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EXAMINATION OF THE PRECONVECTIVE ENVIRONMENT ASSOCIATED WITH A SEVERE NONTORNADIC SUPERCELL: VARIATIONS IN CAPE AND SREH

Matthew J. Bunkers*

National Weather Service Office
Rapid City, South Dakota

1. INTRODUCTION

An understanding of the preconvective synoptic and mesoscale environment is fundamental for the operational forecaster to assess the potential for severe thunderstorm development (Doswell 1987; Johns and Doswell 1992). Consideration of sounding parameters such as convective available potential energy (CAPE), the Bulk Richardson Number (BRN), and storm-relative environmental helicity (SREH) provide initial insight into what type of severe weather (if any) is going to occur. As a caveat, one must continually question the representativeness of the "closest" sounding, and make any modifications deemed necessary. Unfortunately, it is very seldom that the operational forecaster has access to a "proximity" sounding (Brooks et al. 1994), which results in the continual need for data extrapolation both temporally and spatially. Burgess (1988) presents an example in which a sounding only 40 km and one-half hour removed from a supercell failed to give proper indication of its environment.

In the following case-study, a severe nontornadic supercell is examined in light of related published research. It was found that the morphology and evolution of this storm was consistent with the scientific community's current understanding of the supercell; however, certain aspects of its development require further investigation. First, as noted in previous studies, even the most subtle temporal and/or spatial changes in various meteorological parameters demand the utmost scrutiny when assessing convective potential. Using the Rapid City (RAP) sounding, this was evident for both the CAPE and SREH, and relates to the previous subject of sounding representativeness and modification. Furthermore, although various meteorological indices have proven useful in convective forecasting, sole reliance on these indices is not warranted (as illustrated by this example), and could potentially lead the forecaster astray. Finally, the influence of topography on convection can play a very important role in its maintenance and evolution, and this premise is examined using a three-dimensional numerical model of the Black Hills.

2. EVOLUTION OF THE SUPERCELL

During the late afternoon and evening of 16 August 1994, a severe nontornadic supercell generated a considerable amount of localized high wind and hail reports

* *Corresponding author address*: Matthew J. Bunkers, National Weather Service, 300 E. Signal Dr., Rapid City, SD 57701-3800; E-mail: mbunkers@nimbus.ias.sdsmt.edu

Table 1. Local storm reports for Tuesday, 16 August 1994, from the RAP National Weather Service (NWS), located at the RADAR site depicted in Figure 1.

Time (mdt)	Location	Local Storm Report
550 PM	50 NW RAP	70-80 mph winds (Large trees down)
558 PM	45 NW RAP	75 mph winds Golfball size hail
602 PM	50 N RAP	60 mph winds Dime size hail
613 PM	40 N RAP	60 mph winds
700 PM	12 N RAP	65 mph winds Golfball size hail (Broke car windows)
710 PM	15 NW RAP	Dime size hail
715 PM	7 W RAP	Dime size hail
800 PM	5 SE RAP	60 mph winds
910 PM	65 SE RAP	70 mph winds
930 PM	65 SE RAP	60-80 mph winds

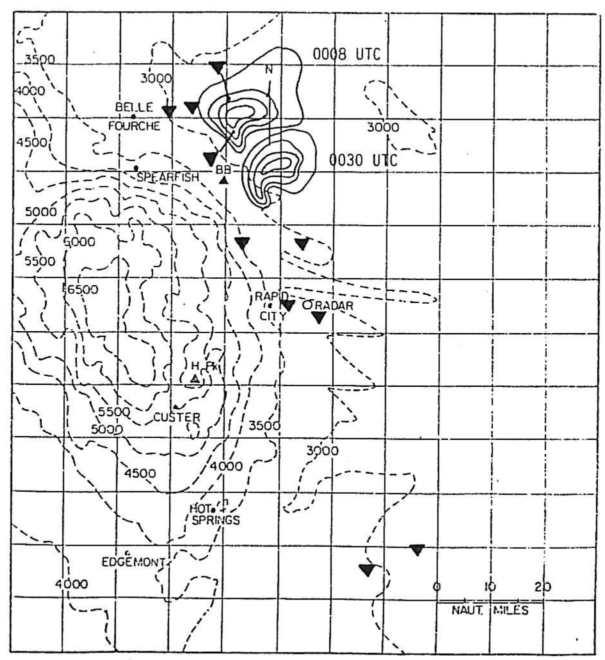

Fig. 1. Composite RAP radar (WSR-74C) overlay of the supercell for 0008 UTC (top) and 0030 UTC (bottom) 17 August 1994. D/VIP levels 2 to 5 are contoured. Triangles indicate locations of storm reports (Table 1). Topography is given in dashed 500 foot intervals, with the Black Hills generally encompassed by the area ≥ 3500 feet.

