J4.5 CLIMATOLOGICAL, METEOROLOGICAL, AND SOCIOLOGICAL IMPLICATIONS FOR THE LARGE NUMBER OF FATALATIES FROM CENTRAL FLORIDA DRY SEASON TORNADOES DURING EL NIÑO

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1. INTRODUCTION

During the overnight hours of 22-23 February 1998, 42 people died in Central Florida in mobile homes and campers from violent tornadoes that formed around midnight on the 22nd and moved rapidly across the peninsula. In the early morning hours of 2 February 2007, 21 people died in Central Florida from violent tornadoes under almost identical circumstances. These deaths occurred despite tornado watches and warnings with long lead times and attempts by the National Weather Service (NWS) and the Media to highlight the overnight tornado threat and emphasize the value of NOAA All Hazard Weather Radios to alert people if they were asleep.

Due to the magnitude of the human loss in these tornado tragedies and others in the southeastern United States in recent years, research into their social science aspects has been conducted. Simmons and Sutter (2005, 2007, and 2008), Sutter and Simmons (2009), and Ashley et. al. (2008) have noted such factors as increased vulnerability of manufactured housing dwellers to violent tornadoes in the overnight hours when warning receipt and confirmation are more problematic, and with the occurrence of these tornado outbreaks outside of the “traditional” tornado season. Sutter and Simmons (2009) noted that the manufactured housing problem has a strong regional component, and that Florida stands out as an outlier with a high number of tornado fatalities in mobile homes. They suggest that a regional focus on warning performance, communication, and dissemination of warnings and other policy-related factors might be effective.

The authors agree that such a regionally focused approach is best. Indeed, it is the authors’ opinions that these recent studies actually underestimate the vulnerability of Central Florida to violent tornadoes. A focus on the social science aspects of the challenge, which is necessary, needs to be combined with a more thorough understanding of the physical science issues and the unique regional climatological and meteorological factors involved. These aspects have a bearing on conclusions drawn from assumptions about the nature of the tornado phenomena in social science research.

Nothing illustrates Florida’s manufactured housing and tornado problem more profoundly than pictures of damage from the three deadliest extratropical cyclone dry season (November 1 – April 30) tornado outbreaks (Figures 1a, b and c) and the deadliest tropical cyclone tornado outbreak in its history (Figure 1d, Hurricane Agnes, June 1972). The iconic symbols of the most tragic tornado outbreaks are manufactured housing frames wrapped around trees. These four outbreaks were responsible for 42% of all tornado fatalities in Florida history.

All four of these events occurred from around midnight to 9 AM and three of the four events occurred during El Niños. The deadliest (1a) and second deadliest (1b) events occurred in the past 11 years in February during El Niños killing 62 people in manufactured homes and campers, and one in a car within a 30 nm radius of Sanford in Central Florida. That’s 63 Floridians lost in a matter of a few hours, and is by far more than all the people killed in Florida from the direct effect of hurricane winds since at least 1950! Since 1882, 206 people have died in Florida tornadoes (Hagemeyer, 2009) and 35% of those deaths occurred in the past 11 years. Tornado deaths are not going down in Florida; they are going up.

Graphs of annual Florida tornado fatalities and population since 1900 are shown on Figure 2a. The spikes in tornado deaths from major outbreaks stand out starkly, and the trend in tornado deaths has steadily increased, as has the population. Figure 2b illustrates that the tornado death rate in Florida is technically falling as a result of rapid population growth, rather than a reduction in tornado deaths. As Florida’s rapid population growth slows, the death rate may increase. But, the issue is not death rate, which is a misleading statistic from the impact perspective. It is the impact in lives lost from these terrible events that is important, not the tornado deaths divided by the population. The “death rate” masks the real human tragedy that society has to deal with over the relatively small area of Central Florida. Without fundamental changes in the way the challenge of reducing tornado mortality in Florida is addressed, it should not be surprising to see tornado outbreak death tolls surpass 50 people in the coming decades.

Another way to look at the challenge is illustrated by Figure 3 which shows the 10 deadliest dry season tornado events in Florida history and the El Niño Southern Oscillation (ENSO) phase of the season. This

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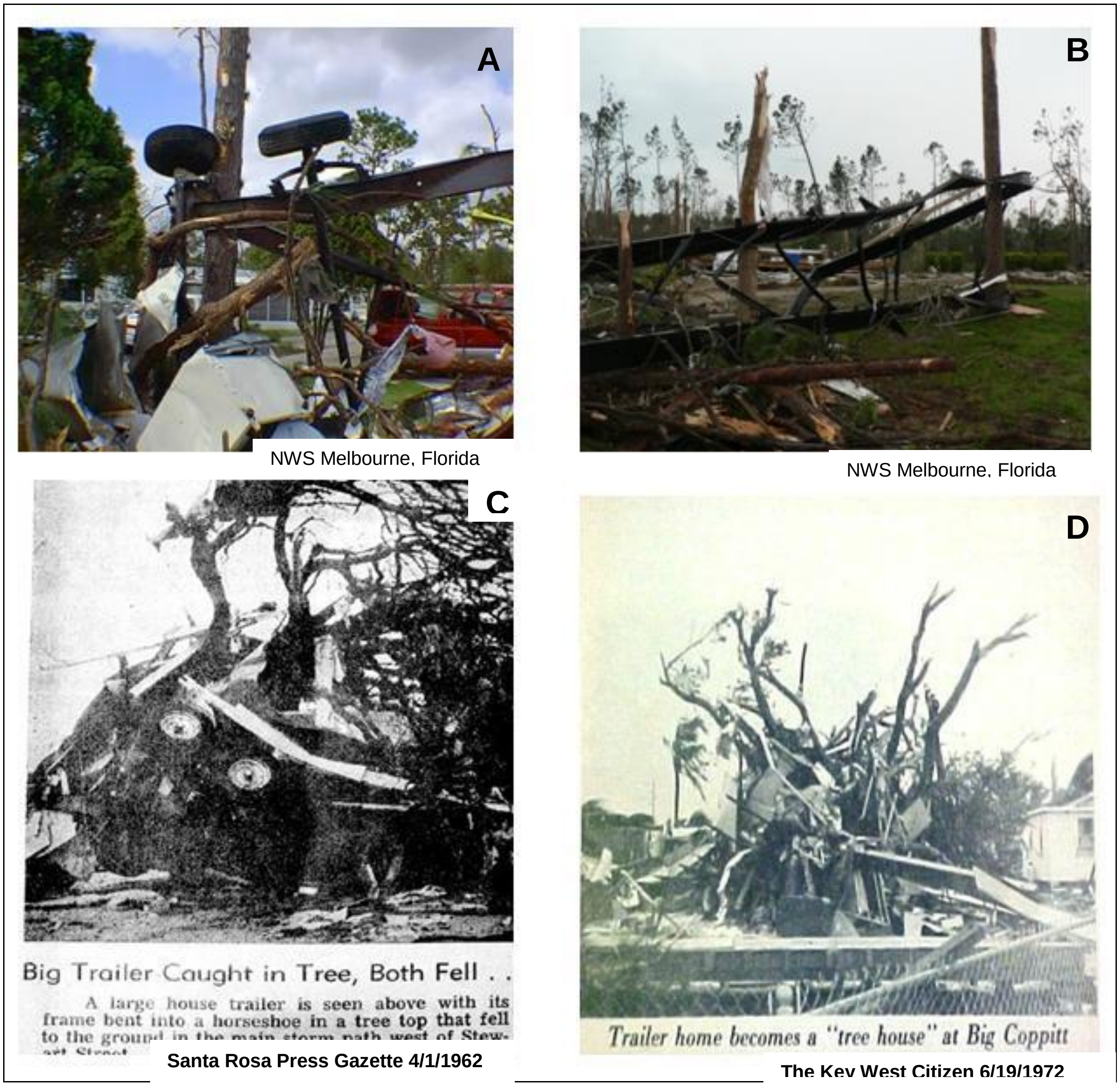
graphic was developed by the authors for educational outreach in preparation for the predicted 2009-10 El Niño. These 10 events are responsible for almost 80% of all known tornado deaths in the dry season. Seven of the ten events were during El Niños, and six events occurring over the Florida peninsula (at or south of 30° N) were during El Niños. Ninety-one deaths occurred during El Niño, 24 during neutral ENSO, and 4 in the one La Niña occurrence. However, most striking is that all four of the events that took place over Central Florida from roughly Tampa/St. Petersburg to Orlando and Daytona Beach occurred during notable El Niños. Reported deaths do not tell the whole story of vulnerability. During the extreme El Niño of 1982-83, two killer tornadoes caused four deaths in Central Florida during the dry season. But, 14 ≥F2 tornadoes caused injuries; the most ever, and the greatest potential for impact on record – fortunately, heavily populated areas were not struck.

The fact is that only a handful of high impact tornadoes during El Niños have caused the vast majority of tornado fatalities in Central Florida as violent tornadoes strike people living in high-density vulnerable housing in the overnight hours. This is really not a difficult challenge to identify, and this knowledge presents a clear opportunity for the social and physical sciences to make a difference through efforts to prevent greater tornado disasters in the future. However, seriously addressing this challenge is a daunting task. As social science research on these deadly tornado outbreaks progresses, so must research into climate variability and the meteorological aspects of tornado outbreaks to improve education, mitigation, situational awareness, and warning decision-making to advance the cause of reducing tornado fatalities in Central Florida.

The authors believe El Niño is a significant influence on climatic variability in Central Florida during the dry season, and that its prediction offers a powerful mitigation and preparedness advancement to help avoid a future spike in tornado deaths as shown on Figure 2a. However, attribution of climatic and meteorological extremes to El Niño remains a controversial subject. The strong physical relationship between the ENSO and peninsular Florida tornado activity needs to be better understood and communicated to decision-makers in a manner that they can plan for and some new ideas will be presented. This is important because conflicting messages and "hyping" reduce the chances that people will take appropriate action to develop all-hazard plans.

The concept of "peak tornado season" needs to be reframed regionally and in the context of impact. An impact-based tornado climatology which clearly defines the tornado scenarios of greatest importance in Florida will be presented. While it may seem obvious that tornadoes at night are potentially more deadly, there appears to be meteorological and climatological factors that result in a greater likelihood of violent tornadoes at night during the Florida dry season. The latest results will be presented.

Central Florida is an area where the convergence of climate variability and societal vulnerability can be extreme, during El Niño. This paper will show that the likelihood of multiple tornado deaths in Central Florida during the dry season is highly correlated with El Niño. However, the attribution of tornado deaths in the aftermath of these devastating events to El Niño or an "Act of God" or "nature" does not address the root cause of the carnage which the authors have seen firsthand during damage surveys – the reality of highly vulnerable housing. There are relatively simple mitigation methods and preparedness concepts that can be implemented to improve safety, given the knowledge of the likelihood of violent nocturnal tornados during El Niño. But plans must be made and executed! An attempt at a comprehensive summary of the relevant issues will be presented, along with ideas on what can be done to reduce tornado deaths in Central Florida in light of the complex climatological, meteorological, and sociological issues at play.



NWS Melbourne, Florida

NWS Melbourne, Florida

Big Trailer Caught in Tree, Both Fell . .

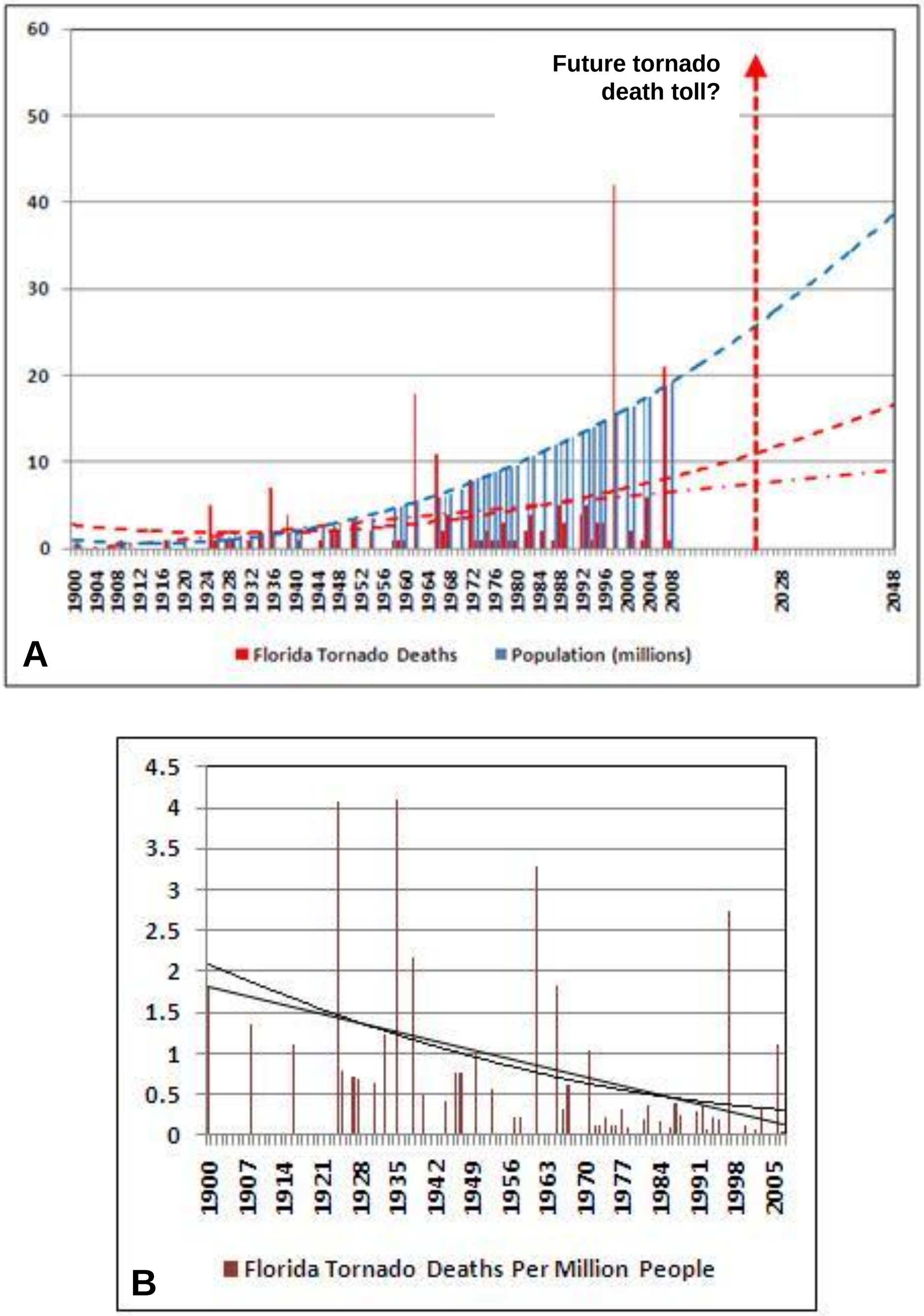
A large house trailer is seen above with its frame bent into a horseshoe in a tree top that fell to the ground in the main storm path west of Stew-

Santa Rosa Press Gazette 4/1/1962

Trailer home becomes a "tree house" at Big Coppitt

The Key West Citizen 6/19/1972

Figures 1a-d. Images from the three deadliest dry season extratropical cyclone tornado outbreaks in Florida history on February 22-23, 1998 (42 dead, **A**), February 2, 2007 (21 dead, **B**), and March 31, 1962 (17 dead, **C**); and the deadliest tropical cyclone tornado outbreak on June 17-18, 1972 (7 dead, **D**). These four events account for 42% of tornado deaths in the history of Florida.



Figures 2a-b. Florida population (blue, in millions) and tornado deaths (red) by year from 1900 to 2008 (A) with second order polynomial projections out to 2048 as dashed lines; linear tornado death trend as dashed-dot line, and (B) Florida tornado death rate per million people with second order polynomial and linear trends indicated. Recent news reports indicate Florida's rapid population growth may be slowing and the extrapolation of population on 2a is likely unrealistic.

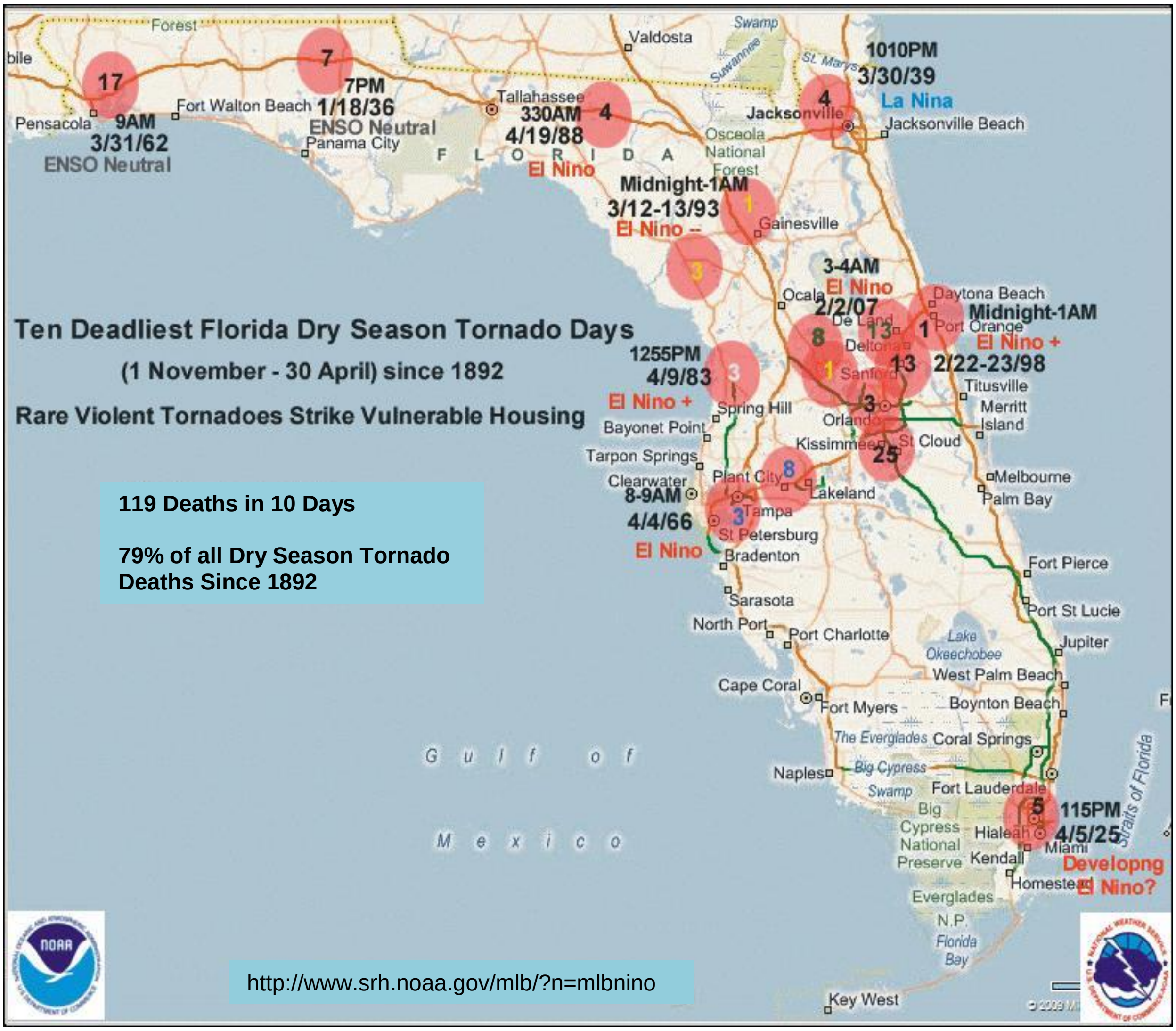


Figure 3. Plots of the approximate dates, times, and locations of killer tornadoes and their associated fatalities for the 10 deadliest Florida dry season tornado outbreaks. These 10 events are responsible for nearly 80% of all known dry season tornado deaths in the history of Florida. ENSO phase is indicated below the date of each outbreak with El Niño conditions in red, La Niña in blue, and neutral in black.

