P4.6 OBSERVATIONS FROM THE 13 APRIL 2004 WAKE LOW DAMAGING WIND EVENT IN SOUTH FLORIDA

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1. INTRODUCTION

Damaging winds affected portions of South Florida during the early morning of April 13, 2004. These winds occurred behind a large area of stratiform precipitation associated with a mesoscale convective system (MCS) that moved across the southeastern Gulf of Mexico during the evening of April 12, 2004 (Fig. 1). Wind speeds sustained between 30 and 50 mph with gusts reaching 76 mph were recorded on Lake Okeechobee.

These winds produced a seiche effect on Lake Okeechobee, resulting in a 5.5 ft maximum water level differential between the north and south sides of this shallow lake (Fig. 8). In addition, damage from the high winds was reported from communities situated along the lake shore.

This paper shows this event to be related to a wake low event, a rare occurrence across South Florida.

2. SYNOPTIC & MESOSCALE ENVIRONMENT

At 00 UTC on April 13, 2004, a 1002-hPa surface low was located over eastern Alabama. An associated cold front stretched across the Gulf of Mexico to the Yucatan Peninsula and a stationary front was located across central Georgia and South Carolina (Fig. 1).

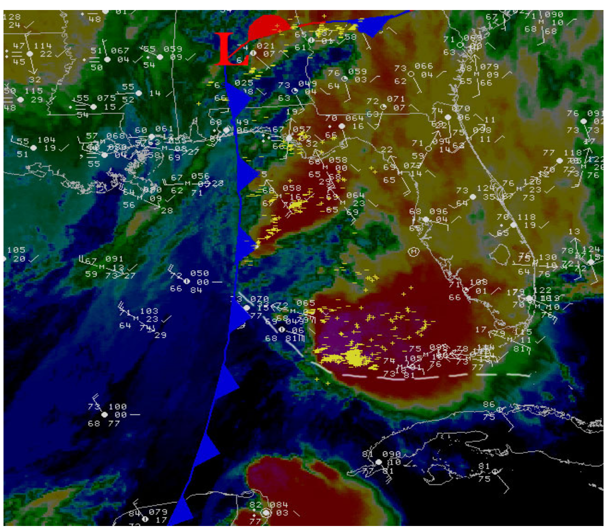

Figure 1. 00 UTC 13 April 2004 overlay of surface observations (white), cloud-to-ground lightning strikes (yellow), and NCEP frontal analysis.

Advection of warm and moist air from the Caribbean was enhanced as an 850-hPa jet strengthened to 30-50 knots (15 to 26-m s^{-1}) by early evening. An outflow boundary from a previous MCS which tracked across South Florida early on the morning of April 12th persisted across the Florida Straits. This boundary exhibited pseudo-warm frontal characteristics, and was lifting northward over South Florida (white dashed line in Fig. 1). To the north of the boundary, a cool and stable surface layer was present over land.

A high amplitude longwave mid/upper tropospheric trough was located over the eastern United States. The axis of this trough extended from the Great Lakes southward to the central Gulf of Mexico while South Florida was upstream of the ridge axis located near 65°W longitude. In addition, a 130-knot (67 m s^{-1}) polar jet and 60-knot (31 m s^{-1}) subtropical jet were splitting over the Gulf of Mexico and South Florida producing significant upper level diffluence over South Florida. This resulted in a Mesoscale Convective System (MCS) developing and moving across the southeast Gulf of Mexico during the evening of April 12, 2004 (Fig. 1).

3. WAKE LOW DYNAMICS

An early model of the structure and life cycle of mesoscale systems producing intense wake lows was proposed by Fujita (1955). This model has been examined and expanded upon by several researchers since. Williams (1963) first quantitatively showed that subsidence warming can account for the reduced pressures in wake lows in a numerical modeling study (Johnson, 2001). Johnson and Hamilton (1988) proposed that a wake low is formed by a descending rear inflow jet and that the warming due to descent was maximized at the back edge of the precipitation area where evaporative cooling was insufficient to offset adiabatic warming (Fig. 2).

