NOTES AND CORRESPONDENCE

Comments on "The North Dakota Tornadic Supercells of 18 July 2004: Issues Concerning High LCL Heights and Evapotranspiration"

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1. Introduction

Kellenbenz et al. (2007, hereafter KGD07) present a case study of supercells in eastern North Dakota on 18 July 2004. Three storms occurred,[1] two of which were tornadic, as discussed in the paper. We commend the authors for documenting many aspects of the event. Further, we believe the study could furnish important nuggets of understanding directly relevant to the prediction of violent (≥F4 damage) tornadoes, particularly those heavily dependent on meso-α to meso-β scale processes, as opposed to broader ''synoptically evident'' (Doswell et al. 1993) outbreaks. We fully support the authors' plea for heightened real-time awareness when most environmental parameters support supercell tornadoes, and the exception(s) lurks on the margins of favorability. We also commend the authors for their diagnostic emphasis and, in particular, their subjective hand analysis of the planar data. This practice should be highly encouraged, as it facilitates greater situational understanding, and sets a positive example for operational diagnoses of basic surface and upper-air data (e.g., Sanders and Doswell 1995; Bosart 2003).

By contrast, we dispute some aspects of KGD07 that, collectively, call into question some of its methods, results, and conclusions. From the framework of scientific reproducibility of both background supporting claims and results themselves, we note analytic errors, questionable interpretations, and misleading statements. Overwhelming emphasis is placed upon a storm that spawned a single, violent tornado (rated F4) in Barnes County, North Dakota—focusing intensely on the environmental lifted condensation level (LCL). In doing so, KGD07 uses automated mesoanalysis graphics in a way that appears overstated and misrepresentative of probable environmental conditions. Our concerns further include the lack of uncertainty about representativeness of the data used in several of the analyses and soundings, and of the conclusions drawn therefrom. The singular Barnes County event appears to be somewhat anomalous with regard to the published climatologies of LCL heights and significant [i.e., ≥F2 damage, after Grazulis (1993)] tornadoes, even by our forthcoming reexamination of the KGD07 data; but it probably is not such an outlier as the authors imply. We also have found contradictions and potential errors in the observed and model sounding analyses, along with several other questionable items. These issues are documented in the next section.

2. Major concerns

a. Representativeness and limitations of automated SPC mesoanalyses

To infer the mesoscale environment of the supercell producing an F4 tornado at 0125 UTC 19 July, KGD07 uses archived graphics from the Storm Prediction Center (SPC) Web site containing automated, objective, hourly analyses derived from a gridded Rapid Update Cycle (RUC) model (Benjamin et al. 2004) three-dimensional analysis field, and modulated by available surface aviation routine weather report (METAR) observations (see Bothwell et al. 2002 for details). These mesoanalyses are culled from 0000 UTC 19 July data (their Figs. 2, 9, and 11) and data at 2300 UTC 18 July (their Figs. 15, 16, and 17). From the absence of discussion to the contrary, it appears that the temporal trends of the SPC graphics were not considered, and

[1] Hereafter, we will refer to these as the eastern, middle, and western storms for clarity.

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that their interpolated LCL and other values were taken as essentially unquestioned truth. Despite the many utilities and advantages of SPC mesoanalyses in the operational setting, several deficiencies exist with the approach applied here.

Fundamentally, SPC mesoanalyses represent diagnostic, and not prognostic, fields. Doswell and Schultz (2006) discuss the importance of distinguishing between the two, as well as the sensitivity of derived diagnostic parameters to variations in observed conditions, including the choice of surface observations used in lifted parcels. Therefore, the most useful and representative analyses for examining the event should most closely match in space and time. A tornadic supercell's environment can be assessed concurrently with at least five milestones relative to its life cycle: convective initiation (first tower), thunderstorm formation (first lightning), supercell character (mesocyclone indication), tornadic phase, and dissipation. Given the heavy KGD07 emphasis on the middle storm (see section 2d) and its single tornado occurring around 0125 UTC, and the hourly production interval of SPC mesoanalyses, the most representative usage for such products either would be at 0100 UTC (pretornado) or some blend of 0100 and 0200 UTC data (for the tornadic phase). Yet without apparent justification, KGD07 employs a set of SPC mesoanalyses from earlier hours.

Whether in an operational or research setting, it is critical to evaluate the tendencies in all pertinent parameters, as opposed to basing decisions or conclusions off a single analytic snapshot in time of one parameter. Mesoscale conditions can change considerably in 1–2 h (e.g., Davies-Jones 1993; Markowski et al. 1998b). For example, our reconstructions of KGD07's 2300 UTC Fig. 17 (our Fig. 1a), but valid at 0100 UTC (our Fig. 1b), 25 min prior to the tornado report, indicate less of what KGD07 deem, ''an environment that could enhance low-level stretching beneath cloud bases and within the lower portion of sustained updrafts,'' closer to actual tornadogenesis than at the 2300 UTC time that KGD07 selected. Yet conditions in the actual atmosphere, on some scale,[2] clearly were favorable for significant tornadoes, given an F4 with the middle storm and two F2s with the eastern storm. This apparent conundrum calls into question not only the choice of temporal sampling, but the case-specific utility of mesoanalyses of the chosen fields. Further, parameters with multivariate input,

