SUMMARY OF 2004 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND MONTHLY FORECASTS

(A very active season with four hurricanes making landfall in the southeastern United States.)

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: http://tropical.atmos.colostate.edu/Forecasts/] - also,

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

Department of Atmospheric Science

Colorado State University

Fort Collins, CO 80523

email: barb@tutt.atmos.colostate.edu

19 November 2004

"METEOROLOGISTS ARE KNOWN TO BE ABSOLUTELY BRILLIANT AT RECONSTRUCTION AND EXPLANATION OF PAST WEATHER EVENTS.... BUT BE SURE NOT TO BRING UP QUESTIONS ABOUT TOMORROW'S RAINFALL"

ANONYMOUS

Acknowledgment

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

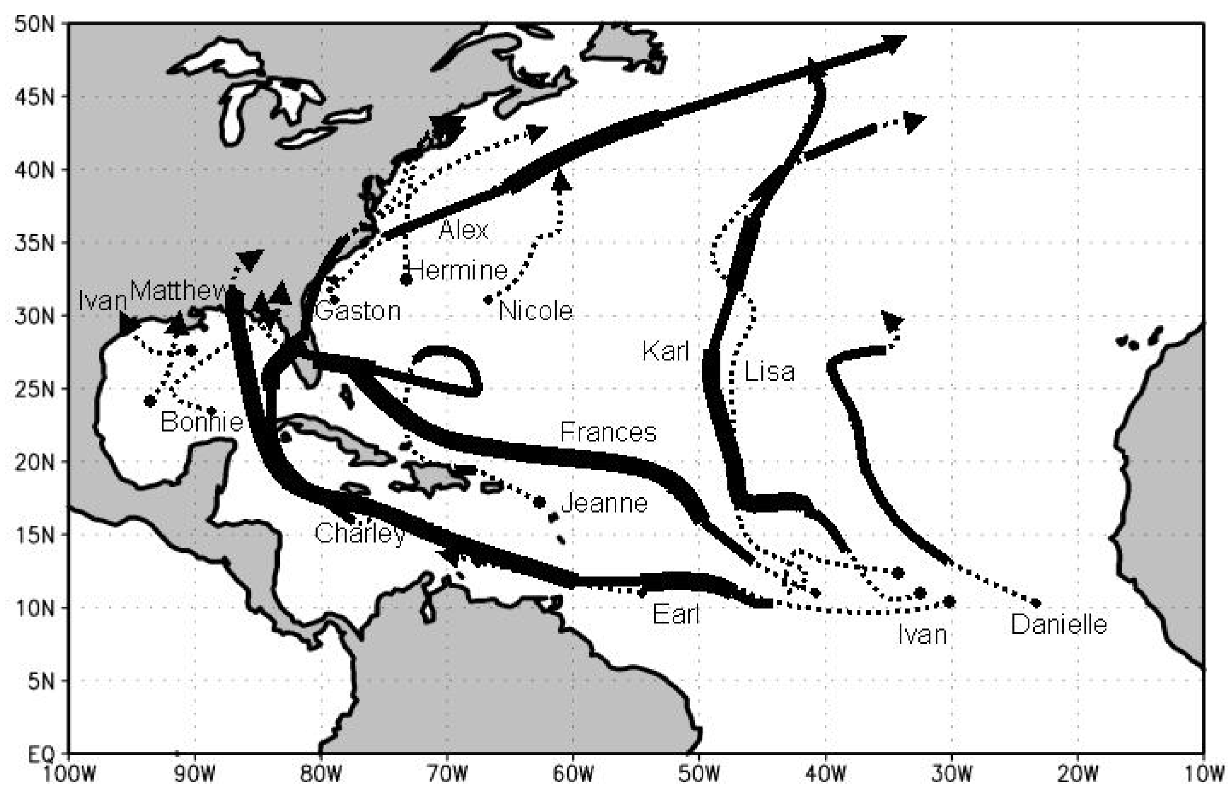
DEFINITIONS

ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2004

		Update	Update	Update	Update	Update	Observed

Forecast Parameter and 1950-2000 Climatology (in parentheses)	5 December 2003	2 April 2004	28 May 2004	6 Aug 2004	3 Sept 2004	1 Oct 2004	2004 Total
Named Storms (NS) (9.6)	13	14	14	13	16	15	14
Named Storm Days (NSD) (49.1)	55	60	60	55	70	96	88.75
Hurricanes (H)(5.9)	7	8	8	7	8	9	8
Hurricane Days (HD)(24.5)	30	35	35	30	40	52	45
Intense Hurricanes (IH) (2.3)	3	3	3	3	5	6	6
Intense Hurricane Days (IHD)(5.0)	6	8	8	6	15	23	23
Net Tropical Cyclone Activity (NTC)* (100%)	125	145	145	125	185	240	228

* 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 2004 and verifies the authors' seasonal and monthly forecasts of this activity. A forecast was initially issued for the 2004 season on 5 December 2003 with updates on 2 April, 28 May, 6 August, 3 September and 1 October of this year.

These forecasts also contained estimates of the probability of U.S. hurricane landfall during 2004. The 6 August update included forecasts of August-only, September-only and October-only tropical cyclone activity for 2004. Our 3 September forecast gave a seasonal summary to that date and included individual monthly predictions of September-only and October-only activity. Our 1 October forecast gave a seasonal summary to that date and included an October-only forecast. We are reasonably pleased with our 2004 seasonal forecasts. Most of our forecast numbers were closer to reality than they would have been had we used a climatology forecast; however, we were unable to forecast the large number of major hurricanes (6) which formed or that the season would be so concentrated during the months of August and September. We consider our earliest seasonal forecast (made 5 December 2003) the best of our forecasts when the extended lead time of the forecast is taken into consideration.

Our monthly statistical forecasts of August-only and September-only activity were not successful in terms of the Net Tropical Cyclone activity (NTC) that occurred. We attribute this to the apparent lack of influence of the very warm equatorial sea surface temperatures in the central Pacific and the higher-than-normal tropical Atlantic sea surface pressure on the Atlantic hurricane season. In most years, these conditions reduce Atlantic hurricane activity. We significantly raised our final forecast for the months of August and September to above-average. We were, however, unable to predict the degree of activity that took place during these two months. We judge our October-only forecasts to be successful in that we forecast (as observed) no major hurricanes and normal to somewhat below-normal activity for the month.

1 Introduction

Table 1: New predictors utilized in our statistical seasonal forecasts issued in early December, early April, and late May respectively. We were not able to obtain any significant increase in hindcast skill incorporating June and July data into our August statistical forecast, and therefore we simply use the late May statistical forecast as our first guess for our early August forecast. We then alter this seasonal forecast by the results of our three individual monthly forecasts of August, September and October.

Early December Seasonal Forecast

Predictor and Sign of Correlation	Location
November 500 MB Geopotential Height (+)	(67.5-85°N, 50°W-10°E)
November SLP (+)	(7.5-22.5°N, 125-175°W)
October-November SLP (-)	(45-65°N, 120-160°W)
September-November SLP (-)	(15-35°N, 75-95°W)
September 500 MB Geopotential Height (+)	(35-55°N, 100-120°W)
July 50 MB U (-)	(5°S-5°N, 0-360°)

Early April Seasonal Forecast

Predictor and Sign of Correlation	Location

February-March 200 MB V (-)	(35-62.5°S, 70-95°E)
February 200 MB U (-)	(5°S-10°N, 35-55°W)
February SLP (+)	(0-45°S, 90-180°W)
February SST (+)	(35-50°N, 10-30°W)
Previous November 500 MB Geopotential Height (+)	(67.5-85°N, 50°W-10°E)
Previous September-November SLP (-)	(15-35°N, 75-95°W)

Late May and Early August Seasonal Forecast

Predictor and Sign of Correlation	Location
May SST (+)	(20-40°N, 15-30°W)
February-March 200 MB V (-)	(35-62.5°S, 70-95°E)
February 200 MB U (-)	(5°S-10°N, 35-55°W)
February SLP (+)	(0-45°S, 90-180°W)
February SST (+)	(35-50°N, 10-30°W)
Previous November 500 MB Geopotential Height (+)	(67.5-85°N, 50°W-10°E)
Previous September-November SLP (-)	(15-35°N, 75-95°W)

Table 2: Predictors utilized in our monthly forecasts for August-only, September-only and October-only Atlantic tropical cyclone activity, respectively. See section 4.2 for a discussion of our monthly predictions and the timetable of their release.

August-only Forecast
Issued in Early August

Predictor and Sign of Correlation	Location
July 200 MB V (-)	(4°S-8°N, 79-105°W)
July SLP (-)	(47-62°N, 156°E-164°W)
July SLP (-)	(25-37.5°N, 25-47.5°W)
July 200 MB U (-)	(35-40°S, 85-110°W)
July 500 MB Geo. Ht. (-)	(27.5-42.5°S, 72.5-95°E)
July 200 MB U (+)	(7.5-17.5°S, 145-180°E)
July 200 MB U (-)	(5°S-5°N, 85-110°W)
June 200 MB U (+)	(80-85°N, 45°W-10°E)
June SLP (+)	(18-30°N, 134-154°E)
April SLP (-)	(10°S-5°N, 35°W-15°E)
February SLP (-)	(52.5-75°N, 5°W-35°E)
January SLP (-)	(30-40°N, 95-110°W)

September-only Forecast Issued in early August

Predictor and Sign of Correlation	Location
July 1000 MB U (+)	(5-15°N, 30-50°W)
July 200 MB Geo. Ht. (+)	(32-42°N, 100-160°E)
May 200 MB V (+)	(0-20°S, 15-30°E)
April 200 MB U (-)	(67.5-85°N, 110-180°E)
April 1000 MB U (-)	(12.5-30°S, 40°W-10°E)
February 1000 MB U (-)	(20-30°N, 15°W-15°E)
January-February 200 MB U (-)	(15-25°N, 120°E-160°W)

September-only Forecast Issued in early September

Predictor and Sign of Correlation	Location
August SLP (-)	(0-30°S, 120-160°E)
August SLP (-)	(20-45°S, 60-90°E)
July-August 1000 MB U (+) (-)	(5-15°N, 30-50°W) - (22.5-35°N, 35-65°W)
July 200 MB Geo. Ht. (+)	(32-42°N, 100-160°E)
May 200 MB V (+)	(0-20°S, 15-30°E)
April 200 MB U (-)	(67.5-85°N, 110-180°E)
April 1000 MB U (-)	(12.5-30°S, 40°W-10°E)
February 1000 MB U (-)	(20-30°N, 15°W-15°E)
January-February 200 MB U (-)	(15-25°N, 120°E-160°W)

October-only Forecast Issued in early August

Predictor and Sign of Correlation	Location
July 200 MB Geo. Ht. (+)	(20-35°N, 5-45°W)
July 200 MB U (+)	(35-47.5°S, 160°E-160°W)
June-July SLP (-)	(10-25°N, 10-40°W)
Previous November SLP (-)	(45-65°N, 115-145°W)

October-only Forecast Issued in early September

Predictor and Sign of Correlation	Location
August SST (+)	(22.5-35°N, 120-150°E)
July-August 200 MB U (+)	(35-47.5°S, 160°E-155°W)
July-August SLP (-)	(12.5-27.5°N, 15-45°W)
Previous November SLP (-)	(45-65°N, 115-145°W)

October-only Forecast Issued in Early October

Predictor and Sign of Correlation	Location
September 200 MB U (+)	(37.5-47.5°S, 0-30°W)
August SST (+)	(22.5-35°N, 120-150°E)
July-August 200 MB U (+)	(35-47.5°S, 160°E-155°W)
July-August SLP (-)	(12.5-27.5°N, 15-45°W)
Previous November SLP (-)	(45-65°N, 115-145°W)

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 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 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 5 predictor model and 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 atmospheric-oceanic 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. Tables 1 and 2 display the predictors utilized in our statististical forecasts for the season and for the individual months of August, September and October, respectively.

2 Tropical Cyclone Activity for 2004

Figure 1 and Table 3 summarize the Atlantic basin tropical cyclone activity which occurred in 2004. All of the seasonal forecast parameters of NS, NSD, H, HD, IH, IHD, and NTC were above the long-period average as predicted in our seasonal forecasts.

