“X” Marks the Spot: Florida, the 2004 Hurricane Bull’s-Eye

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The hurricane season of 2004 has turned out to be one for the record books. The first recorded South American hurricane made landfall in Brazil last March. Hurricane Alex, the first named storm of the North Atlantic hurricane season, was the strongest hurricane ever recorded north of 38 degrees latitude. Hurricane Ivan was the most southerly-forming North Atlantic hurricane recorded. After menacing the Caribbean, Ivan made an official landfall near Mobile, Alabama, but greatly affected the western panhandle region of Florida, which was located within the dangerous northeastern quadrant of the storm. Hurricane-fatigued Floridians, meanwhile, are also still cleaning up from three direct hurricane landfalls, including two major hurricanes. Figure 1 shows the intersection of the paths of Hurricanes Charley, Frances, and Jeanne over Polk County, Florida.

Theories on the cause of this unusually busy hurricane season abound. Some suggest that global warming is affecting tropical weather and influencing the development of "monster" hurricanes. Others conclude that the pattern of U.S. hurricane landfalls has changed, and that Florida is in for an extended period of much more frequent hurricane strikes. Neither of these theories is necessarily the case. This article examines the following two questions: How abnormal was the 2004 hurricane season overall and why was Florida impacted so frequently (4 times) by landfalling hurricanes this year?

Climate Influences on Atlantic Hurricane Formation

ENSO (El Niño-Southern Oscillation) is a well-known climate factor influencing North Atlantic hurricane formation. In general, years with a La Niña (cold Pacific) dominant pattern are more likely to have an increased number of hurricanes, while the counter regime, El Niño, is associated with a decreased number of Atlantic hurricanes [*Bove et al.*, 1998; *Elsner and Bossak*, 2004]. This summer, in fact, there was a slight El Niño episode occurring in the central Pacific, with warm sea-surface temperature (SST) anomalies predicted to continue into 2005 (for current SST data see: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/).
If based solely on current ENSO conditions, North Atlantic hurricane counts in the 2004 season (which began on June 1st) would be expected to be slightly below average. However, recent research has indicated other significant factors in explaining North Atlantic tropical cyclone activity.

Atlantic SSTs are vital to the formation and strengthening of Atlantic tropical cyclones. Years with above normal Atlantic SSTs are correlated with above normal hurricane counts and especially major hurricane counts. This August and September, Atlantic SST anomalies were positive off the coast of Africa and across the ITCZ (http://www.cpc.noaa.gov/products/hurricane/atlsst.html). Moreover, the frequency of Sahelian rain storms moving out over the open Atlantic off Africa is significantly correlated with intense landfalling U.S. hurricanes [*Landsea et al.*, 1992]. A forecast of the July through September 2004 period by the British Meteorological Office (http://www.metoffice.com/research/seasonal/regional/north_africa/pdf/north_africa_2004_prelim) indicated above normal rainfall and storm potential in the areas of the Sahel (southern Sahara desert) where most westward-moving tropical waves are derived. Conditions in the North Atlantic were therefore ripe for higher than usual Atlantic tropical cyclone counts this hurricane season.

In order to determine if this year's hurricane season exhibited abnormal tropical cyclone frequencies, the last five years of activity over the North Atlantic were examined via official tropical cyclone data available from the National Hurricane Center (www.nhc.noaa.gov). Table 1 indicates the number of named storms, hurricanes, U.S. hurricanes, and U.S. major hurricanes from 2000 forward. The 2004 hurricane season does not exhibit unusually deviant tropical cyclone counts. The mean number of North Atlantic named storms (hurricanes) over the previous four years was 14.5 (7); the number observed this year was 14 (9, including the reclassified Hurricane Gaston). The only aberrant trend is the number of U.S. hurricane landfalls (5 this year, compared with the previous 4-year mean of 0.75), and in particular, the fact that three major hurricanes have made landfall this year – two of which have directly struck Florida. Therefore, because there were not a significantly greater number of tropical cyclones in the North Atlantic than usual this year, some other climate feature(s) must be responsible for the high southeastern U.S. landfall counts. The likely culprits involve climate features that influence the track of North Atlantic hurricanes, specifically leading to greater than usual landfalls on the southeastern U.S. coastline.

