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NEW YORK STATE TORNADOES

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1. INTRODUCTION

New York State has a low frequency of tornado occurrence. During the period from 1962 to 1991, New York State averaged 1.2 tornadoes per 10,000 square miles, which ranked 37 out of the 50 states.[1] However, during recent years, there has been a marked increase in the number of tornadoes. During the decade of the 1950's, New York averaged just 1.2 tornadoes per year. The number increased steadily with 3.1 tornadoes occurring per year in the 1960s, 5.4 per year in the 1970s, and 6.7 in the 1980s. Since 1990, the average has been 16.5 per year, with a record 25 tornadoes occurring in 1992.

Greater emphasis on severe weather warning verification, the establishment of spotter networks, and an increased number of post-storm surveys may have contributed to the increased tornado frequency. However, a more active weather pattern during the past few years may have also played a role. During 1992, there was a record number (1293) of tornadoes nationwide, breaking the previous record (1133) set in 1990 (Crowther 1993). Regardless of the causes if the tornado increase, it is clear that tornadoes are an important meteorological hazard in New York State. Since May 1989, meteorological data have been routinely archived at the National Weather Service Forecast Office in Albany, NY (WSFO ALB), as part of the WSFO ALB Mesoscale Climatology Project. The availability of these data have provided the opportunity to study the meteorological conditions favorable for the development of tornadoes.

During the period from 1989-1992, 66 tornadoes occurred on 27 days (Storm Data 1989-1992). Due to missing data and the questionable nature of one reported tornado, 3 days were eliminated from the study. For the remaining 24 tornado days, proximity soundings were constructed and analyzed by using the SHARP (Skew-T Hodograph Analysis and Research Program) Workstation (Hart and Korotky 1991). Atmospheric soundings across the north-eastern United States were examined to determine a sounding representative of the airmass that produced the tornado(es). This sounding was modified by using observed surface temperature, dewpoint, and wind. Additional modifications were made if there

[1] Statistics on tornado climatology were based on information from the National Severe Storms Forecast Center in Kansas City, MO.

was significant thermal advection aloft, or changes in the vertical wind profile. Table 1 lists the tornado days used in this study, and includes information about the time, intensity, and location of the tornadoes.

2. RESULTS

By using the SHARP workstation, various severe weather indices were calculated for each proximity sounding. The results are presented in Table 2 column A; some of the indices are discussed in detail. In addition, temperature, dewpoint, and wind data for each sounding were calculated at various levels throughout the atmosphere and averaged for the 24 cases. Figure 1a and 1b present the thermal profile and hodograph for the mean sounding, respectively. It is important to note that many of the threshold values for severe thunderstorm and tornado development used in this paper, are based primarily on storms studied in the Midwestern United States.

a. Lifted Index

Lifted indices were calculated by lifting the most unstable low-level parcel to 500, and then to 300 mb. In 23 out of 24 cases, the most unstable low-level parcel was located at the surface. The mean lifted index to 500 mb was -6 (°C), and varied from -2 to -8. The standard deviation was 1.5. The mean lifted index to 300 mb was -5. Figure 2a (upper left) gives the distribution of lifted indices to 500 mb.

b. Total Totals Index

The Total Totals (TT) Index considers both the 850 to 500 mb temperature lapse rate, and the moisture at 850 mb to estimate severe weather potential. Values of 50 or 51 usually indicate the possibility of a few severe thunderstorms and isolated tornadoes. Total Totals values from 52 to 55 indicate the possibility of scattered severe thunderstorms and a few tornadoes, while values greater than 55 indicate numerous severe thunderstorms and scattered tornadoes (Miller 1972). The mean TT for the 24 cases was 49, which was below the threshold of 50 for tornadic activity. Values ranged from 43 to 57 with a standard deviation of 3.9. Figure 2a (upper right) reveals the distribution of TT values. More than half the cases (14), had a TT below the tornadic threshold.

c. Sweat Index

The Sweat Index (SI) combines the effects of low level moisture, convective instability, and the wind at 850 and 500 mb, in determining severe weather potential. SI values ranging between 400 to 500 usually indicate a chance for tornadoes. SI values from 500 to 600 indicate tornadoes are likely, and values from 600 to 800 point to scattered tornadoes (Miller 1972). The mean SI of 287 calculated in this study, was well below the tornadic threshold of 400. In fact, only 3 of 24 cases had the SI greater than 400. Values ranged from 165 to 447 with a standard deviation of 75. Figure 2a (lower left) illustrates the distribution of the SI.

d. Convective Available Potential Energy

Convective Available Potential Energy (CAPE) is the vertically integrated positive buoyancy of an adiabatically rising parcel. Since CAPE is proportional to the amount of kinetic energy that a rising parcel gains while it is warmer than its surrounding

environment, it is an excellent measure of latent instability. Values of CAPE varied from 650 to 3425 J/kg with the mean 1878 J/kg. The standard deviation was 706 J/kg. Figure 2a (lower right) gives the distribution of CAPE for the 24 tornado days.

