P12.5

On Low-Level Thermodynamic Parameters Associated with Tornadic and Nontornadic Supercells

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1. Introduction

From recent work by several researchers, it appears that low-level thermodynamic factors are important regarding development of supercell tornadoes. In particular, lifting condensation level (LCL) heights and surface dewpoint depressions suggesting large boundary layer humidity have been shown to be associated with tornadic supercells (Rasmussen and Blanchard 1998, hereafter "RB98") and linked to favorable rear flank downdraft characteristics (Markowski et al. 2002). But less attention has been given to other low-level thermodynamic parameters such as convective inhibition (CIN) and level of free convection (LFC) heights in tornadic and nontornadic supercell cases.

RB98 found that tornadic supercell environments tended to have less CIN than those associated with nontornadic supercells. Also, in simulations involving moderate vertical shear and small to moderate convective available potential energy (CAPE), McCaul and Cohen (2000) and McCaul and Weisman (2001) found that updraft intensity tended to increase when LFC heights were generally lower (between 1.5 and 3.0 km AGL) and buoyancy was increased in low-levels. These results suggest that low-level thermodynamic parameters such as *CIN*, *LFC height*, and *low-level CAPE* (see Fig. 1, reverse-highlighted parameters) may also have relevance regarding tornadic supercell environments. This paper will examine these three parameters using a database of model profiles associated with both tornadic and nontornadic supercells.

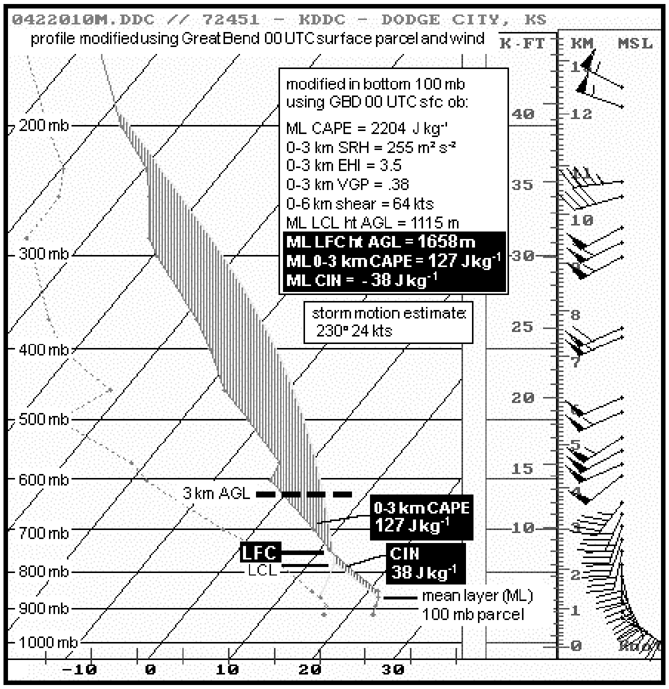

Figure 1. SkewT log*p* diagram of Dodge City, Kansas observed sounding at 00 UTC 4/22/01, modified in lowest 100 mb by Great Bend 00 UTC surface observation. A supercell that later produced an F4 tornado at Hoisington, Kansas, was in progress west of Great Bend (northeast of Dodge City) at this time.

2. Methodology

a. Database

Thompson and Edwards (2000a) have shown Rapid Update Cycle (RUC) profiles to be helpful and timely for estimating and evaluating environments near supercells when actual soundings are not available. The database examined in this study consists of 321 RUC-2 analysis and short-term forecast soundings from 1999, 2000, and 2001 associated with tornadic and nontornadic supercells (see Table 1). Supercells were identified as in Thompson and Edwards (2000b), with 146 profiles obtained from the RUC-2 database that was begun in their study. The other 175 soundings were accumulated independently during 2001. In general, the nearest available RUC-2 grid point in the inflow sector of the supercell was used, within an hour prior to or during the event. Actual observations from nearby surface reporting stations were used to update and modify the boundary layer for these profiles to provide better accuracy (Thompson and Edwards 2000a).

