not form until August 15. This was the latest 'A' storm of the season since Andrew formed in 1992 on August 17.

- Nine named storms occurred during 2009. This is the fewest named storms in a tropical cyclone season since 1997 when eight named storms formed.

- 27.25 named storm days occurred in 2009. This is the fewest named storm days since 1991, when only 24.25 named storm days were recorded.

- Three hurricanes occurred in 2009. This is the fewest hurricanes in a tropical cyclone since 1997 when there were also three hurricanes.

- Five named storms (Ana, Danny, Erika, Fred, and Henri) dissipated over the open ocean in the tropical and sub-tropical Atlantic this year. This is a fairly rare occurrence that typically only occurs in years such as this year that are characterized by high levels of tropospheric vertical wind shear.

- 11.25 hurricane days occurred in 2009. This is the fewest hurricane days since 2002 when 10.75 hurricane days were reported.

- 2 major hurricanes formed during the 2009 hurricane season. The last time that fewer than two major hurricanes occurred in a season was in 1997 when only one major hurricane (Erika) formed.

- 3.25 major hurricane days occurred in 2009. This is the fewest major hurricane days in a season since 2006 when only two major hurricane days were recorded.

- The season accrued an ACE of 50. This is the lowest ACE since 1997 (41) and the 16th lowest of the last 66 years since the aircraft reconnaissance era began in 1944.

- The season accumulated 66 NTC units. This is the lowest NTC since 1997 (54) and the 16th lowest of the last 66 years.

- No Category 5 hurricanes developed in 2009. This is the second consecutive year with no Category 5 hurricanes. The last time that two or more years occurred in a row with no Category 5 hurricanes was 1999-2002.

- No named storms formed in June or July. The last time that no storm activity occurred in June or July was 2004 (Alex formed that year on August 1). This is the 18th year of the past 66 years with no storm formations in June or July.

- August had above-average ACE activity. 29 ACE units were recorded during the month, which is approximately 125% of the 1950-2000 average.

- 58% of seasonal ACE was generated during the month of August. The last time that more than 58% of seasonal ACE was generated during the month of August was in 1942.

- September was very quiet with only 11 ACE units generated during the month. This is the quietest September since 1994 when only 3 ACE units were recorded.

- No ACE was generated between September 13 and October 4. The last time that this occurred was 1991. Prior to that, one has to go all the way back to 1925 to see no ACE generated during three of the most active weeks of the Atlantic hurricane season.

- October was also very quiet with only 2 ACE units occurring. This is the quietest October since 1994 when no tropical cyclone activity occurred.

- Only 13 ACE units occurred during the combined September-October period. This is the fewest ACE units during this two-month period since 1994 (3), and the fifth fewest since the aircraft reconnaissance era began in 1944.

- Hurricane Bill generated 26 ACE units, or 52% of the seasonal total. The last time that one storm generated that much of the seasonal total was Erika in 1997 which generated 63% of the total ACE observed that year.

- Hurricane Fred became the third storm on record to reach major hurricane status east of 35°W, although prior to 1972 when Dvorak satellite estimates from polar-orbiting satellite reconnaissance became routinely available, some storms may have been missed in the eastern part of the Atlantic basin.

- Hurricane Ida became only the second hurricane to reach hurricane status in the Caribbean in November during an El Niño year (where El Niño is defined to be all years since 1950 where the October Nino 3.4 SST anomaly is 0.5°C or greater). The only other storm to reach hurricane status in the Caribbean in November in an El Niño year was Martha in 1969.

- Ida became the second latest tropical cyclone to make landfall along the Gulf Coast, trailing only Hurricane Kate in 1985 (which made landfall on November 21).

- Only two tropical storms (Claudette and Ida) made U.S. landfall this year while no hurricanes made U.S. landfall. This is the first time since 2006 and the 13^{th} time in the last 66 years where no hurricanes made U.S. landfall.

- No hurricanes made landfall along the Florida Peninsula and East Coast. This marks the fourth year in a row with no hurricane landfalls along this portion of the U.S. coastline. The last time that we went four years between hurricane landfalls along the Florida Peninsula and East Coast was 1980-1983.

- No major hurricanes made U.S. landfall this year. Following seven major hurricane landfalls in 2004-2005, the U.S. has not witnessed a major hurricane landfall in the past four years. The four consecutive years between 2000-2003 also experienced no major U.S. hurricane landfalls. Since 1995, the Atlantic basin has had 56 major hurricanes but only 10 (18%) have made U.S. landfall. The long-period average is that approximately 30% of major hurricanes that form in the Atlantic basin make U.S. landfall.

5 Verification of Individual 2009 Lead Time Forecasts

Table 3 is a comparison of our 2009 forecasts for four different lead times along with this year's observations. The June and August forecasts verified reasonably well, while our earlier seasonal forecasts were not particularly successful because of our uncertainty that a significant El Niño would develop this year. Our forecasts all trended downward as we became more confident that an El Niño event was likely to form.

Table 4 provides the same forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts over the 1990-2007 period, using equations developed over the 1950-1989 period. We typically expect to see 2/3 of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values. We issued predictions for eight indices at four different lead times (32 predictions). Of these predictions, 20 of 32 (63%) forecasts were within one standard deviation of observations, and all forecasts were within two standard deviations of observations. Most of our early June and early August forecast parameters verified within one standard deviation. We consider this season's early June and early August forecasts to be reasonably successful. Note how the number of forecast parameters within one standard deviation of observations improved from 2 to 4 to 7 as the forecast date moved from early December to early April and then to our early June and early August forecasts.

Table 3: Verification of our 2009 seasonal hurricane predictions.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	10 Dec 2008	Update 9 April 2009	Update 2 June 2009	Update 4 Aug 2009	Observed 2009 Total
Named Storms (NS) (9.6)	14	12	11	10	9
Named Storm Days (NSD) (49.1)	70	55	50	45	27.25
Hurricanes (H) (5.9)	7	6	5	4	3
Hurricane Days (HD) (24.5)	30	25	20	18	11.25
Intense Hurricanes (IH) (2.3)	3	2	2	2	2
Intense Hurricane Days (IHD) (5.0)	7	5	4	4	3.25
Accumulated Cyclone Energy (ACE) (96.2)	125	100	85	80	50
Net Tropical Cyclone Activity (NTC) (100%)	135	105	90	85	66

Table 4: Verification of our 2009 seasonal hurricane predictions with error bars (one standard deviation). Predictions that lie within one standard deviation of observations are highlighted in red bold font, while predictions that lie within two standard deviations are highlighted in green bold font. In general, we expect that 2/3 of our forecasts should lie within one standard deviation of observations, with 95% of our forecasts lying within two standard deviations of observations. Error bars for storms are rounded to the nearest storm. For example, the hurricane prediction in early August would be 2.2-5.8, which with rounding would be 2-6.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	10 Dec 2008	Update 9 April 2009	Update 2 June 2009	Update 4 Aug 2009	Observed 2009 Total
Named Storms (NS) (9.6)	**14** (±4.4)	**12** (±4.0)	**11** (±3.8)	**10** (±3.3)	9
Named Storm Days (NSD) (49.1)	**70** (±23.9)	**55** ±(19.4)	**50** (±18.3)	**45** (±16.3)	27.25
Hurricanes (H) (5.9)	**7** (±2.5)	**6** (±2.2)	**5** (±2.1)	**4** (±1.8)	3
Hurricane Days (HD) (24.5)	**30** (±12.4)	**25** (±9.5)	**20** (±9.0)	**18** (±8.8)	11.25
Intense Hurricanes (IH) (2.3)	**3** (±1.5)	**2** (±1.4)	**2** (±1.2)	**2** (±1.2)	2
Intense Hurricane Days (IHD) (5.0)	**7** (±4.7)	**5** (±4.4)	**4** (±4.5)	**4** (±4.6)	3.25
Accumulated Cyclone Energy (ACE) (96.2)	**125** (±50)	**100** (±39)	**85** (±39)	**80** (±37)	50
Net Tropical Cyclone Activity (NTC) (100%)	**135** (±49)	**105** (±41)	**90** (±37)	**85** (±33)	66

5.1 Preface: Aggregate Verification of our Last Eleven Yearly Forecasts

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 eleven years. In general, our forecasts are successful at forecasting whether the season will be more or less active than the average season by as early as December of the previous year. We tend to have improving skill as we get closer in time to the start of the hurricane season.

Table 5: The number of years that our tropical cyclone forecasts issued at various lead times has correctly predicted above- or below-average activity for each predictand over the past eleven years (1999-2009).

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	8/11	9/11	9/11	8/11
NSD	8/11	9/11	9/11	9/11
H	7/11	8/11	9/11	9/11
HD	6/11	7/11	8/11	9/11
IH	6/11	7/11	9/11	9/11
IHD	7/11	8/11	10/11	10/11
NTC	6/11	7/11	8/11	9/11
Total	**48/77 (62%)**	**55/77 (71%)**	**62/77 (81%)**	**63/77 (82%)**

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 some interest. In addition, we have recently redesigned all our statistical forecast methodologies using more rigorous physical and statistical tests which we believe will lead to more accurate forecasts in the future. Complete verifications of all seasonal forecasts are available online at http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls. Verifications are currently available for all of our prior seasons from 1984-2008.

