

## THE TAMPA AREA TORNADOES OF OCTOBER 3, 1992: AN EXAMINATION USING HOURLY ROTATIONAL PARAMETERS

Jonathan M. Davies

P.O. Box 781106  
Wichita, Kansas 67278

### 1. INTRODUCTION

On the morning of 10/3/92, unexpected and damaging tornadoes struck the Tampa Bay area in Florida (Fig. 1). Four deaths and more than 75 injuries occurred between 1430 UTC and 1600 UTC in Largo and Pinellas Park. This event was difficult to forecast, and as a result, no watches or warnings were in effect at the time the tornadoes occurred.

Recent observational work by the author and others (e.g., Piltz 1992) suggests that hourly-generated parameters relevant to tornado forecasting, such as those discussed by Johns and Doswell (1992), may be useful in assessing and diagnosing potential for tornadoes associated with supercell thunderstorms. The Tampa case provides an opportunity to examine the evolution of selected parameters using hourly-generated fields prior to the tornadoes. An assessment of the performance of these parameters and fields may be useful regarding future forecast situations of a similar nature.

An isolated case study of a tornado event is of limited value unless the parameters examined can be compared with those in other tornado cases. For comparison purposes in this paper, prior to examining the Tampa case, parameter values are computed for several tornadic and non-tornadic cases in late 1992 to provide a context for assessing the Tampa event. The same parameters are then examined for the Tampa case, and, for additional comparison, a non-tornadic thunderstorm episode occurring in the same area.

### 2. PARAMETERS AND COMPUTATIONS

Although Johns and Doswell (1992) note that the likelihood of supercell development is the major factor in distinguishing between severe thunderstorm and tornado situations in current forecasting, they also point out that forecasting supercells is not equivalent to forecasting tornadoes. As many as 50% or more of mesocyclones that occur do not produce tornadoes (Burgess and Lemon 1990). Significant tornadoes are normally associated with mesocyclone circulations that descend to or develop within low-levels. Numerical modeling studies such as Brooks et al. (1993) indicate that, when examined together, relevant parameters (e.g., storm-relative helicity and inflow in the Brooks study) help explain in part why low-level mesocyclones develop in some supercell cases but not others. It then follows that, although tornadogenesis cannot be addressed directly by current forecasting tools and observational networks, parameters that relate to forecasting rotational potential in thunderstorms (such as those discussed in Johns and Doswell, referred to here as *rotational parameters*) should be able to weigh more than just the supercell/no supercell question. The same parameters, when examined properly *in combination with each other*, should be useful to some degree in assessing potential for low-level mesocyclone development, which is an important distinguishing factor between tornadic and non-tornadic supercell storms.

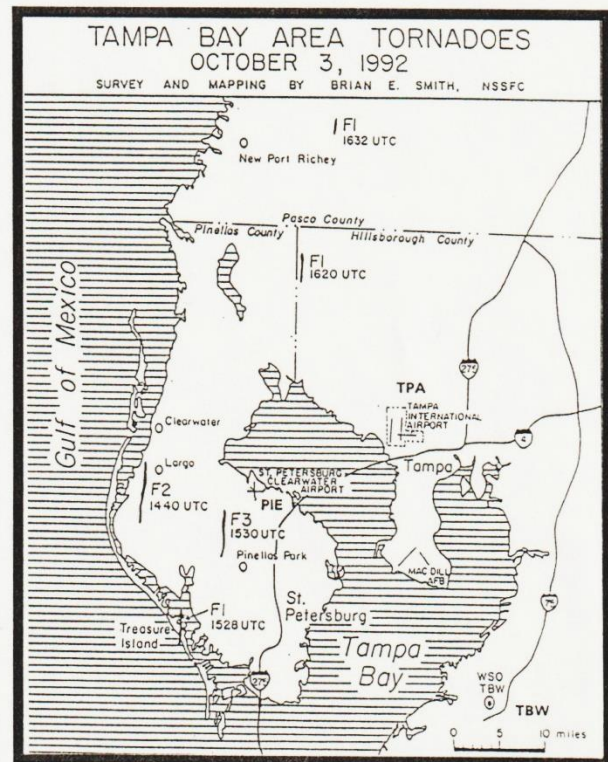


Fig. 1. Mapping of Tampa area tornadoes on 10/3/92, with times and F-scales, by Brian Smith of NSSFC.

