SUMMARY OF 2005 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND MONTHLY FORECASTS

The 2005 Atlantic basin hurricane season was the most active and destructive season on record.

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

Brad Bohlander and Emily Wilmsen, Colorado State University Media Representatives, (970-491-6432) are available to answer various questions about this verification.

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The first 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

Beginning with the issuing of our first seasonal forecast for 2006 Atlantic basin hurricane activity (on Tuesday, 6 December 2005), the order of the authorship of these forecasts will be 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 five years and has been second author on these forecasts for the last four 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 five 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.

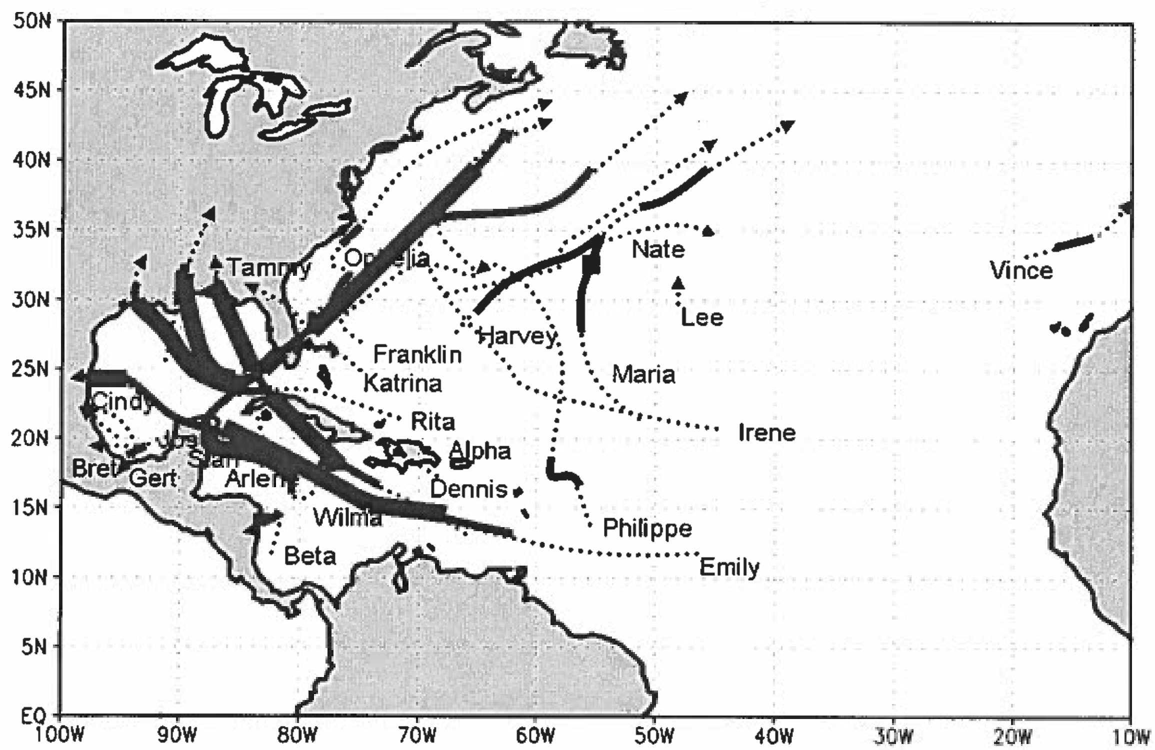
ZWA – Zonal Wind Anomaly – A measure of the upper level (~200 mb) west to east wind strength. Positive anomaly values mean winds are stronger from the west or weaker from the east than normal.

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

ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2005

Forecast Parameter and 1950-2000 Climatology (in parentheses)	3 Dec 2004	Update 1 April 2005	Update 31 May 2005	Update 5 Aug 2005	Update 2 Sept 2005	Update 3 Oct 2005	Observed 2005 Total
Named Storms (NS) (9.6)	11	13	15	20	20	20	23
Named Storm Days (NSD) (49.1)	55	65	75	95	95	100	103.25
Hurricanes (H) (5.9)	6	7	8	10	10	11	13
Hurricane Days (HD) (24.5)	25	35	45	55	45	40	45.25
Intense Hurricanes (IH) (2.3)	3	3	4	6	6	6	7
Intense Hurricane Days (IHD) (5.0)	6	7	11	18	15	13	16.75
Net Tropical Cyclone Activity (NTC)* (100%)	115	135	170	235	220	215	249

*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.



ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2005 and verifies the authors' seasonal and monthly forecasts of this activity. A forecast was initially issued for the 2005 season on 3 December 2004 with updates on 1 April, 31 May, 5 August, 2 September and 3 October of this year. These forecasts also contained estimates of the probability of U.S. hurricane landfall during 2005. The 5 August forecast included forecasts of August-only, September-only and October-only tropical cyclone activity for 2005. Our 2 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-only forecast. We are quite pleased with our 2005 seasonal forecasts. By the start of the hurricane season (June 1), we were predicting a very active season. However, we did not anticipate that this season would break many Atlantic basin records.

Our monthly forecasts for August-only and September-only activity were quite successful, especially when evaluated against the Net Tropical Cyclone (NTC) activity metric. The October-only forecast also successfully called for a very active month; however, we did not anticipate that this would be one of the most active Octobers on record. Overall, we consider our seasonal and monthly forecasts for the 2005 hurricane season to be one of the most skillful that we have issued. Our first forecast for the 2006 season will be issued on Tuesday, 6 December 2005.

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 much less direct correlation with the predictand. A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 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. No one can completely understand the full complexity of the atmosphere-ocean system or develop a reliable scheme for forecasting the myriad non-linear interactions in the full-ocean atmosphere system.

2 Tropical Cyclone Activity for 2005

Figure 1 and Table 1 summarize the Atlantic basin tropical cyclone activity which occurred in 2005. All of the seasonal forecast parameters of NS, NSD, H, HD, IH, IHD and NTC were well above their long-period averages as was predicted in our seasonal forecasts.

3 Individual 2005 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2005 season. See Fig. 1 for the tracks of these tropical cyclones, and see Table 1 for the statistics of these tropical cyclones. Table 2 displays the minimum pressures recorded for the five tropical cyclones in the Atlantic that reached at least Category 4 status.

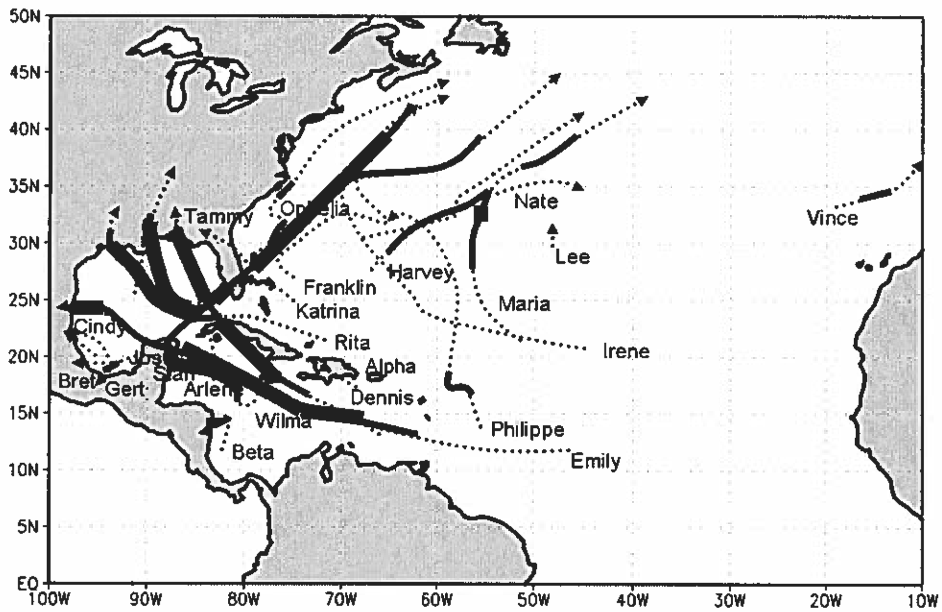


Figure 1: Tracks of 2005 Atlantic Basin tropical cyclones. Dotted lines indicate tropical storm intensity; a thin solid line is Cat. 1 or 2 hurricane intensity, and a thick solid line is major hurricane (Cat. 3-4-5) intensity.

Table 1: Observed 2005 Atlantic basin tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	IHD	NTC
TS	Arlene	June 9-11	60 kt/989 mb	2.50			2.6
TS	Bret	June 29-29	35 kt/1002 mb	0.50			1.9
TS	Cindy	July 5-6	60 kt/992 mb	1.25			2.2
IH-4	Dennis	July 5-11	130 kt/930 mb	5.75	4.00	2.00	23.1
IH-4	Emily	July 12-21	135 kt/929 mb	9.25	6.75	3.75	32.0
TS	Franklin	July 22-29	60 kt/997 mb	8.00			4.5
TS	Gert	July 24-25	40 kt/1005 mb	1.00			2.1
TS	Harvey	Aug. 3-8	55 kt/994 mb	5.50			3.6
H-2	Irene	Aug. 7-8, Aug. 11-18	85 kt/975 mb	8.75	2.75		9.4
TS	Jose	Aug. 22-23	45 kt/1001 mb	0.50			1.9
IH-5	Katrina	Aug. 24-30	150 kt/902 mb	6.00	4.25	2.50	25.1
TS	Lee	Aug. 31-31	35 kt/1007 mb	0.25			1.8
IH-3	Maria	Sep. 2-10	100 kt/960 mb	7.75	4.25	0.25	18.2
H-1	Nate	Sep. 6-10	80 kt/979 mb	4.75	2.00		7.5
H-1	Ophelia	Sep. 7-18	80 kt/979 mb	11.00	5.25		11.9
H-1	Philippe	Sep. 18-23	70 kt/985 mb	5.75	1.75		7.7
IH-5	Rita	Sep. 18-24	150 kt/897 mb	6.25	4.25	3.25	27.7
H-1	Stan	Oct. 2-4	70 kt/979 mb	2.50	0.50		5.7
TS	Tammy	Oct. 5-6	45 kt/1001 mb	1.00			2.1
H-1	Vince	Oct. 9-11	65 kt/987 mb	1.75	0.50		5.5
IH-5	Wilma	Oct. 17-25	150 kt/882 mb	8.75	7.50	4.75	35.7
TS	Alpha	Oct. 22-23	45 kt/998 mb	0.75			2.0
IH-3	Beta	Oct. 27-31	100 kt/960 mb	3.75	1.50	0.25	14.9
Totals	23			103.25	45.25	16.75	249.0

Table 2: Minimum sea level pressures recorded for the five tropical cyclones in the Atlantic basin that reached at least Category 4 status in 2005.

Name	Minimum Sea Level Pressure (mb)
Dennis	930
Emily	929
Katrina	902
Rita	897
Wilma	882

Tropical Storm Arlene: Arlene formed in the northwest Caribbean and became the first named storm of the 2005 hurricane season on June 9 when a ship near the center of the system reported tropical storm-force winds. It then moved into the Gulf of Mexico and intensified in a relatively low vertical wind shear environment. The system tracked northward through the Gulf while strengthening into a strong tropical storm. Before landfall, however, Arlene began entraining dry air and weakened somewhat. Arlene made landfall near Pensacola, Florida on June 11 with maximum sustained winds at landfall estimated at 50 knots. Little damage was reported with the system; however, one person died due to heavy surf.

Tropical Storm Bret: Bret developed in an area of low pressure in the Bay of Campeche on June 28 and was upgraded to a tropical storm when aircraft reconnaissance measured tropical-storm force winds. The system drifted westward and made landfall the following day near Tuxpan, Mexico. It dissipated late on June 29 as its circulation was disrupted by the mountainous terrain of southern Mexico. Bret dumped heavy rain in portions of Mexico which caused damage to hundreds of homes. Two people in Naranjos drowned when their car was swept away by floodwaters.

