Summary of 2004 Atlantic Basin Tropical Cyclone Activity and Verification of Seasonal Forecasts

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ABSTRACT

The 2004 Atlantic basin tropical cyclone season was one of the most active and destructive on record. A total of fourteen named tropical cyclones (sustained winds >= 39 mph), nine hurricanes (sustained winds >= 74 mph), and six intense or major hurricanes (sustained winds >= 111 mph) developed during the season. These six major hurricanes lasted for 22.25 days, which is the most major hurricane days since the 1926 season. The primary reason that the 2004 season will be remembered is the intense destruction that the season caused along the Southeast United States coastline. Hurricanes Charley, Frances, Ivan, and Jeanne combined to cause an estimated $20 billion to $25 billion in insured damage (~$40 billion to $50 billion in actual loss), making this the most destructive year on record. Some of the features present during the 2004 season that combined to make the season so active and destructive were a strong equatorial trough, warm Atlantic sea surface temperatures, reduced vertical wind shear, and a persistent high pressure off the east coast of the United States. In this paper, the authors also verify their 2004 seasonal forecasts issued at various lead times.

Additional keywords: Hurricanes, climate prediction, seasonal hurricane forecasting

INTRODUCTION

Residents of the Southeastern United States will long remember the 2004 Atlantic basin hurricane season. A total of 14 named tropical cyclones, nine hurricanes, and six major hurricanes developed during the season, and Hurricanes Charley, Frances, Ivan, and Jeanne meted out severe destruction throughout Florida and other parts of the Southeastern United States. When the season was over, ISO Property Claims Services Unit (2004) estimated that a total of $21.3 billion in insured damage was wrought by these four systems. This paper discusses the statistics of the 2004 Atlantic basin hurricane season and explains potential reasons for this unusually active season. The author's seasonal forecasts are evaluated and challenges in making these forecasts are discussed. Lessons learned from the 2004 season are also discussed.

2004 ATLANTIC BASIN TROPICAL CYCLONE ACTIVITY

According to data from the National Hurricane Center's Best Track files (2004), the 2004 Atlantic basin hurricane season witnessed a total of 14 named tropical cyclones, nine hurricanes, six major hurricanes, 90.25 named storm days, 45.5 hurricane days, and 22.25 intense hurricane days. Net Tropical Cyclone (NTC) activity for the 2004 season was 229. NTC activity is an aggregate measure of the above six parameters normalized by the percentage of their 1950-2000 season averages (Gray, et al., 1994; Klotzbach and Gray, 2004). NTC activity during the 2004 season was the highest observed in a hurricane season since 1950. Table 1 displays the tropical cyclone statistics by storm, and Figure 1 displays the tracks taken by these storms. Note that Subtropical Storm Nicole is not considered in the statistics since it was never classified as a tropical cyclone.

Although the 2004 season was notable for its total tropical cyclone activity, it will be most remembered in the United States for its landfalling tropical cyclones. Nine tropical cyclones impacted the United

Highest Category	Name	Dates	Max Wind (kts)	Min SLP (mb)	NSD	HD	IHD	NTC
Cat. 3	Alex	8/1 – 8/6	105	957	5.00	3.25	0.75	18.2
TS	Bonnie	8/9 – 8/12	55	1001	3.25	0.00	0.00	2.8
Cat. 4	Charley	8/10 – 8/14	130	941	4.75	3.00	0.50	17.1
Cat. 2	Danielle	8/14 – 8/20	95	964	6.75	3.50	0.00	9.2
TS	Earl	8/14 – 8/15	45	1009	1.25	0.00	0.00	2.2
Cat. 4	Frances	8/25 – 9/7	125	935	12.50	10.00	6.75	45.4
Cat. 1	Gaston	8/28 – 9/1	65	985	3.25	0.25	0.00	5.8
TS	Hermine	8/29 – 8/31	50	1002	2.00	0.00	0.00	2.4
Cat. 5	Ivan	9/3 – 9/16, 9/23	145	910	14.75	11.50	10.00	58.0
Cat. 3	Jeanne	9/14 – 9/27	105	950	13.00	6.50	0.75	23.1
Cat. 4	Karl	9/16 – 9/24	125	938	8.25	7.00	3.50	31.0
Cat. 1	Lisa	9/25 – 10/3	65	987	11.75	0.50	0.00	8.9
TS	Matthew	10/8 – 10/10	40	997	1.75	0.00	0.00	2.3
TS	Otto	11/30 – 12/2	40	995	2.00	0.00	0.00	2.4
Total	14				90.25	45.50	22.25	229.0

Table 1. Observed 2004 Atlantic Basin tropical cyclone activity.