Several parameters from Johns and Doswell are examined in this study. These are:

1) *Helicity* (Davies-Jones et al. 1990) and *instability*, evaluated both separately and in conjunction with each other. The studies by Davies-Jones et al., and Davies and Johns (1993), suggest that most significant mesocyclone-induced tornadoes are associated with helicity magnitudes of  $150 \text{ m}^2\text{s}^{-2}$  or greater. However, the Plainfield, Illinois tornado (Korotky et al. 1993) and other cases show this is certainly not a hard and fast rule. Lazurus and Droegemeier (1990) suggested that a relationship between helicity and CAPE exists that is optimum for producing rotation in thunderstorms. Although not well understood, observations of actual storm environments show that this relationship does exist to some degree (Johns et al. 1993), which further suggests the importance of assessing the trend of these parameters *in combination with each other* for forecasting.

The *energy-helicity index* (EHI) developed by Hart and Korotky (1991), based on preliminary data from Johns et al., is one useful computation that addresses this. Recent experience suggests that EHI values approaching the range of 2.5 to 3.0 and greater (rather than 1.0 as suggested by Hart and Korotky, and LaPenta (1992)) imply significant tornado potential, if other

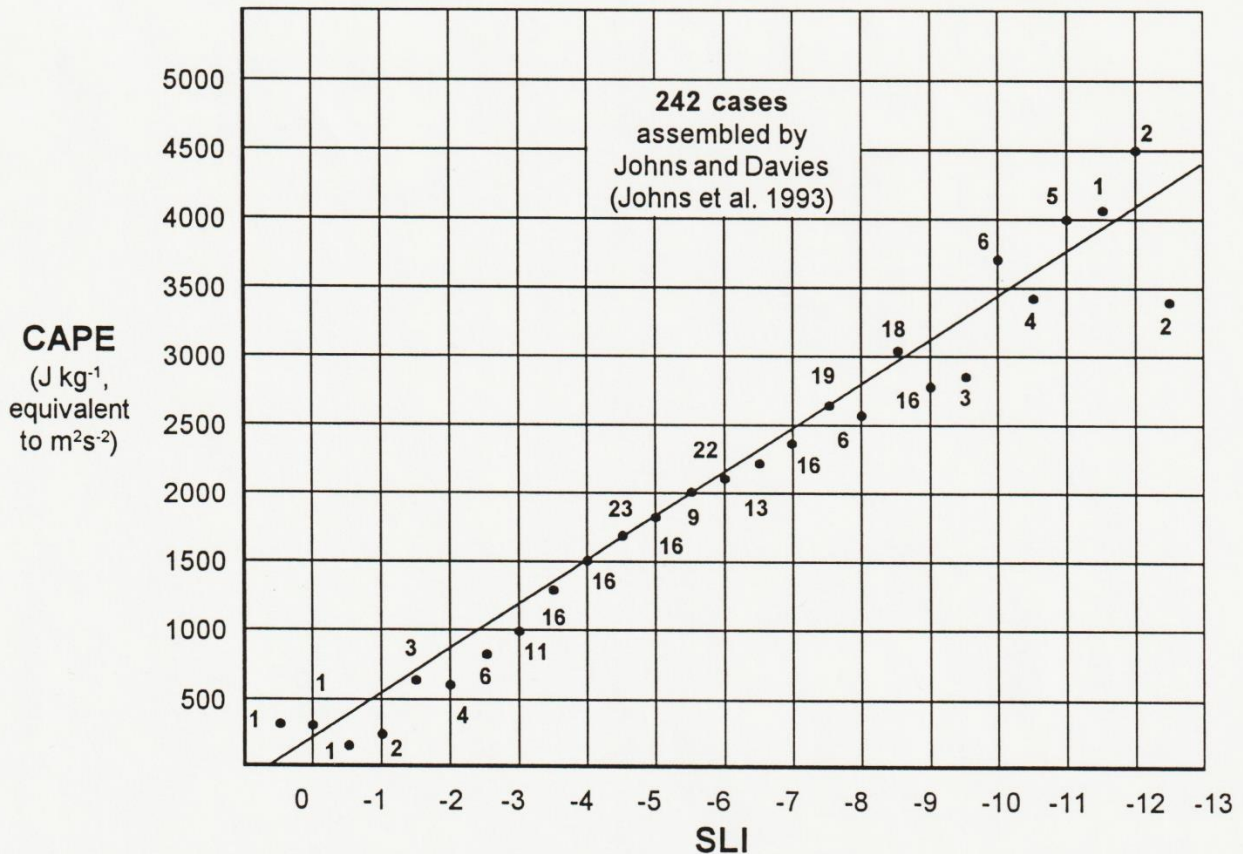


Fig. 2. Diagram showing general relationship between CAPE (computed using mean temperature and moisture in the bottom 100 mb) and surface-based lifted index (SLI) for 242 tornado cases examined in Johns et al. (1993). Averaged CAPE values for all cases exhibiting a specific SLI magnitude (rounded to the nearest .5°C) are shown, with the number of cases indicated above or below each point. The diagonal line is an estimated "best fit" to the data, and was used to develop equation 1 in the text.

parameters such as inflow and mid-level winds are adequate.

2) *Inflow strength.* The modelling study by Lazurus and Droegemeier suggests that environmental storm-relative low-level inflow around 20 kts or greater is required for development of significant tornadoes. The modelling study by Brooks et al. also indicates that strong inflow may act with other processes in some way to prevent a rotating storm's gust front from surging outward so quickly as to undercut its low-level mesocyclone.

3) *Mid-level wind speeds.* A large data set from Davies and Johns suggests that mid-level winds of 25-30 kts or greater are required to support the development of significant mesocyclone-induced tornadoes. Such winds can (1) affect storm motion, thus indirectly affecting storm inflow strength, as noted by Brooks et al., (2) remove precipitation from updrafts, thus reducing to some extent the outflow interference with an updraft, and (3) produce vertical wind shear that supports or enhances vertical perturbation pressure gradients (Rotunno and Klemp 1982) induced by low-level curvature shear (Brooks and Wilhelmson 1990), which in turn intensifies updraft strength.