along the eastern Black Hills in western South Dakota (Table 1, Fig. 1). Radar analysis of this storm revealed that reflectivity characteristics were strikingly similar to the conceptual models of supercell airflow and mesocyclone structure presented by Browning (1964) and Lemon and Doswell (1979), respectively (Fig. 1). Furthermore, the environmental wind shear, in conjunction with the storm's deviant motion to the right of the mean wind, is consistent with three-dimensional numerical modeling studies of splitting thunderstorms (Klemp and Wilhelmson 1978; Wilhelmson and Klemp 1978).

The supercell originated from a multicellular storm system initially exhibiting 12.2 km (40,000 foot) tops as it moved eastward at 8.9 $m \cdot s^{-1}$ (20 mph) across southeastern Montana. Upon entering the plains to the north of the Black Hills in western South Dakota, the radar-indicated (WSR-74C) storm tops grew rapidly to in excess of 15.2 km (50,000 feet). The storm then became more isolated and *accelerated* southeastward along the plains adjoining the eastern Black Hills, and acquired a speed of 15.6 $m \cdot s^{-1}$ (35 mph) (Fig. 1). It was also at this time that the storm took on the characteristic hook shape (Forbes 1981), developed a bounded weak-echo region, and displayed a shift of the maximum radar-echo top toward the low-level inflow notch (Lemon 1980). The supercell eventually evolved into a bow-echo as it moved to the south of RAP. Both visual and radar observations suggested that this was a classic supercell (Doswell et al. 1990).

3. SYNOPTIC CONDITIONS

West-northwest flow was predominant from 700 mb up to the tropopause. Winds were characterized by weak low and mid-level flow (5-15 $m \cdot s^{-1}$), with increasing vertical shear as a 36 $m \cdot s^{-1}$ (70-knot) 300-mb jet-streak was moving into western Wyoming (Fig. 2). An attendant mid-level short-wave trough was moving through eastern Montana and Wyoming, and was most clearly evident in the visible satellite imagery where the trough is delineated by the boundary between the clear skies and convective activity (Fig. 3). [It is also revealed at 300 mb (Fig 2.)]. A broader upper-level trough was located over the Pacific northwest, as is illustrated by the 300 mb wind field (Fig. 2). Western South Dakota was under the influence of the left front quadrant of a 300 mb jet-streak (Fig. 2), which typically is an area characterized by divergence aloft and positive vertical motion (Uccellini 1990). Cold air advection aloft (not shown) and the approaching short-wave/jet-streak were likely providing a more favorable synoptic-scale vertical-motion field with time, increasing the vertical wind shear, and promoting convective destabilization (Doswell 1987).

At 850 mb (not shown), winds were from the south at 5 to 10 $m \cdot s^{-1}$ across the central and southern Plains with neutral to warm temperature advection prevalent over southern South Dakota. Light easterly winds were noted near the Black Hills. Although a low-level jet was not apparent across western South Dakota, the upper-level jet-streak may have been acting to increase the low-level southerly flow through mass adjustment as described by Uccellini (1990).

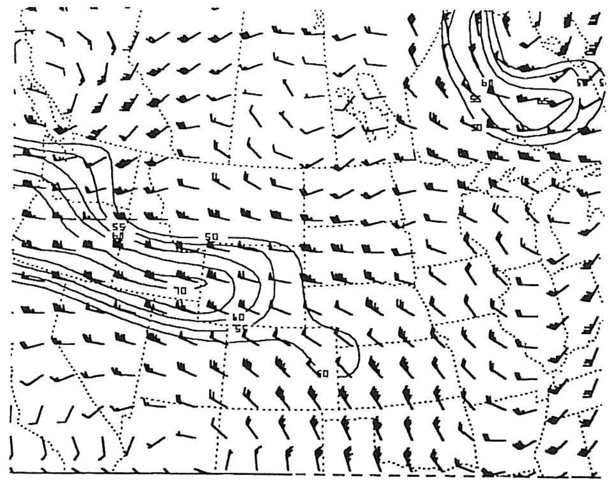

Fig. 2. 0000 UTC 17 August 1994 300 mb analysis of wind speed (≥ 50 knots, solid 5 knot intervals), and conventional wind barbs (knots).