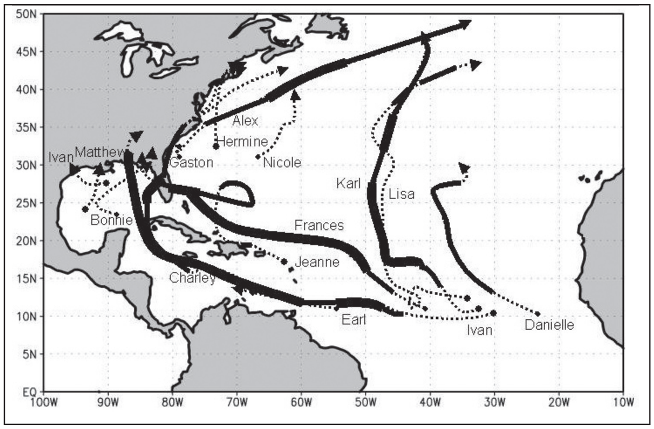

Figure 1. Map showing the tracks taken by the Atlantic basin tropical cyclones of the 2004 season. Dashed lines indicate tropical storm intensity, a thin solid line is Category 1 or 2 hurricane intensity, and a thick solid line is major hurricane (Category 3-4-5) intensity.

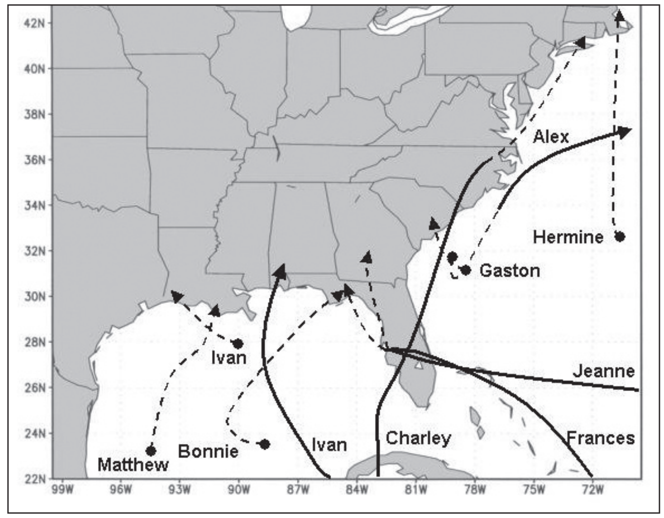

Figure 2. Map showing tropical cyclones impacting the United States coastline during the 2004 Atlantic basin hurricane season.

States coastline, and the tracks of these storms are displayed in Figure 2. Four of these storms (Hurricanes Charley, Frances, Ivan, and Jeanne) caused most of the intense devastation that affected the Southeastern United States and particularly Florida this past year. Table 2 displays estimated insured and total damage from these four hurricanes according to the National Hurricane Center's Tropical Cyclone Reports (2004). These numbers are initial best estimates, and therefore it can be said, with some certainty, that final insured damage estimates will range between $20 billion to $25 billion with total damage estimates of about twice this amount. Brief summaries of these four major hurricanes that severely impacted the United States follow:

HURRICANE CHARLEY

Charley developed from a tropical wave into a tropical depression while passing near Trinidad on Aug. 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 Aug. 11. Charley passed over Cuba as a Category 2 storm on Aug. 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 Aug. 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 Aug. 15. Preliminary insured damage estimates for this system are around $7.4 billion, putting total damage estimates around $14.8 billion. This makes Charley the second most expensive hurricane to hit the United States in history, behind only Hurricane Andrew of 1992.