Areas where the above parameters approach or exceed favorable values should highlight potential for low-level mesocyclone development if thunderstorms occur, and by association, the potential for tornadoes.

Hourly-generated parameter computations are performed using surface observations blended with 6 or 12 hr forecast winds and temperatures aloft from NMC's FD products (see studies by Woodall (1990); Piltz (1992); and Davies and Johns), which are NGM-based (when using the *bulletin* FD product,

rather than the graphic FD product). Storm-relative helicity ( $m^2s^{-2}$ ) is computed for 0-3 km AGL as in Davies-Jones et al., using a storm motion estimation scheme from Davies and Johns. Storm-relative inflow (kts) is computed by subtracting the storm motion vector estimated in the helicity computations from the mean measured wind vector in the 0-2 km AGL layer, deemed a good approximation of a storm's inflow based on sounding results from Bluestein et al. (1989). Mid-level wind speed is computed as the mean measured wind speed (kts) in the 3-6 km AGL layer, as in Davies and Johns.

Because of lack of temperature and moisture detail in the FD forecast data, instability is computed via the surface-based lifted index (SLI; Hales and Doswell 1982) using the forecast temperature at 18000 ft (approximately 500 mb), which is included as part of the information transmitted with the FD forecast. This is then converted to an estimated CAPE (convective available potential energy,  $J kg^{-1}$ , identical to  $m^2s^{-2}$ ) using a formula developed by the author from an examination of CAPE/SLI values in the 242 cases assembled in Johns et al. (Fig. 2):

$$CAPE = -SLI(322) + 208 \quad (1)$$

This comparison is certainly not precise because of the contrasting detail and nature of the CAPE and SLI computations. However, recent experience comparing CAPE values estimated by this formula with actual CAPE values computed from radiosonde data (using mean temperature and moisture in the bottom 100 mb) has shown this computation to be a workable substitute in most cases, even considering the detail limitations

of the FD data. Of course, as with any surface-based thermodynamic parameter, this computation cannot be used in overrunning situations where surface observations in a shallow cool layer do not reflect more unstable conditions present above the boundary layer.

With an estimated CAPE value available, the EHI can then be computed as developed by Hart and Korotky:

$$EHI = H(CAPE)/160000 \quad (2)$$

where H is helicity ( $m^2s^{-2}$ ). This quantity is dimensionless. Computations are done on a personal computer and output

on a printer as numbers over a map of FD forecast locations; analysis of fields is subjective. Parameters are also computed from standard radiosonde data for comparison and verification.