2. AN IMPACT-BASED PENINSULAR FLORIDA TORNADO CLIMATOLOGY

The lead author and colleagues at NWS Weather Forecast Office (WFO) Melbourne, Florida have studied Florida tornadoes and outbreaks of significant tornadoes in detail since 1990. Indeed, the operational application of studies such as Schmocker et. al. (1990), Hagemeyer and Schmocker (1991 and 1993), Hagemeyer and Matney (1993a&b), Hagemeyer and Hodanish (1995), Hagemeyer (1996, 1997a, 1997b, 1998a, 1998b, 1999a, and 1999b), Spratt et. al (1997), and Hagemeyer and Spratt (2002) has generally resulted in excellent situational awareness and significant lead times for tornado forecasts during historic tornado outbreaks over the years. Schmocker et. al (1990) first documented the significance of strong and violent morning tornadoes from January through March that outnumbered afternoon tornadoes and were responsible for most deaths and injuries in Central Florida. Mean tornado touchdown time was found to be before noon for January through March, but in the afternoon for all other months. Hagemeyer and Schmocker (1991 and 1993) reiterated that the winter morning tornadoes were a significant and unique regional forecast challenge.

They found that the environment of morning tornadic thunderstorms was highly sheared and that storms would tend to be low topped, fast moving, and difficult to detect with existing conventional radar. In 1991 there was seldom any lead time for these tornadoes unless they were spotted and reported in time to warn downstream counties. They went on to note: *"The NEXRAD/WSR-88D's high resolution reflectivity, combined with the ability to slice through a storm and diagnose the mesoscale dynamic environment, offers a real promise of improving detection of this type of storm."* The NWS Melbourne WSR-88D became operational in the fall of 1991 and has delivered on the promise of greatly improved tornado warnings. The WSR-88D was instrumental in early tornado detection for the two deadliest tornado outbreaks in Florida history in February 1998 and 2007, and certainly gained many minutes of lead time over old technology radars and no doubt saved lives. But, the resulting high death tolls are troubling.

Reliable warning lead times of 20 minutes or longer seem attainable for these types of tornadoes, but the value of these early warnings may be offset by the early morning occurrence and lack of receipt. Simmons and Sutter (2005) studied the effect of the WSR-88D radar deployment on tornado warnings and fatalities and found it indeed had a significant positive impact. However, they also found that tornadoes occurring during the day produce 66% fewer expected fatalities than an equivalent storm during the night.

NWS meteorologists in Florida are now generally well aware of the greater overnight tornado threat and typically staff for greater workload on midnight shifts in advance of winter storms. Attempts to get this information out to the public have gone on for almost 20 years; even more urgently since 1998. But it has not taken root in the Florida psyche perhaps due to rapid population growth and the lack of local/regional perspective on Florida weather by new arrivals and news reporters that have high turnover. In the wall-to-wall media coverage following the tornado outbreak that killed 21 people in Central Florida on February 2, 2007, the lead author heard varying versions of the following statement by reporters and those being interviewed: *"We expect these kinds of tornadoes in the summer, but not in the middle of the winter at night!"* The author had a frustrating sense of déjà vu – of hearing the same comments following the February 1998 tornado outbreak that killed 42 people. The problem is that this belief is quite wrong in Florida – it is a myth that persists. Generalizations of Midwestern and "tornado alley" tornado anecdotes proliferate in Florida to this day. The challenge of understanding deadly dry season nocturnal tornadoes and using the information in hazard planning is fundamental to reducing fatalities. To develop information that can be used in educational outreach to the media and general audiences, an update of the Florida tornado climatology from the early 1990s in a clear impact-based way is needed to show the relevant issues relating to tornadoes and tornado fatalities.

Killer tornadoes are uncommon in Florida. The lead author has documented every killer tornado in Florida history (Hagemeyer 1996) and updated the data annually through 2008 (79 tornado cases with 206 deaths). These killer tornado events occur in three meteorological synoptic settings: the warm sectors of extratropical (ET) cyclones in the dry season (54 cases, 161 deaths), outer rainbands in the right front quadrant of tropical cyclones (19 cases, 36 deaths) primarily in the wet season (Hagemeyer 1997 and Spratt, et al 1997), and, very rarely, local/mesoscale diurnally-forced convection in the wet season in the absence of any significant low pressure system (six cases, nine deaths or 4% of total). Figure 4 shows the monthly distribution of the tornado deaths associated with these three scenarios. The significance of the dry season killer tornadoes with ET cyclones in winter and early spring is very clear, as is the secondary spike in killer tornado activity with tropical cyclones during the peak of the hurricane season in September. The minimum in deadly tornadoes occurs in July and August with only three deaths. However, these are the same months with the most thunderstorm activity and lightning fatalities in Florida on average. Perhaps that is a significant clue to the source of the summer as deadly tornado season perception. However, the greatest tornado impact is found in well-defined weather scenarios and this knowledge should improve situational awareness and preparedness. This paper will focus primarily on the most impacting tornado scenario, the dry season ET cyclone.

To update the tornado impact climatology, all tornadoes in the NWS Storm Prediction Center's (SPC) database for the Florida peninsula at or south of 30º N were analyzed. Monthly and hourly distributions of the 2,212 tornadoes reported between 1950 and 2008 are shown on Figures 5a-b. These simple climatological analyses reinforce the perception that the afternoon in the summer or wet season is the "tornado season." The peak months of tornado occurrence are indeed June, July, and August, and the peak time of occurrence is from 2 to 5 PM around the time of peak diurnal heating. There is a uniformly distinct minimum of reported tornadoes between 10 PM and 2 AM.

Figure 6a shows the F-Scale distribution of the 2,105 Florida tornadoes with F-scale ratings. The vast majority of the tornadoes (1863, 89%) are weak (F0-1), and 11% (242) are strong and violent (≥ F2). The weak tornadoes have accounted for just 3% of tornado deaths, while strong and violent tornadoes have been responsible for 97%. The ≥ F2 tornado distribution by month (Fig. 6b) mirrors the most impacting tornado scenarios on Figure 4 with a maximum in February and March. There are more ≥F2 tornadoes in January than in May, July, and September. The maximum in June is the result of an unusually large number of tornadoes associated with Hurricane Agnes and three other tropical/hybrid cyclones. There have been only 28 tornadoes rated ≥F3, with 21 occurring in dry season ET cyclones, 7 in tropical cyclones, and none in the wet season non-cyclone weak synoptic regime.

An impact-based tornado climatology of death and injury must focus on ≥F2 tornadoes. There are well-documented concerns about the veracity of Fujita Scale (F-Scale or **F**) and Enhanced Fujita Scale (EF-Scale or **EF**) ratings in tornadoes over time (). The old F-scale and improved EF-scale (implemented on February 1 2007) are similar for F2/EF2 criteria. So, in considering impacts they should be historically comparable and the term ≥F2 is used for strong and violent tornadoes.

The ≥F2 tornadoes were stratified by season: wet (May-October) and dry (November-April), and also by time of day (Figures 7a-b). More than half of the ≥F2 tornadoes occurred in the dry season, yet they caused four times as many deaths as those in the wet season. Most of the dry season strong tornadoes occurred between midnight and noon, while those in the wet season had a clear afternoon maximum, similar to the diurnal distribution of all tornadoes (Figure 5b). However, the few strong tornadoes that did occur between midnight and noon during the wet season were more likely to cause deaths, and were also twice as likely to cause severe damage (≥F3) than the afternoon tornadoes.

The dry season ≥ F2 tornado hourly distribution (7b) displays peaks between 12PM and 2PM, around 12AM, and 08AM. There is an unusual minimum of activity from 3PM to 5PM following the time of peak diurnal heating – the exact opposite of the wet season. Indeed, there has never been a ≥ F2 tornado in the dry season between 4PM and 5PM in 59 years of record. There are more ≥ F2 and ≥F3 tornadoes and fatalities in the dry season overnight period than all other periods. Despite a near equal ratio of killer tornadoes, 83 deaths occurred in the 12 hours between 11PM and 11AM, and only 12 deaths occurred in the 12-hour period from 11AM to 11PM. This result certainly speaks to the greater vulnerability of violent tornadoes occurring late at night and in the morning when most people are sleeping or before most people would be aware of an imminent severe weather threat as they begin their day. However, from a meteorological perspective, the lack of significant tornadoes in the afternoon and the greater number in the overnight and morning hours are remarkable, and even more striking than in the original study of Schmocker et. al (1990).

To gain insight into the relationship of El Niño to tornado impact, the hourly distribution of the ≥F2 tornadoes during the seven strongest El Niño dry seasons since 1950 (Fig. 8) was analyzed. This 7-year subset of the 59 years of data contains 26% of the ≥F2 dry season tornadoes, but is responsible for 83% of the deaths versus 17% in the other 52 seasons! The diurnal difference between the AM period with 24 ≥F2 tornadoes and the PM period with 14 is more striking than for the entire dry season (see fig. 7b). There were 74 tornado deaths from 11PM to 11AM and only 5 from 11AM to 11PM. Incredibly, the seven El Niño dry seasons are responsible for 90% of the overnight and morning dry season deaths since 1950, with the other 52 seasons responsible for 10%. The lack of violent tornadoes in the afternoon in the El Niño years is striking, with only three tornadoes reported in the period from 2PM to 8PM. While it is understandable why a given tornado would be potentially more deadly at night as documented in many recent studies, it also appears that ≥F2 tornadoes are more common and stronger overnight and in the morning than during the afternoon and early evening, which makes the vulnerability issue all the greater.

Studies of vulnerability from nocturnal tornadoes such as Ashley et al. (2008) do not account for significant seasonal and regional tornado variability. Indeed, they do not show a high percentage of nocturnal tornadoes for Florida because they considered the percent of all tornadoes that are nocturnal. So the large number of weak afternoon tornadoes included from the Florida wet season masked the true nature of the problem. However, this low relative percentage of nocturnal total tornadoes may have a bearing on the perception of the public as to when the tornado impact is greatest as the nighttime tornadoes are rarely observed or captured on video.

When tornado outbreaks occur during the overnight/morning period, they have a tendency to produce multiple ≥F2 touchdowns from fast-moving and long-lived supercells. To investigate further, the mean and median path widths and path lengths for the 240 ≥F2 tornadoes with data are shown on Table 1 by time of day and season. The average path length for the dry season AM tornadoes was the highest at 9 nm. The fact that the median was actually much lower than the mean indicates the influence of long-track tornadoes in the dry season AM period. There is not a great difference between dry season AM and PM and wet season AM median track lengths and median path widths. However, there are striking differences between the wet season PM median tornado path length of only 0.3 nm and path width of 30 yards (the smallest of all populations) and the other three periods. This indicates that the majority of the wet season ≥F2 tornadoes in the PM period are small and very short lived; certainly a factor in the very low fatalities in this period compared to the other three periods.

The path lengths and widths of the 38 ≥F2 El Niño tornadoes shown on Figure 8 were also analyzed. The average path length for the AM tornadoes in the seven strongest El Niños was the highest of all at 21.4 nm. Only 10 ≥F2 tornadoes occurred in the 7 strongest La Niñas since 1950, with average path lengths of 3.2 nm. This small sample size included five tornadoes from 12AM-12PM and five from 12PM-12AM.

The profound influence of a relatively few El Niño tornadoes on the Florida tornado death climatology is fascinating. When the 20 longest-tracked dry season ≥F2 tornadoes were examined, 13 were during El Niños on 9 separate days, 6 were in neutral conditions on 3 separate days, and only one was during a La Niña. The 13 El Niño tornadoes had a mean track length of 41 nm, track width of 207 m and an F-scale of 2.5, and they produced 73 deaths. Eleven of the 13 El Niño tornadoes occurred between 11PM and 830 AM. The six neutral tornadoes had mean track length of 35 nm, width of 103m, F-scale of 2.0 (all F2s), and caused 3 deaths. Two tornadoes in the April 4, 1966 outbreak in Central Florida had outlier path lengths of 136 nm and 123 nm that today are considered unrealistic by the authors. Reviewing the press reports of the time, it appears likely that rather than two tornadoes with paths over 100 nm each, there were perhaps four to six tornadoes produced by two cyclical parent supercells with paths lengths in the range of 10s of miles similar to the results of the detailed surveys of the February 1998 and 2007 outbreaks. Correcting this would not substantively change the results noted above other than to increase the number of long-track tornadoes during El Niño.

Simmons and Sutter (2007, 2008) found that tornadoes are more dangerous in the late fall and winter and that expected fatalities are higher in this cool “off peak” season. They attributed this largely to the lack of awareness of tornado risk in the winter, which, as previously stated, is generally true. However, from a meteorological and climatological perspective, Central Florida tornadoes are indeed on average stronger in the dry (cool) season, especially during El Niño conditions, and have a profound nocturnal tendency. Ashley et. al. (2008) noted the highest nocturnal fatality rates in the southern tier of states, despite having relatively few tornadoes compared to the warm season. But they did not focus on significant tornadoes at regional or sub-state scales or the fact that tornadoes are on average stronger during the nighttime period.

This updated climatology confirms that there are two significant tornado impact scenarios in Florida, ≥F2 tornadoes associated with tropical cyclones and ≥F2 tornadoes associated with ET cyclones in the dry season. The great majority of dry season Central Florida tornado deaths since 1950 are a result of nocturnal long-tracked tornadoes during El Niños. They are consistently wider and stronger, move faster, and last longer than tornadoes at other times in Central Florida, and they occur most often overnight or in the morning. These are not “off-hour” or “off-season” tornado events, but a fundamental part of the regional environment of Central Florida and are important observations that need to be considered in future sociological studies. Clearly, afternoons in June, July, and August should not be considered the “Impact Tornado Season” as that is the least likely time for significant tornadoes. These tornadoes should be parsed out in studies relating to vulnerability rather than put in with significant impact tornado populations. This knowledge can be powerful for situational awareness and preparedness if the message can be heard and adopted into hazard plans as there is a high probability of identifying such dangerous tornado scenarios in advance. Deadly tornadoes can occur in any season, but the odds are truly much higher and the potential impact greater during El Niño. The next section will present the physical meteorological and climatological connection.