e. Storm-relative Helicity

Storm-relative helicity (s-rH) is the summation of streamwise vorticity through the inflow layer and gives a measure of the rotational potential of a thunderstorm updraft. According to Davies-Jones et al. (1990), an empirical rule for mesocyclone formation is that the storm-relative winds should have speeds of at least 20 kt and veer by at least 90° in the lowest 3 km of the atmosphere. This combination produces a threshold s-rH value for mesocyclone formation of 150 $(m/s)^2$. S-rH for the 24 tornado days in this study was calculated by using a storm motion based on local radar observations. If radar observations were not available, storm motion was determined by using the text of issued warnings and statements. S-rH in the 0-3 km AGL layer varied from 29 to 595 $(m/s)^2$. The mean was 189 $(m/s)^2$ and the standard deviation was 140 $(m/s)^2$. Figure 2b (upper left) shows the distribution of s-rH. Fourteen of the 24 cases had s-rH less than the 150 $(m/s)^2$ mesocyclone threshold.

Low s-rH does not rule out tornado formation. Studies by Johns and Doswell (1992); Lazarus and Droegemeier (1990); and LaPenta (1992) have shown that there may be a relationship between s-rH and CAPE that contributes to the development of mesocyclones and tornadoes. Tornadoes are possible with weak instability and large s-rH, if the instability is sufficient to initiate and sustain convection. Likewise, marginal s-rH combined with large CAPE may produce tornadoes (see Section 2g). In some cases, local effects may have produced larger storm scale s-rH than calculated in this study. Since all tornadoes are not produced by mesocyclones (Wakimoto and Wilson 1989), the low s-rH may indicate that some of the tornadoes in this study were in fact not produced by a mesocyclone. Non-supercell tornadoes are just beginning to be understood and reliable forecast methods need to be developed (Johns and Doswell 1992).

f. Bulk Richardson Number

The Bulk Richardson Number (BRN) is defined as the ratio of positive buoyant energy to wind shear. Weisman and Klemp (1986) indicated that supercell development is favored with a BRN less than 50, while multicell convection is likely for a BRN greater than 35 (both supercells and multicells occurred with the BRN between 35 and 50). With a BRN below 10, wind shear may be too strong for sustained convection, especially if positive buoyant energy is small. The BRN is not appropriate for storm rotation, because the shear used in its calculation does not address the specific effects of directional and speed shear components (Lazarus and Droegemeier 1990). The mean BRN was 44 with a standard deviation of 38. Figure 2b (upper right) gives the distribution of the BRN. In 75% of the cases, the BRN was less than or equal to 50. For two cases, the BRN was less than 10. These cases occurred in October and November with the CAPE less than 1000 J/kg.

g. Energy-helicity Index

The Energy-helicity Index (EHI) represents potential tornadic intensity as a function of CAPE and s-rH. This index is based on empirical studies of strong (F2 and F3) and violent (F4 and F5) tornadoes. Hart and Korotky (1991) defined the EHI as:

$$EHI = [\ +s\text{-}rH * CAPE\ ] / 160{,}000$$

where +s-rH is the positive s-rH in the 0 to 2 km (AGL) layer. The reliability of the EHI is not conclusive, but values between 1 and 5 appear to indicate the potential for F2 and F3 tornadoes, and values greater than 5 indicate the potential for F4 and F5 tornadoes when other additional severe weather parameters are present (Hart and Korotky 1991; LaPenta 1992).

For this study, the mean EHI was 2.0 with values ranging from 0.75 to 8.33. The standard deviation was 1.55. The highest EHI (8.33), occurred on 10 July 1989, in conjunction with an F4 tornado. Figure 2b (lower left) illustrates the distribution of the EHI. Of the 24 cases studied, 21 had an EHI greater than or equal to 1.

Figure 3 shows the relationship between s-rH, CAPE and maximum tornadic intensity for each case. Curves representing EHI values of 1 and 5 are indicated. Data for this study indicate that an EHI near 1, represents a threshold for tornado intensity from F0 to F4.

h. Storm-Relative Inflow

Lazarus and Droegemeier (1990) noted that storm rotation is dependent not only on helicity, but on the specific combination of velocity and vorticity that produced the helicity. They also state that regardless of the shear, storm-relative low-level turning alone is not sufficient to produce strongly rotating storms; and that adequate storm-relative, low-level inflow is required. Environments with storm-relative inflow less than 20 kt favor multicellular storms; while inflow of greater than 20 kt, with sufficiently high s-rH, favor rotating updrafts and mesocyclones (Lazarus and Droegemeier 1990; Davies-Jones et al. 1990; Hart and Korotky 1991).

In this study, storm-relative inflow was calculated for various levels up to 3 km. The mean value for the maximum inflow was 32 kt and varied from 16 to 52 kt. The standard deviation was 9 kt. The storm-relative inflow was less than the threshold of 20 kt for only the case occurring on 13 October 1990, when a tornado was associated with the remnants of a dying tropical disturbance. This system was barely detectable by the current observational upper air network. Therefore, the proximity sounding may not have been representative of the wind field near the remnants of the tropical system. Figure 2b (lower right) shows the distribution of storm-relative inflow.

i. Storm Motion

As mentioned before, storm motion was based on radar observations, if they were available. If radar observations were not available, storm motion was determined from the text of warnings and statements issued during the event.