### 3. PARAMETER RESULTS FROM CASES IN LATE 1992

Parameters from several severe weather cases that occurred in the latter half of 1992 are briefly examined here to provide a context for assessing parameter values associated with the Tampa case in the next section. Both tornadic and non-tornadic cases are represented, selected from cases for which

**Table 1: Tornadic cases**

Date and time of tornadoes	Location	Maximum F-scale		0-3km Helicity ( $m^2s^{-2}$ )	SLI	EHI	0-2km Inflow (kts)	3-6km wind (kts)	Forecast (Fcst) sites and Sounding (RAOB) sites used
8/30/92 01-02UTC (1 death)	C. WI	F3	Fcst:	312	-4.2	3.1	24	41	GRB-DBQ 8/29/92 23UTC GRB 8/30/92 00UTC
			RAOB:	313	-5.1	3.6	25	41	
9/6/92 00-02UTC	S.C. KS	F2	Fcst:	130	-10.2	2.8	20	26	ICT/PNC 9/5/92 23UTC TOP-OKC 9/6/92 00UTC
			RAOB:	181	-9.7	3.7	21	35	
9/7/92 01-04UTC	W. KS	F0	Fcst:	177	-8.1	3.1	21	28	GCK 9/7/92 00UTC DDC 9/7/92 00UTC
			RAOB:	221	-8.1	3.8	26	28	
11/22/92 04-09UTC (15 deaths)	MS	F4	Fcst:	497	-2.4	3.1	31	58	JAN 11/22/92 03UTC LCH 11/22/92 00UTC
			RAOB:	342	-5.8	4.4	26	57	
11/22/92 21-23UTC (1 death)	N.C. KY	F4	Fcst:	184	-7.7	3.1	21	68	LOU/LEX 11/22/92 21UTC DAY 11/23/92 00UTC
			RAOB:	470	-3.3	3.7	28	66	
11/23/92 04-10UTC (2 deaths)	C. NC	F3	Fcst:	403	-3.3	3.2	22	60	RDU 11/23/92 06UTC GSO-HAT 11/23/92 00-12UTC
			RAOB:	296	-3.4	2.4	23	53	
<b>Parameter averages</b>			<b>Fcst:</b>	<b>284</b>	<b>-6.0</b>	<b>3.1</b>	<b>23</b>	<b>47</b>	
			<b>RAOB:</b>	<b>304</b>	<b>-5.9</b>	<b>3.6</b>	<b>25</b>	<b>47</b>	

**Table 1.** Parameter values and averages for six tornadic cases associated with supercells in late 1992. Forecast (fcst) values blend the appropriate 6 or 12 hr FD forecast winds and temperatures aloft with a surface observation for the same or a nearby site close to the valid time of the forecast and time of tornado occurrence. Sounding (RAOB) values are from appropriate radiosonde sites, for comparison. In the last column, two forecast or RAOB site identifiers separated by '-' indicate that a linear interpolation was performed between values at the two sites to arrive at representative parameter values, following methodology similar to Davies and Johns (1993).

**Table 2: Non-tornadic cases**

Date and time tornadoes expected	Location		0-3km Helicity ( $m^2s^{-2}$ )	SLI	EHI	0-2km Inflow (kts)	3-6km wind (kts)	Forecast (Fcst) sites and Sounding (RAOB) sites used	
9/6/92 18UTC- 9/7/92 01UTC	S. MI/C. & E. IN /N.W. OH	Fcst:	49	-5.8	0.6	12	19	IND 9/6/92 21UTC FNT-DAY 9/7/92 00UTC	
		RAOB:	83	-3.4	0.7	14	23		
9/20/92 23UTC- 9/21/92 04UTC	S. OK/N. TX	Fcst:	179	-5.3	2.2	17	27	SPS 9/20/92 23UTC OKC-SEP 9/21/92 00UTC	
		RAOB:	96	-3.9	0.9	17	29		
10/4/92 10-16UTC	C. & N.E. FL peninsula	Fcst:	216	-3.6	1.9	17	31	MLB/ORL 10/4/92 09UTC AYS-PBI 10/4/92 12UTC	
		RAOB:	233	-2.8	1.6	20	32		
11/1/92 00-05UTC	N. & C. TX *	Fcst:	175	-5.9	2.3	21	35	DAL 11/1/92 00UTC SEP 11/1/92 00UTC	
		RAOB:	167	-5.6	2.1	22	30		
11/4/92 20UTC- 11/5/92 01UTC	S. GA/N.W. FL	Fcst:	96	-2.9	0.7	14	40	TLH 11/4/92 21UTC TLH 11/5/92 00UTC	
		RAOB:	198	-2.0	1.1	22	44		
11/25/92 07-14UTC	S.E. AL/S.W. GA /FL panhandle	Fcst:	171	-5.5	2.1	17	36	PFN 11/25/92 09UTC TLH 11/25/92 12UTC	
		RAOB:	185	-1.6	0.8	20	43		
<b>Parameter averages</b>			<b>Fcst:</b>	<b>148</b>	<b>-4.8</b>	<b>1.6</b>	<b>16</b>	<b>31</b>	
			<b>RAOB:</b>	<b>160</b>	<b>-3.2</b>	<b>1.2</b>	<b>19</b>	<b>34</b>	