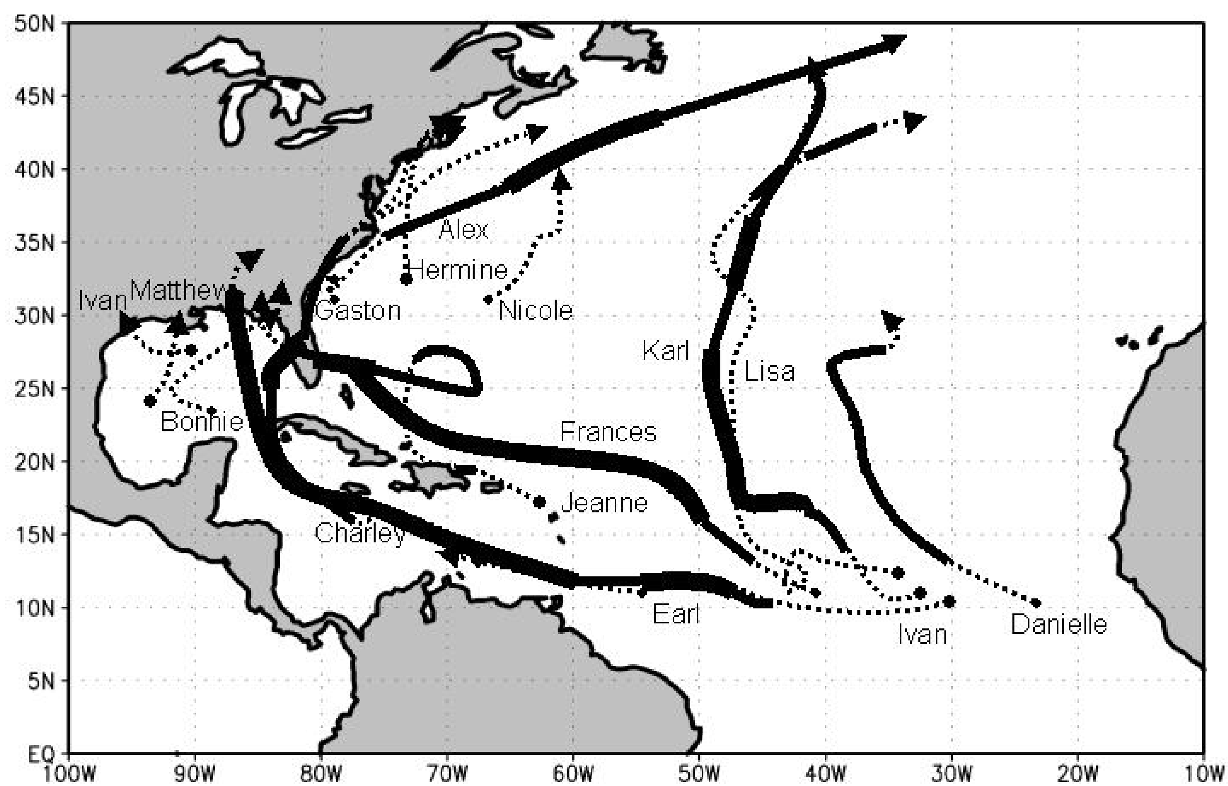


Figure 1: Tracks of 2004 Atlantic Basin tropical cyclones. Dashed lines indicate tropical storm intensity, a thin solid line is Cat 1 or 2 hurricane intensity, and a thick solid line is major hurricane (Cat 3-4-5) intensity.

Table 3: Observed 2004 tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds Knots /lowest SLP in mb	NSD	HD	IHD	NTC
IH - 3	Alex	Aug. 1-6	105 kt/957 mb	5.00	3.25	0.75	18.2
TS	Bonnie	Aug. 9-12	55 kt/1000 mb	3.00			2.8
IH - 4	Charley	Aug. 10-15	125 kt/941 mb	5.25	3.00	0.25	16.5
H - 2	Danielle	Aug. 14-20	90 kt/970 mb	6.75	3.50		9.2
TS	Earl	Aug. 14-16	40 kt/1005 mb	1.75			2.3
IH - 4	Frances	Aug. 25-Sep. 7	125 kt/935 mb	12.25	10.00	7.25	46.9
TS	Gaston	Aug. 28-29, Aug. 31-Sep. 6	60 kt/991 mb	3.00			2.8
TS	Hermine	Aug. 29-31	45 kt/1000 mb	1.50			2.2
IH - 5	Ivan	Sep. 3-17, Sep. 23-24	145 kt/910 mb	14.75	11.50	10.00	67.2
IH - 3	Jeanne	Sep. 14-27	110 kt/950 mb	13.00	6.25	0.75	23.0
IH - 4	Karl	Sep. 17-24	120 kt/938 mb	8.00	6.75	4.00	32.4
H-1	Lisa	Sep. 20-23, Sep. 25-Oct.3	65 kt/987 mb	11.25	0.75		8.9
TS	Matthew	Oct. 8-10	40 kt/997 mb	1.50			2.2
TS	Nicole	Oct. 10-11	45 kt/988 mb	1.75			2.3
Totals	14			88.75	45.00	23.00	228

3 Individual 2004 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2004 season. See Fig. 1 for the tracks of these tropical cyclones, and see Table 3 for the statistics of these tropical cyclones.

Intense Hurricane Alex: Alex developed from a low pressure system off the northeast Florida coast and became the first tropical storm of the 2004 season on August 1 after aircraft reconnaissance measured winds of 41 knots at a flight level of 1000 feet. Alex intensified into a hurricane while brushing the Outer Banks of North Carolina on August 3. It then intensified into a major hurricane while tracking northeastward near the northern edge of the Gulf Stream on August 5. Alex was an atypical tropical cyclone in that it became the most intense hurricane north of 38°N when it reached its maximum intensity of 105 knots. The storm then weakened and became extratropical on August 6 as it moved over markedly colder waters. Initial damage estimates in North Carolina from Alex were put at 2.5 million dollars.

Tropical Storm Bonnie: Bonnie was initially classified as a tropical depression on August 3 while tracking toward the Leeward Islands. However, the system was unable to concentrate convection near its center due its rapid forward movement, and it degenerated into a tropical wave on August 4. The remnant wave began to get better organized over the next few days, and Bonnie became classified as a tropical storm in the southern Gulf of Mexico on August 9 when aircraft reconnaissance measured winds of 56 knots at a flight level of 1500 feet. Bonnie tracked northward through a weakness in the subtropical ridge and intensified to 55 knots as it encountered light vertical shear. The system was then picked up by a trough and moved northeastward, making landfall on August 12 near Apalachicola, Florida with maximum winds at landfall estimated at 40 knots. Bonnie dissipated rapidly after it moved inland later in the day on August 12. There were three reported deaths in the United States from this system; however, damage was minimal.

Intense Hurricane Charley: Charley developed from a tropical wave into a tropical depression while passing near Trinidad on August 9. It became a tropical storm the following day. The system tracked rapidly west-northwestward through an area of warm sea surface temperatures and weak wind shear. It intensified into a hurricane on August 11. Charley passed over Cuba as a Category 2 storm on August 12 and then rapidly intensified into a Category 4 storm while moving through the Florida Straits. It made landfall near Charlotte Harbor late in the day on August 13 with estimated winds at landfall of 130 knots. It then tracked northeastward across the central Florida peninsula, severely affecting Orlando and Daytona Beach before reaching the Atlantic Ocean. Charley made three additional landfalls: a first landfall at Cape Romain, SC with estimated winds of 70 knots, a second landfall near Myrtle Beach with estimated winds of 65 knots, and a final landfall on Long Island, NY as a minimal tropical storm with estimated winds of 35 knots. The system rapidly dissipated after its final landfall on Long Island and was declared extratropical on August 15. Preliminary insured damage estimates for this system are between 6-7 billion dollars, putting total damage estimates between 12-14 billion dollars.[4] This makes Charley the second most expensive hurricane to hit the United States, behind only Hurricane Andrew of 1992.

Hurricane Danielle: Danielle developed from a tropical wave while tracking south of the Cape Verde Islands. It became a named storm on August 14 at 24.8˚W which is the farthest east that a storm has been named since Alberto (2000). The system tracked northwestward and intensified into a hurricane on August 15. Soon after, a mid-level trough picked up Danielle and steered the storm more toward the north. Danielle intensified into a Category 2 hurricane before increasing environmental southwesterly shear from the mid-level trough began to take its toll on the system. It weakened slowly over the next few days and became classified as a remnant low on August 21.

Tropical Storm Earl: Earl developed from a tropical wave while tracking westward toward the Windward Islands. It became classified as a tropical storm on August 14. The storm tracked very quickly westward due to an upper-level ridge to its north, and despite favorable wind shear and sea surface temperatures, it strengthened only slightly due to its rapid forward movement. As it continued to track briskly toward the west, it began to transform into an open wave. Hurricane hunter aircraft were unable to close off a circulation center, and the system was downgraded to a tropical wave on August 16.

Intense Hurricane Frances: Frances formed from a tropical wave while traveling westward across the open Atlantic. The system became a tropical storm on August 25 based on 35 knot winds from satellite estimates. Frances rapidly intensified into a hurricane while being steered westward by an upper-level ridge. During this time, the system was under weak shear and was moving over warm sea surface temperatures, and by August 27, Frances had become the second major hurricane of the year. A shortwave trough caused Frances to turn more northward briefly, but then the upper-level ridge built back in, and Frances continued its move westward, intensifying into a powerful Category 4 hurricane in the process on August 28. Some fluctuations in intensity occurred over the next several days, due in large part to the internal dynamics of the cyclone; however, the system retained major hurricane status while tracking west-northwestward beneath a strong subtropical ridge. Frances began to stall as it approached the Bahamas as the steering currents collapsed. The storm passed over the Bahamas on September 3 with estimated winds of 100 knots. Frances finally made landfall near Sewall's Point, Florida on September 5 as a very large Category 2 hurricane with maximum winds at landfall estimated at 90 knots. Frances slowly tracked west-northwest across the state before emerging into the Gulf of Mexico. It made a second landfall as a 55 knot tropical storm near St. Marks, Florida on September 6. The system dissipated later that day. Insured damage from Frances is estimated at around 4 billion dollars, bringing the total damage estimate to around 8 billion dollars. Frances was responsible for at least 24 deaths.

Tropical Storm Gaston: Gaston developed from a low pressure area located off the southeastern United States coast. It became classified as a tropical storm on August 28. Light shear allowed for strengthening while the system drifted northward. It made landfall near McLellanville, South Carolina on August 29 with estimated 60 knot winds. The system became extratropical while moving over North Carolina and tracked northeastward across Virginia and Maryland. Late on August 30, Gaston regained minimal tropical storm strength after moving over the relatively warm waters off the coast of southern Maryland. By late on August 31, it began to interact with a baroclinic zone and was declared extratropical on September 1. Estimated total damage from Gaston was 15 million dollars. No deaths were reported.

Tropical Storm Hermine: Hermine formed from an area of low pressure in the North Atlantic approximately 325 miles southeast of Cape Hatteras, North Carolina on August 29. The system then became sheared from the south, although it did strengthen to a 45 knot storm the following day. Hermine tracked northward around the periphery of the Bermuda subtropical ridge and made landfall early on August 31 near New Bedford, Massachusetts with maximum winds at landfall estimated at 35 knots. No damage or deaths were reported from the system.

Intense Hurricane Ivan: Ivan formed about 600 miles southwest of the Cape Verde Islands early on September 3. The system tracked westward for the first few days of its life as it was guided by a strong subtropical ridge to its north. It was over very warm sea surface temperatures and moderate easterly shear in its early stages, and it gradually intensified into a hurricane on September 5. Ivan rapidly intensified into a major hurricane later on September 5, and then weakened back to a Category 2 storm the following day. However, this weakening did not last long, and Ivan again became a major hurricane on September 7. It tracked through the southern Windward Islands, wreaking havoc, especially to Grenada where 24 people were reported dead, and up to 85 percent of property on the island was destroyed. Ivan intensified into a Category 4 hurricane later on September 7 and reached Category 5 status early on September 9. Ivan remained at either Category 4 or 5 status for the next few days while continuing its destructive northwestward path through the Caribbean. The system severely impacted Jamaica with an estimated 350 million dollars in damage. It then passed through the Cayman Islands where it damaged 80 percent of all structures. It reached its maximum intensity on September 11 with sustained winds of 145 knots and a central pressure of 910 millibars. Westerly shear began to impact the system as it tracked into the Gulf of Mexico, and it weakened to a Category 3 hurricane before making landfall near Palm Shores, Alabama early on September 16. Damage was especially extensive in the panhandle of Florida, with Pensacola experiencing considerable destruction. Insured damage from Ivan is estimated at between 4-5 billion dollars. This brings total estimated damage in the United States to between 8-10 billion dollars. The storm weakened to a tropical depression later on September 16 as it tracked northeastward through Alabama. However, Ivan was not done. Its remnants tracked northeastward off the mid-Atlantic coastline, and a low-level circulation from Ivan drifted southwestward across the state of Florida into the Gulf of Mexico. Once it reached the Gulf, Ivan intensified and became reclassified as a tropical storm on September 22. It tracked west-northwestward and made landfall as a minimal tropical storm in Cameron Parish, Louisiana on September 23. The system dissipated early the next day.

