Characteristics of East Central Florida Tornado Environments

BARTLETT C. HAGEMEYER AND GARY K. SCHMOCKER

National Weather Service Office, Melbourne, Florida 32935

1. INTRODUCTION

The diagnosis of the dynamic and thermodynamic structure of the environment in which tornadic thunderstorms develop, as well as potential mechanisms to initiate intense convection, are crucial to severe storm forecasting. Over the years many researchers such as *Beebe* [1958], *Darkow* [1969], and *Taylor and Darkow* [1982] have used mean upper air sounding data to investigate the structure of the atmosphere in proximity to tornadic thunderstorms. Recent studies indicate renewed interest in the use of tornado proximity soundings to relate thermodynamic and dynamic variables to tornado intensity [*Riley and Colquhoun*, 1990; *Johns et al.*, 1990] and the examination of the structural characteristics and evolution of different types of tornado proximity soundings [*Schaefer and Livingston*, 1988, 1990].

Characteristically, these studies combine data collected from a large area of the country and contain little data from peninsular Florida. *Byers and Rodebush* [1948] recognized the uniqueness of the peninsular Florida environment and the need for investigation of dynamic mechanisms that result in a United States maximum of thunderstorms in central Florida. Recently, *Golden and Sabones* [1991], using Doppler radar and mesonet data, investigated two tornadic waterspouts near Cape Canaveral in east central Florida. However, a specific, systematic study of the environment of central Florida tornadoes has not been done despite their significance and relatively frequent occurrence [*Kelly et al.*, 1978]. Past work has been primarily confined to case studies of tornadoes in south Florida in the wet season. *Gerrish* [1967] produced a mean tornado sounding for Miami for the wet season, and case studies of wet season tornadoes in south Florida were investigated by *Hiser* [1968], *Gerrish* [1969], *Golden* [1971], and *Holle and Maier* [1980].

These researchers have documented that low-level convergence boundaries, particularly intersecting outflow boundaries, are a triggering mechanism for tornadic thunderstorms in the wet season. *Wakimoto and Wilson* [1989] have proposed a model to explain nonsupercell tornado development in which low-level boundaries play a crucial role in tornadogenesis. This theory may have important applications in central Florida.

The tracking of boundaries with Doppler radar, satellite, and mesonet data aids in the short-term prediction of potentially tornadic thunderstorms, but few boundaries, or boundary intersections, actually result in tornadic development [*Holle and Maier*, 1980]! More information concerning the characteristics of the overlying dynamic and thermodynamic structure in these wet season situations is needed if forecasters are to have much success in assessing the tornado threat.

Over all of central Florida most of the strong and violent tornadoes (F2–F5 [*Fujita*, 1981]) occur in the dry season, and a majority of these occur in the morning [*Schmocker et al.*, 1990]. A more complete understanding of the environment of these tornadoes, which are responsible for most of the deaths and injuries in central Florida, is also needed.

The current situation is one where tornado forecast techniques and conceptual models developed from mean upper air data over the Great Plains and Midwest are applied in central Florida with limited success. This investigation consists of the determination of the mean atmospheric structure of two significant central Florida tornado environments. The results presented should lead to improved severe weather forecasts for central Florida.

2. METHODOLOGY OF CASE SELECTION

This study is unique in that the area of investigation was restricted to the 10 county warning area (CWA) of future National Weather Service (NWS) weather forecast office (WFO) Melbourne in east central Florida. The location of the Melbourne CWA and upper air stations used in this study are shown in Figure 1. On the basis of a climatological investigation of this area by *Schmocker et al.* [1990], tornado characteristics were divided into two seasons: dry season (November through April) and wet season (May through October). The hourly distribution of central Florida tornadoes by season (Figure 2) clearly shows a diurnal afternoon

