Hurricane Season Wind Damage in an Urban Landscape: A Case Study of Jacksonville University Campus

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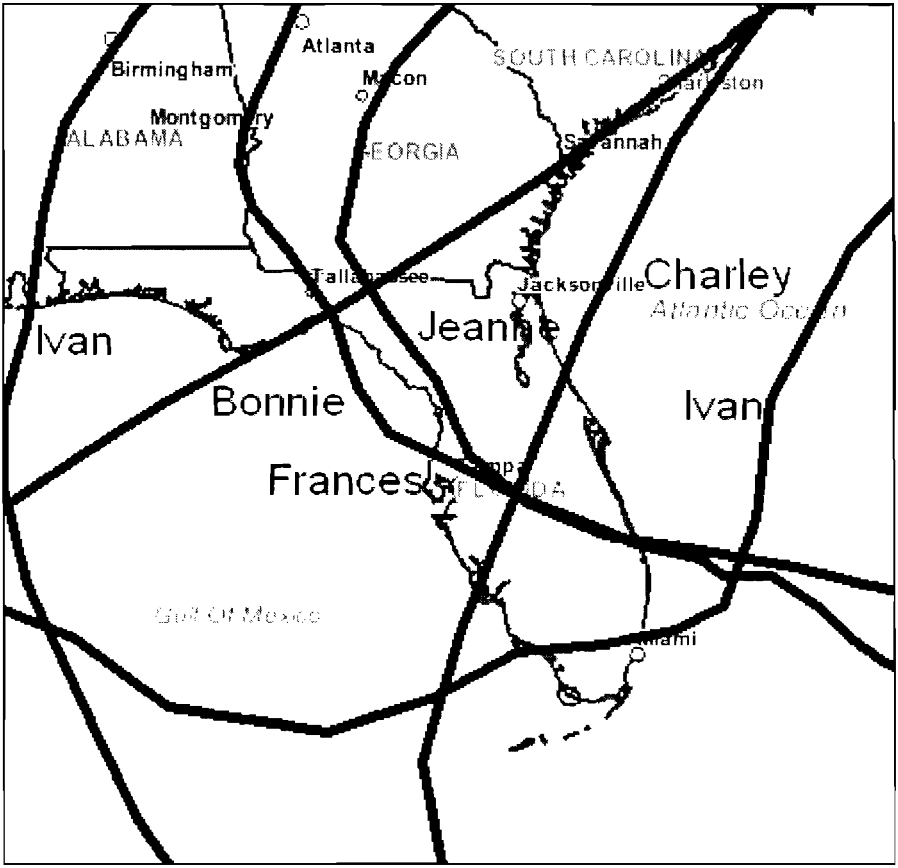
Introduction

Under a scenario of predicted increases in tropical storms Florida is now more susceptible to wind damage than in past decades (Goldenberg et al., 2001; Landsea et al., 1999). No location in the Southeast is free from tropical storm damage, but Florida with its southerly location and peninsular setting is the most vulnerable. Consistent with this geography, Florida was impacted by more tropical systems than any other state during the intense 2004 and 2005 hurricane seasons. Even though 2005 received more notoriety as the busiest and the most costly hurricane season on record, it was the 2004 season that was more devastating to Florida. During 2004 virtually no region in the state escaped tropical storm damage. Indeed, several locations were impacted on numerous occasions, and some cities were hit multiple times within a one month period.

The tropical storm paths of 2004 suggest that Jacksonville and the northeast coast of Florida were largely spared of significant damage (Fig. 1). However, two of the 2004 season hurricanes, Frances and Jeanne, were spatially large systems, and while they were somewhat distant from Jacksonville, they exposed the city to long periods of high winds. Consequently, Jacksonville accrued damage well into the millions of dollars from these two events: power was lost, traffic was disrupted, schools and businesses were closed, and many areas were flooded. This all happened despite the fact that the two first order reporting stations in the city, Naval Air Station Jacksonville (NASJAX) and the Jacksonville International Airport (JIA), only reported one tropical storm force wind reading for each hurricane (34 kt for Frances and 35 for Jeanne).

Figure 1. Paths of tropical systems in Florida during the 2004 hurricane season.



Source: National Oceanic and Atmospheric Administration Coastal Services Center.