Intense Hurricane Jeanne: Jeanne developed from a tropical wave on September 13 and became classified as a tropical storm the following day while located approximately 150 miles southeast of Saint Croix. It tracked west -northwestward under a subtropical ridge and gradually intensified into a hurricane after passing over Puerto Rico where it caused an estimated 200 million dollars in damage due to landslides. The steering currents around Jeanne collapsed over the next couple of days, and the system stalled over Hispaniola, causing intense devastation in the Dominican Republic and especially Haiti. It is estimated that over 2000 people in the port city of Gonaives, Haiti perished in mudslides caused by the slow-moving system. Jeanne weakened during this time to a minimal tropical storm due its interaction with land. By September 19, the system began to drift northward around the periphery of the subtropical ridge. Jeanne intensified back into a hurricane on September 20 due to weak wind shear and tracked northeastward well south of Bermuda. However, an upper-level ridge built over the system, and Jeanne began to drift toward the southeast and then south. The ridge continued to build over the next couple of days, and Jeanne began to track westward toward the coast of Florida. Cool sea surface temperatures due to upwelling from the system and moderate shear inhibited Jeanne from intensifying too much during this time period. However, Jeanne began to track westward at a more rapid rate by September 24, and it began to intensify as it moved over the warm Gulf Stream waters. On September 25, Jeanne made landfall in the northwest Bahamas, while intensifying into a major hurricane. Early on September 26, Jeanne made landfall near Stuart, Florida with maximum winds at landfall estimated at 105 knots. It moved northwestward across the state of Florida and dissipated the next day while tracking northward across Georgia. Jeanne caused considerable damage on both Grand Bahama and Abaco in the northwestern Bahamas, and it is estimated that the system caused between 4-8 billion dollars in insured damage in the United States, bringing the total damage estimate to between 8-16 billion dollars.

Intense Hurricane Karl: Karl developed late on September 16 from a tropical wave while located about 700 miles west-southwest of the Cape Verde Islands. Karl tracked northwestward over the next couple of days while intensifying rapidly into a hurricane due to weak shear conditions and warm sea surface temperatures. A shortwave trough approached from the west and weakened the subtropical ridge, and Karl proceeded to turn more northward. It reached major hurricane status on September 18 and became a Category 4 system the following day. It maintained major hurricane status until September 22, when it weakened to a Category 2 system. Karl briefly regained major hurricane status on September 23, before weakening again as colder sea surface temperatures and increasing wind shear impacted the system. It became extratropical on September 24 while located about 900 miles northwest of the Azores.

Hurricane Lisa: Lisa developed from the tropical wave that immediately followed Karl off the African coast. The system was classified as a tropical storm on September 20. The tropical cyclone was small during its initial stages, and it strengthened to a 60 knot tropical storm due to relatively weak wind shear. However, it soon moved under the outflow of powerful Hurricane Karl, and northerly shear from the larger hurricane caused Lisa to weaken. In addition, a larger wave to its east began to inhibit Lisa's outflow, and it weakened to a tropical depression on September 23 while completing a cyclonic loop in the open Atlantic. By September 25, the strong shear imposed by Karl and an upper-level ridge began to weaken, and Lisa was upgraded to a tropical storm for a second time. An upper-level trough weakened the subtropical ridge, and Lisa began to track north-northwestward. It tracked over the cool wake of Karl and had a difficult time strengthening over the next few days due to these cool sea surface temperatures and strong southwesterly shear. However, by September 28, the shear began to weaken, and Lisa strengthened. It reached hurricane strength on October 1 while located about 1000 miles west of the Azores. Lisa's lifetime as a hurricane was short-lived as it moved over cooler sea surface temperatures, and it became extratropical on October 2.

Tropical Storm Matthew: Matthew formed in a highly sheared system in the Gulf of Mexico on October 8. Although the system was highly sheared, a reconnaissance aircraft found a fairly well-defined circulation, and advisories were started on the tropical cyclone. Matthew weakened to a tropical depression the following day due to 30-40 knots of southwesterly shear. It tracked northeast through the northern Gulf and regained minimal tropical storm status later on October 9. Matthew made landfall as a 35 knot tropical storm on October 10 in Cameron Parish, Louisiana and dissipated later that day. Fairly extensive flooding near Lake Pontchartrain was reported; however, damage from the system was minimal.

Subtropical Storm Nicole: Nicole became identified as a subtropical storm while located near Bermuda on October 10. According to the National Hurricane Center, a subtropical cyclone is: ä non-frontal low pressure system that has characteristics of both tropical and extratropical cyclones." Nicole was classified as subtropical instead of tropical because the strongest winds were far-removed from the center of the system. Convection remained well-removed from the system during its lifetime, and it remained classified as a subtropical storm while tracking northeastward across the Atlantic. It began to merge with an extratropical cyclone during the afternoon of October 11 and was classified as extratropical later that evening.

U.S. Landfall. Figure 2 shows the tracks of all 2004 tropical cyclones which impacted the U.S. Florida was severely affected by four hurricanes this year: Category 2 Hurricane Frances, Category 3 Hurricanes Ivan and Jeanne and Category 4 Hurricane Charley. Note the nearly identical landfall locations of Hurricanes Frances and Jeanne. Table 4 displays the estimated total damage from these four devastating tropical cyclones. Although not actually making landfall, Hurricane Alex caused some damage along the Outer Banks of North Carolina. In addition, Tropical Storms Bonnie, Gaston, Hermine, Ivan and Matthew made landfall along the United States coastline. The last time that eight different tropical cyclones impacted the United States coastline was 1916. Total damage from all 2004 tropical cyclone landfalls could approach 50 billion dollars.

Table 4: Damage estimates of the four U.S. landfalling hurricanes in 2004 (in billions of dollars). We assume that total damage is twice that of insured damage.

Storm	Insured	Total
Charley	7.5	15
Frances	4.5	9
Ivan	4.5	9
Jeanne	6.0	12
Total	22.5	45
Andrew (1992) in 2004 Dollars	20	40

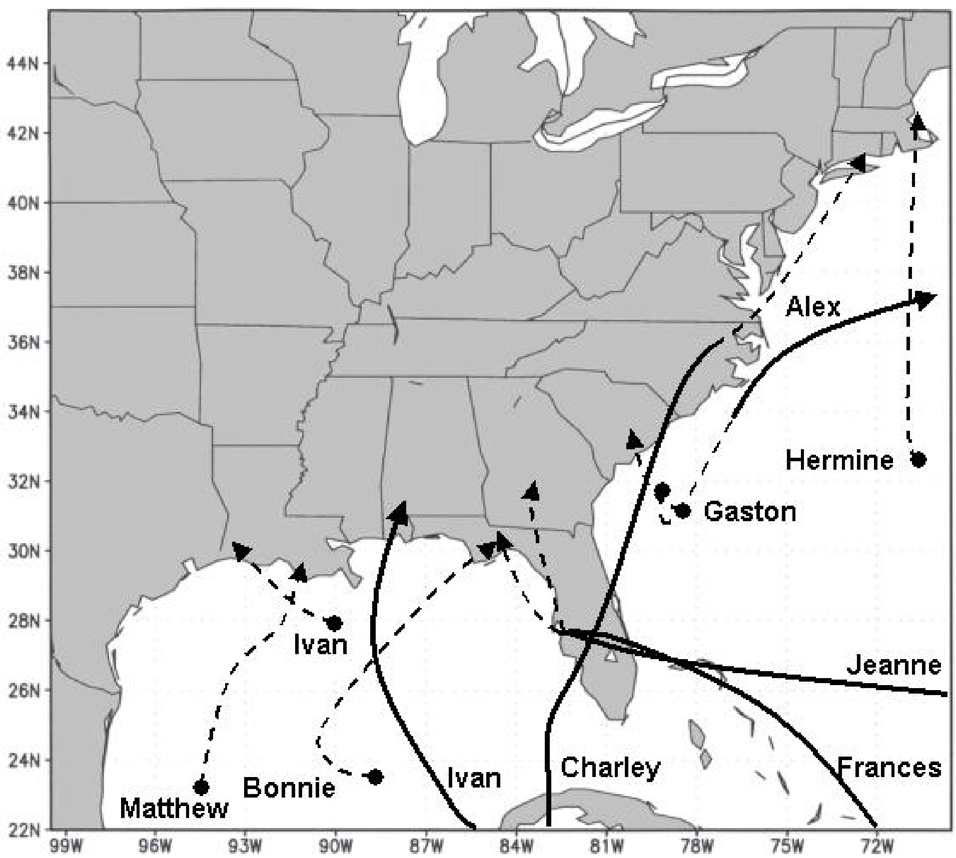


Figure 2: Tropical cyclones making US landfall (TS Bonnie, Category 4 Hurricane Charley, Category 2 Hurricane Frances, TS Gaston, TS Hermine, Category 3 Hurricane Ivan, TS Ivan, Category 3 Hurricane Jeanne, TS Matthew). Although Alex did not technically make U.S. landfall, its eyewall approached the Outer Banks of North Carolina and caused some damage to this area.

3.1 Special Characteristics of the 2004 Hurricane Season

The 2004 hurricane season was unique with its number of U.S. landfalling storms and in a number of other ways:

- There were no named storms before August 1 (Alex). This is the latest start of an Atlantic hurricane season since 2000 (Alberto, August 4).

- The season accumulated 228 NTC units. This is the second highest value since 1950. Only 1950 with 230 NTC units had more.

- 23 intense hurricane days were accrued during the season. The 1950-2000 seasonal average for intense hurricane days was 5.0. 2004 had 4.6 times the average number of seasonal intense hurricane days during the months of August and September. The 2004 season is tied with 1926 for the most intense hurricane days observed in a single hurricane season.

- The National Hurricane Center was writing advisories on one or more storms for 41 consecutive days between August 25 - October 3.

- August and September were incredibly active months. August 2004 had 86 NTC units, the highest NTC on record for that month, and September 2004 had 134 NTC units, the second highest NTC observed since 1950, trailing only September 1961 (141 NTC units).

- The combined August-September NTC of 220 is the most on record extending back to 1950.

- August had more named storms (8) and intense hurricanes (3) than any August on record.

- September had more intense hurricane days (17.75) than any September on record.

- Although the seasonal NTC was extremely high (228), October was very inactive with an NTC of only 9 (average NTC is 17). The most active season since 1950 with an October NTC value of 9 or less was 1989, which had an October NTC value of 6 and a seasonal NTC value of 130.

- Four hurricanes made landfall along the United States coastline (Charley, Frances, Ivan and Jeanne). This is the first time that four or more hurricanes have made landfall since 1985 when six hurricanes made landfall (Bob, Danny, Elena, Gloria, Juan and Kate).

- Three hurricanes made landfall in the state of Florida (Charley, Frances and Jeanne). This is the first time that this has occurred since 1964 (Cleo, Dora and Isbell).

- Two major hurricanes made landfall in the state of Florida (Charley and Jeanne). The last time this occurred was 1950 (Baker and Easy).

- Alex became the most intense hurricane to develop north of 38˙N when it reached an intensity of 105 knots. This eclipses the old record of 100 knots set by Hurricane Ellen in 1973.

- Charley became the first major hurricane to strike Florida since Opal (1995). Charley was the first Category 4 or greater hurricane to strike Florida since Andrew (1992).

- Ivan became the longest-lived intense hurricane on record (10.0 IHD) eclipsing the old record held by the Miami Hurricane of 1926 (9.25 IHD).