HURRICANE FRANCES

Frances formed from a tropical wave while traveling westward across the open Atlantic. The system became a tropical storm on Aug. 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 Aug. 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 on Aug. 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 Sept. 3 with estimated winds of 100 knots. Frances finally made landfall near Sewall's Point, Florida on Sept. 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, FL, on Sept. 6. The system dissipated later that day. Insured damage from Frances is estimated at around $4.5 billion, bringing the total damage estimate to around $9 billion. Frances was responsible for at least 24 deaths.

HURRICANE IVAN

Ivan formed about 600 miles southwest of the Cape Verde Islands early on Sept. 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 Sept. 5. Ivan rapidly intensified into a major hurricane later on Sept.

Storm Name	Insured Damage (Billions)	Total Damage (Billions)
Charley	7.4	14.8
Frances	4.5	9.0
Ivan	7.1	14.2
Jeanne	3.5	7.0
Total	**22.5**	**45.0**

Table 2. Estimated insured and total damage from Hurricanes Charley, Frances, Ivan, and Jeanne obtained from the National Hurricane Center tropical cyclone reports (2004). When two estimates were provided, the average of the two estimates was used for damage assessment.

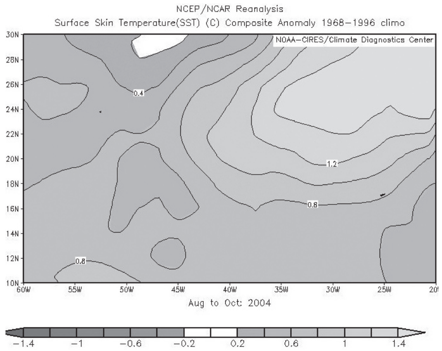

Figure 3. Map showing August-October 2004 Atlantic basin sea surface temperature anomalies derived from the NCEP/NCAR Reanalysis data. Anomalies are computed with respect to the 1968-1996 climatology.

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 Sept. 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 Sept. 7 and reached Category 5 status early on Sept. 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 in damage. It then passed through the Cayman Islands where it damaged 80 percent of all structures. It reached its maximum intensity on Sept. 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, AL, early on Sept. 16. Damage was especially extensive in the panhandle of Florida, with Pensacola experiencing considerable destruction. Insured damage from Ivan is estimated at around $7.1 billion, which brings its total estimated damage in the United States to around $14.2 billion.

The storm weakened to a tropical depression later on Sept. 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 Sept. 22. It tracked west-northwestward and made landfall as a minimal tropical storm in Cameron Parish, LA, on Sept. 23. The system dissipated early the next day.

HURRICANE JEANNE

Jeanne developed from a tropical wave on Sept. 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 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 more than 2,000 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 Sept. 19, the system began to drift northward around the periphery of the subtropical ridge. Jeanne intensified back into a hurricane on Sept. 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 Sept. 24, and it began to intensify as it moved over the warm Gulf Stream waters.

On Sept. 25, Jeanne made landfall in the northwest Bahamas, while intensifying into a major hurricane. Early on Sept. 26, Jeanne made landfall near Stuart, FL, 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 around $3.5 billion in insured damage in the United States, bringing the total damage estimate to around $7 billion.

POTENTIAL REASONS WHY THE 2004 HURRICANE SEASON WAS SO ACTIVE AND DESTRUCTIVE

We hypothesize that several important features combined to make the 2004 Atlantic hurricane season so active and destructive. One of the primary features was the very warm Atlantic sea surface temperatures in the Main Development Region (~10ºN to 20ºN – West African coast to Central America) which has been documented in previous research to relate significantly to increased frequency and intensity of tropical cyclones (Shapiro and Goldenberg, 1998). Figure 3 shows that tropical Atlantic sea surface temperatures averaged about 0.5-1.2ºC above normal. Anomalously warm sea surface temperatures directly affect hurricane development by providing more latent and sensible heat flux for developing systems,