The mean storm motion was from 256° at 34 kt. Speeds ranged from 20 to 50 kt. Twenty-three of the 24 cases moved from between 219° and 309°. One storm moved

from the northeast (20°). In 14 cases, the storms moved from the west or northwest (260° to 310°) indicating the importance of the northwest flow synoptic pattern (Johns 1982).

3. COOL VS. WARM SEASON

Like many other meteorological phenomena, the conditions that produce tornadoes have a strong seasonal and geographic dependence. As mentioned previously, studies (Johns and Doswell 1992; Lazarus and Droegemeier 1990; LaPenta 1992) have shown that tornadoes are possible with weak instability and large shear, if the instability is sufficient to initiate and sustain convection. Likewise, large CAPE combined with marginal shear may produce tornadoes. During the cool part of the year (fall-winter-spring), shear is generally higher due to stronger wind fields. However, CAPE is typically lower due to cooler temperatures and lower moisture availability. The reverse is true during the warm part of the year (summer). Shear is generally lower due to weaker wind fields and CAPE is typically higher due to warmer temperatures and greater moisture availability. This seasonally dependent relationship between CAPE and shear (as measured by s-rH) was examined. In addition, other variables were examined for seasonal dependency.

In order to examine the relationship between CAPE and s-rH during the course of the year, the 24 tornado days were stratified into warm and cool season samples. June through early September was considered the warm season, with the remainder of the year defined to be the cool season. However, if a tornado day was unrepresentative of the season during which it occurred, or if it best fit the typical weather regime expected of the other season, it was inserted into the other sample. The only such event occurred on April 9, 1991, which was placed in the warm season sample. On this day, the synoptic pattern was more typical of the warm season. Maximum surface temperatures were from the upper 70s to mid 80s (°F), and dewpoints were in the 60s (°F).

The seasonal stratification resulted in 16 warm season cases and 8 cool season cases. Figure 4 shows a comparison between the warm season and cool season thermal profiles. Figure 5 shows a comparison of hodographs for all 24 cases, for warm season cases, and for cool season cases. Columns B and C in Table 2 depict mean values of various parameters for the warm and cool seasons, respectively.

As expected, CAPE and s-rH showed a strong seasonal dependence. The warm season mean CAPE was twice that of the cool season, while the mean warm season s-rH was half that of the cool season. The EHI was similar for both seasons. This supports the idea that the balance between CAPE and s-rH is more important for predicting tornado occurrence than either of the individual values (Johns and Doswell 1992; Lazarus and Droegemeier 1990). Unlike the seasonally dependent CAPE and s-rH indices, it appears that a threshold for EHI used to determine tornadic potential, can be applied during all seasons.

Other indices listed in Table 2, and also discussed in Section 2 (LI to 500 and 300 mb, the SI, and the BRN), showed a seasonal dependence. Therefore, no single value of these indices would be very useful in determining tornado potential throughout

the entire year.

For example, the LI to 500 mb (300 mb) had a mean value of -6 (-6) for the warm season and -4 (-2) for the cool season. The greatest difference was found for the LI to 300 mb since it is rare to have enough buoyant energy to lift a parcel to that level during the cool season. The SI averaged 278 for the warm season, and 305 for the cool season. The BRN had warm and cool season averages of 56 and 19 respectively. The Showalter Index (SHI) and the TT had similar averages for the warm and cool seasons and showed no seasonal dependency. The mean SHI for the warm and cool seasons, were -1 and 0, respectively. The mean TT was 49 for both seasons.

4. DISCUSSION/CONCLUSION

The number of sample cases used in this study was small, yet it appears there is some useful information that can be summarized. As noted earlier, many tornado and severe thunderstorm studies have been based primarily on storms located in the Midwestern United States. This study, and previous work by Harnack and Quinlan (1988), suggest that in the northeastern United States tornado threshold values for some indices that are used in the Midwest may be too high. Fourteen TT values (58%) and 21 SI values (88%) were below tornadic thresholds. In addition, 14 of the 24 cases (58%) had s-rH less than the Davies-Jones et al. (1990) threshold for mesocyclone formation.

Low s-rH with large CAPE may produce tornadoes. However, local effects may have produced storm scale s-rH larger than calculated in this study, or low values of s-rH may indicate that some of the tornadoes were not produced by mesocyclones. The data also indicates that an EHI value of near 1, may represent a threshold for all tornadic activity (Fig. 3), rather than only strong and violent tornadoes.

CAPE and s-rH both showed a strong seasonal dependence. The warm season mean CAPE was twice the cool season value, while the warm season mean s-rH was half of the cool season value. The EHI, which combines the two indices, was similar for both the warm and cool seasons.