- Ivan recorded a minimum sea level pressure reading of 910 mb on September 11. This is the most intense hurricane since Mitch (1998) when a minimum sea level pressure of 905 mb was recorded.

- Frances and Ivan combined for 17.25 IHD this year. This eclipses the old record set in 2003 by Fabian and Isabel of 15.5 IHD.

- Frances and Ivan accounted for 107 NTC units.

- Jeanne was the first major hurricane to strike Florida north of West Palm Beach and south of the Georgia/South Carolina border since 1893.

- Six intense hurricanes formed this year (Alex, Charley, Frances, Ivan, Jeanne and Karl) tying with 1961 and 1996 for the second most intense hurricanes since 1950. 1950 had seven major hurricanes.

- Eight named storms made landfall this year (Bonnie, Charley, Frances, Gaston, Hermine, Ivan, Jeanne and Matthew). This is the most storms that have made landfall since 1916 when eight named storms also made landfall.

In summary, the 2004 season was incredibly active during the two months of August and September. Table 5 displays the NTC activity occurring during the months of August and September for the active thermohaline period of 1950-1969, the inactive thermohaline period of 1970-1994, the recent active thermohaline period from 1995-2003, along with the 54-year average of 1950-2003 and the activity in 2004. Note that activity during August and September of 2004 was approximately three times the 54-year average.

Table 5: Yearly average activity experienced during August-September during various multi-decadal periods compared with the activity that occurred in 2004.

Year(s)	August-September NTC
1950-1969	81
1970-1994	56
1995-2003	102
1950-2003	73
2004	220

4 Verification of Individual 2004 Lead Time Forecasts

Table 6 shows a comparison of our 2004 forecasts for six different lead times along with this year's observed numbers. Our seasonal forecast numbers for this year worked out fairly well. We consistently forecast an above average hurricane season for 2004, and that is what occurred. Based on very warm June and July equatorial mid-Pacific sea surface temperatures and higher than normal Atlantic equatorial sea level pressure, we slightly reduced our seasonal forecast of 6 August. This turned out to be a mistake. There has never been a season as active as 2004 when Pacific water temperatures and Atlantic surface pressures were this high.

Table 6: Verification of our 2004 seasonal hurricane predictions.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	**5 December 2003**	**Update 2 April 2004**	**Update 28 May 2004**	**Update 6 Aug 2004**	**Update 3 Sept 2004**	**Update 1 Oct 2004**	**Observed 2004 Total**
Named Storms (NS) (9.6)	13	14	14	13	16	15	14
Named Storm Days (NSD) (49.1)	55	60	60	55	70	96	88.75
Hurricanes (H)(5.9)	7	8	8	7	8	9	8
Hurricane Days (HD)(24.5)	30	35	35	30	40	52	45
Intense Hurricanes (IH) (2.3)	3	3	3	3	5	6	6
Intense Hurricane Days (IHD)(5.0)	6	8	8	6	15	23	23
Net Tropical Cyclone Activity (NTC)(100%)	125	145	145	125	185	240	228

4.1 Preface: Aggregate Verification of our Last Six Yearly Forecasts

We are making progress in better understanding and are consequently improving seasonal prediction skill (as demonstrated by the last six years of our seasonal verifications). Skillful extended range seasonal predictions are indeed possible. The last six years of seasonal forecasts have shown an improved level of forecast skill. With more research our understanding and skill should continue to improve. We define forecast skill as the degree to which we are able to predict the variation of seasonal hurricane activity parameters from their long term climatology. The latter is expressed as the ratio of our forecast error to the observed difference from climatology or:

Forecast Error/Seasonal Difference from Climatology

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 have shown some degree of forecast skill at all lead times. Table 7 shows our average skill score based on 52 years of hindcasts from 1950-2001, and Table 8 displays our skill score in real-time forecasting for the last six years at different lead times for all parameters.

Table 7: Average percent of variation of hindcasts from climatology as a function of different forecast lead times (in percent) for the 52-year period 1950-2001. A value of 45 means that we hindcast 45 percent of the variability from climatology or that we were unable to explain 55 percent of the variability from climatology.

Tropical Cyclone	Early	Early	Early
Parameter	December	April	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 8: Last six years' (1999-2004) average percent of variation of our 'real-time' forecasts from climatology as a function of different forecast lead times (in percent). A value of 45 means that we have predicted 45 percent of the variability from climatology or that we were unable to explain 55 percent of the variability from climatology.

Tropical Cyclone	Early	Early	Early	Early
Parameter	December	April	June	August
NS	30	39	55	47
NSD	25	37	67	34
H	11	27	52	52

HD	25	39	51	55
IH	18	29	39	39
IHD	20	22	25	18
NTC	27	39	46	43

Each of our last six yearly forecasts have shown skill. Figure 3 displays the percent variation from climatology of the average of these six yearly forecasts for hurricane days.

We show considerable skill from the early December forecast for several parameters including hurricane days (HD) and Net Tropical Cyclone (NTC) activity. For these two parameters, our skill was (25% and 27%) from the early December forecast. Somewhat higher forecast skill was present for the later lead times.

Another way to consider the skill of our forecasts over the past six years is to evaluate whether the forecast for each parameter successfully forecast above- or below-average activity. Table 9 displays how frequently our forecasts have been on the right side of climatology for the past six 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 9: 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 six years (1999-2004).

Tropical Cyclone Parameter	Early December	Early April	Early June	Early August
NS	5/6	6/6	6/6	5/6
NSD	5/6	6/6	6/6	5/6
H	4/6	5/6	5/6	6/6
HD	4/6	5/6	5/6	6/6
IH	4/6	4/6	6/6	6/6
IHD	4/6	4/6	6/6	6/6
NTC	4/6	5/6	5/6	6/6
Total	30/42	35/42	39/42	40/42

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 quite low, 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 to be considered of value.

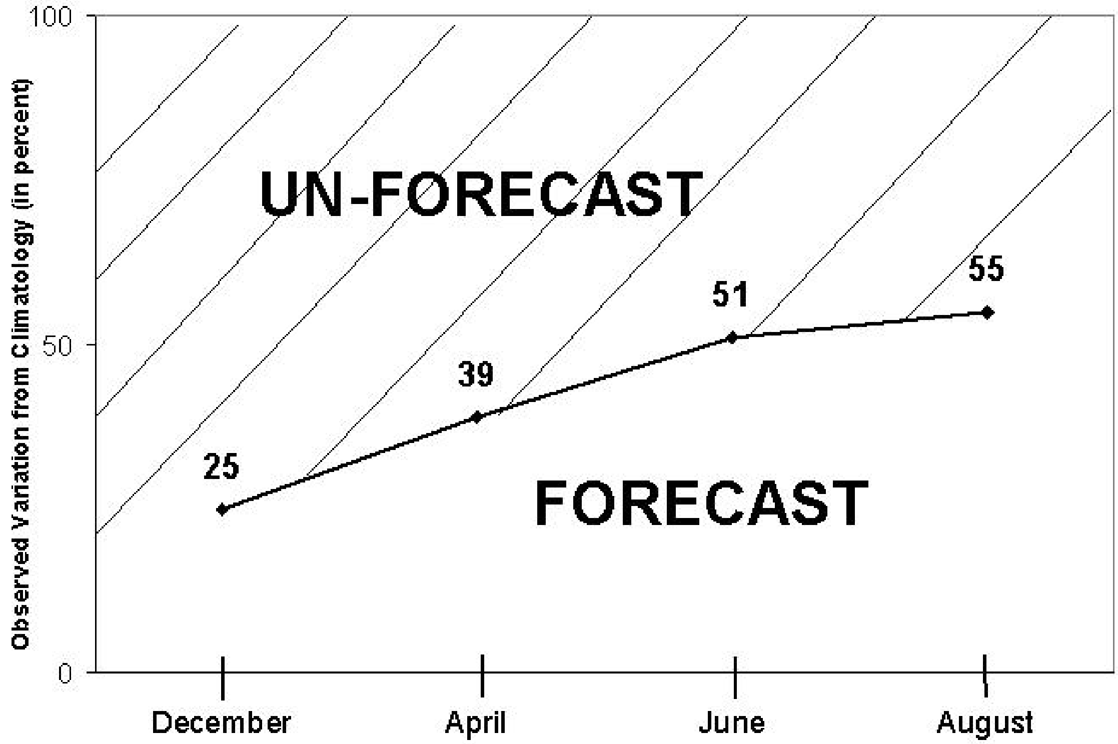


Figure 3: Last six-year average percent of seasonal hurricane days which was forecast at the four individual lead times of early December, early April, early June and early August.

4.2 Predictions of Individual Monthly Atlantic 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 last five seasons, and September-only forecasts have been made for the last three seasons. This is the second 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 recently documented by Blake and Gray (2004) for our August-only forecast and by Klotzbach and Gray (2003) for our September-only forecast - see the last page for references. Klotzbach is presently documenting our new October-only forecast.

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 included data through September for our early October forecasts. Table 10 gives an outline and timetable of the different forecasts and verifications we issue after the end of July.

Table 10: Timetable of the issuing of our after-July monthly forecasts (in early August, early September, and early October), the times of their verifications, and 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 Fcst. and/or Verification	**Based on Data Through**			**Forecasts**	
Early August	July	Forecast for August	Forecast for September	Forecast for October	Full Season Forecast
Early September	August	August Verification and Seasonal Update	Forecast for September	Forecast for October	Remainder of Season Forecast
Early October	September		September Verification and Seasonal Update	Forecast for October	Remainder of Season Forecast

4.3 August-only 2004 Forecast

The August-only forecast significantly underforecast tropical cyclone activity during the month (see Table 11). Part of this under-forecast was due to the high July values of central Pacific equatorial sea surface temperatures and tropical Atlantic sea level pressures. August 2004 was one of the most active Augusts on record, including setting records for the most named storms (8), intense hurricanes (3) and NTC (86) since 1950.

Table 11: Independent August-only forecasts for 2004 including the 6 August statistical forecast for August and the 6 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 2004 Statistical Forecast**	**Adjusted August 2004 Forecast**	**August 2004 Verification**
Named Storms (NS) (2.8)	3.6	4	8
Named Storm Days (NSD) (11.8)	14.3	20	32
Hurricanes (H) (1.6)	1.6	3	4
Hurricane Days (HD) (5.7)	2.3	8	15
Intense Hurricanes (IH) (0.6)	0.3	1	3
Intense Hurricane Days (IHD) (1.2)	-2.0	1	5.25
Net Tropical Cyclone (NTC) (26.4)	20.1	35	86

4.4 September-only 2004 Forecast

Table 12 summarizes our statistical and adjusted forecasts of Atlantic tropical cyclone activity for September 2004 issued on 6 August and 3 September, respectively.

Table 12: Independent September-only forecasts for 2004 including the 6 August statistical forecast for September, the 6 August adjusted forecast for September, the 3 September statistical forecast for September and the 3 September adjusted forecast for September. Observed activity is in the far right-hand column.

TC Parameters and 1950-2000 Sep. Clim. (in parentheses)	6 Aug. Stat. Fcst. (for Sep.)	6 Aug. Adjusted Forecast	3 Sep. Stat. Fcst. (for Sep.)	3 Sep. Adjusted Forecast	Observed Sep. 2004 Activity
NS (3.4)	3.5	5.0	3.6	5.0	4.0
NSD (21.7)	22.3	28.0	24.2	30.0	51.25
H (2.4)	1.6	3.0	1.5	3.0	3.0
HD (12.3)	13.0	15.0	14.1	20.0	29.25
IH (1.3)	1.0	1.0	1.2	2.0	3.0
IHD (3.0)	2.4	3.0	2.8	9.0	17.75
NTC (48)	43.3	55	46.4	85	134

Our September 2004 final adjusted forecast issued on September 3 was satisfactory in that it forecast a very active month. Our early August monthly forecast called for only a slightly more active-than-average month, and we consider this a significant under-forecast. The September statistical forecasts issued in both early August and September called for about average activity during the month of September. Several unusual features helped enhance activity during the month of September. These included a very active monsoon trough in the central tropical Atlantic and favorable tropical cyclone-enhancing conditions associated with this active monsoon trough such as reduced vertical wind shear, high low-level horizontal wind shear and warm Atlantic sea surface temperatures. The combination of these conditions led to a large amount of tropical cyclone activity in the deep tropics during the month of September, as evidenced by the long tracks of Intense Hurricanes Frances and Ivan. The 17.75 IHD accrued during the month of September are the most for any September since 1950 when routine aircraft reconnaissance became available. In addition, September 2004 will long be remembered in the U.S. Southeast as Hurricanes Frances, Jeanne and Ivan devastated this area, with most of the damage occurring in the state of Florida. Total damage in the state of Florida from these systems will likely approach 30 billion dollars. The East Coast trough that had been prevalent most of the time during September in the years of 1995-2003 was replaced by a ridge this September. Therefore, this year, storms tracked westward and made southeast U.S. landfall.