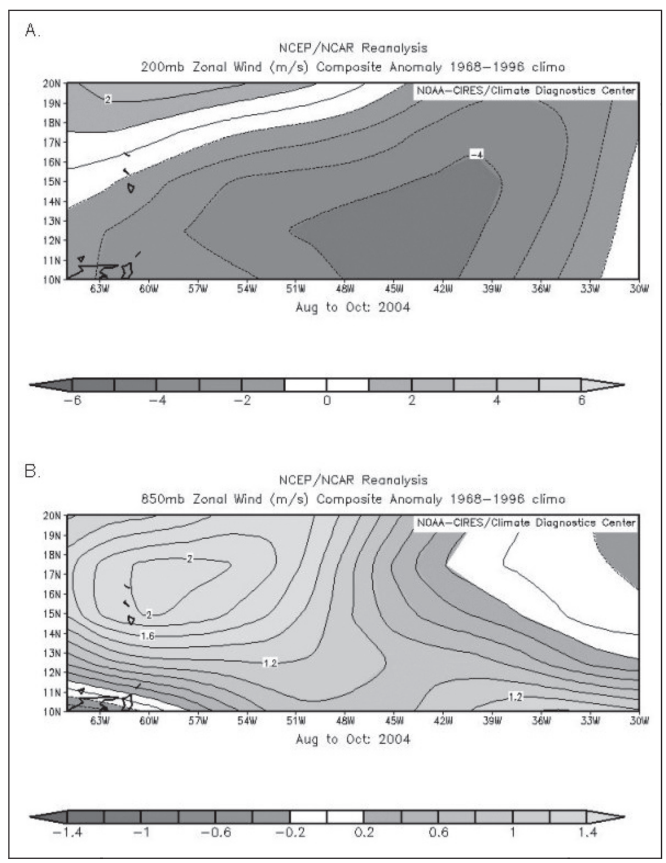

Figure 4A-B: Map showing August-October 2004 Atlantic basin zonal wind anomalies derived from the NCEP/NCAR Reanalysis data for the (A) 200-millibar level and (B) 850-millibar level. Anomalies are computed with respect to the 1968-1996 climatology.

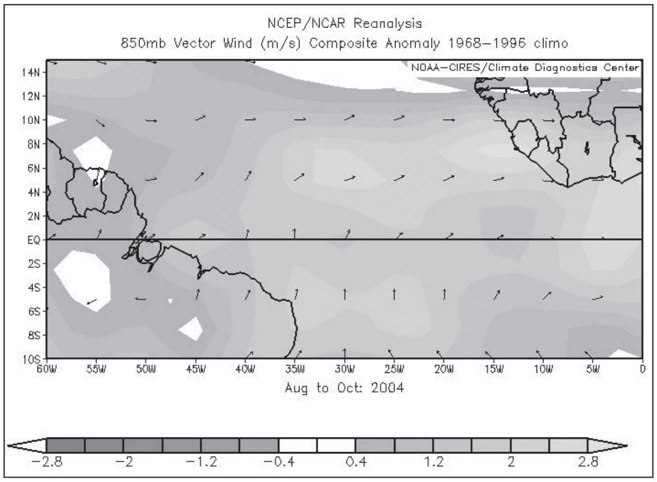

Figure 5. Map showing August-October 2004 Atlantic basin 850 millibar vector wind anomalies derived from the NCEP/NCAR Reanalysis data. Anomalies are computed with respect to the 1968-1996 climatology.

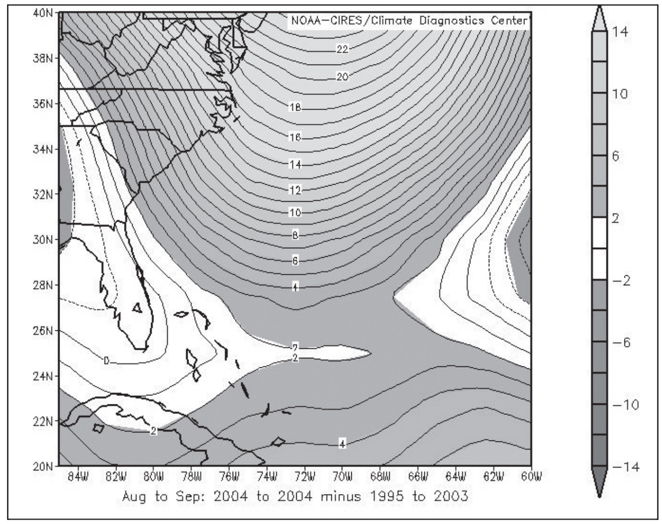

Figure 6. Map showing August-October 2004 500 milibar geopotential height contours differenced from the August-October 1995-2003 500 millibar geopotential height contours. Data is derived from the NCEP/NCAR Reanalysis data.

