J3.2 Evaluation and Interpretation of the Supercell Composite and Significant Tornado Parameters at the Storm Prediction Center

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1. INTRODUCTION

The Storm Prediction Center (SPC) is responsible for monitoring environments conducive to severe thunderstorm development. This challenging task is aided by the use of sounding-derived parameters that can focus forecasters' attention on areas at risk from severe thunderstorm hazards. Multiple parameter indices such as the Energy-Helicity Index (Hart and Korotky 1990) have proven useful in identifying environments supportive of supercell thunderstorms. Building on the benefits of such indices, climatological sounding investigations (e.g., Rasmussen and Blanchard 1998, hereafter RB98; Edwards and Thompson 2000, hereafter ET00), as well as detailed examinations of special field project observations (e.g., Markowski et al. 1998, hereafter M98) have helped refine the importance of various moisture, instability, and vertical shear parameters to the supercell and tornado forecast problems. The techniques discussed in this paper are intended to provide guidance to forecasters in their efforts to discriminate operationally between supercell and non-supercell environments, as well as the potential for nontornadic and significant tornadic supercells.

2. SUPERCELL COMPOSITE PARAMETER (SCP)

The supercell composite parameter was developed as part of the SPC mesoscale analysis web page[1]. The SCP was designed to identify areas with supercell potential through a combination of several related parameters. Specifically, the SCP incorporates MUCAPE (CAPE based on the most unstable parcel in lowest 300 mb), 0-3 km storm-relative helicity (SRH, Davies-Jones et al. (1990)), and the denominator of the Bulk Richardson Number (BRN, Weisman and Klemp (1982), Stensrud et al. (1997)). Each component is normalized to supercell "threshold" values based on these previous studies, as well as parameter distributions derived from Thompson et al. (2002; hereafter T02), with the following formulation for the SCP:

$$\mathbf{SCP} = (\mathbf{MUCAPE} / 1000\ \mathrm{J\ kg^{-1}}) * (\mathbf{0\text{-}3\ km\ SRH} / 150\ \mathrm{m^2\ s^{-2}}) * (\mathbf{BRN\ denominator} / 40\ \mathrm{m^2\ s^{-2}})$$

A sounding with 1000 J $\mathrm{kg^{-1}}$ MUCAPE, 150 $\mathrm{m^2\ s^{-2}}$ 0-3 km SRH, and 40 $\mathrm{m^2\ s^{-2}}$ BRN shear term will result in an SCP value of 1. This SCP formulation was applied to the 458 supercell proximity sounding data set of T02 and 75 discrete nonsupercell storms (Fig. 1). SCP values commonly exceeded 1 for supercells, and values less than 1 were common for discrete nonsupercell storms. It is important to note that these statistics apply only to cases with *discrete storms*, not other convective modes.

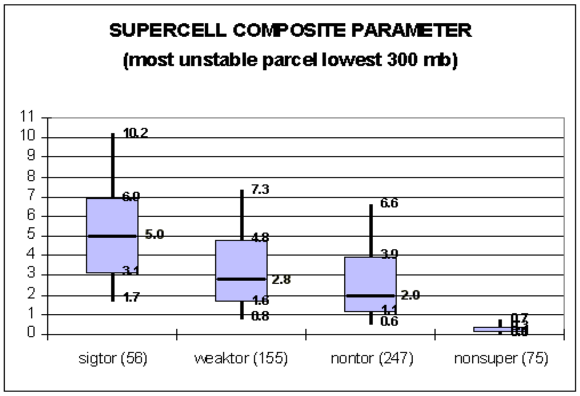

Figure 1. Box and whiskers plot of SCP for F2-F5 tornadic supercells (sigtor), F0-F1 tornadic supercells (weaktor), nontornadic superells (nontor), and a sample of non-supercell discrete storms (number of cases from T02 in parentheses). The shaded boxes represent the middle 50% of the distributions ("box"), and the tops and bottoms of the bars are the 10th and 90th percentiles, respectively ("whiskers"). The horizontal line through each shaded box is the median value for each group of storms.

3. SIGNIFICANT TORNADO PARAMETER (STP)

Numerous studies have identified environmental "ingredients" that appear to favor supercells with significant tornadoes, and the approach used to formulate the SCP has been extended to include several such variables in the STP. The components of the STP have also been calibrated to RUC-2 model analysis close proximity soundings for 533 discrete storms (458 supercells) collected by T02.