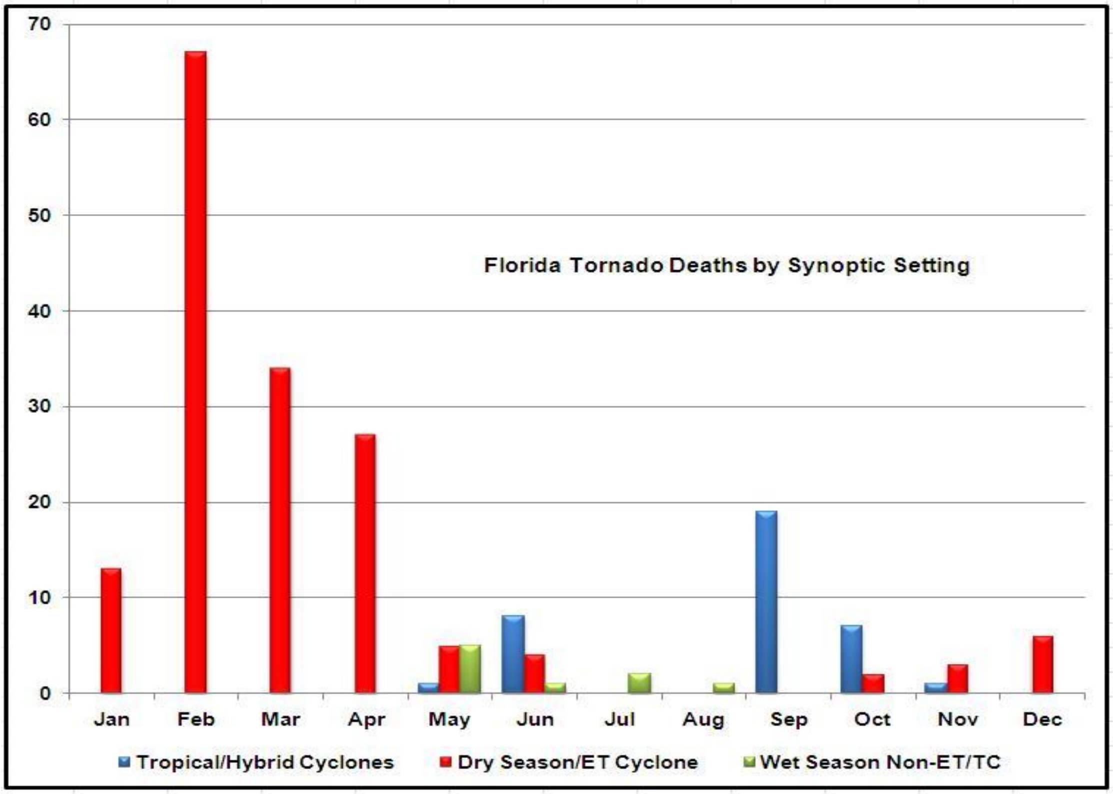
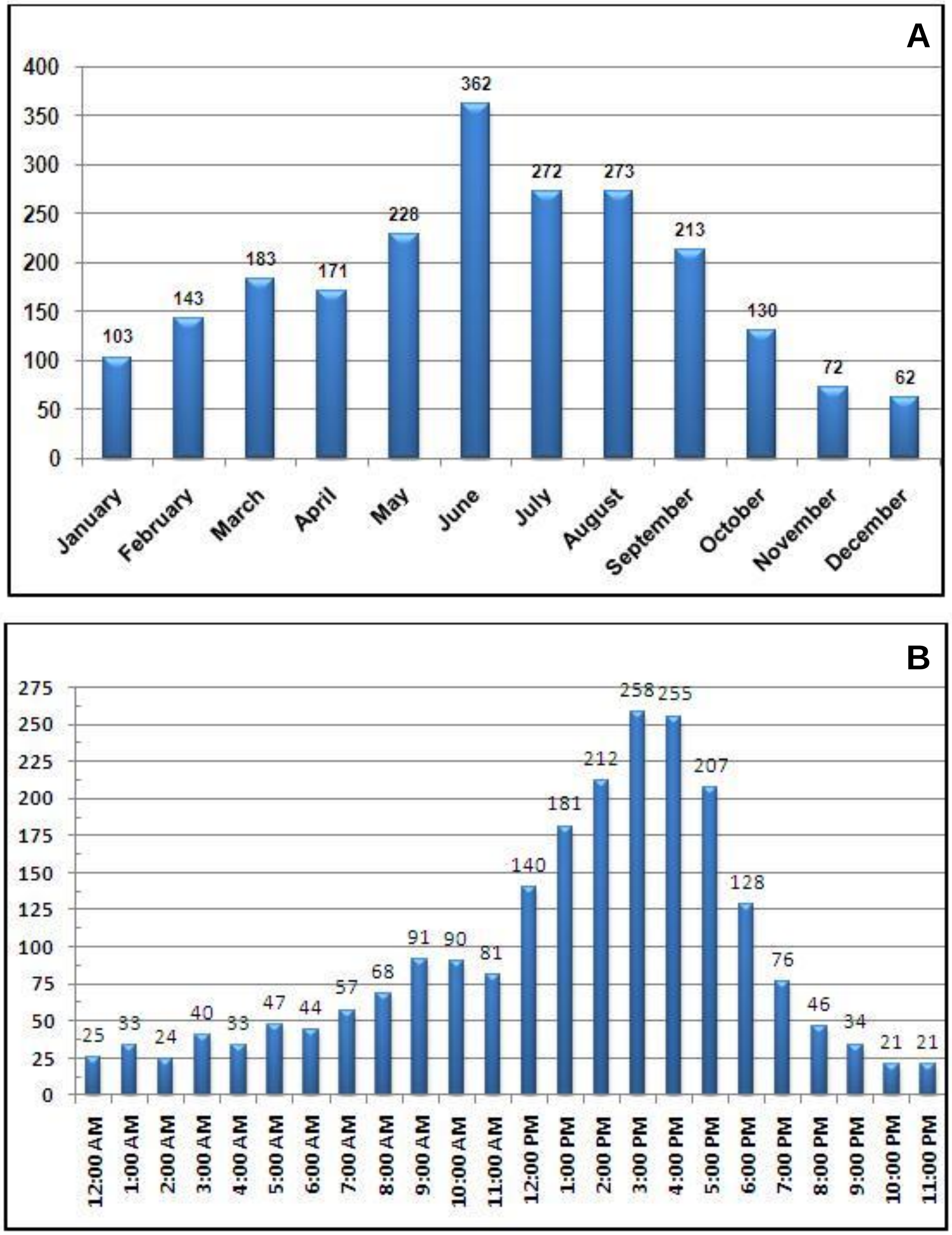
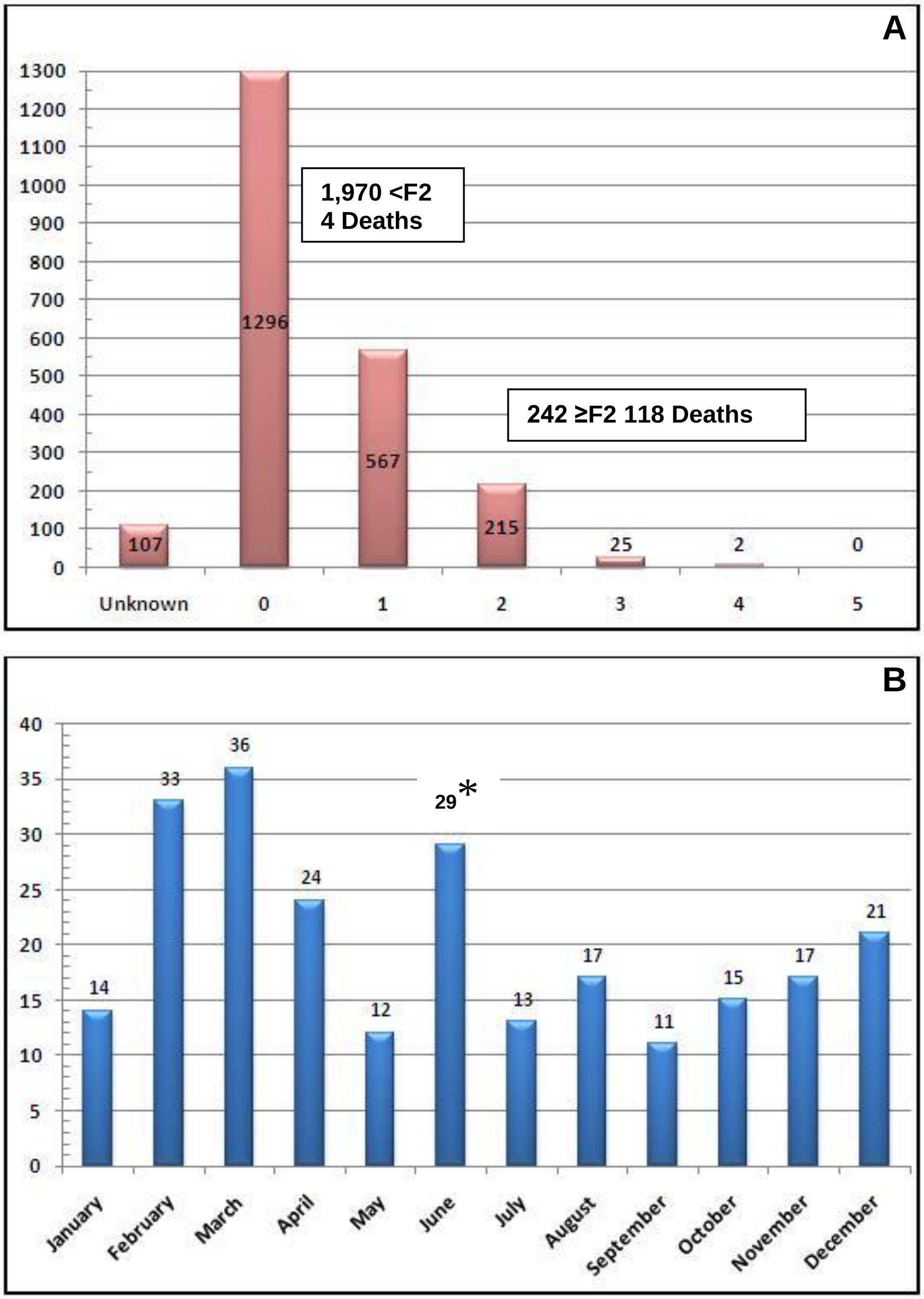


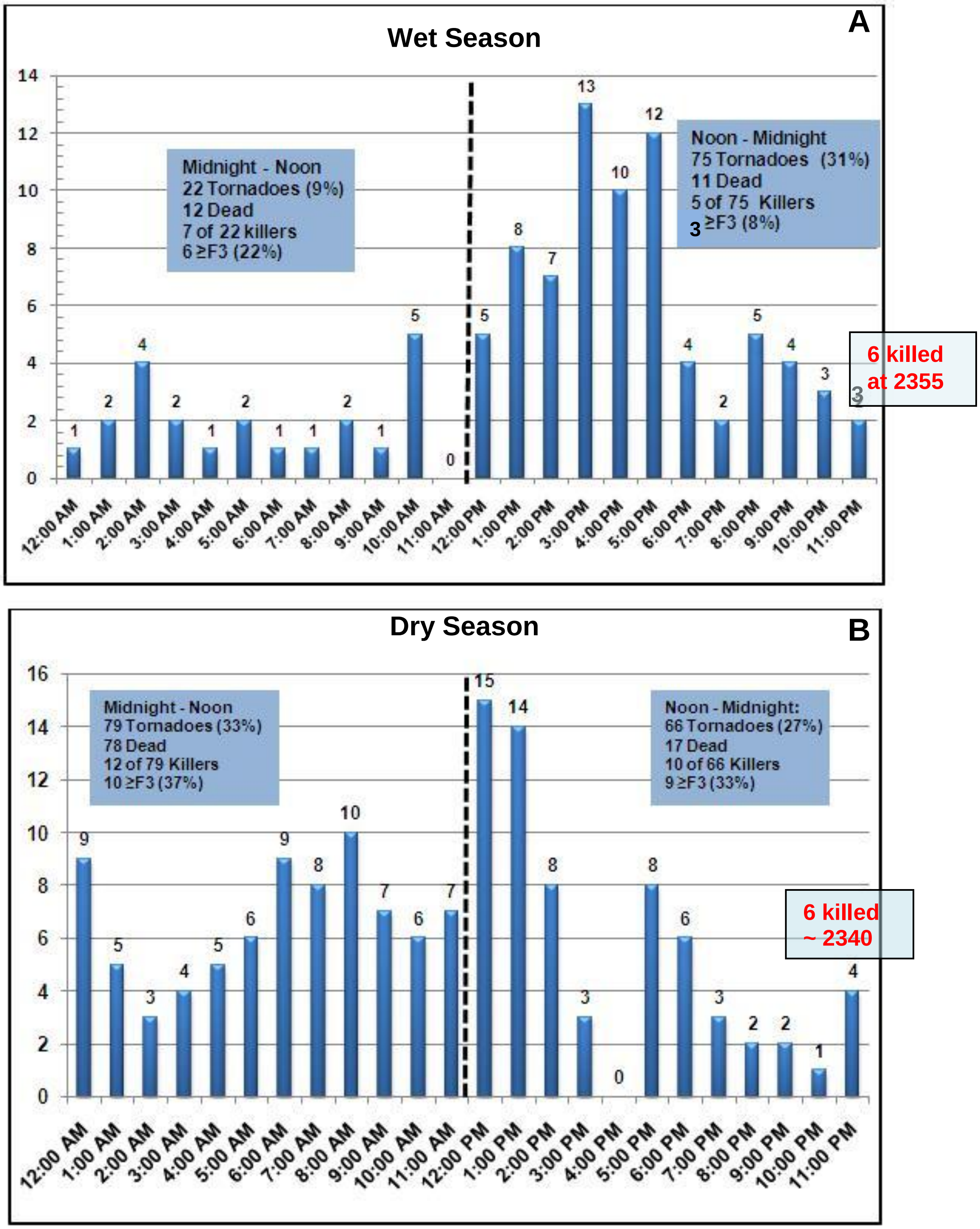
Figure 4. Monthly distribution of Florida tornado deaths by synoptic setting from 1882-2008. Dry season extratropical cyclone in red (161 deaths, 78%), tropical cyclone in blue (36 deaths, 18%), and wet season not associated with ET or tropical cyclones in green (9 deaths, 4%).



Figures 5a-b. Tornadoes reported in the Florida peninsula from 1950-2008 from the NWS SPC database by month (5a) and by hour EST (5b).



Figures 6a-b. Tornadoes reported over peninsular Florida from 1950-2008 by F-Scale (6a) and ≥F2 tornadoes by month (6b) from NWS SPC database. *June includes 14 ≥F2 tornadoes from 4 tropical cyclones.



Figures 7a-b. Hourly distribution (EST) of ≥F2 tornadoes for the peninsular Florida wet season (7a) and dry season (7b) with key statistics from NWS SPC database.

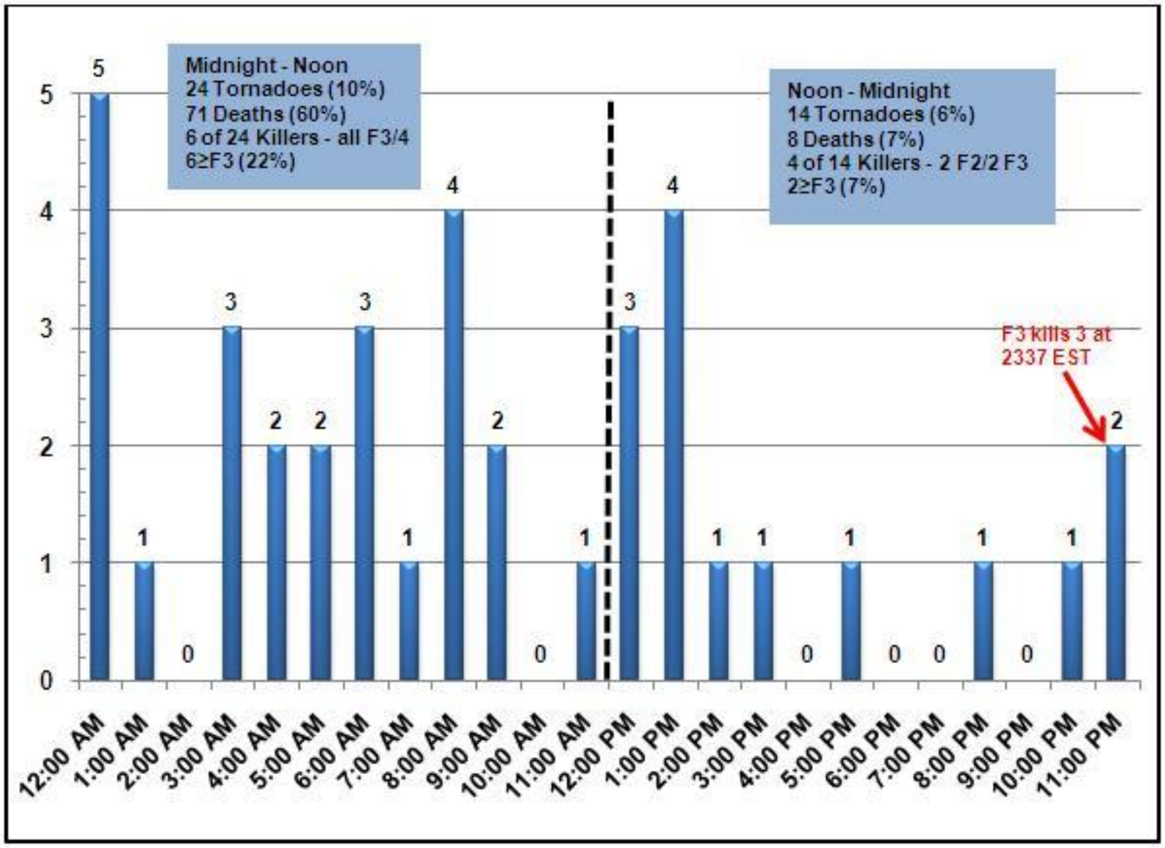


Figure 8. Hourly distribution (EST) of the 38 ≥F2 tornadoes reported during the peninsular Florida dry season for the seven strongest El Niños based on mean October, November, and December Niño 3.0 values since 1950 (1965-66, 1972-73, 1982-83, 1987-88, 1997-98, 2002-03, and 2006-07).

		Path Length (nm)	Path Width (yards)
All (240)			
12AM-12PM (91)	**AVG**	**8.0**	**106**
	MED	**1.5**	**60**
12PM-12AM (139)	**AVG**	**4.8**	**90**
	MED	**2**	**50**
Dry Season (145)			
12AM-12PM (79)	**AVG**	**9.0**	**110**
	MED	**1.5**	**67**
12PM-12AM (66)	**AVG**	**7**	**111**
	MED	**3**	**75**
Wet Season (95)			
12AM-12PM (22)	**AVG**	**5.4**	**122**
	MED	**2.7**	**80**
12PM-12AM (73)	**AVG**	**2.1**	**61**
	MED	**0.3**	**30**
Dry Season El Niño (38)			
12AM-12PM (24)	**AVG**	**21.4**	**144**
	MED	**5.4**	**95**
12PM-12AM (14)	**AVG**	**7.8**	**144**
	MED	**5.6**	**80**

Table 1. Average and Median path length and width for 240 ≥F2 tornadoes reported over the Florida peninsula in SPC database from 1950-2008.

3. EL NIÑO AND SIGNIFICANT TORNADOES IN CENTRAL FLORIDA – THE PHYSICAL CONNECTION

In the aftermath of the record-breaking El Niño of 1997-98 and the deadliest Florida tornadoes of February 1998, there was concern among the scientific community about whether severe local storms could be attributed to El Niño (Glantz, 1998 and Changnon, 2000). The relationship of tornadoes in Florida to El Niño was considered controversial – mostly by those without detailed knowledge of Florida tornado climatology and synoptic environments or a historical perspective. What was lost in the debate is that the increased risk of severe weather for Florida was predicted months in advance based on El Niño. The author had just completed research on peninsular Florida tornado outbreaks (Hagemeyer 1996 and 1997a) and a study of all Florida tornado and severe thunderstorm deaths (1997b), and was well aware that during the last great El Niño of 1982-83 a record number of ≥F2 tornadoes occurred in the Florida dry season. During the tornado events of early 1983, NWS forecasters were very clear on the cause – a jet stream travelling much farther south and stronger than normal resulting in low pressure systems and fronts passing about every five days (Colin 1983). Forecasters interviewed by the media at the time noted the rare conditions and could not recall such an active severe weather season. The connection to El Niño was not realized at the time as the magnitude and impact of the 1982-83 El Niño was not appreciated until it was over, prompting efforts to develop an ENSO monitoring and forecast system for the U.S.

The lead author and colleagues at NWS MLB worked on outreach beginning in the summer of 1997 to get the Emergency Management (EM) community, the Media, and the public focused on the message of preparation for the increased risk for severe weather in Florida for the upcoming 1997-98 dry season. NWS Melbourne developed a special web page in September 1997 illustrating the striking difference in the record-breaking severe weather season of 1982-83 and the strong La Niña season of 1988-89 when severe weather was nearly absent.

Figure 9 shows the conceptual model of the synoptic conditions that lead to the development of ≥F2 tornadoes in Florida. This graphic was used in outreach efforts in the fall of 1997 and is still valid and used today. The message was that during El Niño dry seasons a strong and persistent jet stream often extends over the Gulf of Mexico, resulting in an increase in strong extratropical cyclones affecting Florida with the potential for severe weather, including strong and violent tornadoes. What happened later that season was both historic and tragic. Pielke (2000) noted: “as had been predicted, Florida did experience unusually severe weather during the winter of 1997-1998…. The most prominent event in Florida was the tornado outbreak of February 22-23, 1998, which led to $100 million in damages, the loss of 42 lives, and more than 260 injuries (NWS, 1998). It was the single greatest loss of life to a tornado event in Florida history.

Following the record El Niño of 1997-98, Hagemeyer (1998) completed case studies illustrating that meteorologically and climatologically the strong El Niños of 1982-83 and 1997-98 were very similar. He noted that the next step should be investigation of the physical links between ENSO and observed meteorological elements known to contribute to tornadogenesis which would do more to advance the knowledge of the physical processes involved than simple direct correlations of SST to tornado activity.