This paper represents the first step in an ongoing study to improve forecasting tornadoes in the northeastern United States. To increase the sample size, the area of study should be expanded to include other parts of the northeastern United States. The tornado data base will also be continuously updated. This study focused on confirmed tornado cases, so there are no conclusions about how often the indices were used to predict tornadoes that do not occur. In the future, tornado cases will be compared to severe weather cases that did not produce tornadoes, and to other cases that did not produce severe weather.

ACKNOWLEDGEMENTS

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REFERENCES

Crowther, H. G., 1993: Tornadoes hit new heights. *Weatherwise*, 46, 29-37.

Davies-Jones, R. P., D. Burgess, and M. Foster, 1990: Test of helicity as a tornado forecast parameter. *Preprints, 16th Conf. on Severe Local Storms*, Kananaskis Park, Alta., Canada, Amer. Meteor. Soc., 588-592.

Harnack, R. P., and J. S. Quinlan, 1988: Some synoptic scale relationships involving severe weather in the northeastern United States. *Preprints, 15th Conference on Severe Local Storms*, Baltimore, Amer. Meteor. Soc., 529-532.

Hart, J. A., and W. Korotky, 1991: The SHARP workstation v1.50. A SkewT-hodograph analysis research program for the IBM and compatible PC. NOAA/NWS Charleston, WV, 30 pp.

Johns, R. H., 1982: A synoptic climatology of northwest flow severe weather outbreaks. Part I: Nature and significance. *Mon. Wea. Rev.*, 110, 1653-1663.

Johns, R. H., and C. A. Doswell, 1992: Severe local storm forecasting. *Preprints, Symposium on Weather Forecasting*, Atlanta, Amer. Meteor. Soc., 225-236.

LaPenta, K. D., 1992: Preliminary guidelines for using helicity, buoyancy and the energy-helicity index from the SHARP workstation. *Preprints, Symposium on Weather Forecasting*, Atlanta, Amer. Meteor. Soc., 160-165.

Lazarus, S. M., and K. K. Droegemeier, 1990: The influence of helicity on the stability and morphology of numerically simulated storms. *Preprints, 16th Conference on Severe Local Storms*, Kananaskis Park, Alta., Canada, Amer. Meteor. Soc., 269-274.

Miller., R. C., 1972: Notes on analysis of severe-storm forecasting procedures of the Air Force Global Weather Central. *AFGWC Technical Report No. 200 (Rev)*, Air Weather Service, Scott Air Force Base, 190 pp.

Storm Data, 1989-1992: National Environmental Satellite, Data and Information Services. Asheville, NC.

Wakimoto, R. M., and J. W. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea. Rev.*, 117, 1113-1140.

Weisman, M. L., and J. B. Klemp, 1986: Characteristics of isolated convective storms. *Mesoscale Meteorology and Forecasting*, P. S. Ray Ed., Amer. Meteor. Soc., Boston, 331-357.

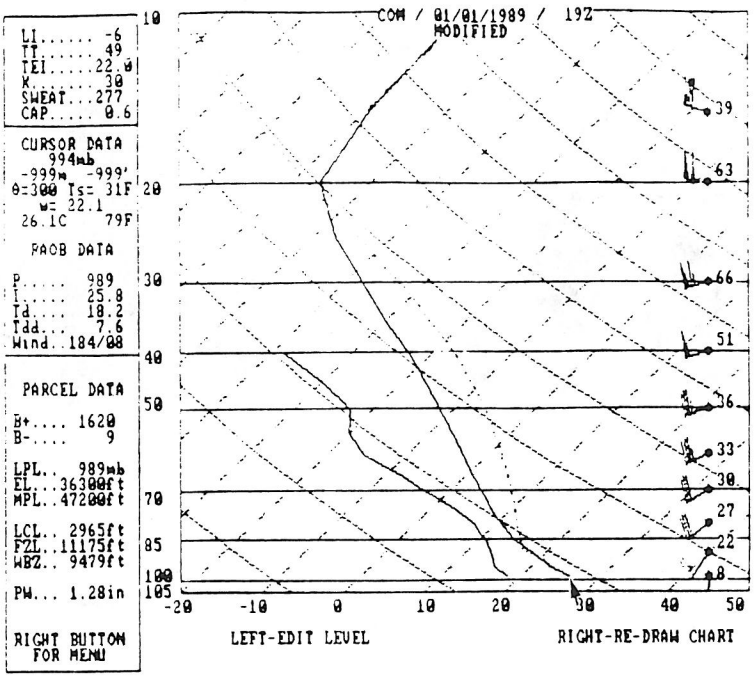


Figure 1a. Mean sounding for 24 tornado cases.