Tropical Storm Cindy: Cindy was classified as a tropical depression on July 3 while moving northwest across the northwest Caribbean. The circulation moved across the Yucatan Peninsula and then moved into the Gulf of Mexico. Although wind shear was not particularly favorable, Cindy was upgraded to a tropical storm on July 5 due to measured flight level winds between 45-50 knots. Cindy strengthened to a strong tropical storm while moving north through the Gulf. It made landfall near Grand Isle, LA as a strong tropical storm with maximum sustained winds at landfall estimated at 60 knots. The system weakened rapidly after landfall and was declared extratropical on July 6. Three individuals' deaths were attributed to Cindy. No damage estimates are available at this time.

Intense Hurricane Dennis: Dennis formed in the southeast Caribbean from a tropical wave. The system was upgraded to a tropical storm on July 5 based on satellite classification estimates. It tracked northwestward underneath a subtropical ridge and intensified into the first hurricane of the 2005 season on July 6. The system continued to intensify, and it became a major hurricane the following day. It made its first landfall on the southern coast of Cuba as a Category 4 hurricane. Dennis weakened to a Category 2 storm while traversing Cuba but then reintensified into a Category 4 storm in the Gulf of Mexico due largely to very warm sea surface temperatures and low vertical wind shear. Dennis weakened to a Category 3 hurricane on July 10 due to cooler ocean temperatures near the coastline. It made landfall near Pensacola, Florida as a Category 3 hurricane. Estimated winds at landfall were between 100-105 knots. Dennis weakened rapidly as it moved inland and became extratropical on July 11. Dennis is estimated to have caused about $3-5 billion dollars in insured damage ($6-10 billion dollars in total damage)[4], with about half of the insured and total damage occurring in the Caribbean. 71 people died due to Hurricane Dennis in the United States and the Caribbean.

Intense Hurricane Emily: Emily formed from a tropical wave while moving westward across the central tropical Atlantic on July 11. It was upgraded to a tropical storm on July 12 based on satellite intensity estimates. Upper-level winds were quite favorable for development, and the system strengthened into a hurricane early on July 14. It brushed by Grenada causing considerable damage on the island that was completely ravaged by Hurricane Ivan just one year earlier. A large ridge caused Emily to continue tracking west-northwestward across the Atlantic. The system tracked over waters with higher oceanic heat content, and it strengthened into a major hurricane later on July 14. Emily continued to intensify and reached Category 4 status on July 15. A large upper low weakened Emily temporarily back to a Category 2 storm later on July 15, but then

[4] We estimate that total damage is twice that of insured damage.

the system restrengthened back into a major hurricane in the western Caribbean as it moved away from the influence of the low. Aircraft reconnaissance measured a central pressure of 929 mb late on July 16, which was the lowest pressure recorded for a tropical cyclone in the Atlantic before August. Hurricane Emily retained its Category 4 status until making landfall on the Yucatan Peninsula on July 18. It weakened to a Category 1 storm over the Yucatan but then restrengthened into a major hurricane on July 19. It continued to move west-northwestward while being steered by a mid-level ridge to its north. It made a second landfall as a Category 3 storm in northern Mexico in the state of Tamaulipas. Twelve people have been reported dead from Hurricane Emily, and insured damage estimates in the Caribbean and Mexico are approximately $250 million dollars, bringing total damage from the system to approximately $500 million dollars.

Tropical Storm Franklin: Franklin formed from a tropical wave that was located just east of the Bahamas on July 21. It was upgraded several hours later to a tropical storm based upon aircraft reconnaissance. It moved northwest through a weakness in the subtropical ridge. Intensification was inhibited by some westerly shear over the system, although Franklin did strengthen into a strong tropical storm on July 23. A shortwave trough picked up the system and steered Franklin towards the north and then the northeast. Northerly shear and dry air took its toll on the system, and Franklin weakened. It tracked south of Bermuda and then accelerated as it moved towards the northeast. It underwent some fluctuations in intensity over the next couple of days before becoming extratropical on July 29.

Tropical Storm Gert: Gert formed in the Bay of Campeche on July 23. The stepped-frequency microwave radiometer measured tropical-storm force winds near the center of Gert, and it was upgraded to a tropical storm on July 24. A ridge north of the system steered it west-northwestward, and the system made landfall late on July 24 just south of Tampico It dissipated over central Mexico the following day. One death was reported from Gert, and some significant flooding occurred. No damage estimates are available at this time.

Tropical Storm Harvey: Harvey formed between the East Coast and Bermuda on August 2. A ship report and satellite estimates caused Harvey to be upgraded to a tropical storm on August 3. Harvey was embedded in west-southwest flow and moved northeastward across the open Atlantic. It tracked close enough to Bermuda to dump heavy rains on the island, but no damage was reported. It intensified somewhat over the next 24 hours, but then westerly shear began to take its toll on the system. It tracked east-northeastward across the open Atlantic and became extratropical on August 8.

Hurricane Irene: Irene formed from a tropical wave in the eastern tropical Atlantic on August 4. The system was under considerable westerly shear and did not become a tropical storm until August 7 when a Quikscat pass showed tropical-storm force wind vectors. Irene was then downgraded back to a tropical depression on August 8 due to strong westerly shear and dry air entrainment weakening the circulation. It strengthened back into a tropical storm on August 11 as it moved northwest under the influence of a subtropical ridge. Irene then turned more towards the north as it entered a weakness in the subtropical ridge, and it also began to strengthen as vertical wind shear decreased. Irene was upgraded to a hurricane on August 15 based on wind measurements from aircraft reconnaissance. Irene strengthened to Category 2 status on August 16 as it encountered favorable conditions under an upper-level anticyclone. It then encountered more westerly shear and weakened back to a tropical storm on August 17. Irene transitioned into an extratropical storm on August 18.

Tropical Storm Jose: Jose formed in the Bay of Campeche on August 22. It was upgraded to a tropical storm later that day as aircraft reconnaissance measured flight level winds of 54 knots. The system moved westward and made landfall in Veracruz, Mexico on August 23. It dissipated later on August 23 as the circulation moved over the mountainous terrain of Mexico. Heavy rains fell in Oaxaca and Veracruz, and eight deaths were reported from the system. No damage estimates are available at this time.

Intense Hurricane Katrina: Katrina formed in a broad area of low pressure in the southeast Bahamas on August 23. A combination of satellite estimates and aircraft reconnaissance caused Katrina to be upgraded to a tropical storm the following day. Katrina moved westward through the Bahamas as it was steered by a subtropical ridge to its north. Despite battling dry air intrusion and some northerly shear, Katrina strengthened into a hurricane on August 25. It made its first landfall as a Category 1 hurricane on August 25 near Hallandale, Florida causing approximately $600 million dollars in insured damage ($1.2 billion dollars in total damage). Estimated winds at the system's first landfall were near 70 knots. Katrina weakened briefly to a tropical storm as it traversed the southern part of Florida, but it then restrengthened into a hurricane once it reached the Gulf of Mexico. Once it entered the Gulf, it encountered an area of low vertical wind shear and very warm sea surface temperatures, including traveling over the very warm waters of the Gulf loop current. It intensified into a major hurricane on August 27 while traveling underneath a very strong upper level anticyclone. Late on August 27, Katrina began rapid intensification due to continued low vertical wind shear and very warm sea surface temperatures. It was upgraded to a Category 5 hurricane during the morning on August 28. During the afternoon of August 28, Katrina's central pressure dropped to 902 mb which made it the fourth lowest pressure ever recorded in the Atlantic at that time. Katrina weakened to a Category 4 hurricane late on August 28 due to a combination of dry air intrusion and an eyewall replacement cycle. However, the system maintained Category 4 intensity until making landfall near Buras-Triumph, Louisiana on August 29 with estimated winds of 125 knots. It made a second landfall near Waveland, Mississippi as a Category 3 hurricane with estimated winds of 110 knots. The system weakened once it made its final landfall, and the final advisory was written on the system on August 30 while it was traveling northward through Tennessee. Katrina became the most damaging and destructive hurricane on record in the United States with estimates of insured damage currently at approximately $50 billion dollars ($100 billion dollars total damage). New Orleans was devastated by the storm with about 80% of the city flooded after storm surge breached several of the levees in the city, and most property along the western Mississippi coastline was either damaged or destroyed. The current death toll from the system is 1302.

Tropical Storm Lee: Lee receives the distinction of being the shortest-lived tropical storm of the 2005 season. It was originally classified as a tropical depression while located about 950 miles east of the Lesser Antilles on August 28. It degenerated into a broad area of low pressure the following day; however, it was reclassified as a tropical depression on August 31. It was upgraded to tropical storm status for six hours later on August 31 due to satellite and microwave estimates; however, it weakened back to a tropical depression as its satellite presentation degraded considerably. Lee moved northeastward around a larger upper-level low and then began to drift as the steering flow weakened. Westerly shear weakened the system considerably, and advisories on the system ceased on September 2 as the center of Lee's circulation became completely exposed.

Intense Hurricane Maria: Maria formed from a tropical wave while located about 1000 miles east of the northern Leeward Islands. Maria overcame some southeasterly shear to be classified as a tropical storm on September 2. Maria moved northwestward around the periphery of a subtropical ridge. It strengthened into a hurricane on September 4 as it traveled through an area of relatively low vertical wind shear and warm sea surface temperatures. It briefly reached Category 3 status early on September 6 but then weakened as it turned northward and northeastward as a trough from Canada caught up to the system. Westerly shear imparted by the trough weakened Maria back to a tropical storm early on September 7. It strengthened back to a hurricane later on September 7 as it interacted with the trough, but then it weakened back to a tropical storm on September 9. Maria began to accelerate to the northeast and completed extratropical transition on September 10.

Hurricane Nate: Nate developed from an area of low pressure located south of Bermuda on September 5. It was upgraded to a tropical storm early the next day based on satellite estimates. The system drifted slowly during the early part of its lifetime due to weak steering currents. An upper-level anticyclone enabled Nate to strengthen into a hurricane on September 7. It passed south of Bermuda and then began to accelerate northeastward as a trough moving off the North Carolina coast created westerly flow over the system. Westerly shear began to take its toll on the system, and Nate weakened to a tropical storm on September 9. It accelerated towards the east and became extratropical on September 10.

Hurricane Ophelia: Ophelia has the distinction of having the most meandering track of the 2005 season. It formed in an area of low pressure in the northwest Bahamas on September 6. It became classified as a tropical storm the following day while tracking slowly northwestward. The system became cut off from the westerlies and meandered near the Florida coast. Ophelia strengthened into a hurricane on September 8 due largely to being in a favorable environment with light southerly shear and sea surface temperatures near 29°C. It weakened back to a tropical storm the following day, possibly due to upwelling of cooler water. A shortwave trough caused Ophelia to begin drifting towards the northeast, and Ophelia restrengthened back into a hurricane on September 10. Ophelia remained nearly stationary for the next couple of days and weakened back to a tropical storm on September 12 while completing a clockwise loop about 250 miles off the Georgia/South Carolina coast. It then intensified back into a hurricane on September 13 as the system started moving northward towards the North Carolina coastline. A shortwave trough caused the system to begin tracking northeastward, and Ophelia buffeted the Outer Banks with hurricane-force winds as it slowly meandered its way northeastward. At its closest pass, it came within 15 miles of Cape Lookout early on September 15. Ophelia then weakened back to a tropical storm later on September 15 as stronger shear began to influence the system. It eventually became caught up in the westerlies and passed within about 75 miles of Nantucket Island as it accelerated northeastward. It became extratropical early on September 18 as it moved over the cold waters of the North Atlantic. Ophelia did considerable damage along the North Carolina coast, with insured damage estimates near $800 million dollars (estimated total damage of $1.6 billion).