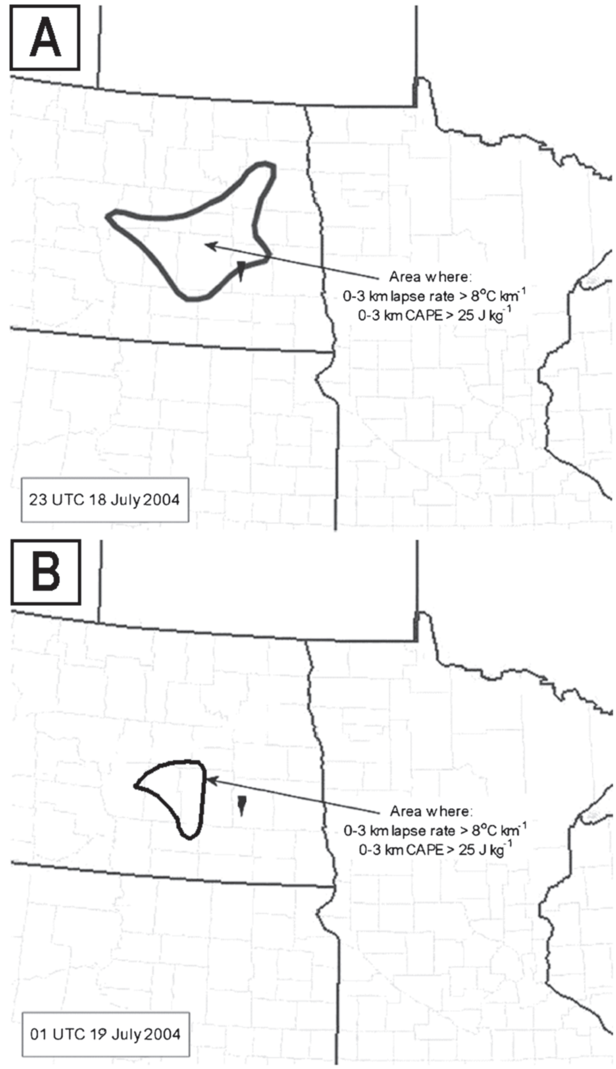


FIG. 1. (a) Reproduction of KGD07's Fig. 17, the area where the 2300 UTC 18 Jul 2004 SPC mesoanalysis of 0–3-km lapse rates $\geq$8°C km^{-1} overlap the 0–3-km CAPE $\geq$25 J kg^{-1}. (b) As in (a) but at 0100 UTC 19 Jul 2004.

such as 0–3-km AGL CAPE, can change due to any or all of the component variables. In this case, it is apparent (though not certain from the data presented) that surface cooling from 2300 to 0100 UTC contributed to the lesser magnitude and spatial extent of both the lapse rate and CAPE in the 3-km AGL layer, thereby shrinking the horizontal juxtaposition of those parameters. Yet the temperature profile above the surface also influences the 0–3-km lapse rate, while moisture strongly affects CAPE. What about those component variables? Such uncertainties, not covered by KGD07, can be important to understanding the evolution of the environment.

KGD07 places a strong and perhaps inordinate emphasis on the mixed layer (ML) LCL, and in particular,

[2] It can be argued that, for a single tornado such as the Barnes County event disproportionately emphasized in KGD07, physical tornadogenesis mechanisms such as stretching are most pertinent on the storm scale, well below the 40-km grid spacing of the SPC mesoanalysis fields, and well below the density of the input surface observational data indicated by KGD07's Fig. 6.

its anomaly with respect to the middle storm and documented climatologies. Objective diagnostic fields utilizing an ML lifted parcel can be quite sensitive to a lack of representative input sounding data above the surface. In Fig. 2 and the text of KGD07, the MLLCL given is for 0000 UTC, using the SPC scheme of modifying the RUC fields based on available surface observations. This brings up several important representativeness issues that will be examined as follows.

MLLCL misleadingly may appear too high because of an overly early sampling time. In the absence of any offsetting drying in the lowest 100 hPa AGL that is not evident in this case, surface diabatic cooling in the ensuing 1–2 h after 0000 UTC would lower the MLLCL. This is apparent in fields (e.g., our Fig. 2) that we reconstructed from the archived SPC mesoanalyses for this event. To their extent of representativeness, the fields indicate the 0000 UTC value was within the 1750-m upper bound for significant tornadic storms in Thompson et al. (2003, hereafter T03), and dropped below 1500 m between 0100 and 0200 UTC when the Barnes County event occurred. Inserting a ~1400 m MLLCL into the T03 distribution yields a value slightly above their 90th percentile for significant tornadoes, and between the 50th and 75th percentiles for all tornadoes.