The understanding of the underlying physical relationship between climate, weather, and ENSO is critical. As discussed in Section 2, historically there is only one way to create an environment favorable for ≥F2 tornadoes in Florida during the dry season: it is almost exclusively found within the warm sector of ET cyclone associated with a jet stream maximum. Hagemeyer and Schmocker 1993 found that the mean tornado outbreak environment vertical profile of U showed a very distinct maximum between 200 and 300 mb. Further, Hagemeyer and Matney (1993a) found that the mean F-scale of Florida tornado outbreaks had the highest correlation with bulk mean environmental wind ($R^2 = 0.74$). In other words, the stronger the environmental winds through the depth of the troposphere, the greater the potential for strong tornadoes. Many things have to happen on the mesoscale and storm scale to produce strong tornadoes in the warm sector of an ET cyclone, but an ET cyclone and jet stream maximum are necessary conditions to set the stage for tornado development.

ET cyclones can have a multitude of societal impacts besides deadly tornado outbreaks, including hail, damaging thunderstorm wind, flooding rainfall, coastal flooding, hazardous marine conditions, strong gradient winds, and beneficial rain. The lead author (Hagemeyer 2000) investigated the physical climate/weather relationship with ENSO for Florida and focused on dry season storminess (the number of significant ET cyclones) as a proxy for tornadoes and severe weather and overall societal impact. There was a strong correlation between ENSO and the number of ET cyclones affecting Florida in the dry season with the greatest number of storms during strong El Niños. The greater the number of ET cyclones impacting Florida in the dry the season the greater the chance that the right ingredients will come together to produce significant tornadoes. Hagemeyer (2001) and Hagemeyer and Almeida (2002 and 2003) developed a dry season forecast of significant ET cyclones for Florida that has proven quite reliable and has been posted on the web for every dry season since 2001-02.

After the 1998 El Niño a number of other researchers conducted statistical studies of Pacific SSTs and U.S. tornadoes with varying results, but found either no or weak correlations with Florida tornadoes. However, many of these studies did not consider relevant tornado strength and regional tornado seasons or the physical aspects of tornadogenesis in an appropriate synoptic setting. Typically, these studies did not have a regional historical context to inform their database development and tried to make broad generalizations without the proper tornado populations to resolve the influence of El Niño. Most recently, Cook and Schaefer (2008), in a study relating ENSO to winter tornado outbreaks, provided an excellent summary of the preceding statistical studies and confirmed early work by the lead author of the role of the jet stream in Florida tornado outbreaks and the much greater chance of tornado outbreaks during El Niños.

Rather than correlating tornado data directly with ENSO, the actual environmental conditions that support ET cyclone development and ultimately tornadogenesis are correlated with ENSO to update the work of Hagemeyer and Almeida (2003, 2004a and 2005) and Hagemeyer (2006a and 2007), to more clearly illustrate the underlying physical relationship. Spatial correlation maps for December through March from 1950 to 2008 of 250 mb zonal wind (10a), 850 mb geopotential height (10b), 500 mb omega (10c), and 1000 mb relative humidity (10d) with the Niño 3.4 index are used to illustrate the relationship between ENSO and Central Florida weather.

The axis of maximum positive correlation for the jet stream winds (10a) extends from the eastern Pacific across the Baja Peninsula, the Gulf of Mexico and the Florida peninsula, indicating that as SSTs in the NIÑO 3.4 area increase, the jet stream wind increases over Central Florida. A strong negative correlation area for 850 mb height is found over the northeast Gulf of Mexico (10b) indicating that as SSTs increase the pressure decreases and this relationship is the strongest of any area in North America. Figure 10b illustrates the tendency for ET cyclones to develop and strengthen over the northeast Gulf of Mexico during El Niños in the exit region of the jet stream. A strong negative correlation area is found for 500 mb omega over the eastern Gulf of Mexico and the Florida peninsula (10c), indicating that as SSTs increase, the vertical velocity decreases, which is indicative of upward vertical motion needed to develop strong convection in the warm sector of the mean Gulf low. A significant positive correlation area is found for 1000 mb relative humidity over the Florida peninsula (10d), showing that as Niño 3.4 increases, the low level moisture increases. This is indicative of increased low level moisture to fuel developing thunderstorms during El Niño.

The jet stream, 850 mb height and 500 mb omega fields on Figures 10a-c show the greatest correlations with Niño 3.4 for all of North America exists over portions of Central Florida. The correlation with 1000 mb RH has a maximum over Central Florida, which is only exceeded over a small portion of the desert southwest. These results are all physically realistic and indicative of El Niño being more favorable for the development of ET cyclones in the Gulf of Mexico with Central Florida in the warm sector where tornadoes are more likely to occur.

Composite anomaly maps (Figs. 11 a-d) of jet stream level wind (250 mb) and 850 mb geopotential height for February through April, the peak Central Florida severe weather season, for the seven strongest El Niños and La Niñas illustrate the striking differences in seasonal physical climatology over Central Florida. During the El Niños, the positive jet stream anomaly is strongest over the Florida peninsula (11a), and a mean negative height anomaly or low pressure center is found over the central Gulf Coast (11b) with a mean warm frontal boundary over extreme north Florida putting the Florida peninsula entirely within the mean warm sector, the most likely area for severe weather. The results for the strongest La Niñas are exactly the opposite with a strong negative jet stream anomaly over Central Florida (11C) and a ridge of positive pressure anomaly (mean ridge axis) across central Florida (11D), which is favorable for quiescent and dry weather. Cross sections of zonal wind, geopotential height, and omega from the surface to 200 mb (not shown) constructed along the axis of the purple line on figure 11d confirmed the vertical continuity of the synoptic features over the Florida peninsula for El Niño (warm sector of ET cyclone) and La Niña (high pressure ridge).

Figures 12a-b show the striking difference in Florida tornado tracks for the same dry seasons during the strongest La Niñas (12a) and the strongest El Niños (12b). There are many more long-tracked ≥F2 tornadoes in Central Florida during El Niño than in La Niña which confirms spatially the impact-based tornado climatology presented in section 2. Plots of winter lightning flash density and synoptic setting for the strong El Niño of 1997-98 and strong La Niña of 2000-01 (Figs. 13a-b) from La Joie et. al. (2008) graphically illustrate the profound difference in thunderstorm activity over the Gulf of Mexico and Florida between the two phases of ENSO.

A probabilistic illustration of this basic relationship between ENSO and dry season ET storms over Florida can be made using logistic regression (Wilks 1995) as in Hagemeyer and Almeida (2004b and 2005) and Hagemeyer (2006a, 2006). Figure 14 shows the logistic regression results for the chance that Florida dry season ET storms will be above normal (>6 in blue) or below normal (<6 in green), given a certain value of Niño 3.4. The probability of above normal storms ranges from near zero for a strong La Niña to near 100% for a strong El Niño. The probability of below normal storms ranges from near zero for a strong El Niño to near 100% for a strong La Niña. The tails of these probability distributions are generally representative of the climatological anomaly patterns in Figure 11a-d.

Central Florida is clearly a center of action for seasonal climate variability caused by ENSO which forces preferred modes of synoptic weather conditions that effect severe weather occurrence. This can be illustrated quite vividly by a western hemisphere vertical cross section of mean zonal wind and specific humidity for February 1998 from the South Pole to the North Pole across the Florida peninsula (Figures 15a-b). The strongest jet stream, the El Niño-enhanced subtropical jet of > 55m/s, is found right over Central Florida with a mean baroclinic zone and warm front immediate to the north. This scenario puts Central Florida within the warm sector of an ET cyclone and under the jet stream for the entire month. An animation of the daily jet stream winds over the U.S. for February 1998 illustrates how synoptic weather systems on the scale of days combine to produce the extreme monthly climate anomalies during the extreme El Niño of early 1998 and greatly increase the odds that extreme severe weather would occur over Central Florida.

Dry season severe weather in Florida is generally limited to the warm sector of an ET cyclone, and the storm track is critical to how much of Florida is contained within the warm sector of a given storm. The unique geography of the Florida peninsula results in an especially challenging preparedness issue for Central and South Florida during El Niño. If an ET cyclone has the southern track required to bring a significant risk of strong tornadoes to the area it generally means that other areas of the U.S. have not been previously impacted by the same storm system. In other words, the severe weather comes in from the Gulf of Mexico and there is no ground truth or storm history to generate media coverage or raise awareness until the first storms move onto the Gulf coast of the peninsula. The plots of all reported U.S. tornadoes from a full day before the start of the four deadliest Central Florida tornado outbreaks to their last tornado (Figs. 16a-d) show that the only tornadoes that occurred in the U.S. were in Central Florida and not part of preceding larger outbreaks. Note that all of these outbreaks coincide spatially with the maxima of parameters correlated with ENSO in Figures 10a-d. Lightning flash density plots over the Gulf of Mexico (Figure 13b) from La Joie, et. al. 2008) for December 1997 through February 1998 during the record El Niño illustrates the effect of the persistent southern storm track in producing vigorous thunderstorm activity over the Gulf of Mexico upstream of the Florida peninsula.

3.1 Dry Season Nocturnal Tornado Occurrence

The tendency for ≥F2 nocturnal and morning tornadoes to occur in the dry season, particularly during El Niños, is a curious phenomenon that greatly increases the risk of fatalities. Hebert, with experience in Florida weather dating to the 1960s (personal communication, 1991) stated: *"…forecasters at Miami and Tampa have long recognized the greater threat of tornadoes when a squall line or clusters of strong thunderstorms approach the Tampa Bay area during the period 2 A.M. until 9 A.M. rather than when one approaches during the afternoon."* This general observation has been verified by the lead author's studies in the 90's and by the updated tornado climatology presented in Section 2. Figure 7b shows over 59 dry seasons that there have been 14 ≥F2 dry season tornadoes between 12AM and 2AM, but only 3 have occurred between 3PM and 5PM – the time of peak diurnal heating. However, more F0-F1 tornadoes have occurred in this same afternoon period (85) than any other period. It is not that there are fewer tornadoes in the afternoon. There are indeed many more, but there are far fewer strong tornadoes. The sample size is sufficient with 145 ≥F2 dry season tornadoes. While the unusual diurnal climatology is real, the fact that tornadoes would not benefit from increased instability from daytime heating is counter-intuitive to operational forecasters. Forecasters have adapted to the reality, but the physical basis for the diurnal ≥F2 tornado distribution remains unclear.

It is unlikely that the large-scale weather factors that contribute to the development of an environment favorable for significant tornadogenesis over Central Florida such as the jet stream, westerly wind maxima in the troposphere, and the passage of ET cyclones and associated warm sectors and cold fronts favor any particular time of day. The physical reason for the greater overnight ≥F2 tornado threat is likely rooted in mesoscale and smaller scale boundary layer processes that influence low-level shear and helicity and inflow into thunderstorms. Johns et. al. (1993) noted that certain combinations of wind shear and instability in the environment of supercell thunderstorms were favorable for the development of strong and violent tornadoes; for example, high wind shear and weak instability or high instability and weaker wind shear.

Hagemeyer and Matney (1993) found that wind shear was the most critical parameter for strong tornadoes in Florida and that instability only needed to be sufficient to produce deep convection. For example, the environment of the typical Central Florida afternoon wet season tornadoes that dominates the overall climatology (Fig. 5b) is characterized by high instability and very weak wind shear and thus very rarely produces supercells with ≥F2 tornadoes. The environment of ≥F2 dry season tornadoes is noteworthy for a very high shear and relatively weak instability environment (Hagemeyer 1997). In other words, instability may be a sufficient condition to produce thunderstorms, but high shear is a necessary condition to produce ≥F2 dry season tornadoes. This does not answer the question of why stronger tornadoes are less likely during the afternoon than in the early morning, but it is a strong clue where to look: diurnally varying aspects of low-level wind shear, helicity, and storm-relative inflow of the tornado environment.

The nocturnal ≥F2 tornado maximum is likely related to the diurnal oscillation of low-level wind due to friction and the interaction of the marine/land boundary layers. The low-level boundary layer wind field over the Florida peninsula ahead of an approaching line of thunderstorms during peak afternoon heating would tend to veer and become more unidirectional relative to winds above as momentum is mixed down to the surface in the coupled airmass. This would tend to reduce low-level directional wind shear, helicity, and inflow ahead of the squall line, perhaps offsetting the contribution of increased instability and limiting the chances of ≥F2 tornadoes. The early morning boundary layer wind field ahead of an a line of storms would tend to be decoupled from the airmass above and back to the east, increasing directional shear, while the air immediately above the boundary layer increases in speed due to lack of friction. This would have a net effect of increasing wind shear, helicity, and inflow ahead of approaching thunderstorms, likely reinforcing existing low-level thermal boundaries and increasing the chances for tornadic supercells. There are also issues relating to organized lines of thunderstorms in a marine boundary layer which does not have a significant diurnal oscillation coming ashore and interacting with a land boundary layer that does have a significant diurnal oscillation.

This is a significant forecast challenge as tornado disasters in Central Florida are the result of just a few long-tracked supercell thunderstorms. Radar images of the three deadliest supercell thunderstorms in Florida history responsible for nearly a third of all tornado deaths are shown on Figures 17a-f. A close-up view of each supercell (Figs. 17b, d, and f) reveals the classic tornadic supercell signatures for which any warning forecaster would immediately issue a tornado warning. However, the radar data 1 to 2 hours prior as these storms came ashore in a broken line (Figs. 17a, c, and e) does not reveal their potential. The process by which certain storms turn into extreme tornadic supercells on the scale of minutes and hours is a universal forecast challenge, but there may well be unique regional processes that effect development due to the unique physical geography of peninsular Florida.

Even though the understanding of nocturnal supercell development is incomplete, given that a winter tornado occurs at night when diurnal cooling and stabilization are normally taking place, it is more likely that the tornado has developed within an environment with strong forced lifting and high shear, and thus the storm is likely to be more dangerous – at the worst possible time. Not only are nocturnal tornadoes potentially more deadly from a sociological aspect, but also the fact that they occur at night generally indicates they are potentially stronger (≥F2) as well. More research is needed in this area to improve significant tornado forecasts in the dry season, including mesoscale modeling studies of boundary layer interactions in a strongly forced nocturnal environment. However, it is clear that El Niño greatly increases the risk of nocturnal ≥F2 tornadoes over Central Florida.