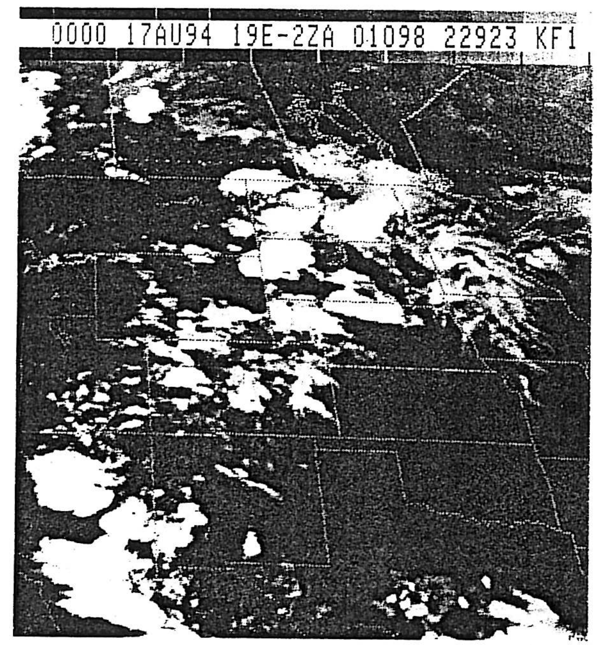

Fig. 3. 0000 UTC 17 August 1994 visible satellite image. The supercell of interest is located under the southern portion of the cloud mass over northwestern South Dakota.

4. OBSERVED AND MODIFIED SOUNDINGS

4.1 Convective available potential energy

The 0000 UTC 17 August 1994 RAP sounding was released two to three hours prior to the supercell passage near the NWS. At the actual time of balloon release (2300 UTC), multicellular thunderstorms were intensifying 60 miles to the northwest of the NWS, with weak convection occurring to the distant southeast. As alluded to earlier, it was during this time that the mesoscale environment was beginning to change quite rapidly. Therefore, one must exercise caution when interpreting this single sounding (and its derived indices), as it likely was not entirely representative of the supercell environment (especially in the lower atmosphere). However, this is a problem faced numerous times by operational forecasters during the course of a severe weather season, and invokes the aforementioned process of sounding modification.

With the above caveat in mind, the RAP sounding indicated moderate instability, wind shear, and moisture (Fig. 4, Table 2). Precipitable water was 0.82 inches, with a dry low-level environment and a relatively moist mid-level. The vertical wind shear was unidirectional (i.e. a straight-line hodograph), changing from east at 12 knots near the surface to westerly at 59 knots near 250 mb (Fig. 4). The BRN was is in the range indicative of supercells (Weisman and Klemp 1986); however, the 0-3 km AGL SREH was only 9 $m^2 \cdot s^{-2}$ (based *a priori* on a storm motion of 296° at 6 knots) (Table 2). The above conditions suggest that thunderstorm development was favorable in the area of concern, and that multicell or supercell storms were possible. Since the SREH was rather low, a question arises concerning the rotational potential of developing storms (Droegemeier et al. 1993). However, these indices should be interpreted with a degree of skepticism. For example, if storm splitting occurred, there would be an increase in streamwise vorticity (i.e. SREH), which in turn would increase the probability for supercells.

Significant differences were noted in the observed CAPE between the surface and mixed-layer parcel methods of SHARP. Nearly 1000 $J \cdot kg^{-1}$ more energy was suggested by the surface-based lifting method (Table 2), which would be enough to sustain vigorous convective development. The smaller value of 227 $J \cdot kg^{-1}$ has been shown to occur with some strong and violent tornado-producing supercells (Johns et al. 1993); however, nearly all of these cases were coincident with strong vertical wind shear. This is characteristic of a strong synoptic system that tends to occur during the cool season. In their study of three mesocyclone-