5.2 Verification of 15-Day Forecasts

This is the first year that we issued fifteen-day forecasts of tropical cyclone activity starting in early August. We decided to discontinue our individual monthly forecasts. These fifteen-day forecasts were based on a combination of observational and modeling tools. The primary tools that were used for these forecasts were: 1) current storm activity, 2) National Hurricane Center Tropical Weather Outlooks, 3) forecast output from global models, 4) the current and projected state of the Madden-Julian Oscillation (MJO) and 5) the current seasonal forecast.

The metric that we tried to predict with these fifteen-day forecasts was the Accumulated Cyclone Energy (ACE) index, which is defined to be the square of the named storm's maximum wind speeds (in 10^4 knots^2) for each 6-hour period of its existence over the fifteen-day forecast period. These forecasts were judged to be too short in length to show significant skill for individual event parameters such as named storms and hurricanes. We issued forecasts for ACE using three categories as defined in Table 6.

Table 6: ACE forecast definition for 15-day forecasts.

Parameter	Definition
Above-Average	Greater than 130% of Average ACE for the 15-Day Period
Average	70% - 130% of Average ACE for the 15-Day Period
Below-Average	Less than 70% of Average ACE for the 15-Day Period

Table 7 displays the six fifteen-day forecasts that were issued during the 2009 hurricane season and shows their verification. The first two forecasts did not verify well, while forecasts three through five verified quite well. We also over-predicted activity with our final 15-day forecast, due to the fact that we thought the favorable MJO phase during that time period would lead to enhanced levels of activity compared with what was observed. However, Ida formed on the last day of our October 21 forecast period and later became a Category 2 hurricane.

Table 7: 15-day forecast verification for 2009. Forecasts that verified in the correct category are highlighted in blue, forecasts that missed by one category are highlighted in green, while forecasts that missed by two categories are highlighted in red.

Forecast Day	Predicted ACE	Observed ACE
8/5/2009	**Below-Average (6 or Less)**	**17**
8/20/2009	**Above-Average (27 or More)**	**13**
9/4/2009	**Below-Average (19 or Less)**	**10**
9/19/2009	**Below-Average (11 or Less)**	**0**
10/6/2009	**Below-Average (6 or Less)**	**1**
10/21/2009	**Average (3.5 – 6.5)**	**2**

One of the primary challenges with the 15-day forecasts this year was that we were largely dependent on the MJO for skill, especially during the second week portion of the forecast. As Figure 12 shows, the MJO did not show coherent propagation around the globe during August-October. It was generally of quite weak magnitude during the forecast period, and therefore, following our two August forecasts, we primarily relied upon the unfavorable seasonal parameters to issue our later 15-day forecasts. We consider these forecasts to have shown some promise, and we intend to issue two-week forecasts during August-October during the 2010 hurricane season. These forecasts will be reduced in length from 15 to 14 days in order to allow for the same issue day of the week (e.g., Wednesday).

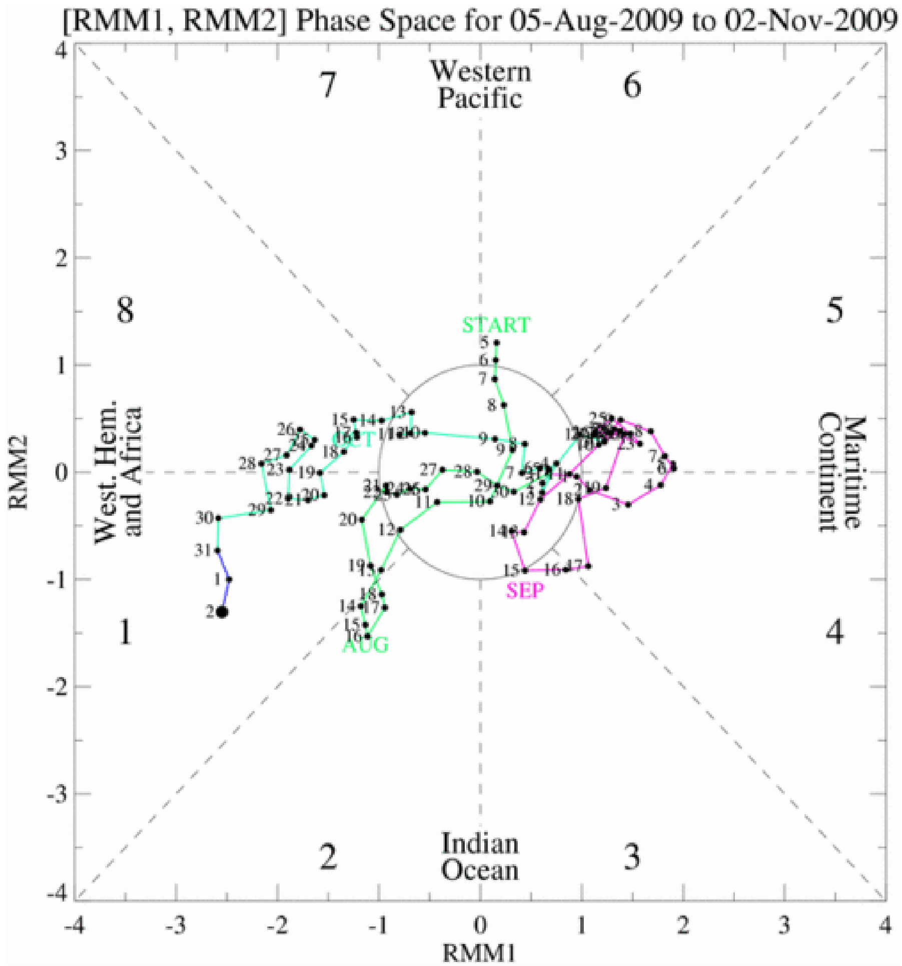

Figure 12: Propagation of the Madden-Julian Oscillation (MJO) based on the Wheeler-Hendon classification scheme over the period from August 5 through November 2. Note that coherent eastward propagation of the MJO during this timeframe was rarely evident and that the magnitude of the MJO was often quite small (e.g., located in the inner circle indicating weak MJO amplitude).

6 Landfall Probabilities

6.1 Landfall Probability Verification

Every hurricane season, we issue forecasts of the seasonal probability of hurricane landfall along the U.S. coastline. For the first time with our June forecast in 2009, we also issued probabilities of landfall for the Caribbean (10-20°N, 60-88°W) and Central America. 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, U.S. probabilities have been calculated 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 overall Atlantic basin Net Tropical Cyclone (NTC) activity and to climate trends linked to multi-decadal variations in North Atlantic SSTA. Table 8 gives verifications of our landfall probability estimates for the United States and for the Caribbean in 2009.

Landfall probabilities for the 2009 hurricane season were estimated to be above-average in early December, near average in April and slightly below-average in June and August due to our seasonal hurricane forecasts calling for above-average activity in December, near-average activity in April, and slightly below-average activity in June and August. The 2009 hurricane season was quiet from a U.S. landfall perspective, with only two tropical storms (Claudette and Ida) making U.S. landfall this year. Damage from Claudette was very minor, while damage estimates from Ida are still preliminary but appear to be quite minimal as well. Tropical Storm Erika and Hurricane Ida passed through the Caribbean in 2009, while Hurricane Ida made landfall in Nicaragua as a Category One hurricane.

Landfall probabilities include specific forecasts of the probability of U.S. 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 13). These 11 units are further subdivided into 205 coastal and near-coastal counties. During the 2009 hurricane season, probabilities of hurricanes and major hurricanes impacting each coastal state were also made available for the first time along with the Caribbean probabilities discussed in the preceding paragraphs. The climatological and current-year probabilities are available online via the Landfalling Hurricane Probability Webpage at http://www.e-transit.org/hurricane. Since the website went live on June 1, 2004, the webpage has received nearly one million hits.

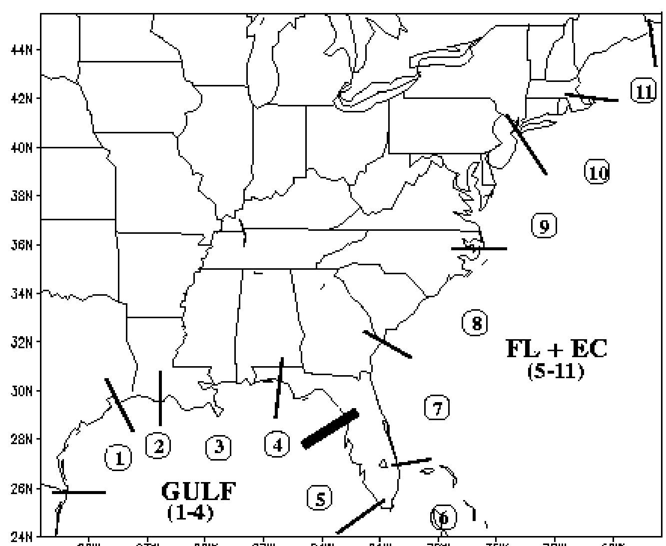

Figure 13: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

Table 8: Estimated forecast probability (percent) of one or more 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), along the Florida Peninsula and the East Coast (Regions 5-11) and in the Caribbean for 2009 at various lead times. No forecasts were issued for the Caribbean in early December and early April. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 4 August forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast, Table (c) is for the Florida Peninsula and the East Coast and Table (d) is for the Caribbean. Early August probabilities are calculated based on storms forming after 1 August.