The sources of damage from landfalling tropical events are storm surge, flooding from heavy rain, and wind damage. Of these causes wind driven tree blowover is a major component of the mean annual $7 billion damage cost of storms across the nation, and this was certainly the case for Jacksonville during Hurricanes Frances and Jeanne (Meade, 2004). Tree blowover is a function of multiple parameters:

wind speed, gustiness, shelter, soil type, soil water content, topography, tree species, tree stem size, ice buildup, parasitic infestation, and others (Alexander, 1964; Swanson, 1988; Foster and Bose, 1992; Everham et al.,1996; Wesley et al., 1998; Clinton and Baker, 2000; Kramer et al., 2001; and Veblen et al., 2001).

This research examines tree blowover in an urban setting by assessing the damage that occurred on Jacksonville University in September of 2004. This damage resulted from two tropical systems, Hurricanes Frances and Jeanne, and one localized microburst occurring between these two major events. The storm events are compared and the characteristics of the tree blowover area analyzed.

Terrestrial Setting

With a population of 735,000 Jacksonville is the fourth largest metropolitan region in the state (U.S. Census, 2000). The city contains a variety of land covers to include natural wetlands, forest, timber farms, residential, industrial, and business. Centrally located in the North Atlantic hurricane region Jacksonville is predisposed to tropical systems. However, the last hurricane to make landfall in Jacksonville was Gloria in 1964. Therefore, it is hypothesized that in this absence of major storms Jacksonville's vegetation has experienced uninterrupted growth creating a landscape that has abundant weak and diseased trees prone to future storm damage.

Jacksonville University, the study area for this research, is in the north central region of the city. The western boundary of the campus is the St. Johns River and the eastern boundary is along a well traveled boulevard with numerous trees and buildings ranging in height from five to fifteen meters. An unforested and unobstructed golf course extends along the western edge of the campus adjacent to the river. Hence, the western aspect is open with a roughness length (z_0) of .03 m, while the eastern aspect is well sheltered with a roughness length of 1.0 m. Campus elevation is from 6 m along the river to 17 m on the eastern edge of the campus. However, the elevation change is abrupt with it all occurring within a horizontal distance of 60 m at an escarpment approximately 300 m east of the St. Johns. Consequently, the campus assumes two levels, a lower level within the St. Johns flood plain, and an upper level where all academic buildings and residential halls are located. Winds from the west have the least obstruction and are aerodynamically favored by the escarpment such that if atmospheric processes are removed westerly winds have greater potential to attain higher speeds than any other cardinal direction (Naess, Clausen, and Sandvik, 2000; Kublonski and Veblen, 2002).

Since the purpose of this analysis is to assess wind induced tree throw in an urban setting, the undeveloped regions of the campus are excluded from the study area. There are 1100 trees within the study area, plus or minus five per cent. The campus provides a typical urban landscape with a mix of open and sparsely wooded areas. The prevailing species of trees include a variety of oaks, palm, sweet gum, hickory, and pine. By far the dominant species are oak, with water oak (*quercus nigra*), laurel oak (*quercus imbricaria*), and live oak (*quercus virginiana*) being the prevailing varieties. Intermixed with the wooded areas are numerous buildings making a landscape that is typical for an urban landscape.

Tropical System Background

The predominant atmospheric processes responsible for damaging wind events in the southeastern United States are air mass thunderstorms, continental mid-latitude cyclones with associated frontal passages, nor'easters, and tropical storms (Martin and Konrad, 2006). Of these phenomena air mass thunderstorms induce the fewest high wind events, and mid-latitude cyclone and nor'easter frequency diminishes from north to south so that Florida experiences few as compared to the rest of the Atlantic coast (Martin and Konrad, 2006; Dolan, Lins, and Hayden, 1988; Colucci, 1976). Tropical systems, however, are hypothesized to be the primary source of damaging winds in Florida and a major source of damage in the Southeast. From 1899 to 2002 Florida was affected by 79 tropical storms with an average of .76 a year, the highest count in the United States. In comparison Georgia, the second state in frequency, was affected by 46 tropical systems with an average of .43 a year (Landreneau, 2003). However, due to track variability, it is not abnormal for specific locations in Florida to experience several decades without a direct hit by a hurricane. Even with these long absences it is hypothesized that tropical systems have a significant impact on the natural landscape and environmental stability in Florida.