Hurricane Philippe: Philippe developed from a tropical wave on September 17 while located about 300 miles east of Barbados. The system moved west-northwestward around the western part of a mid-level ridge. It was upgraded to a tropical storm on September 18 based on satellite and microwave intensity estimates. Philippe strengthened to a hurricane on September 19 as it tracked northward towards a weakness in the subtropical ridge. Outflow from Hurricane Rita imparted westerly shear over Philippe, and it weakened back to a tropical storm on September 20. An upper-level low located to the northwest of Philippe sheared the system for the next couple of days, and Philippe continued to weaken. It began to become embedded in a larger circulation center to its south and then turned towards the west. It became completely absorbed by the larger system on September 24.

Intense Hurricane Rita: Rita developed early on September 18 from a tropical disturbance while located just east of the Turks and Caicos Islands. The system was upgraded to a tropical storm later in the day when aircraft reconnaissance measured flight level winds of 45 knots. Rita moved west-northwestward under a mid-level ridge for the next couple of days. Although inhibited in its early stages from development due to rather strong southerly shear, the shear began to abate as Rita tracked westward, and it intensified into a hurricane on September 20. It passed just south of the Florida Keys as a Category 1 hurricane, causing extensive evacuations but fortunately causing little damage. Once it entered the Gulf of Mexico, Rita intensified into the fifth major hurricane of the 2005 season. The system was under light shear conditions at this time and was passing over the warm loop current in the Gulf of Mexico, and it reached Category 5 status on September 21. Soon after reaching Category 5 status, reconnaissance aircraft measured 899 mb in Rita which was subsequently reduced to 897 mb due to the fact that the dropsonde did not fall directly into the center of the storm. This pressure was the third lowest measured in the Atlantic basin behind Gilbert (1988) - 888 mb and the Labor Day Storm (1935) – 892 mb. Rita then weakened on September 22 as it underwent an eyewall replacement cycle. Rita moved northwestward and then northward as a high pressure to its north continued its way eastward. Slightly stronger shear and cooler ocean waters helped contribute to the weakening of Rita to a Category 3 hurricane on September 23. It made landfall near Sabine Pass early on September 24 as a Category 3 hurricane with maximum sustained winds estimated at 105 knots. Rita weakened rapidly after landfall and was downgraded to a tropical depression late on September 24. There have been 119 deaths attributed to Hurricane Rita, and current insured damage estimates from the system are at $8 billion dollars ($16 billion dollars total damage).

Hurricane Stan: Stan developed from a large area of low pressure in the northwest Caribbean on October 1. It moved westward towards the Yucatan Peninsula and was upgraded to a tropical storm just before landfall on October 2. It moved towards the west across the Yucatan as it was steered by a subtropical ridge to its north. It weakened to a tropical depression late on October 2 as it passed over the peninsula, but it then restrengthened into a tropical storm on October 3 as it moved into the Bay of Campeche. Stan began to intensify in the Bay of Campeche due to an upper-level anticyclone aloft which helped improve upper-level outflow from the system. Also, low vertical wind shear and warm sea surface temperatures contributed to Stan's intensification. It strengthened into a hurricane on October 4 just before making landfall along the southern part of Mexico. It dissipated over the mountainous terrain of Mexico the following day. The system caused considerable damage, death and destruction in Mexico and Central America. Stan brought high winds, flooding and mudslides to Mexico and Guatemala. It has been blamed for 1153 deaths in Mexico and Central America, with over 1000 of these deaths occurring in Guatemala. Damage estimates for Stan are not available.

Tropical Storm Tammy: Tammy formed in a large area of low pressure about 50 miles east of Melbourne, Florida on October 5. It moved northward in response to a ridge over the mid-Atlantic and an upper-level low located in the eastern part of the Gulf of Mexico. Tammy strengthened somewhat as it turned northwest towards the northern part of Florida. It made landfall late on October 5 near Mayport, Florida with winds at landfall estimated at 45 knots. The system turned westward and dissipated over Alabama the following day. Some minor flooding in the southeast United States occurred from the system. Its remnants merged with a cold front and caused extensive flooding in the northeast United States. Many places in western New England, New York and New Jersey reported 6-12 inches of rain with isolated rainfall of up to 20 inches reported. It was the heaviest widespread rain event in the Northeast since Hurricane Floyd (1999).

Hurricane Vince: Vince was one of the most unusual tropical cyclones to ever form in the Atlantic basin. It formed about 150 miles northwest of the Madeira Islands on October 9. This is the farthest north and east that a tropical cyclone has formed in the Atlantic basin. There was debate as to whether the system was tropical or subtropical at this point; however, persistent convection near the center of the system was cited as a cause for its upgrade to a tropical storm. Despite being over cool sea surface temperatures (approximately 24°C), Vince strengthened into a hurricane later that day. It began heading northeast as a cold front moving across the Atlantic accelerated the system. Northwesterly shear began to weaken Vince; however, it was still a tropical storm when it made landfall near Huelva, Spain on October 11. It dissipated over land soon after making landfall. This is the first tropical cyclone in recorded history to make landfall on the Iberian Peninsula. No damage or fatalities were reported from the storm.

Intense Hurricane Wilma: Wilma developed in a broad area of low pressure in the western Caribbean on October 15. The system slowly became better organized and was upgraded to a tropical storm on October 17. Wilma was the 21^{st} named storm of the 2005 season which tied the 1933 season for the most tropical cyclones observed in a single season in the Atlantic basin. The system drifted very slowly towards the south-southwest in a very weak steering flow. It began to intensify in an area of low vertical wind shear and high oceanic heat content. Satellite estimates caused the upgrade of Wilma to a hurricane on October 18. High pressure built over the Gulf of Mexico which caused Wilma to start moving towards the west. Late on October 18, Wilma began one of the most rapid intensifications on record for a tropical cyclone anywhere around the globe. Its pressure dropped 61 mb in 6 hours and 98 mb in 24 hours as tremendous convection developed near the center of the system, and it developed a pinhole eye which was less than 5 miles in diameter. By the time the rapid intensification had ceased, Wilma's central pressure had dropped to 882 mb which was the lowest pressure ever measured in the Atlantic basin, breaking the old record set by Hurricane Gilbert in 1988 of 888 mb. With this phenomenal pressure drop, Wilma also became the third Category 5 hurricane of the 2005 season, joining Katrina and Rita in this distinction. No year before 2005 had reported more than two Category 5 hurricanes in a season. As happens with most intense tropical cyclones, Wilma went through an eyewall replacement cycle and weakened to a Category 4 hurricane late on October 19. Wilma continued to track northwestward towards the Yucatan Peninsula and made landfall near Cozumel on October 21 as a Category 4 hurricane. It drifted slowly north along the eastern part of the Yucatan Peninsula, devastating the peninsula with high winds, heavy rain and considerable flooding. Wilma finally began to accelerate northeastward as a trough developed over the eastern United States. It was downgraded to a Category 2 hurricane on October 22 due its continued interaction with land; however, it restrengthened into a Category 3 hurricane on October 23 as it moved into the Gulf of Mexico and then accelerated towards the south Florida coastline. It made landfall near Everglades City, Florida early on October 24 as a Category 3 hurricane with estimated sustained winds of 105 knots at landfall. It weakened back to a Category 2 hurricane as it traversed the Florida peninsula but then was upgraded to a Category 3 hurricane as it entered the Atlantic later on October 24. A digging trough in the northeast United States caused Wilma to accelerate northeastward, and it began to undergo extratropical transition. Wilma weakened to a Category 2 hurricane on October 25 and was declared extratropical later that day. It is reported that 47 people have died from the effects of Wilma, including 22 in the United States. Damage from the system has been considerable, with an estimated $7 billion dollars in insured damage done in the United States ($14 billion dollars in total damage). Extensive damage also occurred in Mexico.

Tropical Storm Alpha: Alpha became the record breaking 22^{nd} named storm of the 2005 season when it formed about 125 miles southwest of the Dominican Republic on October 22. It moved northwestward towards the Dominican Republic and strengthened slightly over the next 24 hours. The system made landfall southwest of Santo Domingo on October 23 and weakened rapidly to a tropical depression as it interacted with the mountainous terrain of Hispaniola. The depression was tracked for another day for possible signs of regeneration as it moved northward; however, its remnants were soon absorbed by Wilma. 26 deaths in Haiti and Dominican Republic have been blamed on flooding caused by Alpha. Damage reports are not available at this time.

Intense Hurricane Beta: Beta developed late on October 26 in an area of disturbed weather in the southwest Caribbean. It was upgraded to a tropical storm early on October 27 due to satellite intensity estimates. The system slowly drifted northwest as it was in an area of weak southeasterly flow. High pressure slowly built over the Gulf of Mexico and started turning Beta towards the west. Beta became the thirteenth hurricane of the 2005 season, breaking the old record of twelve hurricanes set in 1969, when it was upgraded early on October 29. It continued to intensify due to weak shear and very warm ocean temperatures, and it became the seventh major hurricane of the 2005 season early on October 30. The only other year with seven major hurricanes in a season was 1950. Beta weakened slightly before landfall but was still a Category 2 hurricane when it made landfall in Nicaragua. The system dissipated over land late on October 30. Thousands of people were evacuated due to strong winds and flooding caused by Beta, but fortunately, no deaths have been reported from the system. Damage estimates are not yet available.

U.S. Landfall. Figure 2 shows the tracks of all 2005 tropical cyclones which impacted the United States. The U.S. was affected by four major hurricanes this year: Category 3 Hurricanes Dennis, Rita and Wilma and Category 4 Hurricane Katrina. Table 3 displays the estimated damage from these four major hurricanes. The 2005 season is the most destructive season on record with over $65 billion dollars in insured damage (and probably over $150 billion dollars in total damage). Most of this damage was caused by Hurricane Katrina which devastated Louisiana and Mississippi. In addition to these four major hurricanes, Tropical Storms Arlene, Cindy, and Tammy made landfall in the southeast United States, and Hurricane Ophelia, although not technically making United States landfall, brushed by the coast of North Carolina with hurricane-force winds affecting the Outer Banks and causing substantial damage. The seven different tropical cyclones that made landfall in the United States in 2005 follows up the very active 2004 season where eight different tropical cyclones made United States landfall.

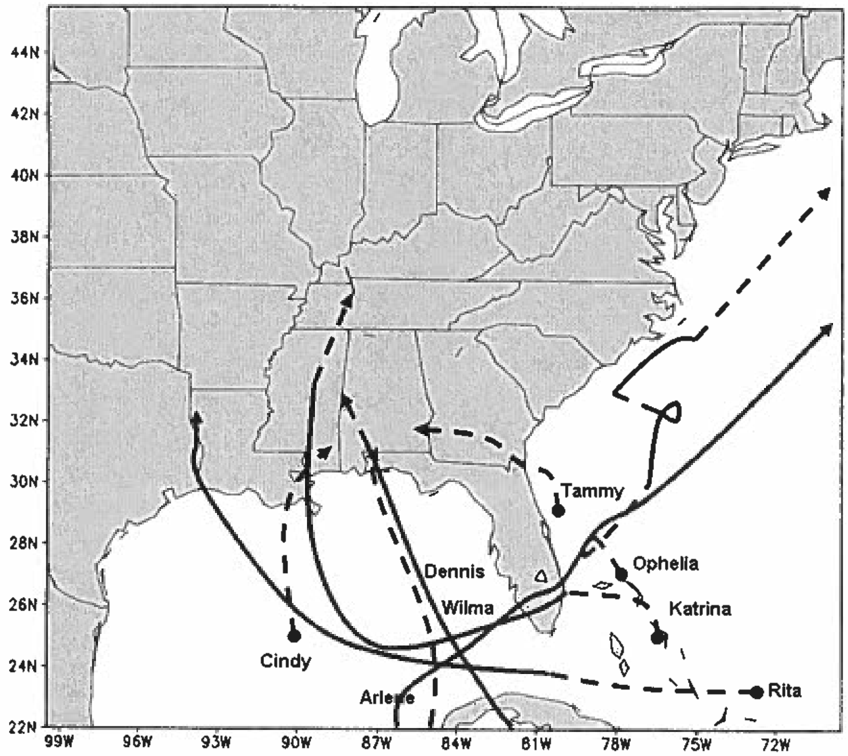


Figure 2: Tropical cyclones making U.S. landfall (TS Arlene, TS Cindy, Category 3 Hurricane Dennis, Category 4 Hurricane Katrina, Category 3 Hurricane Rita, TS Tammy and Category 3 Hurricane Wilma). Although Ophelia did not technically make United States landfall, its eyewall brought hurricane-force winds to the Outer Banks of North Carolina.