\*One brief, weak F0 tornado occurred with this case, but it is unclear whether the tornado was of supercell or non-supercell origin.

**Table 2.** Parameter values and averages for six non-tornadic cases in late 1992. Format and methodology are similar to that used in Table 1.

the author was able to store radiosonde data, surface observations, and NGM-based FD forecast winds and temperatures aloft (hereafter referred to as the *FD forecast*) during late August through November 1992. Preliminary *Storm Data* at the National Severe Storms Forecast Center was used as verification.

#### a. Tornadoic cases

Table 1 summarizes parameter values for six tornado cases that appeared to be associated with supercells when examining preliminary *Storm Data*. Two sets of data are given for each case. The first set gives "forecast" values of parameters at a site near the tornado occurrences using the most recent FD forecast blended with a surface observation at or near the same site, during the tornado event or within one to two hours before the first tornado report. The second set shows values of the same parameters derived from nearby or spatially interpolated radiosonde (RAOB) sites, using methodology similar to Davies and Johns (1993), for verification purposes.

The parameter values derived from radiosondes in Table 1 appear to indicate that the hourly-generated "forecasts" blending the FD forecast data and current surface observations do a reasonable job in most cases of representing the observed parameter values. Furthermore, parameter values for the tornado cases are all close to or within ranges that would be expected to be favorable for low-level rotation and possible tornadoes as discussed in Section 2. It is interesting that, given the wide range of helicity magnitudes (130 to 497  $\text{m}^2\text{s}^{-2}$ ) and surface-based lifted index values (-2.4 to -10.2) encountered, EHI values are in most cases around 3.0 or greater.

#### b. Non-tornadoic cases

Summarized in Table 2 are six cases where thunderstorms occurred, but no tornadoes were reported, even though tornadoes were considered a possibility by forecasters in each case. The format and methodology is similar to that used in Table 1. Note that one or more parameters in each case is marginal or below the range that would appear favorable for low-level rotation and possible tornadoes. The parameter averages from the non-tornadoic cases are also notably less than those in the tornadoic cases. In particular, even though all cases exhibit some instability, and helicity in some cases is greater than 150  $\text{m}^2\text{s}^{-2}$ , EHI values are consistently less than those in Table 1. These results suggest that, in many cases, hourly-generated parameters as discussed in Section 2 using numerical weather prediction model data would be helpful in distinguishing between many tornadoic and non-tornadoic events.

The 10/3/92 Tampa case will now be examined in the context of these results using hourly-generated parameters blending winds aloft forecast data with surface observations.