4.5 October-only 2004 Forecast

Table 13 summarizes our statistical and adjusted forecasts of Atlantic tropical cyclone activity for October 2004 issued on 6 August, 3 September, and 1 October respectively.

Table 13: Independent October-only forecasts for 2004 including the 6 August statistical forecast for October, the 6 August adjusted forecast for October, the 3 September statistical forecast for October, the 3 September adjusted forecast for October, the 1 October statistical forecast for October, and the 1 October adjusted forecast for October. Observed activity is in the far right-hand column.

TC Parameters and	6 Aug.	6 Aug.	3 Sep.	3 Sep.	1 Oct.	1 Oct.	Observed

1950-2000 Oct. Clim. (in parentheses)	Stat. Fcst. (for Oct.)	Adjusted Forecast	Stat. Fcst. (for Oct.)	Adjusted Forecast	Stat Fcst. (for Oct.)	Adjusted Forecast	Oct. 2004 Activity
NS (1.7)	0.4	2.0	1.9	3.0	1.8	3.0	2.0
NSD (9.0)	2.3	5.0	9.8	10.0	9.5	12.0	5.5
H (1.1)	0.3	1.0	1.2	1.0	1.2	2.0	1.0
HD (4.4)	1.1	3.0	4.8	5.0	4.7	8.0	0.75
IH (0.3)	0.1	0.0	0.3	0.0	0.3	0.0	0.0
IHD (0.8)	0.2	0.0	0.9	0.0	0.9	0.0	0.0
NTC (17)	5	10	20	15	18	20	9

We judge this to be a successful monthly forecast. We called for below-average activity in most of our October forecasts. In general, when August and September are very active as they were this year, October also tends to be active. We did not believe that this would be the case based on our October-only forecasts, and this verified. October was a very inactive month. Vertical wind shear was quite weak across the tropical Atlantic throughout most of the months of August and September; however, in October the wind shear across the Atlantic increased considerably, and consequently tropical cyclone activity ceased after Nicole became extratropical in the North Atlantic on October 11. The stronger wind shear across the tropical Atlantic that was evident during the month of October was likely due to the warm ENSO conditions which developed in the late summer-early fall period over the Pacific. October activity is usually strongly suppressed when central equatorial Pacific sea surface temperatures are anomalously warm as they were this year.

5 Verification of 2004 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 14 gives verifications of our landfall probability estimates for 2004.

Table 14: 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 (region 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2004 at various lead times. The mean annual percentage of one or more landfalling systems during the last 100 years is given in parentheses in the August 6 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				Observed
	5 Dec.	2 Apr.	28 May	6 Aug.	Number
TS	85%	87%	87%	85% (80)	5
HUR (Cat 1-2)	79%	81%	81%	79% (68)	1
HUR (Cat 3-4-5)	68%	71%	71%	67% (52)	3
All HUR	93%	95%	95%	93% (84)	4

Named Storms	99%	99%	99%	99% (97)	9

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

	Forecast Date				
	5 Dec.	2 Apr.	28 May	6 Aug.	Observed Number
TS	66%	68%	68%	66% (59)	3
HUR (Cat 1-2)	51%	53%	53%	51% (42)	0
HUR (Cat 3-4-5)	38%	40%	39%	38% (30)	1
All HUR	70%	70%	72%	70% (61)	1
Named Storms	90%	91%	91%	90% (83)	4

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

	Forecast Date				
	5 Dec.	2 Apr.	28 May	6 Aug.	Observed Number
TS	56%	58%	58%	56% (51)	2
HUR (Cat 1-2)	56%	59%	59%	56% (45)	1
HUR (Cat 3-4-5)	48%	52%	52%	47% (31)	2
All HUR	77%	77%	80%	77% (62)	3
Named Storms	90%	92%	92%	90% (81)	5

Active research continues on this 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, 3, and 4-5 intensity for each of 11 units of the U.S. coastline (Fig. 4). These 11 units are further subdivided into 96 subregions based on coastal population, and these subregions are further subdivided into 255 coastal and near-coastal counties. Climatological and current-year probabilities are now available at the following webpage address: http://www.e-transit.org/hurricane.

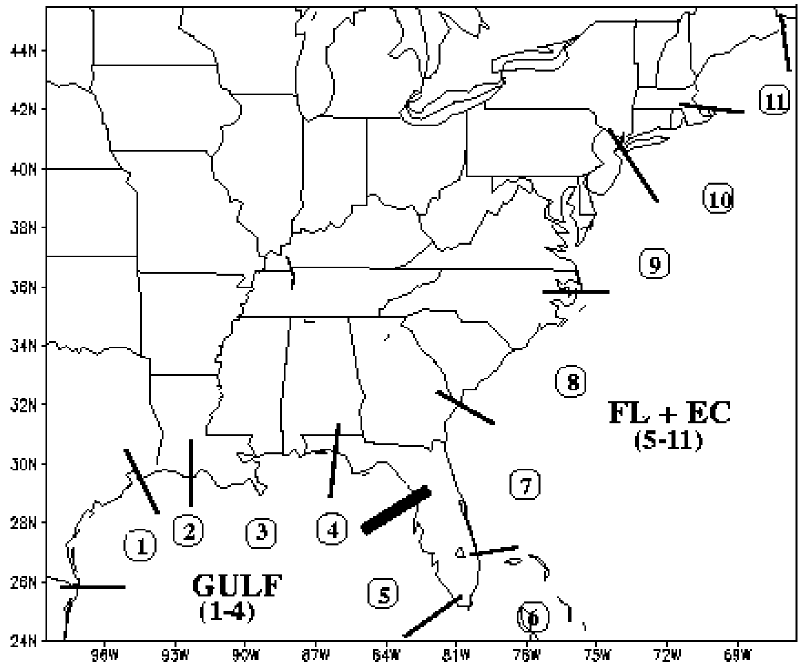


Figure 4: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

Figure 5 offers a summary and a general outline of the landfall probability estimate methodology. These landfall forecast probabilities will be supplemented with additional probability values for each 100 km coastal segment receiving tropical storm force winds (,40 mph), sustained hurricane force winds (,75 mph), and major hurricane (category 3-4-5) force winds (,115 mph). Discussion of potential tropical cyclone-spawned hurricane destruction within each of the 96 different U.S. coastal subregions are also in preparation.

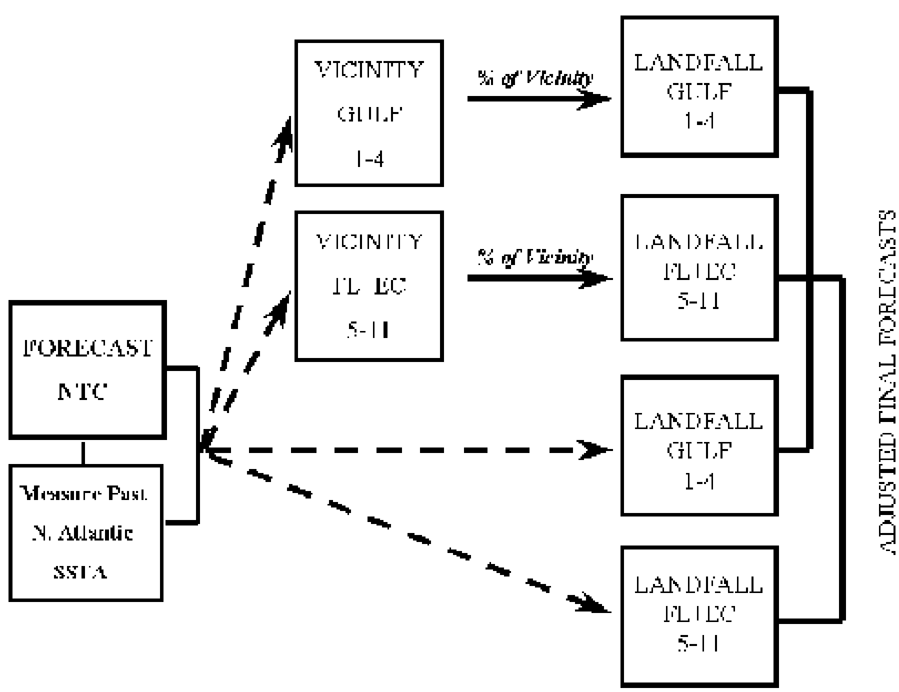


Figure 5: General flow diagram illustrating how forecasts of U.S. hurricane landfall probability are made. We forecast NTC and use an observed measure of the last few years of North Atlantic (50-60˙N, 10-50˙W) SSTA*. Regression equations are then developed from the combination of forecast NTC and measured SSTA* values. A regression is then developed from U.S. hurricane landfall measurements of the last 100 years, and separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

Reasons for August-September Monthly Forecast Underestimate: Long period records indicate that active hurricane seasons almost never occur with such high positive values of Atlantic SLPA or when such high anomalous values of sea surface temperature are present in NINO 3.4 (August-September 2004 values were +0.8˙C). Table 15 lists the 10 most active hurricane seasons of the last 120 years and shows that none had warm NINO 3.4 SSTA. Table 16 shows the 12 inactive Atlantic basin tropical cyclone years of the last century. Note that NINO 3.4 SSTA were nearly as warm this year as the average of the 12 most inactive years. This season's Net Tropical Cyclone (NTC) activity was 228 which is 7 times greater than the activity in the 12 most inactive years. High Atlantic SLPAs and tropical Pacific SSTAs were the major reason that we were hesitant to forecast more than a moderately active season.

Table 15: The 10 most active Atlantic basin NTC years of the last 115 years with accompanying August-September NINO 3.4 SSTA values.

	Seasonal	Aug-Sept NINO 3.4
Year	**NTC**	**SSTA (˙)**
1893	251	-1.21
1916	205	-0.98
1926	239	+0.16
1933	225	-0.98
1950	240	-0.63
1955	196	-0.62
1961	220	-0.37
1995	231	-0.37
1996	198	-0.08
Mean	215	-0.45
2004	228	+0.80
2004 Difference >From Mean	+13	+1.25

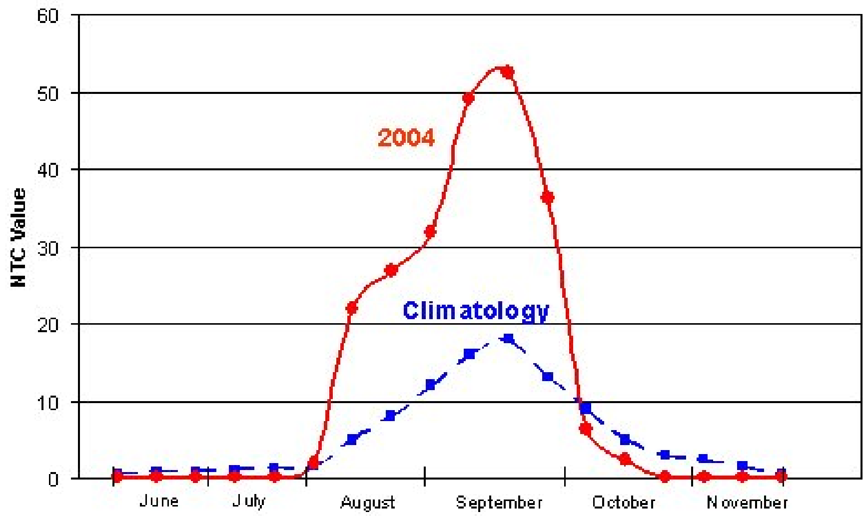
Table 16: The 12 most inactive Atlantic basin NTC years of the last century with accompanying August-September NINO 3.4 SSTA values.