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

	Forecast Date				
	10 Dec.	9 Apr.	2 June	4 August	Observed Number
TS	88%	81%	76%	74% (80%)	2
HUR (Cat 1-2)	78%	69%	64%	62% (68%)	0
HUR (Cat 3-4-5)	63%	54%	48%	46% (52%)	0
All HUR	92%	86%	81%	79% (84%)	0
Named Storms	99%	97%	95%	95% (97%)	2

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

	Forecast Date				
	10 Dec.	9 Apr.	2 June	4 August	Observed Number
TS	70%	60%	55%	53% (59%)	2
HUR (Cat 1-2)	52%	44%	39%	37% (42%)	0
HUR (Cat 3-4-5)	38%	31%	28%	26% (30%)	0
All HUR	71%	62%	56%	54% (61%)	0
Named Storms	91%	85%	80%	78% (83%)	2

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

	Forecast Date				
	10 Dec.	9 Apr.	2 June	4 August	Observed Number
TS	61%	52%	47%	45% (51%)	0
HUR (Cat 1-2)	54%	46%	41%	39% (45%)	0
HUR (Cat 3-4-5)	39%	32%	28%	27% (31%)	0
All HUR	72%	63%	57%	55% (62%)	0
Named Storms	89%	82%	77%	75% (81%)	0

(d) Caribbean (10-20°N, 60-88°W)

Forecast Date

	10 Dec.	9 Apr.	2 June	4 August	Observed Number
TS	---	---	79%	77% (82%)	2
HUR (Cat 1-2)	---	---	53%	51% (57%)	0
HUR (Cat 3-4-5)	---	---	39%	37% (42%)	0
All HUR	---	---	71%	69% (75%)	0
Named Storms	---	---	94%	93% (96%)	2

6.2 Interpretation of Landfall Probabilities

We never intended that our seasonal forecasts be used for individual-year landfall predictions. It is impossible to predict months in advance the mid-latitude flow patterns that dictate U.S. and Caribbean hurricane landfall. We only make predictions of the probability of landfall. Our landfall probability estimates work out very well when we compare 4-5 of our forecasts for active seasons versus 4-5 forecasts for inactive seasons. This is especially the case for landfalling major hurricanes.

High seasonal forecasts of Net Tropical Cyclone activity (NTC) (see Tables 9 and 10) should be interpreted as a higher probability of U.S. or Caribbean landfall but not necessarily that landfall will occur that year. Low seasonal forecasts of NTC do not mean that landfall will not occur but only that its probability is lower than average during that year.

The majority of U.S. landfalling tropical cyclones and Caribbean activity occurs during active Atlantic basin seasons, with below-average Atlantic basin hurricane seasons typically having below-average U.S. and Caribbean hurricane landfall frequency. This is particularly the situation for the Florida Peninsula and the East Coast and the Caribbean.

Table 9 gives observed high to low rankings of NTC for the last 60 (1950-2009) years in association with landfall frequency. Data is broken into numbers of landfalling tropical storms (TS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (MH). Note that high NTC years have substantially increased hurricane landfall numbers, particularly for major hurricanes when compared with low NTC years.

The relationship between Atlantic basin NTC and U.S. landfall is especially strong for major hurricane landfall along Peninsula Florida and the East Coast (Regions 5-11). The Gulf Coast landfall – NTC relationship is weaker except for the most active versus least active seasons. The relationship between NTC and Caribbean major hurricane activity is also quite strong.

Table 10 contrasts the observed U.S. landfall and Caribbean activity ratios associated with our high vs. low 1 June NTC hindcast values for the years of 1950-2009. This table also contrasts the upper 10, upper 20 and upper 30 hindcast NTC values vs. the lowest 10, lowest 20 and lowest 30 hindcast NTC values. Note the very high ratio of U.S. and Caribbean landfall differences between the highest and the lowest values of our 1 June NTC hindcasts. These hindcast differences are especially large for major (Cat 3-4-5) hurricanes which on a normalized (coastal population, inflation, wealth per capita) basis cause about 80-85 percent of hurricane-spawned destruction. It is fortunate that our most skillful 1 June NTC hindcasts best differentiate between the most intense and most destructive landfalling hurricanes. Tropical storm landfall frequencies are not nearly as well related to our 1 June hindcast NTC values.

Our 1 June NTC hindcasts work almost as well at specifying the probability of U.S. landfall for the Florida Peninsula and the East Coast (Regions 5-11) as well as the Caribbean as do the NTC observations. U.S. Gulf Coast landfall is less related to either observed or hindcast NTC.

Table 9: Observed landfall of named storms (NS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (MH) by high versus low **observed** values of Atlantic basin Net Tropical Cyclone (NTC) activity. Values are separately given for the Gulf Coast, the Florida Peninsula and East Coast, the whole U.S. coastline and the Caribbean for the 60-year period from 1950-2009.

	Gulf Coast (Regions 1-4)			Florida + East Coast (Regions 5-11)			Whole US (Regions 1-11)			Caribbean (10-20°N, 60-88°W)		
NTC Values	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***
Top 10 Observed NTC years > 180	20	12	9	31	21	8	51	33	17	51	33	18
Bot 10 Observed NTC years ≤ 52	10	4	1	12	5	1	22	9	2	12	2	1
Top 20 Observed NTC years > 129	41	21	10	41	24	9	82	45	19	88	55	30
Bot 20 Observed NTC years ≤ 83	23	9	4	17	8	3	40	17	7	29	10	4
Top 30 Observed NTC years ≥ 97	54	30	12	64	35	14	118	65	26	123	69	39
Bot 30 Observed NTC years < 97	48	19	8	37	18	7	85	37	15	47	18	7

Table 10: Observed landfall of named storms (NS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (MH) based on high versus low 1 June **hindcast** values of Net Tropical Cyclone (NTC) activity for the Gulf Coast, the Florida Peninsula and East Coast, the whole U.S. coastline and the Caribbean for the 60-year period from 1950-2009.

	Gulf Coast (Regions 1-4)			Florida + East Coast (Regions 5-11)			Whole US (Regions 1-11)			Caribbean (10-20°N, 60-88°W)		
NTC Values	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***	***NS***	***H***	***MH***
Top 10 Hindcast NTC years > 155	24	14	6	32	18	7	56	32	13	49	28	20
Bot 10 Hindcast NTC years ≤ 55	13	8	4	10	6	1	23	14	5	15	5	3
Top 20 Hindcast NTC years > 118	42	21	9	50	29	11	92	50	20	86	52	27
Bot 20 Hindcast NTC years ≤ 88	26	14	7	22	10	2	48	24	9	35	14	7
Top 30 Hindcast NTC years ≥ 102	59	26	11	65	39	17	124	65	28	110	63	32
Bot 30 Hindcast NTC years < 102	43	23	9	36	14	4	79	37	13	60	24	14

But more important than our last 26 years of early June forecasts of the numbers of NS and H is the implication of what these forecasts say as to the probability of U.S. and Caribbean landfall. Higher than average 1 June NTC forecasts are associated with a greater frequency of seasonal NS, H and MH landfall events and lower 1 June NTC forecasts are associated with less frequent NS, H and MH landfall events.

Table 11 shows the number of landfalling tropical cyclones which occurred in our 10 most active forecasts when our real time projects' 1 June prediction of the number of hurricanes was 8 or higher versus those 10 years when our 1 June prediction of the seasonal number of hurricanes was 6 or less. Notice the 3 to 1 difference in landfall of major hurricanes and the nearly 2 to 1 difference in landfalling Cat 1-2 hurricanes for the entire United States. The ratios for the Caribbean are similar, with a greater than 3 to 1 ratio for Caribbean major hurricanes.

Table 11: Number of U.S. and Caribbean landfalling tropical cyclones in the 10 years when our 1 June forecast was for 8 or more hurricanes versus those 10 years when our 1 June prediction was for 6 or fewer hurricanes.

Forecast H	US NS	US H	US MH	Caribbean NS.	Caribbean. H	Caribbean MH
≥ 8 (10 years)	56	29	12	43	23	14
≤ 6 (10 years)	34	15	4	24	14	4

Our individual season forecasts of the last 26 years have had meaning as regards to the multi-year probability of US and Caribbean landfall. Higher statistical relationships are found with our real-time forecasts from 1 August.

7 Summary of 2009 Atmospheric/Oceanic Conditions

In this section, we go into detail discussing large-scale conditions that were present in the atmosphere and in the oceans during the 2009 Atlantic basin hurricane season.

7.1 ENSO

As is usually the case, El Niño-Southern Oscillation (ENSO) presented a significant challenge with our 2009 seasonal hurricane forecasts. We considered the possibility of an El Niño developing with our early December forecast and gave it an increased likelihood of developing with our early April and early June forecasts. By early August, El Niño had arrived. The following are a couple of quotes from earlier forecasts regarding El Niño this year:

(9 April 2009) -

"**We expect current weak La Niña conditions to transition to neutral and perhaps weak El Niño conditions by this year's hurricane season. If El Niño conditions develop for this year's hurricane season, it would tend to increase levels of vertical wind shear and decrease levels of Atlantic hurricane activity.**"

(2 June 2009) -

"We believe that there is a slightly greater chance of a weak El Niño developing this summer/fall then there was in early April. SST anomalies have continued to moderate since then, and the current wind/ocean heat content pattern could likely sustain a weak El Niño. At this point, we believe there is an approximately 70% chance of a weak El Niño (ASO Nino 3.4 > 0.5°C) by the August-October period."

Our definition of weak, moderate and strong El Niño events for the August-October period is based on the August-October-averaged Nino 3.4 index. When this index is between 0.5-1.0°C, we define it as a weak El Niño event, when the index is between 1.0-1.5°C, we define it as a moderate El Niño event, and when the index is greater than 1.5°C, we define it as a strong El Niño event. The August-October-averaged Nino 3.4 index in 2009 was approximately 0.9°C, or a borderline weak/moderate El Niño event.