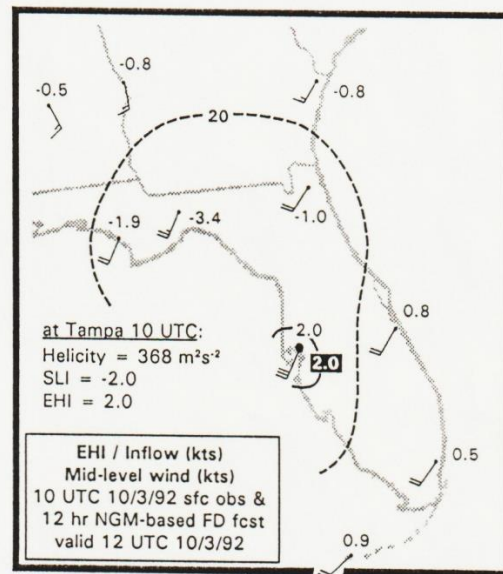
### 4. ANALYSIS OF 10/3/92 TAMPA CASE

Nine hours before the tornadoes, the 6 hr FD forecast valid at 06 UTC 10/3/92 (not shown) blended with surface data from 06 UTC indicated large helicity from northwest Florida southward along the west coast of the Florida peninsula. Inflow was greater than 20 kts across this same area, and a mid-level wind max of 25 to 30 kts was approaching from the west-southwest. Table 3 shows hourly EHI, helicity, and instability at Tampa during the period 06-12 UTC, blending the appropriate FD forecast for St. Petersburg (PIE) with Tampa (TPA) surface observations. At 06 UTC, although helicity is large at Tampa (greater than 400), no instability is indicated (SLI = +1), which yields a poor EHI value of -0.4. Although the lack of instability

**Table 3. Hourly EHI/Helicity/SLI at Tampa 10/3/92 06-12 UTC**

Surface ob time (at TPA)	EHI	0-3km Helicity ( $\text{m}^2\text{s}^{-2}$ )	SLI	NGM-based FD winds and temperatures aloft forecast used (at PIE)
06 UTC	-0.4	420	1.1	6 hr, valid 06 UTC
07 UTC	0.4	424	-0.2	6 hr, valid 06 UTC
08 UTC	1.0	372	-0.7	6 hr, valid 06 UTC
09 UTC	1.6	338	-1.7	12 hr, valid 12 UTC
10 UTC	2.0	368	-2.0	12 hr, valid 12 UTC
11 UTC	2.6	397	-2.7	12 hr, valid 12 UTC
12 UTC	3.1	397	-3.3	12 hr, valid 12 UTC

**Table 3. Hourly energy-helicity index (EHI), helicity, and SLI at Tampa 06 UTC through 12 UTC 10/3/92, computed by blending the 00 UTC 6 hr and 12 hr FD forecasts for PIE (St. Petersburg/Clearwater airport) with hourly surface data for TPA (Tampa International airport).**



**Fig. 3. EHI (values  $\geq 2.0$  enclosed by solid line), 0-2 km inflow  $\geq 20$  kts (enclosed by dashed line), 3-6 km mean wind (full barb = 10 kts) for 10 UTC 10/3/92, from 12 hr FD forecast valid 12 UTC, and surface observations at 10 UTC. Helicity and SLI are shown for Tampa (large dot).**

seems to preclude the possibility of severe weather, the strength of the low-level wind parameters (e.g., helicity and inflow) might suggest that the central Florida area be watched closely for destabilization as a surface low pressure feature (not shown) in the central Gulf of Mexico approaches the west coast of Florida during the early morning hours.

Four hours later using 10 UTC surface data, Fig. 3 anticipates the valid time of the 12 hr FD forecast by two hours, and indicates that destabilization is indeed taking place. Although some veering in the surface winds (not shown) has contributed to reducing helicity values from those indicated at 06 UTC, the SLI is now -2 at Tampa, yielding an EHI that has increased significantly (to 2.0) since 06 UTC (see Table 3). Inflow and mid-level winds in Fig. 3 are significant as well. The fact that showers and thunderstorms (not shown) are already occurring at 10 UTC off the west coast of Florida ahead of the

approaching disturbance, combined with the notable increase in instability and EHI, might suggest that trends in the area be monitored carefully during the next 2 to 3 hours, with the possibility of severe weather in mind.

The 12 hr FD forecast using 12 UTC surface data (Fig. 4, and Table 3) shows that several parameters have continued to strengthen at Tampa. With some surface wind backing (not shown), helicity has increased to near 400, the SLI is now -3, and the resulting EHI has risen above 3.0. Thunderstorms of level 5 intensity are west of Tampa on radar at this time (not shown). This fact, along with the upward trend and strength of EHI values (see Table 3), and support from significant inflow and mid-level winds, might suggest some degree of potential for tornadoes along the west coast of central Florida, pending an examination of 12 UTC upper air data.