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[1] The SPC mesoscale analysis web page can be found at http://www.spc.noaa.gov/exper/mesoanalysis

a. Supercell components:

1. 0-6 km AGL vector shear magnitude. Cloud model simulations by Weisman and Klemp (1982), as well as observational studies by M98, RB98 and Bunkers et al. (2000) all present strong evidence that supercells are most common within environments characterized by 0-6 km shear magnitudes in excess of 20 m s^{-1}. T02 have further refined this guideline shear value for supercells by comparing samples of supercells with non-supercell storms. Within the context of RUC-2 analyses (e.g., the SPC mesoscale analysis web page), the vast majority of supercells occurred where 0-6 km shear magnitudes were 15-20 m s^{-1} or larger. A small sample of storms with marginal supercell characteristics were clustered around 12-17 m s^{-1} 0-6 km shear, and non-supercells were associated with less than 12 m s^{-1} 0-6 km shear.

2. MLCAPE. Lowest 100 mb mean (mixed layer, or 'ML') parcel CAPE, calculated using the virtual temperature correction, is thought to be more representative of boundary layer-based deep convection than single level methods such as MUCAPE. Craven et al. (2002) show that 100 mb mean parcels more closely approximate late afternoon cumulus cloud base height (i.e, lifting condensation level (LCL) height) than surface-based parcels. MLCAPE is less sensitive than surface-based CAPE to both minor surface temperature and dew point fluctuations, and to minor measurement errors at the surface. Therefore, MLCAPE is used as the measure of instability in the STP.

b. Tornado components:

3. 0-1 km SRH. M98, RB98, and ET00 all recognized low-level shear as a strong discriminator between significant tornadic and nontornadic supercells. The authors have expanded the preliminary ET00 investigation to include 458 supercells. A majority of significant supercell tornadoes occurred with 0-1 km SRH in excess of 100 $m^2 s^{-2}$, while SRH values were substantially lower for most nontornadic supercells. The SRH values are based on the storm motion methodology described by Bunkers et al. (2000).

4. ML LCL height. Detailed field observations during project VORTEX, and subsequent field operations, suggest that potential buoyancy within the rear flank downdraft (RFD) is comparable to that of ambient near-surface storm inflow for significant tornadoes, and CAPE is greatly reduced with large CIN in nontornadic RFDs (Markowski et al. 2000). Boundary layer relative humidity has been proposed as a critical factor in modulating RFD CAPE, and this idea is supported by climatological studies such as RB98 and T02 which show significantly lower LCL heights with supercells that produced F2-F5 tornadoes, as compared to nontornadic supercells. T02 found that only one of 56 supercells in their sample produced a significant tornado with a ML LCL height greater than 1750 m, while the majority of values ranged from 750-1250 m.

5. MLCIN. ML CIN is used as a limiting factor in a secondary formulation of the STP. The rationale behind the inclusion of CIN is that the probability of a supercell forming or persisting becomes small as CIN becomes very large. The purpose of CIN in this formulation is to help narrow the spatial threat for surface-based supercells. However, the primary version of the STP, now being calculated as part of the SPC mesoscale analysis web page, displays the MLCIN and STP as separate contour fields.

These five variables are combined in a manner similar to the SCP, with the following formulation for the STP:

$$\mathbf{STP} = (\mathbf{MLCAPE} / 1000\ \mathrm{J\ kg^{-1}}) * (\mathbf{0\text{-}6\ km\ vector\ shear} / 20\ \mathrm{m\ s^{-1}}) * (\mathbf{0\text{-}1\ km\ SRH} / 100\ \mathrm{m^2\ s^{-2}}) * ((2000 - \mathbf{MLLCL}) / 1500\ \mathrm{m}) * ((150 - \mathbf{MLCIN}) / 125\ \mathrm{J\ kg^{-1}})$$

This formulation produces a value of 1 when MLCAPE = 1000 J kg^{-1}, 0-6 km shear = 20 m s^{-1} , 0-1 km SRH = 100 $m^2 s^{-2}$, MLLCL = 500 m, and MLCIN = 25 J kg^{-1}. As any of the CAPE or shear parameters approaches zero, the STP approaches zero. The STP also approaches zero as mean LCL height increases to 2000 m, or CIN increases to 150 J kg^{-1}. The experience of the authors suggests that inclusion of MLCIN is most useful in diagnosing supercell tornado potential prior to storm initiation, whereas mature supercells can persist for several hours after moving into regions of relatively