North Atlantic Tropical Cyclone Development and Steering Mechanisms

It is important to note that the climate factors discussed in the previous section relate only to the frequency and formation of Atlantic hurricanes and not to their continued development and/or intensification. In fact, there are additional climate factors that affect the development of hurricanes in a given year, such as those that inhibit vertical shear. Some of these shear-related factors include the Madden-Julian Oscillation (MJO) and the Quasi-Biennial Oscillation (QBO). The MJO is a strong easterly convection anomaly, generally occurring over the warm Pacific Ocean, which has an approximate 30 to 60 day oscillation period. Recent research has linked the phase of the MJO to hurricane activity in the Gulf of Mexico and Caribbean Sea [*Maloney and Hartmann*, 2000]. In August and September, the MJO was favorable for hurricane development in the North Atlantic Basin, with increased convection occurring across the tropical Atlantic Ocean (for more on the MJO, see http://meted.ucar.edu/climate/mjo/). The QBO, which shifts direction regularly on a basis of about 15 months time, has an easterly and a westerly phase. The easterly phase has been shown to inhibit North Atlantic hurricane formation and development, while the westerly phase is correlated with enhanced North Atlantic hurricane activity. The QBO shifted phase to westerly in the winter of 2004, and the QBO index was significantly positive (i.e., strong westerly phase) during August and September of 2004. Therefore, the state of the QBO this hurricane season was also conducive to North Atlantic hurricane formation and development.

Only relatively recently have climate features that influence North Atlantic tropical cyclone tracks been researched in detail. *Elsner et al.* [2000a] noted the influence of the North Atlantic Oscillation (NAO) on North Atlantic hurricane tracks. The NAO is the normalized pressure difference between the Azores and Iceland. A weaker North Atlantic Oscillation is associated with a greater chance of major hurricane landfalls along the Gulf Coast of the U.S. [*Elsner and Bossak*, 2004]. Hurricanes that form off Africa and move at low latitudes to the west to make landfall on the U.S. coast south of the North Carolina border are termed straight-moving (SM) hurricanes [*Elsner*, 2003] and these SM hurricanes are also significantly correlated with a weaker NAO. The NAO values from May (-0.67) and June (-0.38) are moderately negative, suggesting a weakening of the NAO. The NAO has specific effects upon the Bermuda High pressure system in the Atlantic Ocean. A positive (strong) NAO results in the Bermuda High being shifted more to the east and intensifying, allowing for greater recurvature of North Atlantic hurricanes, and resulting in only an occasional landfall in the U.S. northeast [*Elsner et al.*, 2001]. In contrast, a negative (weak) NAO allows for a more westward Bermuda High, which acts to steer North Atlantic hurricanes toward the southern U.S. Figure 2 demonstrates several factors likely to be influencing the track of this year's U.S. hurricanes, including the position of the Bermuda High. (NAO data: http://www.cru.uea.ac.uk/~timo/projpages/nao_update.htm).

Summary of U.S. Hurricane Activity in 2004

Overall tropical cyclone activity in the North Atlantic was not abnormal in 2004, at least in relation to an expected increase in tropical cyclone activity that was forecast from 1995 forward [*Elsner et al., 2000b; Goldenberg et al.*, 2001]. However, there was an unusual count of major hurricanes this season and an aberrant number of U.S. landfalling hurricanes. Factors such as warm Atlantic SSTs, abundant Sahel rainstorms, and weak to neutral El Niño conditions were optimal for North Atlantic hurricane formation this hurricane season. Both the Madden-Julian Oscillation and the Quasi-Biennial Oscillation were favorable for the continued development and intensification of those tropical cyclones that formed. Finally, the phase of the North Atlantic Oscillation and the position of the Bermuda High likely influenced the tracks of straight-moving hurricanes to make landfall along the southern U.S. coast, without experiencing the recurvature that has been typical during the last several North Atlantic hurricane seasons.

Stochastic U.S. hurricane prediction methodologies based on previously developed regression models [*Elsner and Bossak*, 2001; *Elsner and Bossak*, 2004] will be utilized with final hurricane season climate data to verify these findings. A more statistically rigorous examination of climate influences relating to the 2004 U.S. hurricane events will be forthcoming.