La Niña conditions occurred during the winter of 2008-2009 and began to moderate by early 2009. In 2008, a similar moderation in SSTs was observed during the spring and summer, but unlike 2008, this year's warming continued through the summer and into the fall. Table 12 displays temperatures in the various Nino regions as observed in January, April, July and October of this year, respectively.

Table 12: January anomalies, April anomalies, July anomalies, and October anomalies in the Nino 1+2, Nino 3, Nino 3.4 and Nino 4 regions.

Region	January Anomaly (ºC)	April Anomaly (ºC)	July Anomaly (ºC)	October Anomaly (ºC)
Nino 1+2	-0.1	+0.5	+0.8	+0.0
Nino 3	-0.6	0.0	+1.0	+0.8
Nino 3.4	-1.0	-0.2	+0.9	+1.0
Nino 4	-0.7	0.0	+0.6	+1.2

Over the past few weeks, this moderation has ramped up considerably with current weekly SST anomalies greater than 1.0°C across most of the eastern and central Pacific. This recent warming is likely due to the downwelling phase of an eastward-propagating Kelvin wave that was touched off by anomalous westerly winds in the western and central tropical Pacific several weeks ago (Figure 14). We expect SSTs to warm in the eastern Pacific as the Kelvin wave reaches the west coast of South America (Figure 15).

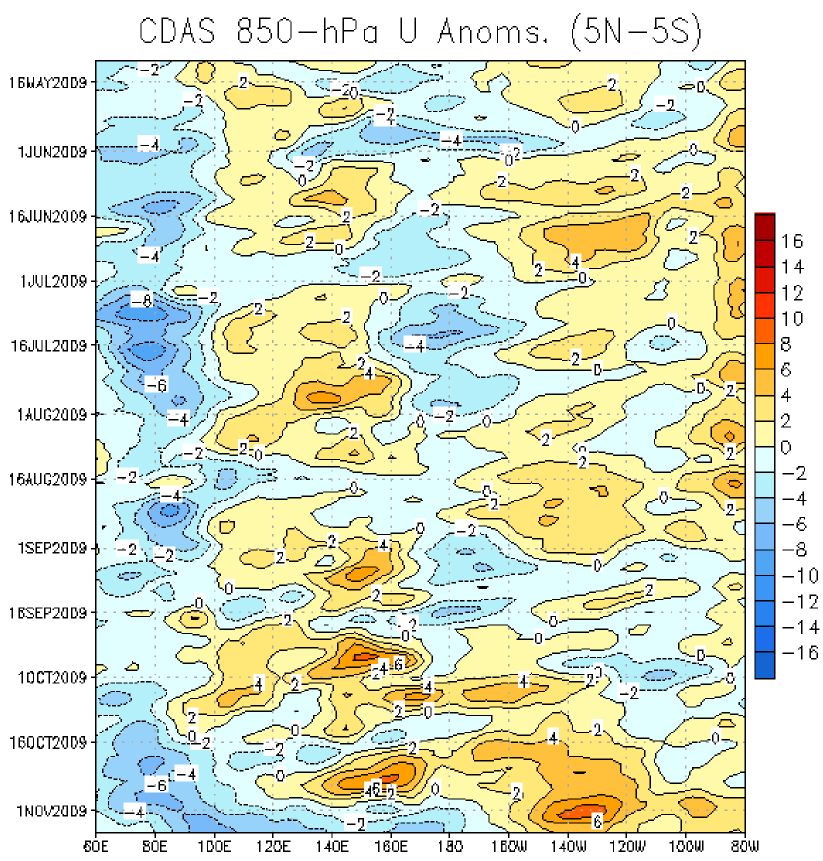

Figure 14: Equatorial wind anomalies in the Indo/Pacific sector. Note the considerable westerly anomalies (brown shading) in the west/central tropical Pacific since the early part of September. This is a typical signature associated with developing El Niño events.

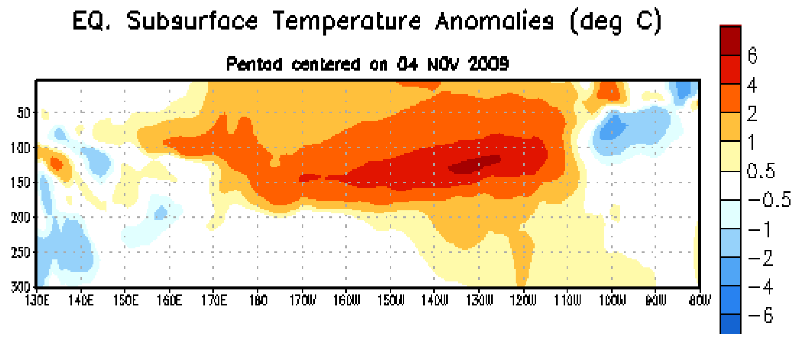

Figure 15: Current sub-surface temperature anomalies in the tropical Pacific. These anomalies are associated with an eastward propagating Kelvin wave which will likely result in continued anomalous warming, especially in the eastern tropical Pacific.

7.2 Intra-Seasonal Variability

Unlike the 2008 hurricane season, the 2009 hurricane season was characterized by only weak intra-seasonal variability. The MJO was generally of weak amplitude during the hurricane season, which allowed for the larger-scale unfavorable conditions associated with a weak to moderate El Niño event to dominate the climate signal this year. In general, both 2007 and 2009 were characterized by weak intra-seasonal variability as determined by the MJO, while 2008 was associated with considerable intra-seasonal variability (Figure 16).

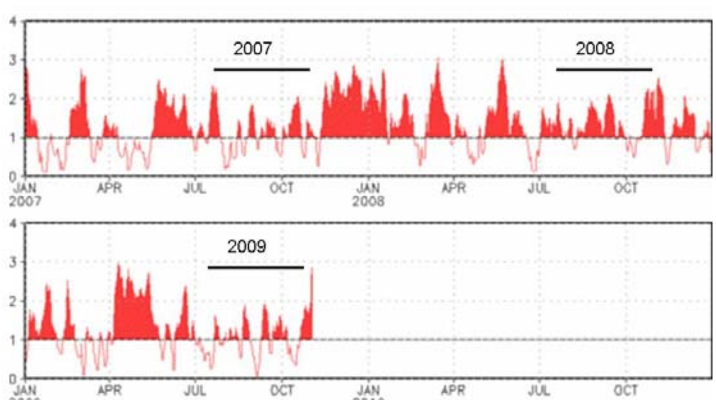

Figure 16: Amplitude of the MJO from January 2007 – October 2009. Lines indicate the climatological peak of the Atlantic basin hurricane season. Note the heightened MJO activity during August-October of 2008 compared with August-October of 2009 and August-October of 2007.

Formation of tropical cyclones during the 2009 hurricane season was more spread out throughout the year with only one clustering of storms from August 15-16 when Ana, Bill and Claudette formed during the span of just two days.

7.3 Tropical Atlantic SST

The tropical Atlantic warmed considerably from the spring to the summer during 2009. Figure 17 displays observed tropical Atlantic SST anomalies over the August-October period, while Figure 18 displays the October-April anomalous warming that occurred. The tropical Atlantic was warmer than normal throughout the most active period of the Atlantic hurricane season, and therefore Atlantic SSTs would have indicated a much more active season than was actually experienced. Features discussed in detail in the upcoming few sections will provide some answers as to why this year's hurricane season was as quiet as it was.

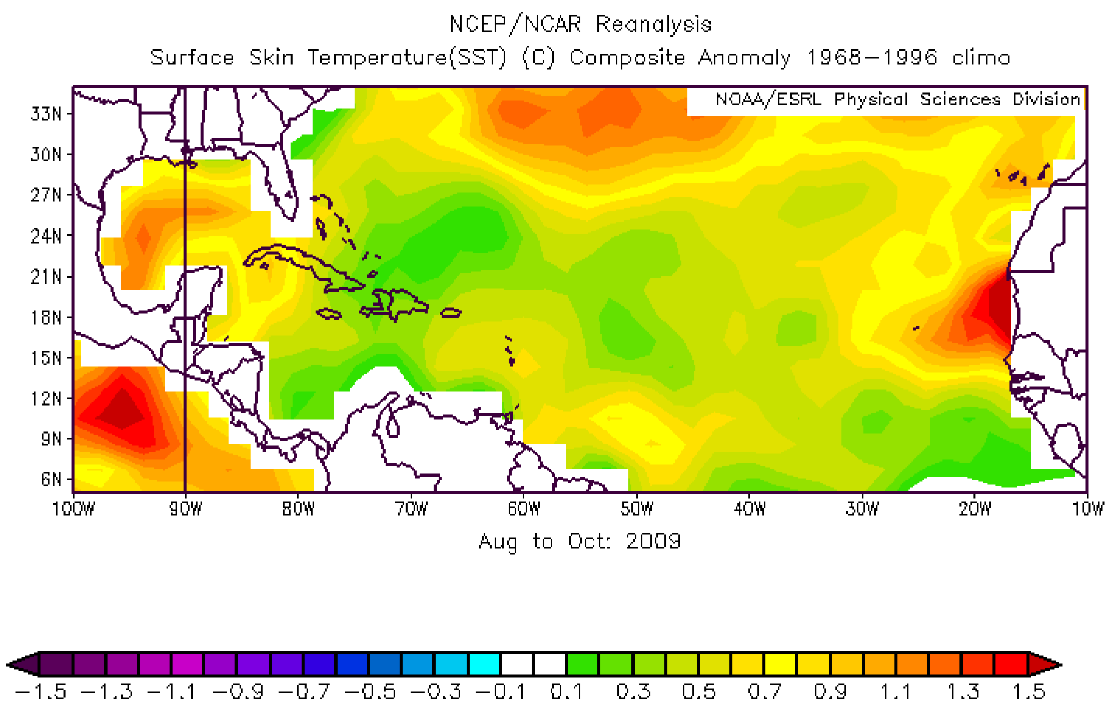

Figure 17: August-October SST anomalies across the tropical Atlantic. Anomalies are calculated with respect to the 1968-1996 base period.