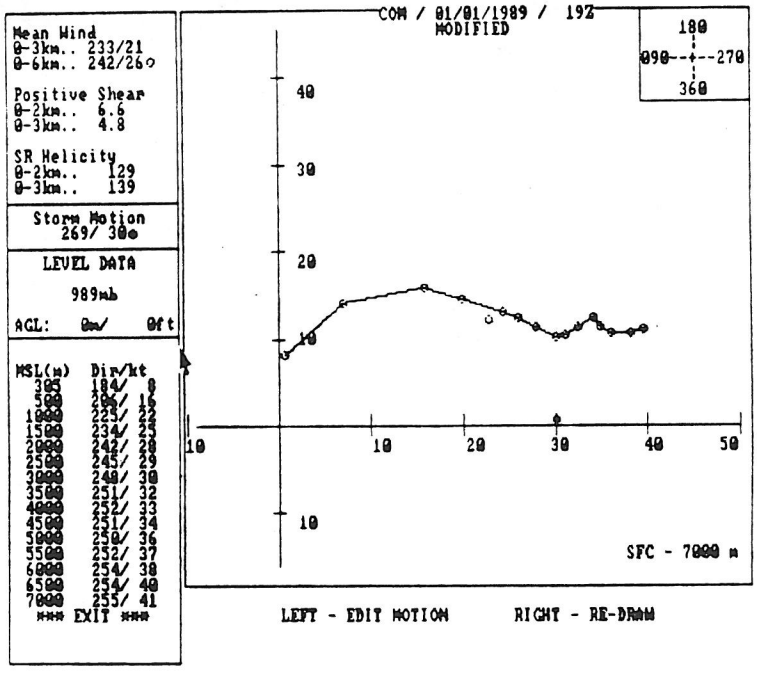


Figure 1b. Mean hodograph for 24 tornado cases.

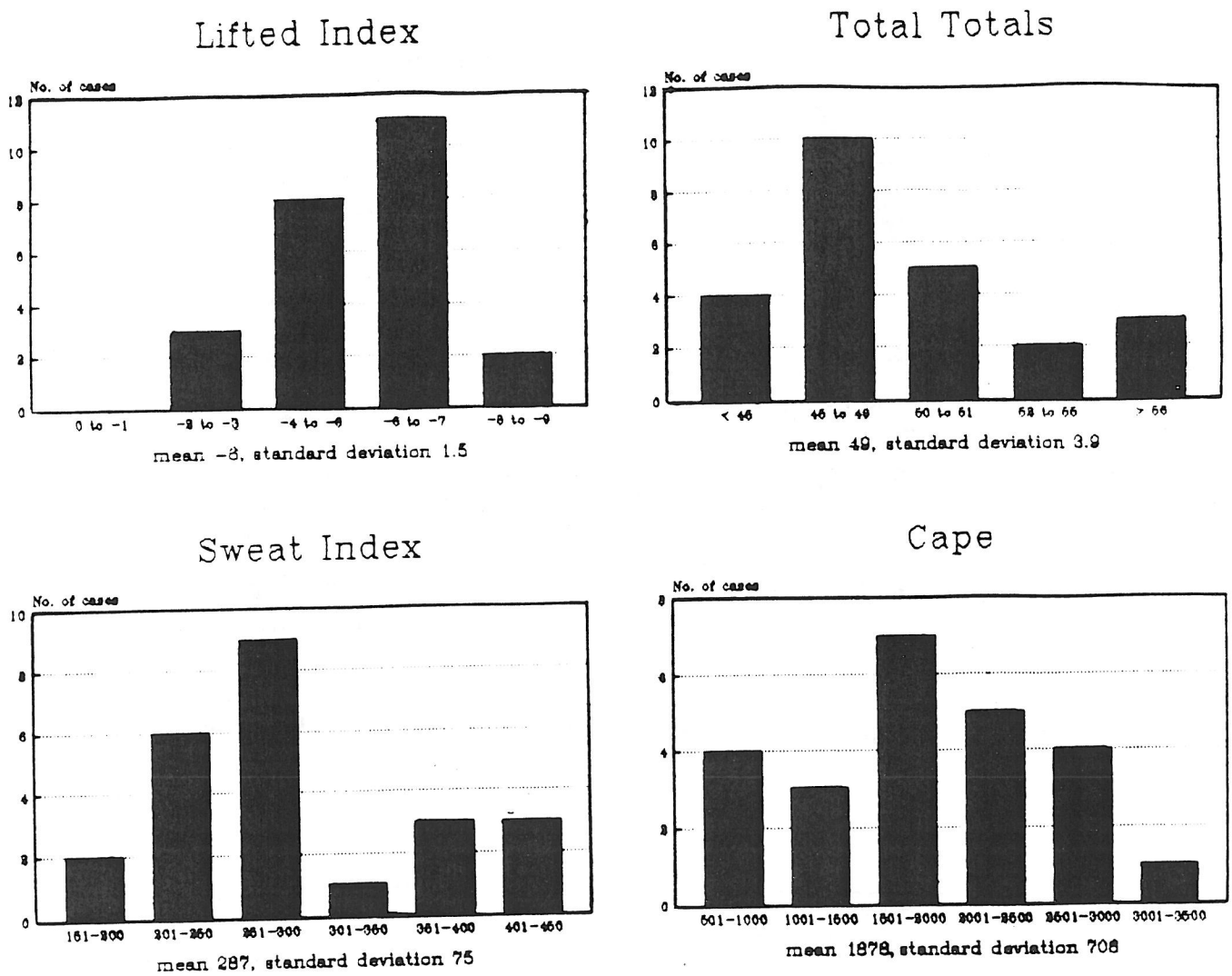


Figure 2a. Distribution of Lifted Index to 500 mb (upper left), Total Totals Index (upper right), Sweat Index (lower left), and CAPE (lower right).

