SUMMARY OF 2008 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL AND MONTHLY FORECASTS

The 2008 hurricane season had activity at well above-average levels. Our project's new forecast techniques proved very successful at anticipating this level of activity.

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

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

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ATLANTIC BASIN SEASONAL HURRICANE FORECASTS FOR 2008

Forecast Parameter and 1950-2000 Climatology (in parentheses)	7 Dec 2007	Update 9 April 2008	Update 3 June 2008	Update 5 Aug 2008	Observed 2008 Total
Named Storms (NS) (9.6)	13	15	15	17	16
Named Storm Days (NSD) (49.1)	60	80	80	90	84.75
Hurricanes (H) (5.9)	7	8	8	9	8
Hurricane Days (HD) (24.5)	30	40	40	45	29.50
Intense Hurricanes (IH) (2.3)	3	4	4	5	5
Intense Hurricane Days (IHD) (5.0)	6	9	9	11	8.50
Accumulated Cyclone Energy (ACE) (96.2)	115	150	150	175	141
Net Tropical Cyclone Activity (NTC) (100%)	125	160	160	190	164

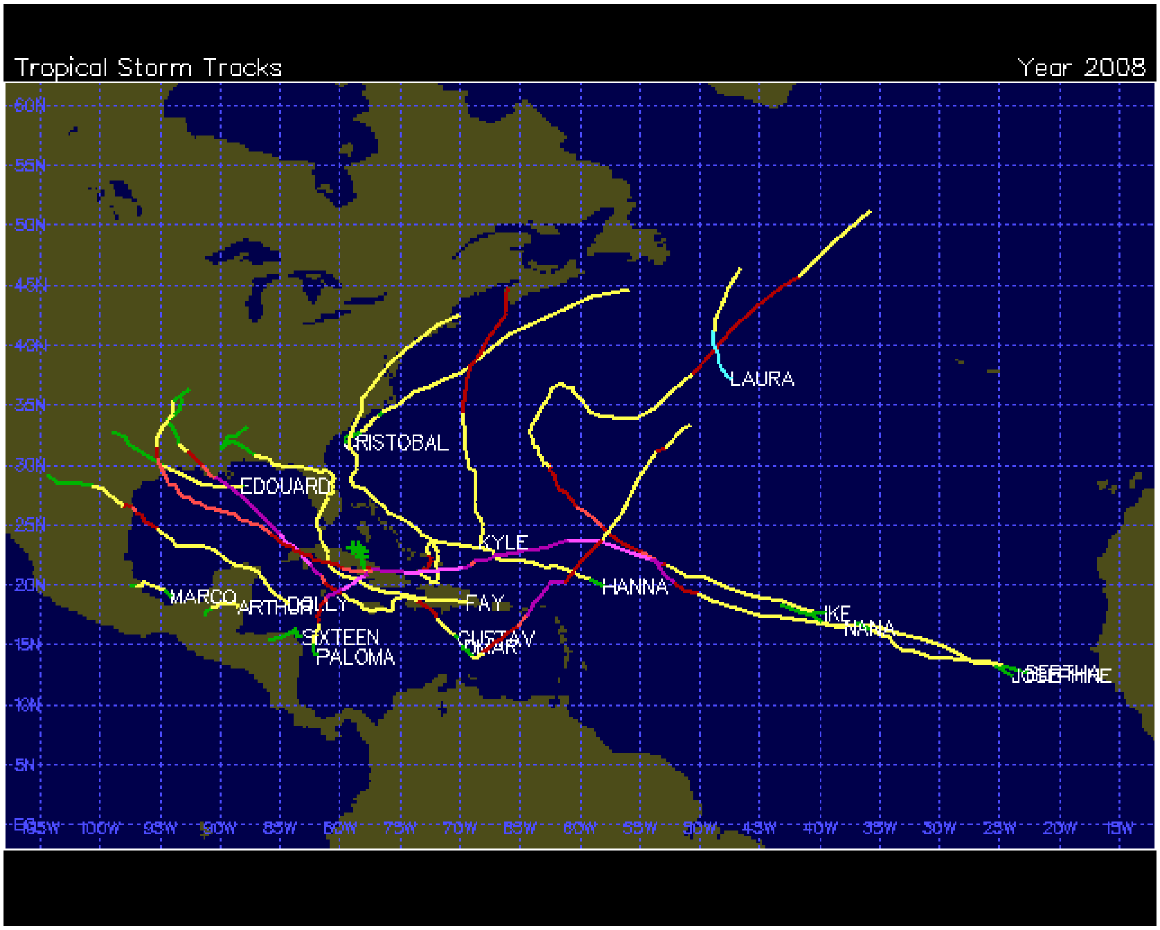


Figure courtesy of Unisys Weather (http://weather.unisys.com)

ABSTRACT

This report summarizes tropical cyclone (TC) activity, which occurred in the Atlantic basin during 2008 and verifies the authors' seasonal and monthly forecasts of this activity. A forecast was initially issued for the 2008 season on 7 December 2007 with updates on 9 April, 3 June, and 5 August of this year. These seasonal forecasts also contained estimates of the probability of U.S. hurricane landfall during 2008. The 3 August forecast included a forecast of August-only tropical cyclone activity. Our 2 September forecast gave a seasonal summary up to that date and included a prediction of September-only activity. Our 1 October forecast gave a seasonal summary through September and included an October-only forecast. All forecast schemes for this year have been recently updated. Unlike our predictions for the 2006 and 2007 hurricane seasons, we are very pleased with the skill of our forecasts for this year. We anticipated a well above-average season, and the season had activity at well above-average levels.

DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SST(s) – Sea Surface Temperature(s)

SSTA(s) – Sea Surface Temperature(s) Anomalies

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

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

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

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

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

Notice of Author Changes

By William Gray

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

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

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

Acknowledgment

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

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

1 Preliminary Discussion

1a. Introduction

The year to year variability of Atlantic basin hurricane activity is the largest of any of the globe's tropical cyclone basins. There has always been and will continue to be much interest in knowing if the coming Atlantic hurricane season is going to be unusually active, very quiet or just average. There was never a way of objectively determining very much about how active the coming Atlantic hurricane season was going to be until the early to mid-980s when global data sets became more accessible.

The prospects of initial value numerical prediction of seasonal hurricane activity were never considered feasible as the skill of numerical modeling does not extend much beyond a few weeks. One could imagine, however, that the global atmosphere and oceans in combination might have some sort of stored memory buried within them that could provide clues as to how active the upcoming Atlantic basin hurricane season was likely to be. The benefit of such empirical investigation (or data mining) was that any precursor relationship that might be found could immediately be utilized without having to have a complete understanding of the physics involved.

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

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

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

1b. Seasonal Forecast Theory

A variety of atmosphere-ocean conditions interact with each other to cause year-to-year and month-to-month hurricane variability. The interactive physical linkages between these precursor physical parameters and hurricane variability are complicated and cannot be well elucidated to the satisfaction of the typical forecaster making short range (1-5 days) predictions where changes in the momentum fields are the crucial factors. Seasonal 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 3-4 semi-independent atmospheric-oceanic parameters together. The best predictors (out of a group of 3-4) do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain a portion of the variance of seasonal hurricane activity that is not associated with the other variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 3-4 other predictors.

In a four-predictor empirical forecast model, the contribution of each predictor to the net forecast skill can only be determined by the separate elimination of each parameter from the full four-predictor model while noting the hindcast skill degradation. When taken from the full set of predictors, one parameter may degrade the forecast skill by 25-30 percent, while another degrades the forecast skill by only 10-15 percent. An individual parameter that, through elimination from the forecast, degrades a forecast by as much as 25-30 percent may, in fact, by itself, show little direct correlation with the predictand. A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 3-4 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. Despite the complicated relationships that are involved, all of our statistical models show considerable hindcast skill. We are confident that in applying these skillful hindcasts to future forecasts that appreciable real-time skill will result.

2 Tropical Cyclone Activity for 2008

Figure 1 and Table 1 summarize the Atlantic basin tropical cyclone activity which occurred in 2008. A well above-average season was experienced for most tropical cyclone parameters. See page 4 for acronym definitions.

3 Individual 2008 Tropical Cyclone Characteristics

The following is a brief summary of each of the named tropical cyclones in the Atlantic basin for the 2008 season. See Figure 1 for the tracks of these tropical cyclones, and see Table 1 for statistics of each of these tropical cyclones. Online entries from Wikipedia (http://www.wikipedia.org) were very helpful in putting together these tropical cyclone summaries.

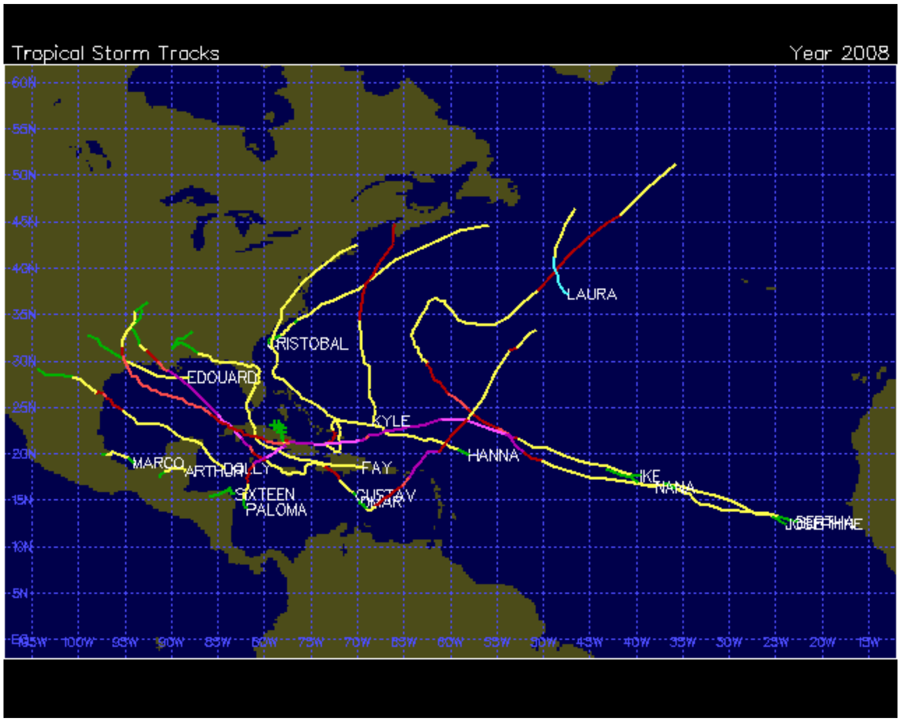


Figure 1: Tracks of 2008 Atlantic Basin tropical cyclones. Figure courtesy of Unisys Weather (http://weather.unisys.com).

Table 1: Observed 2008 Atlantic basin tropical cyclone activity.

Highest Category	Name	Dates	Peak Sustained Winds (kts)/lowest SLP (mb)	NSD	HD	IHD	ACE	NTC
TS	Arthur	May 31 – June 1	35 kt/1005 mb	0.75			0.4	2.0
IH-3	Bertha	July 3 – 20	105 kt/948 mb	17.25	7.50	0.75	28.4	25.3
TS	Cristobal	July 19 – 23	55 kt/1000 mb	3.75			3.2	3.0
H-2	Dolly	July 20 – 24	85 kt/964 mb	4.00	1.25		5.3	6.8
TS	Edouard	August 3 – 5	55 kt/997 mb	1.75			1.5	2.3
TS	Fay	August 15 – 24	55 kt/986 mb	8.25			6.7	4.5
IH-4	Gustav	August 25 – September 2	130 kt/941 mb	7.50	4.00	2.00	18.5	23.7
H-1	Hanna	August 28 – September 7	70 kt/978 mb	10.00	0.75		10.5	8.5
IH-4	Ike	September 1 – 14	125 kt/935 mb	12.50	10.00	4.00	38.3	36.2
TS	Josephine	September 2 – 5	55 kt/994 mb	3.50			2.8	2.9
H-1	Kyle	September 25 – 29	70 kt/984 mb	3.50	1.25		4.7	6.6
TS	Laura	September 29 – October 1	50 kt/993 mb	2.50			2.3	2.6
TS	Marco	October 6 – 7	55 kt/998 mb	1.00			1.2	2.1
TS	Nana	October 12 – 13	35 kt/1005 mb	0.75			0.4	2.0
IH-3	Omar	October 14 – 18	110 kt/959 mb	4.25	2.25	0.50	6.7	16.4
IH-4	Paloma	November 6 – 9	125 kt/943 mb	3.50	2.50	1.25	9.9	18.9
Totals				84.75	29.50	8.50	140.6	163.8

Tropical Storm Arthur: Arthur formed from an area of low pressure in the northwestern Caribbean on May 31. The system soon tracked inland over Belize as it moved west-northwestward, guided by a high pressure system over the Gulf of Mexico. The system maintained minimal tropical storm intensity (35 knots) until late on June 1 when it was downgraded to a tropical depression. It dissipated early on June 2. The remnants of Arthur caused heavy rainfall and flooding in Belize, with five fatalities directly attributed to the system.

Intense Hurricane Bertha: Bertha formed from a tropical wave in the eastern Atlantic on July 3. It reached tropical storm status later that day, becoming the farthest east that a storm has formed in July in the deep tropics. A mid-level ridge kept Bertha on a west-northwest heading. The system slowly gained strength over the next couple of days, as cool sea surface temperatures inhibited intensification. By July 6, Bertha encountered warmer waters while shear remained low, and the system subsequently strengthened, reaching hurricane status on July 7. Bertha then underwent rapid intensification, achieving major hurricane status early on July 8. It then reached a weakness in the subtropical ridge, causing a more north-westward track. It encountered cooler waters and increased shear on this track, causing weakening back to a minor hurricane later on July 8. Bertha underwent an eyewall replacement cycle during July 10-11, weakening to a Category 1 hurricane while doing so. Steering currents collapsed over Bertha soon after, causing the system to drift over the next couple of days. Due to its slow forward speed, Bertha initiated significant upwelling of cooler sub-surface water, causing a reduction to tropical storm strength. During this time, Bertha brought strong tropical-storm force winds to Bermuda. A ridge began to build to the east of Bertha, imparting a more easterly course to the tropical cyclone. By late on July 17, Bertha weakened to a 50 knot tropical cyclone, but it soon regained hurricane strength, despite cooling sea surface temperatures. Bertha weakened to a tropical storm again early on

July 20 and became extra-tropical later that day. No fatalities were directly attributed to the system, and damage from the cyclone was reported as minimal. Bertha was the longest-lived tropical cyclone in recorded history for the month of July.