How well did the RUC (root of SPC mesoanalyses) and Eta Model (in KGD07's Figs. 13 and 14), whether modified or unmodified, represent the contributing thermodynamic parameters aloft for the MLLCL (temperature, dewpoint, and pressure), as well as at surface? KGD07 offers only superficial discussion of moisture depth issues, especially given the presence of a persistent surface boundary to focus storm initiation, and ignores the possibility of error sources with moisture observations above the ground. The lifted parcel saturation point, or LCL as applied here [see Betts (1982) for a thorough conceptual and physical discussion of the LCL], can be very sensitive to thermodynamic profiles throughout the ML (e.g., 100 hPa AGL as used here), not just at ground level as with a surface-based (SB) parcel. This sensitivity fosters our concerns with the usage of SPC mesoanalysis as well as with the sounding parcel choice and modifications discussed in section 2b below.

KGD07 states, "It is important to note that axes of enhanced moisture along convergence zones can *only* occur when a local moisture source, such as ET, is present." [Italics added for emphasis.] Evapotranspiration (ET) can influence surface moisture enhancement intensely, as noted by the authors, and certainly could have here. We do not dispute that, but instead, challenge the quoted statement's implication that *no other possibilities* besides localized sources exist for enhancing the moisture. In fact, the authors themselves touch briefly

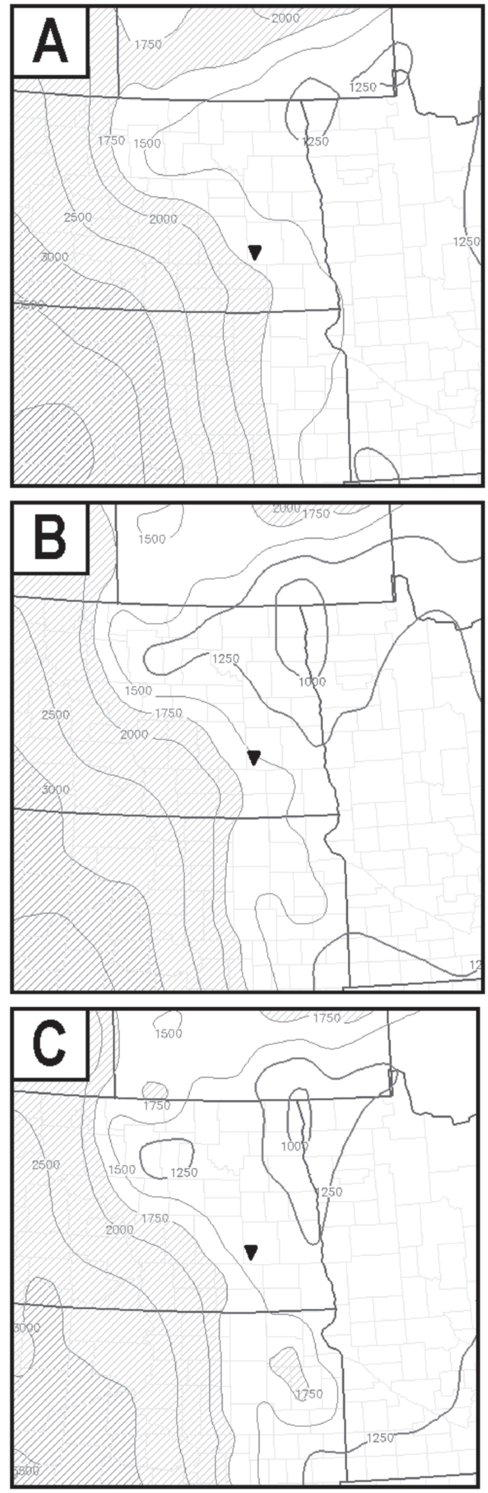


FIG. 2. Monochrome reproduction of operational SPC mesoanalyses of LCL (m AGL) for 18 Jul 2004: (a) 0000, (b) 0100, and (c) 0200 UTC. The location of the Barnes County tornado corresponds to the solid triangle. Shading represents the 1750-m LCL value beyond which significant tornadoes did not occur in the T03 database.

on one such method at the end of their section 3. Apparent concentration of moisture near boundaries [a.k.a. "moisture pooling" after Johns and Hirt (1987)] relates to local variations of vertical moisture fluxes *and* boundary layer mixing heights, each of which may dominate (but not necessarily eliminate) the influence from advection or horizontally differential vertical mixing. In short, while ET can exert the greatest influence on such enhancement, changes in moist layer depth may play *some* part, as may advective processes (which, as the authors note, appear minor to negligible here). The association of increasing moist-layer depth with ascent is described by Banacos and Schultz (2005), who also show that surface moisture flux convergence (MFC) is directly proportional to mass convergence. SPC mesoanalysis graphics (not shown) indicate a persistent MFC axis near the zone of convective initiation. Sustained low-level ascent along this boundary, therefore, may have altered the vertical moisture distribution locally, thus impacting the ML parcel. Such local deepening of the moist layer may have contributed to lower MLLCL heights in the immediate vicinity of the Barnes County supercell. Though the RUC-based SPC graphics only hint at such an occurrence, the relatively coarse horizontal grid spacing of the SPC mesoanalysis fields (40 km; Bothwell et al. 2002) and the presence of a distinct boundary suggest that local variations in the moisture topography are plausible, if not probable. Our modification of an archived 2300 UTC RUC sounding (not shown) farther northeast at Grand Forks, near the boundary and in proximity to the larger, more productively tornadic eastern storm, indicates this process through a much deeper moist boundary layer than that sampled by the authors' Aberdeen, South Dakota, sounding (their Fig. 8).