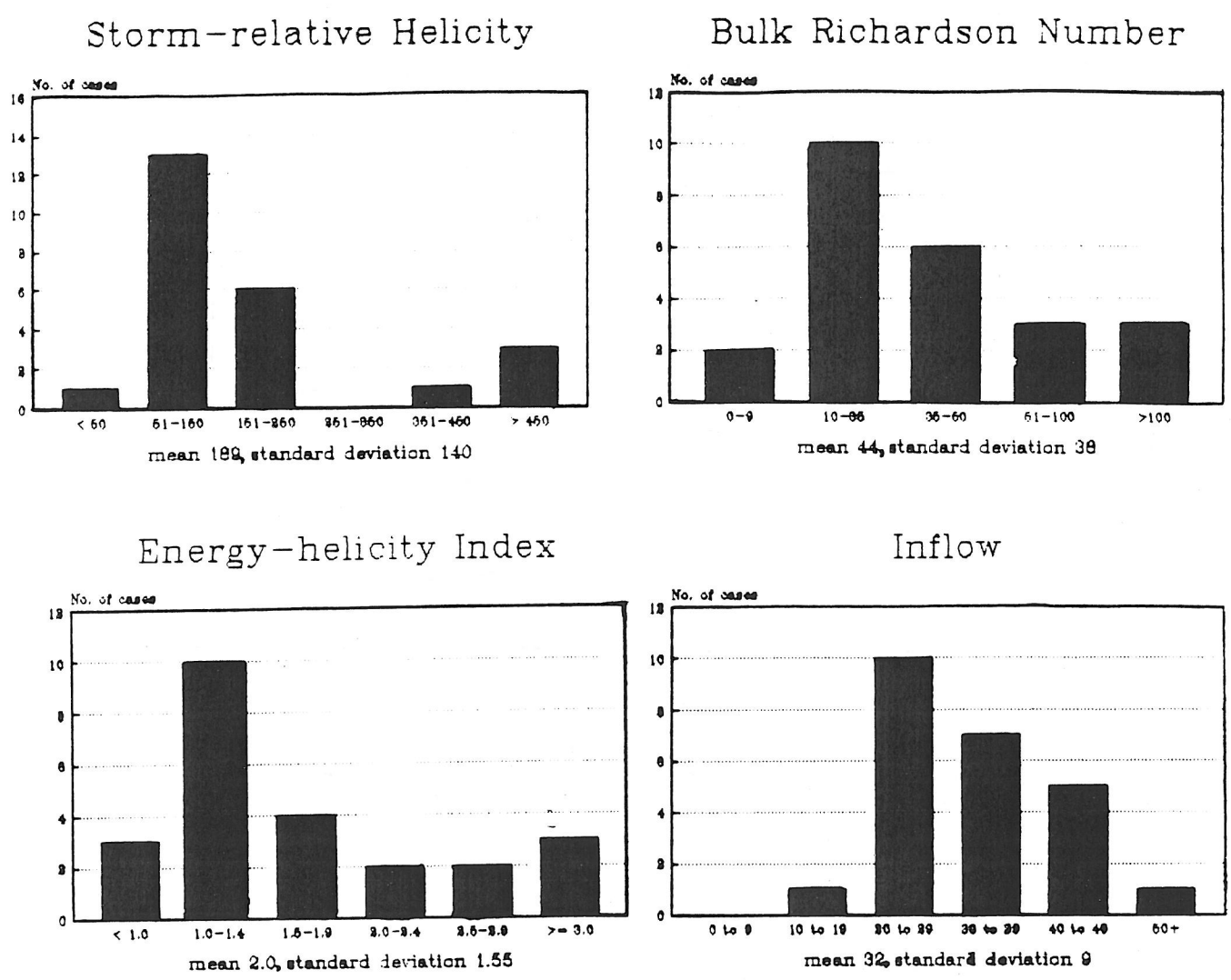


Figure 2b. Distribution of Storm-relative Helicity (upper left), Bulk Richardson Number (upper right), Energy-helicity Index (lower left) and Maximum Storm-relative Inflow (lower right).