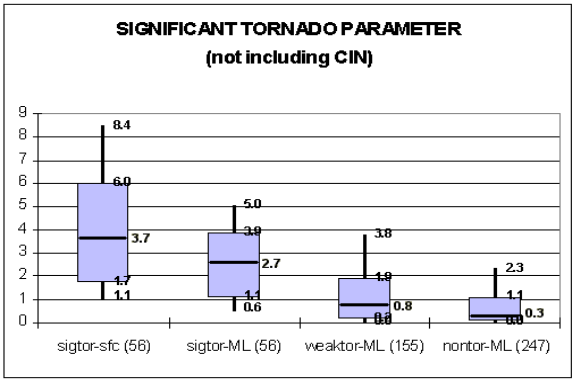


Figure 2. Box and whiskers plot of STP (conventions the same as Fig. 1). "ML" denotes the 100 mb mean parcel, while "sfc" represents the surface parcel.

large MLCIN. Based on the latter, the ability of the STP to discriminate between significant tornadic and nontornadic supercells in the T02 data set improved by excluding MLCIN from the formulation. Also, the specific STP components purposely vary from SCP to reduce the chance of a particular weak or unrepresentative parameter value corrupting both indices simultaneously.

Figure 2 shows the distribution of STP values (without MLCIN) for the groups of 458 supercells in the T02 data set. The STP distributions for significant tornadic and nontornadic supercells are offset by roughly 2 quartiles, and an STP value of 1 appears to be a reasonable guideline to discriminate between significant tornadic and nontornadic supercells.

4. CASE EXAMPLES

The previous section examined STP point values based on RUC-2 analysis soundings. However, the spatial distribution of the STP values is just as valuable to forecasters as single point values, since supercells do not always occur within the relative maxima in the STP. The spatial distribution is especially important in the vicinity of strong gradients, where specific point values may be misleading. The following examples document STP performance for cases with and without significant tornadoes.

a. 16 Dec 2000 - Tuscaloosa, AL F4 tornado

Several clusters of severe storms formed during the late morning and afternoon hours across Mississippi and Alabama. Within these clusters, supercells produced strong tornadoes from northern Alabama to southeastern Alabama. The most significant tornado of the day (F4 damage) struck Tuscaloosa between 18 and 19 UTC, or near the time of Fig 3. The background environment of these storms was characterized by moderate instability (MLCAPE near 1500 J kg^{-1}), and low LCL heights with strong vertical wind shear throughout the troposphere. This combination of parameters resulted in relatively large STP values over a large portion of Mississippi and Alabama, which appeared to be supportive of multiple significant tornadoes.

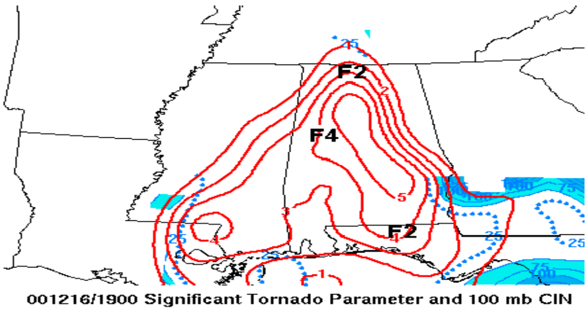


Figure 3. RUC-2 model based objective analysis of STP (heavy solid lines), with MLCIN plotted separately (J kg^{-1}, shaded greater than 50 J kg^{-1}) valid 19 UTC 16 December 2000. Selected F-scale damage ratings are for tornadoes from 18-20 UTC.

b. 9 October 2001 - multiple F3 tornadoes in western Oklahoma and eastern Nebraska

Supercells developed during the early afternoon hours across southwestern Oklahoma, and and during the late afternoon across Kansas and southeastern Nebraska. Hourly objective analyses derived from RUC-2 model analysis soundings revealed an environment of rich low-level moisture, large MLCAPE, and substantial vertical wind shear. The STP parameter (with CIN), as shown in Fig. 4 near the beginning of the tornado episode, correctly focused on a small area of southwestern Oklahoma where two tornadoes produced F3 damage. A secondary relative maximum in Nebraska corresponded to a small cluster of tornadoes, the strongest of which produced F3 damage. Nontornadic supercells occurred in the relative minimum in STP across Kansas, where LCL heights and CIN were somewhat greater than in the tornado areas to the north and south.

