Precursors to Southwest Florida Warm Season Tornado Development

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(Manuscript received 29 May 2009; in final form 16 January 2010)

ABSTRACT

Predicting and warning for tornadoes developing near the complex coastline of urban Lee and Charlotte counties in Southwest Florida is often a challenge. The closest National Weather Service Doppler radar is 130-180 km to the northwest. Four warm season tornado days were initially examined from coastal southwest Florida. Those cases showed a number of similarities in the synoptic and mesoscale patterns and processes leading to tornado development. Easterly flow and gulf coast sea breeze development interacted with local topography to create cyclonic mesoscale circulations around 50 km in diameter. These circulations likely lead to more predictable boundary collisions and enhanced convection with strong updrafts capable of supporting brief tornadoes. An additional nineteen case days were gathered by collecting dates of tornadoes in Lee and Charlotte counties and parsed to include only those days with similar vertical wind profiles. To gain more insight into the patterns of various interactions, the cases were composited to show ambient flows and the degree of instability. Thirty warm season tornado events that occurred on 23 different days from 1980-2008 are examined from coastal southwest Florida to identify synoptic and mesoscale environments associated with tornado development. The results of this study should help forecasters identify the profiles conducive to southwest Florida tornado development.

1. Introduction

Predicting and warning for warm season (May-Sep) tornadoes developing near the complex coastline of urban Lee and Charlotte counties in southwest Florida is often a challenge. Sea breeze circulations develop along the east and west coasts of the Florida peninsula and move inland, often interacting. Pielke (1974) modeled sea breeze interactions and found that Lake Okeechobee influenced convection over southwest Florida. Wolf (2004) depicted that, similarly to a sea-breeze interaction, "rapidly developing but short-lived convective cells [were] oriented along and near the lake-enhanced boundary". Wakimoto and Wilson (1989) and Brady and Szoke (1989) hypothesized that intersecting boundaries are followed by a convective updraft, and subsequently a weak non-supercell tornado may form. A combination of low-level mesocyclonic *Corresponding author address*: Dr. Jennifer M Collins, Department of Geography, University of South Florida, 4202 East Fowler Avenue, NES 107 Tampa, Florida 33620

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circulations and sub-cloud layer convergence may initiate convective updrafts, possibly leading to tornadogenesis (Lee and Wilhelmson 1997).

When the subtropical high that typically extends across the state of Florida during the summer months is north of Lee and Charlotte counties, easterly flow develops and sea breeze mergers occur toward the southwest portion of the peninsula. The nearest National Weather Service (NWS) WSR-88D radar at Ruskin FL near Tampa Bay (TBW – see Fig. 1) is 130-180 km from the tornado locations in Lee and Charlotte counties. Although radar reflectivity and velocity resolution improved to 0.25 km by 0.5 degree in 2008, at this distance, smaller tornado related circulations may not be well resolved by the radar. In addition, the radar beam overshoots the lower levels of convection. In the absence of spotter reports as the tornado is developing, warnings may not be issued. Many of the tornadoes reported over southwest Florida develop as waterspouts (Golden 1971) and move onto the populated land area causing localized damage (Fig. 2). Typically, Florida experiences persistent convective activity due to the interaction of mesoscale convergence zones, especially during Florida's warm season (Collins et al. 2000). Based on Storm Data from 1972-2008 obtained from the National Climatic Data Center (NCDC 2009), 94% of the warm season tornadoes that developed over Lee and Charlotte counties in Florida were F0 - F1 on the Fujita Scale, or EF0 - EF1 on the Enhanced Fujita Scale (McDonald et al. 2006) and the other 6% were rated F2 or EF2. Serious injuries and deaths are rare but property damage is often high, ranging from \$100K to \$2.5M.

Thirty warm season tornado events that occurred on 23 different days from 1980-2008 are examined from coastal southwest Florida to identify synoptic and mesoscale environments associated with tornado development. These cases were characterized by similar flow regimes with significant convective development during the afternoon and evening hours. Interestingly,

none of the May cases fit this pattern. Figure 3 shows the touchdown locations and paths of the longer track tornadoes, and some symbols represent more than one tornado touchdown location. An understanding of these cases is expected to lead to improved tornado forecasts and warnings by operational meteorologists.

2. Data collection and methodology

Objectively analyzed maps were obtained from Plymouth State University Weather Center (2009) to determine surface conditions. Local Analysis and Prediction (LAPS) software ingests surface mesonet data to produce the wind plots and streamlines analyses. The LAPS analyses are less reliable at places and times where data are sparse such as over the Gulf of Mexico or prior to the widespread use of automated surface observing systems. Skew-T atmospheric sounding data were collected from the University of Wyoming (2009) for the Tampa Bay radiosonde site at Ruskin, FL (TBW – see Fig. 1) area to examine sounding characteristics. A composite of the sounding data was created by taking the mean of all observations within +/- 5 hPa for every 10 hPa level. No sounding observations were used twice when more than one tornado occurred on a case day. We analyzed common variables that indicate moisture and instability, including virtual convective available potential energy (CAPEv) that lifts the mean parcel in the lowest 500 m above ground level (Doswell and Rasmussen 1994), the virtual lifted index (LIv), precipitable water (PW, Benwell 1965), and vertical wind profiles. Mean vertical vector winds were calculated using a vector average of the significant levels in the layers. The mean wind values are a vector mean of both mandatory and significant levels. No vertical weighting scheme was used, therefore each value ranks equally. The circulations which produced tornados were examined by viewing WSR-88D radar storm relative motion (SRM) using the NWS Weather Event Simulator (Magsig and

Page 2002) and GR2Analyst (Gibson 2008). GR2Analyst is a commercial radar analysis software package that incorporates level II WSR-88D radar data and is widely used by NWS forecasters. The radar data were collected from the NCDC. The SRM product which was used subtracts the average motion of all radar identified storm cells from the preceding volume scan to better highlight storm scale circulations. When the radar calculated storm motion is not representative of some of the convective elements, then storm scale circulations, particularly weaker ones, may not be as apparent. For the cases shown, the default storm motion did not affect identification of storm scale circulations using the SRM. Visible satellite data were obtained via email from the Cooperative Institute for Meteorological Satellite Studies (CIMSS). Composite plots of geopotential heights at 1000, 500, and 300 hPa were produced from NCEP/NCAR Reanalysis data (Kalnay et al. 1996) through the NOAA/ESRL Physical Sciences Division interactive plotting and analysis pages (PSD 2009).

