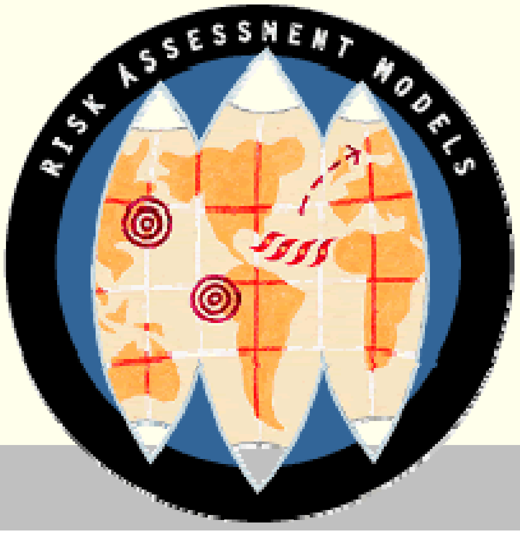

2007 Hurricane Season Outlook

RMS Special Report

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INTRODUCTION

All major forecasting groups predict an active 2007 hurricane season. This is reminiscent of forecasts made at the beginning of last year's season, although 2006 turned out to be much quieter than predicted, showing great contrast to preceding active seasons, particularly 2005. The poorly predicted 2006 season was a result of unforeseen climatological factors, notably a late developing El Niño and excess dry air over the Atlantic Ocean.

This paper reviews the 2006 hurricane season and the climatological factors that contributed to its relative quietness compared with the period since 1995 and the notorious recent seasons of 2004 and 2005. It then focuses on the seasonal forecasts for the 2007 hurricane season, and summarizes the catastrophe response support and products that Risk Management Solutions (RMS®) is providing in 2007.

The 2006 Hurricane Season in Review

The 2006 Atlantic hurricane season got off to an early start, with the first named storm (Alberto) forming on June 11, one month earlier than usual, based on the 50-year long term average[1]. Typically, this would be a precursor to a highly active hurricane season. However, the season failed to live up to this early potential. In total there were just ten named storms[2], five of which reached hurricane status; only two of those five reached Category 3 status or above. Statistically, this is 20% below the 1950–2005 climate norm and the quietest season since 2002, when only four hurricanes formed.

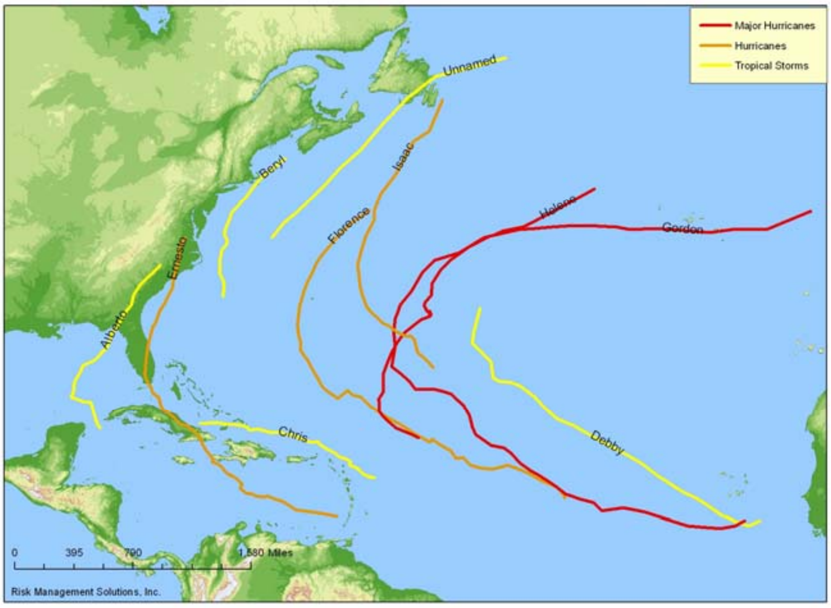

Figure 1: All named storms during the 2006 Atlantic hurricane season

Perhaps the most notable feature of the 2006 hurricane season was the fact that there were no landfalling hurricanes anywhere along the U.S. coastline, which is only the twelfth such occurrence since 1950 (Ernesto was a tropical storm by the time it made landfall). This also meant that property damage and economic and insured losses associated with the 2006 hurricane season were exceptionally low, particularly when compared with the previous two years. The estimated total insured losses attributed to the 2006 hurricane season were accountable to one storm, Tropical Storm Ernesto, for which the Property Claims Services (PCS) division of ISO estimated total insured losses to be just under $250 million, compared with an estimate of total insured losses of $64 billion in 2005, according to the Insurance Information Institute.