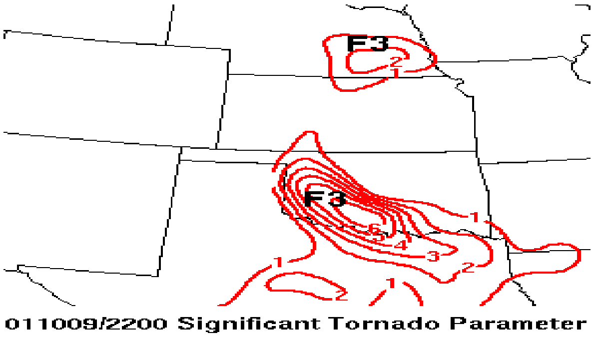


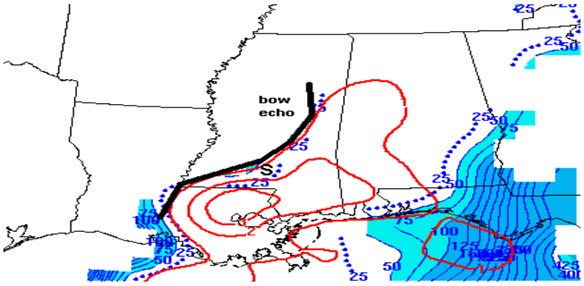
Figure 4. RUC-2 model based objective analysis of STP (including MLCIN) valid 22 UTC 9 October 2001. Selected F-scale damage ratings are for tornadoes from 21-23 UTC.

c. 16 Feb 2001 - Lousiana/Mississippi/Alabama convective mode "failure"

The STP suggested the potential for significant tornadoes in the area from southeastern Louisiana to west central Alabama (Fig. 5). In spite of moderate STP values, no tornadoes were reported across Mississippi, Louisiana, or Alabama.

This case exposes a limitation of the STP - it is predicated on the initiation and persistence of *discrete supercells*. The dominant convective mode on 16

February 2001 was linear as a damaging bow echo raced across central Mississippi and northern Alabama. A supercell (‘S” in Fig. 5) formed in southern Mississippi by early afternoon, but only an hour after initiation this storm encountered the strong cold pool trailing the bow echo, and failed to produce any tornadoes.

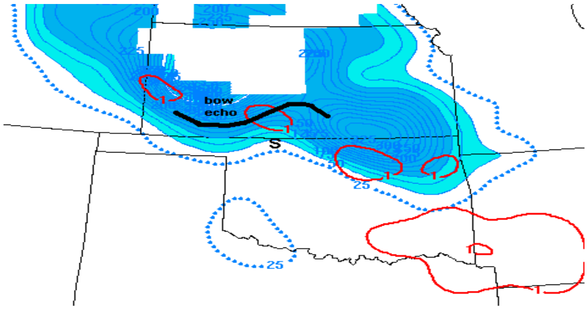


010216/1900 Significant Tornado Parameter and 100 mb CIN

Figure 5. Same as Fig. 3, except for 19 UTC 16 February 2001. The heavy solid curve marks the position of a bow echo, and the ‘S”is the genesis location of a short-lived supercell.

e. 27 May 2001 - Kansas/Oklahoma nontornadic case

A cluster of severe thunderstorms developed across southwestern Kansas during the afternoon of 27 May 2001. These storms evolved into a southeastward moving bow echo, with embedded supercells. Although damaging winds were widespread along the path of this bow echo from southwestern Kansas to southern Oklahoma, no tornadoes were observed during the afternoon or evening across Kansas or northwestern Oklahoma. An isolated nontornadic supercell did persist for two hours near Enid, OK, to the southeast of the bow echo. STP values were generally less than 1 across the area affected (Fig. 6), primarily as a result of only modest low-level shear and relatively high ML LCL heights.



010527/2300 Significant Tornado Parameter and 100 mb CIN

Figure 6. Same as Fig. 5, except for 23 UTC on 27 May 2001.

5. CONCLUSIONS

Results from a statistical analysis of 458 discrete supercells show the supercell composite (SCP) and significant tornado (STP) parameters have the ability to discriminate between supercell and non-supercell storms, and between significant tornadic and nontornadic supercells. However, each parameter can mislead an unwary forecaster in cases where linear convective modes dominate at the expense of discrete supercells. Given our limited understanding of convective initiation and the factors that control convective mode, limiting false alarms will continue to hinge on our ability to produce reliable and accurate forecasts of convective mode(s) and evolution.

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