Table 3: United States damage estimates for the four major hurricanes that made U.S. landfall in 2005 (in billion of dollars). We assume that total damage is twice that of insured damage.

Storm Name	Insured Damage	Total Damage (Assumes Twice Insured Damage)
Dennis	2	4
Katrina	50	100
Rita	8	16
Wilma	7	14
Total	67	134

3.1 Special Characteristics of the 2005 Hurricane Season

The 2005 hurricane season was the most active and destructive season on record, and therefore had many unique characteristics.

Seasonal Characteristics/Records

- 23 named storms formed during the 2005 season. This is the most named storms in a single season, breaking the old record of 21 named storms set in 1933. However, there was no satellite coverage during 1933, and therefore it is quite possible that there may have been one or more storms that were missed during the 1933 season.

- 13 hurricanes formed during the 2005 season. This is the most hurricanes in a single season, breaking the old record of 12 hurricanes set in 1969.

- 7 intense or major (Category 3-4-5) hurricanes formed during the 2005 season. This ties the single-season record for intense hurricanes set in 1950.

- 103.25 named storm days were recorded during the 2005 season. This is the second most named storm days in a single season, trailing only the 1995 season (120.5 named storm days).

- 16.75 intense hurricane days were recorded during the 2005 season. This ties 2005 with the 2003 season for the third most intense hurricane days observed since 1950.

- The season accumulated 249 NTC units. This breaks the record of 230 NTC units which was set in 1950.

- Three Category 5 hurricanes formed during the 2005 season (Katrina, Rita, and Wilma). This is the most Category 5 hurricanes recorded in a single season, breaking the old record of two Category 5 hurricanes set in 1960 and 1961. Also, when the 2004-2005 seasons are combined, four Category 5 hurricanes have formed (Ivan, Katrina, Rita and Wilma). This ties the consecutive-year record set in 1960-1961 when four Category 5 hurricanes also formed.

- Seven named storms made United States landfall during 2005 (Arlene, Cindy, Dennis, Katrina, Rita, Tammy and Wilma). This puts the 2005 season in a tie for second place for landfalling storms behind the 1916 and 2004 seasons where eight named storms made landfall.

- The 2005 season was the most damaging in history for United States landfalling storms, largely due to Hurricane Katrina. Insured damage estimates for the 2005 season are nearly $70 billion dollars, which shatters the old records set in 1992 and 2004, which when adjusted for inflation, were each approximately $25 billion dollars in insured damage.

Monthly Characteristics/Records

The following is a list of characteristics of the individual months of the 2005 seasons along with records that were set during the 2005 season. Monthly records for this evaluation began in 1950.

June

- Two named storms formed (Arlene and Bret). Only 1957, 1959, 1968, and 1986 have had two or more named storms form during the month of June.

July

- Five named storms formed (Cindy, Dennis, Emily, Franklin, and Gert). This is the most on record for the month.

- Two major hurricanes formed (Dennis and Emily). This is the most on record.

- 25.25 named storm days occurred. This is the most on record.

- 10.75 hurricane days occurred. This is the most on record.

- 5.75 intense hurricane days occurred. This is the most on record.

- 64% Net Tropical Cyclone (NTC) activity was recorded. This more than doubles the old record of 26% set in 1996.

August

- Five named storms formed (Harvey, Irene, Jose, Katrina and Lee). Only 1990, 1995 and 2004 have had more than five named storms form during the month of August.

September

- Five hurricanes formed (Maria, Nate, Ophelia, Philippe and Rita). This ties 1955, 1969, 1981, 1998 and 2000 for the most hurricanes to form during the month of September.

October

- Six named storms formed (Stan, Tammy, Vince, Wilma, Alpha and Beta). This ties 1950 for the most named storm formations during the month of October.

- Four hurricanes formed (Stan, Vince, Wilma and Beta). Only 1950 had more hurricanes develop during the month of October.

- Two intense hurricanes formed (Wilma and Beta). This ties 1950, 1961, 1964 and 1995 for the most intense hurricanes to form during the month of October.

- Five intense hurricane days occurred. Only 1954 and 1961 recorded more intense hurricane days.

- 66% Net Tropical Cyclone (NTC) activity was recorded. This breaks the old record of 63% set in 1950.

November

- As of November 16, no tropical cyclone activity was recorded during the month. Since 1950, 33 of 56 years have had no named storm development during November. Very few seasons have witnessed tropical cyclone development after November 18.

Individual Storm Characteristics/Records

What follows are some notable characteristics/records set by storms occurring during the 2005 season:

- Dennis became the most intense hurricane on record before August when a central pressure of 930 mb was recorded.

- Emily eclipsed the record previously set by Dennis for lowest pressure recorded for a hurricane before August when its central pressure reached 929 mb.

- Katrina's central pressure dropped to 902 mb. At the time, it was the fourth lowest pressure ever measured in the Atlantic basin.

- Katrina's central pressure at landfall was 918 mb. This is the third lowest pressure recorded at landfall behind the Florida Keys storm of 1935 – 892 mb and Hurricane Camille of 1969 – 909 mb.

- Katrina became the most destructive storm on record with an estimated $50 billion dollars in insured damage. This shatters the old record of approximately $25 billion dollars (normalized to 2005 dollars) in insured damage set by Hurricane Andrew (1992).

- Rita's central pressure dropped to 897 mb. At the time, it was the third lowest pressure ever measured in the Atlantic basin.

- Vince was the furthest north and east that a storm has ever developed in the Atlantic basin.

- Vince was the first tropical cyclone in recorded history to strike the Iberian Peninsula.

- Wilma reached Category 5 intensity. Wilma was the third Category 5 of the season. This is the first time that three Category 5 storms have formed in one year, breaking the record of two Category 5 storms set in 1960 and equaled in 1961.

- Wilma's central pressure dropped to 882 mb. It was the lowest pressure ever measured in the Atlantic basin, eclipsing the old record of 888 mb set by Hurricane Gilbert (1988).

- Alpha became the 22^{nd} named storm of the 2005 season. This breaks the old record of 21 named storms set in 1933.

- Beta became the 13^{th} hurricane of the 2005 season. This breaks the old record of 12 hurricanes set in 1969.

In summary, the 2005 Atlantic basin hurricane season was an incredibly active and destructive one. Net Tropical Cyclone (NTC) activity records were set for the entire season as well as the individual months of July and October.

4 Verification of Individual 2005 Lead Time Forecasts

Table 4 is a comparison of our 2005 forecasts for six different lead times along with this year's observations. Our seasonal forecasts for the 2005 season worked out quite well. As the season approached, we consistently increased our forecast, and by early August, we were predicting activity at near-record levels for the year.

4.1 Preface: Aggregate Verification of our Last Seven Yearly Forecasts

We are improving our skill in seasonal prediction due to an improved level of understanding. This improved skill is clearly demonstrated by the last seven years of our seasonal 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 4: Verification of our 2005 seasonal hurricane predictions.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	3 Dec 2004	Update 1 April 2005	Update 31 May 2005	Update 5 Aug 2005	Update 2 Sept 2005	Update 3 Oct 2005	Observed 2005 Total
Named Storms (NS) (9.6)	11	13	15	20	20	20	23
Named Storm Days (NSD) (49.1)	55	65	75	95	95	100	103.25
Hurricanes (H) (5.9)	6	7	8	10	10	11	13
Hurricane Days (HD) (24.5)	25	35	45	55	45	40	45.25
Intense Hurricanes (IH) (2.3)	3	3	4	6	6	6	7
Intense Hurricane Days (IHD) (5.0)	6	7	11	18	15	13	16.75
Net Tropical Cyclone Activity (NTC)* (100%)	115	135	170	235	220	215	249

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. By this measure, each of the eight parameters of our seasonal forecasts has shown some degree of forecast skill at all lead times. Table 5 shows our average skill score based on 52 years of hindcasts from 1950-2001, and Table 6 displays our skill score in real-time forecasting for the last seven years at different lead times for all parameters.

Table 5: 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

Table 6: Last seven years' (1999-2005) average percent of variation of our 'real-time' forecasts from climatology as a function of different forecast lead times (in percent).

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	28	38	54	56
NSD	21	31	60	48
H	7	22	41	51
HD	20	42	61	54
IH	17	24	38	52
IHD	18	21	31	34
NTC	22	35	46	57

Each of our last seven yearly forecasts has shown skill. Figure 3 displays the percent variation from climatology of the average of these seven yearly forecasts for Net Tropical Cyclone (NTC) activity.

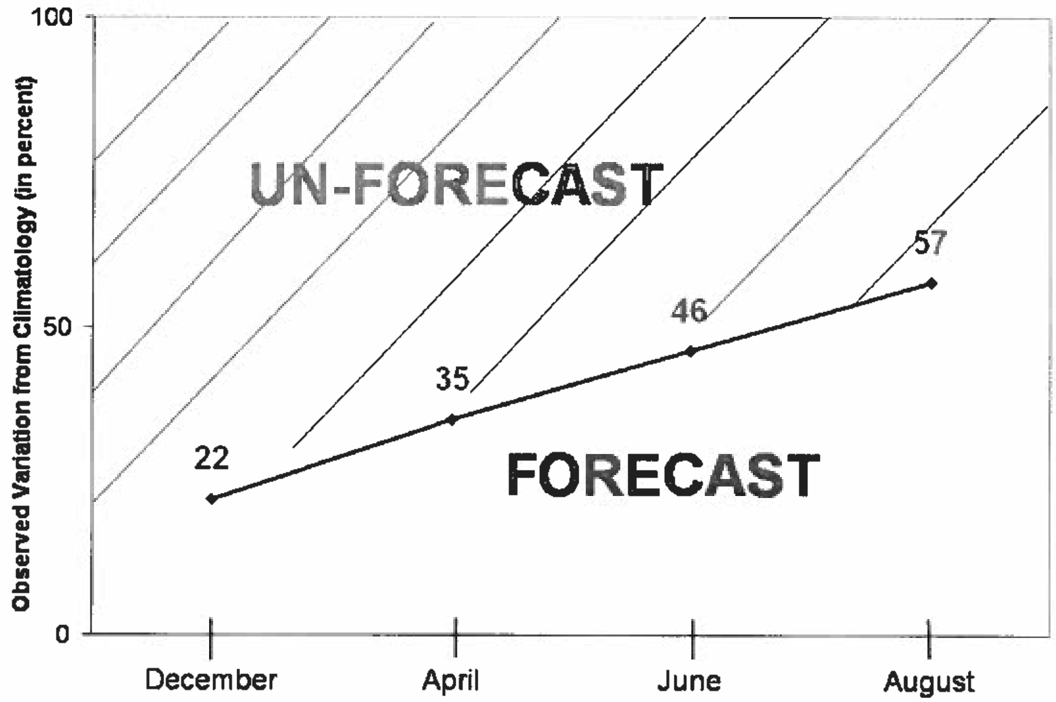


Figure 3: Last seven-year percentage of seasonal Net Tropical Cyclone (NTC) activity which was forecast at the four individual lead times of early December, early April, early June and early August.

Although not large, we show skill from the early December forecast for all parameters. Higher forecast skill is present for the later lead times.