Parameters computed from the 12 UTC radiosonde at Tampa (Fig. 5 shows hodograph only and parameter values for

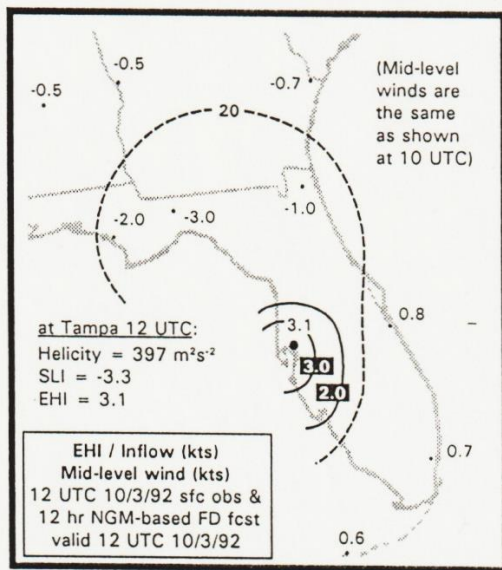


Fig. 4. As in Fig. 3, except for 12 UTC 10/3/92, using surface observations at 12 UTC.  $EHI \geq 2.0$  is analyzed (solid lines), and 3-6 km winds are omitted (these are the same as in Fig. 3).

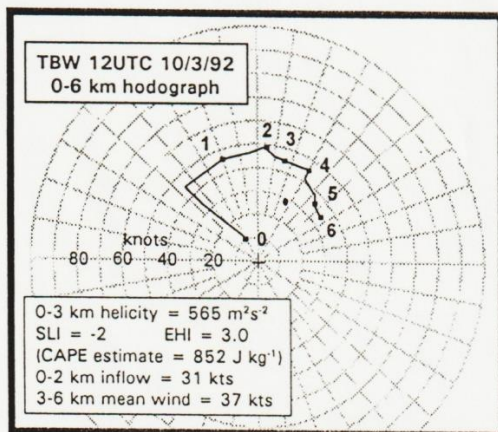


Fig. 5. 0-6 km hodograph and parameters computed from 12 UTC 10/3/92 radiosonde at Tampa-Ruskin (TBW). Estimated storm motion is shown by dot.

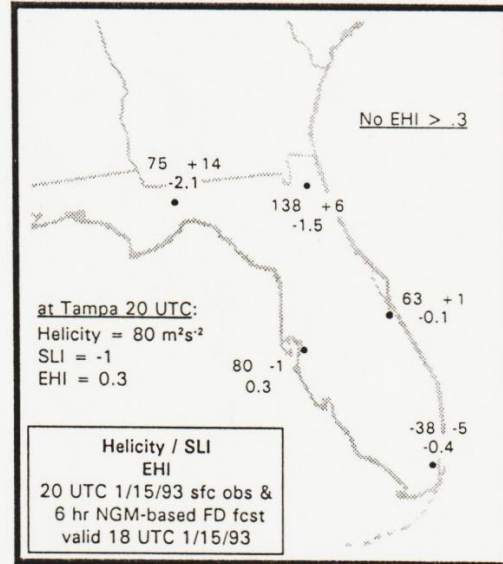


Fig. 6. Helicity, SLI, and EHI shown at (from upper left to lower right) Tallahassee, Jacksonville, Tampa, Melbourne, and Miami for 20 UTC 1/15/93, from 6 hr FD forecast valid 18 UTC, and surface observations at 20 UTC.

TBW) indicate that the FD forecast verifies reasonably well in most aspects. The Tampa sounding was missing above 400 mb, but blending of the Tampa radiosonde data with the upper portion of the 12 UTC sounding from Cape Canaveral (roughly 110 miles east, not shown) yields a CAPE near  $850 \text{ J kg}^{-1}$ , a value very close to that estimated from the Tampa sounding SLI (-2). Although the observed Tampa thermodynamic profile is not as unstable as forecast by the NGM-based FD data, the observed helicity is larger than forecast, so that the helicity/instability combination yields a significant EHI (3.0), which is close to the EHI value (3.1) derived using the FD forecast data and current surface data. Inflow and mid-level winds are stronger than forecast, around 30 kts and 35 kts, respectively.