	Seasonal	Aug-Sept NINO 3.4
Year	**NTC**	**SSTA (˙)**

1905	25	+ 1.71
1907	13	+0.43
1914	4	+1.22
1925	10	+0.71
1930	37	+1.15
1968	46	+0.31
1972	28	+1.42
1982	37	+1.08
1983	32	+0.09
1986	38	+0.71
1987	47	+1.82
1997	54	+2.36
Mean	32	+0.98
2004	228	+0.80
2004 Difference >From Mean	+196	-0.18

6 Why was This Year so Active With Major Hurricanes?

Although we forecast an above-average 2004 season (14 NS, 8 H, 3 IH, NTC of 145 for our forecasts of 4 April and 28 May) we lowered our forecast slightly (13 NS, 7 H, 3 NS, NTC of 125) in early August. This proved to be a mistake. There is no way that we or anyone else could have foreseen how active August-September would be (see Figure 6a) with anomalously high June-July Atlantic sea level pressures and anomalously warm NINO 3.4 sea surface temperatures. These two months were especially active for the number of Atlantic basin major hurricanes (6) that formed and the large impact that four of these major hurricanes would have on southeastern U.S. residents. This year did not behave like any other year we have studied.



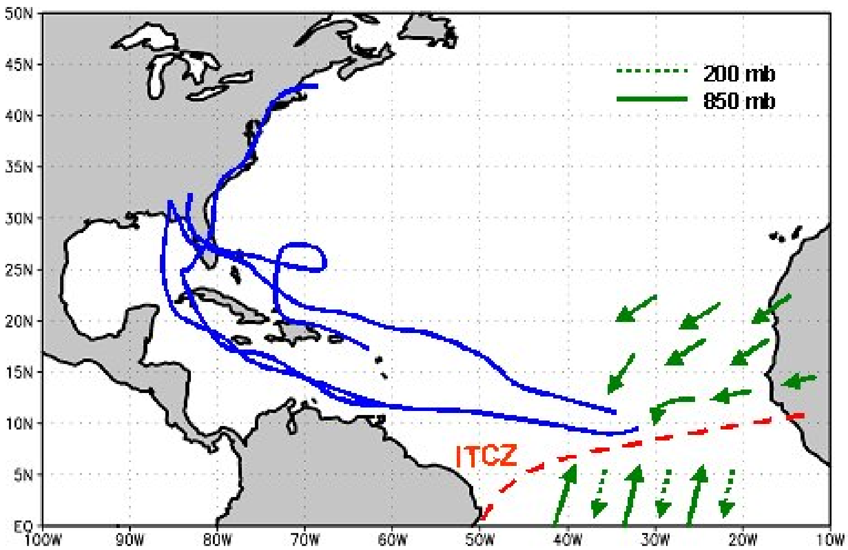


Figure 6: Atlantic basin tropical cyclone activity in the 2004 season as shown (a) by NTC for ten-day periods for the season 2004 (solid line) compared with the 1950-2003 climatology (dotted line) and (b) by the tracks of the four hurricanes that struck the United States. The enhanced August-September ITCZ is also shown.

We hypothesize that the combination of two basic processes were responsible for making the 2004 hurricane season so destructive. The Atlantic equatorial trough or Intertropical Convergence Zone (ITCZ) was very strong this year as shown in Figure 6b. Associated with a strong equatorial trough are typical conditions necessary for tropical cyclone development such as increased lower-tropospheric horizontal wind shear, reduced tropospheric vertical wind shear, and increased concentration of vertical motion. Combined with these favorable development conditions for 2004, there were also favorable surrounding cyclone steering currents that prevented poleward movement of these tropical cyclones until they reached the longitudes of the United States. Major hurricane destruction is dependent upon an enhancement of hurricane formation frequency in the central tropical Atlantic and the simultaneous presence of favorable environmental steering currents that prevent the hurricane's recurvature before it strikes land.

The NCEP/NCAR reanalysis data has shown that since 1995, the Atlantic Ocean thermohaline circulation (THC) has undergone a large increase in strength. This strength has been inferred from an increase in high latitude Atlantic sea surface temperatures. The strengthening of the THC has caused an increase in Northern

Hemisphere sea surface temperatures compared with the Southern Hemisphere. In addition, over the last 15 years, there has also been a tendency for the Western Hemisphere to warm relative to the Eastern Hemisphere. These temperature changes have led to an increased Northern to Southern Hemisphere energy flux during the Northern Hemisphere summer months. The summer hemisphere always feeds energy to the winter hemisphere through cross-equatorial low-level flow from the winter to the summer hemisphere at low levels and opposite summer to winter hemisphere flow at upper levels. Associated with an increased cross-equatorial energy flux is the establishment of a stronger equatorial trough in the summer hemisphere. This is what happened to the Atlantic equatorial trough in August-September of this year.

Figure 7a shows standardized anomalies of the average August-September 850 mb (£#1.5 km) minus 200 mb (£#12 km) meridional wind in the area of 5˙N-15˙S; 45˙W-0˙ from 1950 to 2004. Positive anomalies indicate above-average August-September energy flux from the Northern to the Southern Hemisphere and a stronger Atlantic equatorial trough. Note the stronger equatorial trough that has been present during the last 10 years when there has been a large increase in Atlantic major hurricanes (3.8 per year) compared with the period of 1970-1994 when the annual average number of major hurricanes was 1.5.

Another feature often present with a strong equatorial trough is warm tropical Atlantic sea surface temperatures in the area from 4˙N-14˙N and 25˙W-50˙W. Figure 7b displays the August-September Atlantic sea surface temperature standardized anomalies in this region since 1950. Note the very warm sea surface temperatures in this region during the last ten years. Warm Atlantic sea surface temperatures have been shown to enhance tropical cyclone formation.

Figure 7c is the addition of Figures 7a and 7b and what we consider to be a general measure of the strength of the mid-Atlantic equatorial trough. The magnitude of sea surface temperature anomalies in the tropical Atlantic and the strength of the cross-equatorial flow during August-September is taken to be an estimate of the strength of the equatorial trough. Note how strong the equatorial trough has become over the past ten years and how strong the trough was during August-September of 2004.

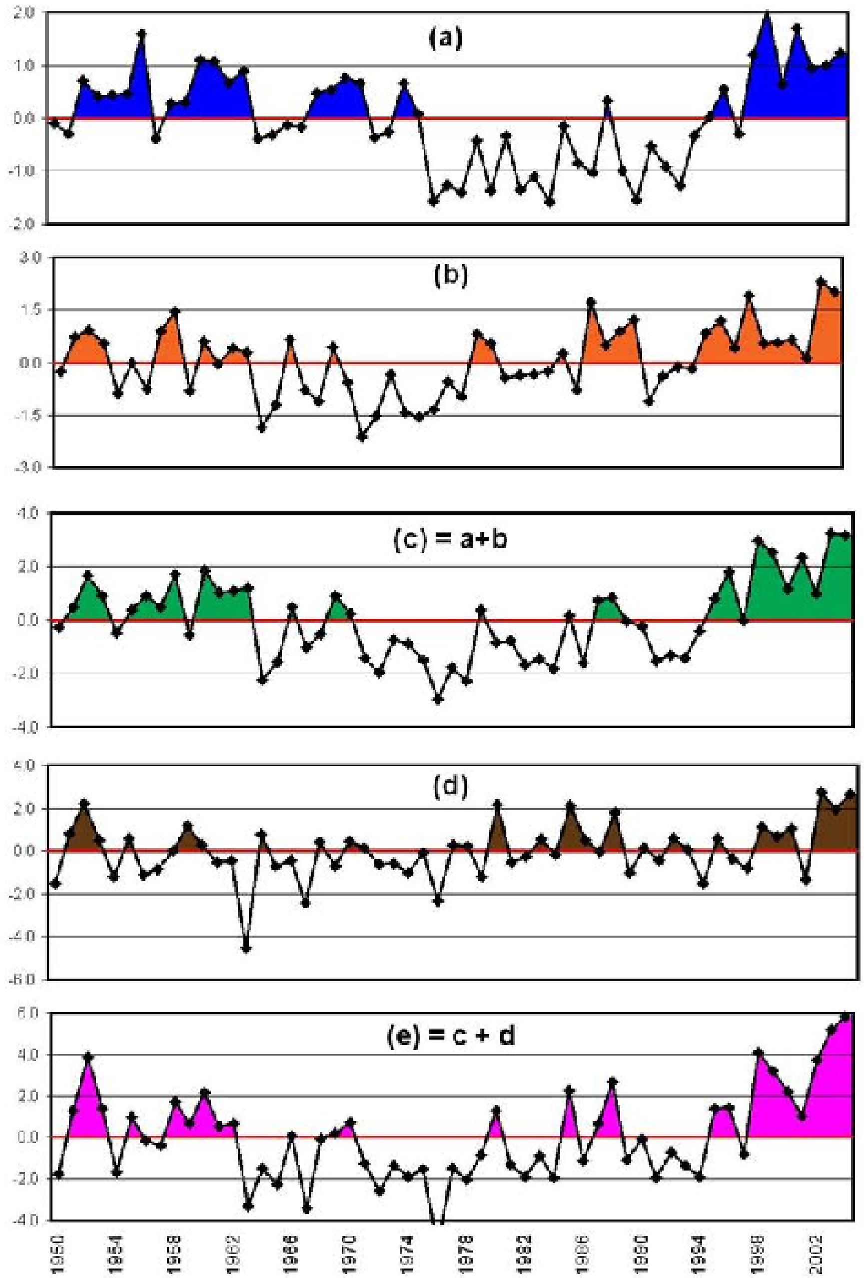


Figure 7: (a) August-September standardized anomalies of 850 mb minus 200 mb meridional wind (5°N-15°S, 45°W-0°) for 1950-2004, (b) August-September sea surface temperature standardized anomalies (4°N-14°N, 25°-50°W), (c) Addition of Figs./ 7a and 7b, (d) August-September steering current defined as the August-September 500 mb height standardized anomalies in the following regions (40°N-55°N; 60°W-80°W plus 25°N-45°N; 120°W-160°W minus 35°N-70°N, 100°W-120°W and (e) Addition of Figs. 7c and 7d.

When a strong equatorial trough exists in the northern tropical Atlantic as it did during the 2004 season, and in seven of the nine previous hurricane seasons (1995-1996, 1998-2001, 2003), easterly waves (about one every 2 to 3 days or about 60 per hurricane season) moving westward into the open Atlantic from West Africa progress into an area of more favorable environmental conditions for tropical cyclone formation. When strong equatorial trough conditions are present, it is possible to have 8 to 10 of these 60 easterly waves develop into named tropical cyclones. By contrast, when the equatorial trough is weak, as few as 0 to 2 of these waves will develop.

This season, when the equatorial trough was strong, five tropical cyclones were named at locations east of 45˙W and south of 15˙N (Danielle, Frances, Ivan, Karl and Lisa), a phenomena not observed in the past 55 years.

Figure 7d is a quantitative measure of the August-September westerly steering currents by year since 1950. This steering current is determined from the August-September standardized anomalies of the 500 mb (£#5.8 km) height field in the three regions of 40˙N-55˙N, 60˙W-80˙W (area 1); 35˙N-70˙N, 100˙W-120˙W (area 2); and 25˙N-45˙N, 120˙W-160˙W (area 3). The net steering current is calculated as a combination of area 1 plus area 3 minus area 2.

These heights measure the degree of stationarity of the 500 mb wave patterns during August-September of each year. Heights were well above-average in area 1 located off the U.S. northeast coast. Such a height field prevents recurvature of lower latitude tropical cyclones allowing them to move far enough westward so that they have a good chance of making landfall along the U.S. southeast coastline.

Figure 7e is the addition of Figure 7c and Figure 7d. This represents the combined strength of the August-September Atlantic equatorial trough and the magnitude of the August-September westward environmental steering current. The sum of these two terms gives a quantitative measure of the potential of U.S. hurricane landfall during August and September of each year since 1950. Note how 2004 has the highest value of any August-September period since 1950. We judge this unusually high combination of trough strength plus steering values to be the primary explanation as to why four hurricanes (three major hurricanes) impacted the southeastern United States this year.

7 This Year's Destructive Hurricane Tracks

Most of this year's hurricanes had long westward tracks that were a-typical of the tracks of most hurricanes during the recent years of 1995-2003. This was due to the differences in middle-latitude westerly wind patterns as compared to most years between 1995-2003. Figure 8 shows the tracks of the four major hurricanes which caused considerable damage in the southeast United States this year, and Figure 9 shows the tracks of all major hurricanes from 1995-2003.