3. Analysis and Discussion

Four warm season tornado days from 2006-2008 were initially examined from coastal southwest Florida. The synoptic pattern leading to tornado development for these cases occurs with dominant low level (surface to 700 hPa) easterly flow (Fig. 1). This easterly flow shown at 1600-1700 UTC 08 June 2008 (Fig. 4a-b) weakens along Florida's west coast in response to diurnal warming over land areas and a sea breeze circulation begins from 1800-1900 UTC (Fig. 4c-d). A northwesterly sea breeze develops to the north while to the south the coastline shape creates a southerly sea breeze. This regime creates a convergent pattern that sometimes evolves into a mesoscale (~50 km) cyclonic circulation near the coast as shown from 2000-2100 UTC (Fig. 4e-f). In the cases with a sufficient density of surface observations, the mesoscale circulation is evident

up to 1.5 hours prior to tornado development. As the west coast and east coast sea breezes merge, the cyclonic circulation fades. An additional nineteen case days from 1980 to 2005 were gathered by collecting dates of tornadoes in Lee and Charlotte counties and parsed to include only those days with similar vertical wind profiles. Older cases with a lower density of surface observations may not resolve the circulation. The mesoscale circulation is not easily identifiable using satellite data. This circulation likely enhances convection at the sea breeze interface and appears to be a precursor to tornadic development.

a. Synoptic conditions

Surface synoptic conditions varied for the cases but the common factor was an inverted low pressure trough intersecting the sub-tropical ridge over peninsular Florida with an east to southeast surface wind regime. A sampling of the most recent cases illustrates the similarities.

- 1. 1800 UTC 16 Sep 2007 (Fig. 5a.): Synoptic conditions indicate a moderate high pressure ridge which extends southward along the Mississippi valley. An inverted trough of low pressure is noted along the southwest coast of Florida.
- 2. 1800 UTC 08 Jun 2008 (Fig.5b.): A high pressure ridge across northeast Florida is intersected by a weak trough along the west coast.
- 3. 1800 UTC 13 Jun 2008 (Fig.5c.): A high pressure ridge extends along the eastern seaboard across the Florida panhandle and over the Gulf, with an inverted trough along the west coast of Florida. East to southeast surface flow continued during this period with the surface ridge axis north of the area over northern Florida.

b. Sounding Data

Our area of interest is approximately 120 km from TBW where the soundings were taken. The 1200 UTC TBW soundings (Table 1) for the twenty-three case days indicated that the CAPEv ranged from 31 to 2723 Jkg⁻¹. The LIv ranged from -7.52°C to 0.32°C. PW ranged from 26 to 52 mm with most of the cases having mid level (700 to 300 hPa) dry layers. These broad ranges and sometimes low values indicate that soundings taken hours earlier and up to 120 km away are not necessarily representative of conditions during tornadogenesis, however they do establish a general atmospheric pattern on tornado days. The mean vertical winds were more consistent considering both direction and speed. Low level vertical wind profiles were generally southeast to northeast while mid level flow ranged from north to east. The winds were light averaging 4 ms⁻¹ in the low levels and 5.5 ms⁻¹ in the mid levels. Variability exists in the soundings but all 23 case days had easterly wind flow in the lower levels, a northerly wind component in the mid to upper levels, some instability (CAPEv>0), and the mid levels had dry layers with 20 to 60 degree Celsius dewpoint depressions. Figure 6a is a TBW sounding that is representative of the case profiles. The composite sounding plot of all case days between 1980 and 2008 (Fig. 6b) may be used as a guide for providing tornado outlook information when that general pattern is met. Low-level wind flow was east (93 degrees) at 4 ms⁻¹ while mid-level flow had a variable north to east component averaging 52 degrees at 5.5 ms⁻¹. Mid-level dry layers are noted in the composite. Other mean parameter values in the composite sounding are CAPEv 1433 Jkg⁻¹, LIv -4.0°C, and PW 38 mm.

c. Radar, Streamlines, and Tornado Damage Descriptions

Three sample cases of WSR-88D Doppler radar storm relative motion (SRM) and mesoscale circulations depicted in wind plots and streamline analyses from LAPS are shown in Figs. 7a-c. These cases show similar precursor patterns up to an hour or more in advance of

tornadogenesis, as indicated by the LAPS overlays which precede the reflectivity times. Easterly gradient flow and gulf coast sea breeze development interact with local geography to create a brief, up to an hour long, cyclonic coastal mesocirculation. The following descriptions are based on Storm Data (NCDC 2009).

The 2100 UTC 16 September 2007 streamlines (Fig. 7a) show a broad area of cyclonic circulation centered within the red circle During the next hour thunderstorms developed rapidly northward along the sea breeze producing a waterspout that moved onto Fort Myers Beach at 2225 UTC and traveled north until 2227 UTC causing damage to a hotel and tiki bar. This funnel retracted and reappeared six minutes later over Cape Coral and lasted until 2258 UTC. The SRM from 2213 UTC (Fig. 7a) indicates a couplet of inbound (green) and outbound (red) rotation associated with the tornado along the leading edge of the northward propagation of the convection. Of the 138 homes that were damaged, six homes received moderate damage and one home was destroyed. The damage path length was 6.4 km and width was only 25 m causing EF0 damage except for a home nearly cut in half with EF1 damage. Damage was estimated to be around \$4M. One injury occurred, and thirty people were displaced from their homes.