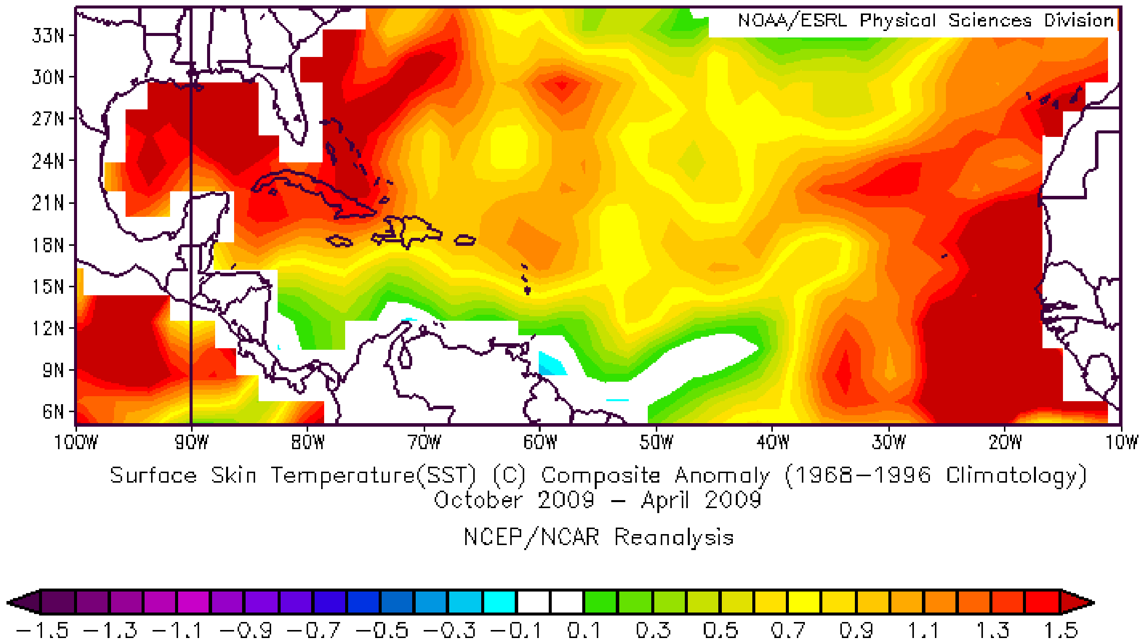

Figure 18: (October 2009) minus (April 2009) SST anomaly. Note that almost the entire tropical and subtropical Atlantic warmed in an anomalous manner during this time period.

7.4 Tropical Atlantic SLP

Tropical Atlantic sea level pressure values are another important parameter to consider when evaluating likely tropical cyclone activity in the Atlantic basin. In general, lower sea level pressures across the tropical Atlantic imply increased instability, increased low-level moisture, and conditions that are generally favorable for tropical cyclone development and intensification. The August-October portion of the 2009 Atlantic hurricane season was generally characterized by slightly below-normal sea level pressures. Figure 19 displays August-October 2009 tropical and sub-tropical sea level pressure anomalies in the North Atlantic. Below-average anomalies dominated the basin. Across the Main Development Region (MDR) (10°N-20°N, 20°W-70°W), sea level pressure anomalies were approximately 0.25 mb below the 1995-2008 average and approximately 0.4 mb below the 1950-2000 average. These types of sea level pressure anomalies would typically be associated with a much more active hurricane season than what was observed.

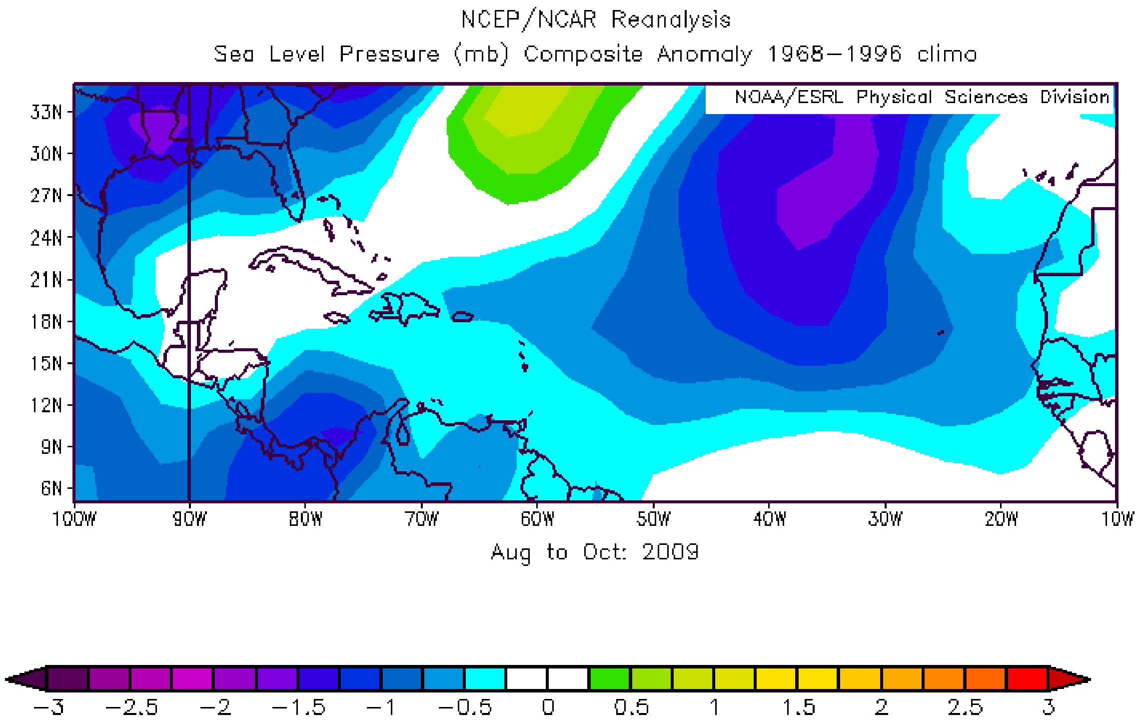

Figure 19: August-October 2009 tropical and sub-tropical North Atlantic sea level pressure anomalies. Sea level pressure anomalies were slightly below-average across the tropical Atlantic.

7.5 Tropical Atlantic Vertical Wind Shear

Tropical Atlantic vertical wind shear was the critical component in determining the reduced level of tropical cyclone activity experienced in the Atlantic basin this year. Excessive levels of vertical wind shear inhibit tropical cyclone development and intensification by tilting the vortex and reducing the ability of the system to develop a warm core. Vertical wind shear during the climatologically most active portion of the hurricane season (from August to October) was at above-average levels, especially across the Caribbean (Figure 20). Note that five of this season's named storms (Ana, Danny, Erika, Fred and Henri) died over tropical waters due to their encountering regions of strong tropospheric vertical wind shear. It is very unusual to have a season in which such a high number of named storms dissipated within generally favorable tropical thermodynamic conditions.