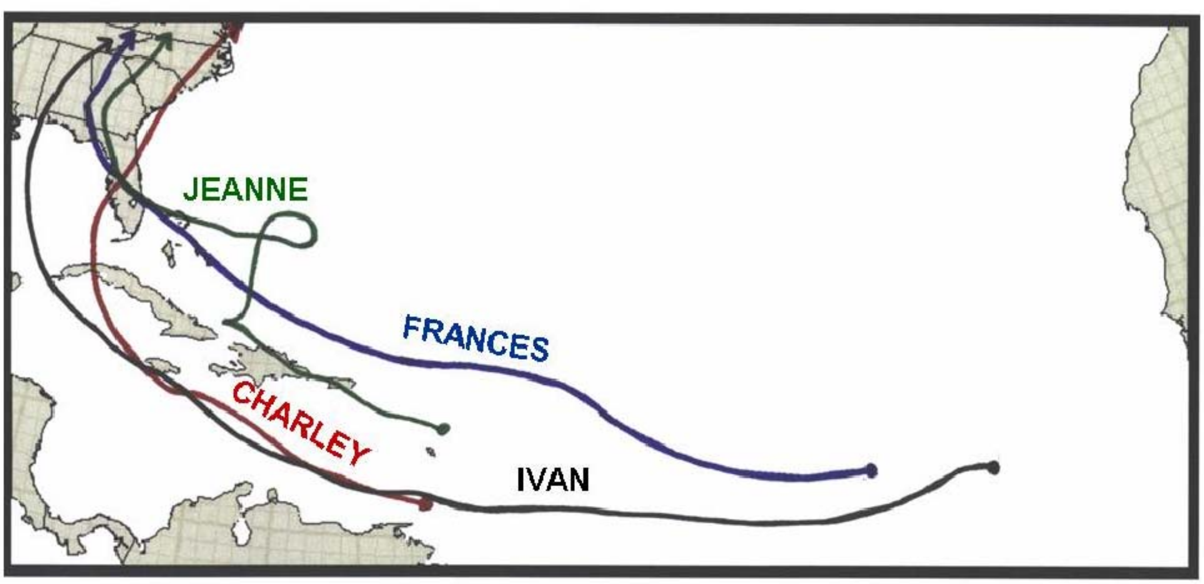
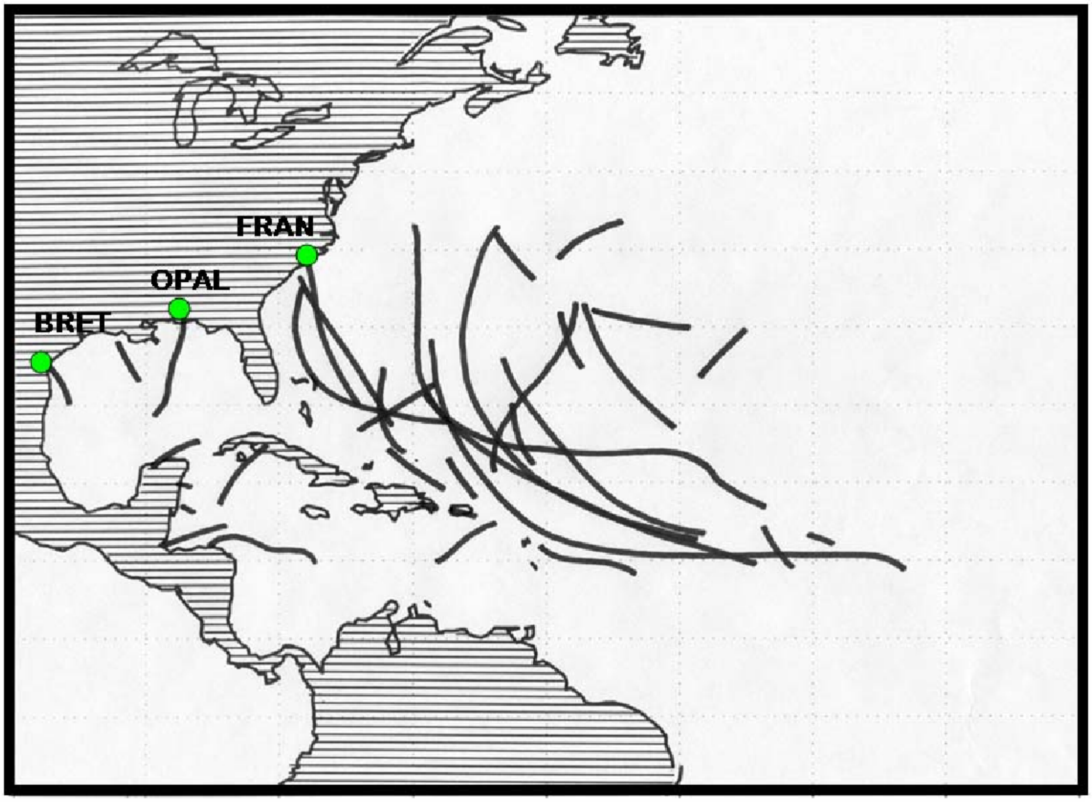


Figure 8: Tracks of the four destructive storms that impacted the United States in 2004.



1995-2003 Intense Hurricane Tracks (32 tracks)

Figure 9: Tracks of all intense hurricanes from 1995-2003.

Favorable formation conditions as occurred this year are not uncommon and have occurred in many prior years (but usually not with high Atlantic SLPA values and a very warm central equatorial Pacific SSTA pattern that was present this year). What is unique about this year is not the large amount of hurricane activity which developed in the tropical Atlantic but having this high number of formation events occur in combination with anomalously high West Atlantic upper-level ridge activity in the latitude belt between 35-50°N (Fig. 10). The Bermuda high was stronger than normal and caused anomalously strong upper-level easterly steering current winds in the west Atlantic sub-tropical belt. This caused a high percent of the central Atlantic systems to take long westward tracks up to the longitudes of the United States before recurving.

The mean westerly wind conditions of August-September of this year showed a trough along and over the western North American continent and a ridge over the eastern North American continent and western Atlantic. This East Coast ridge protected this year's west-northwest moving hurricanes against the impinging influence of the middle-latitude westerlies that act to turn the westerly moving cyclones to the right and then recurve them. Most of this season's hurricanes kept moving westward and did not recurve until they got in the longitudes of the southeast United States. These long-lived and intense hurricanes were the ones that affected the U.S. severely this year. We were thus unlucky in the positioning of the westerly ridge-trough patterns relative to the tropical Atlantic.

The westerly wind pattern this year was generally opposite to the typical middle-latitude ridge-trough patterns that occurred during the years of 1995-2003 when a ridge pattern was typically present over the North American West Coast and a trough near the North American East Coast and the western Atlantic (compare Figs. 10 and 11). During these recent nine years the North American East Coast trough acted to bring about an impingement of middle-latitude westerlies into sub-tropical and tropical latitudes and deflected the westward moving tropical hurricanes to the north and recurved them. Few made it far enough west to impinge on the United States. From 1995-2003, only 3 of 32 major hurricanes hit the United States. This year, we have had 4 of the 6 major hurricanes that formed strike the United States. Three of these came ashore as major hurricanes.

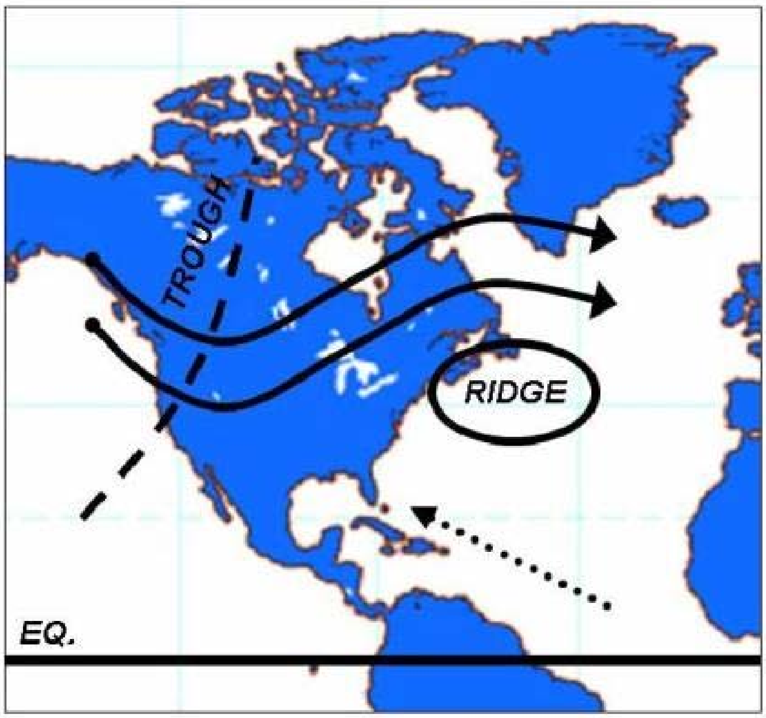


Figure 10: Predominant flow pattern in August-September 2004.

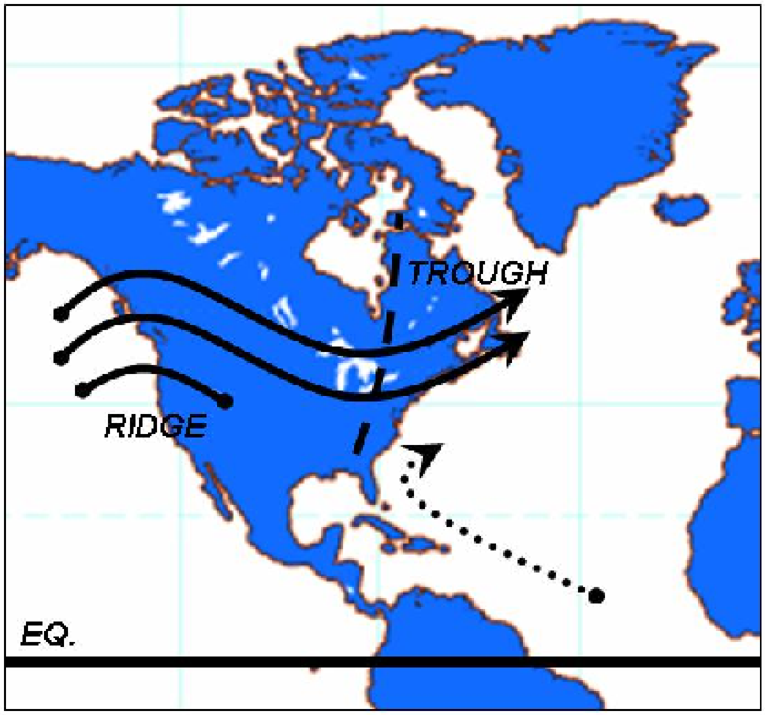


Figure 11: Predominant flow pattern for August-September 1995-2003.

8 It Could Have Been Worse

Florida's four destructive hurricanes fortunately came ashore along coastlines that were not very densely populated. Pensacola, FL was the largest Florida community feeling the direct brunt of one of these four damaging hurricanes. The coastal and inland areas around Punta Gorda-Port Charlotte (where Charley came ashore), and Stuart (where Frances and Jeanne came ashore) do not have large coastal populations. The three major Florida coastal population concentrations from Tarpon Springs to Sarasota, West Palm Beach to South Miami, and Daytona Beach to Melbourne (and inland to Orlando) were all removed from the direct brunt of these four hurricanes. Economic loss many times greater could have occurred if the center of any one of these four hurricanes had come into one of these more concentrated Florida population areas. For instance, it has been estimated that if Hurricane Andrew (1992) had come inland just 15-20 miles north of its actual landfall near Homestead that it would have caused two to three times the $40 billion dollars (adjusted to 2004 dollars) in property loss that resulted.

9 Florida's Unlucky 2004 August-September

The five named storms (4 hurricanes, 3 major hurricanes and 1 tropical storm) that affected Florida over a 48 day period are unprecedented in terms of historical records going back 130 years, although they are well within the range of natural climate fluctuations on the climate scale. What makes August-September 2004 so special in regards to landfalling hurricanes in Florida is the unusual combination of high hurricane activity and very favorable surrounding hurricane steering currents that advected the hurricanes from the deep tropics across Florida (see Fig. 10).