thereby enhancing convection and thunderstorm development in easterly waves.

Another factor we believe led to an active hurricane season was reduced vertical wind shear in the tropical Atlantic. Large levels of vertical wind shear have been shown in many previous studies to reduce tropical cyclone activity by shearing off the tops of developing systems and inhibiting convection concentration (Gray, 1968; DeMaria, 1996; Goldenberg and Shapiro, 1996). Predominate wind flow in the tropical Atlantic is from the west at upper levels and from the east at lower levels, and therefore, easterly anomalies at upper levels and westerly anomalies at lower levels is associated with a reduction in vertical wind shear. Figure 4A shows that 200-millibar winds from August-October 2004 were anomalously from the east in most of the tropical Atlantic. Figure 4B shows that 850-millibar level winds from August-October were anomalously from the west in most of the tropical Atlantic, thereby contributing to a reduction in 200-850 millibar level vertical wind shear and enhancing tropical cyclone development.

Another feature that was present during the 2004 Atlantic basin hurricane season was anomalously strong cross-equatorial flow from the southern to northern hemisphere at low levels. Figure 5 shows the 850-millibar vector winds from August-October whereby this anomalously strong cross-equatorial flow is clearly seen. Stronger cross-equatorial flow relates to a stronger than average equatorial trough which provides more favorable conditions for development of low-latitude hurricanes.

The above factors led to a very active Atlantic hurricane season in 2004; however, it must be considered that most years from 1995-2003 were also quite active. What distinguished the 2004 season from these previous nine years were steering currents that steered storms westward across the United States coastline before recurving them to the north and east. During the previous nine years, there was a trough along the east coast of the United States which picked storms up and steered them out to sea before they could make U.S. landfall. The presence of this trough is clearly evident by the fact that only three of the 32 major hurricanes that formed during that period made United States landfall. The long-period climatological average is for about one out of every three major hurricanes to make United States landfall.

Figure 6 displays the clear difference in steering patterns between the 2004 season and the previous nine years. A 500-millibar level anticyclone is clearly seen to predominate during the 2004 season compared with the previous nine years. The steering flow around this anticyclone tends to drive storms further westward, as evidenced by the five landfalling hurricanes of the past year. The persistence and strength of this mid-level anticyclone is considered the primary reason why the 2004 season witnessed so many United States landfalls.

Forecast Parameter and 1950–2000 Climatology (in Parentheses)	12/5/03	4/2/04	5/28/04	8/6/04	9/3/04	10/1/04	Observed
Named Storms (9.6)	13	14	14	13	16	15	14
Named Storm Days (49.1)	55	60	60	55	70	96	90.25
Hurricanes (5.9)	7	8	8	7	8	9	9
Hurricane Days (24.5)	30	35	35	30	40	52	45.50
Intense Hurricanes (2.3)	3	3	3	3	5	6	6
Intense Hurricane Days (5.0)	6	8	8	6	15	23	22.25
Net Tropical Cyclone Activity (100)	125	145	145	125	185	240	229

Table 3. Seasonal tropical cyclone forecasts for the 2004 Atlantic basin hurricane season, issued by the Tropical Meteorology Project at Colorado State University.

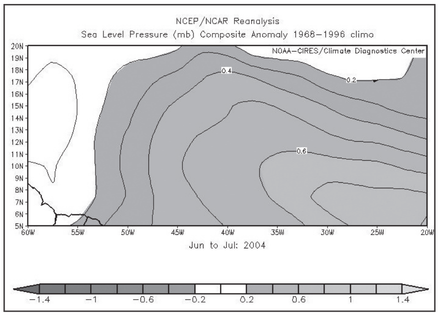

Figure 7. Map showing June-July 2004 Atlantic basin sea level pressure anomalies derived from the NCEP/NCAR Reanalysis data. Anomalies are computed with respect to the 1968-1996 climatology.