From 1886-1992 the annual mean number of tropical storms was 8.4, and the mean number of hurricanes was 4.9 (National Hurricane Center, 2006). However, conditions favoring tropical storm formation vary between years and even assume decennial periodicity (Goldenberg et al., 2001). The active 2004-2005 tropical seasons had 45 tropical systems, 23 of which were hurricanes. More importantly, research indicates that after three decades of reduced tropical storm activity, the Atlantic hurricane region is now entering a cycle of increased storm frequency and intensity (Goldenberg et al., 2001). At the same time population growth and development in the Southeast has soared. The annual cost of tropical storm damage in the ten years prior to 2004 was 5 billion dollars annually, and that number is small compared to the damage from the 2004 and 2005 seasons (Meade, 2004). However, Pilke and Landsea (1998) indicate that when tropical storm damage is normalized by population growth, development, and inflation, the cost of hurricane damage in the late 1990's was no greater than in the 1940's, another period of heightened tropical activity. Consequently, extreme hurricane damage is not a new phenomenon, but awareness may be heightened because of the transition from a period of reduced activity to a period of increased activity.

Hurricanes Frances and Jeanne in September 2004

Hurricane Frances was the sixth tropical event in the north Atlantic during 2004 and the fifth hurricane. Its winds were 125 kt at its strongest level making it a Category 4 hurricane on the Saffir-Simpson Scale. Formation occurred on 25 August and it dissipated to an extra-tropical system on 10 September. Landfall was from the east southeast at Hutchinson Island on the central Florida coast on 5 September as a Category 2 hurricane (Fig. 1). In interior Florida it turned to the northwest into the Gulf of Mexico, and then moved north making landfall again in the Florida Panhandle. Even though it appeared that Frances was some distance from Jacksonville, it was spatially a very large storm, and the area it impacted was extensive. Consequently, Jacksonville experienced potentially damaging winds for a 35 hour period.

Hurricane Jeanne formed on 13 September 2004, and it dissipated into a tropical depression on 27 September. Like Frances, Hurricane Jeanne made landfall at Hutchinson Island on the central Florida Coast. It was a Category 2 hurricane at landfall with winds of 105 kt. Jeanne's direction of impact was from the east, and like its landfall, its path across Florida was much like that of Hurricane Frances moving inland and then turning north along the west coast of Florida (Fig. 1). Although it was not as large as Frances, it was a spatially large. It was also a very wet system exposing the interior of Florida, Georgia, South Carolina, North Carolina, and Virginia with large amounts of precipitation and local flooding.

The following characteristics made Hurricanes Frances and Jeanne similar systems; 1) landfall, 2) path through Florida, 3) intensity and winds, 4) size, 5) duration in Florida, and 6) rainfall amounts. Hence, both storms impacted the city of Jacksonville in a like manner and within three week period, providing an opportunity to compare the damage from two distinct systems in succession.

Methodology

Wind induced tree blow over was inventoried on the Jacksonville University campus and then juxtaposed with the wind profile for both Hurricanes Frances and Jeanne. All limbs and trees in excess of four inches were counted. The threshold of four inches was used as a sufficient standard to induce an insurance claim or monetary loss. Downed trees and limbs were cataloged within twelve hours of the of the storm passage to insure accountability prior to clean-up. Parameters assessed were:

1) Type of tree damage ....Uprooting, trunk failure, limb damage.

2) Direction of fall ....Measured with compass. Damaged trees often twist as they fall. This provides a good estimate.
3) Species of tree ....Some tree species are more prone to damage than others.
4) Location of damage .... Determined by GPS.
5) Spatial pattern.................... Nearest Neighbor analysis.

Wind and gust observations used here are from the Automated Surface Observing System (ASOS) at the Jacksonville International Airport (JIA), the closest (15 km) and most thorough source of wind data. Sustained winds are the hourly one minute average given in knots, and gusts are defined as increases in wind in excess of 10 kt for 5 seconds. Gust observations were especially important because these instantaneous pulses of energy are a primary source of tree blow over (Kondo, Tsuchiya, and Sanada, 2002). Frequency counts of hourly winds and gusts by direction were determined for each storm.