The following method was used to modify the lowest 100-150 mb of the RUC-2 profiles using actual surface observations:

1) If the observed surface temperature was cooler than the model profile, the profile was interpolated in the lowest 50 mb.
2) If the observed surface temperature was warmer than the model profile, or the surface dew point more moist, the lowest 100-150 mb was warmed

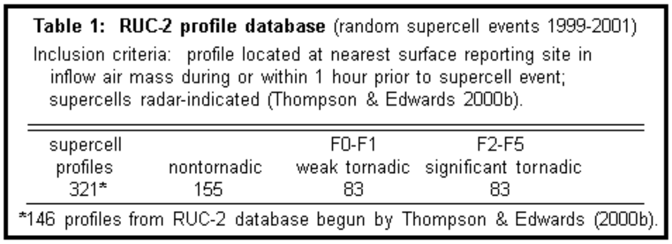

Table 1: RUC-2 profile database (random supercell events 1999-2001)

Inclusion criteria: profile located at nearest surface reporting site in inflow air mass during or within 1 hour prior to supercell event; supercells radar-indicated (Thompson & Edwards 2000b).

supercell profiles	nontornadic	F0-F1 weak tornadic	F2-F5 significant tornadic
321*	155	83	83

*146 profiles from RUC-2 database begun by Thompson & Edwards (2000b).

Table 1. Description of RUC-2 profile database used in this study.

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and interpolated as needed using a depth to allow a surface parcel to have some CIN with the LFC above the LCL.

3) If the observed surface dew point was more moist than the model profile, the moisture profile in the lowest 100 mb was increased accordingly using interpolation.

After working with a variety of profile shapes and environments, this method seemed workable and reasonably realistic in correcting unlikely or unphysical low-level thermodynamic patterns (e.g., LFC below LCL, or LFC on the ground) that resulted when observed surface observations were warmer and/or more moist than model-derived boundary layer data.

b. Computations

For thermodynamic comparisons in convective situations, Doswell and Rasmussen (1994) recommend using the most unstable parcel in the lowest 300 mb. But regarding supercell tornado potential, Markowski et al. (2002) suggest that surface-based or near-surface parcels are most relevant for assessing CAPE and CIN. As “near-surface” parcels for this study, thermodynamic parameters were computed using the *most unstable* of three lifted parcel choices from the *lowest 100 mb*:

(i) A surface parcel.
(ii) A mixed parcel from the lowest 50 mb.
(iii) A mixed parcel from the lowest 100 mb.

Because the virtual temperature correction (Doswell and Rasmussen 1994) is not used in many operational sounding analysis software applications, and resulting sounding analysis examples without the correction are visually more straightforward, results in this short paper will be presented without this correction.

3. Results

a. *Convective inhibition (CIN)*

Convection was ongoing at the time of all profiles in this study. In this context, CIN is viewed to suggest the degree of stable layer near the ground, rather than as a guideline related to potential for convective initiation.

Figure 2 shows distributions of CIN for nontornadic, weak tornadic, and significant tornadic supercell cases from the RUC-2 database. Box and whiskers graph distributions similar to RB98 are used, where the hatched boxes contain the middle 50% of the events, and the median is a horizontal black bar. The vertical bars contain the middle 80% of the events. A signal is present suggesting that CIN associated with tornadic supercell cases tends to be lower than for nontornadic supercell cases, similar to results in RB98.

As noted in RB98, supercells occurring with large CIN are suggestive of “elevated” storms (Colman 1990) that are less likely to produce tornadoes. Numerical simulations by Leslie and Smith (1978) suggest that strong low-level stability (e.g., large CIN) works against generation of intense surface vorticity.

Because strengths of factors that contribute to surface vorticity generation (e.g., boundaries, shear-updraft interactions, etc.) vary greatly between environments, it is difficult to suggest specific CIN values that are “too large” to support tornadoes. In this study, with CIN > 150 J kg^{-1}, only 9 of 44 supercells (20 %) were tornadic, while *no* significant tornadoes occurred with CIN > 160 J kg^{-1}. It then appears that supercells persisting in environments with near-surface CIN larger than roughly 150-200 J kg^{-1} are *least* likely to produce significant tornadoes because of the relatively deep low-level stable layer. From Fig. 2, most supercells that produce significant tornadoes are associated with near-surface CIN values less than 50-100 J kg^{-1}.

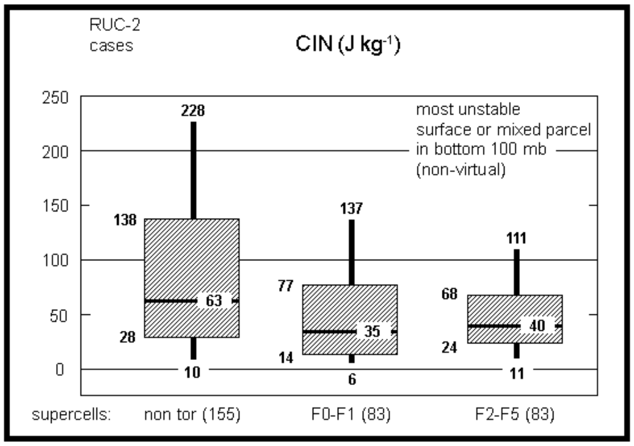

Figure 2. Box and whiskers graphs of CIN (J kg^{-1}) for RUC-2 supercell cases, computed as described in text. Cases are grouped as significant tornadoes (“F2-F5”; right), weak tornadoes (“F0-F1”; middle), and nontornadic (“non tor”; left). Hatched boxes denote 25th to 75th percentiles, with horizontal bar showing median value. Vertical bars above and below boxes extend to the 10th and 90th percentiles.