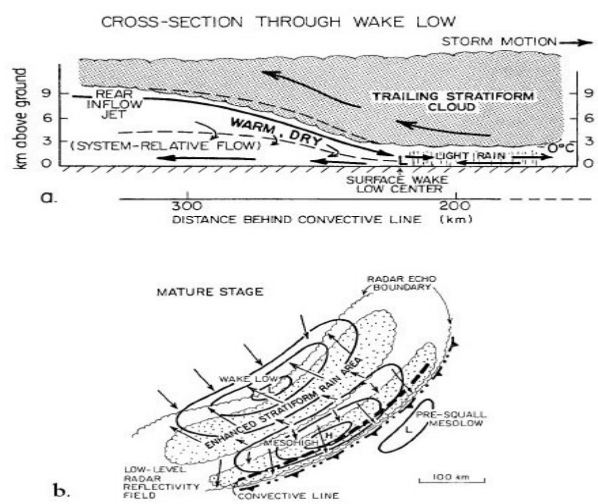

Figure 2. Schematic cross section through wake low, from Johnson and Hamilton (1988).

This suggestion was furthered by Stumpf (1991) who contended that stratiform precipitation regions can be dynamically significant phenomena, generating rapidly descending inflow jets at their back edges, capable of producing lower-tropospheric warming, intense low level pressure gradients, and strong low level winds.

4. WAKE LOW OBSERVATIONS

4.1 Vertical Wind/Temperature Profiles

Upper atmospheric wind and temperature profiles were similar to other well documented cases where the environment supported mesoscale convective systems (Maddox 1983), as well as case studies from events in the Mississippi Valley (Gaffin, 1999) and Oklahoma (Hunter, 1989). The wind above 850-hPa was unidirectional from the southwest and speeds increased with height. Near the surface, light easterly winds were found to the north of the quasi-warm frontal boundary with southeast to south winds in the warm sector. Rawinsonde observations from Key West and Miami revealed precipitable water values of 1.84 and 1.76 inches respectively. Observed values of precipitable water prior to MCS development are typically in excess of 1.4 inches (Maddox 1980).

Soundings derived from Local Analysis and Prediction System (LAPS) objective analyses across Lake Okeechobee indicated warming by as much as 2 to 3°C in the layer between 650 and 850-hPa from 7 to 8 UTC (Fig. 3). An equal degree of cooling was depicted between 450 and 650-hPa in the same time period.

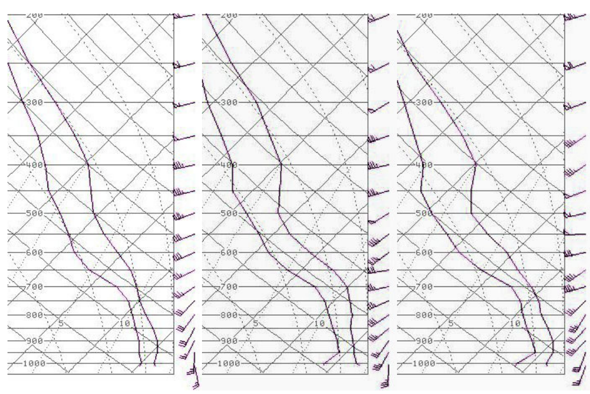

Figure 3. LAPS analysis skew-t log-p diagrams over Lake Okeechobee from 07, 08, and 09 UTC April 13.

Additionally, between 08 and 09 UTC, the LAPS soundings show descent of the anomalously warm air to the 850-hPa to surface layer, especially near the lake where the atmosphere lacked an elsewhere substantial temperature inversion in the boundary layer. Note that over mainland South Florida, LAPS analyses are typically quite reliable due to the increased number of mesonet, aircraft, and NWS observations that are readily available, particularly within the last few years (Etherton et al., 2004; Etherton and Santos, 2004).