The only systems to affect U.S. land were three tropical storms: Alberto, Beryl, and Ernesto, the lowest number of named storms to come ashore since 2001.

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[1] This paper uses climatological averages starting from 1950 because this is when the offshore data is more likely to be comprehensive and reliable.

[2] Includes an unnamed tropical storm, which was upgraded by the National Hurricane Center from a tropical depression in mid- December, after the official end to the hurricane season in November.

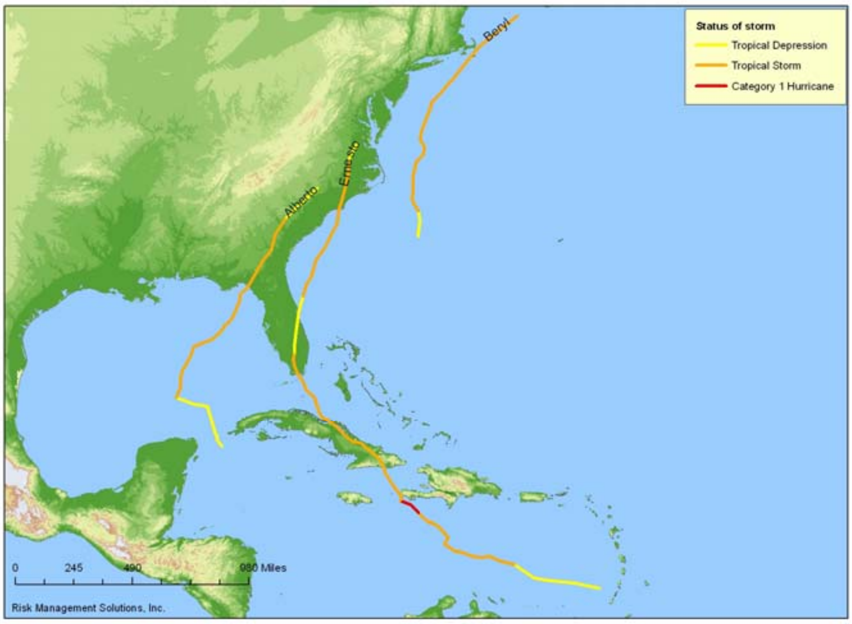


Figure 2: Landfalling storms in 2006

Alberto made landfall about 50 mi (80 km) southeast of Tallahassee, Florida on June 13, with maximum sustained winds around 46 mph (74 km/hr), causing minimal damage. Tropical Storm Beryl formed on July 18 and ran parallel to the East Coast of the U.S., crossing over Nantucket Island, Massachusetts on July 20 with maximum sustained winds of 51 mph (82 km/hr), causing very little damage as well. The Caribbean also fared well, with only Tropical Storm Chris tracking through the southern Bahamas as a tropical depression on August 4, followed by Tropical Storm Ernesto at the end of August, which became the third storm to make landfall on the U.S. mainland during 2006. No storms affected Mexico's Caribbean coast, allowing time for recovery following Hurricane Wilma's devastating impacts on the Yucatán Peninsula in September 2005.

Ernesto was the first hurricane to develop in 2006, and was declared a hurricane on August 27 while located approximately 80 mi (129 km) south of the southern coast of Haiti with maximum sustained winds of 75 mph (121 km/hr) and a minimum pressure of about 992 mb. The hurricane very quickly deteriorated as the circulation interacted with the mountainous terrain of Haiti, and Ernesto was downgraded to a tropical storm less than 12 hours after becoming a hurricane. According to the National Hurricane Center (NHC), the center of circulation passed offshore very near the southwestern tip of Haiti on August 28, by which time the intensity had decreased to 46 mph (74 km/hr). The weakening trend continued as Ernesto moved northwest toward Cuba so that when Ernesto made landfall along the southeast coast of Cuba on August 28, maximum sustained winds were only 40 mph (64 km/hr). The center of Ernesto remained inland over Cuba for about 18 hours before emerging off the north central coast on August 29 and tracking northwest toward Florida. Ernesto made its first U.S. landfall in Florida at 05:00 UTC on August 30 as a tropical storm, with maximum sustained winds of 45 mph (74 km/hr). Florida was subject to gusty winds and rain as Ernesto tracked relatively quickly north-northeast, emerging over the Atlantic Ocean near Cape Canaveral, Florida early on August 31. Initially, there was little concern over Ernesto in Florida. However, after emerging into the Atlantic, Ernesto re-intensified over warm waters before making a second U.S. landfall in North Carolina, with maximum sustained winds of 70 mph (111 km/hr), bringing heavy rain and strong winds to Virginia and the Carolinas. In the U.S., nine deaths were attributed to the storm, and over 600,000 homes and businesses lost power in affected areas. As the remnants of Ernesto moved inland, the severe weather spread through the Mid-Atlantic States, causing disruption as far afield as New York City and Washington D.C., and resulting in total insured losses of $245 million across eight states.