The 2100 UTC 08 June 2008 streamlines (Fig. 7b) show the precursor mesocyclonic circulation centered over northeastern Lee County. Under easterly surface flow, convection began along the convergent Lake Okeechobee breeze boundaries, creating an outflow boundary that propagated west. The outflow boundary then intersected the west coast sea breeze briefly amplifying convection that moved north and produced the tornado. The 2102 UTC SRM (Fig. 7b) shows a rotational velocity couplet associated with the tornado that was produced by two intersecting boundaries over northern Lee County near Bayshore Manor. Tornado wind speeds were estimated as EFO, but with a small pocket of EF1 damage, mostly occurring in a mobile home

community. One injury occurred. Minor damage was sustained to carport roofs and sheds. The tornado path length was 8 km, 30 m wide, and lasted from 2055 UTC-2115 UTC. In this case the mesocyclonic circulation developed within the hour preceding the tornado but observation data didn't show the complete picture until just before the tornado developed.

The 2000 UTC 13 June 2008 streamlines (Fig. 7c) again show a precursor cyclonic circulation in the vicinity of the tornado. This tornado occurred around 2045 UTC on the leading edge of a thunderstorm gust front. As the outflow boundary intersected the gulf coast sea breeze convective development toward the north occurred. The brief touchdown which lasted from 2045-2048 UTC affected 12 homes with EF0 damage to shingles and a pool cage. One home suffered 50% roof damage and another home sustained minor damage, including a fallen fence, and some roof damage which led to minor flooding. The tornado path length was estimated about 500m and the width at 25 m. The 2047 UTC SRM (Fig. 7c) shows a rotational velocity couplet associated with the tornado over the Cape Coral area in Lee County.

The radar loop of reflectivity and SRM for 16 September 2007 (Fig. 7d) from GR2Analyst shows convective development northward as the east and west coast sea breezes merge. This is seen in the reflectivity loop with propagation of stronger signatures northward. The SRM loop shows the brief thunderstorm circulation associated with the tornado moving from south to north as the convection builds northward.

d. GOES Satellite data.

The sequence of GOES images from 16 September 2007 (Figs. 8a-c) shows strong convection propagating northward along the coast and over the Cape Coral area. This pattern of south to north convective development and propagation was common in many of the cases even

though the winds from the surface to 500 hPa were typically from the east to northeast. Satellite loops (Figs. 8d-f) of development for the most recent three cases illustrate the development over coastal southwest Florida. The three loops of 1 km resolution visible imagery show similar scenarios with the east coast sea breeze and associated convection moving across south Florida and merging with the west coast sea breeze creating convective development thereafter. Localized circulations associated with the tornadoes that were seen in radar velocity data appear to be linked with converging outflow boundaries seen in each of the satellite loops. The east coast sea breeze interacts with Lake Okeechobee and convective outflow boundaries and becomes more irregularly shaped as it moves westward. Also evident in the satellite loops is the stabilizing effect of Lake Okeechobee under easterly flow that creates a cloud free area downwind of the lake.

e. Composite synoptic patterns.

An examination of the twenty-three warm-season tornado days between 1980 and 2008 revealed similar surface patterns as detailed in the composite plots of 1200 UTC geopotential heights at 1000, 500, and 300 hPa (Fig. 9a-c). Figure 9a shows heights at 1000 hPa associated with a ridge over the mid Atlantic states, with a long fetch of easterly flow over Florida. This differs from the inverted trough seen in the 1800 UTC case examples (Fig. 5a-c.) that were 6 hours later. Higher in the atmosphere at 500 hPa (Fig. 9b), the center of the high is over the lower Mississippi valley ridging eastward over Florida with weak flow over the Florida peninsula. At 300 hPa (Fig. 9c), the ridge is farther southwest with a northerly wind component over Florida.

4. Conclusions

A sampling of recent warm season tornado cases examined from coastal southwest Florida show a number of similarities in the synoptic and mesoscale pattern and processes leading to tornado development. Easterly gradient flow and gulf coast sea breeze development interact with local geography to create a cyclonic coastal mesocirculation. This circulation likely leads to more predictable boundary collisions and enhanced convection with strong updrafts capable of supporting brief non-supercell tornadoes. Easterly low level flow, east-northeast mid level flow, and instability to support strong convection are the common attributes of these cases. Ambient flow direction and magnitude, and degree of instability are important factors in the timing of various boundary interactions and resulting circulations, leading to tornado development along the complex coastline. This populated urban area is particularly challenging to warn for convection growth and tornado development. Based on preliminary results from this study, forecasters responsible for issuing warnings for southwest Florida have a pattern to recognize that develops prior to warm season tornadogenesis.

The next step in this research is to find null cases over Lee and Charlotte counties where the pattern did not produce tornadoes. Then the Weather Research and Forecasting (WRF) model will be utilized to examine moisture transport, stability profiles, and wind profiles as well as explicit predictions of thunderstorm development and evolution. The WRF model may also provide more insight into the influence of Lake Okeechobee.

Acknowledgements. The authors gratefully thank the University Corporation for Atmospheric Research (UCAR) and the National Weather Service (NWS) Cooperative Program for Operational Meteorology, Education and Training (COMET) for providing funding for this project. The authors would like to acknowledge the use of the Linux cluster provided by Research Computing, University of South Florida (USF). Many thanks for Dan Noah's initiation of this project who worked alongside Dr. Collins to prepare the grant application. The authors appreciate the assistance of Tom Whittaker from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) who assisted us in obtaining the high-resolution satellite imagery. Special thanks to David Roache from The University of South Florida who assisted us with displaying the Skew-T data. The authors would like to thank Steven Weiss (Storm Prediction Center) and Andrew Devanas (NWS Key West) for their suggestions and comments.