Tropical Storm Cristobal: Cristobal formed from an area of low pressure off of the Georgia coast on July 19. It intensified into a tropical storm later that day while situated in an environment of relatively low vertical wind shear. A mid-level ridge to its southeast caused Cristobal to move in a northeastward direction. Cristobal reached its maximum intensity of 55 knots on July 21, before encountering higher levels of vertical wind shear. A mid-latitude trough accelerated Cristobal towards the northeast, and it completed extra-tropical transition on July 23. No fatalities or damage were attributed to Cristobal.

Hurricane Dolly: Dolly formed from a strong tropical wave in the western Caribbean on July 20. A mid-level ridge near Florida caused Dolly to track northwestward during the early part of its lifespan. Dolly brushed by the northern tip of the Yucatan Peninsula and intensified into a hurricane on July 22, due to a combination of warm waters and an upper-level anti-cyclone enhancing Dolly's outflow. Dolly intensified into a Category 2 hurricane before making landfall on South Padre Island, Texas on July 23. The system quickly weakened once making landfall, being downgraded to a tropical storm early on July 24 and a tropical depression later on July 24. Dolly was responsible for 21 fatalities. According to ISO's Property Claim Services, Dolly caused an estimated $525 million dollars in insured damage. Using a rough two to one estimate of total to insured damage, Dolly cost about $1 billion dollars in the United States. Dolly was the strongest storm to make landfall in Texas since Hurricane Bret (1999).

Tropical Storm Edouard: Edouard formed from an area of low pressure in the Gulf of Mexico on August 3. It intensified to tropical storm status later that day. An area of high pressure located over the southern United States caused Edouard to track towards the west. Significant northerly shear which then shifted to moderate southerly shear inhibited Edouard from intensifying during the early part of its lifetime. Shear began to weaken as Edouard neared the Texas coast, and the system intensified to 55 knots before making landfall between High Island and Sabine Pass on August 5. The system was downgraded to a tropical depression later that day. No fatalities were reported from Edouard. Damage was minimal.

Tropical Storm Fay: Tropical Storm Fay formed from an area of low pressure in the Mona Passage on August 15. Due to a mid-level ridge to its north, Fay moved westward across Hispaniola over the next couple of days while remaining a weak tropical storm. Fay strengthened somewhat while passing south of Cuba and curved more towards the northwest as it encountered a weakness in the ridge. By early on August 18, Fay had begun to curve more towards the north and crossed Cuba. After emerging in the Florida Straits, Fay began to strengthen modestly, although strong intensification was inhibited by southwesterly vertical wind shear and dry air entrainment. Fay made its first landfall near Key West as a 50 knot tropical storm late on August 18 with a second landfall at Cape Romano, Florida as a 50 knot tropical storm early on August 19. Fay actually intensified over land throughout the day on August 19, reaching a maximum intensity of 55 knots while located over central Florida. However, the land interaction then began weaken to Fay as the system continued its traverse over the Florida Peninsula. By early on August 20, the system was located near Melbourne, Florida. At this point, steering currents over Fay collapsed, and it slowly drifted northward along the east coast of Florida. Fay's center eventually drifted offshore and strengthened slightly before a ridge to its north imparted a more westerly steering impulse to Fay. Fay made yet another Florida landfall as a 50 knot tropical storm near Flagler Beach, Florida on August 21. Fay slowly drifted westward across Florida while gradually weakening over the next day. The center of Fay emerged over the extreme northern portion of the Gulf of Mexico early on August 23. Fay strengthened slightly over the Gulf before making its fourth and final Florida landfall near Carrabelle, Florida later on August 23. The system finally was downgraded to a tropical depression as it drifted slowly westward across north Florida early on August 24. Fay was responsible for 25 direct fatalities, while damage from the system is unknown. Fay became the first system in U.S. history to make four landfalls in the same state, breaking a record of three landfalls in the same state set by Hurricane Gordon in Florida in 1994.

Intense Hurricane Gustav: Gustav formed from an area of low pressure in the central Caribbean on August 25 and was upgraded to a tropical storm later that day. Gustav tracked towards the northwest due to a mid-level high pressure system located over Florida. Gustav formed in a favorable environment and intensified into a hurricane early on August 26 while tracking towards southern Haiti. Gustav weakened to a tropical storm while slowly traversing the mountainous terrain of southern Haiti. Gustav emerged over the western Caribbean a much weaker tropical cyclone with winds of about 40 knots. The center reformed south under the deep convection and intensified to a strong tropical storm before making landfall in the southern part of Jamaica on August 28. A mid-level ridge over Florida continued to drive Gustav west across Jamaica. After leaving Jamaica, Gustav strengthened rapidly to a hurricane on August 29, due to a favorable environment consisting of very deep, warm water and an upper-level anticyclone over the top of the system. Gustav continued to rapidly intensity into a major hurricane by early on August 30, reaching Category 4 status later on August 30. Gustav barreled into western Cuba as a 130-knot storm late on August 30. The interaction with land impacted Gustav considerably, weakening it to a Category 3 hurricane by early on August 31. A mid-level ridge over the southeastern United States continued to impart a northwesterly track on Gustav. Southerly shear and some dry air entrainment prevented Gustav from strengthening while tracking across the Gulf of Mexico. The system weakened slightly to a 95-knot (Category 2) tropical cyclone before making landfall near Cocodrie, Louisiana on September 1. Gustav weakened quickly after landfall, being downgraded to a tropical storm early on September 2 and a tropical depression later that day. Gustav caused considerable amounts of damage on Haiti, Jamaica, Cuba as well as Louisiana. Approximately 138 deaths have been attributed to Gustav, including 43 in the United States. ISO’s Property Claim Services estimates that Gustav did approximately $1.9 billion dollars in insured damage in the United States. Observed damage was much less than was originally predicted, due to Gustav's weakening before landfall and a track that kept the most damaging winds and surge out of the New Orleans metropolitan area.

Hurricane Hanna: Hanna formed from a tropical wave while located northeast of the Leeward Islands on August 28. Hanna was upgraded to a tropical storm later that day while moving northwestward across the Atlantic. Westerly shear was quite strong over the system due to a strong upper-level low to its west, and the system had difficulty strengthening. Over the next couple of days, the shear began to relax over Hanna, and it intensified to a hurricane on September 1. Strong northerly shear began to impact Hanna later that day, due in part to outflow from Hurricane Gustav, and it weakened back to a tropical storm on September 2 while completing a counter-clockwise loop near the Turks and Caicos Islands. During this time period, Hanna brought tremendous amounts of rain to Haiti, causing considerable amounts of damage and devastation. A sub-tropical ridge began to build north of Hanna which eventually caused the system to track towards the northwest. An upper-level low in the northwest Bahamas caused copious amounts of dry air to be ingested into Hanna which inhibited intensification. Hanna entered a slightly more favorable environment and intensified to a strong tropical storm (60 knots) before making landfall early on September 6 near the North/South Carolina border. Hanna rounded a mid-level ridge and began to curve towards the north and northeast while tracking along the mid-Atlantic coast. By early on September 7, Hanna had completed extra-tropical transition. Hanna was responsible for 536 deaths, 529 of which occurred on Haiti. Hanna caused about $100 million in total damage in the United States.

Intense Hurricane Ike: Ike formed from a tropical wave in the eastern tropical Atlantic on September 1. It was upgraded to a tropical storm later that day while traveling westward underneath a sub-tropical ridge located to its north. After intensifying slowly for the next couple of days, Ike began to rapidly intensify on September 3. Ike was classified as a hurricane later on September 3 and was then upgraded to a major hurricane just three hours later. Ike reached Category 4 status on September 4 before beginning to weaken in the face of northerly shear. A strong mid-level ridge built over Ike during this time period, causing the system to track west-southwestward across the central Atlantic. Northerly shear continued to impact Ike, and it weakened to a 95-knot Category 2 hurricane on September 6. However, this shear soon weakened, and Ike re-intensified to a Category 4 hurricane later on September 6. Ike continued on its west-southwest heading, pounding the Turks and Caicos Islands as well as Haiti and the Dominican Republic before barreling into eastern Cuba. The system made landfall in eastern Cuba early on September 8 as a Category 3 hurricane. Ike then weakened to a Category 2 hurricane while tracking across Cuba. Ike weakened to a minimal hurricane with 65 knot winds before exiting western Cuba on September 9. Ike then began to intensify in the Gulf of Mexico as it tracked northwest towards Texas, reaching Category 2 status on September 10. More importantly than Ike's maximum sustained winds was the size of the wind field associated with the cyclone. Ike's sustained hurricane-force winds extended out to at least 100 miles in several quadrants by September 11. Since the system was so large, even though synoptic conditions were somewhat favorable for intensification, Ike intensified slowly, reaching 95-knot maximum sustained winds before making landfall near Galveston Island, Texas on September 13. The system weakened to a tropical storm later on September 13 and was downgraded to a tropical depression early on September 14. Ike did a tremendous amount of damage in the Turks and Caicos, Haiti, Cuba and the United States. A total of 143 deaths between the Caribbean and the United States have been blamed on Ike. Ike is estimated to have caused $4 billion in damage in Cuba, with an estimated $8.1 billion in insured damage inflicted in the United States according to ISO's Property Claim Services. This estimate would make Ike the fifth most destructive tropical cyclone in US history based on insured damage adjusted to 2007 dollars.

Tropical Storm Josephine: Josephine formed from a tropical wave while located south of the Cape Verde Islands on September 2. The system was upgraded to a tropical storm six hours later while tracking westward under a sub-tropical high in the east-central portion of the sub-tropical Atlantic. Josephine intensified steadily under an area of low shear; however, an upper-level trough began to impinge on the cyclone on September 3 imparting increasing westerly and then southerly shear over the system. After reaching its maximum intensity of 55 knots on September 3, Josephine weakened considerably over the next day. The system tenaciously fought shear throughout the day on September 4, with occasional bursts of deep convection near the center of the cyclone. By late on September 5, the relentless southerly shear caused Josephine to weaken to a tropical depression, and it was downgraded to a remnant low early on September 6.

Hurricane Kyle: Kyle formed from an area of low pressure north of Puerto Rico late on September 25. Fairly strong south-westerly shear inhibited intensification of Kyle during its formation stages; however, it relented somewhat on September 26, allowing the system to intensity as it tracked generally northward between a strong cut-off low off the east coast of the United States and a mid-level high near Bermuda. Kyle intensified into a hurricane while accelerating northward on September 27. Despite being a very asymmetric cyclone due to strong shear, Kyle reached a maximum intensity of 70 knots during the day on September 28. As the system continued to accelerate north-eastward, it tracked over much cooler water and became classified as an extra-tropical cyclone soon after making landfall as a Category 1 hurricane near Yarmouth, Nova Scotia on September 29. Kyle brought deadly rains to Puerto Rico prior to being classified as a tropical storm, with four fatalities attributed to the system on the island. Mudslides on Puerto Rico and minor damage in Nova Scotia were attributed to the system.

Tropical Storm Laura: Laura formed from a non-tropical area of low pressure while located about 750 miles west of the Azores. It was initially given a sub-tropical storm classification (with 50 knot sustained winds) when named by the National Hurricane Center on September 29. Laura tracked northwestward and began to acquire tropical characteristics over sea surface temperatures in the 25-26°C range. As Laura began to separate from an upper-level low, it was classified as a tropical storm on September 30. Laura began to weaken late on September 30 as it tracked over progressively cooler waters. By October 1, deep convection had dwindled to the point where advisories on Laura were suspended.

Tropical Storm Marco: Marco formed from a small area of low pressure in the Bay of Campeche on October 6. Aircraft reconnaissance later that day indicated that Marco had strengthened into a tropical storm with maximum sustained winds of 55 knots. A mid-level ridge to Marco's north steered the system west-northwestward across the Bay of Campeche. Marco made landfall along the central coast of Mexico on October 7. The tiny system dissipated rapidly over the mountains of Mexico. No damage or fatalities were reported from Marco. Marco was most notable for its small size. At one point, tropical-storm force winds were estimated to extend only 10 nautical miles from the center of the system. If this fact is confirmed in the best-track post-season analysis, Marco could be the smallest tropical cyclone on record, beating the old record set by Cyclone Tracy in 1974.

Tropical Storm Nana: Nana formed from a tropical wave in the eastern tropical Atlantic on October 12. Strong upper-level westerlies caused the center of the circulation to be exposed well to the west of the deep convection. A mid-level ridge steered Nana towards the west-northwest during its brief lifetime. Strong westerly shear continued over Nana, and the system was downgraded to a tropical depression on October 13.

Intense Hurricane Omar: Omar formed from an area of low pressure in the eastern Caribbean on October 13. Strong northwesterly shear inhibited rapid development; however, Omar was able to become better organized and become classified as a tropical storm on October 14. The shear began to relax later that day, and Omar rapidly intensified into a hurricane late on October 14 while over the very warm, deep waters of the Caribbean Sea. Omar began to accelerate towards the northeast on October 15 as a deep mid-latitude trough picked up the system. Early on October 16, as the shear briefly abated, Omar rapidly intensified into a major hurricane, reaching a maximum intensity of 110 knots while battering the northern Leeward Islands. Omar then began a period of incredibly rapid weakening, as strong vertical wind shear and dry air entrainment destroyed the cyclone. By early on October 17, Omar had been downgraded to a tropical storm while accelerating northeastward. The system briefly intensified back into a hurricane later on October 17 before succumbing to the continued strong vertical wind shear and cooler sea surface temperatures. Omar was downgraded to a remnant low on October 18. Moderate damage was sustained in the Lesser Antilles due to Omar. No exact damage estimates are available at this point. One indirect fatality was attributed to the system.

Intense Hurricane Paloma: Paloma formed from an area of low pressure in the southwestern Caribbean Sea on November 5. A large upper-level anti-cyclone and minimal levels of vertical wind shear provided a very favorable synoptic environment for strengthening, and Paloma strengthened rapidly, reaching tropical storm strength early on November 6 and hurricane strength early on November 7 while tracking slowly northward. Paloma reached major hurricane strength late on November 7 and pummeled the Cayman Islands while beginning to turn northeastward. Paloma was generally steered by a ridge over the Caribbean and a trough over the eastern United States. The system intensified into a Category 4 hurricane while approaching Cuba. Strong vertical wind shear began to impinge upon the cyclone on November 8, and this feature, along with copious amounts of dry air and land interaction over Cuba rapidly weakened Paloma. Paloma weakened to a tropical storm on November 9 and was downgraded to a tropical depression later that day. Considerable damage was reported on the Cayman Islands and Cuba from Paloma. No monetary estimates are available at this time. One fatality on Cuba was attributed to Paloma.