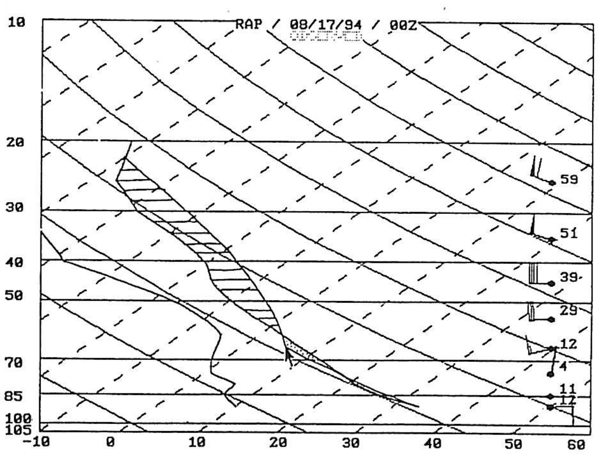

Fig. 4. 0000 UTC 17 August 1994 observed RAP sounding. Using the surface parcel, areas of positive CAPE are hatched, and areas of negative CAPE are dotted. The pointer is directed at the lifting condensation level (LCL).

Table 2. 0000 UTC 17 August 1994 selected sounding parameters for RAP, derived from SHARP (Hart and Korotky 1991).

Surface-Based (Mixed-Layer ≡ lowest 100 mb)	
<u>Observed</u>	<u>Modified</u>
CAPE = 1203 $J \cdot kg^{-1}$ (227 $J \cdot kg^{-1}$)	CAPE = 2071 $J \cdot kg^{-1}$ (799 $J \cdot kg^{-1}$)
LI = -4 (-1)	LI = - 7 (-3)
BRN = 24 (4)	BRN = 32 (12)
CAP = 1.9 °C (3.4 °C)	CAP = 2.4 °C (3.5 °C)
0-3 AGL SREH = 9 $m^2 \cdot s^{-2}$	0-3 AGL SREH = 411 $m^2 \cdot s^{-2}$

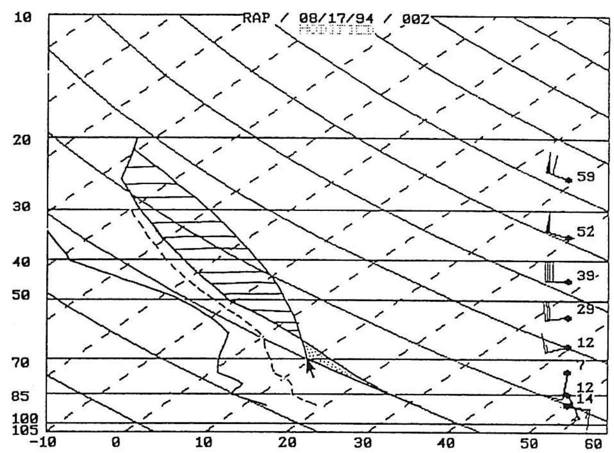

Fig. 5 Same as Figure 4, but for the modified 0100 UTC RAP sounding. Wet-bulb temperature is also plotted with the dashed line.

induced tornadoes, Monteverdi and Quadros (1994) found that the tornadic supercells resulted when the CAPE was measured from 393-552 $J \cdot kg^{-1}$, but the low-level shear was unusually strong and associated with cool-season synoptic disturbances.

Upon modification of the RAP sounding to reflect the changes in low-level winds, moisture, temperature, and storm motion, there was a notable increase in the CAPE (Fig. 5, Table 2). As with the unmodified sounding, there was also a large discrepancy in CAPE between the two lifting methods (over 1200 $J \cdot kg^{-1}$). Since the supercell was moving relatively fast it seems logical that there would not be enough time for "mixing" to occur over a depth of 100 mb, and that the surface air would be the likely source of inflow to the supercell (e. g. Korotky et al. 1993). This was supported as the measured cloud base was 6500 feet AGL, in good agreement with the surface-based LCL. Given the strength and speed of the supercell, the observed cloud base, and the lack of a strong synoptic-scale system, it appears that the surface-based lifting method was most reliable in representing CAPE for this case.

Several things can be noted from the above discussion. First, both modified values of CAPE seem sufficient to support supercell development, even with strong vertical wind shear lacking. Invoking the notion that the interaction between the updraft and sheared flow can produce nonhydrostatic pressure gradients which enhance updraft strength provides even more support for either method

(Weisman and Klemp 1986). Of most significance was the sensitivity of the CAPE to a subtle increase in low-level moisture and the forecast slight cold-air advection aloft. Secondly, it is also possible that the sounding did not adequately sample the supercell environment (e.g. Burgess 1988), which would especially bias the mixed-layer method of computing CAPE. This may at least partially explain the "large" discrepancy between the two methods. Finally, this example shows that one should not place too much weight on any one parameter or index, as it can be misleading.