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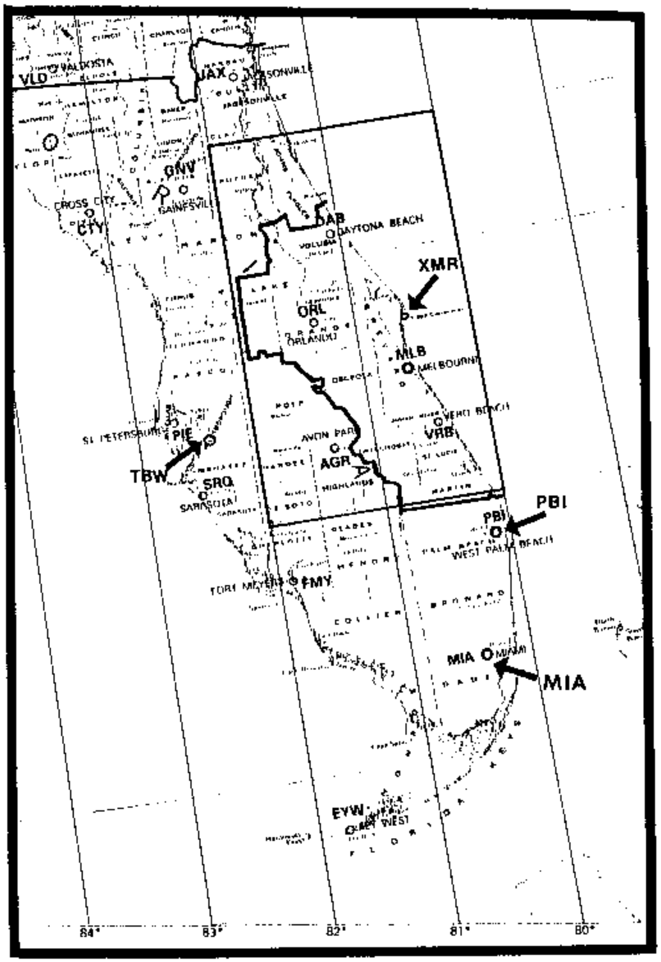

Fig. 1. Peninsular Florida. The location of the future WFO Melbourne 10 county warming area is enclosed by a bold line in east central Florida. Upper air stations are indicated by bold arrows: Cape Canaveral (XMR), Miami (MIA, moved to PBI in 1977), Tampa Bay (TBW), and West Palm Beach (PBI).

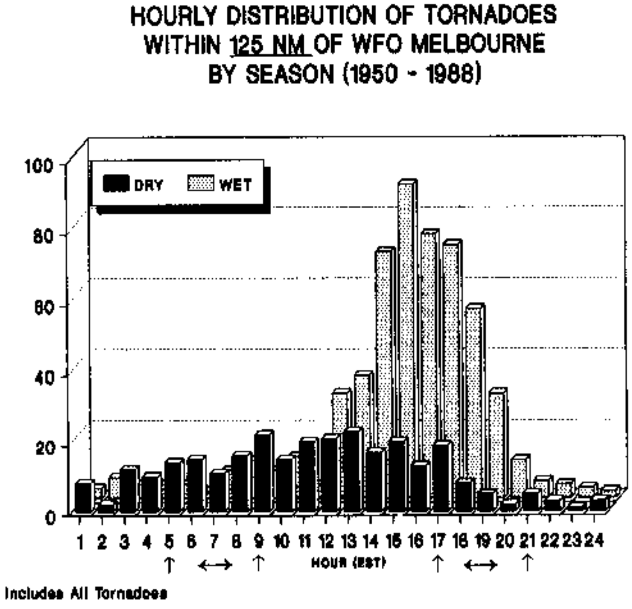

Fig. 2. Hourly distribution of dry season and wet season tornadoes within 125 nautical miles of future WFO Melbourne. The time intervals of this studies cases (1200 UTC (0700 EST) and 0000 UTC (1900 EST) ±2 hours) are shown by the arrows along the x axes.

maximum in the wet season while the dry season is characterized by fewer tornadoes but a more even hourly distribution with significant morning activity.

The distributions of F2–F5 tornadoes and those that have caused injury and death specifically in future WFO Melbourne's CWA are shown in Figure 3. After peaking in March and April, strong tornado activity drops off sharply in May, as the influence of vigorous mid-latitude disturbances diminishes and the transition from dry to wet season takes place. The increase in August and September is due to tornadoes associated with tropical cyclones. Climatological analyses indicate that an attack on the problem by seasonal and diurnal divisions is necessary.