During September — the traditional climatological peak of the hurricane season — the only notable storm was Hurricane Florence, which caused small amounts of damage and disruption in Bermuda as it passed within 60 mi (95 km) of the island, with hurricane force winds up to 70 mi (110 km) from the center. According to the National Hurricane Center (NHC), maximum sustained winds increased from 80 mph (130 km/hr) to 90 mph (145 km/hr) as the storm passed Bermuda. A maximum gust of 110 mph (180 km/hr) was recorded on the island. However, due to the storm's distance from the island and Bermuda's strict building codes, Florence caused only minor damage and power outages to Bermuda.

The year 2006 was the first year since 1992 that no hurricane-strength storms developed in the Gulf of Mexico. Activity was focused in the open Atlantic rather than the Gulf of Mexico and Caribbean Sea, and the majority of tracks followed a northward and northeastward direction over open water (Figure 1). The reason many of the storms remained over the open waters of the Atlantic can be attributed to the position of the Bermuda High. The Bermuda High is a fairly stationary high-pressure system, usually located near Bermuda, that acts to steer storms as they move from the eastern Atlantic and track west toward the Caribbean and U.S. The position and size of the Bermuda High is key to the direction that storms will take. In 2004 and 2005, when U.S. landfalls were plentiful, the Bermuda High was situated more to the west-southwest, and steered systems west into the Caribbean and Gulf of Mexico. In 2006, the Bermuda High was smaller and shifted toward the eastern Atlantic, steering storms such as Florence, Gordon, Helene, and Isaac north before re-curving northeastward into the cooler waters of the North Atlantic.

One of these storms, Hurricane Gordon, exhibited a somewhat unusual eastward extent and tracked as far northeast as the Azores, striking the islands as a Category 1 storm on September 20. Hurricanes in the Azores are very rare, but not unprecedented. Records between 1851 and 2005 show that nine hurricanes impacted the Azores during that period. The most recent prior to Gordon was Hurricane Charley, in 1992.

One of the major factors that stands out when reviewing the 2006 hurricane season is that it was statistically the quietest season since 2002, showing great contrast when compared with the recent upswing in hurricane activity evident since 1995 and the hyperactive year of 2005. The lack of activity took many people by surprise, including the three main forecast groups: the Tropical Meteorology Research Group led by Dr William Gray of the Department of Atmospheric Science, Colorado State University (CSU); the National Oceanic and Atmospheric Administration (NOAA); and Tropical Storm Risk (TSR). Each group over-predicted tropical storm activity, and their forecasts failed to show any accuracy. Both CSU and TSR failed to capture the inactive season in their forecasts until August. Why was the 2006 hurricane season so difficult to forecast? A large part of the over-prediction of the 2006 hurricane season has been attributed to unforeseen environmental factors such as increased mid-level dryness in the tropical Atlantic and a late-developing El Niño.

SAHARAN DUST STORMS AND 2006 HURRICANE ACTIVITY

Evan *et al*., 2006, recently discovered a link between reduced hurricane activity in the Atlantic and thick clouds of dust that periodically rise from the Sahara Desert and flow off Africa's western coast over the eastern tropical Atlantic, which is the main breeding ground for Atlantic hurricanes during August, September, and October. Hurricanes need heat and moisture for development; the presence of dry, warm air from dust storms hinders development by increasing the energy barrier that must be overcome to allow warm, moist air to rise from the surface of the water, where it can subsequently produce thunderclouds and result in cyclones.