b. LFC height

Figure 3 shows distributions of LFC heights for the RUC-2 database, suggesting that supercell tornado events tend to be associated with lower LFC heights. Lower LFC heights above ground imply less CIN and more CAPE in low-levels, which may also imply potential for increased low-level accelerations. Most tornadic supercells appear to be associated with LFC heights below 2000-2200 m.

c. Low-level CAPE

Figure 4 shows distributions of 0-3 km CAPE

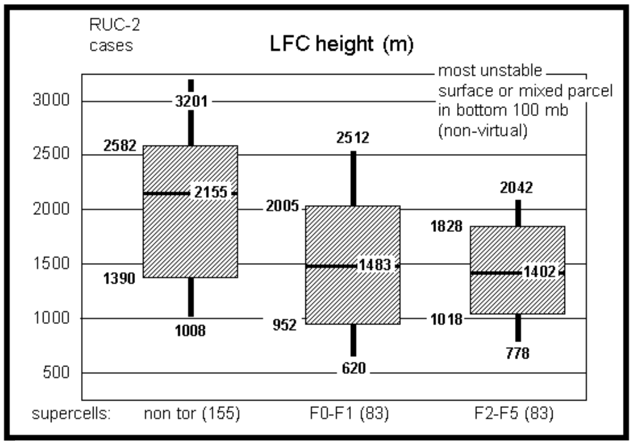

Figure 3. As in Fig. 2, except LFC height above ground (m).

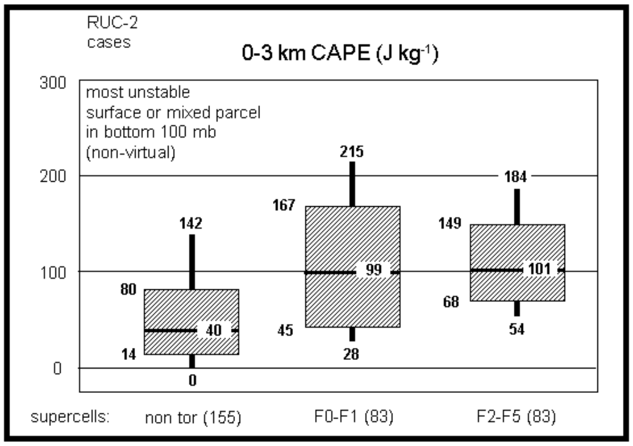

Figure 4. As in Fig. 2, except CAPE below 3 km AGL (J kg^{-1}).

(CAPE$_{0\text{-}3}$) for the RUC-2 database. Although there is some broad scatter in the weak tornado cases, it can be seen that the profiles associated with supercell tornadoes tend to have more low-level CAPE than those associated with nontornadic supercell events. As with lower LFC heights, more CAPE located closer to the ground may suggest potential for significant low-level parcel accelerations and possibly increased low-level stretching.

Thompson et al. (2002, this volume) found less separation in CAPE$_{0\text{-}3}$ values between tornadic and nontornadic supercell cases when using a larger database of RUC-2 profiles. That study did not update or modify profiles using actual surface observations, and used a different lifted parcel methodology, both of which could affect comparisons between the two studies. However, the difference in results may also highlight the sensitivity of low-level CAPE computations to boundary layer conditions and lifted parcel used, suggesting caution in placing much emphasis on such a parameter operationally. The wide range of CAPE$_{0\text{-}3}$ values associated with tornadic supercells in Fig. 4 (ranging from < 50 J kg^{-1} to > 200 J kg^{-1}) does not suggest much discrimination ability when using this parameter apart from other low-level thermodynamic factors and shear characteristics.