4.2 Satellite Imagery

Subtle hints of subsiding air could be found both in the GOES-12 infrared and water vapor satellite imagery. Infrared satellite showed cloud tops warming 10°C in the 30 minutes between 0845 UTC and 0915 UTC, and the corresponding water vapor imagery suggests mid-tropospheric drying was taking place from Lake Okeechobee southwest to the Gulf of Mexico (Fig. 4).

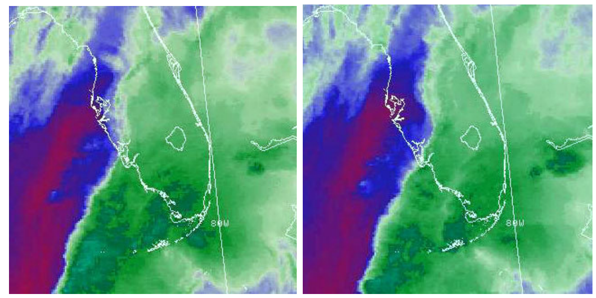

Figure 4. GOES-12 Water Vapor Image from 0845 UTC (left) and 0915 UTC (right). Red indicates mid level dry air while green indicates moist air.

4.3 High-Resolution Radar Data

A large area of stratiform rain covered much of South Florida between 06 and 10 UTC while discrete rotating thunderstorms were embedded in the leading edge of the precipitation. A band of high velocities were observed on the trailing edge of the stratiform precipitation shield. Radial velocities from the Miami radar exceeded 50 knots (26 $m\ s^{-1}$) and are shaded yellow and light blue in Fig. 5 (white circles). Maximum radial velocities of up to 106 knots (55 $m\ s^{-1}$) were also detected (colored white). The radar beam height of the 0.5° tilt was around 6,000 feet at the distance of the sharp reflectivity gradient. Radar data from the elevation angles sampling near 12,000 feet (1.5 degrees and above) showed the presence of 10 to 20 dBz echoes extending 25 miles to the northwest beyond those in the lowest scan.

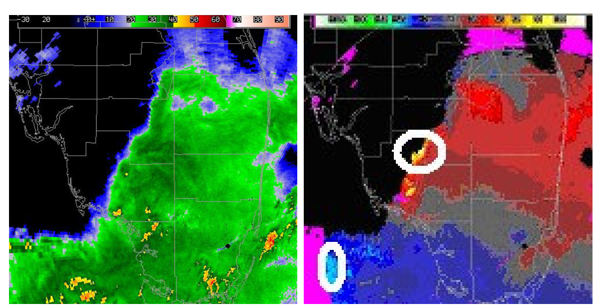

Figure 5. Miami radar at 0918 UTC, near time of peak gust in Fig. 6a. 0.5° reflectivity (left) and 0.5° velocity (right). Outbound velocities in red, inbound blue.

4.4 Surface Observations

Two distinct pressure falls and wind speed maxima occurred as the back edge of the precipitation shield passed over Lake Okeechobee. The first gust was to 25 m s^{-1} around 0745 UTC and the second, more intense gust, reached 34 m s^{-1} near 0915 UTC (Fig. 6a). Pressure falls of up to 4 to 5 mb were observed in the hour preceding the observed peak gusts.

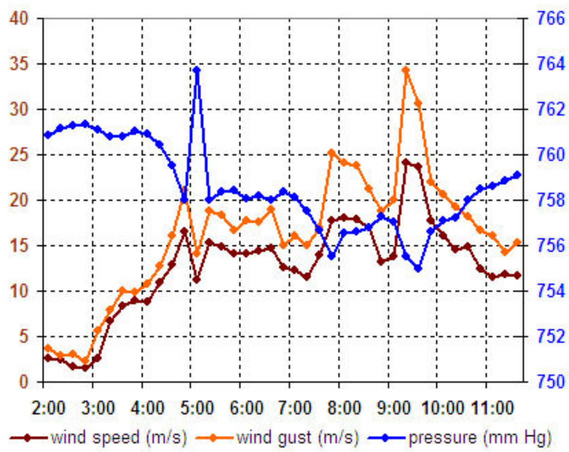

Figure 6a. 15 minute wind speed, wind gust, and pressure from the South Florida Water Management Division (SFWMD) weather station L005 on the north end of Lake Okeechobee from April 13, 2004. All times are in UTC. *Data courtesy of SFWMD.*