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TABLES AND FIGURES

Table 1. 1200 UTC TBW sounding data for 23 warm season tornado days in Lee and Charlotte counties during 1980-2008 including low level (LL) mean wind (surface to 700 hPa), mid level (ML) mean wind (700 to 300 hPa), CAPEv, virtual lifted index (LIv) and precipitable water (PW).

	1200 UTC	TBW						
	Case Date	LL Wind (°/ms ⁻¹)	ML Wind (°/ms ⁻¹)	CAPEv (Jkg ⁻¹)	LIv (°C)	PW (mm)		
1	08 August 1980	113/6.0	057/6.0	1345	-4.44	39		
2	25 August 1986	065/3.5	096/5.0	1530	-5.31	46		
3	02 September 1986	145/1.5	026/2.0	1726	-4.99	51		
4	21 August 1987	116/1.5	033/3.0	1746	-3.72	47		
5	06 September 1989	088/5.0	091/7.5	1024	-2.78	48		
6	02 June 1990	151/2.5	095/3.0	1239	-4.46	48		
7	02 September 1990	073/2.5	088/6.0	1976	-5.57	50		
8	13 September 1990	103/7.0	112/6.5	1904	-5.04	45		
9	07 September 1991	035/3.0	037/4.0	2153	-5.79	47		
10	17 June 1992	024/3.5	026/7.0	865	-2.15	43		
11	16 September 1992	118/5.0	065/6.0	1898	-5.28	46		
12	09 August 1993	096/4.5	048/7.0	2400	-5.04	37		
13	10 June 1995	102/5.5	026/7.5	2428	-7.52	40		
14	15 September 1995	109/3.5	340/6.5	2205	-5.23	46		
15	10 August 1997	159/2.5	343/3.5	259	-1.50	46		
16	09 June 2000	041/6.5	067/5.5	31	0.32	27		
17	10 June 2002	013/4.0	027/8.5	36	-0.53	26		
18	08 June 2004	089/2.0	101/1.0	725	-2.27	44		

19	15 July 2005	157/4.5	090/3.0	1244	-4.70	52
20	21 June 2006	059/4.5	009/5.0	2092	-5.7	43
21	16 September 2007	055/2.0	022/6.0	2723	-4.8	48
22	08 June 2008	095/7.5	083/10.5	317	-2.8	36
23	13 June 2008	082/4.5	358/5.0	148	-0.4	43



Figure 1. Diagram of sea breeze regimes leading to tornado development over southwest Florida. Charlotte (a) and Lee (b) counties are shaded in green, and location of the NWS WSR-88D radar and radiosonde at Ruskin, FL is also shown.



Figure 2. Cape Coral tornado damage, 16 September 2007. Courtesy of Lee County Emergency Management.

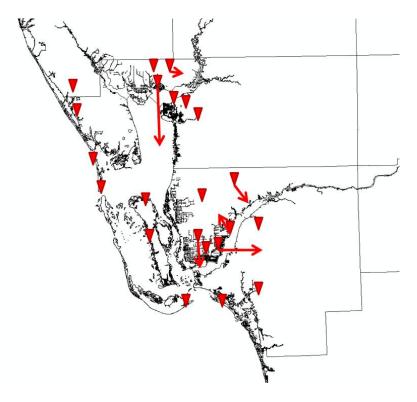


Figure 3. Tornado touchdown locations and paths (indicated by arrows) of the longer track tornadoes based on NCDC data 1980-2008.

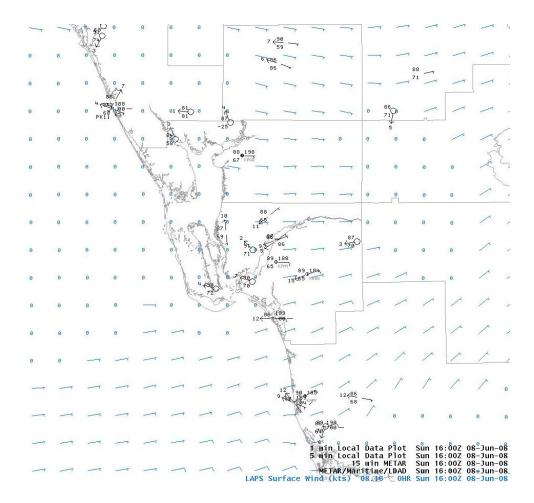


Figure 4a. LAPS and surface observations at 1600 UTC 08 June 2008.

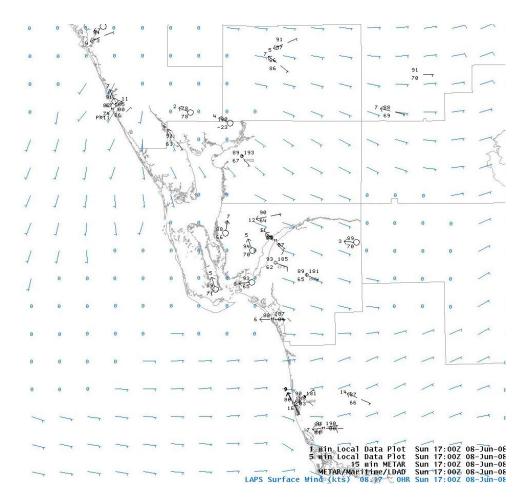


Figure 4b. LAPS and surface observations at 1700 UTC 08 June 2008.