Specific wind parameters examined here were; 1) storm duration, where duration is defined by the first to last sustained 20 kt wind, 2) the frequency count of hours of sustained winds above 20 kt, 3) the frequency count of all observed gusts above 20 kt, 4) additionally, all hourly winds and gusts were placed in billets of 10 kt increments and counted, starting at 20 kt and going up to the highest wind gusts of 60 kt, and 5) all winds and gusts were counted by direction. Though it does not typically cause damage, 20 kt was used as threshold because it exceeds the mean wind by a factor of more than two, and it provides a signature of a distinctive atmospheric event.

Results

Hurricanes Frances and Jeanne were similar wind events for the city of Jacksonville (Table 1). The highest wind for Frances at JIA was 34 kt, and the highest for Jeanne was 35 kt. These were the only two readings at tropical storm force (34 kt) during the entire 96 hour period of both storms. Frances had a longer duration, but the fre-

Table 1. Wind characteristics observed at the Jacksonville International Airport.
A) High wind column is the highest wind observed for each storm (kt). Duration is the number hours from the first to last 20 kt reading (hrs). Hours of High Wind is the count of hours of winds above 20 kt during the duration of the storm. Gusts is the count of gusts above 20 kt for each bin given in kt.
B) The count of hours above 20 kt from the identified direction.

A.)

	High Wind	Duration	Hours of High wind	Gusts >20<30	Gusts >30<40	Gusts >40<50	Gusts >50
Frances	34	56 hrs	32	108	42	12	2
Jeanne	35	38 hrs	33	64	39	5	0

B.)

	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW
Frances	9			13	4	5		1		
Jeanne		4	4	4	3	3	1	7	3	

quency of hours that reported sustained winds above 20 kt was similar for both storms. Indeed, Jeanne had one more hour of winds above 20 kt than Frances. Gusts on the other hand were much more frequent during Frances than Jeanne. This is partly a consequence of the 20 kt wind threshold used in this research. Frances had a longer duration in Jacksonville than Jeanne, but in that period there were more hours with wind observations below the 20 kt threshold for Frances. Hence, Frances had more opportunities to induce low value gust events between 20 and 30 kt that originated from unreported winds below 20 kt. Indeed, the 20-30 kt gust bin provided a substantially higher number of gusts for Frances, with 108 gusts in this category, as compared to 64 for Jeanne. In the higher gust bins, those bins that would induce more damage, the frequency between the two storms was much closer. Nevertheless, Frances had more gusts above 40 kt and two gusts above 50 kt, while Jeanne had no gusts at JIA above 50 kt. From this it is reasonable to suggest that Frances was a

Table 2. Tree damage on Jacksonville University campus.
Species code: WO-Water Oak, P-Pine, LO-Live Oak, lo-Laurel Oak, oth-other species.

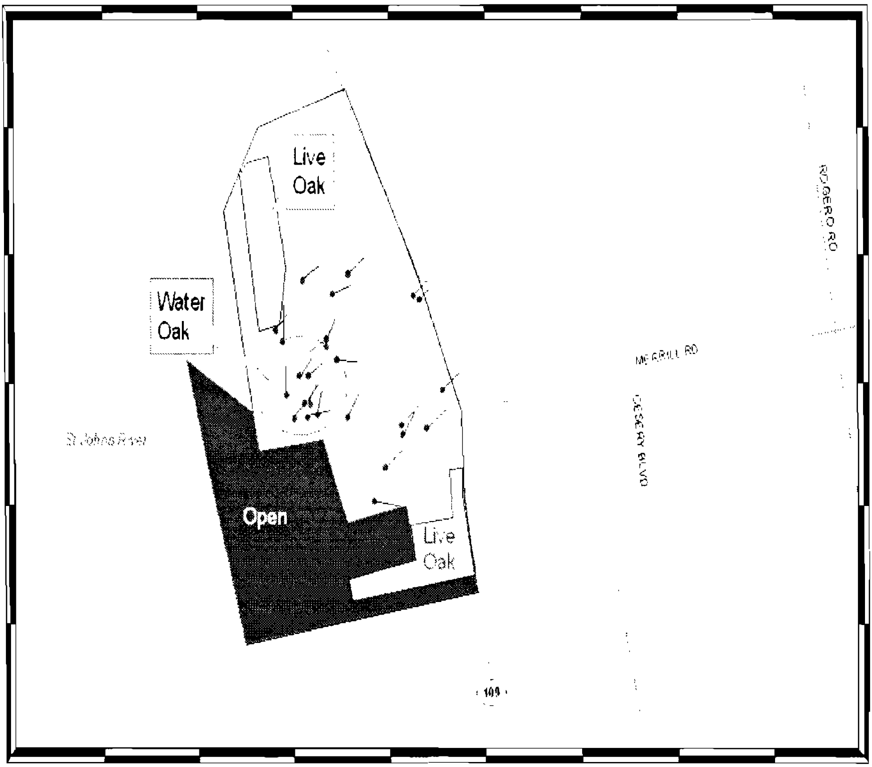
Storm	Total	Wind Direction	Decayed	Sheared	Signs of Decay	Uprooted	Species
Frances	26	NE-25 SW-1	17	2	7		WO24 /P1
Jeanne	8	Variable		8			LO6/WO2
M-burst	12	NE-12		8		4	lo4/P1/oth7