Given the related difficulty with accurately resolving the horizontal and vertical moisture enrichment or other physical processes, it is risky to rely on small-scale details depicted in the SPC mesoanalysis graphics in situations characterized by a paucity of direct observations. Examples include KGD07's Fig. 6 with the lack of observed thermodynamic data aloft near the boundary, as well as their Fig. 2, where details such as small closed contours and zigzags simply may be artifacts of the objective analysis scheme, in the presence of limited data density. At a minimum, KGD07 should have acknowledged more fully the uncertainties involved with such an approach, as well as the nontrivial potential for considerable error.

b. *Sounding modification methods and representativeness*

Observed (KGD07, Fig. 8) and Eta Model soundings (their Figs. 13 and 14) are analyzed inconsistently with annotated labels on the very same figures, as well as with the main text. Although ML parcels are discussed, the lifted parcel in each graphic clearly uses surface temperature and dewpoints, and not ML values.[3] Analyzing the same observed sounding shown in their Fig. 8, but for a surface-based parcel such as KGD07 actually used, yields an SBCAPE of 4279 J kg^{-1} and an SBLCL of 1156 m. The LCL in this sounding, therefore, is very sensitive to parcel choice, with a difference of over 0.5 km in the LCL height between the true ML parcel and the actual SB parcel used. Since ML and not SB parcels were used by Rasmussen and Blanchard (1998, hereafter RB98), T03, and Craven and Brooks (2004, hereafter CB04), however, values of SBLCL or other SB parameters cannot be directly compared with results from those prior studies.

The Eta Model sounding modification of Fig. 14 also raises questions. Why was only the dewpoint and not the temperature adjusted for the surface observation? Whether for a surface-based lifted parcel or an ML parcel, both temperature and dewpoint influence the LCL, which is the parameter under heaviest scrutiny in KGD07. To produce a more representative[4] parcel than that shown in Fig. 14, we printed and then subjectively hand analyzed the 0100 UTC surface map in Fig. 6 for dewpoint and temperature, every 2°F (not shown). An 88°F isotherm and 71°F intermediate isodrosotherm each cross the tornado path about 25 min later. We then used these values and the same parcel lifting method as was apparent in the KGD07 sounding graphics, for an "apples to apples" comparison. The resultant graphically[5] modified Eta sounding in Figs. 13 and 14 yields an estimated MLLCL (with T_v correction) of ~1400 m

[3] KGD07 do not specify incorporating the virtual temperature (T_v) correction (Doswell and Rasmussen 1994). Visual inspection of their Figs. 8, 13, and 14 indicates not, which would be another critical analytic oversight if true. We have used T_v in our analyses for these comments and it was employed in the T03, Rasmussen and Blanchard (1998), and Craven and Brooks (2004) studies cited by KGD07.

[4] Although arguably beyond the scope of the KGD07 work, we note that even our ML modifications may overestimate surface temperature and LCL in the storm's immediate environment. We strictly use their Fig. 6, whose data resolution is too coarse to account for potential meso-γ-scale effects such as anvil shadowing (Markowski et al. 1998a) that may cool the inflow temperature and lower LCL locally. This is evident in the satellite imagery in Fig. 4 of KGD07, where the eventual tornado location is under heavy shadow by 0045 UTC.

[5] A graphical skew-T technique was applied to KGD07's Figs. 13 and 14 since we did not possess the numerical Eta sounding; therefore, our values are represented as approximations to the nearest kilometer rather than as precise integers. Nonetheless, even at the relative coarseness compelled by such analysis, our contentions regarding the choice of sounding modification technique and its impact on LCL are strongly evident.

AGL. The full modification using thermal and dewpoint values results in an MLLCL near or below 1400 m AGL. The result of correcting both the mistaken lifted parcel choice in KGD07 and the failure to modify the surface temperature is a lowered LCL. Compared to findings from previous studies cited in KGD07, the ''corrected'' MLLCL approximation resides in the 50th–75th percentile range for weakly ($\leq$F1 damage) tornadic supercells in Fig. 7 of T03, the 90th–100th percentile range for significant tornadoes in T03, and RB98's 75th–90th percentile range for significant tornadoes. While still somewhat atypical, the revised modification to the Eta indicates the LCL is lower, and therefore less extreme of an anomaly, than is concluded in KGD07. This assumes, of course, that the KGD07 choice of a base sounding itself adequately represents conditions associated with the middle storm. Forecast Eta soundings with the Betts–Miller–Janjić (BMJ; from Janjić 1994) convective parameterization scheme have been shown (Baldwin et al. 2002) to distort the preconvective boundary layer structure. As a result, use of the Eta to ''benchmark'' the local surface environment is questionable (e.g., with surface dewpoint representation).