Another way to consider the skill of our forecasts over the past seven years is to evaluate whether the forecast for each parameter successfully forecast above- or below-average activity. Table 7 displays how frequently our forecasts have been on the right side of climatology for the past seven 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 7: 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 seven years (1999-2005)

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	6/7	7/7	7/7	6/7
NSD	6/7	7/7	7/7	6/7
H	5/7	6/7	6/7	6/7
HD	5/7	6/7	6/7	7/7
IH	5/7	5/7	7/7	7/7
IHD	5/7	5/7	7/7	7/7
NTC	5/7	6/7	6/7	7/7
Total	**37/49 (76%)**	**42/49 (86%)**	**46/49 (94%)**	**47/49 (96%)**

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 modestly skillful is likely of interest.

4.2 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 six seasons, and September-only forecasts have been made for the last four seasons. This is the third year that we have issued an October-only forecast.

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 8 gives an outline and timetable of the different forecasts and verifications we issue in early August, early September and early October.

Table 8: 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

4.3 August-only 2005 Forecast

The August-only forecast was very successful this year. Our adjusted forecast predicted a very active month, and activity during the month was well above average. August 2005 will forever be remembered for generating the most devastating storm in recorded history in the Atlantic basin as Hurricane Katrina devastated Louisiana and Mississippi. Hurricane Katrina was largely responsible for making August 2005 a very active month. Table 9 displays the statistical forecast, the adjusted monthly forecast and the observed activity that occurred in August 2005.

Table 9: Independent **August-only** forecasts for 2005 including the 5 August statistical forecast for August and the 5 August adjusted forecast for August. Observed activity is in the far right-hand column.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	August 2005 Statistical Forecast	Adjusted August 2005 Forecast	August 2005 Verification
Named Storms (NS) (2.8)	3.2	5	5
Named Storm Days (NSD) (11.8)	12.1	20	21
Hurricanes (H) (1.6)	1.3	3	2
Hurricane Days (HD) (5.7)	6.7	10	7
Intense Hurricanes (IH) (0.6)	0.9	1	1
Intense Hurricane Days (IHD) (1.2)	2.8	3	2.5
Net Tropical Cyclone Activity (NTC) (26%)	33.7	50	42

4.4 September-only 2005 Forecast

The September-only forecast was also very successful this year. Our adjusted forecast issued in early August successfully predicted about 150% of average September activity, and the early September update maintained this forecast. The National Hurricane Center was writing advisories constantly from September 2-24 as Hurricanes Maria, Nate, Ophelia, Philippe and Rita tracked across the Atlantic. It should also be noted that all five named storms that developed in September became hurricanes. September 2005 spawned one of the strongest storms in the Atlantic on record as Hurricane Rita's pressure dropped to 897 mb. Rita then went on to make landfall in southwest Louisiana and caused considerable damage in this part of the Gulf Coast. Table 10 displays the statistical and adjusted September forecasts issued on 5 August and 2 September, respectively as well as the observed activity that occurred in September 2005.

Table 10: Independent **September-only** forecasts for 2005 including the 5 August statistical forecast for September, the 5 August adjusted forecast for September, the 2 September statistical forecast for September and the 2 September adjusted forecast for September. Observed activity is in the far right-hand column.

Tropical Cyclone Parameters and 1950-2000 September Average (in parentheses)	5 Aug. Stat. Fcst. (for Sep.)	5 Aug. Adjusted Forecast	2 Sep. Stat. Fcst. (for Sep.)	2 Sep. Adjusted Forecast	Observed Sep. 2005 Activity
Named Storms (NS) (3.4)	4.0	5	2.7	5	5
Named Storm Days (NSD) (21.7)	25.9	31	17.4	31	36
Hurricanes (H) (2.4)	3.5	4	3.0	4	5
Hurricane Days (HD) (12.3)	13.0	22	9.4	22	18
Intense Hurricanes (IH) (1.3)	1.4	2	1.7	2	2
Intense Hurricane Days (IHD) (3.0)	1.1	6	0.0	6	3.5
Net Tropical Cyclone Activity (NTC) (48%)	49	80	54	80	73

4.5 October-only 2005 Forecast

The October-only forecast successfully called for an active month; however, we did not expect it to be as active as it turned out to be. Two major hurricanes formed during the month (Wilma and Beta), and the central pressure in Wilma (882 mb) was the lowest ever recorded in the Atlantic basin. October 2005 ended up being the most active October on record in terms of Net Tropical Cyclone (NTC) activity, just edging out 1950 for this distinction. Six named storms also formed during the month which tied it with 1950 for the most named storms to ever form in October. Table 11 displays the statistical and adjusted October forecasts issued on 5 August, 2 September, and 3 October respectively as well as the observed activity that occurred in October 2005.

Table 11: Independent **October-only** forecasts for 2005 including the 5 August statistical forecast for October, the 5 August adjusted forecast for October, the 2 September statistical forecast for October, the 2 September adjusted forecast for September, the 3 October statistical forecast for October and the 3 October adjusted forecast for October. Observed activity is in the far right-hand column.

TC Parameters and 1950-2000 Oct. Clim. (in parentheses)	5 Aug. Stat. Fcst. (for Oct.)	5 Aug. Adjusted Forecast	2 Sep. Stat. Fcst. (for Oct.)	2 Sep. Adjusted Forecast	3 Oct. Stat. Fcst. (for Oct.)	3 Oct. Adjusted Forecast	Observed Oct. 2005 Activity
NS (1.7)	2.1	3	1.5	3	1.7	3	6
NSD (9.0)	11.0	13	8.1	13	9.0	13	18.5
H (1.1)	1.3	2	1.0	2	1.1	2	4
HD (4.4)	5.4	7	4.0	6	4.4	6	10
IH (0.3)	0.4	1	0.3	1	0.3	1	2
IHD (0.8)	1.0	2	0.7	1	0.8	1	5
NTC (17%)	21	35	16	30	17	30	66

5 Verification of 2005 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 12 gives verifications of our landfall probability estimates for 2005.

Landfall probabilities for the 2005 hurricane season were well above their climatological averages, and the season was notable for having four intense landfalling hurricanes along the United States coastline. This is the second straight year that landfall probabilities have been well above average, and frequent landfalls have occurred.

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 4). 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 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 half-a-million hits.

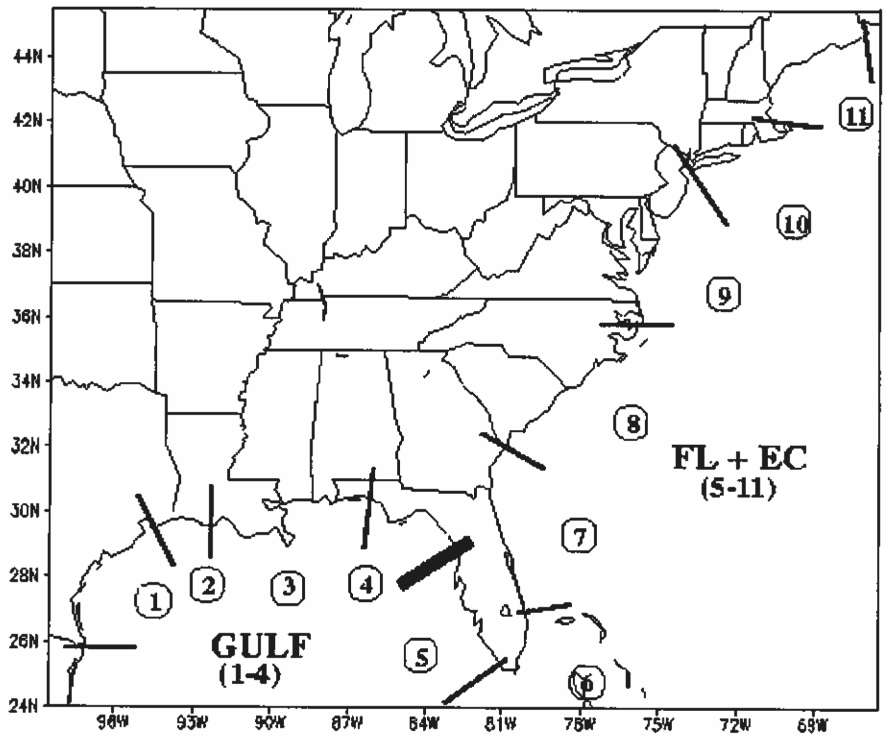


Figure 4: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

Table 12: 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 2005 at various lead times. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 5 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				
	3 Dec.	1 Apr.	31 May	5 Aug.	Observed Number
TS	86%	87%	89%	89% (80%)	3
HUR (Cat 1-2)	80%	82%	85%	85% (68%)	1
HUR (Cat 3-4-5)	69%	73%	77%	77% (52%)	4
All HUR	94%	95%	97%	97% (84%)	5
Named Storms	99%	99%	99%	99% (97%)	8

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

	Forecast Date				
	3 Dec.	1 Apr.	31 May	5 Aug.	Observed Number
TS	67%	69%	72%	71% (59%)	2
HUR (Cat 1-2)	52%	54%	58%	58% (42%)	0
HUR (Cat 3-4-5)	39%	41%	44%	44% (30%)	3
All HUR	71%	73%	77%	76% (61%)	3
Named Storms	90%	92%	94%	93% (83%)	5

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

	Forecast Date				
	3 Dec.	1 Apr.	31 May	5 Aug.	Observed Number
TS	57%	59%	61%	61% (51%)	1
HUR (Cat 1-2)	57%	60%	65%	64% (45%)	1
HUR (Cat 3-4-5)	49%	53%	59%	58% (31%)	1
All HUR	79%	82%	86%	85% (62%)	2
Named Storms	91%	92%	95%	94% (81%)	3

6 Synopsis of Similarities and Differences Between the 2004 and 2005 Atlantic Basin Hurricane Seasons

Both the 2004 and 2005 Atlantic basin hurricane seasons have been very active and destructive. In this section, we examine the similarities and differences between these two seasons:

6.1 Similarities Between the 2004 and 2005 Atlantic Basin Hurricane Seasons

- Both seasons were very active in terms of Net Tropical Cyclone activity. 2004 was the third most active season on record accumulating 229 NTC units, while 2005 was the most active season on record accumulating 249 NTC units.

- Both seasons witnessed many intense (Category 3-4-5) hurricane formations. Six major hurricanes developed during 2004, while seven major hurricanes developed during 2005.

- Both seasons were very active landfalling seasons. Three major hurricanes (Charley, Ivan and Jeanne) made landfall during 2004, while four major hurricanes (Dennis, Katrina, Rita and Wilma) made landfall during 2005. A total of eight named tropical cyclones (Bonnie, Charley, Frances, Gaston, Hermine, Ivan, Jeanne, and Matthew) made landfall during 2004, while seven named tropical cyclones (Arlene, Cindy, Dennis, Katrina, Rita, Tammy and Wilma) made landfall during 2005.

- Both seasons were characterized by well above-average Atlantic sea surface temperatures, below-average vertical wind shear across the tropical Atlantic and a strengthened Atlantic Intertropical Convergence Zone (ITCZ).

- Both seasons were characterized by above-average heights along the East Coast of the United States which imparted steering currents that caused systems to track westward across the longitudes of the United States before recurving.

6.2 Differences Between the 2004 and 2005 Atlantic Basin Hurricane Seasons

- Tropical cyclone activity during 2004 was very concentrated during the months of August and September; whereas, during the 2005 hurricane season, activity was spread out from June through October.

- No tropical cyclone activity occurred during June-July 2004, while 2005 had record activity for the June-July period.

- 2004 was the most active August-September on record for Net Tropical Cyclone (NTC) activity, accruing 220 NTC units during the two-month period.

2005 accrued 114 NTC units during the same period, barely half of the activity that occurred during 2004.

- 2004 was characterized by long-lived intense hurricanes. Frances was an intense hurricane for 6.75 intense hurricane days, while Ivan was the longest-lived intense hurricane on record accruing 10 intense hurricane days. The longest-lived intense hurricane of the 2005 hurricane season was Wilma which accumulated 4.75 intense hurricane days.