stronger wind event than Jeanne in Jacksonville, but not substantially.

High winds in Jacksonville from Frances and Jeanne began with north to northeasterly winds and ended with southerly winds. Because of its large size and slow initial speed Frances induced a longer period of winds from the northeast. However, after turning north in central Florida, Frances exited the state farther west and more rapidly than Jeanne, resulting in fewer southerly winds. In comparison, Jeanne's path rotated around Jacksonville providing an equal number of winds from north and south. During Frances 22 of the 32 hours of the winds above 20 kt were from the northeast to east and only 1 hour was from the south. Conversely, Jeanne had 17 out of 33 hours of winds with a southerly component. Because of the long fetch of water to the south of Jacksonville and the high frequency of southerly winds, substantially more flooding occurred during Jeanne, the weaker event, highlighting the importance of wind direction in storm events.

Substantially more tree damage occurred in the study area during Hurricane Frances than Jeanne (Table 2). Of the 26 trees and limbs damaged during Frances 25 fell to the southwest resulting from northeast winds. The lone tree that went down to the northeast was surrounded by numerous two and three story academic buildings, and its divergent direction may have been induced by turbulent eddies. By far the tree species affected most by Frances was the water oak (*quercus nigra*), 24 of the 26 trees damaged. The Nearest Neighbor coefficient, r, for the distribution of downed trees from Frances is .51, where 0 is perfectly clustered and 1 is perfectly random. This matches

Figure 2. Trees downed during Hurricane Frances on the Jacksonville University campus.
Spikes indicated the direction of wind (180 degrees from fall). Outlined areas indicate a dominance of tree species.



Source: Author.

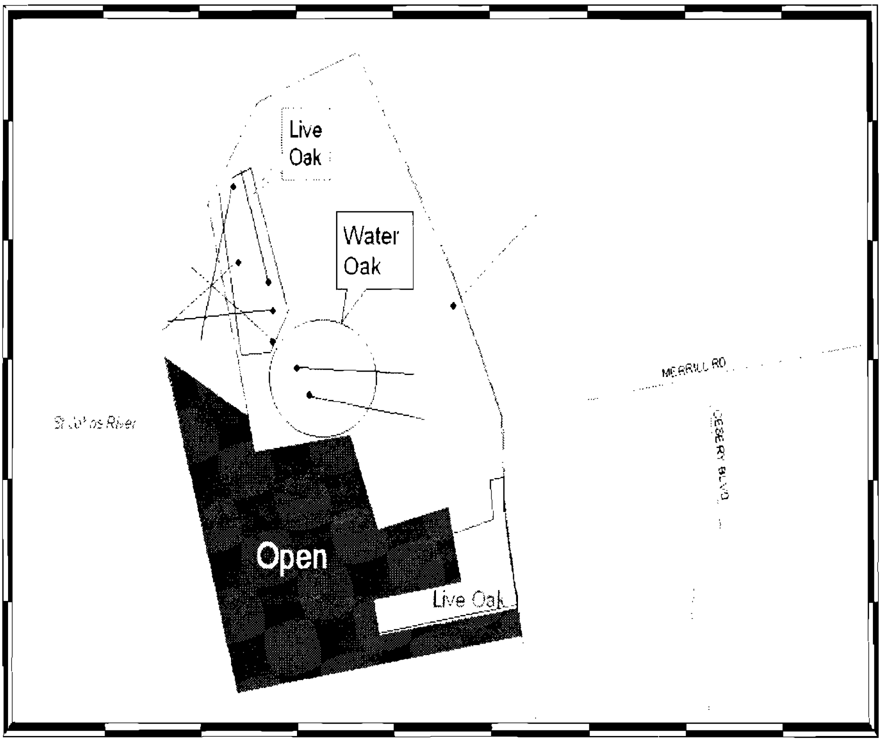
the distribution of water oaks and the pattern of damage in the study area (Fig. 2). Water oaks are dispersed throughout the campus and accordingly the down tree pattern was widespread. But there are locations where water oak is especially abundant, and in these high density areas the damage was pronounced. One such location is a water oak grove in the central part of campus circled on Fig. 2, and the observed clustering of downed trees in this area is noteworthy. Hence, the overall pattern of downed trees throughout the campus during Frances was neither clustered nor random. Importantly, 18 out of the 26 trees and limbs brought down during Frances were determined to be diseased, structurally weak, or already damaged, and the 9 remaining trees exhibited conditions of poor quality.