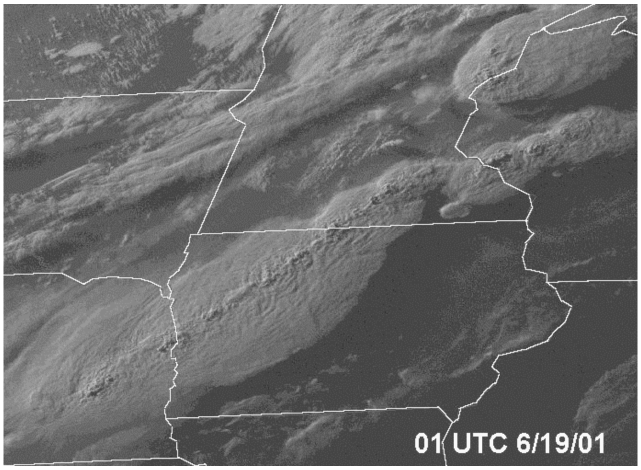

Figure 5. Visible satellite photo at 01 UTC 6/19/01 showing storms ahead of a cold front from Minnesota to Nebraska.

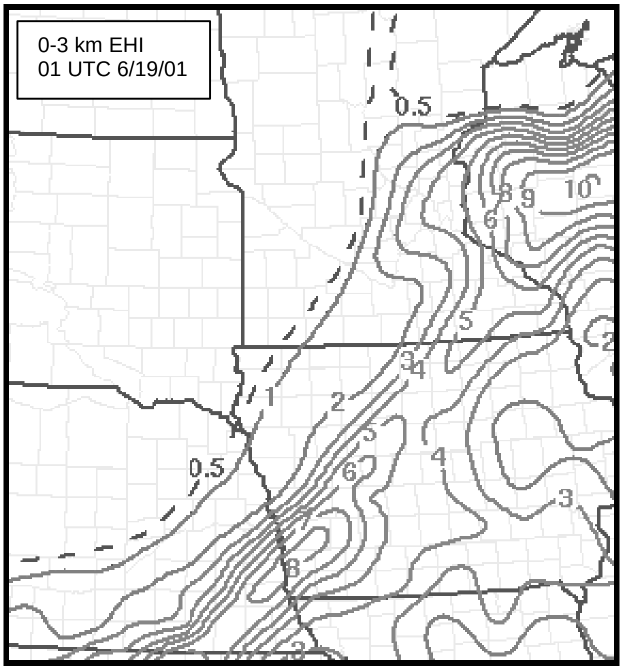

Figure 6. Depiction of 0-3 km EHI at 01 UTC 6/19/01 from Storm Prediction Center (SPC) mesoanalysis page, incorporating RUC-2 data. Courtesy John Hart and SPC.

4. Potential operational use

A look at an event involving thunderstorms and supercells over a large area suggests how low-level thermodynamic parameters from this study might add useful information to accepted shear-CAPE methods in highlighting awareness of increased *potential* for supercell tornadoes.

After 00 UTC on 19 June 2001, scattered thunderstorms (including several supercells) were located over parts of Minnesota, Wisconsin, Iowa and Nebraska ahead of a cold front (Fig. 5). The only significant tornado occurred with a long-lived supercell in northwest Wisconsin (Fig. 7) where 3 people were killed. Figure 6 shows 0-3 km energy-helicity index (EHI, Davies 1993) and Fig. 7 shows LFC heights, both fields generated at the Storm Prediction Center (SPC) using RUC-2 profiles merged with early evening surface observations. EHI was large from Kansas to Wisconsin, suggesting good potential for storm rotation over a broad area of several states. But the lowest LFC heights (< 2000 m) were found in east central Minnesota and northwest Wisconsin. In this case, the lower LFC heights (implying less CIN and more low-level CAPE) appeared to help highlight the general area where a significant long track tornadic supercell occurred in the vicinity of an east-west surface boundary over northwest Wisconsin.

5. Discussion

The data examined in this study suggest that, given shear-CAPE environments favorable for significant supercell thunderstorms, tornadoes are somewhat more likely when smaller CIN, lower LFC heights, and more low-level CAPE are present in the general environment.

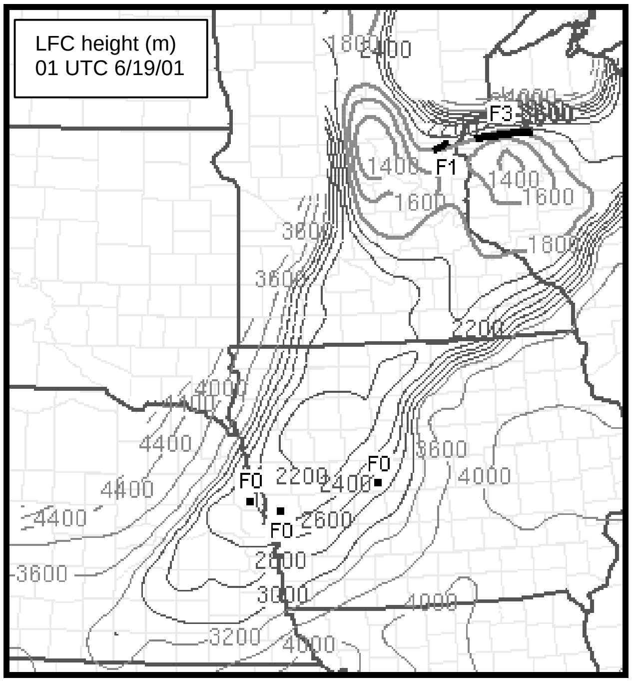

Figure 7. As in Fig. 6, except LFC height (m). Tornado locations and tracks are marked and labeled by intensity.