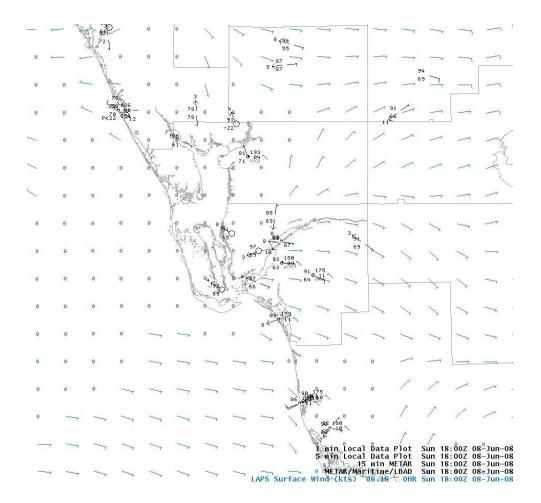


Figure 4c. LAPS and surface observations at 1800 UTC 08 June 2008.

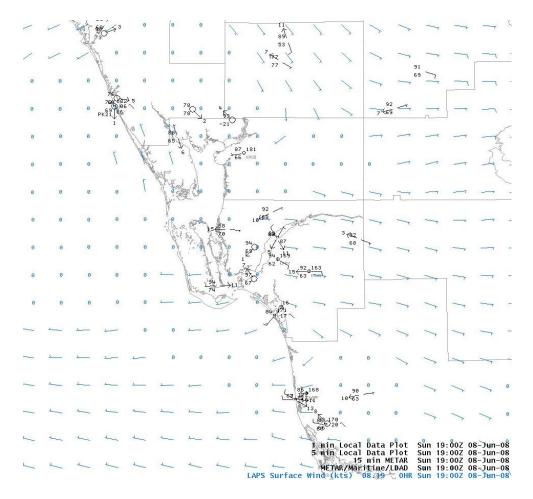


Figure 4d. LAPS and surface observations at 1900 UTC 08 June 2008.

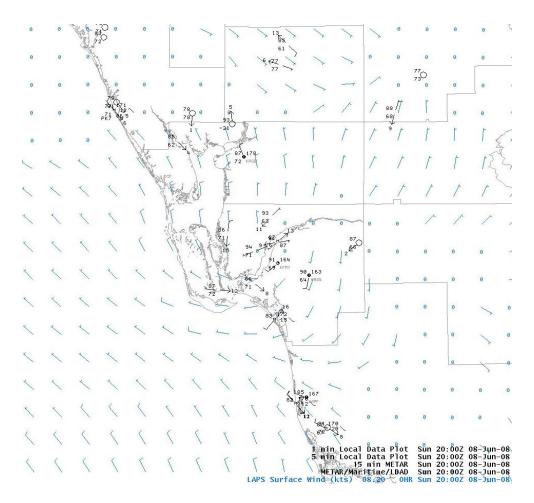


Figure 4e. LAPS and surface observations at 2000 UTC 08 June 2008.

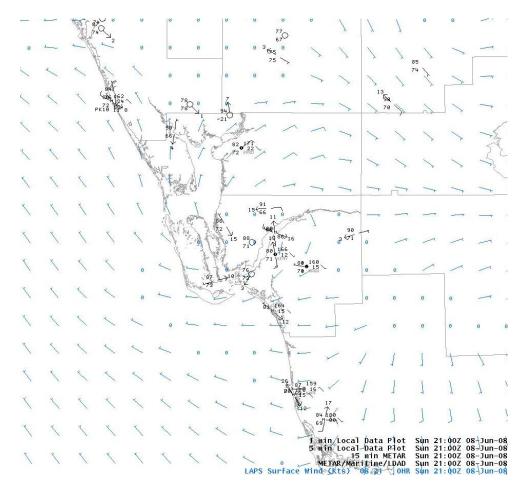


Figure 4f. LAPS and surface observations at 2100 UTC 08 June 2008.

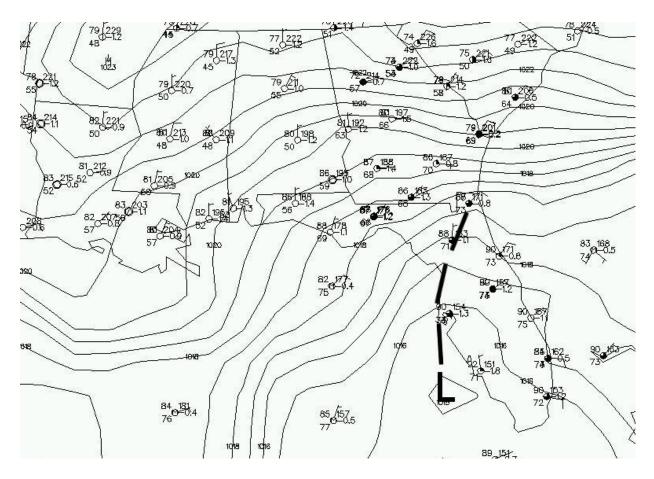


Figure 5a. Surface sea level pressure (SLP) patterns 1800 UTC 16 September 2007.

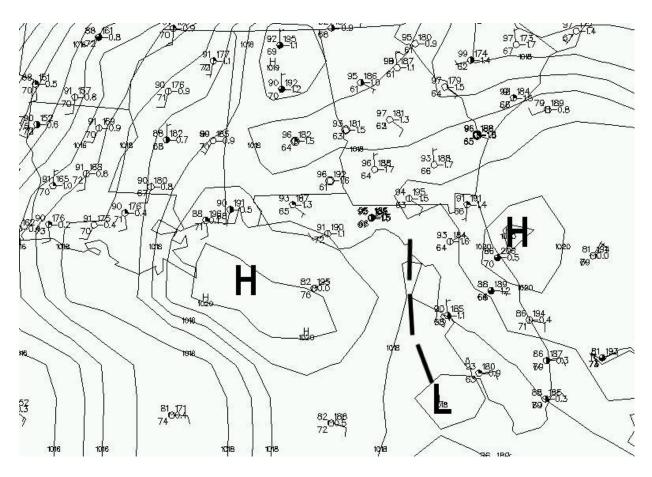


Figure 5b. Surface SLP patterns 1800 UTC 08 June 2008.