U.S. Landfall. Figure 2 shows the tracks of all tropical cyclones that made landfall in the United States in 2008. Three tropical storms and three Category 2 hurricanes made U.S. landfall this year: Hurricane Dolly, Tropical Storm Edouard, Tropical Storm Fay, Hurricane Gustav, Tropical Storm Hanna and Hurricane Ike. Table 2 displays the estimated damage from the three hurricanes. Dolly and Gustav caused considerable damage. Hurricane Ike was the fifth most damaging system on record. The 2008 Atlantic hurricane season was one of the most damaging seasons on record.

Figure 2: Tropical cyclones making U.S. landfall (Hurricane Dolly, Tropical Storm Edouard, Tropical Storm Fay, Hurricane Gustav, Tropical Storm Hanna and Hurricane Ike). A dashed line indicates tropical storm strength, while a solid line indicates hurricane strength.

Table 2: United States damage estimates from the three hurricanes that made U.S. landfall in 2008 (in billions of dollars) according to ISO's Property Claim Services. We assume that total damage is twice that of insured damage. Damage from the three tropical storms that made U.S. landfall was minimal

Storm Name	**Insured Damage**	**Total Damage (Assumes Twice Insured Damage)**
Dolly	0.5	1.0
Gustav	1.9	3.8
Ike	8.1	16.2
Total	**10.5**	**21**

4 Special Characteristics of the 2008 Hurricane Season

The 2008 hurricane season had the following special characteristics:

- Another early-starting season. Arthur formed on May 31. The climatological average date for the first named storm formation in the Atlantic, based on 1944-2005 data, is July 10.

- Sixteen named storms formed during the 2008 season. Since 1995, 13 of the last 14 seasons have had more than the 1950-2000 average of ten named storms. Since aircraft reconnaissance began in 1944, only 2005 (28 named storms), 1995 (19 named storms) and 1969 (18 named storms) have had more named storm formations than 2008.

- Eight hurricanes formed during the 2008 season. This number is exactly the average of the most recent active period (1995-2007).

- Five major hurricanes formed during the 2008 season. Since aircraft reconnaissance began in 1944, only seven years have had more than five major hurricanes in the Atlantic basin.

- 84.75 named storm days occurred in 2008. This is more than double the number of named storm days that occurred in 2007, despite only one more named storm forming in 2008. This is the seventh highest seasonal total of named storm days since 1944.

- 29.50 hurricane days occurred in 2008. This is more than twice the number of hurricane days that occurred in 2007.

- 8.50 intense hurricane days occurred in 2008. This is the highest number of intense hurricane days since 2005, when a whopping 17.75 intense hurricane days were observed.

- The season accrued an ACE of 141. This ranks 2008 as the 15th highest ACE value observed over the 1944-2008 period (65 years).

- The season accumulated 164 NTC units. This ranks 2008 as the 13th highest NTC value observed over the 1944-2008 period (65 years).

- No Category 5 hurricanes developed in 2008. This is only the second year since 2002 with no Category 5 hurricanes in the Atlantic. 2006 also had no Category 5 hurricanes.

- July 2008 was especially active. Three named storms, two hurricanes and one major hurricane formed during the month. Since 1944, only 1966, 1995, 1997 and 2005 had more named storm formations in July. Since 1944, only 1966 and 2005 had more hurricane formations. Since 1944, only 2005 had multiple major hurricane formations (Dennis and Emily) during July.

- July 2008 accrued 37 ACE units. This is the second highest on record for July since 1944, trailing only 2005 (60 ACE units). July 2008 also tallied 35 NTC units, which is the second highest since 1944 (also trailing 2005 which accrued 70 NTC units).

- August, September and October all recorded slightly above-average NTC values. August had 31 NTC units (119% of the long-term average), September had 56 NTC units (117% of the long-term average), and October had 21 NTC units (117% of the long-term average).

- Three named storms formed during October. Only eight years since 1944 have had more than three named storms form during October.

- November was quite active. Since 1944, only four other Novembers have had a major hurricane (1956 - Greta, 1985 - Kate, 1999 - Lenny, and 2001 - Michelle).

- Paloma became the second strongest hurricane during the month of November (125 knots). Only Lenny (1999) had a stronger intensity in November (135 knots).

- Paloma accumulated the least ACE (10 units) for a storm that reached an intensity of 125 knots or greater.

- 2008 became the first year on record with five consecutive months of a storm at major hurricane intensity (July – November).

- Three hurricanes made landfall along the U.S. Gulf Coast. This is the most U.S. landfalls since 2005 in the Gulf, which witnessed four landfalls. Prior to 2005, the previous year with three or more U.S. hurricane landfalls in the Gulf was 1985 which also had four hurricane landfalls.

- No hurricanes made landfall along the Florida Peninsula and East Coast. This marks the third year in a row with no hurricane landfalls along this portion of the U.S. coastline.

- No major hurricanes made U.S. landfall this year. Following seven major hurricane landfalls in 2004-2005, the U.S. has not witnessed a major hurricane landfall in the past three years.

- Six named storms in a row (Dolly through Ike) made U.S. landfall. This breaks the old record of five named storms in a row which occurred in 1971, 1979, 1985, 2002, and 2004.

5 Verification of Individual 2008 Lead Time Forecasts

Table 3 is a comparison of our 2008 forecasts for four different lead times along with this year's observations. Note how well this year's seasonal forecasts verified. We consider our April and June forecasts to have been especially successful. We believed that given the extremely active early season and the climate parameters observed up to August that the remainder of the season was likely to be somewhat more active than it was. The rest of the season had activity at somewhat above average levels, while Gustav and Ike both caused tremendous amounts of devastation in the United States and in the Caribbean.

Table 4 provides the same forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts over the 1990-2007 period, using equations developed over the 1950-1989 period. We typically expect to see 2/3 of our forecasts to verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values. We issued predictions for eight indices at four different lead times (32 predictions). Of these predictions, 27 of 32 (84%) forecasts were within one standard deviation of observations, and all forecasts were within two standard deviations of observations. We consider this season's forecast to have been quite successful.

Table 3: Verification of our 2008 seasonal hurricane predictions.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	7 Dec 2007	Update 9 April 2008	Update 3 June 2008	Update 5 Aug 2008	Observed 2008 Total
Named Storms (NS) (9.6)	13	15	15	17	16
Named Storm Days (NSD) (49.1)	60	80	80	90	84.75
Hurricanes (H) (5.9)	7	8	8	9	8
Hurricane Days (HD) (24.5)	30	40	40	45	29.50
Intense Hurricanes (IH) (2.3)	3	4	4	5	5
Intense Hurricane Days (IHD) (5.0)	6	9	9	11	8.50
Accumulated Cyclone Energy (ACE) (96.2)	115	150	150	175	141
Net Tropical Cyclone Activity (NTC) (100%)	125	160	160	190	164

Table 4: Verification of our 2008 seasonal hurricane predictions with error bars (one standard deviation). Predictions that lie within one standard deviation of observations are highlighted in red bold font, while predictions that lie within two standard deviations are highlighted in green bold font. In general, we expect that 2/3 of our forecasts should lie within one standard deviation of observations, with 95% of our forecasts lying within two standard deviations of observations. These error bars are larger than was provided in our original forecasts as they are now based on a more realistic measure of likely forecast skill. Error bars for storms are rounded to the nearest storm. For example, the hurricane prediction in early August would be 7.2-10.8, which with rounding would be 7-11.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	7 Dec 2007	Update 9 April 2008	Update 3 June 2008	Update 5 Aug 2008	Observed 2008 Total
Named Storms (NS) (9.6)	**13** (±4.4)	**15** (±4.0)	**15** (±3.8)	**17** (±3.3)	16
Named Storm Days (NSD) (49.1)	**60** (±23.9)	**80** ±(19.4)	**80** (±18.3)	**90** (±16.3)	84.75
Hurricanes (H) (5.9)	**7** (±2.5)	**8** (±2.2)	**8** (±2.1)	**9** (±1.8)	8
Hurricane Days (HD) (24.5)	**30** (±12.4)	**40** (±9.5)	**40** (±9.0)	**45** (±8.8)	29.50
Intense Hurricanes (IH) (2.3)	**3** (±1.5)	**4** (±1.4)	**4** (±1.2)	**5** (±1.2)	5
Intense Hurricane Days (IHD) (5.0)	**6** (±4.7)	**9** (±4.4)	**9** (±4.5)	**11** (±4.6)	8.50
Accumulated Cyclone Energy (ACE) (96.2)	**115** (±50)	**150** (±39)	**150** (±39)	**175** (±37)	141
Net Tropical Cyclone Activity (NTC) (100%)	**125** (±49)	**160** (±41)	**160** (±37)	**190** (±33)	164

5.1 Preface: Aggregate Verification of our Last Ten Yearly Forecasts

A way to consider the skill of our forecasts is to evaluate whether the forecast for each parameter successfully forecast above- or below-average activity. Table 5 displays how frequently our forecasts have been on the right side of climatology for the past ten years. In general, our forecasts are successful at forecasting whether the season will be more or less active than the average season by as early as December of the previous year. We tend to have improving skill as we get closer in time to the start of the hurricane season.

Table 5: The number of years that our tropical cyclone forecasts issued at various lead times has correctly predicted above- or below-average activity for each predictand over the past ten years (1999-2008).

Tropical Cyclone Parameter	**Early December**	**Early April**	**Early June**	**Early August**
NS	8/10	9/10	9/10	8/10
NSD	8/10	9/10	9/10	8/10
H	7/10	8/10	8/10	8/10
HD	6/10	7/10	7/10	8/10
IH	6/10	6/10	8/10	8/10
IHD	7/10	7/10	9/10	9/10
NTC	6/10	7/10	7/10	8/10
Total	**48/70 (69%)**	**53/70 (76%)**	**57/70 (81%)**	**57/70 (81%)**

Of course, there are significant amounts of unexplained variance in a number of the individual parameter forecasts. Even though the skill for some of these parameter forecasts is somewhat low, especially for the early December lead time, there is a great curiosity in having some objective measure as to how active the coming hurricane season is likely to be. Therefore, even a forecast that is only modestly skillful is likely of interest. In addition, we have recently redesigned all our statistical forecast methodologies using more rigorous physical and statistical tests which we believe will lead to more accurate forecasts in the future. Complete verifications of all seasonal and monthly forecasts are available online at http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls. Verifications are currently available for all of our prior seasons from 1984-2007.

5.1 Predictions of Individual Monthly TC Activity

A new aspect of our climate research is the development of TC activity predictions for individual months. On average, August, September and October have about 26%, 48%, and 17% or 91% of the total Atlantic basin NTC activity. August-only monthly forecasts have now been made for the past nine seasons, and September-only forecasts have been made for the last seven seasons. This is the sixth 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. These efforts have been documented in our August, September and October forecasts for this year.

Quite skillful August-only, September-only and October-only prediction schemes have been developed based on 60 years (1948-2007) of hindcast testing using a statistically independent jackknife approach. Predictors are derived from the months immediately proceeding the month being forecast. For example, the September forecast would include predictors utilizing the months of July and August.

5.2 August-only 2008 Forecast

Our August 2008 forecast called for well above-average NTC activity. August 2008 witnessed slightly above-average activity (Table 6). We have now correctly predicted above- or below-average August NTC in seven out of nine years (Table 7) and have had a smaller forecast error than climatology in six out of nine years. Forecast error standard deviations are provided based upon cross-validated hindcast errors over the 1948-2007 period. Although not our most accurate forecast, both observed ACE and observed NTC lie barely outside one standard deviation of our forecast value.

Table 6: CSU forecast and verification of August-only hurricane activity. Error bars are provided based upon one standard deviation of cross-validated forecast errors over the 1948-2007 hindcast period.

Tropical Cyclone Parameters and 1950-2000 August Average (in parentheses)	August 2008 Forecast	August 2008 Verification
Named Storms (NS) (2.8)	4 (±1.1)	4
Named Storm Days (NSD) (11.8)	20 (±4.4)	19.75
Hurricanes (H) (1.6)	3 (±0.8)	1
Hurricane Days (HD) (5.7)	10 (±3.2)	3
Intense Hurricanes (IH) (0.6)	1 (±0.4)	1
Intense Hurricane Days (IHD) (1.2)	3 (±1.5)	1.50
Accumulated Cyclone Energy (ACE) (24)	40 (±13)	26
Net Tropical Cyclone Activity (NTC) (26)	45 (±13)	31

Table 7: Predicted, observed, and climatological NTC for our nine August-only forecasts of 2000-2007. Years where we have correctly predicted an above- or below-average August are in bold-faced type.

Year	Observed NTC	Predicted NTC	Climatological NTC
2000	**42**	**33**	**26**
2001	**9**	**22**	**26**
2002	**7**	**18**	**26**
2003	26	22	26
2004	**89**	**35**	**26**
2005	**41**	**50**	**26**
2006	12	50	26
2007	**35**	**32**	**26**
2008	**31**	**45**	**26**

August 2008 was characterized by a very slow first half of the month with just one weak tropical storm forming (Edouard). However, the second half of August was very active with three formations (Gustav, Hanna and Ike). We attribute the quiet first half of the month and active second half of the month to fairly strong Madden-Julian Oscillation (MJO) activity which took place during the month. When investigating an aggregate measure such as NTC, August 2008 had slightly above-average activity.

From a large-scale perspective, atmospheric and oceanic conditions were generally favorable for an active month. Sea level pressures were quite low (Figure 3). Typically, low sea level pressures lead to active Atlantic basin hurricane seasons through an implied increase in instability and weaker-than-normal trades. August sea level pressures across the tropical Atlantic were estimated to be near their lowest values since 1948. The only August with SLP anomalies comparable to August 2008 was August 1955. August 1955 had the third most NTC on record for the month, trailing only August 2004 and August 1893.