Examination of the eastern (multiple tornadoes, two significant) and western (nontornadic) storms' apparent surface environments as given in KGD07 indicates lower and higher LCLs, respectively, than for the middle storm, which is consistent with the statistical trends of LCL and tornado production evident in T03's Fig. 7 and in RB98's Fig. 15. KGD07, however, gave LCL and other environmental characteristics associated with the eastern and western storms scant attention, a concern discussed in section 2d below.

Furthermore, the KGD07 (Fig. 14) modification done to the Eta moisture profile above the surface makes two unverifiable assumptions: 1) the dewpoint value remains constant at 800 hPa but moistens substantially at ~850 hPa, resulting in considerable steepening of the isodrosothermal lapse rate only in the intervening ~50 hPa, and 2) the shape of the dewpoint profile is maintained from the ground to 850 hPa, but moistened uniformly. The moisture representativeness uncertainties discussed in section 2a also apply here. What observational information or technique in the literature exists to support this particular mode of modification, along with the accompanying presumption about the vertical moisture profile above the surface? The suppositions that 1) the Eta profile shape is correct and 2) such surface modifications apply to the profile below 800 hPa are highly questionable—especially given poor Eta performance with boundary layer structure in diurnal heating cycles and when BMJ shallow convection activates.

The observed Aberdeen (ABR) sounding (KGD07, Fig. 8) was taken in the ''free'' warm sector, well removed from the apparent convergence boundary with which the Barnes County storm was closely associated. The ABR sounding was characterized by a marked loss of moisture below the 100-hPa AGL threshold depth of the ML calculation. The vertical moisture distribution along the trough and convergence line (Barnes County for the middle storm, extreme eastern North Dakota for the eastern storm) may be deeper, or otherwise substantially different, rendering the representativeness of the ABR sounding uncertain. The dewpoint depression adjustment yields a lower LCL than the ML parcel at ABR. This acknowledges the possible ET role, especially if several days of sustained ET activity upstream contributed more moisture than just that sufficient to maintain high dewpoints in the skin layer. But how much vertical mixing was there? As part of a successor to the T03 study (Thompson et al. 2007), we fortuitously had collected a RUC analysis sounding from Grand Forks, North Dakota, at 2300 UTC, because it was within our proximity criteria (30 min and 40 km) for the initiation of one of the eastern storms, also a ''SigTor'' case, given the F2 ratings of two of its tornadoes. To the degree that the RUC sounding was representative,[6] a much deeper moist layer may have existed, extending well above 100 hPa AGL. Modification of the ABR sounding for a deeper moist layer such as on the RUC sounding, and which was quite probable elsewhere along the boundary including Barnes County, lowers the LCL by varying magnitudes (not shown), depending on the lifted parcel choice and chosen dewpoint values through the mixed 100-hPa AGL layer.

c. *Misapplications of previous studies*

RB98, T03, and CB04 utilize independent proximity sounding samples. LCL height distributions from these studies reveal 90th percentile MLLCL values of ~1300–1600 m AGL for significant tornado cases. Still, 10% of the significant tornadic supercells occurred with MLLCL heights greater than ~1300–1600 m AGL. The MLLCL height in the 18 July 2004 North Dakota case appeared to be roughly 1400–1500 m AGL, based on the hourly 0100–0200 UTC mesoanalyses bracketing the tornado time.

The authors seem to suggest a deterministic view of the distributions, as if significant tornadoes have not

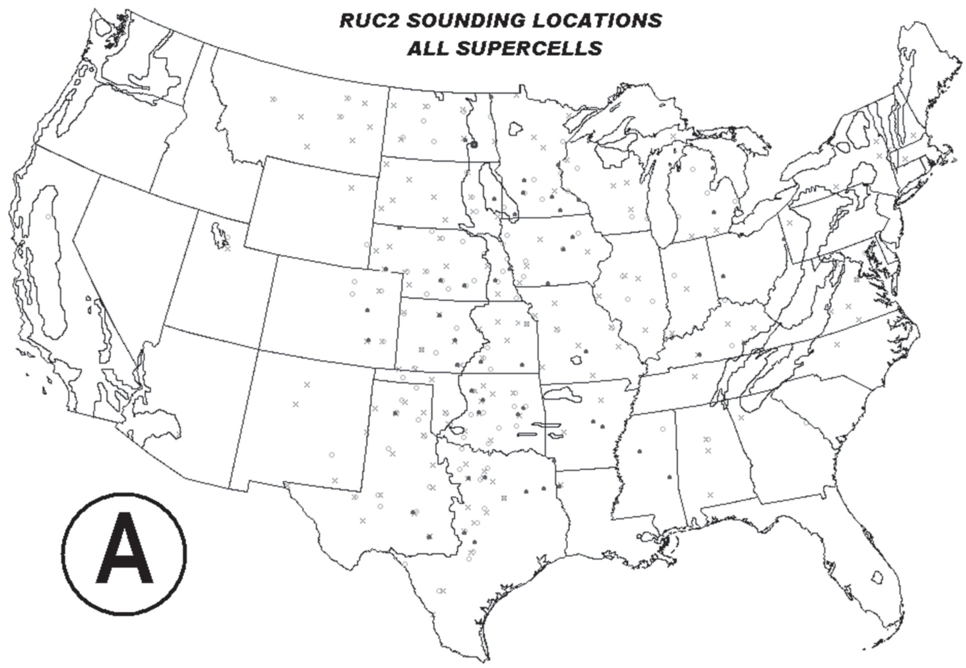
[6] This RUC sounding was much closer in space and time to its associated (eastern) storm and to the boundary than the ABR sounding was to Barnes County (middle storm).