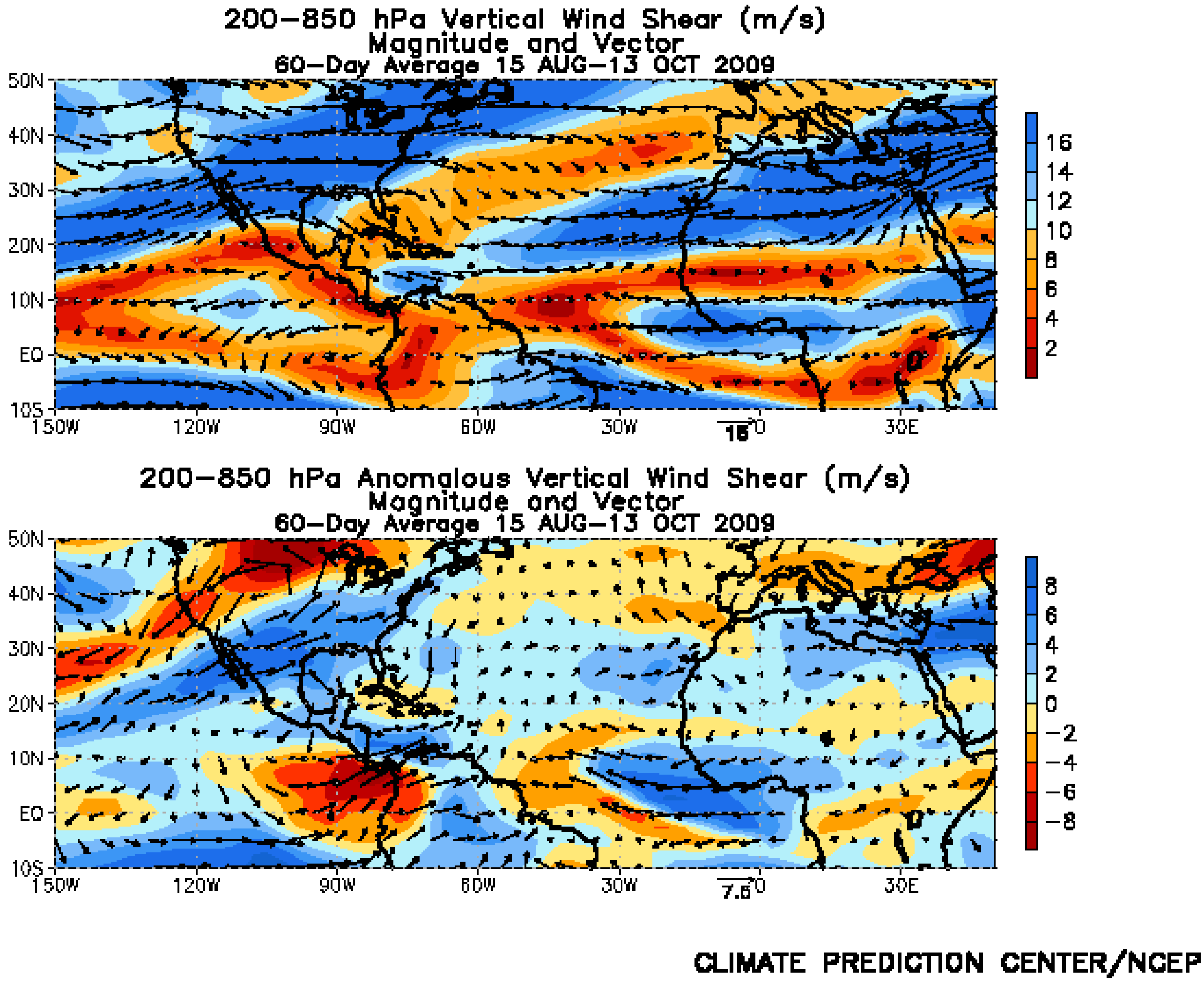

Figure 20: Total and anomalous vertical wind shear as observed across the Atlantic from August 15 – October 13. Vertical wind shear was enhanced across the Main Development Region (10-20°N, 20-70°W) and was at very high levels across the Caribbean (10-20°N, 60-88°W).

The August-October averaged 200-850 mb vertical wind shear across the Main Development Region (10-20°N, 20-70°W) was 9.3 ms^{-1} which was the highest vertical shear magnitude over this three-month period since the El Niño year of 2002. The 2009 August-October MDR value was also approximately 2 ms^{-1} greater than the 1995-2008 average vertical shear.

The August-October averaged 200-850 mb vertical wind shear across the Caribbean (10-20°N, 60-88°W) was quite strong. The estimated value this year was 9.7 ms^{-1} which was the strongest vertical wind shear observed over this three-month period since 1986. It is also approximately 5 ms^{-1} greater than the 1995-2008 average. This very strong shear is likely the primary reason why the Caribbean was very quiet this year.

7.6 Tropical Atlantic Moisture

The 2009 Atlantic hurricane season was characterized by anomalously dry air at mid-levels in the atmosphere. This feature is typical for El Niño years, as enhanced subsidence over the Caribbean and tropical Atlantic is associated with an eastward-shifted and weaker Walker Circulation as typically occurs in El Niño years. Dry air is associated with subsidence and suppressed deep convection, which significantly inhibits tropical cyclone formation. One can see that the cold pixel count (a measure of deep convection) was significantly reduced below the climatological average during August-October (Figure 21).

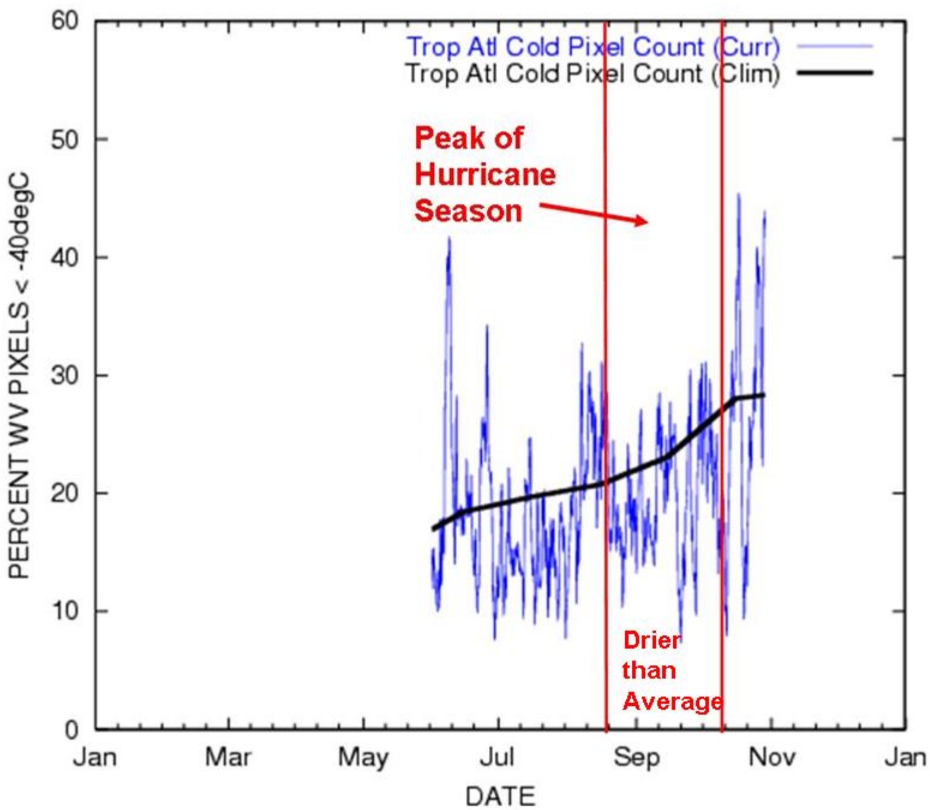

Figure 21: Percentage of water vapor pixels colder than -40°C. This is a measure of deep convection. Note that, in general, during the peak of the hurricane season, convection was suppressed in the tropical Atlantic.

Relative humidity values at 500 mb were reduced by approximately 3-7% compared with climatology across the Main Development Region (Figure 22). The August-October-averaged MDR 500 mb relative humidity was 31% which is the lowest observed value in the NCEP Reanalysis which dates back to 1948. However, it is important to note that relative humidity values during the earlier period of the Reanalysis may have been over-estimated. Nevertheless, it was certainly a very dry year across the tropical Atlantic.

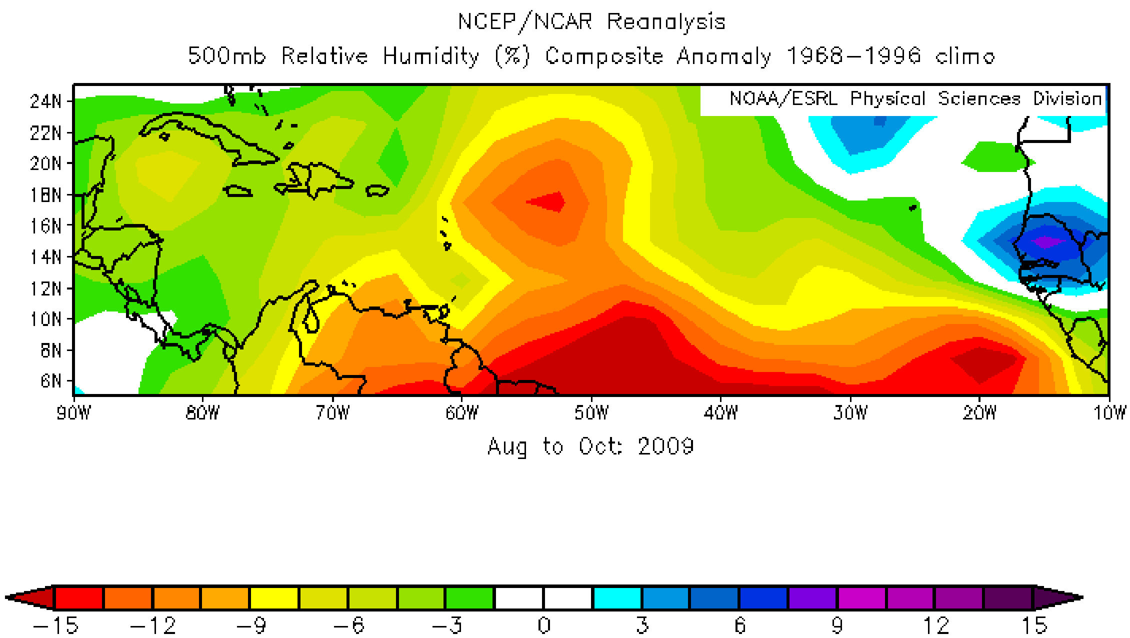

Figure 22: August-October 500-mb relative humidity anomalies across the tropical Atlantic. Note the enhanced dryness in the mid-Atlantic.

7.7 Steering Currents

Both Bill and Danny threatened the East Coast of the United States during the latter part of August. The United States was fortunate during the period from August 15 – September 15 to have not been impacted by a tropical cyclone, as the predominant steering current pattern favored East Coast landfall. A trough of low pressure was located in the Midwest, while a ridge of high pressure was located over the western Atlantic (Figure 23). This pattern resulted in anomalous southerly flow which tended to steer systems poleward off the East Coast of the United States (Figure 24). In the case of Major Hurricane Bill, a trough of low pressure moving off of the East Coast recurved the storm before it could make U.S. landfall. In Danny's case, the tropical cyclone merged with an extra-tropical cyclone while located a few hundred miles off of the coast of North Carolina.