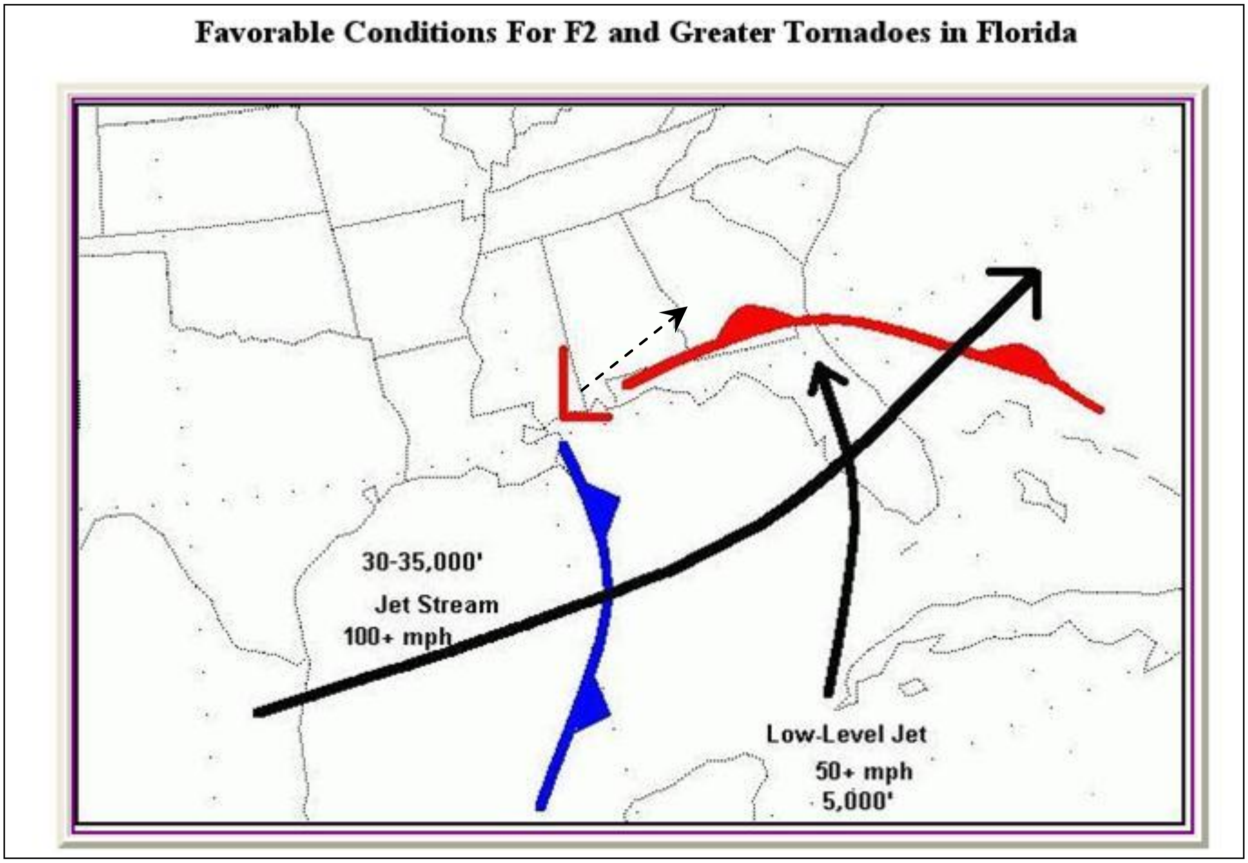
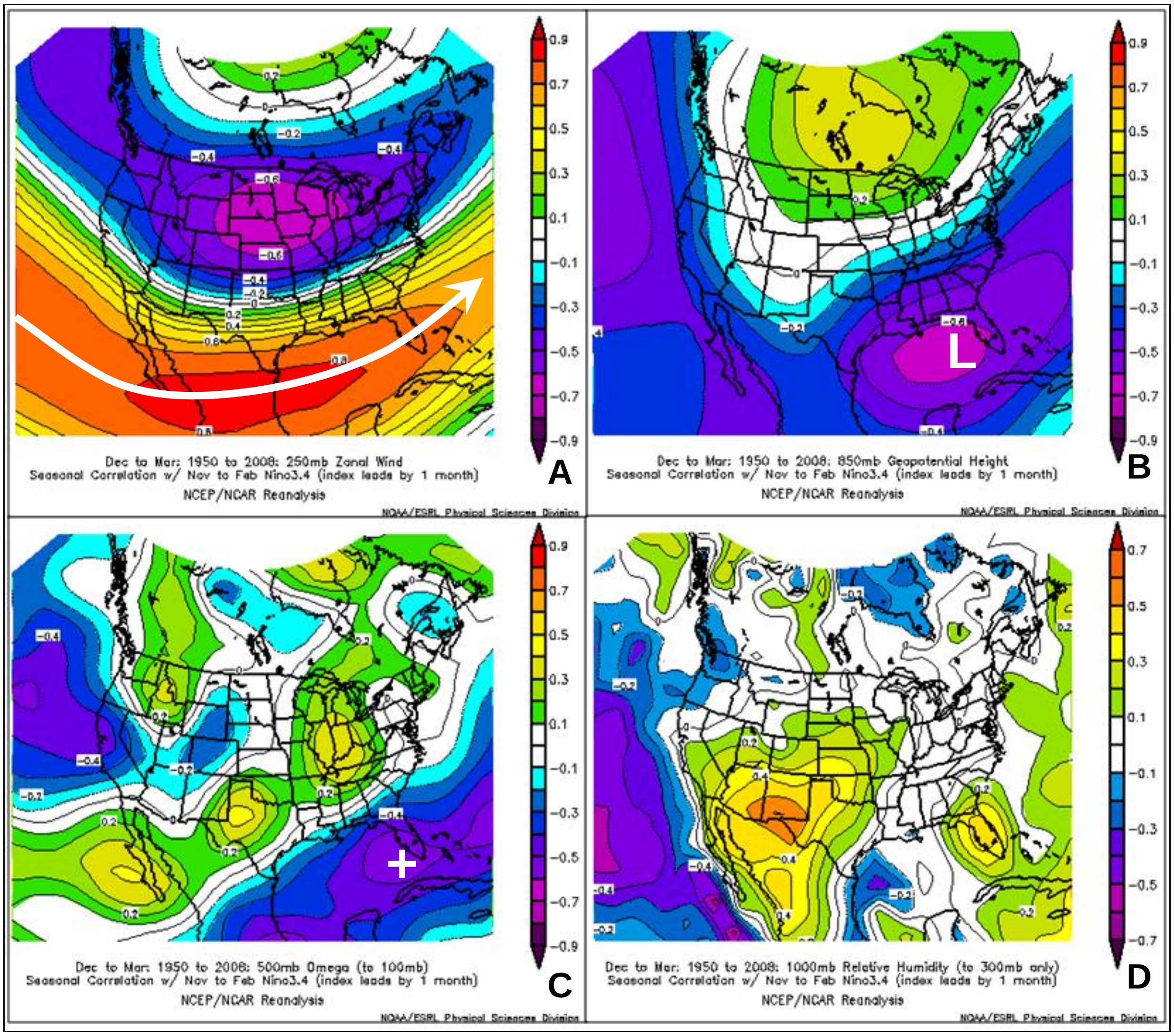
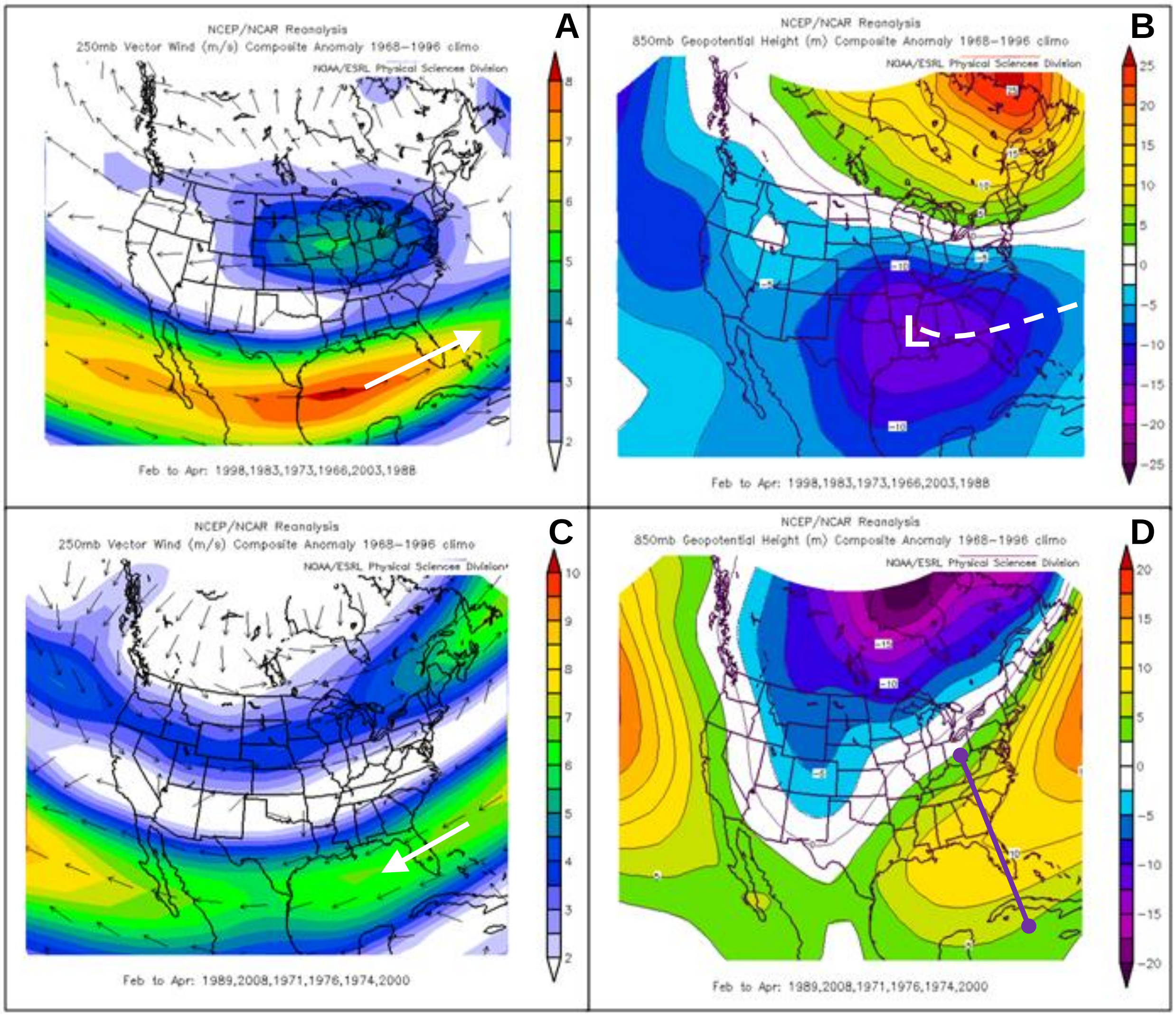


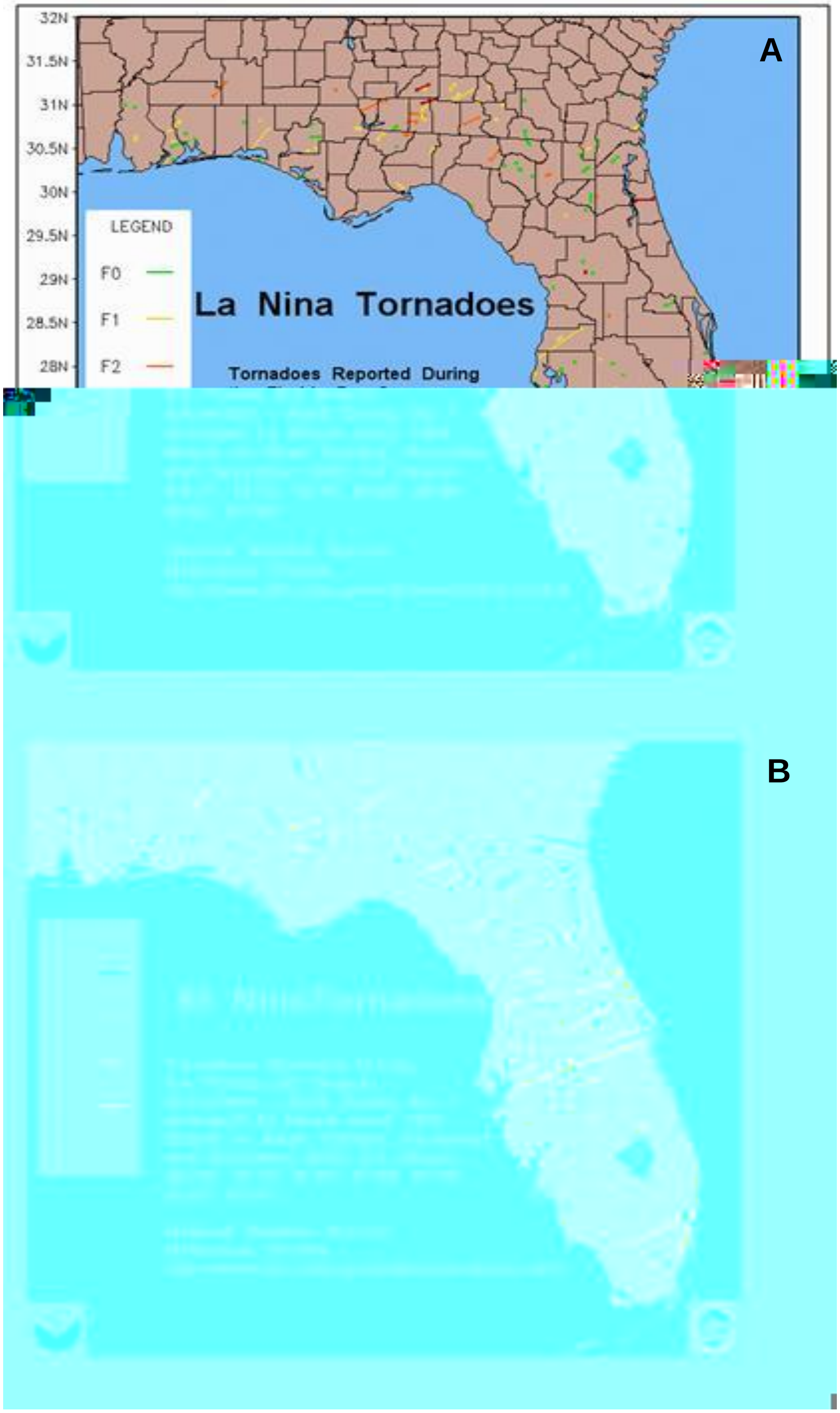
Figure 9. Conceptual model of favorable synoptic conditions for ≥F2 tornadoes in the Florida Dry Season (from Hagemeyer 1997).



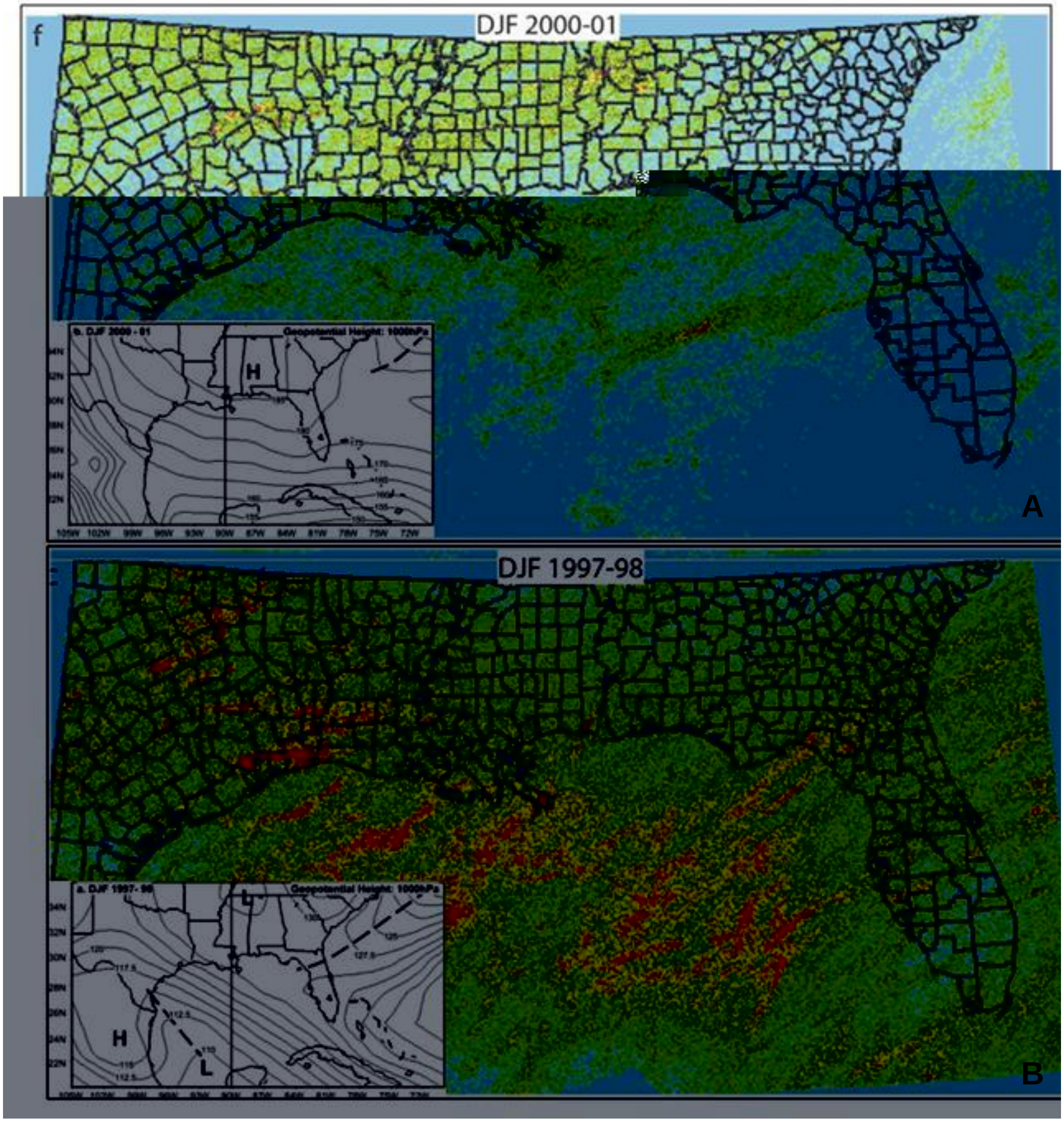
Figures 10a-d. Seasonal spatial correlations for December to March of 250 mb zonal wind (10a), 850 mb geopotential height (10b), 500 mb Omega (10c), and 1000 mb relative humidity (10d) with the November to February Niño 3.4 SST index (images from NCEP Reanalysis , Kalnay et. al. 1996).



Figures 11a-d. Composite analyses of 250 mb vector wind (m/s) and 850 mb height anomalies for February, March and April for the seven strongest El Niños (11a and11b) and the seven strongest La Niñas (11c and 11d). Location of cross section along 81.5º W shown in purple on panel “D” (Images from NCEP Reanalysis, Kalnay et. al. 1996).



Figures 12a-b. Plots of dry season tornado tracks color coded by F-scale for the seven strongest La Niñas (12a) and for the seven strongest El Niños (12b) since 1950 based on mean October, November, and December Niño 3.0 values.



Figures 13a-b. December, January, and February mean lightning flash density and mean 1000mb geopotential height (inset) for 2000-01 (a) and 1997-98 (b) (from La Joie and Laing, 2008).