10 Florida's Unusually Lucky Last 38 Years

It is important that Floridians view this terribly damaging landfall season from a longer period perspective. Overall Florida has been extremely fortunate in recent years. Between 1966-2003 (38 years) the Florida Peninsula has experienced the landfall of only one major hurricane (Andrew, 1992) (Fig. 12). But in this long major hurricane lull period since the mid-1960s, Florida's population and coastal development has exploded. Few of the new Floridians have experienced a major hurricane hit. Most Floridians were not prepared for this unusual onslaught of four devastating storms in such a short period of time. But old-timers who lived in Florida in the 1930s through the 1950s well remember that Florida used to be hit by many hurricanes. Between 1928-1965 (41 years) the Florida Peninsula experienced 14 major (Cat. 3-4-5) hurricane landfalls (1 per 3 years).

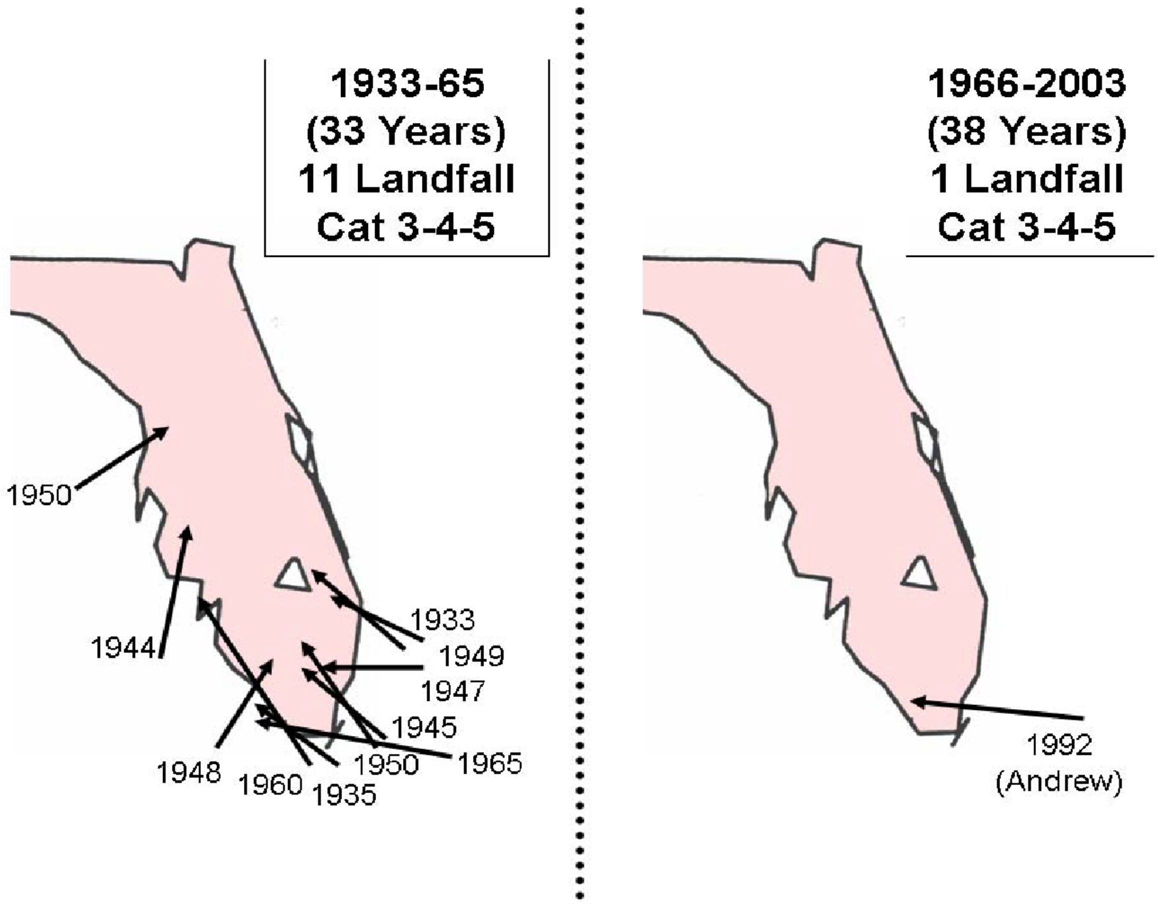


Figure 12: Schematic illustrating just how lucky Florida has been over the past 38 years.

For many years we have been discussing how lucky Florida had been with regards to its few recent landfalling major hurricanes. We said it was inevitable that this period of few major hurricane strikes would end and that the long period climatology would eventually reassert itself. There was no way, however, of knowing that the law of averages would try to catch up to its deficit so rapidly in one year!

11 Is Human-Induced Global Warming Involved?

Florida residents should not interpret the four damaging hurricane landfalls in their state in August-September 2004 to be related, in any way, to the much publicized human-induced global warming hypothesis. Although an unusual event (likely occurring only about once every 100-200 years), these four strong landfalls are a rare combination of an above-average season of major hurricane activity together with unusually favorable broad-scale steering currents that drove mid-Atlantic tropical cyclones westward instead of allowing them to recurve over the open ocean. Such a combination of high tropical cyclone frequency and special westward steering currents is not frequent but well within the range of natural climate fluctuations and might be considered from a statistical point-of-view as a rare 2 to 3 sigma event. There would be little discussion of this year's hurricanes activity if these four major storms had not made U.S. landfall, which could have just as easily occurred if the middle latitude steering currents were a little different. It was not frequency but track which made this season so unique.

Although the Atlantic basin has been very active this year, as have eight of the last 10 Atlantic basin seasons, the other six global tropical storm basins which account for most of the globe's tropical cyclone events (about 88 percent) have not shown a similar increase. In fact, global net tropical cyclone activity has actually shown a small decrease in the other basins during the last 10 years. If global warming (natural or man-made) were the cause of the increased Atlantic basin activity, we should have seen an increase in the other storm basins as well. This has not occurred.

Atlantic basin major hurricane activity can increase or decrease during periods when the mean global surface temperature is warming or when it is cooling. During the period of the early 1970s to the mid-1990s, when the globe was warming, Atlantic basin major hurricane activity was actually below average. During the period of the mid-1940s to early 1970s there was a small net cooling of the global surface temperature, and Atlantic basin major hurricane activity was above average. We can explain these multi-decadal variations in Atlantic basin major hurricane activity as resulting from multi-decadal variations in the Atlantic Ocean thermohaline circulation (see our previous forecast discussions). Paleo climatology data has shown that such multi-decadal Atlantic thermohaline circulation changes have occurred many times in the past.

There has been a small global surface warming since the mid-1970s and also when global temperatures are averaged over the last 100 years. We believe this global warming is a natural consequence of a slowing down of the global ocean's sinking (or deep water formation) in the North and South polar regions. The globe undergoes warming when polar region deep-water formation is reduced as it was between the late 1960s to mid-1990s and on average over the last century. By contrast, during the periods between the mid-1940s and the early 1970s, there was enhanced polar deep-water formation, and the global mean surface temperature underwent a modest cooling.

We believe that the global mean surface temperature changes that have been observed over the last 30 years and over the last century are mostly of natural origin (ocean-forced) and likely not a result of any human influence. We do not attribute Florida's four landfalling hurricanes during August and September to be related in any way to human influences. Similarly, the ten typhoons that struck Japan this year are a consequence of anomalously warm tropical central Pacific sea surface temperatures and changing pressure patterns that steered storms into the Japanese Islands. It would be a mistake to relate the high U.S. and Japanese landfalls with human-induced global warming.

12 Florida's Future Hurricane Seasons

Floridians should view this year's onslaught of hurricane activity as a rare anomaly. This year's landfalling hurricane activity does not by itself represent the beginning or the end of any cycle or trend for landfalling hurricanes. This year will have no bearing on what will occur in future years anymore than the great paucity of Florida landfalling major hurricanes between 1966-2003 had any bearing on this year's landfalling systems. The probability of having hurricane-spawned winds, rain, and storm surge at any spot in any year along the U.S. coastline is very low. We would not recommend that anyone move out of Florida or decide not to move to

Florida solely because of the threat of hurricanes. Florida hurricanes must be accepted as one small negative of an otherwise pleasant climate.

13 Imbalance in Hurricane Research Funding

There is much yet to be known about hurricanes, especially in years like this one where forecast precursor signals did not fit the pattern of previously active seasons. These are natural threats to coastal residents of the U.S. that are not being studied as much as they should be. The amount of research directed to the better understanding and the prediction of hurricanes is minuscule in comparison to the massive research funding being directed to human-induced global warming research, which at best, remains a nebulous hypothesis. We need a better balance in federal research expenditures. The residents of the southeastern U.S. have not been well served by the federal government in its research allocations. Is going to Mars more important than obtaining a better understanding and developing better forecasts of hurricanes?

14 Forecasts of 2005 Hurricane Activity

We will be issuing our first forecast for the 2005 season on Friday, 3 December 2004. This 3 December forecast will include the dates of all of our follow-on updated 2005 forecasts. All of these forecasts will be available at our Web address given on the front cover

(http://tropical.atmos.colostate.edu/Forecasts/)

15 Acknowledgments

The first author gratefully acknowledges valuable input to his CSU project research over many years by former graduate students and colleagues Chris Landsea, John Knaff and Eric Blake. A number of other meteorologists have furnished us with the data and given valuable assessments of the current state of global atmospheric and oceanic conditions. This includes 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 assistance over a number of years. We have profited over the years from many indepth 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. We also thank Bill Bailey of the Insurance Information Institute for his sage advice and encouragement.

The financial backing for the issuing and verification of these forecasts has in part been supported by the National Science Foundation, but this NSF support is insufficient. We appreciate the financial support of the Research Foundation of AIG - Lexington Insurance Company (a member of the American International Group) for the last two years. We are also grateful to the Research Foundations of the United Services Automobile Association (USAA) and to State Farm Insurance for their past year support. We thank the GeoGraphics Laboratory at Bridgewater State College for their assistance in developing the Landfalling Hurricane Probability Webpage.

16 Citations and Additional Reading

17 Verification of the Last 5 Years of Forecasts

Table 14: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 1999-2003. Verification of our earlier year forecasts for the years 1984-1998 are given in our late November seasonal verifications (on this Web location).

		Update	Update	Update	
1999	**5 Dec 1998**	**7 April**	**4 June**	**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(HDP)	130	130	130	130	145
Major Hurricanes (Cat. 3-4-5)	4	4	4	4	5
Major Hurr. Days	10	10	10	10	15
Net Trop. Cyclone (NTC) Activity	160	160	160	160	193

		Update	Update	Update	
2000	**8 Dec 1999**	**7 April**	**7 June**	**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(HDP)	85	85	100	90	85
Major Hurricanes (Cat. 3-4-5)	3	3	4	3	3
Major Hurr. Days	6	6	8	6	5.25
Net Trop. Cyclone (NTC) Activity	125	125	160	130	134

		Update	Update	Update	
2001	**7 Dec 2000**	**6 April**	**7 June**	**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(HDP)	65	65	75	75	71
Major Hurricanes (Cat. 3-4-5)	2	2	3	3	4
Major Hurr. Days	4	4	5	5	5
Net Trop. Cyclone (NTC) Activity	90	100	120	120	142

		Update	Update	Update	Update	
2002	**7 Dec 2001**	**5 April**	**31 May**	**7 August**	**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(HDP)	90	85	75	35	25	31
Major Hurricanes (Cat. 3-4-5)	4	3	2	1	1	2
Major Hurr. Days	7	6	5	2	2	2.5
Net Trop. Cyclone (NTC) Activity	140	125	100	60	45	80

		Update	Update	Update	Update	Update	
2003	**6 Dec 2002**	**4 April**	**30 May**	**6 August**	**3 Sept**	**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(HDP)	100	100	100	80	80	125	129
Major Hurricanes (Cat. 3-4-5)	3	3	3	3	3	2	3

Major Hurr. Days	8	8	8	5	9	15	17
Net Trop. Cyclone (NTC) Activity	140	140	145	120	130	155	168

Footnotes:

[1]Professor of Atmospheric Science

[2]Research Associate

[3]Research Associate

[4]We have estimated that total damage is about twice that of insured damage.

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