Although the instability in this case, evaluated as an isolated parameter, might at first appear marginal or too weak to support severe weather, the strong helicity and upward trend of the EHI, along with other supporting parameters, seems to indicate potential for thunderstorm rotation and possible tornadoes. The helicity/instability combination, inflow, and mid-level wind speeds would certainly tend to associate this case with the tornadic cases in Table 1 from Section 3, rather than the non-tornadic cases in Table 2.

For comparison to the 10/3/92 case, Fig. 6 portrays hourly-generated parameters on an afternoon when tornadoes were expected but did not occur along the west-central coast of Florida. The helicity and instability fields are shown for 20 UTC on 1/15/93 using the 6 hr FD forecast valid at 18 UTC blended with 20 UTC surface data, shortly before thunderstorms moved through the Tampa area. Although mid-level winds are moderately strong (34 kts at Tampa, not shown), the combination of helicity (80) and instability (-1) is poor, resulting in an EHI of only 0.3. Inflow at Tampa is also poor (14 kts at 20 UTC, not shown). EHI values computed during the afternoon in central Florida continued low, and inflow remained weak. The parameter values on this particular day thus appear too weak to support significant thunderstorm rotation based on the other examples in this paper, and may offer a partial explanation as to why no tornadoes occurred.

## 5. DISCUSSION AND CONCLUSIONS

Numerical storm simulation studies such as Brooks and Wilhelmson (1990) and McCaul (1990) have shown that the interaction of strong low-level curvature shear (i.e., helicity) with a thunderstorm updraft can significantly intensify and enhance updraft strength in the absence of strong instability through the creation of vertical perturbation pressure gradients (Rotunno and Klemp 1982). In fact, the 12 UTC 10/3/92 Tampa hodograph (Fig. 5) bears a striking resemblance to one of McCaul's simulation hodographs from Hurricane Danny (see McCaul's Fig. 1), another case where buoyancy is relatively low. In the Tampa case, the Hurricane Danny case, and other cases, it appears that the strong low-level curvature shear serves to interact with and enhance updrafts that are initiated in an environment that is only marginally unstable by "normal" severe weather standards.

Such situations are a problem for forecasters to diagnose because it is difficult to subjectively assess what combinations of helicity and instability might optimize this process. The EHI, which is based on a large data set that involves a wide range of helicity/instability combinations (Johns et al. 1993), overcomes some of this problem by assigning a number to a given helicity/instability combination which can be monitored for trends that might otherwise be difficult to see when following the progress of two separate parameters. Table 3 in Section 4 shows the continuous upward trend of EHI values at Tampa prior to the tornadoes. The apparent increase in rotational potential is not as evident or dramatic when noting the evolution of the separate helicity and instability values, also shown in Table 3.

This study supports the author's experience that EHI values in the range of 2.5 to 3.0 or greater are more indicative of potential for significant mesocyclone-induced tornadoes than values of 1.0 or greater suggested in preliminary work by Hart and Korotky (1991) and LaPenta (1992). Although many cases occur where tornadoes are reported with lesser EHI values, many of these tornadoes appear to be weak and short-lived, with some probably of non-supercell origin (Wakimoto and Wilson 1989). It is also important to point out that large EHI values do not guarantee tornado development when thunderstorms occur. As noted earlier, the forecasting parameters, coarse model data, and sparse location networks used here cannot address tornado development directly, but only suggest the presence of factors and processes that would make low-level mesocyclone development more likely.

Apart from the notion of "threshold" values or ranges, this study suggests that monitoring of EHI trends is important, particularly regarding tornado forecast situations that involve environments characterized by *opposite extremes of helicity and instability*. This includes cases that involve strong instability but marginal helicity (the *reverse* of the 10/3/92 Tampa environment). The data from Tables 1 and 2 in Section 3 also reinforce the idea that recognition of environments having potential to produce significant tornadoes depends on proper assessment of rotational parameters *in conjunction with each other*, including parameters such as inflow and mid-level wind speeds.

It is always easier to examine a given forecast situation in hindsight, knowing what the outcome was, than to deal with the same situation in real time while events unfold. The Tampa case examined in this paper is no exception. However, after reviewing hourly-generated rotational parameters leading up to the tornadoes, it appears that such products might have been helpful in many respects. It is hoped that this study will encourage meteorologists to experiment more widely with the EHI and other diagnostic rotational parameters using numerical

weather prediction model data when assessing the potential for mesocyclone-induced tornadoes.

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