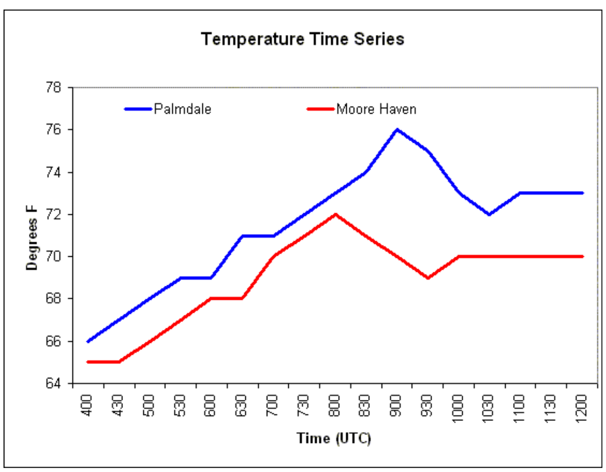

Figure 6b. 30 minute temperature data for Palmdale and Moore Haven (red circles in Fig. 7). *Data courtesy of the Florida Agricultural Weather Network (FAWN) and AWS Convergence Technologies, Inc.*

The well mixed marine layer near Lake Okeechobee and the southwest Florida coast (similar temperature and wind behaviors to those in Fig. 6a were observed in Naples on the southwest Florida coast) allowed the high wind speeds to be registered in those areas. The effect on inland locations was primarily a rise in temperature, since the presence of a strong surface-based inversion prevented the strongest winds from reaching the surface. The temperature at Palmdale climbed from 69°F (21°C) at 06 UTC to 76°F (24°C) at 09 UTC, with nearly 50% of that rise occurring between 08 and 09 UTC (Fig. 6b). Although not of the same magnitude, a similar temperature trend was observed in Moore Haven.

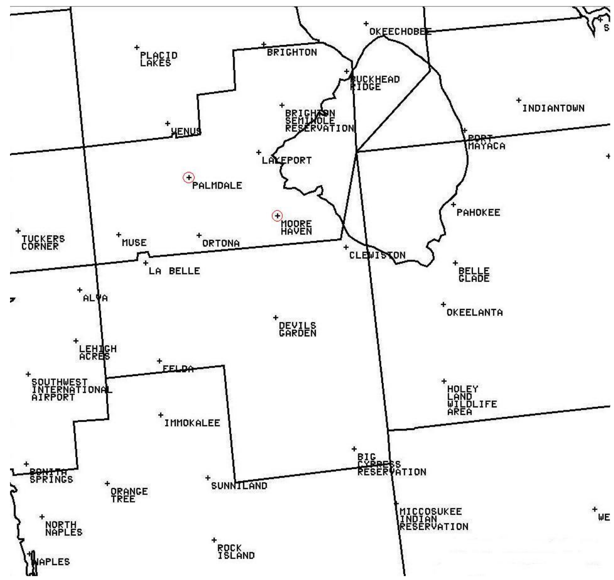

Figure 7. Lake Okeechobee and surrounding cities and towns.

4.5 Wind Damage Reports

The strong winds inflicted damage to communities near Lake Okeechobee as well as along the Gulf of Mexico. The winds severely damaged several mobile homes along the south shore of the lake, and blew out a store window in Belle Glade (Fig. 7). A 50-knot wind gust at the Fort Myers Southwest Florida International Airport pushed a Boeing 737 aircraft into a jetway bridge. Roofs, carports, and other structures were damaged in Cape Coral, Fort Myers, Moore Haven, South Bay, Belle Glade, and Pahokee (Fig. 7).