Upper air data were available for 0000 and 1200 UTC for TBW, PBI, and MIA (note that the MIA site was deactivated and moved 100 km north to PBI in 1977). Only 1200 UTC soundings were available for XMR since 1980. With these data limitations in mind, tornado candidate cases were considered by looking at first spatial, then temporal, selection criteria. Printouts of all tornadoes reported in Florida supplied by the Verification Section, National Severe Storms Forecast Center (NSSFC), were reviewed for cases of tornado touchdowns in the Melbourne CWA (Figure 1) that occurred within ±2 hours of standard observation times (0000 UTC (1900 EST) and 1200 UTC (0700 EST)) from 1980 to 1988. This resulted in 16 0000 UTC cases and seven 1200 UTC cases and reflects the fact that fewer tornadoes occur at 1200 UTC than at 0000 UTC (see Figure 2). Dry season morning tornadoes often are stronger than wet season tornadoes, so five additional 1200 UTC cases were added by searching the tornado records back to 1975 to get a larger sample. Twenty-eight candidate cases were thus identified (16 0000 UTC and 12 1200 UTC) and soundings obtained. Six soundings were removed because of poor data quality and/or contamination by deep convective. Four tropical cyclone cases were also removed from this data set. This selection criterion yielded nine 1200 UTC dry season cases and nine 0000 UTC wet season cases.

The upper air station nearest to a reported tornado was designated the proximity sounding for each season. Since 0000 UTC wet season proximity data were not available for Cape Canaveral, but 1200 UTC data were, a 1200 UTC XMR wet season precedent sounding (12 hours prior to tornado touchdown, ±2 hours) was examined to provide useful information on tornado precursor conditions. Soundings were then pressure averaged at 50-mbar intervals to 200 mbar. Mean soundings and diagnostic parameters for the seasonal atmospheres were computed, and vertical profiles

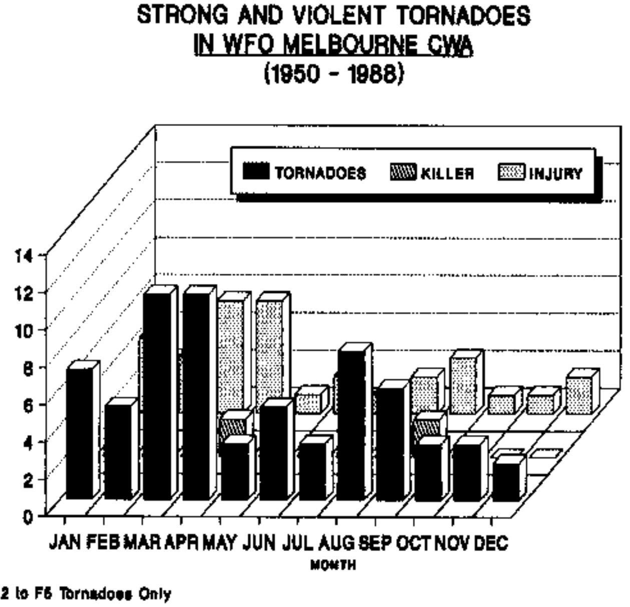

Fig. 3. Monthly distribution of strong and violent (F2–F5) tornadoes, and killer and injury tornadoes reported within future WFO Melbourne's CWA.

of temperature (T), dew point (T_d), and wind components (U and V) were constructed for dry and wet season tornado proximity and wet season tornado precedent, atmospheres. These seasonal profiles were then compared to seasonal mean atmospheres.

3. Results

3.1. *Case Tornado Characteristics*

Of the nine dry season cases, five had F2 tornadoes, two had F1 tornadoes, and two had F0 tornadoes. Two cases had multiple tornadoes. Of the nine wet season cases, one had multiple tornadoes, four had F1 tornadoes, and five had F0 tornadoes. The mean time of occurrence was 1220 UTC (0720 EST) and 2240 UTC (1740 EST) for the dry and wet season cases, respectively.

3.2. *Mean Soundings and Diagnostic Parameters*

Skew-T, Log-P plots and hodographs of the dry and wet season mean tornado proximity soundings are shown in Figure 4. A summary of diagnostic parameters derived from the mean soundings are shown in Table 1.