Perhaps parameters such as CIN, LFC, and low-level CAPE will be most useful in detecting supercell storm environments that are significantly "elevated" with a large stable layer near the ground where significant tornadoes are less likely to occur (see RB98). Such cases can have *favorably low* LCL heights (RB98), but will also have *relatively high* LFC heights and large near-surface CIN. ***A low LCL does not necessarily imply a low LFC***.

In his definition of "elevated" storms, Colman (1990) included only those storms located on the cool side of surface fronts or boundaries. Figure 8 suggests a different kind of "elevated" storm environment – one located *in the warm sector* south of a surface front, with an elevated mixed layer inversion creating the deep stable layer. In the Fig. 8 case, a supercell storm developed west of this "capped" environment, but continued eastward as an intense cell persisting for several hours through an area with large near-surface CIN (> 200 J kg^{-1}). The supercell did not produce any tornadoes, although several tornado warnings were issued based on radar.

Compare Fig. 8 with Fig. 1 earlier showing the environment associated with a supercell on the following evening that produced an F4 tornado. Although the shear-CAPE environments were impressive for both profiles, notice that in Fig. 1 the LFC was more than 1 km *lower*, and that CIN was *less* by more than 150 J kg^{-1}.

Because supercells in "elevated" environments are relatively common, and such environments are not always readily apparent from the synoptic setting (e.g., the case in Fig. 8), examination of low-level thermodynamic fields such as LFC height and near-surface CIN can be useful in detecting such settings. Of 57 supercell cases from the RUC-2 database in this study with LFC height > 2200 m and CIN > 125 J kg^{-1}, only 2 cases (4%) were associated with significant tornadoes, while 48 cases (84%) were associated with no tornadoes at all.

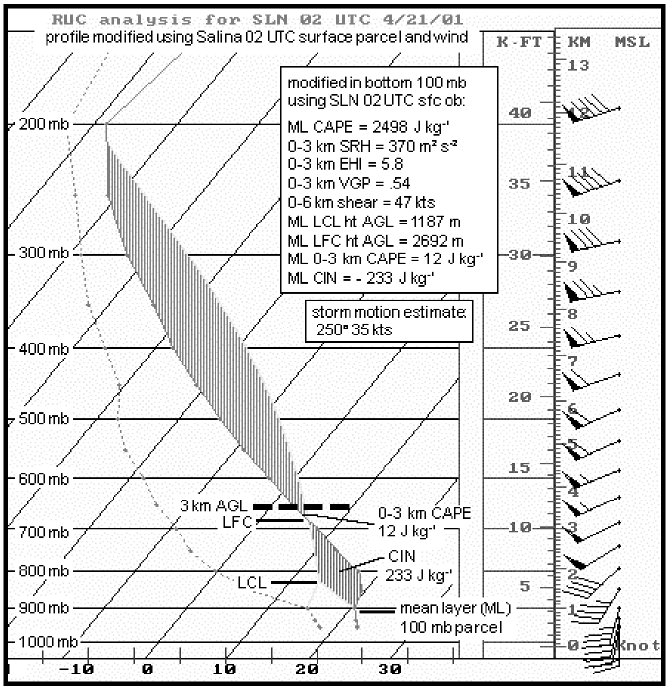

Figure 8. As in Fig. 1, except RUC-2 analysis profile for Salina, Kansas at 02 UTC 4/21/01, modifed in the lowest 100 mb using Salina 02 UTC surface observation. This warm sector "elevated" profile was associated with a long-lived nontornadic supercell.

It should be emphasized that *ongoing* tornadic supercells in an environment with favorable shear-CAPE and low-level thermodynamic characteristics can move into and persist in larger CIN environments with higher LFC heights (e.g., movement into cooler air north of a boundary). In such cases, tornadoes with a strong and mature supercell may continue for a time before the storm becomes significantly "elevated".

Further research is planned regarding detectable low-level thermodynamic characteristics in combination with established parameters assessing wind shear and CAPE in tornado forecast situations.

6. Acknowledgements

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7. Key references

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