Acknowledgements

I would like to thank Kate Ciembronowicz (ETI-USGS) for assistance with figures, and Dr. James B. Elsner (Florida State University) for helpful comments and suggestions.

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TABLE 1. North Atlantic Tropical Cyclone Statistics, 2000-2004.

Year	Named Storms	Hurricanes	U.S. Landfalls	Major Hurricane Landfalls
2004	14	9*	5*	3
2003	16	7	2	0
2002	13	4	1	0
2001	15	9	0	0
2000	14	8	0	0

* Tropical Storm Gaston was later reclassified as a hurricane in the post-storm analysis.

FIGURE 1. The tracks of Hurricanes Charley, Frances, and Jeanne across central Florida. The tracks intersect over Polk County, near the cities of Bartow, Lakeland, Lake Wales, and Haines City. Point symbols represent official center positions of each hurricane as reported by the National Hurricane Center.

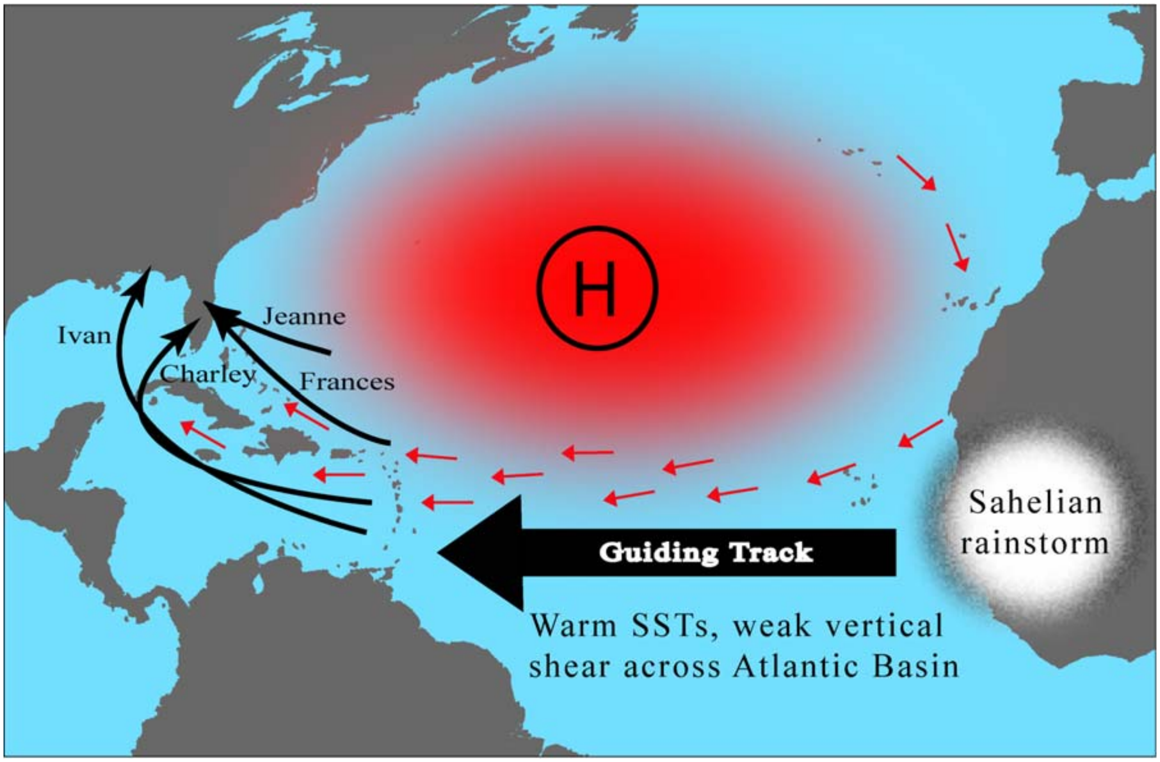

FIGURE 2. Influence of the Bermuda High on North Atlantic tropical cyclone tracks. A negative NAO results in a more westward high pressure center, thereby influencing the tracks of Atlantic tropical cyclones. Optimal conditions for hurricane development and intensification in the North Atlantic increase the risk of a landfalling U.S. hurricane.