The 2006 hurricane season has been correlated with a high number of dust storms, and satellite imagery shows that much of the eastern tropical Atlantic was covered with Saharan dust, notably during August. Jeffrey Halverson, a research meteorologist at the University of Baltimore County, reported that out of 12 of the seedling storms coming off the African west coast, several were associated with a veil of dust, which hindered their development. It is now widely accepted that August hurricane activity was greatly reduced due to excess amounts of dust in the atmosphere. Evans *et al*. also found that during periods of intense hurricane activity, i.e., 2005, dust was relatively scarce in the atmosphere.

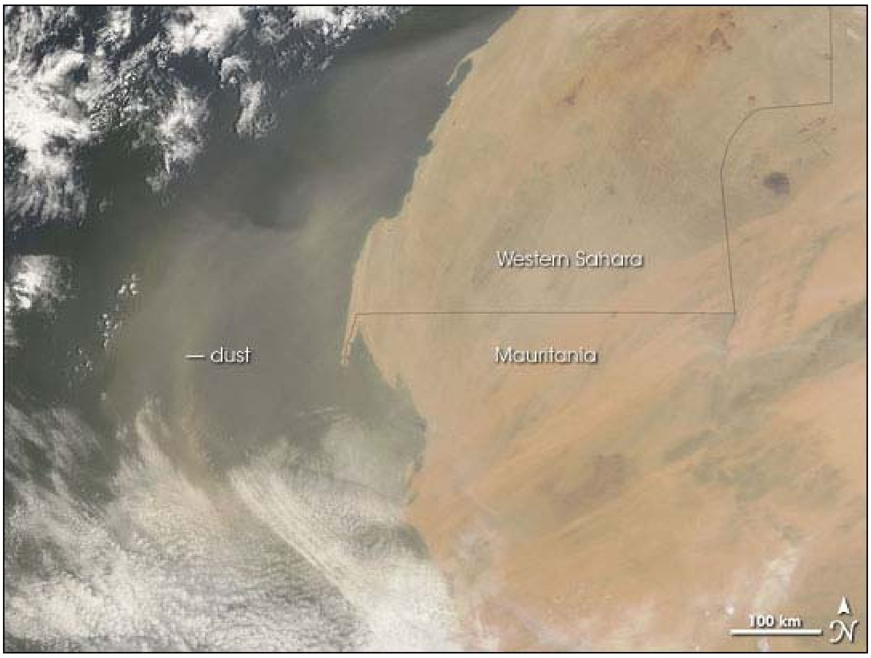


Figure 3: A plume of dust blowing off the west coast of Western Sahara and Mauritania on July 23, 2006. (Source: NASA Earth Observatory)

The 2006 El Niño

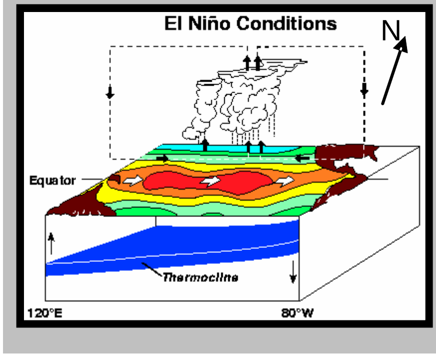
It has long been accepted that there is a strong relationship between El Niño/Southern Oscillation (ENSO) and hurricane activity (Gray, 1984). The theory states that hurricane frequency in the Atlantic declines during El Niño years due to ENSO-driven teleconnections that increase the vertical wind shear over the Caribbean and Atlantic. Increased wind shear helps prevent disturbances from developing and intensifying into hurricanes by spreading the latent heat needed for development over a larger area. Previous El Niño years can be correlated with lower than normal hurricane activity in the Atlantic; for example, in 2002, only four hurricanes formed (compared with an average of eight), and in 1997, only three hurricanes formed. Although this relationship is used as one of the key predictors in seasonal forecasts of Atlantic hurricane activity, the 2006 El Niño developed late and was therefore not incorporated into forecasts until August.

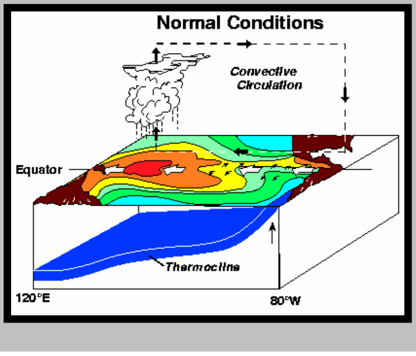
The 2006 El Niño began to materialize in May, when sea surface temperature (SST) anomalies transitioned from negative to positive across the equatorial Pacific. Between May and December, the positive SST anomalies increased, reaching their peak around October. An El Niño event was declared in August when specific parameters in the atmosphere reached the threshold values that officially define an El Niño event. From that point on, a relatively weak El Niño developed rapidly between August and October, suppressing Atlantic hurricane activity during this period, after the season's initial early start with Alberto.