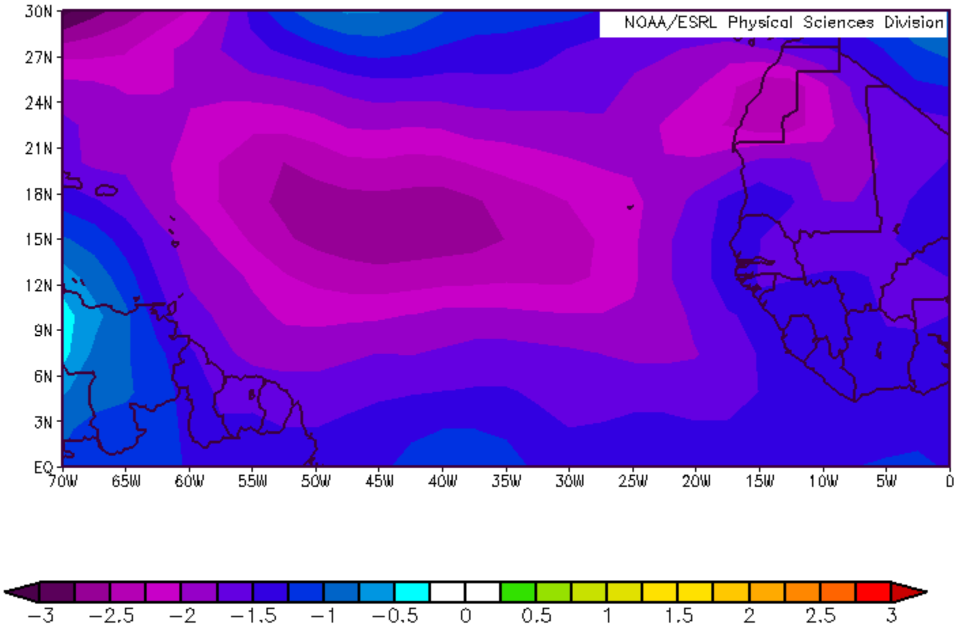


Figure 3: Tropical Atlantic sea level pressure anomalies during August.

Vertical wind shear values across the tropical Atlantic were at about average values (Figure 4) according to CIRA's real-time genesis parameter (DeMaria et al. 2001) during the month of August. Low-level trade winds were weaker than normal, while upper-level westerlies were slightly stronger than normal.

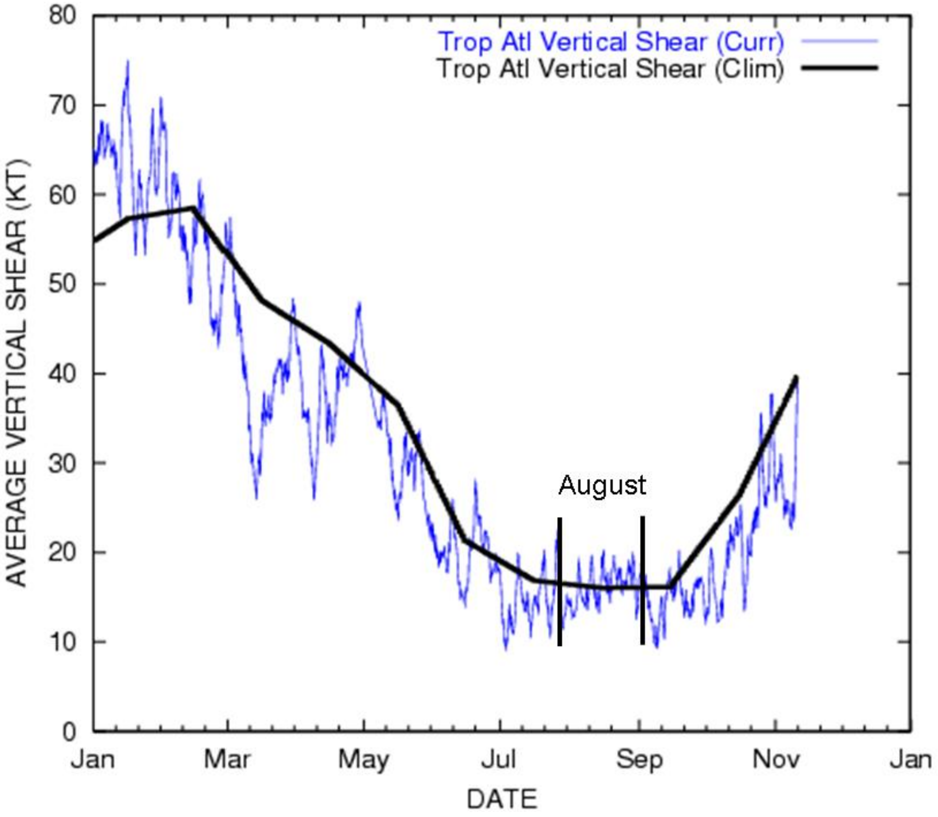


Figure 4: Tropical Atlantic vertical shear. Figure courtesy of the Cooperative Institute for Research in the Atmosphere (CIRA). Values of vertical wind shear during August were near their long-period average values.

5.3 September-only 2008 Forecast

Our September 2008 forecast called for well above-average NTC activity. September 2008 did have above-average activity but not to the level that we predicted (Table 8). We have now correctly predicted above- or below-average September NTC in six out of the last seven years. Forecast error standard deviations are provided based upon cross-validated hindcast errors over the 1948-2007 period.

Although not our most accurate forecast, both ACE and NTC were at above-average levels in September 2008. A more in-depth analysis of the atmospheric and oceanic conditions that were present during September 2008 follows.

Table 8: CSU forecast and verification of September-only hurricane activity made in early September. Error bars are provided (in parentheses) based upon one standard deviation of cross-validated hindcast errors over the 1948-2007 period.

Tropical Cyclone Parameters and 1950-2000 September Average (in parentheses)	September 2008 Forecast	September 2008 Verification
Named Storms (NS) (3.4)	5 (±1.3)	4
Named Storm Days (NSD) (21.7)	35 (±9.0)	29.00
Hurricanes (H) (2.4)	4 (±1.1)	3
Hurricane Days (HD) (12.3)	20 (±5.6)	13.00
Intense Hurricanes (IH) (1.3)	2 (±0.7)	1
Intense Hurricane Days (IHD) (3.0)	8 (±2.7)	4.50
Accumulated Cyclone Energy (ACE) (48)	85 (±22)	59
Net Tropical Cyclone Activity (NTC) (48)	90 (±18)	56

The early portion of September was very active, with Ike forming on the first of the month and Josephine on the second of the month. Gustav made landfall as a strong Category 2 storm in central Louisiana on September 1. Hanna intensified into a hurricane during the early part of September, bringing torrential rains and flooding to Hispaniola before making landfall near Myrtle Beach, SC as a strong tropical storm on September 6. Ike reached Category 4 status and brought devastation to both the Turks and Caicos Islands and Cuba as it tracked through the northern Caribbean. Ike also exacerbated already devastating flooding from Hanna in Hispaniola. Following weakening over Cuba, Ike re-strengthened to a Category 2 hurricane and became a very large tropical cyclone in the northern Gulf of Mexico. Ike made landfall near Galveston Island early on September 12, causing extensive damage and destruction in the eastern part of Texas. Despite the active season that occurred, a significant lull in storm formations occurred during September. Between Josephine that formed on September 2 and Kyle who formed on September 25, no tropical cyclones developed. This is unusual, considering that the three-week period during the middle of September is typically the most active period for storm formations in the Atlantic. However, very active seasons in the past have had similar types of lulls in September. For example, only one storm (Hurricane Marilyn) formed between August 27 and September 26 in 1995, which had a total of nineteen named storms and eleven hurricanes. A full discussion of intra-seasonal variability in the 2008 hurricane season is provided in Section 7.2.

In general, large-scale conditions favored an active month in September. Figures 5 and 6 display September sea level pressure anomalies and September sea surface temperature anomalies, respectively. When comparing conditions in September with those in August, pressure anomalies remained below average in September, while sea surface temperature anomalies warmed somewhat during September. The Tropical North Atlantic (TNA) index of sea surface temperatures (5.5°N-23.5°N, 57.5°W-15°W) increased from 0.39°C in August to 0.53°C in September.

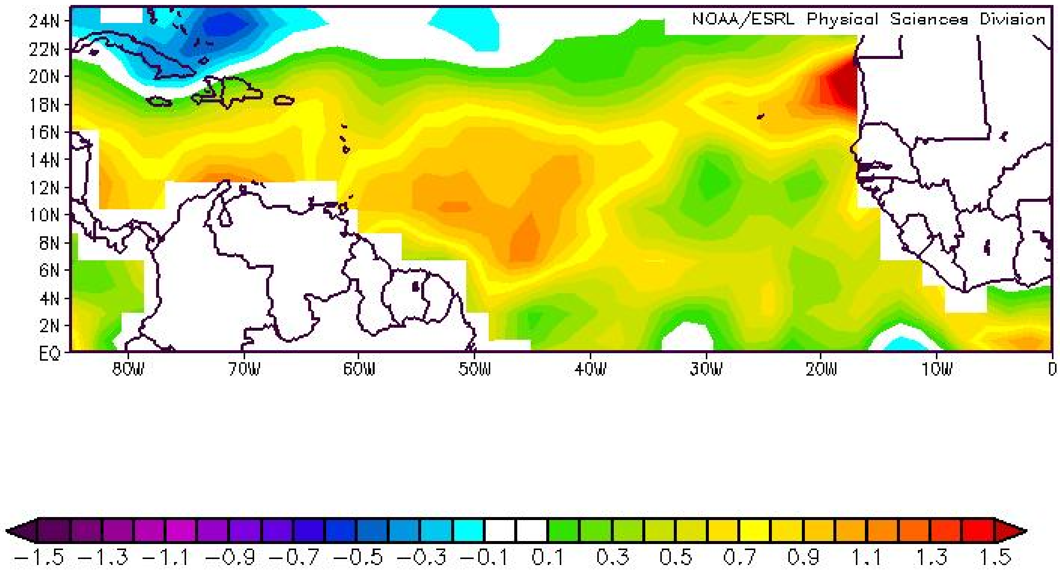


Figure 5: September SST anomalies over the tropical Atlantic.

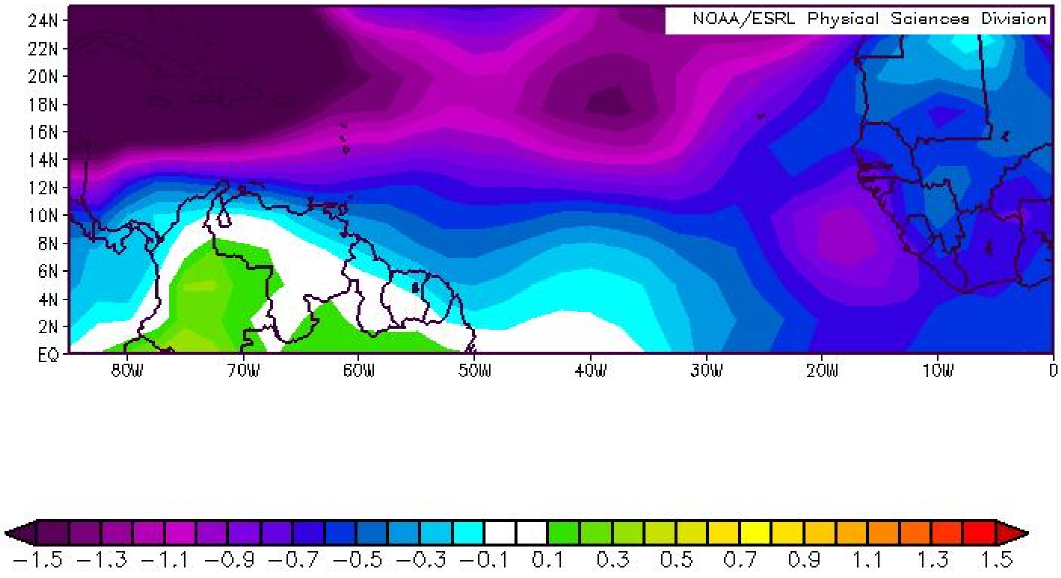


Figure 6: September SLP anomalies over the tropical Atlantic.

5.4 October 2008 Forecast

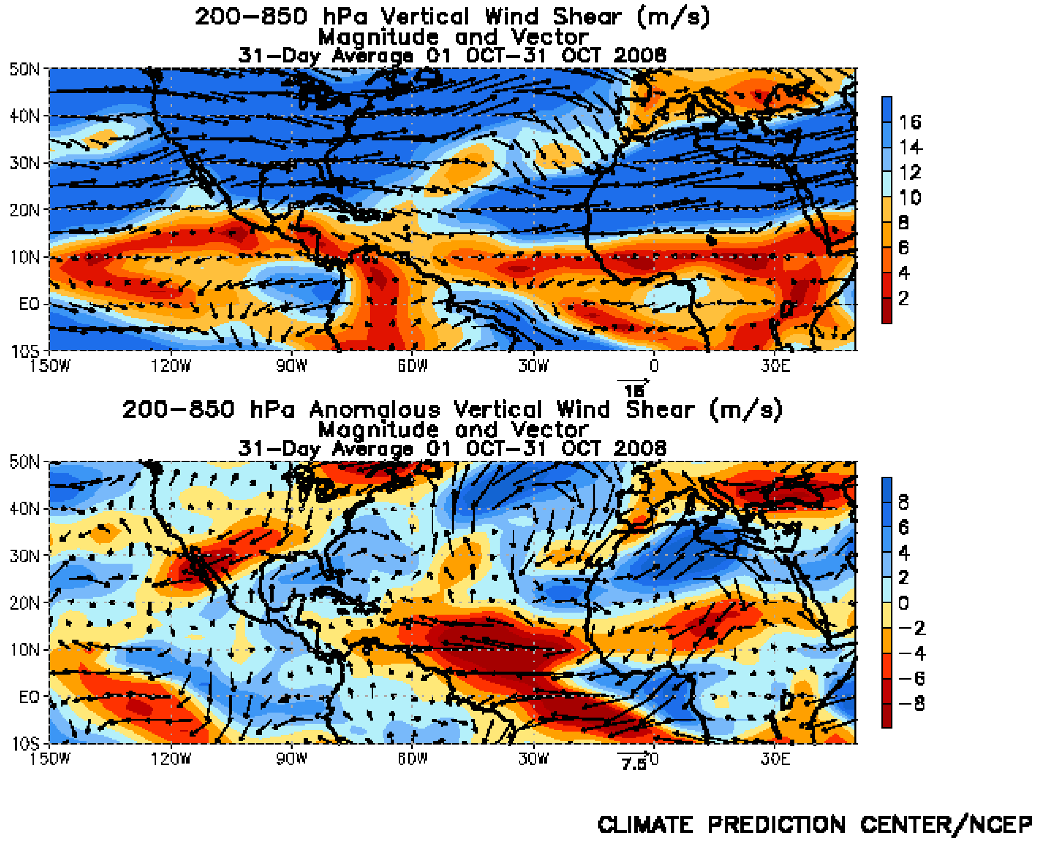
Our October 2008 forecast called for well above-average NTC activity. As was the case in August and September, October 2008 had slightly above-average activity, but not to the level that we predicted (Table 9). Forecast error standard deviations are provided based upon cross-validated hindcast errors over the 1948-2007 period. A more in-depth analysis of the atmospheric and oceanic conditions that were present during October 2008 follows.