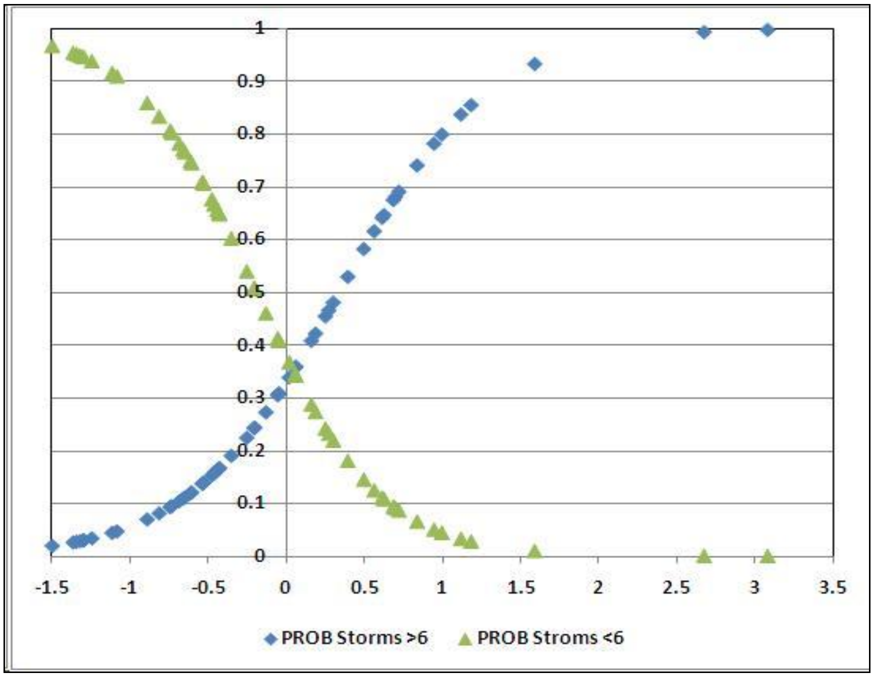
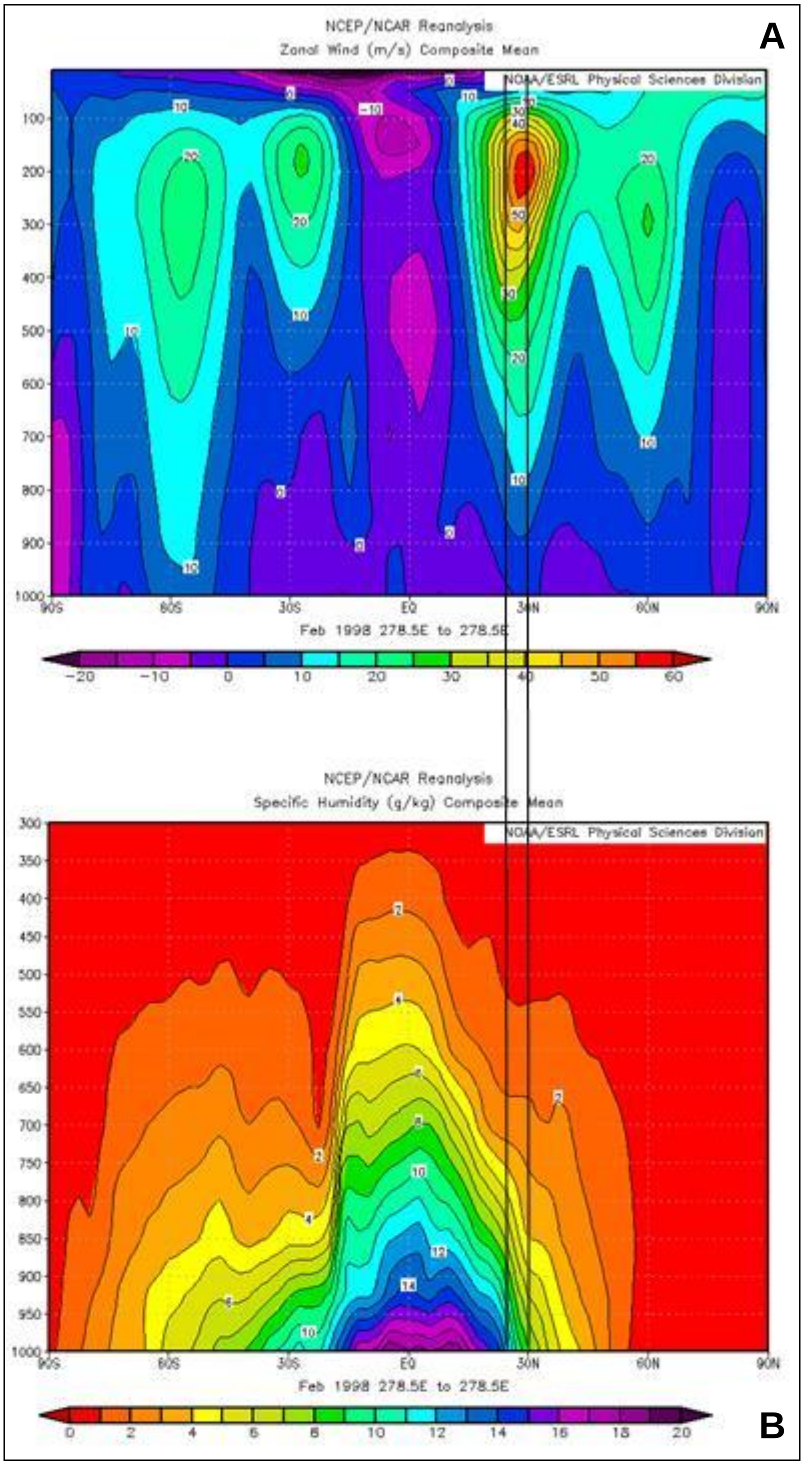
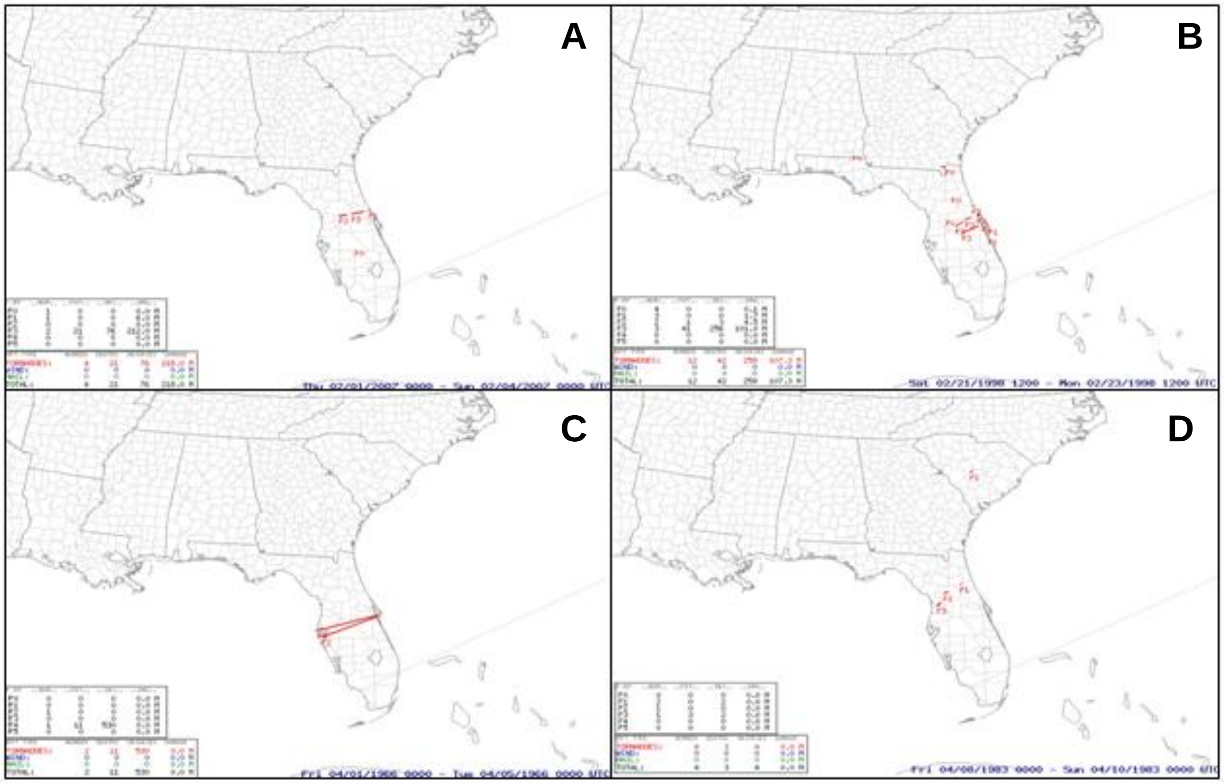


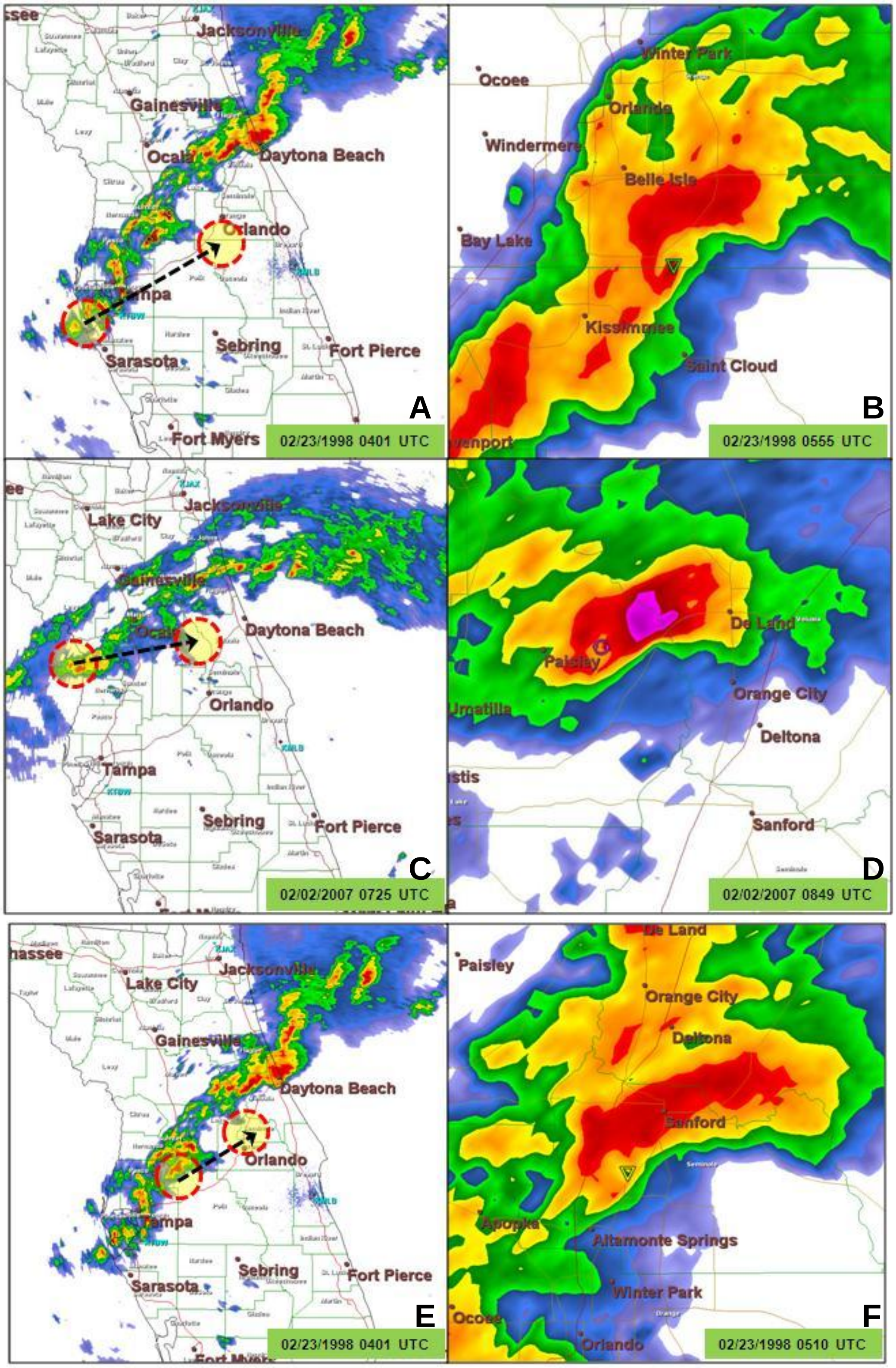
Figure 14. Plots of the probability of Florida dry season storms being above normal (>6) in blue and being below normal (<6) in green versus average Niño 3.4 for October through March (one month lead) using logistic regression techniques as in Hagemeyer (2006a, 2006b, and 2007a).



Figures 15a-b. Western Hemisphere vertical cross sections from the South Pole to the North Pole along 81.5º west longitude (approximately through the Florida peninsula) from the surface to 10 mb for zonal wind (m/s, Fig. 15a) and from the surface to 300 mb for specific humidity (g/kg, Fig. 15b) for February 1998. The two vertical black lines indicate the approximate latitude of the Florida peninsula (images from NCEP Reanalysis, Kalnay et. al. 1996).



Figures 16a-d. Reported tornado tracks starting a full day before the four deadliest Central Florida tornado outbreaks from the SPC Severe Plot program through the last tornado for the February 2007 (A), February 1998 (B), April 1966 (C), and April 1983 (D) killer tornado outbreaks.



Figures 17a-f. Lowest level reflectivity images from the NWS Melbourne, Florida WSR-88D for the three deadliest tornadic supercells in Central Florida history (B, D, and F) and their locations 1 to 2 hours prior (A, C, and E) for February 23, 1998 0401 UTC (A) and 0555 UTC (B, 25 killed), February 2, 2007 0725 UTC (C) and 0849 UTC (D, 21 killed) , and February 23, 1998 0401 UTC (E) and 0510 UTC (F, 16 killed).

4. CENTRAL FLORIDA - WHERE EL NIÑO AND CULTURAL HOUSING PRACTICES COLLIDE

The potential impact of a tornado is a function of its strength, path length and width, speed of movement, time of day, and vulnerability of the people and structures in its path. It has been shown that El Niño has a profound effect on increasing the risk of violent, long-tracked, and fast-moving nocturnal tornadoes in Central Florida. Central Florida is also one of the most tornado-vulnerable areas in the United States.

Reports of early killer tornadoes in Florida often did not have detailed descriptions of structures damaged. Typically, these early tornadoes struck what were described as a "small home," "frame home," "tenant home," or "farm house." These structures were generally light-framed and unanchored "cottage" construction. On few occasions in the pre-1960s record was specific mention made of the quality of construction. For example, the tornado of April 19, 1901, in Dade County that caused one fatality was said to have occurred in a "substantial home." This would seem to indicate that the great majority of early fatalities occurred in humble residences of vulnerable construction. Figure 18a is a photo of the April 1925 Miami tornado that killed five people, to this day the deadliest tornado in South Florida history, showing typical small cottages of the time.

The tornado outbreak of March 31, 1962, near Milton in the Florida panhandle killed 17 people (at that time, the deadliest in Florida history) in a high-density development of small unanchored frame houses sitting on concrete block piers. Figure 18b shows a picture of the remaining blocks of some of the houses swept away and destroyed and a surviving small house blown off its piers in the background. NWS Storm Data indicates that all 17 deaths occurred in "homes" with at least a single death in 10 separate homes, indicative of the high density.

The first specific mention of a tornado fatality in a "trailer" was not until the April 4 1966 tornado outbreak in Central Florida that killed 11 people during a strong El Niño (the second deadliest up to that time). This outbreak featured one of only two F4 tornadoes reported in the history of Florida (the other was in April 1958, another strong El Niño). It appears that only 1 death occurred in a "trailer", and the other 10 deaths occurred in homes of unspecified nature. Press reports of the time noted: "Dozens of homes in a fashionable residential section of the north side of Tampa were demolished or badly damaged," an area where no deaths occurred. So, the lack of specific mention of the nature of the housing quality where the deaths occurred may mean they were at the very least of ordinary construction of the day or older homes of modest construction. There is ample evidence that tornado deaths not occurring in manufactured housing prior to 1966 occurred in housing units of similar vulnerable construction methods.

Since that first tornado death in a trailer in April 1966, 37 of the 53 killer tornado events and 106 of the 142 tornado deaths in Florida have been associated with manufactured housing, campers, or trailers. However, most of the 36 other deaths were also in vulnerable locations such as cottages, homes on blocks, an unreinforced block shed, a balcony, porches, and small homes. There were three cases of trees falling on structures, causing a single death each involving males aged 70, 79, and 86. There were only two cases of tornado fatalities in cars with four fatalities. Tornado deaths are typically a result of blunt force trauma from ≥EF2 tornadoes (≥ 110 mph 3-second wind gusts). As previously discussed, deaths from F0 and F1 tornadoes (Fig. 6a) are rare and occurred in highly vulnerable locations. Tornado deaths in well-built single family homes are quite rare in Central Florida.

The number of manufactured homes constructed nationwide grew rapidly from only 134,000 units prior to 1960 to over 2.2 million in the 1970's (Fig. 19a). The greatest numbers of these homes were installed in Central Florida where they provided fast, easy, and affordable housing to sustain rapid growth fueled by the influx of retirees and job seekers to the area. There were approximately 850,000 manufactured housing units in Florida as of the 2000 census; more than any other state. Figure 20 shows the total number of manufactured homes by county in the Nation. Central Florida clearly stands out as having the greatest concentration of manufactured homes and this is exactly the same area that shows the greatest sensitivity to the ENSO signal.

Figure 21a shows a close-up of Central Florida with the number of manufactured homes indicated by county, totaling about 550,000. The black dots on Figure 21a are the locations of manufactured housing parks licensed by the Florida Department of Business and Professional Regulation. Other permanent manufactured housing units not in licensed parks (for example, unassociated rural units) are included in the county totals. However, campgrounds and RV parks which can contain anything from people in tents next to their vehicles to large motor homes that rent spaces on a daily to monthly basis are not included. For example, the Ponderosa RV Park in Osceola County, which has 200 rental spaces and was the site of 10 tornado deaths in February 1998, is one of hundreds across Central Florida not indicated on Figure 21a. There are tens of thousands of campground, fish camp, and RV rental spaces in Central Florida which are likely to be 80 to 100% occupied by tourists and seasonal visitors during the dry season. These people are the least likely to be aware of the uniqueness of the significant Florida impact tornado climatology.

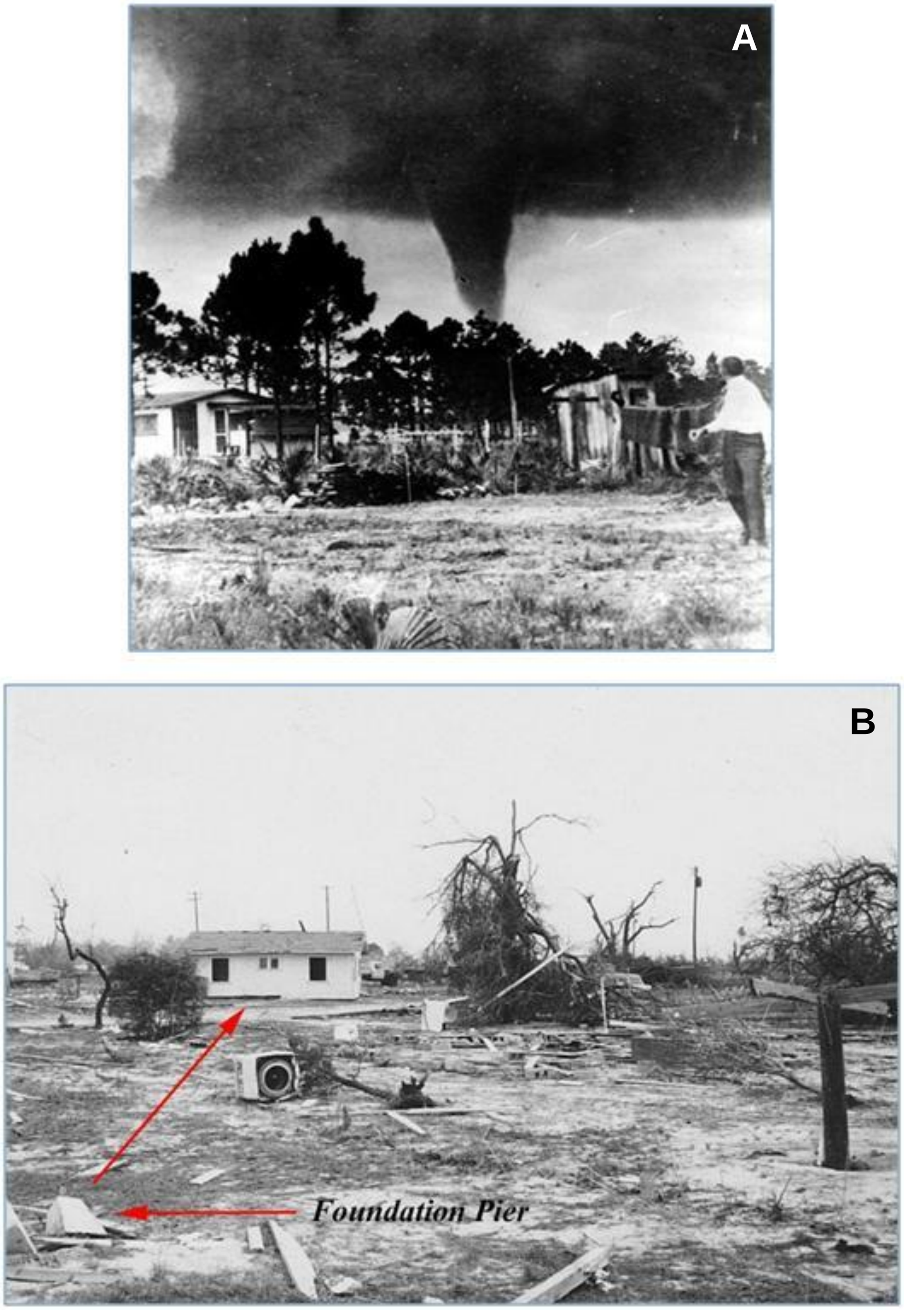
Although improved building codes were established in 1994 in the aftermath of Hurricane Andrew (1992), they do not apply to the more than

600,000 homes occupied year round that were already in Florida at the time (Figure 19b), or the unknown number of seasonally occupied homes and campgrounds (http://flhousingdata.shimberg.ufl.edu/a/geo_portal). Figure 21b shows that except for Sumter County, which has undergone recent rapid growth of site built single family homes in and around the Villages, over 80% of the permanent manufactured housing units in Central Florida were built prior to 1994 when building codes were strengthened. There are no exact figures on the number of manufactured housing units in Central Florida that predate the first basic Housing and Urban Development (HUD) code in 1976, but it is likely between 100,000 and 200,000. This concentration of older code manufactured housing makes Central Florida the most vulnerable region of the nation to strong tornadoes.