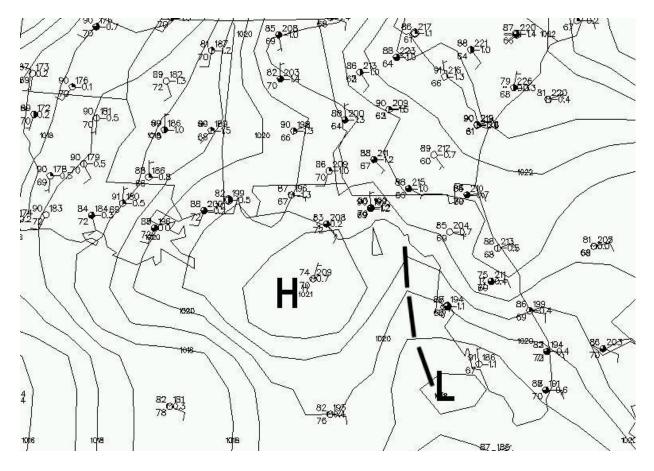


Figure 5c. Surface SLP patterns 1800 UTC 13 June 2008.

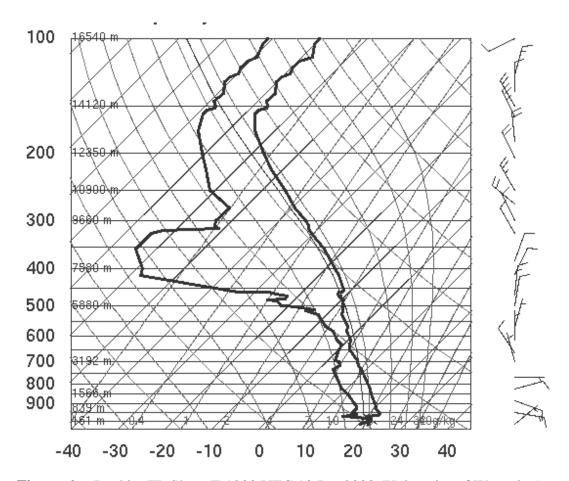


Figure 6a. Ruskin, FL Skew-T 1200 UTC 13 Jun 2008 (University of Wyoming).

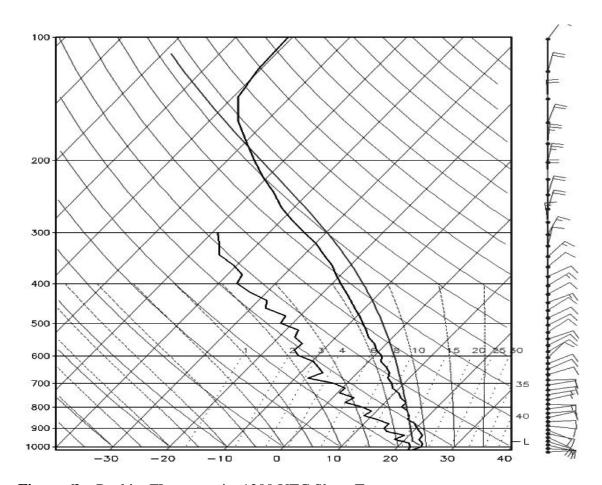


Figure 6b. Ruskin, FL composite 1200 UTC Skew-T.

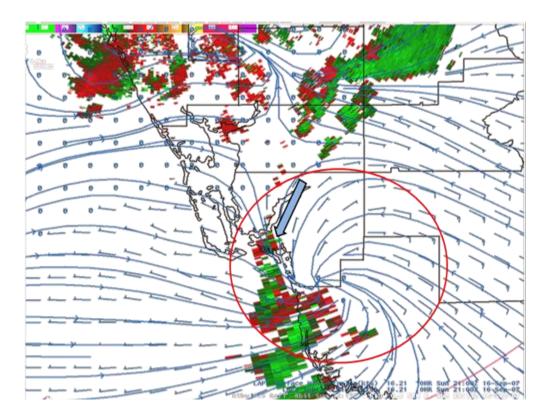


Figure 7a. 16 Sep 2007 2213 UTC SRM and 2100 UTC surface streamlines of wind direction. Inbound (outbound) velocities are represented by shades of green (red) from greater than zero-24.9 ms⁻¹. The arrow indicates the tornado location and the red circle indicates the mesocyclonic circulation.

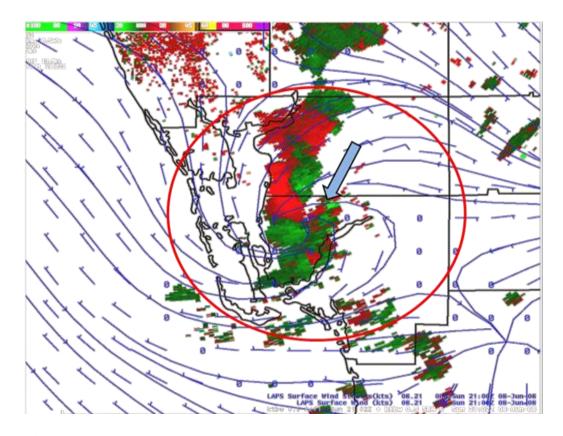


Figure 7b. 08 June 2008 2102 UTC SRM and 2100 UTC surface streamlines of wind direction. Inbound (outbound) velocities are represented by shades of green (red) from greater than zero-24.9 ms⁻¹. The arrow indicates the tornado location and the red circle indicates the mesocyclonic circulation.