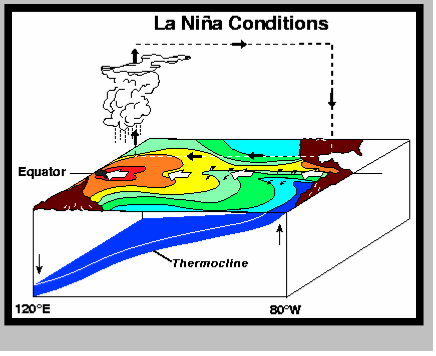
The late arrival and rapid development of El Niño meant that the initial forecasts of seasonal forecasting groups were unable to take El Niño into account. This contributed to the over-

El Niño/Southern Oscillation

The El Niño/Southern Oscillation (ENSO) is the most prominent year-to-year climate fluctuation on Earth (McPhaden, 2004). It originates in the tropical Pacific with unusually warm (El Niño) and unusually cold (La Niña) events recurring approximately every 3–7 years. During an El Niño event, the trade winds in the central and western Pacific relax, allowing for warmer than average surface waters in the eastern tropical Pacific Ocean and a weakened SST gradient across the equatorial Pacific. The eastward displacement of the warm SSTs results in a displacement of the atmospheric circulation, which in turn forces changes in weather patterns across the globe. In normal, non-El Niño conditions, the trade winds blow west across the tropical Pacific. A La Niña is generally the opposite of an El Niño, with cooler than average surface waters in the eastern tropical Pacific and enhanced trade winds.







prediction of the 2006 hurricane season early on. El Niño conditions are difficult to predict, and ENSO predictability depends on the time period from which it is estimated (Chen *et al.*, 2004). This difficulty is recognized as a "spring barrier" in ENSO prediction (Chen *et al.*, 2004); for example, ENSO predictions that are made between June and December are generally more accurate than those that are made between February and May. Chen *et al.*, 2004, also point out that larger El Niño and La Niña events have a greater predictability than smaller events.

Since January 2007, the pattern of anomalously warm SSTs associated with the El Niño has rapidly disappeared from the equatorial Pacific east of the International Date Line. According to the Climate Prediction Center (CPC), the main area of anomalously warm SSTs along the equator had become centered well to the west of the International Date Line, which is consistent with the disappearance of El Niño. Observations from late March to April show that below average SSTs in the equatorial Pacific have persisted and SST anomalies have increased in the eastern equatorial Pacific over this 4-week period. Overall, the ENSO indicators are neutral, but the chances of a La Niña developing in 2007 are higher than average. Based on data since 1950, the observed cooling within the region is the strongest cooling on record, according to Klotzbach and Gray, 2007.

La Niña often but not always follows El Niño, with a classic example occurring in 1997–1998. Most major climate centers expect that a La Niña event will develop in the coming months for the following reasons:

- The El Niño decayed earlier than normal, which allowed time for a La Niña to develop during the critical March to June period.
- A large pool of cold, sub-surface water is persisting in the central to eastern tropical Pacific, which may be the first sign of an emerging La Niña.
- The upper ocean heat content anomalies have been negative since January 2007, indicating that subsurface conditions are favorable for the development of La Niña.
- The majority of statistical and coupled models are predicting that SST anomalies will become increasingly negative during the next three months.

La Niña has the opposite affect on the atmosphere as El Niño; all other factors being equal, La Niña reduces vertical wind shear over the Caribbean and Atlantic and acts to favor hurricane development. A study by Pielke and Landsea (1999) investigates the relationship between U.S. Atlantic hurricane damage and different ENSO phases. Based on historical data, the study concluded that there have been increased property, economic, and insured losses during La Niña years and reduced losses during El Niño years.

Historically, the year with the most striking property and economic losses was 2005, where total insured losses were approximately $64 billion (Insurance Information Institute). That year was an ENSO-neutral year, but other environmental factors played a part in contributing to these high losses, notably SSTs in the Gulf of Mexico. Hurricane Katrina, which struck the Mississippi and Louisiana coastline in late August, was responsible for a large portion (over 50%) of total losses.