The general thermodynamic structure of the mean dry season sounding (Figure 4) has both similarities and differences when compared with the classic Midwestern tornadic environment [*Doswell*, 1982]. Both environments display a pronounced deep, dry layer in the middle and upper levels overlaying a moist layer. However, the Florida dry season profile exhibits a deeper moist layer than is the case with the "classic" profile. The most notable difference is the lack of any mean capping inversion or steep lapse rate overlying a well-mixed moist layer. An inspection of all individual soundings in the data set revealed the presence of a few minor inversion layers, but none of the low-level moist layers were capped by an inversion.

Dry season stability indices are less than for typical Midwestern tornado cases [*Miller*, 1972]. This is probably because midtropospheric temperatures are generally warmer over Florida; also, because these are morning tornado cases, there is not much contribution to destabilization from diurnal heating.

The dry season hodograph shows strong shear in the lower levels and winds veering with height. This is similar to the mean F1 and F2 tornado hodographs documented by *Riley and Colquhoun* [1990]. A comparison of the wind profile with *Miller*'s [1972] key tornado forecast parameters reveals that the low, middle, and upper level jets of the mean dry season soundings are all in the strong category.

The wet season mean proximity sounding and hodograph (Figure 4) are unlike any of the classic tornado environments [*Miller*, 1972] and represent a regional hybrid. There is a general similarity to the mean dry season sounding in that a distinct dry layer overlies the moist layer; thus it is most unlike *Newton*'s [1980] type C and *Miller*'s [1972] type II for the Gulf Coast and southeastern regions which are typified by high moisture through the troposphere.

The wet season proximity hodograph is quite different from the dry season. It exhibits very weak shear in the lower levels, and winds are nearly unidirectional from the west. Tornadic thunderstorms forming in this type of an environment would likely be of the nonsupercell variety [*Wakimoto and Wilson*, 1989].

3.3. *Relative Atmospheric Profiles*

To determine, what, if anything, is unusual about the dry and wet season proximity and wet season precedent tornado atmospheres profiles of potential temperature θ, wet-bulb potential temperature θw, U, and V were computed and compared to seasonal means [*U.S. Department of Defense*, 1983].

3.3.1. *Dry season.* Comparisons of mean dry season profiles to adjusted seasonal means (average for all months with cases, January through April) are shown in Figures 5*a*–5*d*. Potential temperature values are significantly higher than mean values below 800 mbar and above 400 mbar but are only slightly above mean between about 700 and 450 mbar indicating less static stability below 700 mbar when compared to normal. More notable is θ_w greatly exceeding normal values below 650 mbar (Figure 5*b*). The mean atmosphere has a degree of convective instability with a θ_w minimum around 800 mbar, but the depth of the moist layer in the mean tornado atmosphere is about twice as deep, and convective instability is much greater.

The high U values of the mean tornado profile, reaching a maximum of 45 m s^{-1} at 200 mbar, are not significantly higher than seasonal means (Figure 5*c*). Indeed, there are only