Figure 22 shows the location of licensed manufactured housing parks with the tornado tracks for the February 1998 and 2007 events which killed a combined 63 people overlain. It is quite clear that the impact could have been much worse. There are very few locations in Central Florida where a long tracked ≥F2 tornado would not pass through an area of old code manufactured housing parks. Indeed, in a detailed survey of the February 2007 Groundhogs Day Tornado that killed 21 people, many miles of tornado track were over unpopulated marsh and grass lands between Lady Lake and Lake Mack where the deaths occurred.

Sutter and Simmons (2007 and 2009) found that Florida had a largest proportion of casualties occurring in tornadoes rated F3 or weaker, and that Florida manufactured housing fatalities occur disproportionately in F1-F3 tornadoes when compared to other states. However, considering Central Florida's unique regional tornado climatology discussed previously, the resulting fatalities are consistent with the large number of structures vulnerable to tornadoes. The F-scale rating of killer tornadoes in Florida is affected by the fact that, by definition, manufactured housing, particularly old code, is completely destroyed at the EF3 level. In other words, there is nothing left to rate a tornado higher than EF3. There have only been two F4 tornadoes in Florida history and no F5s. The lead author experienced this issue first hand during field surveys of the February 1998 and 2007 tornado outbreaks. The only damage indicators left when all the old code manufactured housing is swept away and destroyed are trees, and there is no reliable way at present to use trees to rate a tornado higher than F3. The lead author and other NWS personnel considered the damage in the February 2007 outbreak at the high end of EF3, but had nothing but trees left to evaluate. The bottom line is that ≥F2 tornadoes are more than sufficient to cause high casualty rates when they strike vulnerable housing common to Central Florida. A large percentage of the Central Florida housing stock can be completely destroyed by ≤F3 tornadoes.

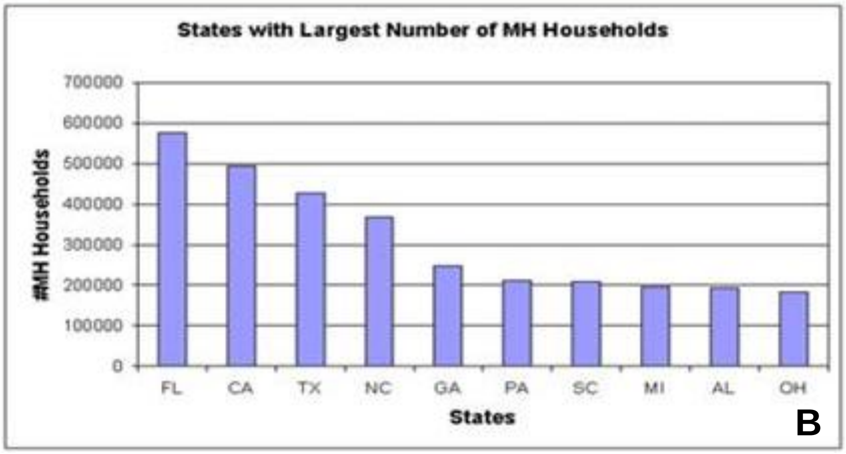
Sutter and Simmons (2009) suggest a regionally focused policy response might seek to target high risk states such as Florida which stands out as an outlier for manufactured housing fatalities. However, this "outlier" status is a result of comparing tornado deaths to the proportion of mobile homes of the total housing stock and leads to an under appreciation of true vulnerability. Florida's ratio of manufactured housing to total homes of ~11% is not particularly high relative to other southeastern states. However, this statistical approach is akin to the "death rate" discussed earlier and does not account for the high total number of vulnerable housing units in Central Florida, far more than any other like-sized area of the Nation (Figure 20) and in an area at great risk from violent tornadoes. The authors agree a regional approach is the best; and a detailed consideration of vulnerable housing population for a specific region as introduced here, just as a detailed tornado climatology has been done, is a way to more accurately assess vulnerability. It is the total number of people at risk, including seasonal rentals of old code manufactured housing and campgrounds and RV parks, that is important in a region or sub-region. There is no population more vulnerable to tornadoes in the United States than that of Central Florida, and they are at the intersection of the extreme seasonal variability forced by ENSO. The next section will review some of the issues related to reducing tornado casualties in Central Florida.



http://www.ksre.k-state.edu/wdl/climate/historicalphotoshtml/twisters03.htm
http://www.kimandmikeontheroad.com/milton_tornado_of_1962.htm

Figures 18a-b. Picture of the Miami killer tornado of April 1925 (A) with low cost housing typical of the time in the foreground and picture of small frame houses swept from their foundation piers (B) in the Milton killer tornado of March 1962.

Year of Construction of Year-Round Occupied Housing Units by Type 1995				
	Manufactured Homes		All Other Housing Units	
Year of Construction	Number	Percent of Total	Number	Percent of Total
1995 (Part Year)	136,000	2.2	674,000	0.7
1990-94	1,183,000	19.2	5,795,000	6.3
1985-89	852,000	13.8	7,266,000	7.9
1980-84	811,000	13.2	6,484,000	7.1
1975-79	1,054,000	17.1	10,054,000	11
1970-74	1,184,000	19.1	8,741,000	9.5
1960-69	809,000	13.1	13,458,000	14.7
Pre-1960	134,000	2.1	39,059,000	42.7
Total Units	6,164,000	100%	91,531,000	100%
Median Year		1980		1965



Figures 19a-b. Number of manufactured homes installed by year as of 1995 (a) and the number of manufactured home households by state as of early 1995.
(source:http://govinfo.library.unt.edu/seniorscommission/pages/final_report/g5.pdf)

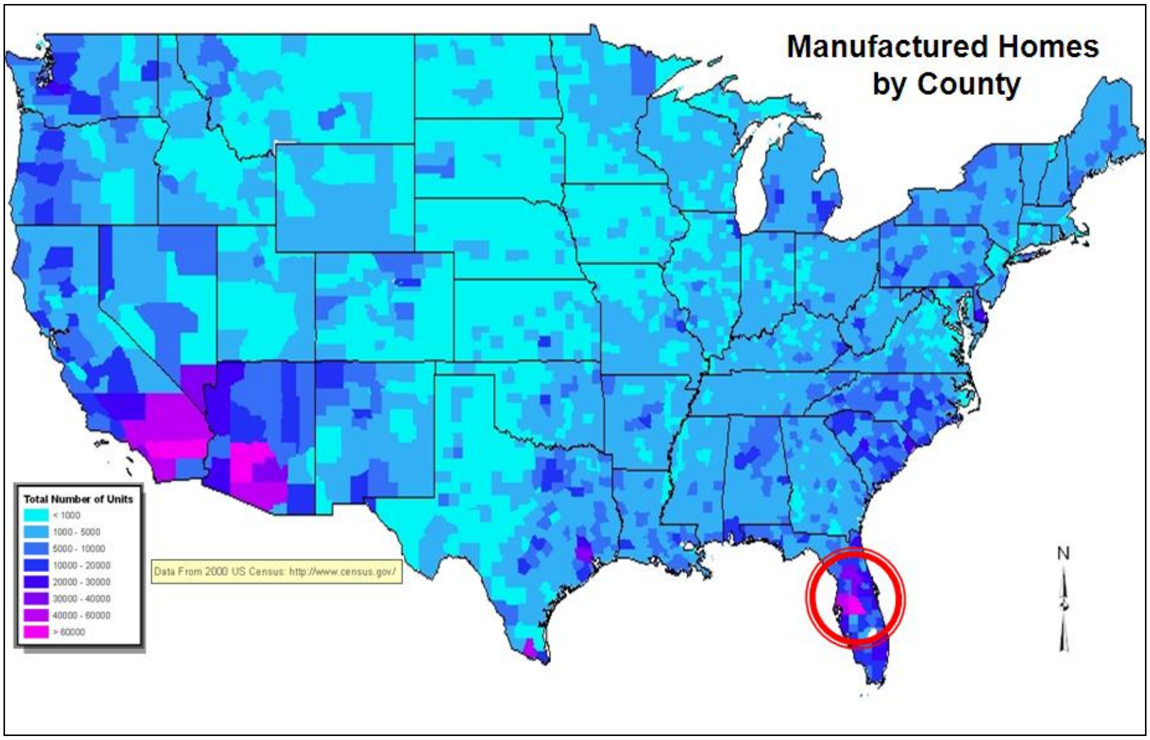
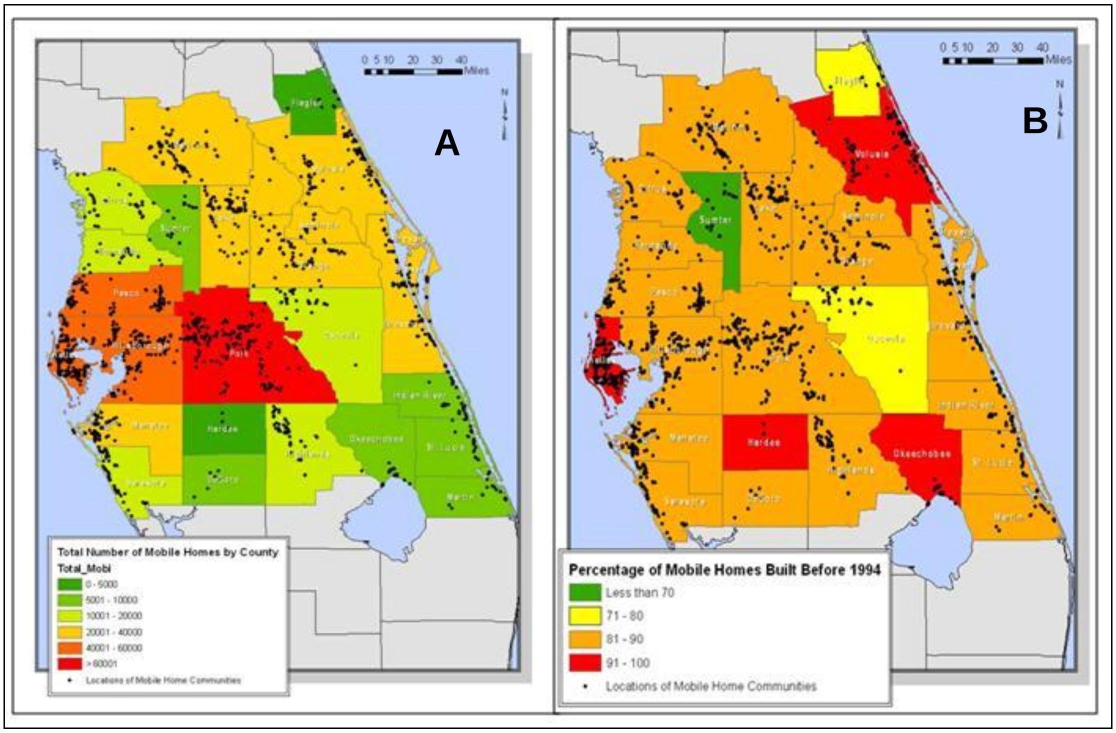


Figure 20. Total number of U.S. manufactured homes by county from the 2000 U.S. census. Central Florida is indicated by the red circle and has the greatest number of manufactured homes per unit area than anwhere in the U.S.



Figures 21a-b. Total number of Central Florida manufactured homes by county (21a) and the percentage of the manufactured homes installed before the improved building codes were implemented in 1994 (21b).

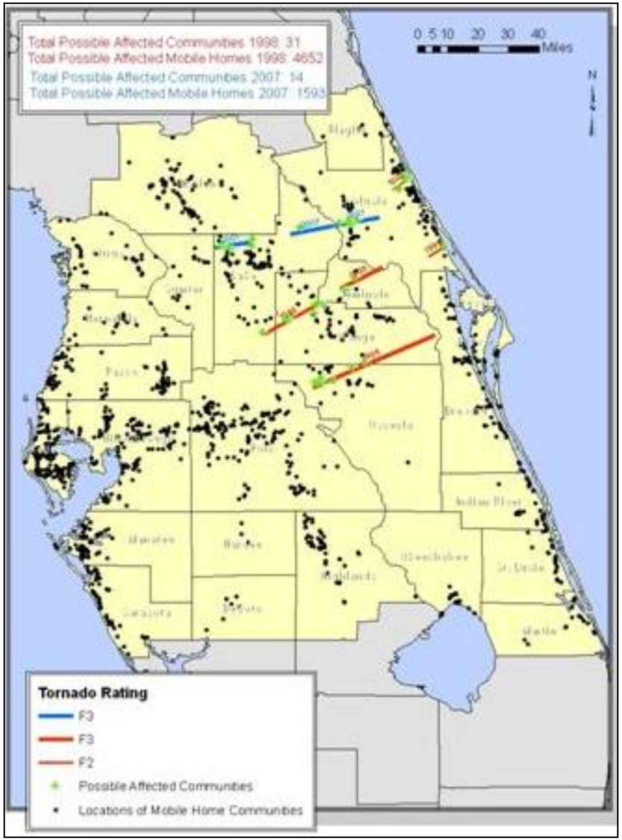
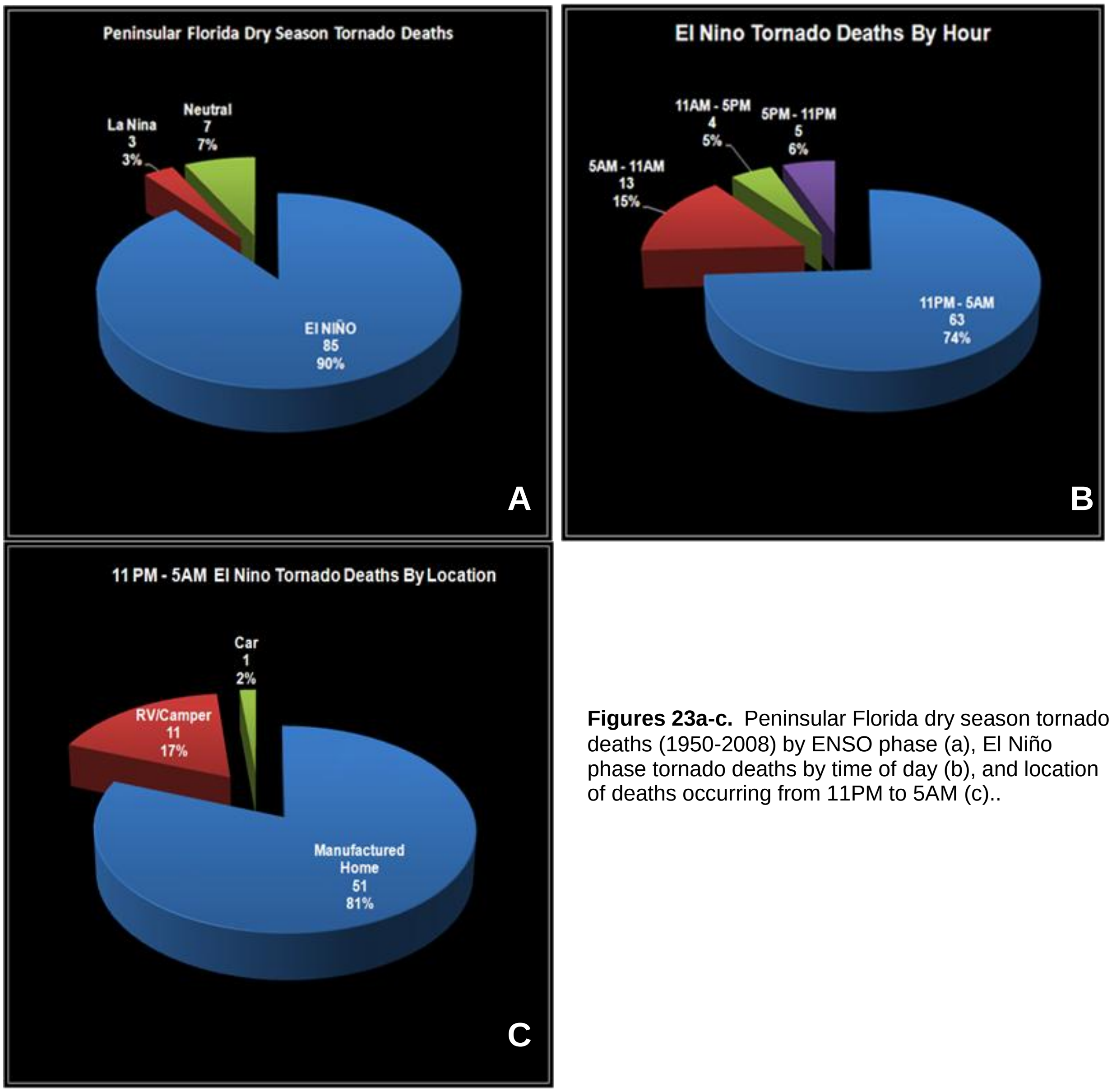


Figure 22. Map of liscenced manufactured home communities (black dots) in Central Florida overlain with the tornado tracks of the February 22-23, 1998 and February 2, 2007 tornado outbreaks.



Figures 23a-c. Peninsular Florida dry season tornado deaths (1950-2008) by ENSO phase (a), El Niño phase tornado deaths by time of day (b), and location of deaths occurring from 11PM to 5AM (c)..

5. THE FLORIDA TORNADO CASUALTY MITIGATION CHALLENGE

The small area of Central Florida has been the focus for so many tornado fatalities because its unique physical geography and cultural housing practices directly intersect with a planetary scale shift in the winter storm track during El Niño. History indicates the convergence of these factors that produce tragic tornado events should be predictable and thus avoidable. Regarding the February 1998 tornado outbreak, Pielke (2000) wrote: *The case of the tornado outbreak in Florida in February 1998 should serve as an important lesson—skilled predictions, by themselves, are an insufficient condition for society to realize benefits.* The root causes of these disasters might be that residents in vulnerable housing either failed to receive, or respond properly to, tornado watches and warnings. However, consider the scope of the overall challenge: a million people may be at risk on a typical winter night across Central Florida; old code manufactured housing stock will last many more decades and people will continue to occupy tens of thousands of temporary accommodations and campground spaces during the peak impact tornado season. And, finally, violent winter tornadoes will return, most likely in the overnight or early morning during an El Niño period. With this basic understanding of the challenge, are rare, but deadly, tornadoes the price society pays for affordable housing and winter migration for a large segment of the population? Are more deadly tornado outbreaks in Florida inevitable? And, if that is unacceptable, what can be done?

There is a very strong physical relationship between ENSO and Florida dry season tornadoes; however, the authors do not believe that the meteorological and climatological challenges of predicting ≥F2 tornadoes in the Central Florida dry season have been solved and that only the societal issues need to be addressed. There is much more that can be done to inform decision-makers. The following discussion addresses some of the physical meteorological/climatological and decisions-making issues by examining what challenges and barriers remain and where efforts might be focused. While this paper concentrates primarily on the Central Florida peninsula during El Niño periods, the issues are the same throughout Florida during the dry season when severe weather threatens.