Katrina was a strong Category 5 hurricane on approach to the coastline, although it weakened to a strong Category 3 just prior to landfall. Katrina experienced two periods of rapid intensification during its lifecycle. The first began on August 26 at 06:00 UTC, just after passing the tip of Florida, where Katrina intensified from a rather small Category 1 storm with maximum sustained winds of 75 mph (120 km/hr) to a Category 3 storm with maximum sustained winds of 115 mph (132 km/hr). This period of intensification was due in large part to the warm waters of the Gulf Loop Current, a belt of particularly warm water extending into the Gulf of Mexico from the Yucatán Peninsula. Intensification was halted temporarily by an eyewall replacement cycle (a process where the inner eyewall deteriorates while a larger, outer eyewall forms around it), but was followed by a second period of rapid intensification starting at 00:00 UTC on August 28, when Katrina intensified from a Category 3 storm with maximum sustained winds of 115 mph (132 km/hr) to a Category 5 storm in just 12 hours. The storm reached peak intensity after 18 hours (18:00 UTC on August 28) with maximum sustained winds of 172 mph (277 km/hr) and a central pressure of 902 mb, making Katrina the fourth most intense Atlantic hurricane on record as of that time. Katrina maintained Category 5 status for approximately 24 hours — another remarkable feature of the storm. Sea surface temperatures in the Gulf of Mexico were generally one to two degrees Celsius above the long-term average, and the warm temperatures extended to a considerable depth through the upper ocean layer. These conditions not only contributed to the rapid intensification, but also allowed Katrina to maintain its incredible intensity prior to landfall.

TROPICAL CYCLONES AND SEA SURFACE TEMPERATURES

Tropical cyclones develop from tropical depressions — regions of low pressure that form in favorable conditions such as low wind shear and warm sea surface temperatures (SSTs). Hurricanes are a class of tropical cyclone that occurs in the Atlantic Basin, which encompasses the subtropical and tropical northern Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. The official North Atlantic hurricane season runs from June 1 to November 30; however, hurricane frequency tends to show distinct monthly variation, with peak activity occurring in September.

Just as the frequency of hurricane activity varies throughout the season, so does the area of formation. SSTs largely determine where storms develop during the season, and must be greater than 26°C (79°F) for cyclogenesis (cyclone formation) to occur. SSTs in the Gulf of Mexico and off the Atlantic coast of Florida are often warm enough to support the development of early season tropical depressions or cyclones, which form from remnants of early summer cold fronts. These fronts have enough associated instability to create disturbances capable of developing into tropical depressions or stronger storms. This type of activity generally declines by July; the "Cape Verde" season then begins in August, and runs through October. Cape Verde storms develop from low-pressure atmospheric disturbances, known as easterly waves, that form near the coast of West Africa and move westward across the Atlantic Ocean, carried by the prevailing atmospheric flow. These storms tend to become intense, and commonly strike the East Coast of the U.S. As November begins, the Cape Verde season comes to an end, and the focus of potential storm development returns to the western Caribbean and the Gulf of Mexico. The passage of the first major cold front often signals the end of the season as the SSTs cool and no longer support tropical cyclone development.

Erb, 2006, investigated several environmental factors that were believed to have been responsible for Katrina's rapid intensification. He not only found that SSTs in the Gulf of Mexico were above 30°C (very warm for waters in the Gulf of Mexico), but also found that factors such as low-level relative humidity and vertical wind shear proved optimal for intensification.

Katrina reduced in strength just prior to landfall as the inner eyewall deteriorated during a second eyewall replacement cycle. Erb hypothesized that the slight decrease in intensity may have been caused by a slight increase in wind shear and cooler SSTs closer to the coast.