4.2 *Storm-relative environmental helicity*

Similar to the CAPE, the SREH changed impressively over a very short period of time, owing largely to a change in storm motion. Initially, the observed hodograph was unidirectional (not shown) and the multicellular storm motion was toward the east. This yielded a very small 0-3 km AGL SREH (9 $m^2 \cdot s^{-2}$, Table 2), as little streamwise vorticity was present. With the limited storm inflow and streamwise vorticity, mesocyclone formation was precluded. However, two significant changes occurred as the multicellular storm began evolving into a supercell. First, low-level easterly and southeasterly flow increased in advance of the storm which produced a veering of the vertical wind-shear vector in low-levels (Fig. 6). Second, as the storm motion vector became farther displaced from the hodograph, the storm-relative flow increased (Fig. 6). When taking these two factors into account, the 0-2 km AGL SREH increased to 301 $m^2 \cdot s^{-2}$ and the 0-3 km AGL SREH became 411 $m^2 \cdot s^{-2}$ (Table 2) The deviant storm motion (~ 60-70° to the right of the mean wind) substantially contributed to the supercell inflow (~20 $m \cdot s^{-1}$). The storm inflow, SREH, and BRN (Table 2) were all within the range for that of mesocyclonic storms (Droegemeier et al. 1993). Furthermore, Klemp and Wilhelmson (1978) demonstrate that a clockwise turning of the wind shear vector with height in low-levels favors the development of a cyclonic right-moving storm, which corroborates well with the observations on 16 August 1994.

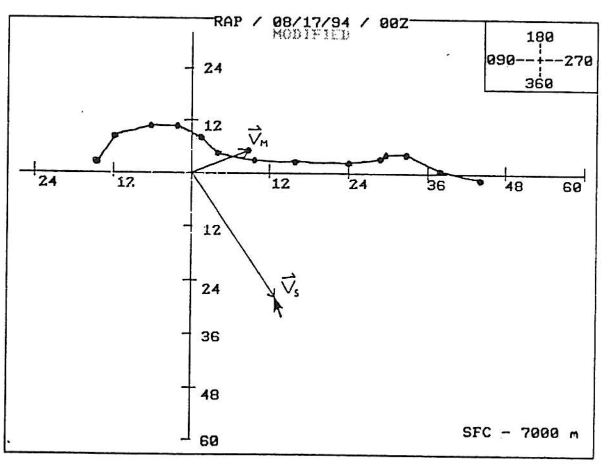

Fig. 6. 0000 UTC 17 August 1994 modified RAP hodograph based on a storm motion of 335° at 30 knots. The 0-6 km mean wind and storm motion vectors are given.

This case clearly demonstrates how important it is, operationally, to continually modify the hodograph for expected/observed storm motion and environmental winds (especially in the low-levels), as helicity can be highly volatile. This premise is advocated by Korotky et al. (1993), who state that it is important to evaluate a range of storm motions that will maximize the low-level shear, inflow, and helicity. By updating the SREH hourly, one can assess the potential for rotating storms, which often lead to severe weather. This alludes to just one of the many valuable functions of the Doppler wind profilers in the Profiler Demonstration Network (e.g. Brooks et al. 1994).

5. MESOSCALE INFLUENCES

The strength and motion of the supercell are believed to have been strongly influenced by various factors acting on the mesoscale. First, an area of weak surface low pressure was noted in southwestern South Dakota (Fig. 7), possibly in response to the upper-level jet (Fig. 2). Due to the flow around this low, moisture was pooling along the eastern Black Hills as dewpoints of 12.8-15.6 °C (55-60 °F) were being advected into the region (Fig. 7). RAP observations from 2200 UTC to 0100 UTC support this as east winds increased by 2.6-5.1 $m \cdot s^{-1}$ (5-10 knots) and dewpoints rose 5.6 °C (10 °F). Second, this destabilization was concomitant with upslope flow along the eastern Black Hills (Fig. 7). The upslope flow was further examined using a three-dimensional, hydrostatic, Eulerian, primitive equation model of the Black Hills (which is a version of the Colorado State University mesoscale model [Pielke 1974, 1984]), also described by Hjelmfelt et al. (1994). The 0000 UTC observed RAP sounding was used as input. Model results suggest that enhanced boundary-layer convergence and upward vertical motion were present along the eastern Black Hills (Fig. 8), which is consistent with other modeling (Hjelmfelt et al. 1994) and observational (Kuo and Orville 1973) studies of the Black Hills. Note that the surface wind