occurred previously with higher LCL heights. The aforementioned studies and results from Davies (2006) indicate otherwise. We suggest that a probabilistic approach to the assessment of LCL for tornado potential is more appropriate. Significant tornado chances diminish noticeably as the MLLCL height increases from roughly 1500 to 2000 m AGL, but consensus probabilities from the cited studies do not approach zero until after values exceed ~2000 m AGL. However, assigning specific probabilities to the diagnostic or prognostic utility of a parameter is exceedingly difficult using a singular event, rendering any parametric generalizations that can be drawn from this case as dubious, at best. Also, LCL height is not meant to suggest the damage rating that can be achieved by any given individual tornado in a regime, as the authors inferred in their brief comparison of the tornado production between the middle and eastern supercells in their sections 2 and 6. Instead, the use of LCL heights is better suited to providing information about the conditional probability that an environment can support significant tornadoes. See section 2d for more discussion thereon.

In their conclusions, KGD07 state, "It should be emphasized that prior studies regarding tornadoes and LCL heights have been statistical in nature, and were likely biased toward the eastern United States and lower ground elevations." This is undocumented and overgeneralized. Our perusal of the same studies cited by KGD07 indicates that the eastern U.S. bias claims vary from weak to nebulous, speculative, or completely false, depending on the reference; the authors also provided no evidence whatsoever of a statistical bias in those studies. In T03, for example, although more of the cases strictly are below the 450-m topographic contour that underlies the path of the Barnes County tornado (our Fig. 3a), the majority are in the Great Plains states at comparable elevations. This partly is a function of the geography of tornadic supercells during the T03 sampling period, and partly because of a software problem described in T03 that forced the omission of soundings with a surface pressure ≥1000 hPa, mainly near the Gulf and Atlantic coasts. No "eastern" bias is evident whatsoever in T03; in fact, it is quite the opposite. The great majority of T03 tornadic supercell locations clearly lie in the central United States, west of the Mississippi River, and outside even our relatively broad depiction of the "eastern United States" (Fig. 3b). More compact geographic definitions only would serve to refute the eastern bias claim more resoundingly. Indeed, the Great Plains states from Texas to North Dakota and westward to the eastern edge of the Rocky Mountains contain more cases in T03 than any other similarly sized area of the nation.

As for other cited studies, RB98 do not discuss the geographic distribution of their tornado proximity sounding analyses. Our own independent mapping of their significant tornadoes (all ≥F2 ratings in 1992; not shown) using the SPC database (after Schaefer and Edwards 1999) reveals no eastern U.S. bias given that more such tornadoes occurred west versus east of the Mississippi River. A geographic map of all tornadoes used by CB04 similarly shows no apparent eastern U.S. bias. We further mined the SPC database for only those tornadoes in the 2-month (July–August) averaging period of CB04 corresponding to that within which the KGD07 event occurred (e.g., Fig. 9 in CB04). More occurred east than west of the Mississippi River, but 5 of 34 total significant tornadoes were either inside or within 50 km outside of the North Dakota boundaries. Indeed, in the SPC–CB04 data, no other part of the nation clearly has a *greater* concentration of ≥F2 tornado reports than North Dakota in the same climatologically favorable time period. This hardly amounts to any sort of bias *against* North Dakota events, especially considering the state's lack of population and structures as mentioned by KGD07.

All supercell cases in Markowski et al. (2002, hereafter M02), which supports RB98's conclusions on LCL and tornadoes, were in Great Plains states, mostly on terrain higher than that of the Barnes County tornado. KGD07 writes, "Furthermore, observed surface dewpoint depressions near the Barnes County area were around 10°C, a range suggested to be 'nontornadic' by Markowski et al. (2002) when considering storm inflow and rear-flank downdraft characteristics." This is a misinterpretation of M02 in that KGD07 imposes binary cutoffs on the M02 statistics, then attributes them to the prior study. Instead of asserting that LCL or dewpoint depression differentiates tornadic from nontornadic storms, M02 found that LCL, while the best single predictor of rear-flank downdraft buoyancy, is only tied to about 35%–40% of its variance. Also, M02 mentions that high-LCL supercells still may produce warm rear-flank downdrafts containing mostly large drops and large hail. With higher LCL, rear-flank downdraft buoyancy and likely tornadogenesis probability appear to get more sensitive to the microphysics. The Rasmussen (2003) update to RB98 discusses LCL within the context of the tendency for increasing LCL height with westward extent in the United States, and indicates that even the erroneous KGD07 LCL may not be as anomalous as the latter study implies, the corrected LCL height even less so. Davies and Johns (1993) did not discuss LCL, and only briefly discussed a related parameter (level of free convection) in the separate context of establishing a hypothetical upper bound for computing storm-relative helicity.