Tree damage during Jeanne was decidedly different. Here only 8 trees were damaged as compared to 26 in Frances, and only one tree fell, the rest were destroyed limbs. Furthermore, all damage occurred in various directions and the seven limbs that fell were in a straight line in one small area (Fig. 3). The one fallen tree occurred 400 meters from the area of concentrated damage and is considered to be an outlier. Indeed, a nearest neighbor coefficient of .81 for all the damaged trees during Jeanne indicates that the damage was more random. But if the outlier is removed that value goes to .4 indicating more clustering. Finally, the damaged species included 5 Live Oak (*quercus virginiana*), a particularly sturdy tree, but a tree that has large, heavy, and horizontal limbs.

Discussion

No trees were uprooted during Hurricane Frances, the first storm assessed here. All damaged trees were sheared at ground level, along the trunk, or at a large limb. Furthermore, all damage occurred because of decayed or deteriorating wood (Fig. 4). Since Hurricane Frances was the first tropical system to impact Jacksonville since 1964, it is hypothesized that Frances culled the old, damaged, and weak trees leaving healthier trees more capable of withstanding future high wind events. Frances induced damage also highlights the importance of tree species. Water oak are known for their short lives and poor structural quality, while other trees, such as the live oak are more preferred in built-up areas. Homeowners, city administrators, and other agencies responsible for property should know the tree species in the area under their control. However, as increased duration between catastrophic events creates a physical environment more prone to damage, it also induces a lapse of knowledge about the characteristics of trees, topography, aspect, and land cover which may

Figure 3. Trees downed during Hurricane Jeanne on the Jacksonville University campus.
Graphics as Figure 2.



Source: Author.

also contribute to storm destruction (McCure, 1993).

With Hurricane Frances' initial high wind impact from the northeast, it is not surprising that all trees and limbs, except for one, fell to the southwest. It is not possible to discern a preferred wind direction for damage from one season of activity, especially since cyclones are counterclockwise flowing phenomena. But tropical storms have their highest winds in the right front quadrant of movement, and a typical path for Atlantic region tropical systems is from east to west in the tropics, then curving north around the Bermuda High. Combining

Figure 4. Typical tree damage during Hurricane Frances.
Decomposed wood fractured at the trunk.

Source: Author.

this typical storm path with the counterclockwise flow, it is hypothesized that northeast winds may cause the greatest damage in the southeastern United States (Martin and Konrad, 2006). The prevailing direction of damage from Frances in no way validates this hypothesis, but it is compatible with it. It is also noteworthy that the greatest damage occurred from the direction that is the most protected from wind. Conversely, the least sheltered and most vulnerable direction, south-southwest to northwest, had little discernable damage, even though there were 13 hours of high winds from this directions during Jeanne.