Table 9: CSU forecast and verification of October-only hurricane activity made in early October. Error bars are provided (in parentheses) based upon one standard deviation of cross-validated hindcast errors over the 1948-2007 period.

Tropical Cyclone Parameters and 1950-2000 October Average (in parentheses)	October 2008 Forecast	October 2008 Verification
Named Storms (NS) (1.7)	3 (±1.1)	3
Named Storm Days (NSD) (9.0)	15 (±5.8)	6.75
Hurricanes (H) (1.1)	2 (±0.8)	1
Hurricane Days (HD) (4.4)	7 (±2.8)	2.25
Intense Hurricanes (IH) (0.3)	1 (±0.4)	1
Intense Hurricane Days (IHD) (0.8)	2 (±0.9)	0.50
Accumulated Cyclone Energy (ACE) (17)	30 (±10)	9
Net Tropical Cyclone Activity (NTC) (18)	35 (±10)	21

The early portion of October was quite active, with Marco, Nana and Omar forming during the first half of the month. Omar formed in the south-central Caribbean and rapidly intensified into a major hurricane on October 16. Omar caused moderate amounts of damage in the Lesser Antilles before weakening rapidly late on October 16.

Large-scale conditions remained quite favorable during October. Figure 7 displays vertical wind shear anomalies observed during October. Note the large area of anomalously weak shear across the Main Development Region of the tropical Atlantic that was present during October. Figure 8 displays sea surface temperature anomalies as observed on October 15. Note that the tropical Atlantic remained quite warm, likely due to the reduced trade winds observed throughout most of the summer and fall.


200–850 hPa Vertical Wind Shear (m/s)
Magnitude and Vector
31–Day Average 01 OCT–31 OCT 2008

200–850 hPa Anomalous Vertical Wind Shear (m/s)
Magnitude and Vector
31–Day Average 01 OCT–31 OCT 2008

CLIMATE PREDICTION CENTER/NCEP

Figure 7: October vertical wind shear anomalies across the Atlantic.

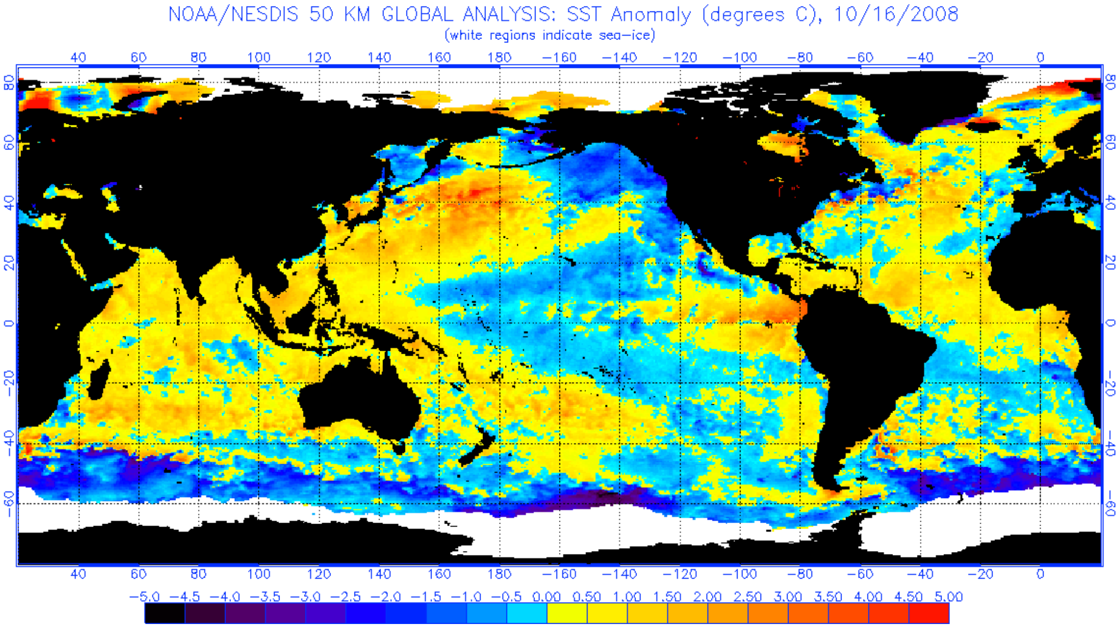

NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST Anomaly (degrees C), 10/16/2008
(white regions indicate sea–ice)

Figure 8: SST anomalies as observed on October 16.

6 U.S. Landfall Probabilities

6.1 2008 U.S. Landfall Probability Verification

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, probabilities have been calculated through a statistical analysis of all U.S. hurricane and named storm landfalls during a 100-year period (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions. Net landfall probability is statistically related to overall Atlantic basin Net Tropical Cyclone (NTC) activity and to climate trends linked to multi-decadal variations in North Atlantic SSTA. Table 10 gives verifications of our landfall probability estimates for 2008.

Landfall probabilities for the 2008 hurricane season were estimated to be well above their climatological averages due to our prediction for an active season. The 2008 hurricane season was very active from a U.S. landfall perspective, with three tropical storms and three Category 2 hurricanes making U.S. landfall this year: Hurricane Dolly, Tropical Storm Edouard, Tropical Storm Fay, Hurricane Gustav, Tropical Storm Hanna and Hurricane Ike. On average, the United States experiences approximately 3.6 named storm, 1.9 hurricane, and 0.7 major hurricane landfalls per year. Although no major hurricanes made landfall in 2008, two storms made landfall at just below major hurricane status (Gustav and Ike at 95 knots). As noted before, 2008 was one of the most destructive years on record from a damage perspective.

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

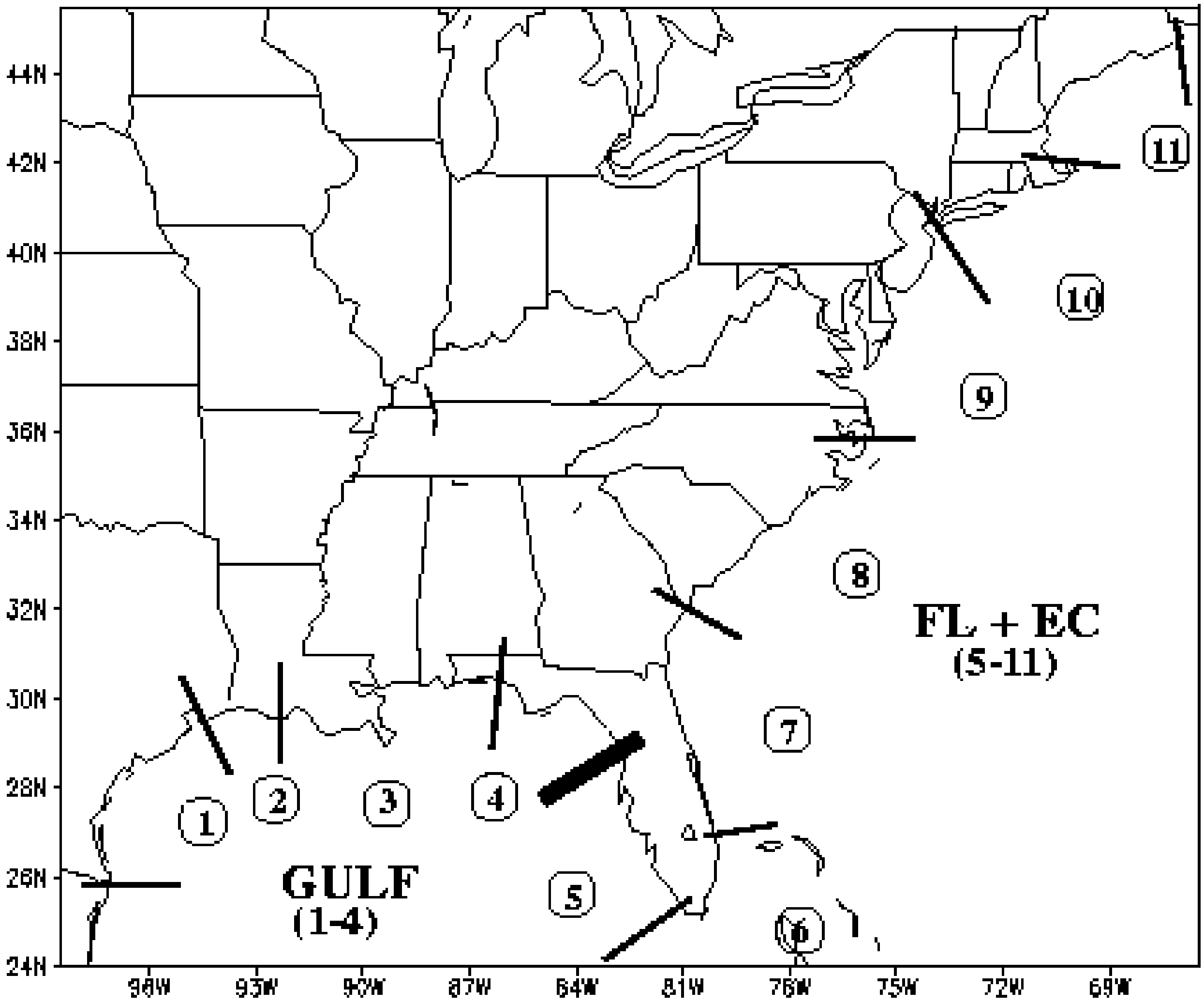


Figure 9: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

Table 10: Estimated forecast probability (percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes, and category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11) for 2008 at various lead times. The mean annual percentage of one or more landfalling systems during the 20th century is given in parentheses in the 5 August forecast column. Table (a) is for the entire United States, Table (b) is for the U.S. Gulf Coast, and Table (c) is for the Florida Peninsula and the East Coast. Early August probabilities are calculated based on storms forming after 1 August.

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

	Forecast Date				
	7 Dec.	9 Apr.	3 June	5 August	Observed Number
TS	86%	92%	92%	91% (80%)	3
HUR (Cat 1-2)	76%	84%	84%	82% (68%)	3
HUR (Cat 3-4-5)	60%	69%	69%	67% (52%)	0
All HUR	90%	95%	95%	94% (84%)	3
Named Storms	99%	99%	99%	99% (97%)	6

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

	Forecast Date				
	7 Dec.	9 Apr.	3 June	5 August	Observed Number
TS	67%	76%	76%	74% (59%)	1
HUR (Cat 1-2)	50%	59%	59%	57% (42%)	3
HUR (Cat 3-4-5)	36%	44%	44%	42% (30%)	0
All HUR	68%	77%	77%	75% (61%)	3
Named Storms	89%	94%	94%	94% (83%)	4

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

	Forecast Date				
	7 Dec.	9 Apr.	3 June	5 August	Observed Number
TS	58%	67%	67%	66% (51%)	2
HUR (Cat 1-2)	52%	60%	60%	59% (45%)	0
HUR (Cat 3-4-5)	37%	45%	45%	43% (31%)	0
All HUR	70%	78%	78%	77% (62%)	0
Named Storms	87%	93%	93%	92% (81%)	2

6.2 Interpretation of U.S. Landfall Probabilities

We never intended that our seasonal forecasts be used for individual-year landfall predictions. It is impossible to predict months in advance the mid-latitude flow patterns that dictate U.S. hurricane landfall. We only make predictions of the probability of U.S.

landfall. Our U.S. landfall probability estimates work out very well when we compare 4-5 of our forecasts for active seasons versus 4-5 forecasts for inactive seasons. This is especially the case for U.S. landfalling major hurricanes.

<u>High seasonal forecasts of Net Tropical Cyclone activity (NTC) (see Table 11) should be interpreted only as a higher probability of U.S. landfall but not necessarily that landfall will occur that year. Low seasonal forecasts of NTC do not mean that landfall will not occur but only that its probability is lower than average during that year.</u>

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

Table 11 gives observed high to low ranking of NTC of the last 58 (1950-2007) years in association with U.S. landfall frequency. Data is broken into numbers of U.S. landfalling tropical storms (TS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (IH). Note that high NTC years have increased U.S. hurricane landfall numbers, particularly for major hurricanes.

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

Table 12 contrasts the observed U.S. landfall ratios associated with our high vs. low 1 June NTC hindcast values for the years of 1950-2007. This table also contrasts the upper 10, upper 20 and upper 29 (half of data set) hindcast NTC values vs. the lowest 10, lowest 20 and lowest 29 hindcast NTC values. Note the very high ratio of U.S. landfall differences between the highest and the lowest values of our 1 June NTC hindcasts. These hindcast differences are especially large for major (Cat 3-4-5) hurricanes which on a normalized (coastal population, inflation, wealth per capita) basis cause about 80-85 percent of U.S. hurricane spawned destruction. It is fortunate that our most skillful 1 June NTC hindcasts best differentiate between the most intense and most destructive U.S. landfalling hurricanes. Tropical storm landfall frequencies are not nearly as well related to our 1 June hindcast NTC values.

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

Table 11: Observed U.S. landfall of tropical storms (TS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (IH) by high versus low observed values of Net Tropical Cyclone (NTC) activity for the Gulf Coast, the Florida Peninsula and East Coast and the whole U.S. coastline for the 58-year period of 1950-2007.

	Gulf Coast (Regions 1-4)			Florida + East Coast (Regions 5-11)			Whole US (Regions 1-11)		
NTC Values	***TS***	***H***	***IH***	***TS***	***H***	***IH***	***TS***	***H***	***IH***
Top 10 Observed NTC years > 160	11	8	6	9	11	9	20	19	15
Bot 10 Observed NTC years ≤ 50	7	3	1	7	4	0	14	7	1
Top 20 Observed NTC years > 117	18	12	9	14	18	13	32	30	22
Bot 20 Observed NTC years ≤ 82	19	6	5	10	5	3	29	11	8
Top 29 Observed NTC years ≥ 93	23	19	10	26	23	16	49	42	26
Bot 29 Observed NTC years ≤ 93	26	10	9	17	10	6	43	20	15

Table 12: Observed U.S. landfall of tropical storms (TS), Cat 1-2 hurricanes (H) and Cat 3-4-5 hurricanes (IH) based on 1 June hindcasts of NTC for the 58-year period from 1950-2007.