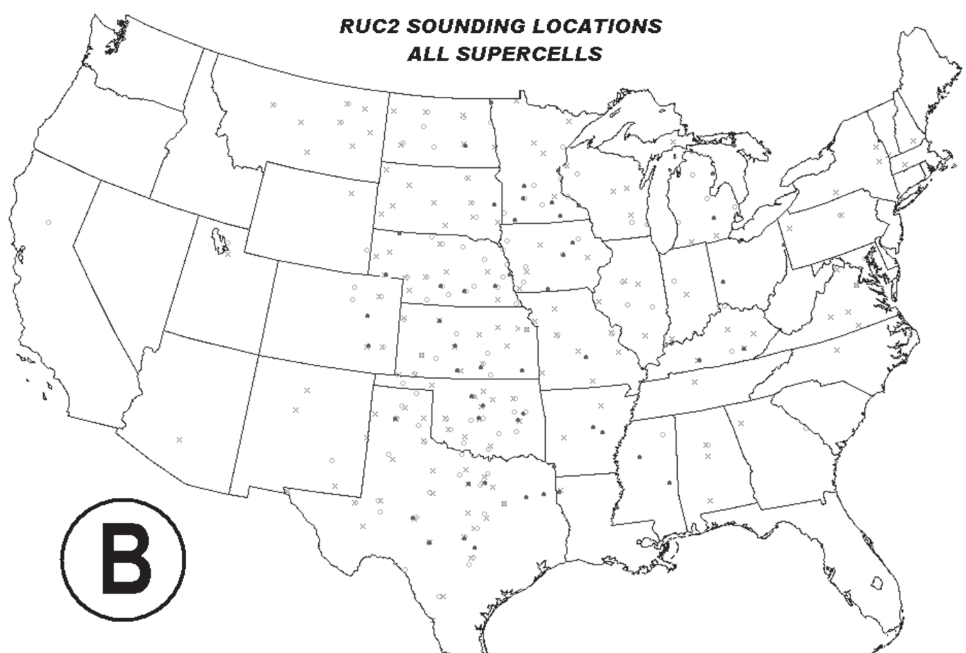


FIG. 3. Copies of Fig. 1a from Thompson et al. (2003), with the addition of (a) shading in areas with ground elevations >450 m MSL for the Barnes County tornado and (b) shading a liberally defined version of the ''eastern United States'' (all states wholly east of the Mississippi River).

d. Emphasis on a single tornadic storm

In a regional supercell and tornado event, the KGD07 focus, almost entirely on the middle supercell that produced a lone F4 tornado, was overly restrictive. Only cursory discussion was made of the most productive tornadic storm, with two significant (F2) and several other tornadoes over a 3-h span, amidst apparently lower LCL and at least comparable ET influence. Why is there is no mention whatsoever of the nontornadic western storm that moved through a drier environment apparently characterized by the highest MLLCL of any of the storms, while producing only a few reports of hail up to 1.75 in. (4.45 cm)? Such unbalanced and limited focus, with important information not considered (e.g., the possibility of a deeper moist layer to the east near the longer-lived and more prolifically tornadic storm, and any assessment at all about the western storm), suggests that a more thorough examination of the data could temper a preferred finding regarding LCL. We suggest that each of the three storms merited more analytic scrutiny than was performed on the middle one, with a comparison and contrasts being drawn concerning their apparent environments and sensible weather reports, along with utilization of the time trends of parameters shown by various cited studies to be related to tornado occurrence in large sample sizes. Therewith, the study would be a far more robust contribution to the literature related to forecasting tornado potential in a regime characterized by mesoscale variability of associative parameters (including, but not limited to, LCL).