Unlike the tree damage from Frances, the diversity of directions of downed trees and limbs during Hurricane Jeanne seems to challenge the above hypothesis. However, seven of the eight damaged trees were in a straight line and within a small area. Since all of them were damaged in different directions it is possible that the damage was induced by a small, F0-F1, tornado. This cannot be verified by either eye witness or the chaotic radar signature of an over passing tropical storm. But small and numerous tornadoes are common in the unstable and turbulent atmosphere of a tropical system, so it would not be unexpected. If it was a small tornado, then it was a random higher wind vortex whose damage signature is independent of the larger originating system.

While a goal of this study was to compare damage from two similar tropical systems impacting the same study area within a period of three weeks, a coincidental local phenomenon occurred between Hurricanes Frances and Jeanne that was worthy of inclusion in this research. After the passage of Frances on 6 September the atmosphere remained unstable for several days spawning numerous strong air mass thunderstorms. One event on the afternoon of 9 September produced a microburst within the study area. This event generated straight line, but unmeasured, high winds from the northeast. True to the characteristics of a microburst, the storm was short-lived, but strong enough to blow over twelve trees on campus in less than a one minute period, more than were damaged during the entire 36 hour period of Hurricane Jeanne. Uniquely, all of the trees damaged in this storm were healthy trees with no noticeable structural weaknesses. Indeed, seven of the trees were entirely uprooted from the ground with no wood fractures (Fig. 5). Because of the strong straight line winds and the saturated soil from several days of rain the entire healthy root systems were lifted. The microburst generated northeasterly winds and all damage was to the southwest, but since this was a non-tropical phenomenon it bears little impact on this study. Also, since microbursts leave small footprints, the high winds generated by this event were not observed at any of the local meteorological observing station, although wind gusts below 15 kt were measured at this general time frame at the JIA. Considering the extent of the damage, combined with personal observation of the event, the winds were

Figure 5. Uprooted healthy tree damaged during microburst between Hurricanes Frances and Jeanne.

Source: Author.

estimated to be well in excess of 40 kt.

From this it is surmised that the tree damage induced by the first system, Hurricane Frances, culled the unhealthy and weak trees, leaving stronger trees that were capable of resisting later wind events. When a microburst followed Frances by only three days the damage was to healthy trees, but it was caused by a combination of saturated soil and high winds. Finally, three weeks after Frances, Jeanne experienced relatively little tree damage. Additionally, if it is true that the tree damage during Jeanne was caused by a small tornadic event, as suggested here, then virtually no damage was caused by straight line tropical storm winds during Jeanne, even though it was a similar wind event as Hurricane Frances.

Conclusion

As observed with Hurricanes Frances and Jeanne, locations even on the periphery of the storm can have substantial damage. Jacksonville, Florida experienced only minimum tropical storm winds, and then only two times out of 96 hour period. Yet, out of a population of 1100 trees in one urban setting 34 trees were damaged or destroyed, 26 in the initial storm, 3 per cent of the population. Since tropical systems are frequent in the southeast United States this type of damage represents an important component of the natural environment. Tropical storms cull out weak vegetation that may either be already diseased, decayed, or dead. In the case of the 2004 tropical season in Jacksonville, Florida, the first system, Frances, targeted the weak and deteriorating trees leaving strong vegetation that could withstand the following wind events.

However, tropical storm impact in an urban landscape causes substantial damage to human development, and it is important for residents in areas prone to tropical systems to have an understanding of the potential threats. The damage from Hurricane Frances and Jeanne on the campus of Jacksonville University indicates that having an understanding of tree species is critical when preparing for tropical storm damage. In the case of the southern coastal regions of the south, water oaks are especially vulnerable, and home owners would be wise to determine their position, age, and condition if present on one's property. The damage from the 2004 season in Jacksonville also suggests further research, especially in terms of prevailing directions for wind damage. The dominant direction of damage in this one season was from northeasterly winds. If this could be validated through longer term analyses the benefit to Southeastern communities would substantial.

Human memory is typically less than a generation, while climate patterns function in blocks of decades, centuries, millennia, and longer. Population in coastal regions of the southeastern United States has exploded in the past few decades, and now that a new cycle of increased tropical storm activity has been breeched the public seems to only accept the view that it is anomalous, when in reality tropical systems are frequent phenomena in the Southeast and an important component of the landscape.