	Gulf Coast (Regions 1-4)			Florida + East Coast (Regions 5-11)			Whole US (Regions 1-11)		
NTC Values	***TS***	***H***	***IH***	***TS***	***H***	***IH***	***TS***	***H***	***IH***
Top 10 hindcast NTC years > 160	8	5	3	8	19	10	16	24	13
Bot 10 hindcast NTC years ≤ 50	4	5	2	8	5	0	12	10	2
Top 20 hindcast NTC years > 117	18	7	6	16	24	13	34	31	19
Bot 20 hindcast NTC years ≤ 82	12	9	6	15	10	1	27	19	7
Top 29 hindcast NTC years ≥ 93	26	13	8	22	21	19	48	34	27
Bot 29 hindcast NTC years ≤ 93	23	16	11	21	12	3	44	28	14

But more important than our last 24 years of early June forecasts of the numbers of NS and H is the implication of what these forecasts say as to the probability of U.S. landfall. Higher than average 1 June forecasts of NS and H are associated with a greater frequency of NS and H U.S. landfall events and lower 1 June forecasts of NS and H have been associated with less frequent landfall.

Table 13 shows the number of U.S. landfalling tropical cyclones which occurred in 9 of the last 24 years when our real time project's 1 June prediction of the number of hurricanes was 8 or higher versus those 9 years when our 1 June prediction of the seasonal number of hurricanes was 6 or less. Notice the 3 to 1 difference in landfall of major hurricanes and the nearly 2 to 1 difference in landfalling Cat 1-2 hurricanes.

Table 13: Number of U.S. landfalling tropical cyclones in the 9 years when our 1 June forecast was for 8 or more hurricanes vs. the 9 years when our forecast was for 6 or less hurricanes.

Forecast H	NS	H	IH	Atlantic basin H
≥ 8 (9 years)	50	28	12	76
≤ 6 (9 years)	32	15	4	48

High vs. Low Forecast Atlantic Basin Named Storms (NS)

We also find large differences in U.S. landfalling tropical cyclone numbers in the 6 years when our real-time 1 June forecast of named storms was 14 or higher vs. the 6 years when our 1 June named storm forecast was 9 or less (Table 14). Note the large U.S. landfalling frequency differences, especially for intense hurricanes (IH).

Table 14: U.S. tropical cyclone landfalls occurring following our 6 of 24 years of 1 June forecasts of 14 or more NS in comparison with our 6 of 24 years of NS forecasts of 9 or fewer NS.

Forecast NS	NS	H	IH	Atlantic basin NS
≥ 14 (6 years)	33	18	8	94
≤ 9 (6 years)	15	9	3	45

Our individual season forecasts of the last 24 years have had meaning as regards to the multi-year probability of US landfall. Higher statistical relationships are found with our real-time forecasts from 1 August. We also find only slightly less hindcast landfall skill associated with our newly developed extended-range early December and early April predictions of NTC.

7 Summary of 2008 Atmospheric/Oceanic Conditions

In this section, we go into detail discussing large-scale conditions that were present in the atmosphere and in the ocean during the 2008 Atlantic basin hurricane season.

7.1 ENSO

El Niño-Southern Oscillation (ENSO) was one of the biggest challenges in our 2008 hurricane forecast. We discussed extensively in our seasonal forecasts about the potential for the development of a warm El Niño event during this summer and fall. We successfully predicted that ENSO would not develop during this year's hurricane season.

Following La Niña conditions during the winter of 2007-2008, ENSO warmed considerably during the spring and summer, reaching warm neutral conditions by August 2008. However, unlike what occurred in 2006 when the late spring and early summer warming continued and an El Niño developed and put a significant damper on activity, the initial warming this year abated, retreating to cool neutral conditions by the end of October. Table 15 displays SST anomalies in the four Nino regions during April, July and October, respectively. Note the considerable warming that occurred from April to July and the cooling that occurred from July to October. Also note that we had a very strong anomalous SST gradient from the eastern Pacific to the central Pacific (Nino 1+2 – Nino 4) in April (+1.4°C) and July (+1.1°C). This anomalous SST gradient had been eradicated by October. One of the primary reasons why we believe that El Niño conditions were not able to establish themselves this summer and fall was due to the anomalously strong trades that persisted near the date line over the past few months (Figure 10). Strong trades encourage mixing, upwelling and help to diminish the impact that eastward propagating Kelvin waves have at warming the mixed layer.

Table 15: April anomalies, July anomalies, October anomalies, the difference between April and July anomalies, and the difference between July and October anomalies, respectively.

Region	April Anomaly (ºC)	July Anomaly (ºC)	October Anomaly (ºC)	July – April Anomaly (ºC)	October-July Anomaly (ºC)
Nino 1+2	+0.4	+0.8	-0.3	+0.4	-1.1
Nino 3	-0.2	+0.6	-0.1	+0.8	-0.7
Nino 3.4	-0.9	+0.1	-0.2	+1.0	-0.3
Nino 4	-1.0	-0.3	-0.2	+0.7	+0.1

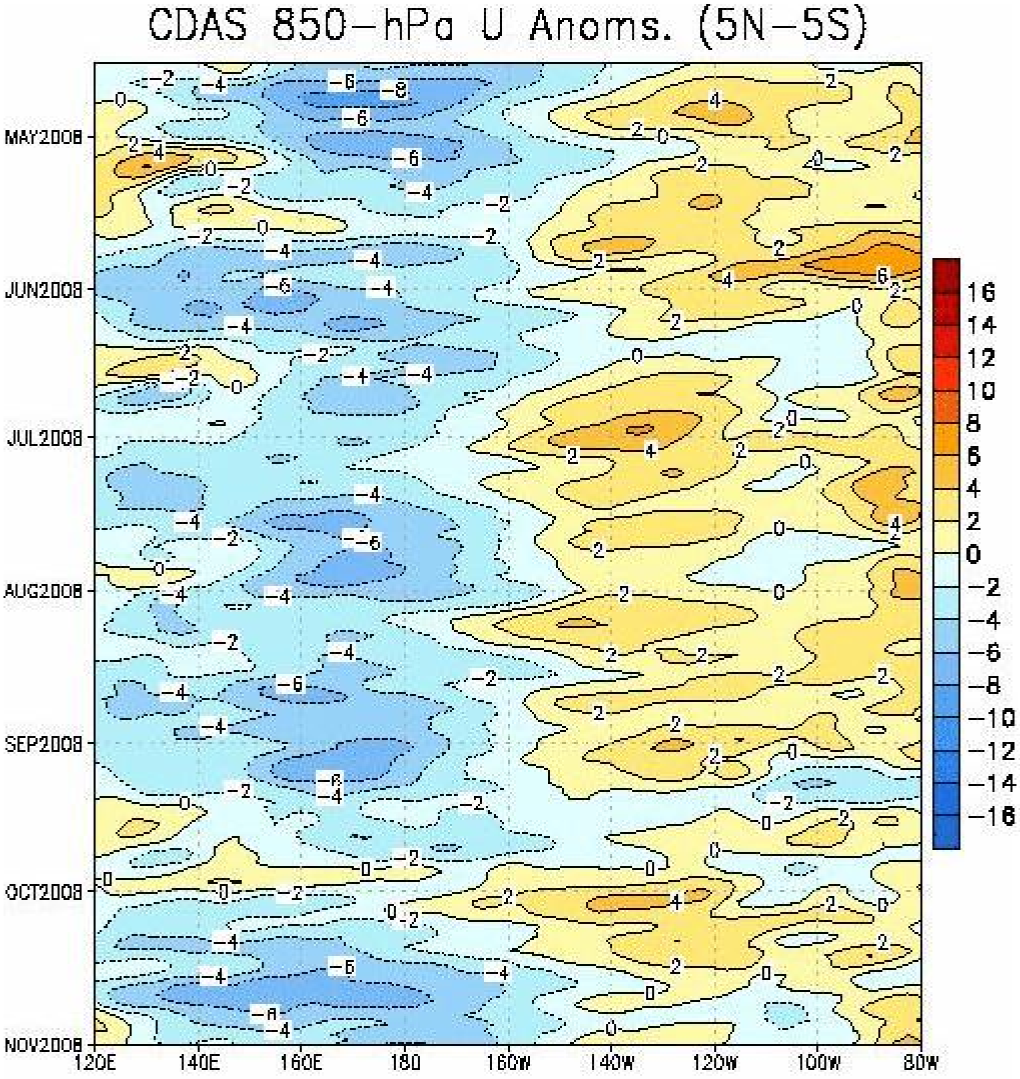


Figure 10: Time-longitude plot of 850-mb zonal winds across the tropical Pacific. Note the anomalous easterly flow that persisted near the dateline from April – October of 2008.

7.2 Intra-Seasonal Variability

Intra-seasonal variability was a predominant characteristic of this year’s hurricane season. Very active periods of TC activity were followed by periods with very little activity. One of the primary reasons why we believe there was a pronounced lull during the climatologically most active portion of the hurricane season was due to the convectively-capped phase of the Madden-Julian Oscillation (MJO) that dominated the Atlantic for most of the month of September. Evidence of the reduction in convection over the tropical Atlantic can be seen by examining a time series of cold pixel count (a measure of deep convection) from the Cooperative Institute for Research in the Atmosphere (Figure 11). Note that, in general, there was much-reduced convection over the tropical Atlantic during September of this year when compared with August of this year.

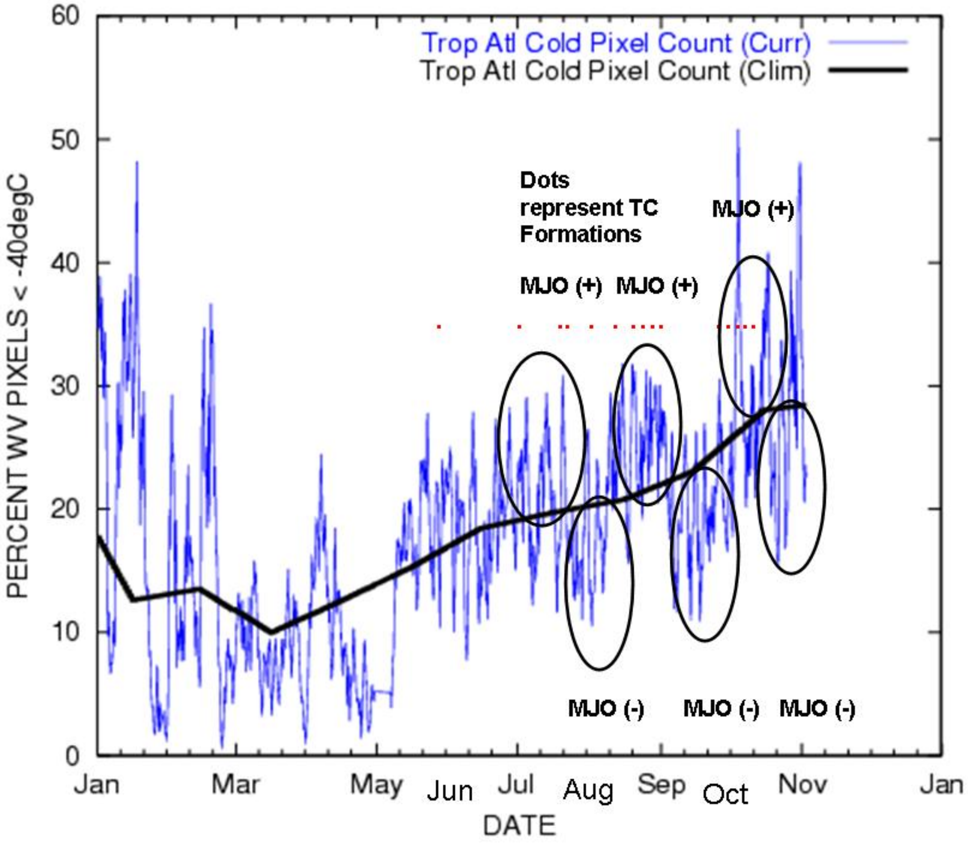


Figure 11: Tropical Atlantic cold pixel count. Figure adapted from an original provided by the Cooperative Institute for Research in the Atmosphere (CIRA).

This was one of those years where the 40-50 day MJO appears to have had a prominent influence on Atlantic basin hurricane activity. The MJO modifies TC formation conditions through a general enhancement and suppression of tropical Atlantic subsidence as shown in Figure 11. More cold pixels imply weaker subsidence and more hurricane activity.

The apparent strong influence of the MJO observed in the difference in upper-level velocity potential anomalies between an inactive MJO phase (Figure 12) and an active MJO phase (Figure 13) appeared to play an important role this year in explaining why we have seen such a strong time clustering of tropical cyclones. During the 18-day period from 3 July to 20 July, 3 named storms formed including major hurricane Bertha, the longest-lived tropical cyclone on record for the month of July. Over the 24-day period between 21 July and 14 August, only one short-lived tropical storm formed (Edouard). In the 22-day period between 3 September and 24 September, no named storms formed in the Atlantic (Figure 12), due largely to upper-level convergence dominating the tropical Atlantic. From 25 September to October 14, 5 named storms, 2 hurricanes and 1 major hurricane formed. From October 14 through the end of the month of October, no named storms formed. Table 16 summarizes the strong time clustering of this year's storms during July-October.

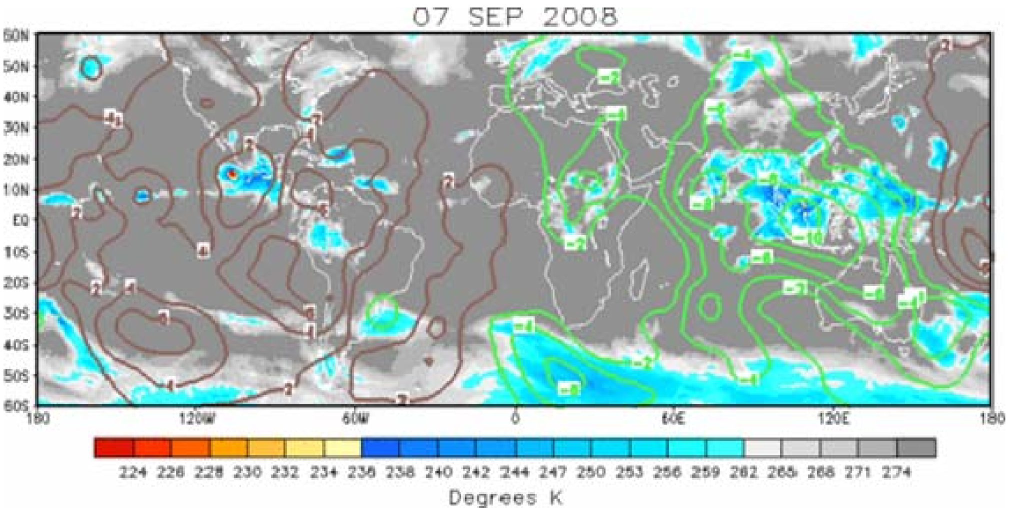


Figure 12: Upper-level velocity potential anomalies as observed on September 7, 2008. Note that anomalous upper-level convergence dominated the tropical Atlantic, as evidenced by the brown colors over the tropical Atlantic. This led to a three-week suppression of hurricane activity during the middle of September.