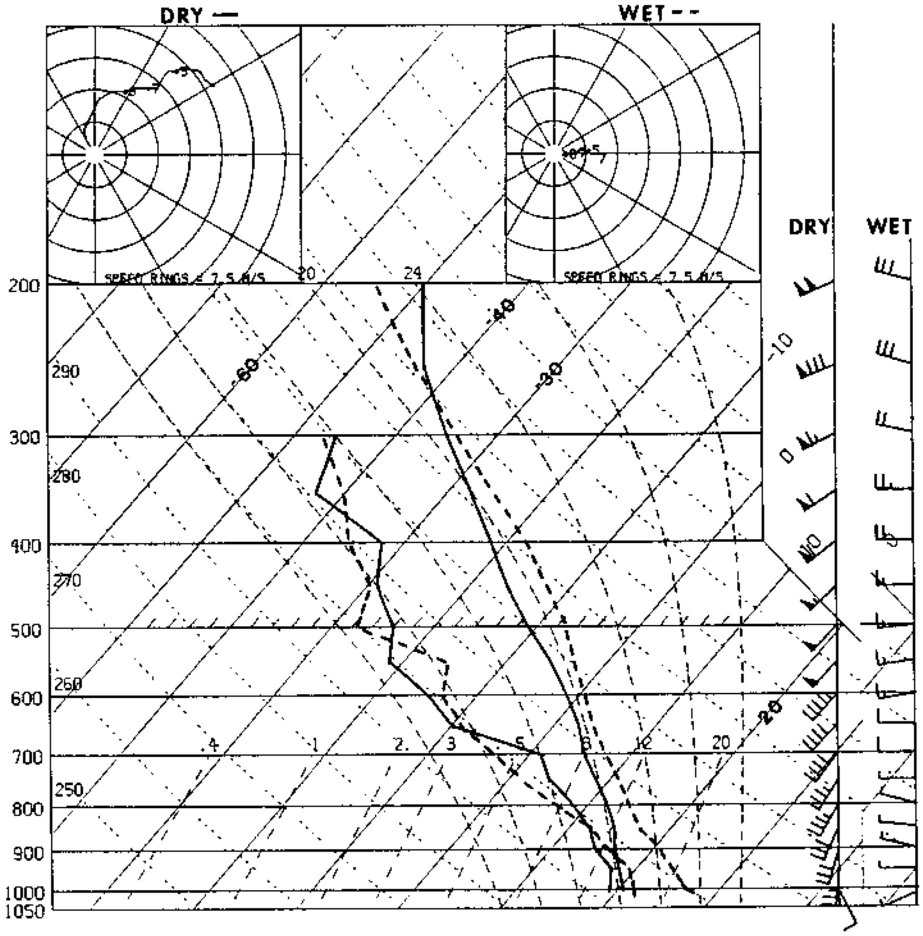

Fig. 4. Skew-T, Log-P thermodynamic profiles for mean dry season proximity (solid lines) and mean wet season proximity (dashed lines) tornado environments. Hodographs and vertical wind profiles (half wind barb 2.5 m s^{-1}, a full wind barb 5 m s^{-1}, and a pendant 25 m s^{-1} are also shown.

minor differences (<5 m s^{-1}) from the surface to 250 mbar. This is not the case with the southerly wind (V) components (Figure 5*d*), where mean seasonal V is nearly zero and is greatly exceeded by the mean tornado environment at all levels. Very strong shear of V is found in the lowest 100 mbar, and there is an indication of a midlevel southwest jet between 600 and 400 mbar and an upper jet at 200 mbar.

3.3.2. *Wet season.* Comparisons of the mean wet season precedent and proximity profiles to adjusted seasonal means (average for months with cases, May through July) are shown as Figures 6*a*–6*d*. Except for differences at the surface due to diurnal heating the potential temperature values of the precedent and proximity atmospheres are very close to the mean seasonal values (Figure 6*a*) indicating there is little difference in the vertical temperature structure between a nontornado and tornado day in the wet season. Comparisons of θ_w profiles (Figure 6*b*) show the depths of the moist layers are nearly the same with θ_w minima around 650 mbar in all three atmospheres. Proximity wet-bulb potential temperature values are 2° higher at the surface and the same at 650 mbar when compared to the tornado precedent sounding taken 12 hours earlier. This indicates a much greater degree of convective instability and illustrates how diurnal heating can nearly double CAPE (see Table 1) between 1200 UTC (904 J/kg) and 0000 UTC (1683 J/kg).

The most outstanding feature of the wet season tornado kinematic environment was found to be the existence of significantly increasing shear, and westerly winds greatly exceeding seasonal means, in the mid and upper troposphere (Figure 6*c*). The trend and magnitude of the V component is generally very close to seasonal means (Figure 6*d*).

All nine wet season cases had westerly winds in the mid and upper troposphere, and eight cases were westerly from the surface to 200 mbar. This dominance of westerly flow cases has several causes. *Hagemeyer* [1991] found that lower tropospheric flow is westerly over central Florida into June and that persistent easterly flow does not appear until well into the wet season. Most cases presented here oc-