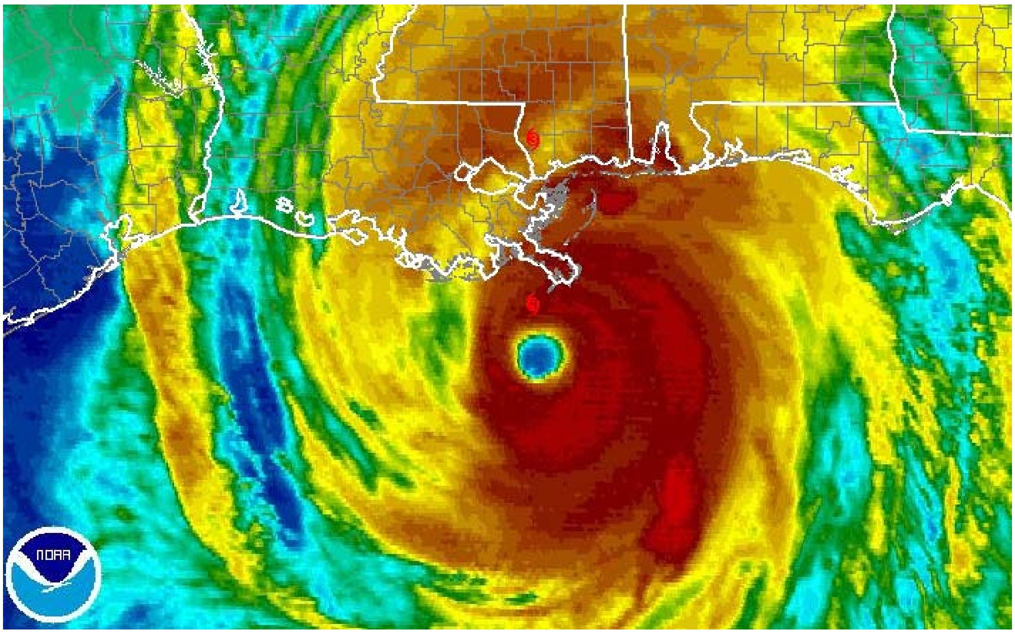


Figure 4: Satellite image of Katrina just prior to landfall.

2007 ATLANTIC HURRICANE SEASON OUTLOOK

With the dissipation of last year's El Niño conditions and a potential La Niña event on the horizon, all tropical forecasting groups are expecting the 2007 Atlantic hurricane season to return to the high levels of activity that have occurred in most years since 1995. Forecasts issued since December have continued to anticipate an above-average season in terms of both tropical cyclone development and hurricane landfalls. An average season (based on the period from 1950–2005) would experience approximately ten tropical storms, six of which would become hurricanes and three of which would become major hurricanes (Saffir-Simpson Category 3 or higher).

In March 2007, Tropical Storm Risk (TSR) significantly increased their expectation for an active hurricane season, with activity rising from 60% above the norm (February forecast) to 75% above the norm (March forecast). It also noted that the forecast released in March was the highest March forecast for activity in any year since the TSR initiated real-time forecasts in 1984. The main reason for the increased forecast is the expectation that a weak La Niña will develop during the summer.

The latest forecasts, issued in May, continue to anticipate an active season. NOAA's seasonal forecast from the Climate Prediction Center (CPC), issued on May 22, indicates that there is a 75% chance of above-normal activity, a 20% chance of near-normal activity, and a 5% chance of below-normal activity. NOAA also expects the vast majority of tropical storms and hurricanes to form over the tropical Atlantic Ocean from August through October. NOAA points out that the prediction for an above-normal hurricane season reflects the expected combination of the following two factors: the continuation of conditions that have been conducive to above-normal Atlantic hurricane seasons since 1995; and, the strong likelihood of either ENSO-neutral or La Niña conditions in the tropical Pacific Ocean.

According to Colorado State University's (CSU) May 31 forecast (which remained unchanged from their April 3 forecast), 17 named storms are expected, 9 of which are forecast to become hurricanes, and 5 to become major hurricanes. They also state that landfall probabilities for the U.S. coastline are well above their long-period averages. Klotzbach and Gray (2007) anticipate that the current neutral ENSO conditions will either remain neutral or will transition to cool ENSO conditions (La Niña) by the summer/fall.

In terms of landfalls, CSU estimates the probability of a major U.S. hurricane landfall to be about 140% of the long-period average, with a 74% probability of at least one major hurricane landfall somewhere on the U.S. coastline. Historically, above-normal seasons have averaged 2–4 hurricane strikes in the continental U.S. and 2–3 hurricanes in the region around the Caribbean Sea. However, according to the Climate Prediction Center, at these extended ranges it is not possible to confidently predict the number or intensity of landfalling hurricanes.

Table 1 summarizes the forecasts from CSU, TSR, and NOAA for the 2007 hurricane season and compares them with past averages.