- Tropical cyclones formed further eastward during the 2004 hurricane season than they did during 2005. During 2004, five tropical cyclones (Danielle, Frances, Ivan, Karl and Lisa) were named south of 15°N and east of 40°W; whereas, no tropical cyclones were named south of 15°N and east of 40°W during 2005.

- Landfall activity during 2004 was concentrated along the United States East Coast and the Florida Peninsula; whereas, landfall activity was concentrated along the United States Gulf Coast during 2005. During 2004, one landfalling hurricane (Ivan – Category 3) was recorded along the Gulf Coast, while four landfalling hurricanes were recorded along the East Coast and the Florida Peninsula (Charley – Category 4, Frances – Category 2, Gaston – Category 1, and Jeanne – Category 3). During 2005, three major hurricanes (Dennis – Category 3, Katrina – Category 4, and Wilma – Category 3) made landfall along the Gulf Coast, while two hurricanes (and only one major hurricane) (Katrina – Category 1 and Wilma – Category 3) made landfall along the East Coast and Florida Peninsula.

7 Discussion of Differences Between the 2004 and 2005 Atlantic Basin Hurricane Seasons

Although both the 2004 and 2005 Atlantic basin hurricane seasons were very active and destructive, as pointed out briefly in the previous section, there were many differences between the two seasons. In this section, we investigate some of these differences in greater detail.

7.1 Seasonality Differences

One of the major differences between the two seasons was the way that activity throughout the season occurred. Figure 5 displays Net Tropical Cyclone (NTC) activity by ten-day periods for both seasons. Note the high-amplitude peaking of activity during August-September of 2004 and the large amount of activity during July 2005. We attribute a large part of why there was so much early activity during 2005 compared with the 2004 season due to the more favorable thermodynamics present during 2005. In general, it is hypothesized that thermodynamics (i.e., sea surface temperatures, vertical instability, etc.) are what determines when the Atlantic basin hurricane season starts; whereas, it is dynamic effects (i.e., vertical wind shear) that dictate when the Atlantic basin season ends. Figure 6 displays the difference in Atlantic basin sea surface temperatures in June-July 2005 compared with June-July 2004. Atlantic sea surface temperatures were much warmer during the early part of the 2005 Atlantic basin hurricane season.

Another difference between the two seasons was that activity during August-September was much greater in 2004 than it was in 2005. There was somewhat more wind shear in the tropical Atlantic during August-September 2005, as evidenced by the increased westerly flow shown in Figure 7. Vertical wind shear is unfavorable for tropical cyclone development, and we believe that this increase in vertical wind shear likely inhibited tropical cyclone formation east of the Leeward Islands during August-September 2005.

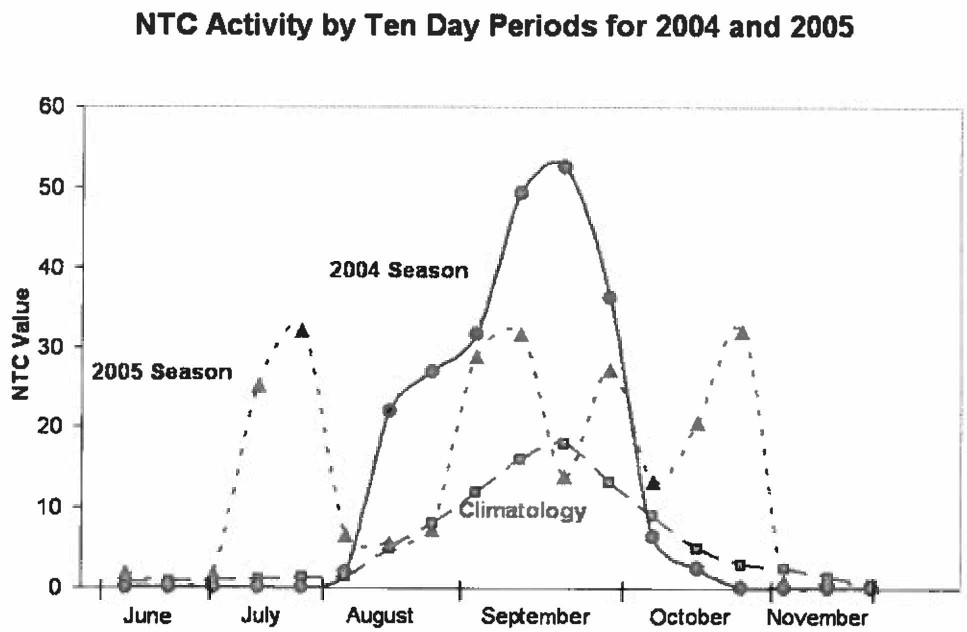


Figure 5: NTC activity by ten-day periods for the 2004 and 2005 Atlantic basin hurricane seasons.

As mentioned earlier, the end of tropical cyclone activity in the Atlantic is usually governed by vertical wind shear. During 2004, Atlantic basin hurricane activity declined rapidly during the early part of October; whereas, October 2005 witnessed six named storm and two major hurricane formations. Usually, October activity forms further westward (i.e., in the Caribbean), and October 2005 was no exception. We attribute the much greater activity of October 2005 compared with 2004 to much weaker vertical wind shear in 2005. Figure 8 displays the difference in 200 mb winds between the two seasons, and 2005 had much stronger easterly anomalies, indicative of reduced vertical wind shear.

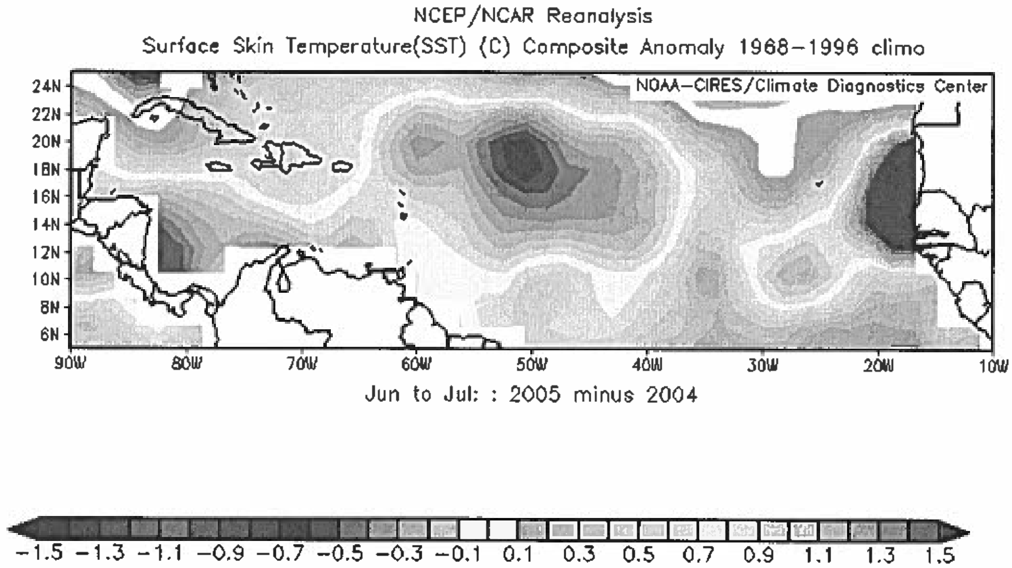


Figure 6: June-July 2005 sea surface temperatures minus June-July 2004 sea surface temperatures in the tropical Atlantic.

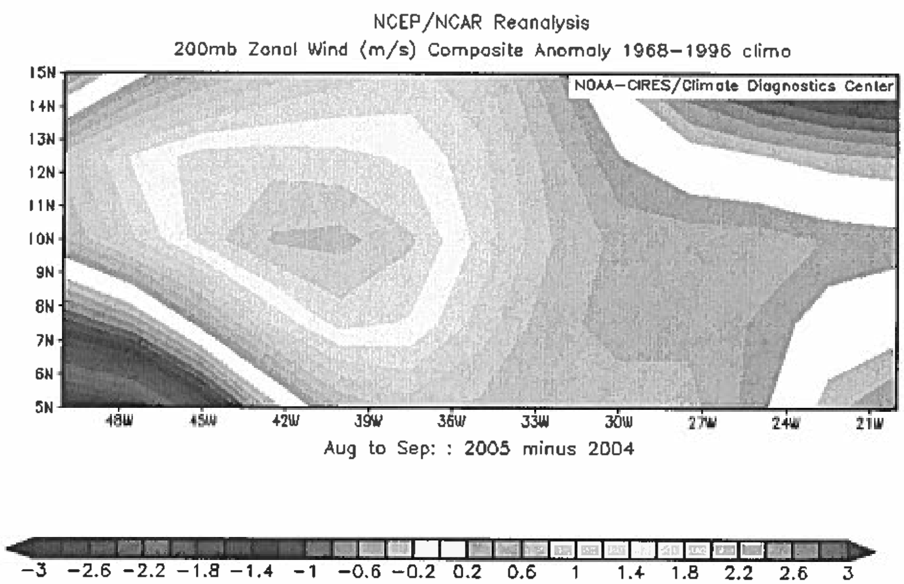


Figure 7: August-September 2005 200 MB U minus August-September 2004 200 MB U in the tropical Atlantic.

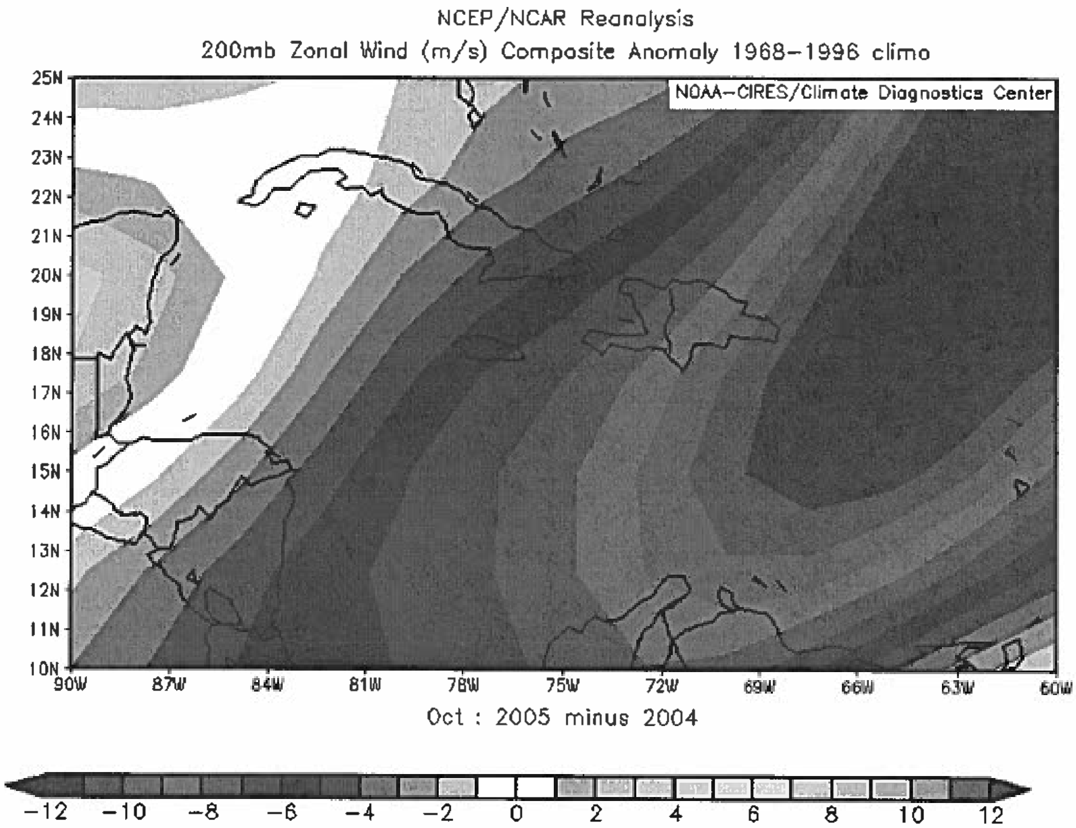


Figure 8: October 2005 200 MB U minus October 2004 200 MB U in the tropical Atlantic.