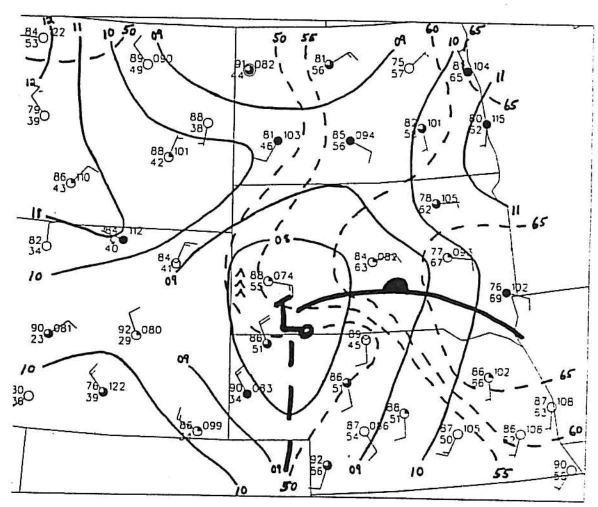

Fig. 7. 0000 UTC 17 August 1994 surface observations for the Northern Plains. Sea-level pressure (1 mb, solid) and dewpoint (5 °F, dashed) are subjectively analyzed.

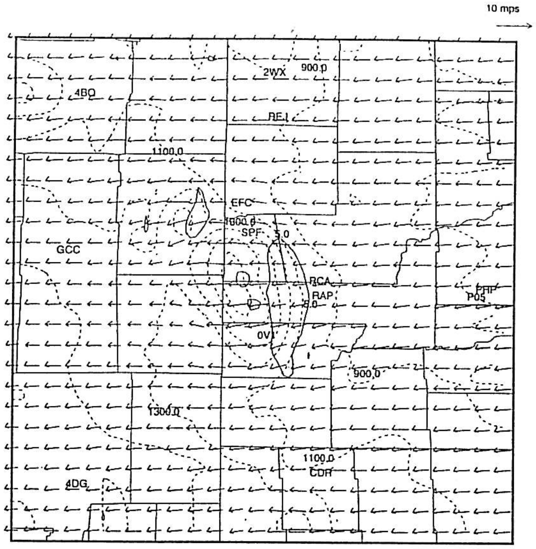

Fig. 8. Model output of surface wind vectors (scaled at top right) and 250 m vertical motion (5 cm·s^{-1}, solid). Topography is given in dashed 200 m intervals.

vectors are directed perpendicular to the Hills with an area of 5 cm·s^{-1} upward vertical motion along the eastern slopes. It was at this time that the supercell was rapidly developing and approaching RAP as it turned sharply to the right of the mean wind (Fig. 1). This degree of turning generally has not been observed with other right-moving storms (e.g. Browning 1964). Therefore, the deviant motion (consisting of both cell movement and propagation) is best explained by the enhanced convergence and moisture advection along the eastern Black Hills. It was not until the storm passed to the south of the Black Hills that it weakened, indicative that the storm was entering a less favorable convective environment.

6. SUMMARY

The synergism of synoptic and mesoscale forcings are believed to be responsible for the nontornadic severe supercell of 16 August 1994. On the synoptic scale, an upper level jet/trough was promoting large-scale ascent and destabilization. On the mesoscale, an increase in the CAPE and SREH (which were ultimately important for the supercell development) appeared to be related to enhanced moisture convergence in the lee of the Black Hills. Instability decreased as moisture was advected along the eastern Black Hills, and upslope flow resulted in enhanced convergence and upward vertical motion as indicated by a three-dimensional numerical model of the Black Hills. These factors led to a storm movement (propagation) significantly to the right of the mean environmental wind.

Although this is just a single case, it underscores the need for the continual monitoring of the (pre-) convective environment in order to ascertain the potential for thunderstorm development. Changes can occur rapidly both spatially and temporally, which can make a seemingly "benign" setting into one that has explosive potential. Furthermore, overdependence on various meteorological indices is unwise. For example, the initial SREH and mixed-layer CAPE gave little indication of supercell development on this day. Therefore one must use these indices with a degree of skepticism, and be prepared to modify the indices based on expected/observed changes in the sounding and mesoscale environment.