TABLE 1. Mean Diagnostic Parameters

	Dry Prx	Wet Pre	Wet Prx
Freezing level (m AGL)	4104	4351	4477
Wet-bulb zero (m AGL)	3360	3410	3419
Showalter index (°C)	−0.8	−1.1	1.5
Lifted index (°C)	−1.8	−3.5	−3.4
Totals index (°C)	48	48	43
Cross totals index (°C)	23	22	19
Vertical totals index (°C)	25	26	24
K Index (°C)	33	31	26
SWEAT Index	325	194	168
Precipitable water (cm)	3.8	4.2	3.9
LCL height (m)	386	596	882
LCL mixing ratio (g/kg)	13.9	15.8	16.1
LFC height (m)	2584	2109	1484
CCL height (m)	631	1187	1236
EL temperature (°C)	−26.2	−51.1	−55.0
EL level height (m)	8150	11727	12346
Convective temperature (°C)	24.1	30.6	31.2
CAPE (J/kg)	164	904	1683
Bulk Richardson Number	1.5	166	576
Mean 0- 6-km wind (m/s)	215/19	260/06	267/04
Assumed storm motion	245/14	290/04	297/03
Absolute helicity (m^2/s^2)	250	10	06
Mean 3–10 km wind (m/s)	230/28	268/12	271/09
Mean shear 850–200 mbar (m/s)	34	14	13

Parameters were computed from mean dry and wet season proximity and from mean wet season precedent, tornado soundings. AGL is above ground level.

curred early in the wet season when westerly disturbances are more likely compared to late in the wet season when easterly flow dominates. Additionally, undisturbed easterly flow early in the wet season tends to be drier and to have a shallower moist layer than later in the wet season [*Hagemeyer*, 1991] and is thus less likely to produce strong thunderstorms and tornadoes.

There is also a bias toward west flow cases on the east coast in the ±2 hours from 0000 UTC selection criterion used in this study that can be explained by reviewing a study of spatial patterns of south Florida convection, without regard to severity, done by *Blanchard and Lopez* [1985]. They identified three basic patterns of convection over south Florida during the summer. Type I exhibits weak southeast flow with early development of convection along the East Coast Sea Breeze convergence zone (ECSB) which moves inland and merges with the West Coast Sea Breeze convergence zone (WCSB) west of the central peninsula. Type II exhibits stronger, dry, east flow with early passage of the ECSB with limited convection which is quickly advected to the west coast to merge with the WCSB and move out into Gulf. Type III exhibits southwest to northwest flow over central Florida with the westerly flow advecting the WCSB inland while the ECSB remains anchored along the east coast by ambient flow, causing stronger circulations and convergence. Outflow boundaries from the WCSB convection in the central peninsula interact with the ECSB and other outflow boundaries to enhance convection before dissipation during the evening. Type III days exhibit greater echo coverage, and dissipation takes place much later in the day, whereas on type I and II days, convective activity develops earlier and moves through east central Florida before the 0000 UTC (±2 hours) selection criteria.

The wet season tornado cases presented here are clearly westerly flow type III cases, but it is important to note that the wind speeds between 500 and 200 mbar on the mean wet season tornado precedent sounding are twice as high as for the mean type III day sounding for MIA and PBI produced by *Blanchard and Lopez* [1985].

Stronger upper level winds and shear appear to be an important factor in significant wet season tornado cases. The strong, damaging, tornado that struck Miami on June 17, 1959, developed in the evening in westerly flow, and *Hiser* [1968] found that the most outstanding synoptic weather feature at the time of the tornado was a 47 knot (24 m s^{-1}) westerly wind speed maximum at 12 km.

Although the wet season data sample is small (five F0 and four F1 cases) there does appear to be a positive relationship between higher middle and upper tropospheric wind speeds and shear and tornado strength. The maximum upper level winds associated with F1 tornadoes were not lower than 20 m s^{-1}, while values as low as 10 m s^{-1} were associated with F0 tornadoes. More research is planned on this aspect of the wet season environment.

Tornadoes and waterspouts also occur in easterly flow, but no east flow wet season cases are included in this study, because, as stated earlier, they would tend to occur in east central Florida well before 2 hours prior to 0000 UTC. Research is planned on these east flow events in the future.

4. CONCLUDING REMARKS

We have examined dry and wet season environmental profiles relative to seasonal means. However, to put this information to good use operationally, forecasters must diagnose the whole picture in detail and understand the interactions and physical processes involved to the degree that technology allows. Key factors that effect whether thunderstorms on one day may be tornadic or not depend on the characteristics of the overlying airmass and on the probable existence, and strength, of low-level triggering boundaries. While low-level boundaries are necessary for convective initiation, the overlying atmosphere plays an important role in the development of tornadic thunderstorms. NEXRAD/WSR-88D with its ability to detect, track, and possibly quantify the strength of low-level boundaries, as well as diagnose the dynamic environment at much higher spatial and temporal resolutions than the current upper air network, offers the promise of improving short-term forecasting of tornadic thunderstorms in east central Florida.