7.2 Track Differences

Both the 2004 and 2005 hurricane seasons had frequent United States landfalls; however, there were some differences in mid-level steering flow patterns that were likely responsible for the differences in track between the two years. As Figures 9 and 10 show, the 2004 hurricane season had more frequent East Coast and Florida peninsula landfalls; whereas, 2005 had more frequent Gulf Coast landfalls. Although both years featured above-average heights along the East Coast, Figure 11 shows that the upper-level ridge feature was shifted somewhat west during the 2005 season. Therefore, the storms that moved westward during the 2005 season tended to be steered into the Gulf of Mexico. This anomalous ridging was clearly evident during the 2005 season, especially for Hurricanes Katrina and Rita which rapidly intensified and slowly tracked westward across the Gulf of Mexico before beginning recurvature towards the United States coastline.

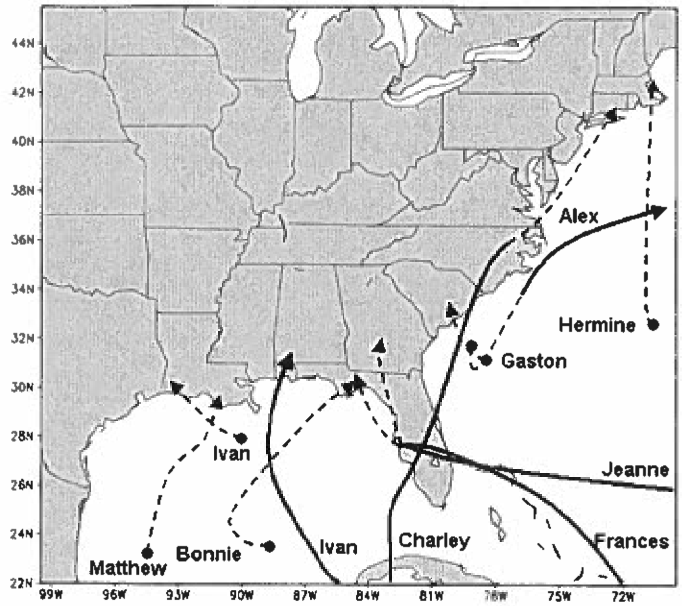


Figure 9: Tracks of United States landfalling tropical cyclones during the 2004 season. Dashed tracks indicate tropical cyclones of tropical storm intensity, while solid tracks indicate tropical cyclones of hurricane intensity.

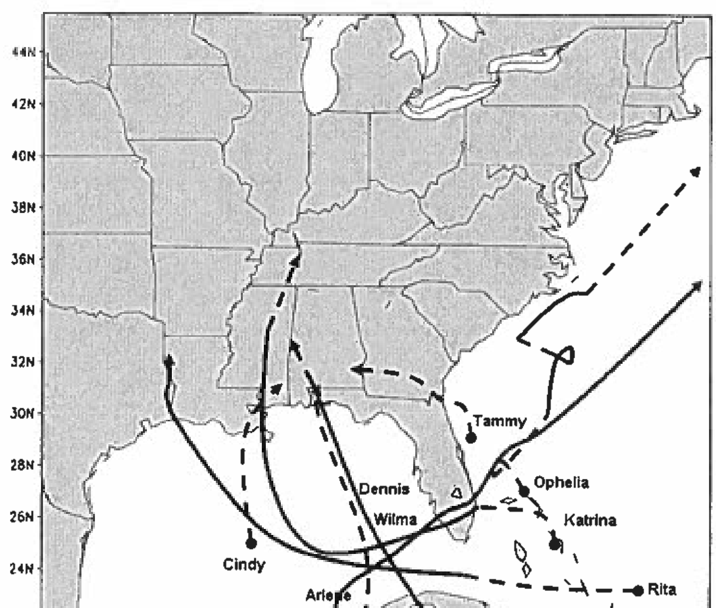


Figure 10: Tracks of United States landfalling tropical cyclones during the 2005 season. Dashed tracks indicate tropical cyclones of tropical storm intensity, while solid tracks indicate tropical cyclones of hurricane intensity.

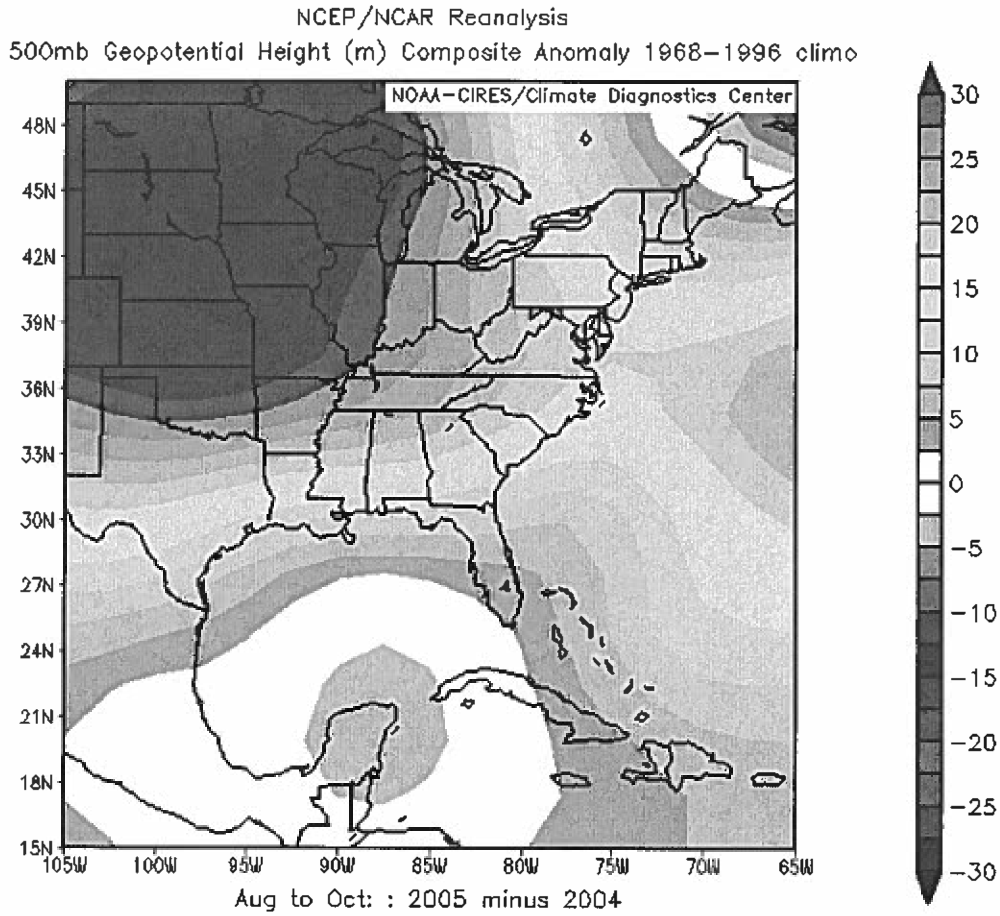


Figure 11: August-October 2005 500 MB geopotential height minus August-October 2004 500 MB geopotential height along the East Coast of the United States. Note the anomalous ridging in the upper Midwest during the 2005 hurricane season.

8 Differences between the 2004-2005 Hurricane Seasons and the Active Hurricane Seasons of 1995-1996, 1998-1999 and 2003

The 2004 and 2005 hurricane seasons have been some of the most active on record, but when compared with the very active recent seasons of 1995-1996, 1998-1999 and 2003, the activity of the past two years has not been that extraordinary. Table 12 compares the average activity of the 2004-2005 seasons with the average activity of the 1995-1996, 1998-1999 and 2003 seasons. Although activity during 2004-2005 has been slightly greater, the major difference in these past two seasons compared with the earlier active years is the difference in steering flow.

Table 12: Average seasonal Atlantic basin tropical cyclone activity during 2004-2005 compared with average seasonal Atlantic basin tropical cyclone activity during 1995-1996, 1998-1999 and 2003.

Tropical Cyclone Parameter	2004-2005	1995-1996; 1998-1999; 2003	Ratio (As Percentage)
Named Storms	18.5	14.8	125%
Named Storm Days	96.8	89.0	109%
Hurricanes	11.0	9.0	122%
Hurricane Days	45.4	45.5	100%
Intense Hurricanes	6.5	4.4	148%
Intense Hurricane Days	19.5	13.1	149%
Net Tropical Cyclone Activity	239	188	127%

Although most seasons between 1995-2003 were quite active, there tended to be a trough of low pressure located along the East Coast of United States which recurved most major hurricanes before they could make United States landfall. From 1995-2003, only 3 of 32 (9%) major hurricanes that formed in the Atlantic basin actually made United States landfall. However, over the past two seasons, anomalous ridging has been present along the East Coast, and 7 of 13 (54%) major hurricanes that formed have made United States landfall as major hurricanes. The climatological average based on landfalls during the 20^{th} century is that approximately 30% of all intense hurricanes make United States landfall. Figure 12 shows the anomalous ridging in the northeast United States that was present during the past two hurricane seasons.

When United States landfalls over the past eleven years are examined, the coastline of the United States has still been somewhat fortunate compared with the past-century average. Over the past eleven years, 10 of 45 (22%) major hurricanes have made United States landfall which is still slightly below the 20^{th} century climatological average of 30%.

These past two seasons have been incredibly active and destructive. Although we believe that we are in an active multidecadal era for Atlantic basin tropical cyclone activity that began in 1995, we do not expect to see as many landfalls in the upcoming years as we have seen in 2004-2005. It has been the unfortunate combination of near-record activity combined with unusually strong onshore steering currents which has made these past two seasons so destructive.

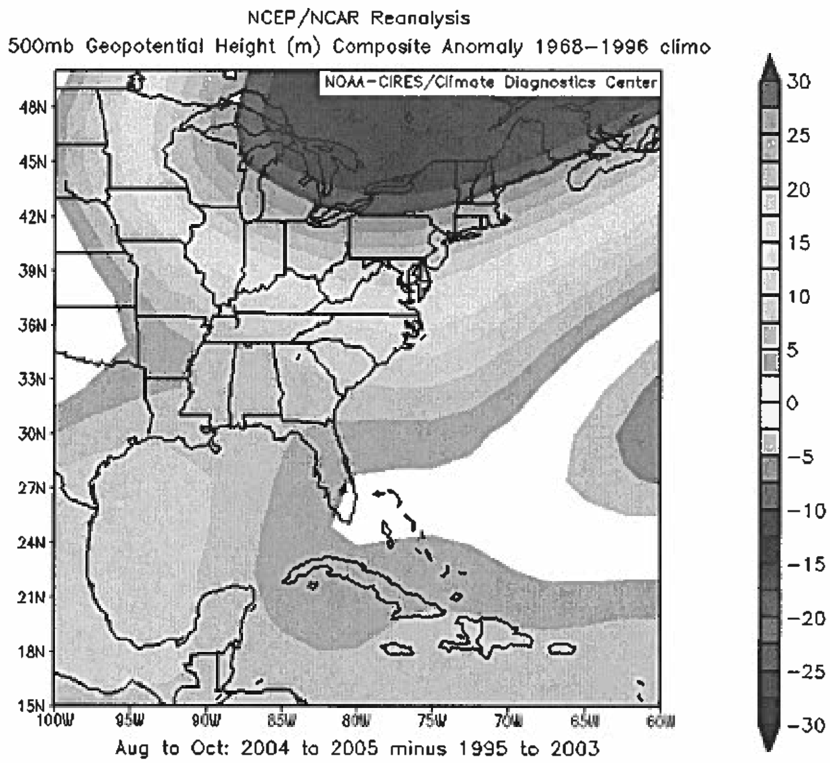


Figure 12: August-October 2004-2005 500 MB geopotential height minus August-October 1995-2003 500 MB geopotential height along the East Coast of the United States. Note the anomalous ridging along the East Coast over the past two seasons.