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REFERENCES

Brooks, H. E., C. A. Doswell III, and J. Cooper, 1994: On the environments of tornadic and nontornadic mesocyclones. *Wea. Forecasting*, **9**, 606-618.

Browning, K. A., 1964: Airflow and precipitation trajectories within severe local storms which travel to the right of the winds. *J. Atmos. Sci.*, **21**, 634-639.

Burgess, D. W., 1988: The environment of the Edmond, Oklahoma, tornadic storm. Preprints, *15th Conf. on Severe Local Storms*, Baltimore, MD, Amer. Meteor. Soc., 292-295.

Doswell, C. A. III, 1987: The distinction between large-scale and mesoscale contribution to severe convection: A case study example. *Wea. Forecasting*, **2**, 3-16.

____, A. R. Moller, and R. W. Przybylinski, 1990: A unified set of conceptual models for variations on the supercell theme. Preprints, *16th Conf. on Severe Local Storms*, Kananaskis Park, Alberta, Canada, Amer. Meteor. Soc., 40-45.

Droegemeier, K. K., S. M. Lazarus, and R. Davies-Jones, 1993: The influence of helicity on numerically simulated convective storms. *Mon. Wea. Rev.*, **121**, 2005-2029.

Forbes, G. S., 1981: On the reliability of hook echoes as tornado indicators. *Mon. Wea. Rev.*, **109**, 1457-1466.

Hart, J. A., and W. D. Korotky, 1991: The SHARP Workstation - v1.50. A Skew T/Hodograph Analysis and Research Program for the IBM and Compatible PC. User's Manual. NOAA/NWS Forecast Office, Charleston, WV, 62 pp.

Hjelmfelt, M. R., G. Kondrasuk, and D. Priegnitz, 1994: Effects of the Black Hills on mesoscale airflow and precipitation patterns. Preprints, *6th Conf. on Mesoscale Processes*, Portland, OR, Amer. Meteor. Soc., 566-569.

Johns, R. H., and C. A. Doswell III, 1992: Severe local storms forecasting. *Wea. Forecasting*, **7**, 588-612.

____, J. M. Davies, and P. W. Leftwich, 1993: Some wind and instability parameters associated with strong and violent tornadoes. Part II: Variations in the combinations of wind and instability parameters. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards, Geophys. Monogr.*, No. 79, Amer. Geophys. Union, 583-590.

Klemp, J. B., and R. B. Wilhelmson, 1978: Simulations of right- and left-moving storms produced through storm splitting. *J. Atmos. Sci.*, **35**, 1097-1110.

Korotky, W. D., R. W. Przybylinski, and J. A. Hart, 1993: The Plainfield, Illinois, tornado of August 28, 1990: The evolution of synoptic and mesoscale environments. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards, Geophys. Monogr.*, No. 79, Amer. Geophys. Union, 611-624.

Kuo, J-T., and H. D. Orville, 1973: A radar climatology of summertime convective clouds in the Black Hills. *J. Appl. Meteor.*, **12**, 359-368.

Lemon, L. R., and C. A. Doswell III, 1979: Severe thunderstorm evolution and mesocyclone structure as related to tornadogenesis. *Mon. Wea. Rev.*, **107**, 1184-1197.

____, 1980: Severe thunderstorm radar identification techniques and warning criteria. NOAA Tech. Memo., NWS NSSFC-3, Kansas City, MO, 60 pp.

Monteverdi, J. P., and J. Quadros, 1994: Convective and rotational parameters associated with three tornado episodes in northern and central California. *Wea. Forecasting*, **9**, 285-300.

Pielke, R. A., 1974: A three-dimensional numerical model of the sea breezes over south Florida. *Mon. Wea. Rev.*, **102**, 115-139.

____, 1984: *Mesoscale Meteorological Modeling*. Academic Press, New York, 599 pp.

Uccellini, L. W., 1990: The relationship between jet streaks and severe convective storm systems. Preprints, *16th Conf. on Severe Local Storms*, Kananaskis Park, Alberta, Canada, Amer. Meteor. Soc., 121-130.

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, 331-358.

Wilhelmson, R. B., and J. B. Klemp, 1978: A numerical study of storm splitting that leads to long-lived storms. *J. Atmos. Sci.*, **35**, 1974-1986.