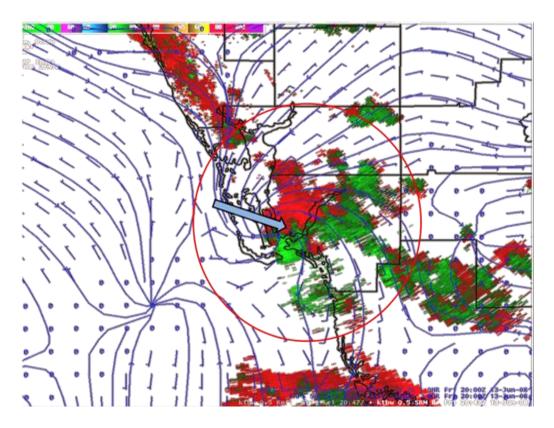


Figure 7c. 13 June 2008 2047 UTC SRM and 2000 UTC surface streamlines of wind direction. Inbound (outbound) velocities are represented by shades of green (red) from greater than zero-24.9 ms⁻¹. The arrow indicates the tornado location and the red circle indicates the mesocyclonic circulation.

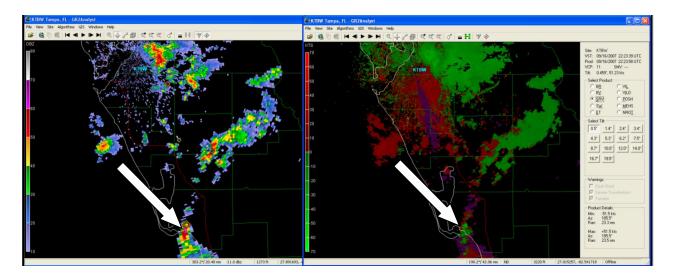


Figure 7d. 16 September 2007 2203 - 2253 UTC <u>loop</u> of two panel base reflectivity and storm relative motion. Arrow indicates the tornado location. Diamonds represent relative hail size estimations.

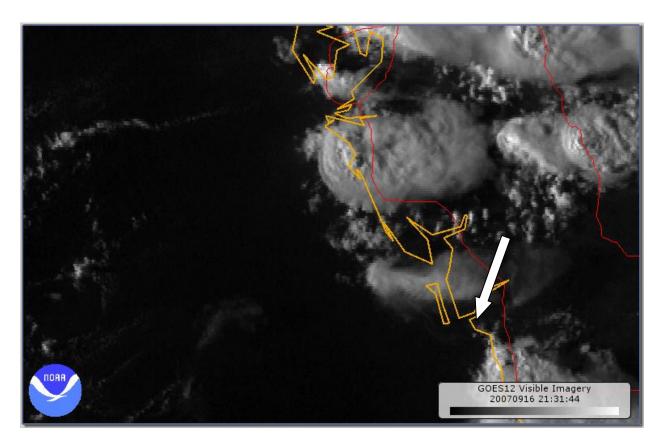


Figure 8a. GOES 12 visible satellite imagery 2131 UTC 16 September 2007. The arrow indicates the tornado location.

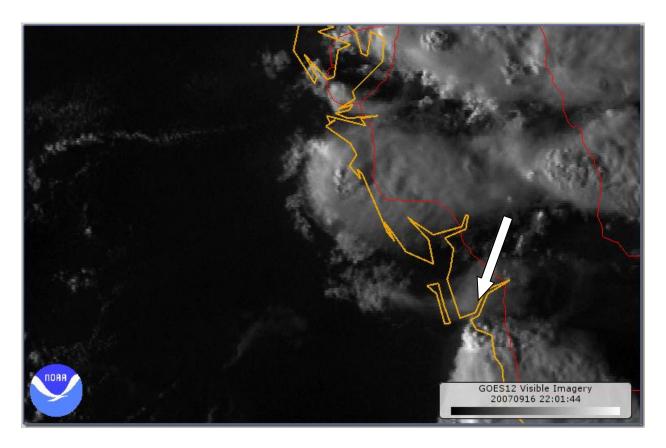


Figure 8b. GOES 12 visible satellite imagery 2201 UTC 16 September 2007. The arrow indicates the tornado location.

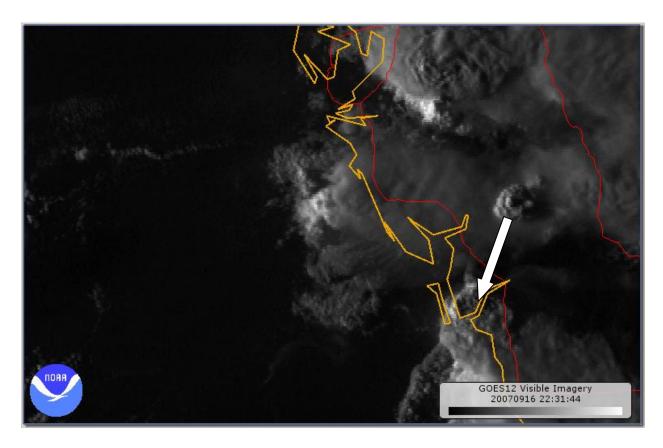


Figure 8c. GOES 12 visible satellite imagery 2231 UTC 16 September 2007. The arrow indicates the tornado location.

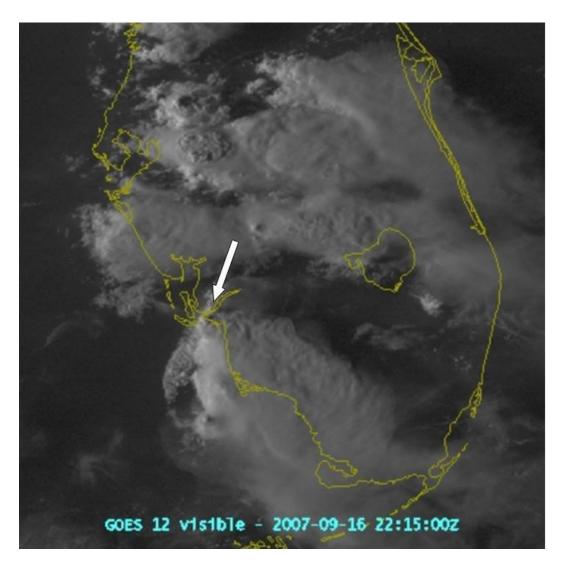


Figure 8d. GOES 12 visible satellite imagery 16 September 2007 <u>loop</u>. The arrow indicates the tornado location.