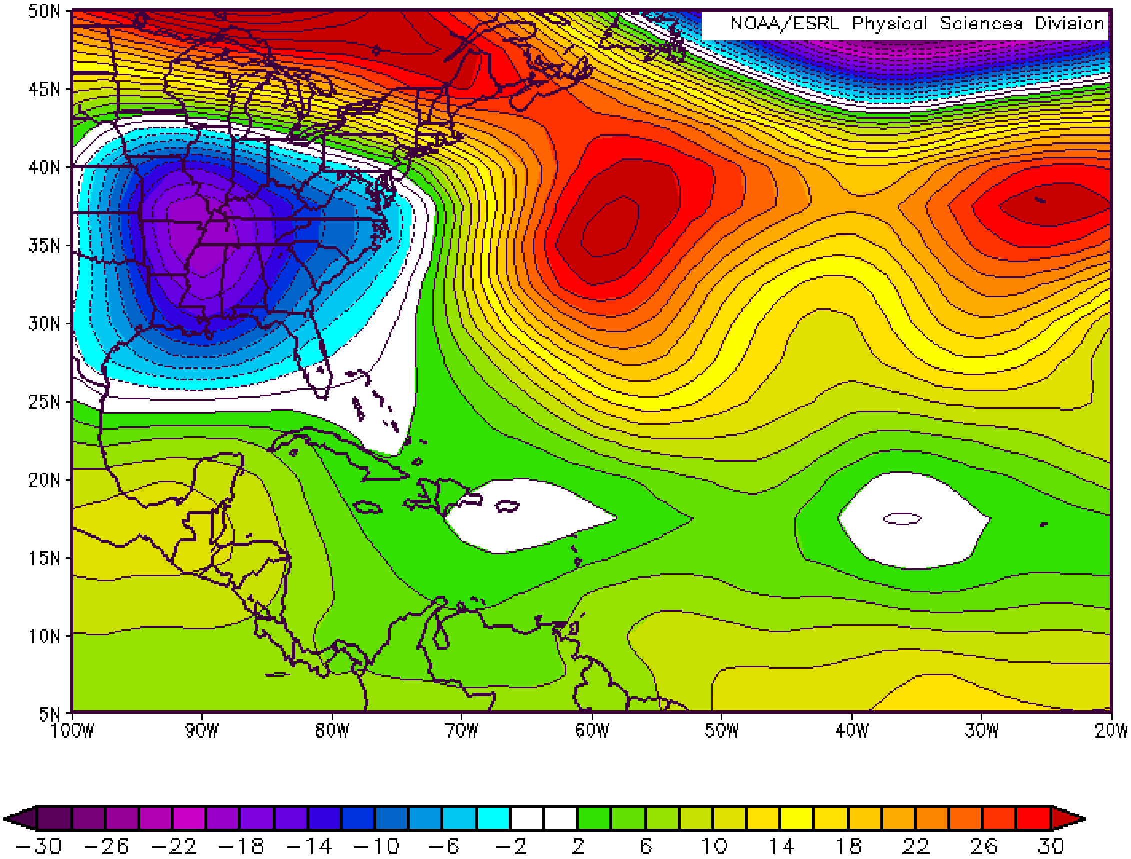

Figure 23: 700 mb height anomalies in the western portion of the Atlantic basin from August 15, 2009 – September 15, 2009. Note the anomalous troughing over the Midwest and ridging over the western Atlantic. This pattern drives anomalous southerly flow along the East Coast of the United States and is an enhancement to recurvature.

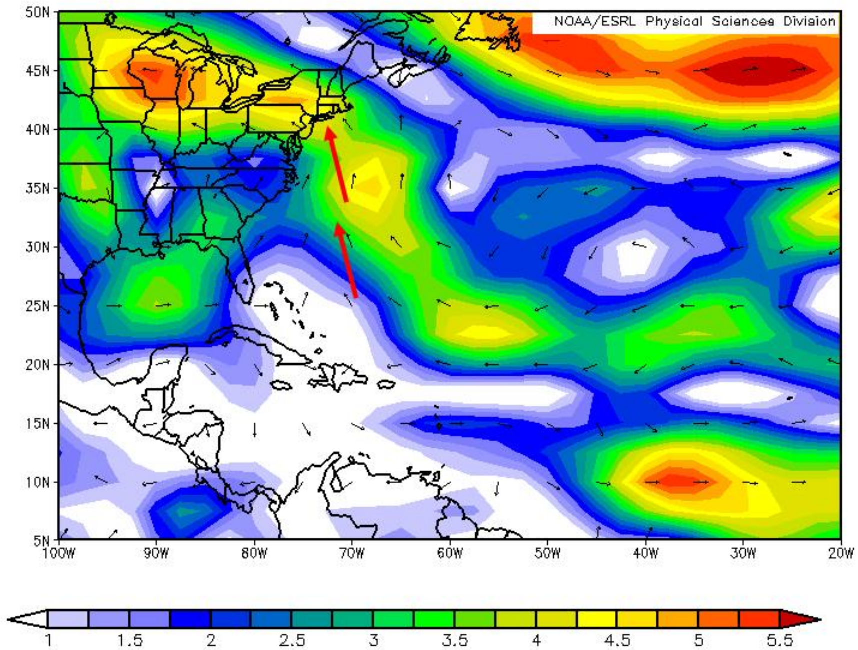

Figure 24: August 15, 2009 – September 15, 2009 anomalous 700 mb vector wind flow. The red arrows highlight the predominant steering motion towards the East Coast of the United States.

7.8 Summary

The 2009 Atlantic hurricane season was the quietest season since the unusually strong El Niño year of 1997. We believe that the primary reason why the season was so quiet was due to enhanced levels of vertical wind shear and very dry air at mid levels over the mid-Atlantic that was associated with this season's moderate El Niño event. This combination of unfavorable dynamic and thermodynamic conditions was enough to overwhelm the generally favorable warm tropical Atlantic sea surface temperatures and favorable below-average sea level pressures.

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

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Southeast landfalling hurricanes of 2004 (Charley, Frances, Ivan and Jeanne) raised questions about the possible role that global warming played in these two unusually destructive seasons. In addition, three Category 2 hurricanes (Dolly, Gustav and Ike) pummeled the Gulf Coast last year causing considerable devastation.

The global warming arguments have been given much attention by many media references to recent papers claiming to show such a linkage. Despite the global warming of the sea surface that has taken place between the mid 1970s to late 1990s and the general warming of the last century, the global numbers of hurricanes and their intensity have not shown increases in recent years except for the Atlantic since 1995 (Klotzbach 2006).

The Atlantic has seen a very large increase in major hurricanes during the 15-year period of 1995-2009 (average 3.9 per year) in comparison to the prior 25-year period of 1970-1994 (average 1.5 per year). This large increase in Atlantic major hurricanes is primarily a result of the multi-decadal increase in the Atlantic Ocean thermohaline circulation (THC) that is not directly related to global sea surface temperatures or CO_2 increases. Changes in ocean salinity are believed to be the driving mechanism. These multi-decadal changes have also been termed the Atlantic Multidecadal Oscillation (AMO). The THC is the Atlantic component of the global ocean Meridional Overturning Circulation (MOC).

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

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

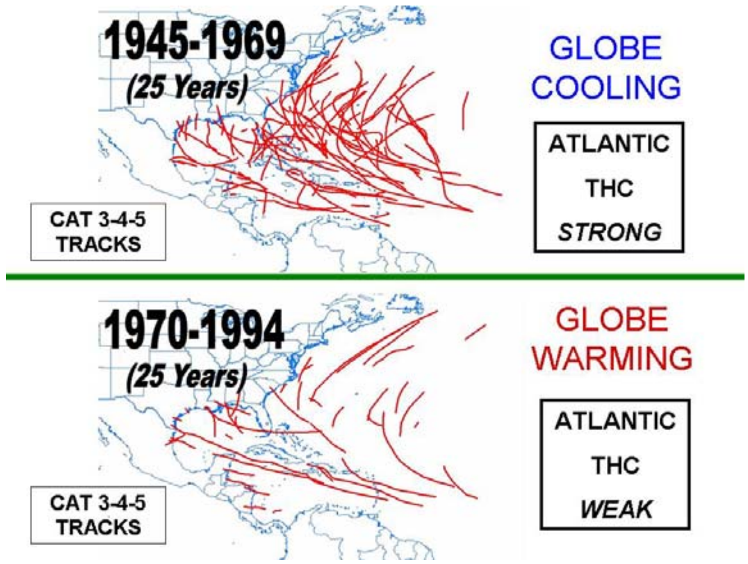

Figure 25: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than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

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 13). Although global mean ocean and Atlantic sea surface temperatures have increased by about 0.4^{o}C between these two 55-year periods (1900-1954 compared with 1955-2009), the frequency of US landfall numbers actually shows a slight downward trend for the later period. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 44-year period of 1922-1965 (24 landfall events) and the 44-year period of 1966-2009 (7 landfall events) was especially large (Figure 26). For the entire United States coastline, 38 major hurricanes made landfall during the earlier 44-year period (1922-1965) compared with only 26 for the latter 44-year period (1966-2009). This occurred despite the fact that CO_2 averaged approximately 365 parts per million (ppm) during the latter period compared with 310 ppm during the earlier period.