4.6 Lake Okeechobee Water Level

Rises and falls were recorded by the U.S. Army Corps of Engineers water level gages on Lake Okeechobee in response to the high winds, and corresponded closely with the time of greatest wind speeds. Figure 8 shows that the lake level was fairly uniform near 14.5 feet until rapidly rising between 04 and 05 UTC (23:00 to 00:00 EST) when the average north end gages initially peaked at 15.9 feet. A second peak of 17.6 feet occurred around 09 UTC (04:00 EST). A lake level minimum was measured at the south end gages around 11 UTC (06:00 EST) when the average level fell to 12.1 feet.

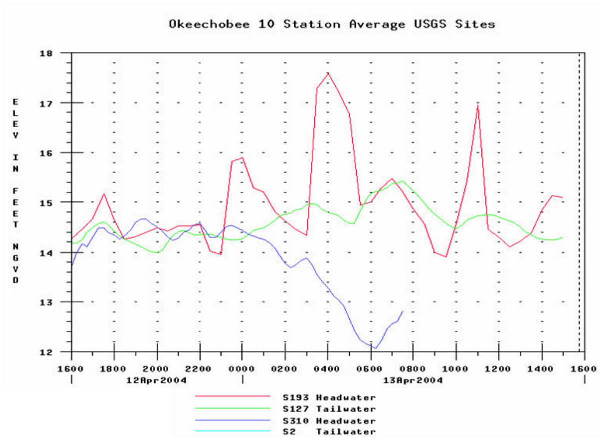

Figure 8. Mean lake level from Lake Okeechobee gauges near the north end of the lake (red) and the south end (blue). *Image courtesy of the U.S. Army Corps of Engineers.*

4.7 Numerical Modeling Data

The 00 UTC run of the workstation ETA, run locally at the National Weather Service Miami office, depicted an area of deep layer subsidence along the trailing edge of a cluster of rain and thunderstorms. The forecast of 700 hPa vertical motion valid at 08 UTC showed maximum downward motion of 10 µb s^{-1} (Fig. 9).

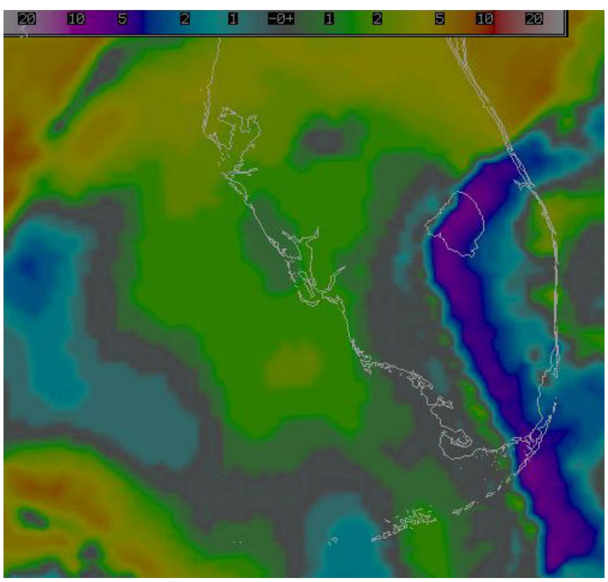

Figure 9. Hydrostatic Workstation ETA 700-hPa vertical motion field 8-hour forecast valid 08 UTC April 13, 2004.

Furthermore, LAPS low level analyses showed the coupling of lower pressure west of the lake and a meso high to the south where debris from the MCS that moved across the southeast Gulf of Mexico the evening of the 12th was producing light to moderate rainfall and more dominant evaporational cooling at the low levels. Figure 10 shows the 925 mb height analysis from the 11Z LAPS analysis depicting this well.