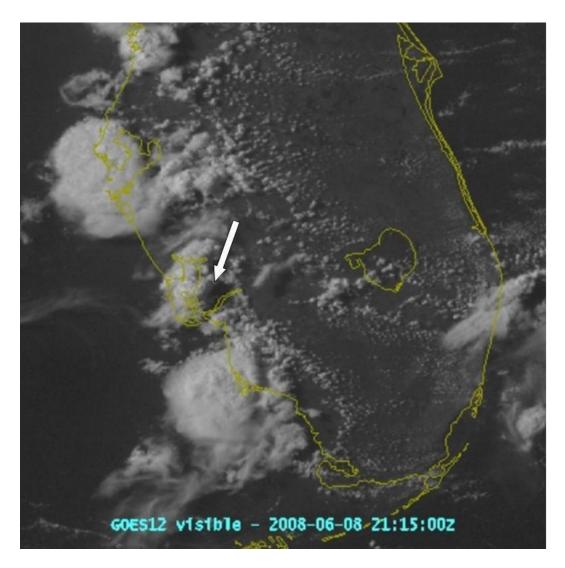


Figure 8e. GOES 12 visible satellite imagery 08 June 2008 <u>loop</u>. The arrow indicates the tornado location.

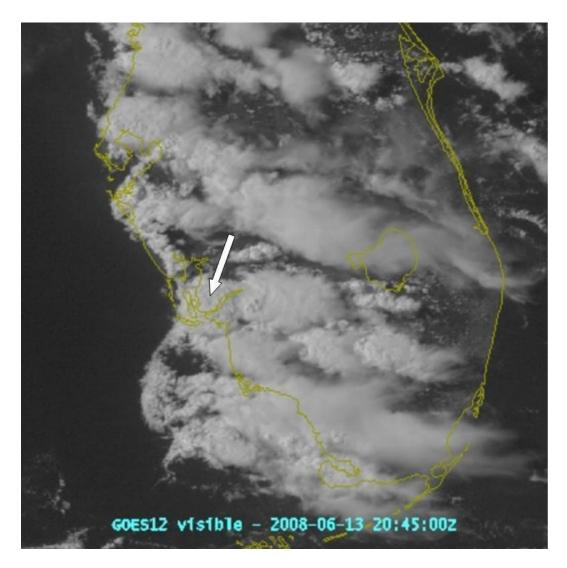


Figure 8f. GOES 12 visible satellite imagery 13 June 2008 UTC <u>loop</u>. The arrow indicates the tornado location.

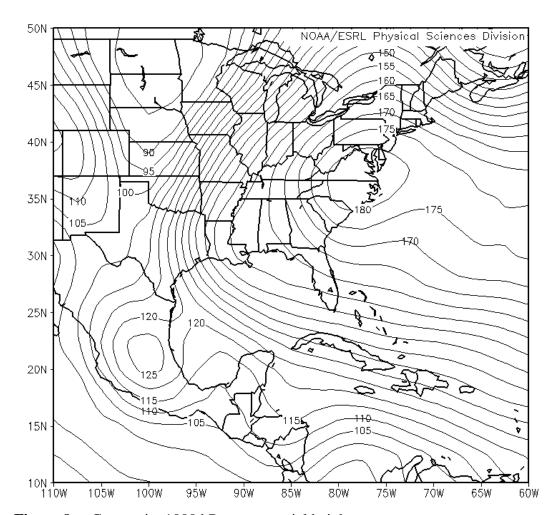


Figure 9a. Composite 1000 hPa geopotential height.

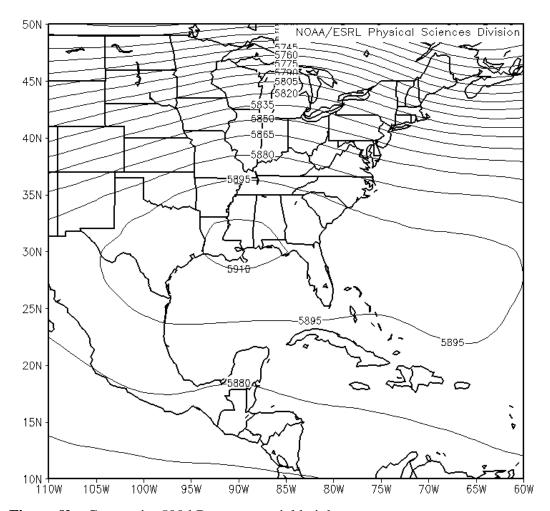


Figure 9b. Composite 500 hPa geopotential height.

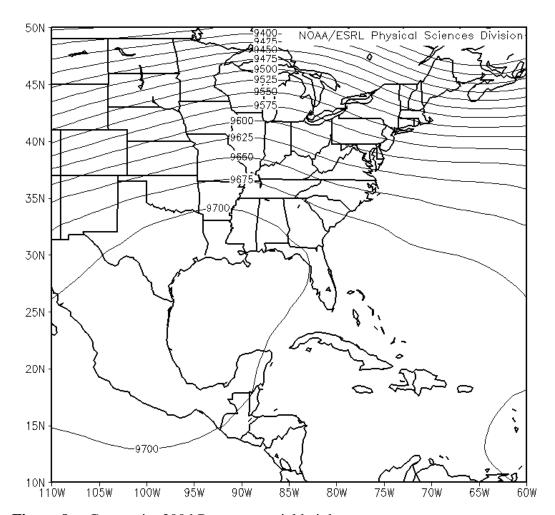


Figure 9c. Composite 300 hPa geopotential height.