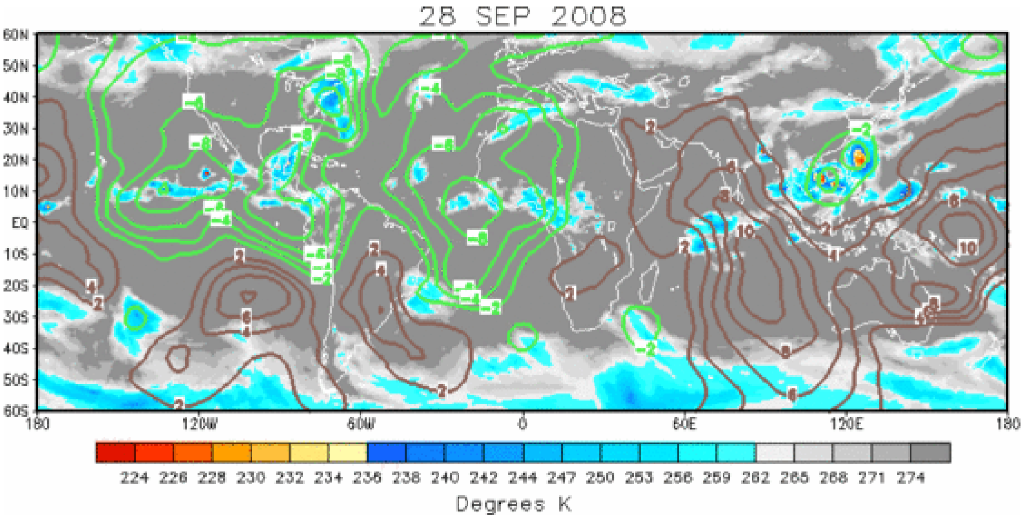


Figure 13: Upper-level velocity potential anomalies as observed on September 28, 2008. Green colors correspond to upper-level divergence which promotes convection and enhances hurricane activity.

Table 16: Illustration of how 2008 Atlantic named storm formations during July-October clustered into three distinct active periods of 56 days (13 formations occurred) and three distinct inactive periods of 64 days (1 formation occurred).

Period	Named Storm Formations	MJO Phase
July 3 – 20 (18 Days)	3	**Positive**
July 21 – August 14 (25 Days)	1	Negative
August 15 – September 2 (18 Days)	5	**Positive**
September 3 – September 24 (22 Days)	0	Negative
September 25 – October 14 (20 Days)	5	**Positive**
October 15 – October 31 (17 Days)	0	Negative

7.3 Tropical Atlantic SST

The tropical Atlantic underwent anomalous warming during this year's hurricane season. We believe that the primary reason why this occurred was due to the fact that trade wind strength across the tropical Atlantic was well below average (Figure 14). Weaker trades imply less mixing and upwelling, typically leading to anomalous warming. African dust outbreaks during June-September were at near-average levels, providing neither a large warming or cooling impact on this season's tropical Atlantic SSTs.

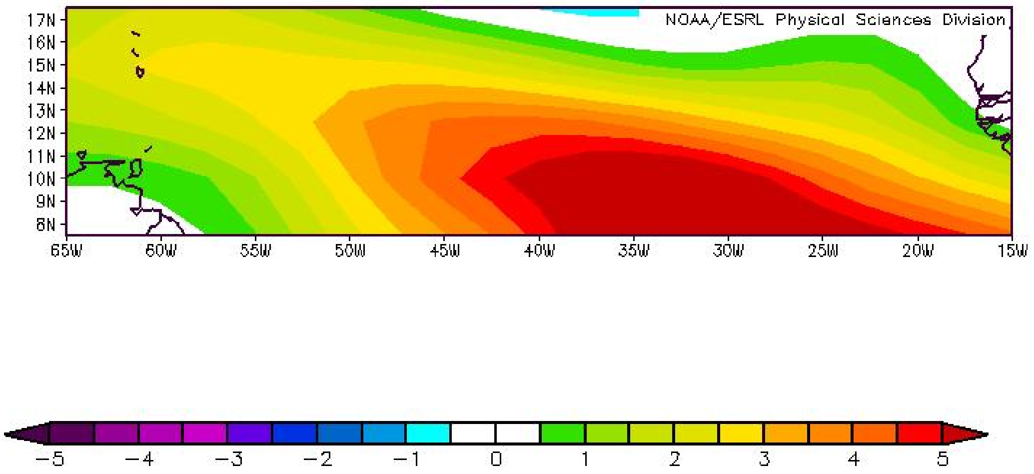


Figure 14: Anomalous August-October 850 mb zonal winds across the tropical Atlantic. Note that winds are anomalously out of the west, implying weaker trades.

Figure 15 displays the anomalous warming that took place from July to October. According to the Tropical North Atlantic (TNA) SST index (5.5°N-23.5°N, 57.5°W-15°W), anomalous values increased approximately 0.4°C from July to October (Table 17).

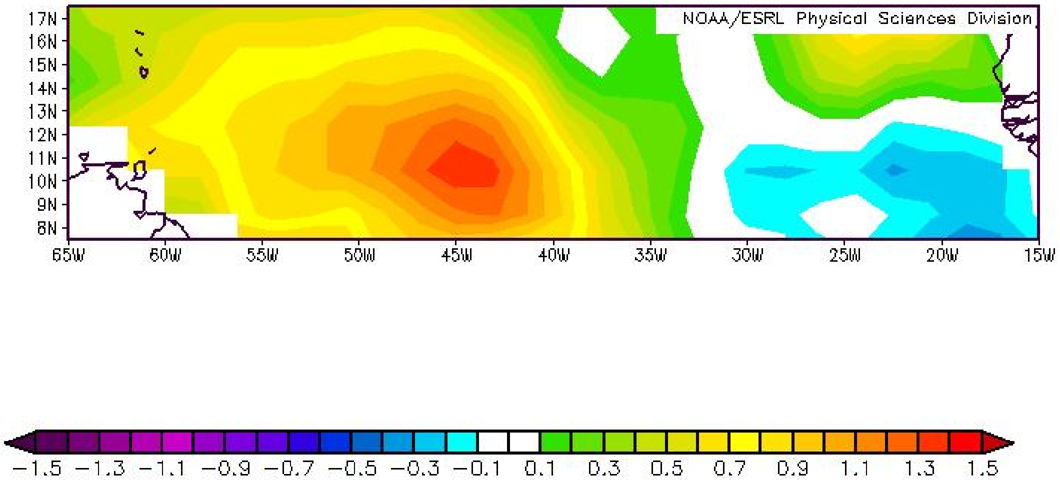


Figure 15: Anomalous tropical Atlantic SST changes from July to October in the Main Development Region (MDR). In general, the tropical Atlantic warmed considerably during this time period.

Table 17: TNA SST index (5.5°N-23.5°N, 57.5°W-15°W) values from July – October. Note the anomalous warming that took place.

Month	TNA Index (°C)
July	+0.29
August	+0.39
September	+0.53
October	+0.55

7.4 Tropical Atlantic SLP

Tropical Atlantic sea level pressure values are another important parameter to consider when evaluating likely tropical cyclone activity in the Atlantic basin. Lower-than-normal sea level pressures across the tropical Atlantic imply increased instability, increased low-level moisture, and conditions that are generally favorable for tropical cyclone development and intensification. Figure 16 displays August-October 2008 tropical and sub-tropical sea level pressure anomalies in the North Atlantic. Below-average anomalies dominate the basin. Across the Main Development Region (MDR) (10°N-20°N, 70°W-20°W), sea level pressure anomalies were at near-record low levels. According to the NCEP reanalysis which began in 1948, the only year with lower sea level pressures across the MDR in August-October was 1955.

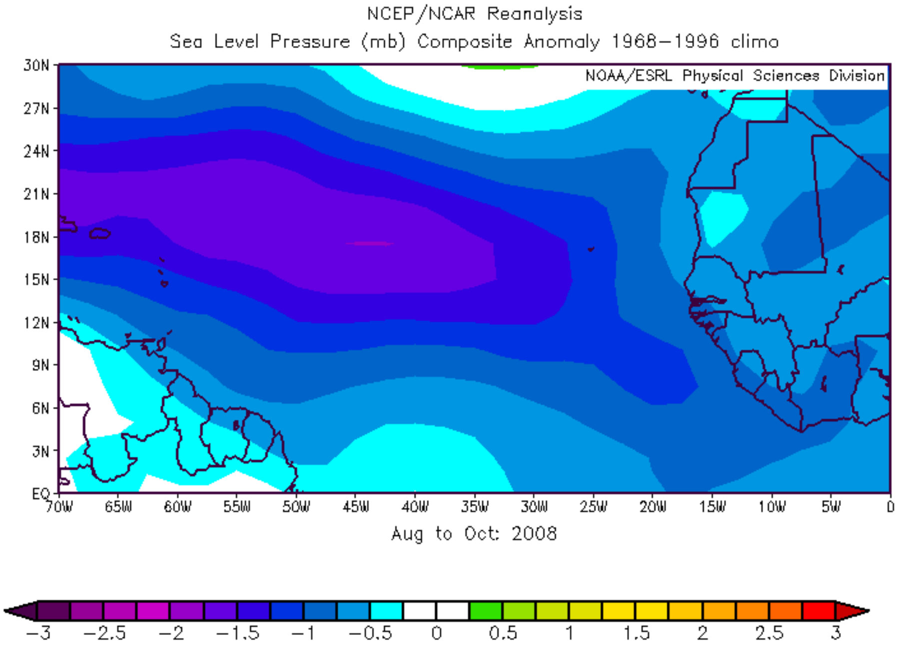
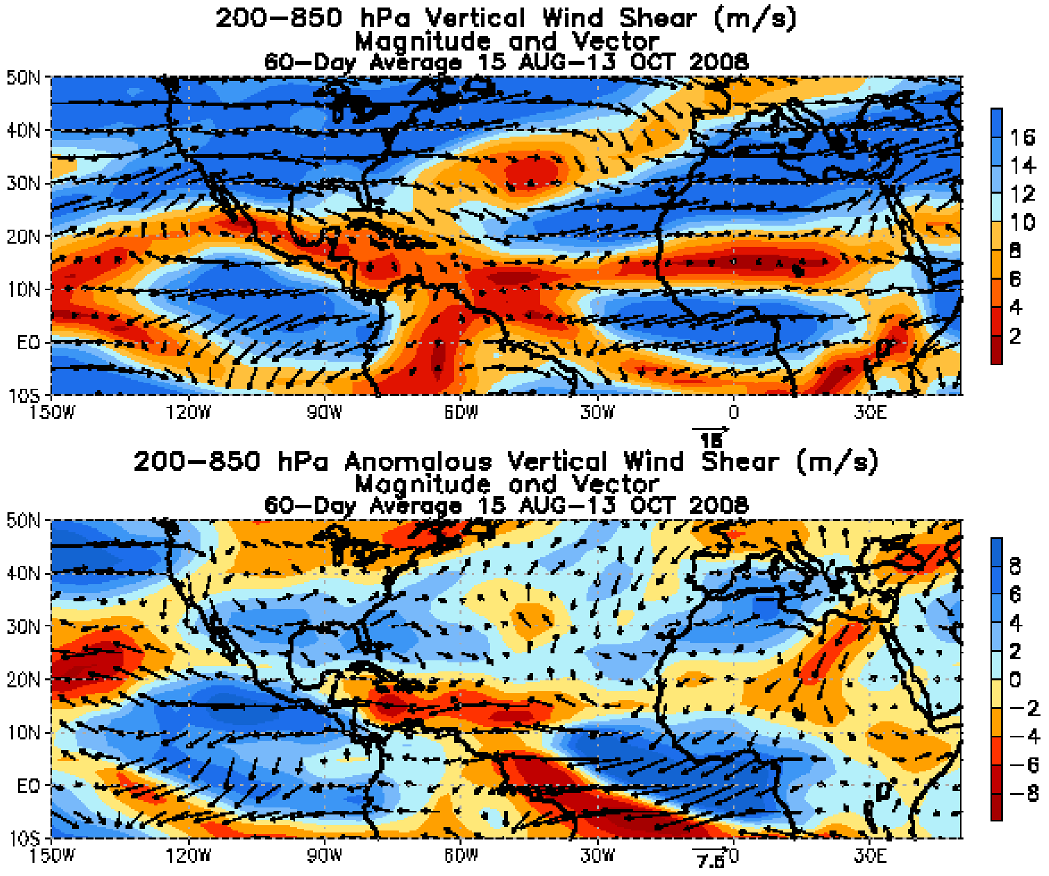


Figure 16: August-October 2008 tropical and sub-tropical North Atlantic sea level pressure anomalies. Sea level pressure anomalies were at near-record low levels.

7.5 Tropical Atlantic Vertical Wind Shear

Tropical Atlantic vertical wind shear is a critical component in determining the level of tropical cyclone activity experienced in the Atlantic basin. Excessive levels of vertical wind shear inhibit tropical cyclone development and intensification by tilting the vortex and reducing the ability of the system to develop a warm core. Vertical wind shear during the climatologically most active portion of the hurricane season (from mid-August through mid-October) was at below-average levels (Figure 17). These levels of reduced vertical wind shear likely helped contribute to the active hurricane season that was experienced in 2008.



200–850 hPa Vertical Wind Shear (m/s)
Magnitude and Vector
60–Day Average 15 AUG–13 OCT 2008

200–850 hPa Anomalous Vertical Wind Shear (m/s)
Magnitude and Vector
60–Day Average 15 AUG–13 OCT 2008

CLIMATE PREDICTION CENTER/NCEP

Figure 17: Total and anomalous vertical wind shear as observed across the Atlantic from August 15 – October 13. Note that vertical wind shear was reduced by approximately 2-6 ms^{-1} across most of the MDR.

7.6 Steering Currents

Several storms impacted the United States from the latter part of August through the middle portion of September. One of the reasons was due to the presence of a fairly strong mid-latitude ridge that steered these storms west and inhibited early recurvature into the westerlies. Figure 18 displays the 500 mb height anomaly pattern that was present across the Atlantic from August 15 – September 15.