References

Alexander, R. R. 1964. Minimizing wind fall in clearcuttings in spruce-fir forests. *Forest Science* Vol. 10, 130-142.

Clinton, B. D., and C. R. Baker. 2000. Catastrophic windthrow in the southern Appalachians: characteristics of pits and mounds and initial vegetation response. *Forest Ecology and Management* 126, 51-61.

Colucci, S. 1976. Winter Cyclone frequency over the Eastern United States and adjacent western Atlantic. *Bulletin of the American Meteorological Society* 57, 548-553.

Dolan, R., H. Lins, and B. Hayden. 1988. Mid-Atlantic Coastal Storms. *Journal of Coastal Research* 4, 417-433.

Everham, E. M. and P.W. Brokaw. 1996. Forest damage and recovery from catastrophic wind. *The Botanica Review*, 62, n2, p113.

Foster, D. R. and E. R.Bose. 1992. Patterns of forest damage resulting from catastrophic wind in central New England *Journal of Ecology*, 80, 79-98.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, and W. M. Gray. 2001. The Recent Increase in Atlantic Hurricane Activity: Caues and Implications. *Science* 293/5529: 474-480.

Kramer, M. C., A.J. Hansen, M.L. Tuper, and E.J. Kissenger. 2001. Abiotic controls on long term windthrow disturbances and temperate forests dynamics in southeast Alaska. *Ecology* 82, 2749-2768.

Kondo, K., M. Tsuchiya. and S. Sanada. 2002. Evaluation of the effect of micro-topography on design wind velocity. *Journal of Wind Engineering and Industrial Aerodynamics* 90, 1707-1718.

Kublonski, D. and T.T. Veblen. 2002. Influence of fire history and topography on the pattern of a severe wind blowdown in a Colorado subalpine forest. *Journal of Ecology* 90, 806-819.

Landreneau, D. 2003. Atlantic tropical storms and hurricanes affecting the United States: 1899-2002. National Weather Service Forecasting Office / NOAA.
http://www.srh.noaa.gov/lrh/research/tropical.htm

Landsea, C. W., R. A. Pielke, Sr., A. M. Mestas-Nunez, and J. A. Knaff.1999. Atlantic Basin Hurricanes: Indices of Climatic Changes. *Climatic Changes* 42, 89-129.

Martin, J. and C. K. Konrad. 2006. Directional Characteristics of Potentially Damaging Wind Gusts in the Southeast United States. *Physical Geography*.

McCure, H. 1993. Ten ways to reduce job site wind damage. *Professional Builder* 67, 28.
Meade, C. 2004. Strengthening windstorm hazard mitigation: An examination of public and private efforts. RAND Report to the U.S.

House of Representatives Committee of Science

Naess, A., P.H. Clausen, and R. Sandvik. 2000. Gust factors for locations downstream of steep mountain ridges. *Journal of Wind Engineering and Industrial Aerodynamics* 87, 131-147.

National Hurricane Center / National Oceanic and Atmospheric Administration. 2006. Tropical Cyclone Climatology http://www.nhc.noaa.gov/pastprofile.htm

National Oceanic and Atmospheric Administration / Coastal Services Center. 2004 Storm Track Query. http://hurricane.csc.noaa.gov/hurricane/index.htm

Pielke R. A. Sr, and C. W. Landsea. 1998. Normalized Hurricane Damages in the United States: 1925-95. *Weather and Forecasting* 13, 621-631.

Swanson, F. J., T.K. Kratz, N. Caine, and R.G. Woodmansee. 1988. Landform effects on ecosystem pattern and processes. *Biosciences* 38, 92-98.

United States Census Bureau. 2000. Florida by Place. www.factfinder.census.gov.

Veblen, T. T., T.D. Kulakowski, K.S. Eisenhart, and W.L. Baker. 2001. Subalpine forest damage from a severe wind storm in northern Colorado. *Canadian Journal of Forest Research* 31, 2089-2097.

Wesley, D. A., G. Paulos, M. Meyers, J. Snook, and A. Jadson. 1998. Observation and forcing mechanisms during the October 1997 Front

Range blizzard and forest destruction. American Meteorological Society: Eighth Annual Conference on Mountain Meteorology. Flagstaff, AZ.