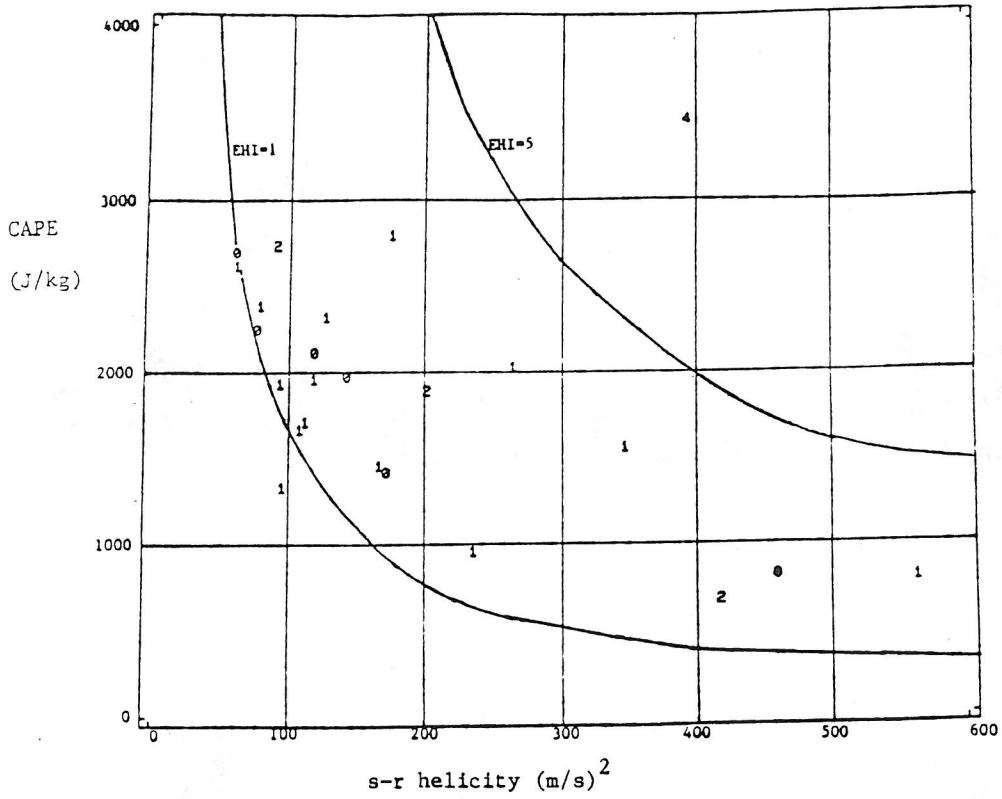


Figure 3. Relationship between 0-2 km positive Storm-relative Helicity, and tornado intensity. (Lines drawn for EHI equal to 1 and 5).

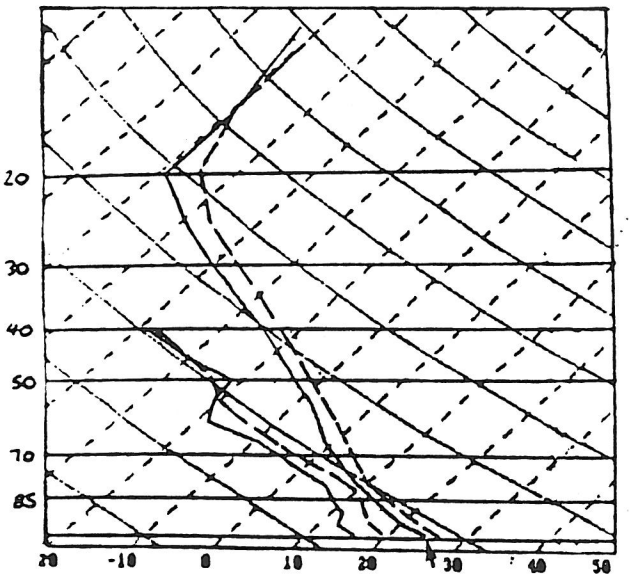


Figure 4. Comparison of warm season (dashed line) and cool season (solid line) mean soundings.

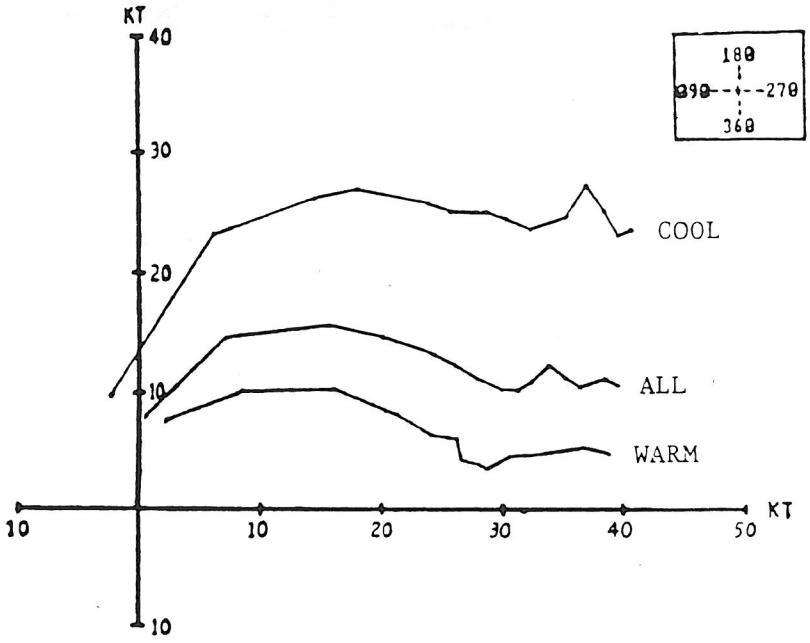


Figure 5. Comparison of warm season and cool season hodographs for all cases.