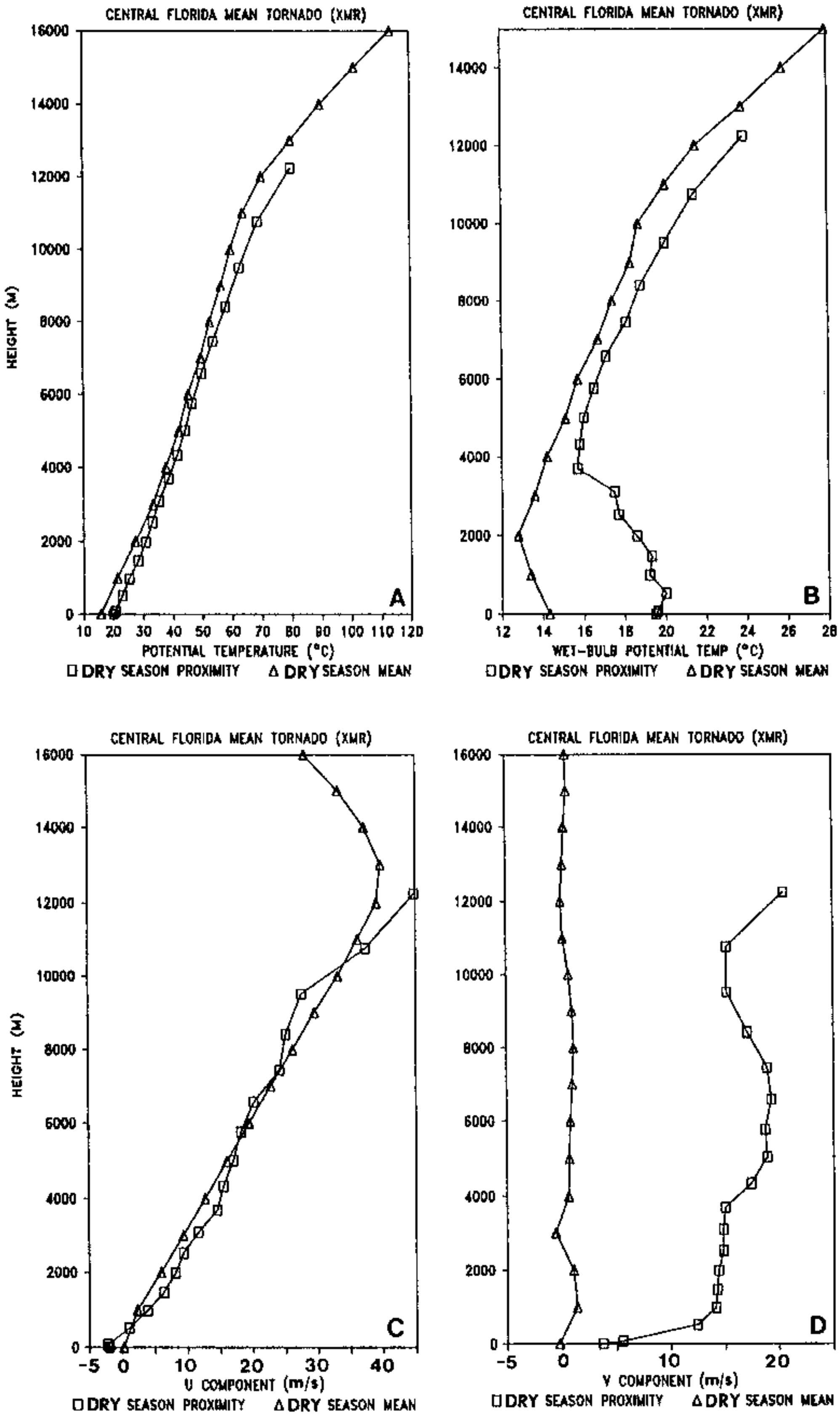

Fig. 5. Mean vertical profiles of (*a*) θ, (*b*) θ_w, (*c*) U, and (*d*) V for mean dry season tornado proximity cases and the mean dry season environment.