2004 ATLANTIC BASIN TROPICAL CYCLONE FORECAST VERIFICATION

Table 3 displays the author's seasonal forecasts for the 2004 hurricane season. In general, the forecasts were successful considering that an above-average hurricane season was announced from the earliest forecasts issued in early December 2003. However, the degree of activity that took place during the 2004 season was not anticipated accurately. Also, the early August forecast update was lowered from earlier forecasts. This was in large part due to June-July conditions that were typically associated with inactive hurricane seasons, namely above-average sea level pressures in the tropical Atlantic and above-average sea surface temperatures in the central Pacific (typically associated with an El Niño event)

Figure 7 displays sea level pressure anomalies in the tropical Atlantic during the months of June-July. On average, pressure was above average by about 0.5 millibars throughout the Atlantic. This deviation is quite small in the middle latitudes; however, it is significant in the tropics. In general, above-average sea level pressure implies increased stability and drier middle levels in the atmosphere and increased vertical wind shear (Knaff, 1997). These above-average sea level pressures in the tropics tend to persist from month to month; however, in this case, they did not and, as was already mentioned, vertical wind shear was below average August-October.

Another reason why the early August forecast was lowered for tropical cyclone activity was the anomalously warm sea surface temperatures in the Nino 3.4 and 4 regions in the central Pacific. There had never been a year in the past with such warm sea surface temperatures in the central Pacific that witnessed above-average activity to the level that was witnessed in 2004. Table 4 displays the Nino 3.4 sea surface temperature anomalies for the 10 most active Atlantic basin NTC years of the last 115 years. Note how much warmer the 2004 season was compared with the average of these 10 seasons. Also, note that the 2004 season had Nino 3.4 temperatures greater than 0.5ºC above that of any of the other 10 seasons. In general, when anomalously warm temperatures are observed in the Central Pacific, vertical wind shear increases over the Caribbean, and tropical cyclone activity in the Atlantic is reduced (Gray, 1984; Goldenberg and Shapiro, 1996). During the 2004 season, even though sea surface temperatures were anomalously warm, convection over the central Pacific was about average, and vertical wind shear over the Atlantic was below average. The authors are currently investigating reasons for this behavior.

CONCLUSION

The 2004 Atlantic hurricane season was one of the most active and destructive on record. The heightened activity of the 2004 season is attributed to near-record warmth in the tropical Atlantic, reduced vertical wind shear and increased convergence as evidenced by an enhanced equatorial trough. In addition, the increased United States landfalls witnessed in the 2004 season is mostly attributed to a mid-level anticyclone that steered storms westward. This is in direct contrast to seven of the nine years of 1995-2003 (excluding 1997 and 2002) which were also very active. In these years, however, a trough persisted off the east coast of the United States and steered most storms out to sea.

Year	Seasonal NTC	August-September Nino 3.4 SSTA (ºC)
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	229	+0.80
2004 Difference From Mean	**+14**	**+1.25**

Table 4. The 10 most active Atlantic basin NTC years of the last 115 years with accompanying August-September Nino 3.4 SSTA values.

The author's seasonal forecasts for the 2004 season verified fairly well; however, the degree of activity that occurred was not forecast. The author's inability to predict a more active hurricane season is attributed to several factors. In previous years, the cross-equatorial flow at low latitudes as an additional qualitative predictor was not thoroughly evaluated. This parameter will be taken into account in future years. As mentioned previously, even though the 2004 season witnessed warm temperatures in the central Pacific reminiscent of El Niño conditions, the atmosphere did not respond in the way that is typically expected (i.e., increased westerly shear across the Caribbean and tropical Atlantic). This is another area for further research being conducted by the authors. In conclusion, many special features discussed in this paper combined to make the 2004 Atlantic basin hurricane season such a notable one.

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