9 Why Has There Been a Ridge Along the East Coast During the 2004-2005 Hurricane Seasons?

A natural question emanating from the previous discussion is "What has caused the ridge to develop along the East Coast during the Atlantic hurricane season over the past two seasons?" We believe that a primary driver of the ridging along the East Coast has been a considerable warming of sea surface temperatures in the central Pacific. Figure 13 shows the difference in Pacific sea surface temperatures during August-October 2004-2005 from August-October 1995-2003. Central Pacific sea surface temperatures have warmed considerably over the past two seasons, and an anomalous wavetrain emanating from this heat source has propagated downstream across North America and into the Atlantic Ocean. Figure 14 shows the difference in 500 mb heights in the Northern Hemisphere during August-October 2004-2005 from August-October 1995-2003. One can clearly see the development of a ridge in the central Pacific near the center of the anomalous warming, with a downstream trough located in the western part of the United States. Ridging predominates along the East Coast, and another trough is seen near Iceland. This fairly stationary wavetrain setup imparts anomalously strong westward steering flow for most Atlantic basin tropical cyclones, and therefore we have witnessed many landfalls over the past two years.

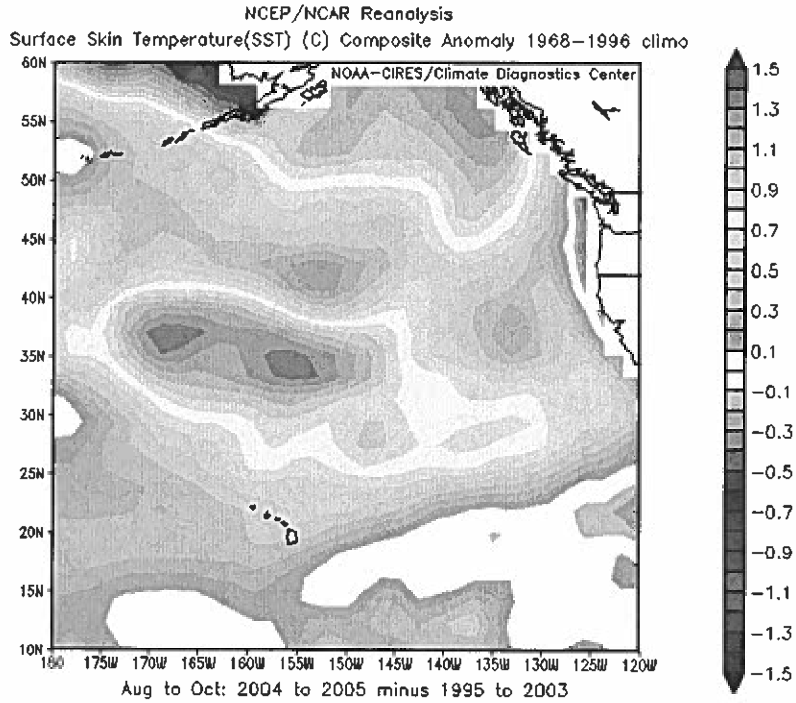


Figure 13: August-October 2004-2005 sea surface temperatures minus August-October 1995-2003 500 MB sea surface temperatures in the northeast Pacific. Note the large warming in the central Pacific.

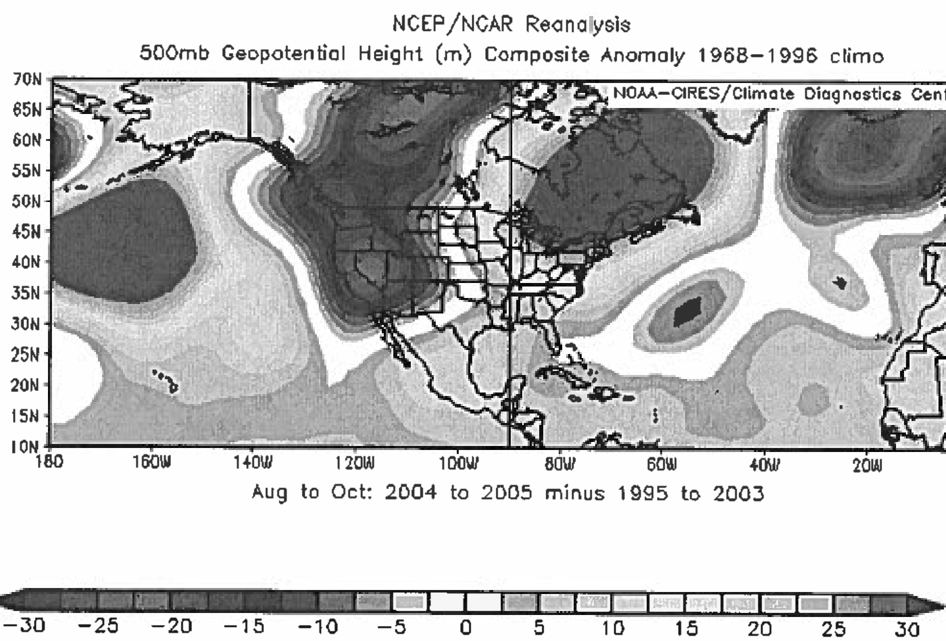


Figure 14: August-October 2004-2005 500 mb geopotential heights minus August-October 1995-2003 500 mb geopotential heights from 10°-70°N, 0°-180°W. Note the anomalous wavetrain that has been present during the past two summers.

10 Quotes from Previous Forecasts Regarding the Likely Increase in United States Hurricane Landfalls

The large increase in hurricane-spawned destruction of the last two seasons has not surprised us as much as it likely has surprised many others. We have been anticipating a great upsurge in hurricane destruction for many years. The following are a few quotes from previous forecast papers:

April 1989: "Because of the rapid growth in U.S. coastal population and property investment in recent years… it would appear that major increases in hurricane-spawned coastal destruction are inevitably to come."

August 1996: "There has been a significant lull in the incident of intense category 3-4-5 hurricanes striking the U.S. East Coast, Florida and Caribbean basin (except for 1995) during the last 25 years. We see this trend as a natural consequence of the slowdown in the Atlantic Ocean Thermohaline Conveyor Belt circulation which appears to be associated with a long list of concurrent global circulation changes during the last quarter century... Both historical and geological (proxy) records indicate that this lull in major hurricane activity will not continue indefinitely; the return of increased major landfalling hurricane activity should be expected within the next decade or so… Increased intense hurricane activity striking U.S. coastal areas is an assured threat to the U.S., much more so than earthquakes, greenhouse gas warming and other environmental problems which are receiving comparatively much greater attention."

June 1997: "Recent data and historical and geological (proxy) records indicate that this extended lull in major hurricane activity is unlikely to continue. A new era of major hurricane activity appears to have begun with the unusually active 1995 and 1996 seasons… 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 previously experienced."

April 2001: "It is highly likely that climatology will eventually right itself, and we must therefore 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."

August 2001: "We owe our good fortune to a persistent upper-air trough which has been located along the U.S. East Coast during a high percentage of the time during the last six hurricane seasons. This fortunate trend has caused a large portion of otherwise northwest moving major hurricanes to be recurved to the north before they reached the U.S. coastline. However, our good luck cannot be expected to continue forever."

May 2002: "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 as future storms begin to impact the very greatly increased coastal population and property values."

May 2003: "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."

11 Is Global Warming Responsible for the Large Upswing in 2004-2005 US Hurricane Landfalls?

11.1 Background

The recent U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma and the four Florida landfalling hurricanes of 2004 (Charley, Frances, Ivan and Jeanne) has raised questions about the possible role that global warming may be playing in these last 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 of about 0.3°C that has taken place over the last 3 decades, the global numbers of hurricanes and their intensity have not shown increases in recent years expect for the Atlantic.

The Atlantic has seen a very large increase in major hurricanes during the last 11-year period of 1995-2005 (average 4.0 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 Multi-Decadal 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 of the last 15 years with an earlier 15-year period (1950-64) 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 1950-64 as compared with global warming during 1990-2004.

11.2 Discussion

There is no physical basis for assuming that global hurricane intensity or frequency is necessarily related to global mean surface temperature changes of less than ± 0.5°C. As the ocean surface warms, so too does global upper air temperatures to maintain conditionally unstable lapse-rates and global rainfall rates at their required values. Seasonal and monthly variations of sea surface temperature (SST) within individual storm basins show only very low correlations with monthly, seasonal, and yearly variations of hurricane activity. Other factors such as tropospheric vertical wind shear, surface pressure, low level vorticity, mid-level moisture, etc. play more dominant roles in explaining hurricane variability than do surface temperatures. Although there has been a general global warming over the last 30 years and particularly over the last 10 years, the SST increases in the individual tropical cyclone basins have been smaller (about half) and, according to the observations, have not brought about any significant increases in global major tropical cyclones except for the Atlantic which as has been discussed, has multi-decadal oscillations driven primarily by changes in Atlantic salinity. No credible observational evidence is available or likely will be available in the next few decades which will be able to directly associate global surface temperature change to changes in global hurricane frequency and intensity.

Most Southeast coastal residents probably do not know how fortunate they had been in the prior 38 year period (1966-2003) leading up to 2004-2005 when there were only 17 major hurricanes (0.45/year) to cross the U.S. coastline. In the prior 40 year period of 1926-1965, there were 36 major hurricanes (0.90/year or twice as many) that made U.S. landfall. It is understandable that coastal residents were not prepared for the great upsurge in landfalling major hurricanes in 2004-2005.

We should interpret the last two years of unusual large numbers of U.S. landfalling hurricanes as natural but very low probability years. During 1966-2003, the U.S. hurricane landfall numbers were substantially below the long-term average. In the last two seasons, they have been much above the long-term average. This is how nature works. We should not try to read more into these years than this. Although the 2004 and 2005 hurricane seasons have had an unusually high number of major landfall events, the overall Atlantic basin hurricane activity has not been much more active than five of the recent hurricane seasons since 1995 (i.e., 1995-1996, 1998-1999, 2003). What has made the 2004-2005 seasons so unusually destructive is the higher percentage of major hurricanes which moved over the U.S. coastline. These landfall events were not primarily a function of the overall Atlantic basin net major hurricane numbers, but rather of the favorable broad-scale Atlantic upper-air steering currents which were present the last two seasons. It was these favorable Atlantic steering currents which caused so many of the major hurricanes which formed to come ashore.

It is rare to have two consecutive years with such a strong simultaneous combination of high amounts of major hurricane activity together with especially favorable steering flow currents. The historical records and the laws of statistics indicate that the probability of seeing another two consecutive hurricane season like 2004-2005 is very low. Even though we expect to see the current active period of Atlantic major hurricane activity to continue for another 15-20 years, it is statistically unlikely that the coming 2006 and 2007 hurricane seasons, or the seasons which follow, will have the number of major hurricane US landfall events as we have seen in 2004-2005.

12 Forecasts of 2006 Hurricane Activity

We will be issuing our first forecast for the 2006 hurricane season on Tuesday, 6 December 2005. This 6 December forecast will include the dates of all of our updated 2006 forecasts. All of these forecasts will be made available at our web address given on the front cover: http://hurricane.atmos.colostate.edu/Forecasts.

13 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 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 first 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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15 Verification of Previous Forecasts

Table 12: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 1999-2004.

1999	5 Dec. 1998	Update 7 April	Update 4 June	Update 6 August	Obs.
No. of Hurricanes	9	9	9	9	8
No. of Named Storms	14	14	14	14	12
No. of Hurricane Days	40	40	40	40	43
No. of Named Storm Days	65	65	75	75	77
Hurr. Destruction Potential	130	130	130	130	143
Intense Hurricanes	4	4	4	4	5
Intense Hurricane Days	10	10	10	10	15
Net Tropical Cyclone Activity	160	160	160	160	193

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