The forecast challenge of mitigating tornado deaths in the Florida dry season is rooted by the degree of inherent forecast uncertainty. The two great uncertainties are the severity of storms and the vulnerability of the area of greatest impact. If NWS forecasters knew with certainty which areas would be hit by strong tornadoes 24 hours, 12 hours, or even a few hours in advance then the tornado fatality challenge could be largely mitigated. The authors have been told by EMs that if the NWS could give them a high confidence forecast that ≥F2 tornadoes will occur in their county a day in advance they could act aggressively to provide public sheltering. The reality is such forecast confidence is not possible.

The challenge of forecasting impacts from ET storms is that while being relatively common extreme tornado impacts are rare and highly localized occurrences. ET cyclones in the dry season have caused many more fatalities in Florida than tropical cyclones since 1950. However, the preparedness challenge for ET cyclones is fundamentally different from tropical cyclones. It is generally known, often a few days in advance, that tropical cyclones will impact a large area, and preparedness activities proceed with a great deal of societal involvement and organization, especially with regard to evacuations. There is also a significant risk of killer tornadoes in the wet season associated with outer rainband tropical cyclones (Fig. 7a), and residents of manufactured homes have the option of going to public shelters or leaving the area due to long lead times prior to impact. Occupancy rates of campgrounds and RV parks are also very low in the wet season compared to the dry season. False alarms relating to tropical cyclones may be more charitably tolerated than from ET cyclones due to their relative infrequency and likelihood of some impact, even if not an extreme impact which may have been forecast. Even in the busiest years, preparedness actions for tropical cyclones may only be needed a few times. During an El Niño there may be 12 to 18 (18 in 1997-98) strong ET storms affecting Florida during the dry season. Each may have the potential to produce tornadoes, but only a few may produce strong tornadoes affecting a small area. There is a clear risk of de-sensitizing the decision-making public with frequent severe weather threats. The most dangerous result might be the loss of confidence in the NWS forecast and the subsequent inability to elicit appropriate responses for a devastating tornado outbreak that could come in the weeks ahead.

The magnitude and area impacted from the three deadliest tornadic supercells in the history of Florida (Figs 17a-f) were not apparent one hour prior to the first fatalities. Florida tornado disasters are classic high impact low probability events. It is a matter of scale, as the warning forecaster becomes increasing confident that strong tornadoes will affect a specific area the time and area for action decreases dramatically. The seasonal forecast of winter storms and severe weather potential from the ENSO is robust, and the stage may be set for tornadic storms by the approach of an ET cyclone. But the occurrence of strong tornadoes depends on the near-storm environment on a scale of minutes and miles. The odds of any one area getting hit by a given tornado in a winter storm are very small. This is significant, as even when 42 people were killed by tornadoes in February 1998, less than one-tenth of one percent of the million or so people living in vulnerable housing were directly impacted by the tornadoes. Therefore, the lack of direct impact experience by the majority of the population can have the unexpected effect of reinforcing people’s decisions to stay in vulnerable housing.

Many manufactured home residents say they feel secure because previous severe-weather events did not damage their homes (“Mobile-home owners brace for tornado season in Central Florida”, Orlando Sentinel, 12/22/2009). They often determine some reason that the storms have missed them over the years, such as they are in a “low spot.” Others leave their fate to a “higher power”. A man whose neighbors were killed in the February 2007 tornadoes stated: "Sure, it bothers me, but it's up to the Lord when I go. I can't do anything about that" (“Despite 2007 Orlando-area tornadoes, mobile homes still popular”, Orlando Sentinel, 2/2/2008). Do the compelling statistics on ≥F2 tornado fatalities and vulnerable housing motivate people to take action to prepare or mitigate, or is the historical evidence so overwhelming that they result in fatalistic behavior? One cannot scare people into action; indeed, the desired reaction may be the opposite – inaction or denial. NWS forecasters, EMs, and state and local governments responsible for the safety of large numbers of residents find the loss of any person in their area of responsibility unacceptable. However, from the perspective of a given individual among hundreds of thousands at risk on a winter night, it is perhaps understandable why they may find reasons to challenge such odds.

NOAA/NWS launched an El Niño Communication Campaign in the summer of 2009 based on the forecast of the 2009-2010 El Niño event, and an unprecedented level of outreach with EM and Media partners was accomplished. Much of the research and figures prepared for this paper was developed in an effort to provide improved education and outreach for the expected impacts of the 2009-10 El Niño event and to motivate preparedness in Florida. The message was regionally tailored for parts of Florida by the NWS WFOs. Graphics such as Figures 3 and 12(a-b) and pie charts of the updated statistical analyses of the tornado threat (Figures 23a-c) were developed to simplify the issues for the public. The annual Florida Hazardous Weather Awareness Week was moved up from February to late January to allow more time for people to plan and prepare for the peak of the severe weather season. Updated educational information on severe weather and El Niño was included in the FDEM 2010 Florida Severe Weather Awareness Guide. NWS WFOs in Florida conducted Media and EM workshops and press conferences on El Niño impacts that generated many TV, newspaper, and web articles to further raise awareness.

The traditional Media (TV, radio, and print) is and has been a critical partner in NWS and EM outreach efforts. With the proliferation of Internet Media and the expansion of the “blogosphere,” many other voices have been added to the discourse which potentially enables more people to get the message. It also makes the mission of getting a focused and coherent message out more challenging. There is a fine line between getting the message out through outreach to educate and elicit an appropriate response and “hyping” a subject to appeal to an increasingly fragmented public attention span. The ability to predict regional climate variability during El Niño events that can allow people to prepare for and mitigate negative impacts and exploit the positive impacts has advanced considerably in recent years. But, often these potentially useful predictions and educational efforts are interpreted within the context of the larger issues of climate change and anthropogenic global warming (AGW) to the point where there is inevitably a contrarian position by a vocal minority and apathy by the majority who tune out long-range forecast information in the Media - a situation dubbed recently as “climate fatigue” (Vol. 326, SCIENCE www.sciencemag.org 13 November, 2009).

Many online news sites now offer readers the opportunity to comment on articles. The following exchange contains the first three comments (edited for brevity) regarding an education outreach article on the increased risk of tornadoes in Central Florida for the 2009-2010 El Niño, with content provide by NWS Melbourne and local EMs (Tornado Warning: El Niño Could Spawn More Deadly Twisters, Orlando Sentinel November 3, 2009):

1 - Hi this is the first year for me living in Florida where as the El Niño pattern is here.
Here is an article that talks about the possible tornadic activity tonight through April for all of you newbie's to Orlando's El Niño pattern (and for those who are interested in this as well), Please be safe!!!!!

2 - If you don't have a weather radio, get one. No ifs, ands, or buts about it. It's a $20 investment that can save your life.
3 - I'm not at all surprised by the scare tactics the local weatherman use around here. The scare tactics and exaggerations go on everywhere but they are particularly noticeable (sic) in Orlando. … Of course we could get tornados here (they occur everywhere in the US) but they tend to be very small and of short duration in peninsular Florida. Typically F0 or F1 type. …I wouldn't stress out about the POSSIBLE tstorms that move through tonight. I know I'll be sleeping fine.

The first two comments were helpful and presented favorable responses to the outreach effort. The third comment is strongly contrarian and full of unscientific disinformation that is exactly the opposite of reality and the type of anecdotal knowledge mentioned previously that needs to be overcome. To what extent these types of exchanges are typical of what goes on in personal interactions, public forums, workplaces, and neighborhoods, and what effect they have on people’s motivation to prepare, the authors cannot say. However, subjectively, they seem to occur whenever people discuss weather and climate forecasts. This is a significant challenge to overcome at a time when forecasts of impacts from climate variability are advancing rapidly.

To improve NWS forecaster situational awareness and address the issue of uncertainty, specialized warning training was completed at NWS Melbourne using radar simulations from past tornado outbreaks. Anomaly analyses of numerical model fields relevant to producing the large-scale environment favorable for tornado development were developed and used to compare with the anomaly fields of past tornado outbreaks to put developing ET cyclones into historical context. The Florida NWS WFOs and SPC also took action to increase awareness of the threat of nocturnal tornado outbreaks by reducing the probability threshold from 15% to 10% of ≥F2 nocturnal tornadoes for Public Severe Weather Outlooks (issued overnight between December 1, 2009 and March 31, 2010). These Public Severe Weather Outlooks incorporate enhanced wording to increase awareness i.e. *“…the potential for a significant tornado after dark warrants heighted safety precautions. Tornadoes during the overnight hours at this time of year can be particularly dangerous because they are usually fast-moving and obscured by rain and darkness.”* Similar enhanced wording is also now included in tornado watches issued for overnight periods. NWS offices in Florida now routinely hold on-line briefings for EMs in their areas of responsibility for any significant ET cyclones. The EMs and media can also interact directly with the NWS forecasters via an on-line instant messaging system. These recent improvements allow an unprecedented level of coordination between the NWS, EMs, and the Media to rapidly and consistently spread the word about any developing tornado threats.

A relatively new concept called "Warn-On-Forecast" (Stensrud et al. 2009), rather than the current paradigm of warning-on-detection, might help bridge the gap between tornado watches and warnings by providing probabilistic information on tornado threats for areas smaller than the watch area, but larger than a typical tornado warning and provide longer lead times. Because tornado warnings are currently based upon radar detection, little uncertainty information is provided, and lead times are limited. Forecasters often act on the principle that it is better to issue a tornado warning for marginal storms than to have a potentially devastating tornado strike without warning. This can lead to many false alarms and de-sensitization of the public. The warn-on-forecast concept might be particularly applicable to the winter nocturnal tornado forecast challenge highlighted on Figure 17a-f where storms moving onshore from the Gulf of Mexico in an environment favorable for strong tornadoes has a relatively high probability of producing tornadoes, but does not meet the criteria for issuing traditional tornado warnings. It is not clear if the majority of people could understand and utilize the concept of tornado probability due to the inherent low probabilities of occurrence; however, it may work well to supplement the current system which is fraught with deterministic temporal and spatial lead time and false alarm issues. Advances in mesoscale modeling and radar analyses would make this concept more robust in the future. But, enough experience currently exists to begin experimenting which this approach under certain situations such as the nocturnal winter tornadoes.

Implementation of the "Warn-On-Forecast" system would take a significant amount of training and outreach before people in Central Florida might be able to effectively use uncertainty or probabilistic information in their decision-making process to help mitigate the tornado challenge. However, while the current system is far from perfect, it does provide enough information for successful personal decision making. In addition to the early pre-season outreach efforts, the Florida Dry Season Forecast is issued monthly, starting in late summer, Hazardous Weather Outlooks are issued daily out to 7 days, Tornado Watches are typically issued several hours before tornadoes occur, and Tornado Warnings lead-time range from several minutes up to 45 minutes in some cases. There is no guarantee that tornado warnings (even for strong tornadoes) will *always* be issued in advance. A good all-hazards plan can compensate for an imperfect forecast and save lives. But, a poor all-hazards plan, or lack of any plan can't take advantage of even a perfect forecast and instead lead to disaster. The stakes are high. It is a cliché to say "get a plan," but motivating people to take personal responsibility and develop simple tornado preparedness and mitigation plans is the first step.

Critical aspects of an effective all-hazards plan for the decision-maker includes knowledge of hazards, vulnerability assessments, mitigation options, the ability to receive watch/warning information or some other trigger to implement pre-determined plans, and identification of shelter and a means to get there. A frank vulnerability assessment must include the fact that old code manufactured homes, old cottage-style light frame houses, tents, campers, and RVs are not viable shelters from strong tornadoes. With regard to housing mitigation, inspections in the wake of the February 1998 and 2007 Central Florida tornado disasters found many manufactured houses were improperly tied down – especially older ones. The reality is that while adding/upgrading tie downs might improve home safety somewhat for weak tornadoes, it is unlikely to be economically feasible to make old code manufactured housing safe from ≥F2 tornadoes with any amount of tie down improvements. Likewise there is no structural mitigation possible for the thousands of individuals temporarily living in campgrounds. The most economical and effective mitigation option for these high-risk scenarios is to move to an effective shelter prior to the arrival of a tornado.

Receiving HWOs and tornado watches and warnings is the first step in activation of all-hazards plans. NOAA Weather Radio (NWR) is considered the best method to receive this information, especially during the overnight hours in the dry season when most people are asleep and not tuned in to other media. In the aftermath of both the February 1998 and 2007 Central Florida tornado outbreaks widespread adoption of NWR occurred across Florida, especially in schools, government centers, nursing homes, and retirement centers. After the 2007 tornado outbreak, tens of thousands of NWRs were sold in Central Florida as a result of major corporate promotions with the idea that they would be the primary means to receive tornado warnings at night. Improvements have been made by the NWS in reducing the size of tornado warnings (78% reduction of tornado warning areas within east-central Florida since implementation of 'storm-based warnings' in late 2007) and improved hazard coding in higher end NWRs to allow listeners to receive only warnings for specific, user-defined hazards and areas significantly reducing local false alarms. However, there are several issues that make widespread use of NWR problematic.

Many users ultimately do not leave their low cost NWRs on or in alert mode, especially at night, because the programmable warning areas are too large (county-based) and the radios do not incorporate the high level of selectable programming offered by the higher end NWRs. The result is that people are often awoken at night for an alert that does not apply to their area or their interests and ultimately is considered a nuisance (**BAMS** volume 90, 12, 1766-1767). Many NWR customers have unrealistic expectations of the spatial and temporal scale of warnings that are beyond the state of the science. Another significant issue is the single point of failure associated with many NWR circuits due to a non-redundant telecommunication line which carries EAS codes and warnings from the NWS office to the NWR transmitter site. A loss of the telecommunication line (even momentarily) means that warnings will not be received by the public via NWR.

The staff of NWS Melbourne always recommends that users have a backup means of receiving warnings such as e-mails and text messages sent to cell phones, pagers, and computers. While the timeliness of such unofficial warning information can not be guaranteed, the ability to receive such critical information from two independent sources significantly raises the likelihood of message receipt until a more reliable system can be fielded. The NWS Weather Radio Improvement Program (WRIP) is expected to address these issues in the next few years. Since the synoptic conditions that favor nocturnal strong tornadoes are typically well forecast, the NWS Melbourne implemented the practice of including reminders in HWOs issued during the morning prior to an overnight tornado threat in the dry season to check the operation of NWRs, replace batteries, and be ready to receive overnight alerts. This is a way to limit the number of false alarms as an approaching ET cyclone at night in an El Niño is the time to have radio’s fully operational! Ultimately, the most effective method to ensure receipt of information to implement tornado plans is for a family member to stay up throughout the night to monitor weather information.

The selection of an implementation trigger for a tornado plan has a great bearing on time-to-shelter and shelter location options. Plan triggers could be the seasonal forecast of an El Niño dry season, the HWO, or a tornado watch or warning. NWS Melbourne in coordination with area EMs, now recommends that people in vulnerable housing consider either spending the night in a nearby permanent home with friends, relatives, or neighbors when the threat of overnight tornadoes exists, or to move to a nearby (more) secure shelter upon issuance of a tornado watch, then return once the tornado threat is over. This type of sheltering should be coordinated in advance as part of a family tornado plan. If the plan trigger is a tornado warning or, lacking that, the imminent approach of a tornado, it must include quick access to a nearby shelter. Decisions made at the last minute are rarely effective. Tornado shelters for manufactured homes are an option depending on financial ability. Residents of campgrounds and RV parks should be aware of any nearby shelter options, such as a recreation center, laundry room, or restroom/bathing facilities, but these may not be available and may not be safe. Indeed, in discussions with various stakeholders, the issue of the safety of ad-hoc group shelters was raised. In others words, is the risk of concentrating people into a large shelter of unknown vulnerability greater or less than people remaining dispersed in individual vulnerable shelters? Any plan that includes concentrating people from vulnerable housing into one structure must include a structural assessment of the viability of that group shelter.

Often, the decision comes down to the lesser of several imperfect choices, but planning ahead can still reduce the threat of death or injury. For example, the decision should not come down to a choice of seeking shelter in a vehicle or a ditch. The authors agree with Simmons and Sutter (2007) that seeking shelter in a vehicle is an example of a desperate last-minute shelter option due to lack of planning. However, for some decision-makers, realistically, there may be no better shelter readily available. Examples of compromise plans that are far from perfect, but are economical, and limit unnecessary implementation of a tornado plan while increasing to a degree the safety of occupants include receiving information on an approaching tornado, taking shelter in the interior-most room of a manufactured home wearing helmets and covering up with heavy blankets and pillows for protection, or to do likewise in vehicles for those in extremely vulnerable housing such as in campgrounds with no viable shelter options nearby.

The sheer magnitude of the Florida tornado vulnerability challenge is daunting, but not insurmountable. To better inform decision-makers on high impact tornadoes, improvements need to be made in understanding the dry season nocturnal tornado environment, short-term radar interpretation and technology, and data integration and mesoscale modeling. Forecasts of ENSO continue to improve, but seasonal impact forecasts such as for the Florida dry season are only as good as the Pacific SST forecasts. However, current weather and climate information is more than sufficient for decision-makers to implement effective tornado plans. Older manufactured homes and small frame houses are realistic low-cost housing options and thousands of people will continue to enjoy wintering and winter vacations in Florida. However, frank outreach efforts to educate the public on the low probability-high impact tornado risk and to motivate them to prepare detailed plans must continue. How much effort and serious consideration currently goes into the formulation of family disaster plans across Central Florida? There are low-cost, low-impact options to improve survivability, but without personal responsibility, little will happen to improve the situation. There are direct and indirect costs involved in implementing a tornado plan such as lost work and time and other circumstances unique to each individual/family/business. Risk tolerance versus potential loss – including loss of loved-ones must be considered carefully for each case/individual – no one can make these decisions for them. The bottom line: is the value of what one risks losing worth the occasional inconvenience of erring on the side of safety?

The lead author spoke at the one-year remembrance ceremonies for those killed during the Central Florida tornadoes in Lady Lake and Lake Mack in February 2007. The grief in these small, tight-knit communities that were impacted that night was still palpable, even though the healing process was well underway. If one were to ask someone who had lost a family member to the tornadoes of 1998 or 2007, to what lengths they would go to have a different outcome – they would likely say “whatever it takes”. In such a context, false alarms don’t seem particularly inconvenient. Given the current state of the science, an elevated false alarm rate likely will be tolerated, if accurate lead-time warnings can be issued. However, individuals (especially those in vulnerable housing) must have a means to receive such warnings and possess the ability to quickly enact their all-hazards plan in order to limit future tornado disasters.

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7. DISCLAIMER

The views expressed are those of the authors and do not necessarily represent those of the National Oceanic and Atmospheric Administration or the National Weather Service.

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