Tendencies of LCL and other parameters, distilled from large sample sizes[7] of soundings, have been shown to relate statistically to significant tornadoes (e.g., RB98, T03, CB04). However, damage ''intensity'' of individual, singular tornado events may have little more than associative meaning with apparent environmental parameters, and vice versa. Unfortunately, the authors seem to make a common mistake of casually transposing the terms *damage* and *intensity* with regard to describing and comparing specific tornadoes. In practice, a tornado damage rating is influenced not only by multiscale interactions and often unknown meteorological factors governing vortex intensity at ground level, but by geospatial happenstance and by subjective judgment of the damage assessor. The presence of sufficiently well-built targets in a tornado's path is the major determining factor of tornado ratings (e.g., Doswell and Burgess 1988; Doswell 2007). This is especially true in areas of sparse population and construction, as reinforced by the Barnes County tornado's serendipitous encounter with the farmstead structures in KGD07's Fig. 3 that garnered its F4 designation. Given the irregular and sometimes nebulous relationship between intensity of any given tornado vortex and the damage it may cause, the subjectivity inherent to tornado damage ratings (e.g., Marshall 2002; Edwards 2003; Guyer and Shea 2003), and the possibility that many tornadoes

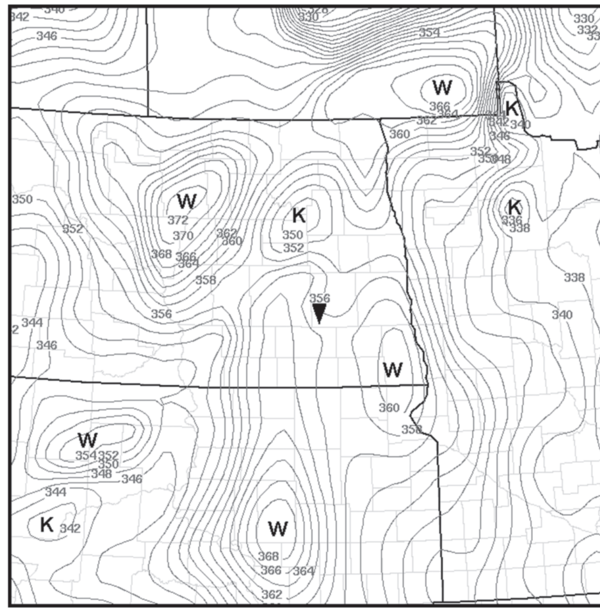


FIG. 4. SPC mesoanalysis of surface θ_e (K, dark gray) from 0100 UTC 19 Jul 2004. Maxima and minima are annotated with a customary thermal W and K, respectively. Location of the Barnes County tornado corresponds to the solid triangle.

historically were rated inappropriately by one or two categories [as discussed by Doswell and Burgess (1988) and Grazulis (1993)], the categorical statement on p. 1211 that the eastern storm ''produced weaker tornadoes'' appears overly certain.

e. *Misplaced or misleading analytic maxima*

In their conclusions, the KGD07 statement, ''the F4 tornadic thunderstorm formed in an area of maximum surface temperature and dewpoints,'' is at least misleading, if not inaccurate, based on the 0100 UTC analysis presented in their own Fig. 6 and the text discussion early in section 3. In that figure, the time chosen for analysis was 0100 UTC, closest to the reported tornado time for conventional surface observations, but not corresponding to the closest hour of storm formation. In fact, there is no specific mention of the genesis time for this supercell in the paper, only for the eastern storm; however, the young maturity of the middle cumulonimbus in the authors' Fig. 4 satellite image indicates it actually developed at least an hour before tornado time. That potentially important temporal discontinuity aside, the 0100 UTC observed thermal maximum evident in KGD07's Fig. 6 over central South Dakota, in particular, missed southwestern Barnes County by at least 300 km. Observed dewpoints were maximized at 73°F at Grand Forks, North Dakota, and Sisseton South Dakota, each ~150 km from southwestern Barnes County;

[7] See Doswell (2007) for an in-depth discussion of the meaning of sample size with regard to tornado occurrence data quality, hypothesis testing, and convincing evidence in support of conclusions.

though our subjectively analyzed isodrosothermal axis (not shown) appears to pass more closely (~70 km) to the east.

The implicit ambiguity of the above-quoted statement also is rather confusing. Did the authors instead intend to express that some combined entity, a function of temperature and moisture such as θ_e, was maximized near the tornado location? If so, that premise is in doubt as well. SPC mesoanalysis of surface θ_e from 0100 UTC (Fig. 4) indicates maxima over extreme southeastern North Dakota, east-central South Dakota, and north-central North Dakota, all removed by >125 km from southwestern Barnes County. The 0000 UTC surface θ_e analysis from SPC (not shown), closer to the apparent time of the supercell's genesis, shows the initiation region to be nearly equidistant from a 351-K minimum ~100 km to the northwest and a 369-K maximum to the southwest.

3. Summary and conclusions

While KGD07 provides insightful information about the mesoscale setting for a northern Great Plains tornado event, we have major concerns with several analytic methods employed by KGD07 and disagree with some of their key results and conclusions. These issues revolve primarily around the representativeness, application, and interpretation of SPC mesoanalysis data and sounding information; contradictory and misstated sounding analysis techniques; the overemphasis on just one of the three storms involved in the regional event; and the weaknesses of the single-event case study approach for drawing broader conclusions about the utility or anomaly of specific environmental parameters. Despite the limitations of singular case studies, important insights into operational tornado prediction can be distilled from an event like this when it is documented and analyzed in a more thorough, fluid, and scientifically rigorous manner, even if the magnitude of its exceptional character may not appear as outstanding as first hypothesized.

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