Table 1. New York State Tornadoes: Date, time, location, intensity and season (1989-1992).

Date	Number	Time (EST)	Counties	Intensity	Season
6-24-89	1	1436-1442	Oneida	F1	warm
7-10-89	1	0520-0527	St. Lawrence	F1	warm
	2	1327-1425	Montgomery, Schoharie Albany, Greene	F4	
	3	1658-1704	Putnam	F2	
	4	1815	Suffolk	F2	
10-14-89	1	1815-1818	Chenango	F2	cool
11-16-89	1	1015	Madison	F0	cool
	2	1115	Westchester	F0	
	3	1140-1158	Sullivan	F1	
	4	1205-1231	Orange	F1	
	5	Unknown	Hamilton	F0	
	6	1320-1324	Saratoga	F1	
	7	1350-1358	Saratoga	F0	
	8	1430-1432	Rensselaer	F0	
5-17-90	1	1512-1516	Herkimer	F0	cool
6- 9-90	1	2100-2103	Delaware	F0	warm
6-21-90	1	1630-1645	Delaware	F0	warm
6-29-90	1	1857	Orange	F0	warm
	2	1948-1951	Putnam	F0	
8-10-90	1	1445-1515	Richmond	F0	warm
8-28-90	1	1750	Chautauqua	F0	warm
	2	1815	Cattaraugus	F0	
	3	1820	Schuyler	F2	
	4	1901	Onondaga	F0	
	5	1920	Herkimer	F1	
	6	2030-2033	Albany	F0	
10-13-90	1	1335-1340	Sullivan	F1	cool
10-18-90	1	1838	Rockland	F0	cool
4- 9-91	1	1545	Chautauqua	F0	warm
	2	1615	Erie	F1	
	3	1730	Livingston	F1	
4-30-91	1	1620	Cayuga	F1	cool
5- 1-91	1	1340	Erie	F0	cool
	2	1415	Wyoming	F1	
	3	1845	Fulton	F1	
6-12-91	1	1510	Westchester	F0	warm
5- 2-92	1	1510	Chenango	F0	cool
	2	1510-1515	Chenango	F1	
	3	1605-10	Schoharie	F1	
	4	1625	Rensselaer	F1	
	5	1625	Rensselaer	F1	
6-24-92	1	1630-35	Montgomery	F1	warm
7- 5-92	1	1400	Fulton	F0	warm
	2	1415	Fulton	F0	
	3	1440	Saratoga	F0	

	4	1512	Saratoga	F0	
	5	1600	Dutchess	F0	
	6	1600	Otsego	F1	
	7	1800	Cortland	F0	
7-12-92	1	2035	Chautauqua	F2	warm
	2	2110	Erie	F1	
	3	1615	Broome	F1	
7-17-92	1	1700	Cattaraugus	F1	warm
7-31-92	1	1615	Cortland	F1	warm
	2	1910-1945	Dutchess	F1	
8- 4-92	1	1300	Washington	F1	warm
	2	1305	Herkimer	F0	
9 -3-92	1	1425	Oneida	F0	warm
	2	1555	Broome	F1	
	3	1710-1730	Westchester	F0	
	4	1800	Tioga	F0	

Table 2. New York State tornado mean parameters for the 24 cases, for warm and cool season cases (1989-1992).

	(A) All Cases	(B) Warm Cases	(C) Cool Cases	
Number of cases	24	16	8	
Positive Buoyancy(CAPE)	1878	2250	1133	J/kg
Negative Buoyancy	6	5	7	J/kg
Precipitable Water	1.4	1.5	1.2	inches
Bulk Richardson No.	44	56	19	
Lifted Index to 500 mb	-6	-6	-4	
Lifted Index to 300 mb	-5	-6	-2	
Showalter Index	-1	-1	0	
Vertical Totals	26	26	27	
Cross Totals	23	23	22	
Total Totals	49	49	49	
Sweat Index	287	278	305	
K index	30	31	28	
0-6 km mean Wind Direction	231	232	228	degrees
0-6 km mean Wind Speed	30	27	37	kt
Storm motion - Direction	256	258	254	degrees
Speed	34	32	39	kt
0-3 km s-r total Helicity	189	142	284	$(m/s)^2$
0-2 km +s-r Helicity	191	139	296	$(m/s)^2$
0-2 km total shear	7	7	9	10^{-3} s^{-1}
Energy-helicity Index	2.0	2.1	1.8	
Wet Bulb Zero	10442	10569	10188	ft
Maximum Parcel Level	47722	49530	45463	ft
Equilibrium Level	38633	39718	36463	ft
Theta-E Max	343	346	335	K
Maximum Inflow	32	29	37	kt
Maximum Streamwise Vorticity	59	37	104	* 10^{-3} s^{-1}