Table 13: U.S. landfalling tropical cyclones by intensity during two 55-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Intense Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1900-1954 (55 years)	208	113	44	+0.4^{o}C
1955-2009 (55 years)	184	90	36	

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

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

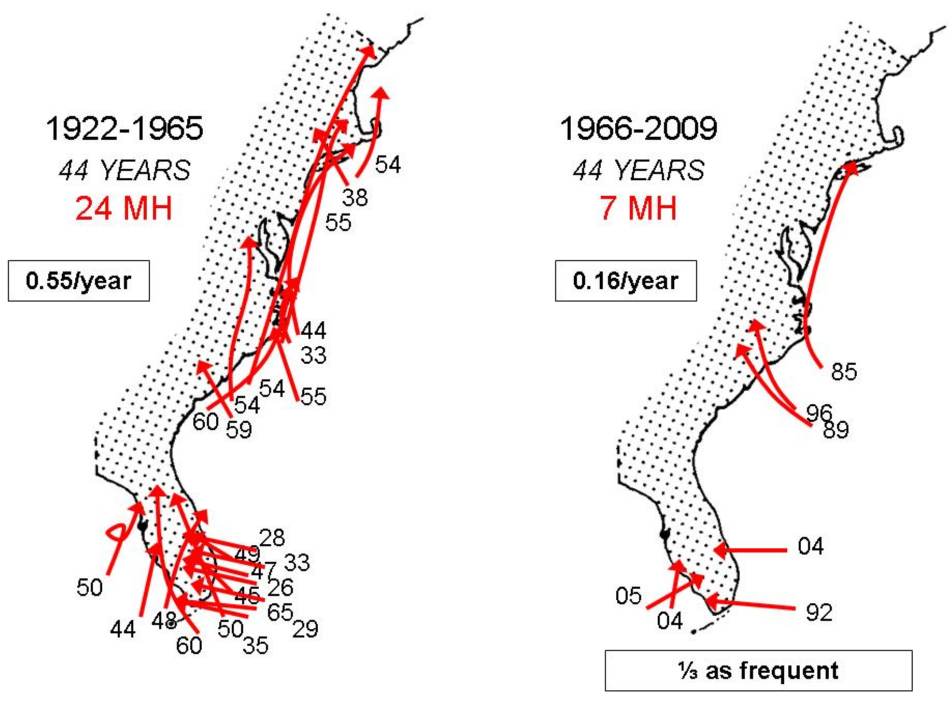

Figure 26: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 44-year period of 1922-1965 versus the most recent 44-year period of 1966-2009.

9 Anticipated Large Increase in US Hurricane Destruction

The large increase in the hurricane-spawned destruction that occurred in 2004, 2005 and 2008 has not surprised us. We have been anticipating a great upsurge in hurricane destruction for many years as illustrated by the statements we have made in previous seasonal forecast reports such as:

"…major increases in hurricane-spawned coastal destruction are inevitable." (April 1989)

"A new era of major hurricane activity appears to have begun…. As a consequence of the exploding U.S. and Caribbean coastal populations during the last 25-30 years, we will begin to see a large upturn in hurricane-spawned destruction – likely higher than anything previous experienced." (June 1997)

"We must expect a great increase in landfalling major hurricanes in the coming decades. With exploding southeast coastal populations, we must also prepare for levels of hurricane damage never before experienced." (April 2001)

"If the future is like the past, it is highly likely that very active hurricane seasons will again emerge during the next few years, and the prospects for very large U.S. and Caribbean increases in hurricane damage over the next few decades remains high. We should indeed see future hurricane damage much greater than anything in the past." (May 2002)

"Regardless of whether a major hurricane makes landfall this year, it is inevitable that we will see hurricane-spawned destruction in coming years on a scale many, many times greater than what we have seen in the past." (May 2003)

These projections of increased U.S. hurricane destruction were made with our anticipation that the Atlantic thermohaline circulation (THC) (which had been very weak from the late-1960s to the mid-1990s) would be changing to a stronger mode making for a large increase in Atlantic basin major hurricane activity. The THC has become much stronger since 1995. **These projections were made with no consideration given to rising levels of atmospheric CO_2.**

We were very fortunate during the early part of this strong THC period in that only 3 of 32 major hurricanes that formed in the Atlantic between 1995-2003 made U.S. landfall. Since then, we have had 7 of 24 major hurricanes make U.S. landfall. The long-term average is that approximately 1 in 3.5 major hurricanes that forms in the Atlantic makes U.S. landfall.

10 Forecasts of 2010 Hurricane Activity

We will be issuing our first forecast for the 2010 hurricane season on Wednesday, 9 December 2009. This 9 December forecast will provide a qualitative assessment of the likely physical factors that will impact storm activity during the 2010 hurricane season. In addition, this December forecast will include the dates of all of our updated 2010 forecasts. All of these forecasts will be made available online at: http://hurricane.atmos.colostate.edu/Forecasts.

11 Acknowledgments

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

The financial backing for the issuing and verification of these forecasts has been supported in part by the National Science Foundation. We also thank the GeoGraphics Laboratory at Bridgewater State College for their assistance in developing the Landfalling Hurricane Probability Webpage.

12 Citations and Additional Reading

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Gray, W. M., J. D. Sheaffer and C. W. Landsea, 1996: Climate trends associated with multi-decadal variability of intense Atlantic hurricane activity. Chapter 2 in “Hurricanes, Climatic Change and Socioeconomic Impacts: A Current Perspective", H. F. Diaz and R. S. Pulwarty, Eds., Westview Press, 49 pp.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

13 Verification of Previous Forecasts

Table 14: Verification of the authors' early August forecasts of Atlantic named storms and hurricanes between 1984-2009. Observations only include storms that formed after 1 August. Note that these early August forecasts have either exactly verified or forecasted the correct deviation from climatology in 23 of 26 years for named storms and 20 of 26 years for hurricanes. If we predict an above- or below-average season, it tends to be above or below average, even if our exact forecast numbers do not verify.

Year	Predicted NS	Observed NS	Predicted H	Observed H
1984	10	12	7	5
1985	10	9	7	6
1986	7	4	4	3
1987	7	7	4	3
1988	11	12	7	5
1989	9	8	4	7
1990	11	12	6	7
1991	7	7	3	4
1992	8	6	4	4
1993	10	7	6	4
1994	7	6	4	3
1995	16	14	9	10
1996	11	10	7	7
1997	11	3	6	1
1998	10	13	6	10
1999	14	11	9	8
2000	11	14	7	8
2001	12	14	7	9
2002	9	11	4	4
2003	14	12	8	5
2004	13	14	7	9
2005	13	20	8	12
2006	13	7	7	5
2007	13	12	8	6
2008	13	12	7	6
2009	10	9	4	3
Average	**10.8**	**10.2**	**6.2**	**5.9**
1984-2009 Correlation		**0.62**		**0.61**

Table 15: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2004-2008. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

2004	5 Dec. 2003	Update 2 April	Update 28 May	Update 6 August	Update 3 Sept.	Update 1 Oct.	Obs.
Hurricanes	7	8	8	7	8	9	9
Named Storms	13	14	14	13	16	15	14
Hurricane Days	30	35	35	30	40	52	46
Named Storm Days	55	60	60	55	70	96	90
Major Hurricanes	3	3	3	3	5	6	6
Major 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.
Hurricanes	6	7	8	10	10	11	14
Named Storms	11	13	15	20	20	20	26
Hurricane Days	25	35	45	55	45	40	48
Named Storm Days	55	65	75	95	95	100	116
Major Hurricanes	3	3	4	6	6	6	7
Major Hurricane Days	6	7	11	18	15	13	16.75
Net Tropical Cyclone Activity	115	135	170	235	220	215	263

2006	6 Dec. 2005	Update 4 April	Update 31 May	Update 3 August	Update 1 Sept.	Update 3 Oct.	Obs.
Hurricanes	9	9	9	7	5	6	5
Named Storms	17	17	17	15	13	11	9
Hurricane Days	45	45	45	35	13	23	20
Named Storm Days	85	85	85	75	50	58	50
Major Hurricanes	5	5	5	3	2	2	2
Major Hurricane Days	13	13	13	8	4	3	3
Net Tropical Cyclone Activity	195	195	195	140	90	95	85

2007	8 Dec. 2006	Update 3 April	Update 31 May	Update 3 Aug	Update 4 Sep	Update 2 Oct	Obs.
Hurricanes	7	9	9	8	7	7	6
Named Storms	14	17	17	15	15	17	15
Hurricane Days	35	40	40	35	35.50	20	11.25
Named Storm Days	70	85	85	75	71.75	53	34.50
Major Hurricanes	3	5	5	4	4	3	2
Major Hurricane Days	8	11	11	10	12.25	8	5.75
Accumulated Cyclone Energy	130	170	170	150	148	100	68
Net Tropical Cyclone Activity	140	185	185	160	162	127	97

2008	7 Dec. 2007	Update 9 April	Update 3 June	Update 5 August	Obs.
Hurricanes	7	8	8	9	8
Named Storms	13	15	15	17	16
Hurricane Days	30	40	40	45	30.50
Named Storm Days	60	80	80	90	88.25
Major Hurricanes	3	4	4	5	5
Major Hurricane Days	6	9	9	11	7.50
Accumulated Cyclone Energy	115	150	150	175	146
Net Tropical Cyclone Activity	125	160	160	190	162