Table 1: 2007 Storm Forecasts and Comparison to Past Averages

Forecast Issuer	**Date Issued**	**Named Storms**	**Hurricanes**	**Major Hurricanes (> Category 3)**
CSU	31 May 07	17	9	5
TSR	3 May 07	12–20	6–12	2–6
NOAA	22 May 07	13–17	7–10	3–5
1995–2006 Average	—	13	8.2	3.9
1950–2005 Average	—	10.3	6.2	2.7

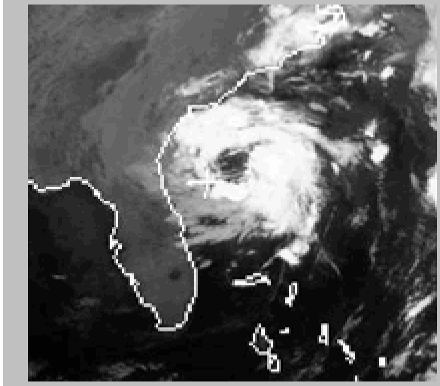
Although the official start date of the hurricane season is June 1, the 2007 season got off to an early start when Subtropical Storm Andrea formed on May 9. Andrea formed off the southeast coast of the U.S., approximately 150 mi (240 km) northeast of Daytona Beach, Florida with maximum sustained winds of 46 mph (74 km/hr) and a minimum central pressure of 1003 mb. With SSTs at only 25°C (77°F), the organization of the system deteriorated and Andrea dissipated by early May 10. Off-season storms are not unheard of, but Andrea was the first named storm to form in May since Arlene in 1981, and the first pre-season storm since Ana in April 2003.

GLOBAL CLIMATE CHANGE

Hurricane activity in the North Atlantic has shown a marked increase since 1995, indicating that the Atlantic Basin is in a period of elevated activity. Since 1995, the number of Atlantic Basin

WHAT ARE SUBTROPICAL STORMS?

Subtropical storms are non-frontal low pressure systems that have characteristics of both tropical and extratropical cyclones. There are two types of subtropical cyclones: the upper-level low (the most common of the two), and the mesoscale low. Compared with tropical cyclones, subtropical systems have a relatively broad zone of maximum winds located farther from the center, and a less symmetric wind field and distribution of convection.



Infrared satellite image taken at 12:00 UTC on May 9, showing Subropical Storm Andrea off the southeast coast of the U.S.

Source: Dundee Satellite Receiving Station hurricanes has surpassed the long-term average every year, with the exceptions of 1997, 2002, and 2006 — all El Niño years. Fluctuations in the numbers of past hurricanes are evident over decadal time scales.

For example, the period from 1970–1994 experienced a trough in activity levels, while the 1950s and part of the 1960s showed raised levels of activity. The latest increase in basin activity has been attributed to multi-decadal cyclical variations in conditions that affect hurricane development (Goldenberg *et al.*, 2001; Elsner *et al.*, 2000), principally changes in SSTs. However, recent publications have dismissed the multi-decadal cycle and attributed changes in hurricane frequency and intensity to global warming. Emanuel, 2005, suggests that increasing SSTs, caused by global warming, have the potential to increase hurricane intensity and storm lifetime. Webster *et al.,* 2005, examined the number of tropical cyclones and intensity over the past 35 years and concluded that global data indicates a 30-year trend toward more frequent and intense hurricanes. This trend is consistent with climate model simulations that a doubling of CO_2 may increase the frequency of the most intense cyclones.

The annual number of all hurricanes across the Atlantic Basin has increased to an average of 8.2 since 1995, compared with an average of 6.1 annual hurricanes from 1950–2006. However, the elevated activity has been particularly apparent in the number of major hurricanes, with an annual Atlantic Basin average of 3.9 major hurricanes since 1995, compared with an annual average of 2.7 in the period from 1950–2006.

RMS' annual gathering of hurricane experts in September 2006 resulted in the consensus that the period of elevated activity witnessed in the Atlantic Basin since 1995 is expected to last for a period significantly longer than the next five years (the medium-term perspective). At the same time, it was recognized that not all individual years in the next decade are expected to be more active than average, as seasonal activity depends on various climatological factors, such as the state of ENSO.

The occurrence of eight major U.S. landfalling hurricanes in 2004 and 2005 sparked an active debate in the scientific community about the role of global climate change in increasing hurricane frequency and intensity. The debates, which focus on the reasons for the high state of current hurricane activity, continue among leading climatologists: those who view natural, multi-decadal variability as the principal cause, and those who also see a significant human influence on climate change. Despite the uncertainties in the cause of the increased activity since 1995, RMS continues to recommend using a forward-looking view of risk rather than one that is represented by long-term historical averages.

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