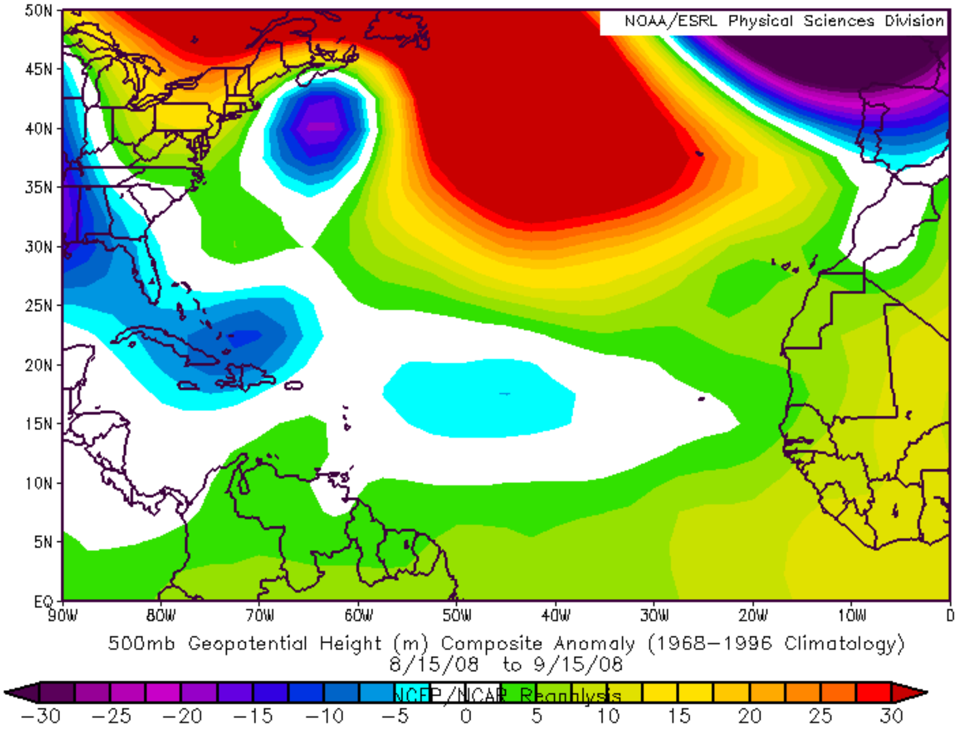


Figure 18: 500 mb height anomalies across the Atlantic from August 15 – September 15.

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

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

The global warming arguments have been given much attention by many media references to recent papers claiming to show such a linkage. Despite the global warming of the sea surface that has taken place over the last 3 decades, the global numbers of hurricanes and their intensity have not shown increases in recent years except for the Atlantic (Klotzbach 2006).

The Atlantic has seen a very large increase in major hurricanes during the 14-year period of 1995-2008 (average 3.9 per year) in comparison to the prior 25-year period of 1970-1994 (average 1.5 per year). This large increase in Atlantic major hurricanes is primarily a result of the multi-decadal increase in the Atlantic Ocean thermohaline circulation (THC) that is not directly related to global sea surface temperatures or CO_2 gas increases. Changes in ocean salinity are believed to be the driving mechanism. These multi-decadal changes have also been termed the Atlantic Multidecadal Oscillation (AMO).

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

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the sea surface temperatures. Vertical lapse rates will not be significantly altered. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will change significantly if global ocean temperatures were to continue to rise. For instance, in the quarter-century period from 1945-1969 when the globe was undergoing a weak cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period from 1970-1994 when the globe was undergoing a general warming trend, there were only 38 major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 19). Atlantic sea surface temperatures and hurricane activity do not necessarily follow global mean temperature trends.

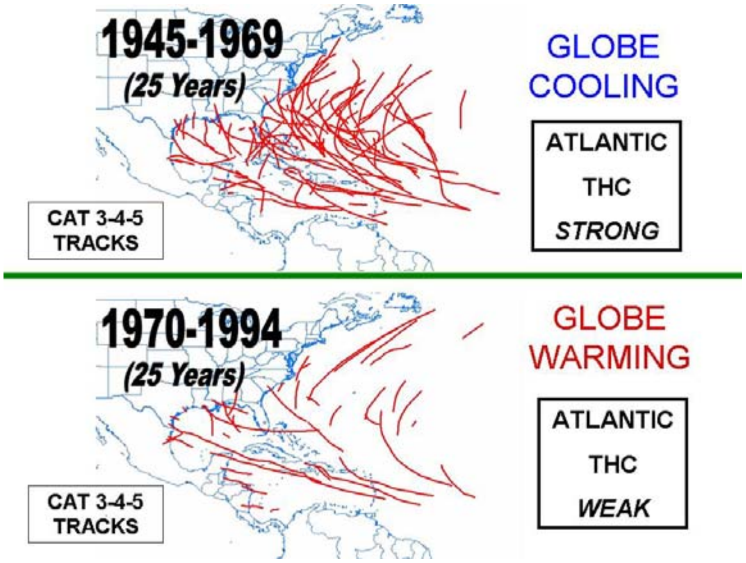


Figure 19: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was less than 1/2 as frequent during the latter period despite warmer global temperatures.

The most reliable long-period hurricane records we have are the measurements of US landfalling tropical cyclones since 1900 (Table 18). Although global mean ocean and Atlantic sea surface temperatures have increased by about 0.4°C between these two 50-year periods (1900-1949 compared with 1959-2008), the frequency of US landfall numbers actually shows a slight downward trend for the later period. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 43-year period of 1923-1965 (24 landfall events) and the 43-year period of 1966-2008 (7 landfall events) was especially large (Figure 20). For the entire United States coastline, 39 major hurricanes made landfall during the earlier 43-year period (1923-1965) compared with only 22 for the latter 43-year period (1966-2008). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period (Figure 21). This figure illustrates that caution must be used when extrapolating trends into the future. Obviously, U.S. major hurricane landfalls will continue.

Table 18: U.S. landfalling tropical cyclones by intensity during two 50-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Intense Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1900-1949 (50 years)	189	101	39	+0.4°C
1959-2008 (50 years)	167	85	33	

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

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

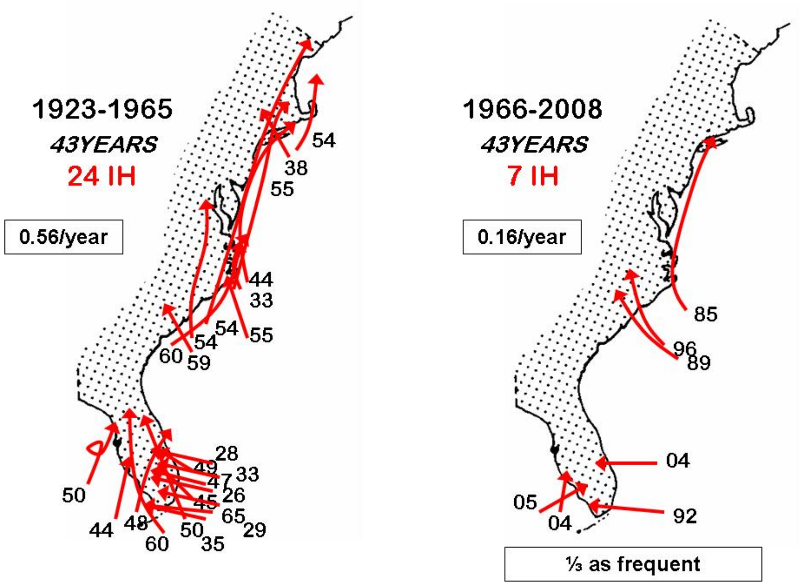


Figure 20: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 43-year period of 1923-1965 versus the most recent 43-year period of 1966-2008.

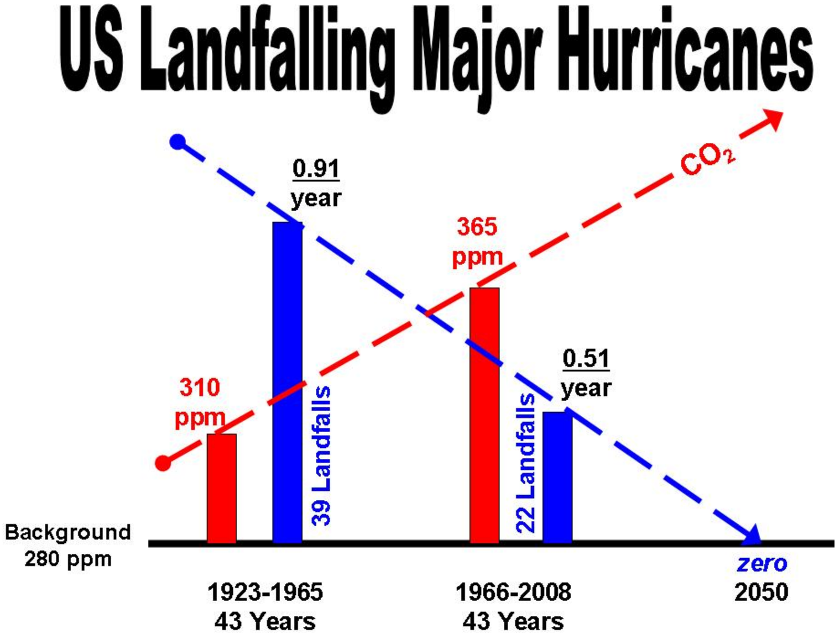


Figure 21: Portrayal of decreasing US total major hurricane landfalls over the last 43 years despite a mean rise in atmospheric CO_2. This figure illustrates that caution must be used when extrapolating trends into the future. Obviously, U.S. major hurricane landfalls will continue.

Although 2005 had a record number of tropical cyclones (28 named storms, 15 hurricanes and 7 major hurricanes), this should not be taken as an indication of something beyond natural processes. There have been several other years with comparable hurricane activity to 2005. For instance, 1933 had 21 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 named storm had tracks west of 60^oW where surface observations were more plentiful. If we eliminate all the named storms of 2005 whose tracks were entirely east of 60^oW and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storm total by seven (to 21) – the same number as was observed to occur in 1933.

Utilizing the National Hurricanes Center's best track database of hurricane records back to 1875, six previous seasons had more hurricane days than the 2005 season. These years were 1878, 1893, 1926, 1933, 1950 and 1995. Also, five prior seasons (1893, 1926, 1950, 1961 and 2004) had more major hurricane days. Although the 2005 hurricane season was certainly one of the most active on record, it was not as much of an outlier as many have indicated.

The active hurricane season in 2008 lends further support to the belief that the Atlantic basin remains in an active hurricane cycle associated with a strong thermohaline circulation and an active phase of the Atlantic Multidecadal Oscillation (AMO). This active cycle is expected to continue for another decade or two at which time we should enter a quieter Atlantic major hurricane period like we experienced during the quarter-century periods of 1970-1994 and 1901-1925. Atlantic hurricanes go through multi-decadal cycles. Cycles in Atlantic major hurricanes have been observationally traced back to the mid-19th century, and changes in the AMO have been inferred from Greenland paleo ice-core temperature measurements going back thousand of years.

9 Forecasts of 2009 Hurricane Activity

We will be issuing our first forecast for the 2009 hurricane season on Wednesday, 10 December 2008. This 10 December forecast will include the dates of all of our updated 2009 forecasts. All of these forecasts will be made available online at: http://hurricane.atmos.colostate.edu/Forecasts.

10 Acknowledgments

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

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12 Verification of Previous Forecasts

Table 19: Verification of the authors' early August forecasts of Atlantic named storms and hurricanes between 1984-2008. Observations only include storms that formed after 1 August. Note that these early August forecasts have either exactly verified or forecasted the correct deviation from climatology in 23 of 25 years for named storms and 19 of 25 years for hurricanes. If we predict an above- or below-average season, it tends to be above or below average, even if our exact forecast numbers do not verify.

Year	Predicted NS	Observed NS	Predicted H	Observed H
1984	10	12	7	5
1985	10	9	7	6
1986	7	4	4	3
1987	7	7	4	3
1988	11	12	7	5
1989	9	8	4	7
1990	11	12	6	7
1991	7	7	3	4
1992	8	6	4	4
1993	10	7	6	4
1994	7	6	4	3
1995	16	14	9	10
1996	11	10	7	7
1997	11	3	6	1
1998	10	13	6	10
1999	14	11	9	8
2000	11	14	7	8
2001	12	14	7	9
2002	9	11	4	4
2003	14	12	8	5
2004	13	14	7	9
2005	13	20	8	12
2006	13	7	7	5
2007	13	12	8	6
2008	13	12	7	6
Average	**10.8**	**10.3**	**6.2**	**6.0**
1984-2008 Correlation		**0.62**		**0.58**

Table 20: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2003-2007. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

2003	6 Dec. 2002	Update 4 April	Update 30 May	Update 6 August	Update 3 Sept.	Update 2 Oct.	Obs.
Hurricanes	8	8	8	8	7	8	7
Named Storms	12	12	14	14	14	14	14
Hurricane Days	35	35	35	25	25	35	32
Named Storm Days	65	65	70	60	55	70	71
Hurr. Destruction Potential	100	100	100	80	80	125	129
Intense Hurricanes	3	3	3	3	3	2	3
Intense Hurricane Days	8	8	8	5	9	15	17
Net Tropical Cyclone Activity	140	140	145	120	130	155	173

2004	5 Dec. 2003	Update 2 April	Update 28 May	Update 6 August	Update 3 Sept.	Update 1 Oct.	Obs.
Hurricanes	7	8	8	7	8	9	9
Named Storms	13	14	14	13	16	15	14
Hurricane Days	30	35	35	30	40	52	46
Named Storm Days	55	60	60	55	70	96	90
Intense Hurricanes	3	3	3	3	5	6	6
Intense Hurricane Days	6	8	8	6	15	23	22
Net Tropical Cyclone Activity	125	145	145	125	185	240	229

2005	3 Dec. 2004	Update 1 April	Update 31 May	Update 5 August	Update 2 Sept.	Update 3 Oct.	Obs.
Hurricanes	6	7	8	10	10	11	14
Named Storms	11	13	15	20	20	20	26
Hurricane Days	25	35	45	55	45	40	48
Named Storm Days	55	65	75	95	95	100	116
Intense Hurricanes	3	3	4	6	6	6	7
Intense Hurricane Days	6	7	11	18	15	13	16.75
Net Tropical Cyclone Activity	115	135	170	235	220	215	263

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

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