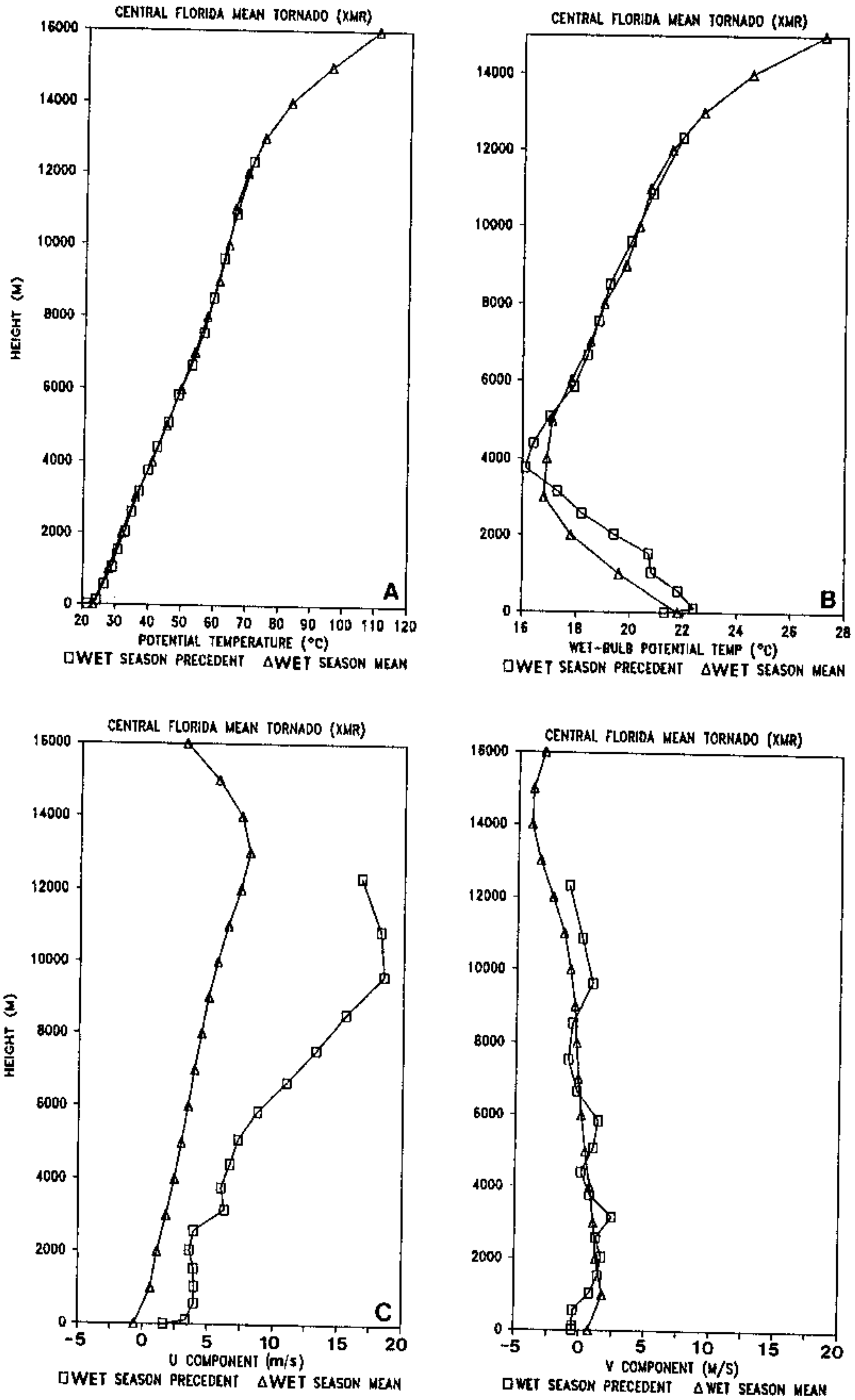

Fig. 6. Mean profiles of (*a*) θ, (*b*) θ_w, (*c*) U, and (*d*) V for mean wet season tornado precedent and proximity cases and the mean wet season environment.

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