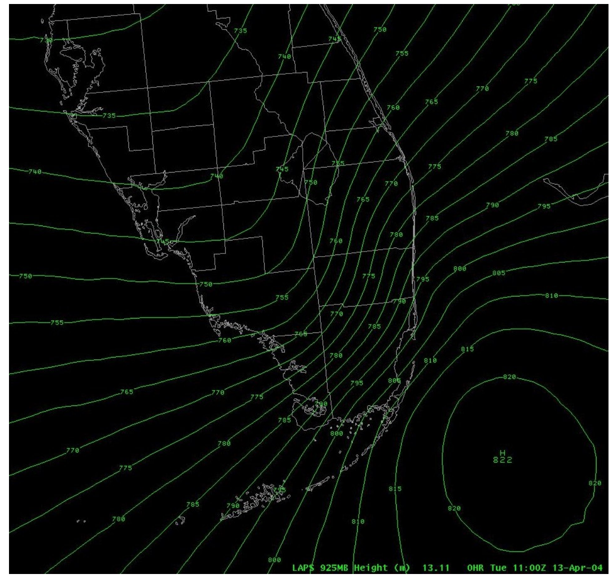

Figure 10. 11 UTC April 13, 2004 925 mb LAPS Height Analysis.

5. DISCUSSION

The passage of the trailing edge of the stratiform precipitation shield and associated band of high wind velocities, as depicted by the lowest elevation angle radar scan (Fig. 5), coincided with the time of peak wind gust and short-duration pressure minima (Fig. 6a). This was observed in official NWS and mesonet surface data from within Lake Okeechobee and surrounding areas.

Both direct and indirect evidence of subsidence was found in the observational and numerical model datasets. Infrared satellite data showed a narrow band of significant cloud top warming while the water vapor imagery indicated mid-tropospheric drying. LAPS soundings revealed a descending warm layer during the two hours before a 76 mph (34 m s^{-1}) wind gust was observed on Lake Okeechobee. The 00 UTC NWS Miami workstation ETA model predicted a band of strong downward vertical motion which closely matched the observed event.

The LAPS analyses (Figs. 3 and 10) depicted mid-tropospheric cooling while radar detected hydrometeors generating weak 10-20 dBZ echoes at 12,000 feet. The objective analyses also indicated lower tropospheric warming occurring and strong pressure gradients, while radar detected no precipitation size hydrometeors at 6,000 feet. This lends credibility to the idea that evaporative cooling was the dominant dynamic mechanism in the mid-levels, while adiabatic warming was occurring in the low-levels. Surface observations showed temperature increases of 3 to 4°C around the time of the highest observed peak wind and even greater during the 5 to 6 hours period preceding the highest observed peak wind. This suggests that that evaporative cooling was indeed insufficient to offset adiabatic warming, as was found in Johnson and Hamilton (1988).

6. CONCLUSIONS

These data clearly support the contention that this high wind event was the result of a wake low, a rare event across South Florida. While the presence of wake lows may be apparent in real-time, the magnitude of such events can be difficult to assess until later.

Challenges remain in our quest to better observe and predict the strength of wake low wind events in an operational environment. Most critically, many of the observational datasets are not available to a forecaster rapidly enough to provide insight to the degree found in this examination. LAPS analysis latencies are typically around 1 hour, while many of the mesonet surface observations are made available every 30 minutes. The mesonet sites on Lake Okeechobee record peak wind gust data, but only sustained winds were available to forecasters at the time. Sites interrogated to acquire instantaneous data during the event, including official NWS and mesonet sites, didn't capture the magnitude of the situation due to the fact that a significant inversion prevented the strongest winds from reaching the surface in most of these land based locations.

Information available to meteorologists in assessing potential for wake low damaging wind events has been greatly enhanced over the last few years, and will no doubt continue to improve dramatically. Monitoring and timely assimilation of these observational and forecast datasets can help us recognize and provide accurate and timely warnings for damaging wake low events.

7. REFERENCES

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