Reply

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1. Introduction

We appreciate the efforts that Dr. Doswell has expended in the preparation of both the text and figure components of his comment regarding our note (Kennedy et al. 1993; hereafter given as KWS). Doswell's (1995) comments (referred to here as D95) focus on the following three aspects of KWS: 1) the synoptic setting, 2) the representativeness of the Peoria sounding, and 3) the atypical nature of the tornadic event. We shall address these three issues in order, and we will also seek to identify key viewpoints that we share with Doswell.

2. The synoptic setting

Doswell has correctly identified a data time error in the surface analysis shown as Fig. 1aWS. As he deduced, the valid time for the surface data is 1900 UTC, not 1900 CDT as indicated in our figure. The resultant 5-h time discrepancy compromises the applicability of the KWS surface analysis to the subsequent tornado event.

Doswell's surface analyses highlight the existence of a cool pool that tracked across the southern half of Illinois in association with a large region of convection (D95 Figs. 1 and 3). It should be noted that Doswell's 0000 UTC surface temperature analysis fails to include the Terre Haute, Indiana (HUF), observation. The 20°C temperature reported at HUF alters the extent and shape of the cool pool (Fig. 1a). The corrected cool pool is broken into two smaller areas flanking the warm dry intrusion identified in Fig. 1 of D95. (This intrusion is referred to as "warm, moist" in the text of D95.) As in KWS, the general pattern of a cool-air region retreating eastward from central Illinois is still present.

Using the 1900 UTC surface data, KWS diagnosed a developing warm front across Illinois (KWS Fig. 1a). This feature can still be identified in the same general area across central Illinois at 0000 UTC (Fig. 1b). At both 1900 and 0000 UTC, our frontal positioning was guided by the location of a surface pressure trough. The character of the front was based on the warmer surface temperatures observed in western Illinois and Missouri. Weak warm-air advection was also present at 0000 UTC over these same areas at 850 mb (850-mb temperatures are shown in KWS Fig. 1b). During the 24-h period ending at 1200 UTC 20 May 1989, the PIA radiosonde data showed a consistent 2°C warming in the layer between 940 and 750 mb.

Doswell's surface analyses have emphasized the cool pool generated by convective storms that traversed Illinois during the afternoon hours. The KWS analysis focused on the synoptic-scale warm advection that was spreading into the area from the southwest. Both of these analyses implied that warming at low levels would contribute to airmass destabilization. Doswell identified a "warm, dry intrusion" (Fig. 3, D95) where this thermal destabilization was presumably maximized.

In addition to the presence of a "warm, dry intrusion," Doswell also notes that the Bement tornado occurred within a satellite-depicted "dry slot" (KWS Fig. 2). Since cases of severe weather development within the dry slot have been reported (Carr and Millard 1985), Doswell indicates that this satellite image should have suggested an increased threat of supercell development in eastern Illinois. However, Carr and Millard (1985) found that dry-slot convection develops only under rather specific conditions that act in concert to destabilize the dry-slot environment. A detailed inspection of the dry slot associated with the Bement storm shows that the destabilization processes found by Carr and Millard (1985) were largely inactive: 1) Moisture convergence at the surface, as noted in KWS, was insignificant. 2) Cloudiness restricted surface insolation in the east-central Illinois portion of the dry

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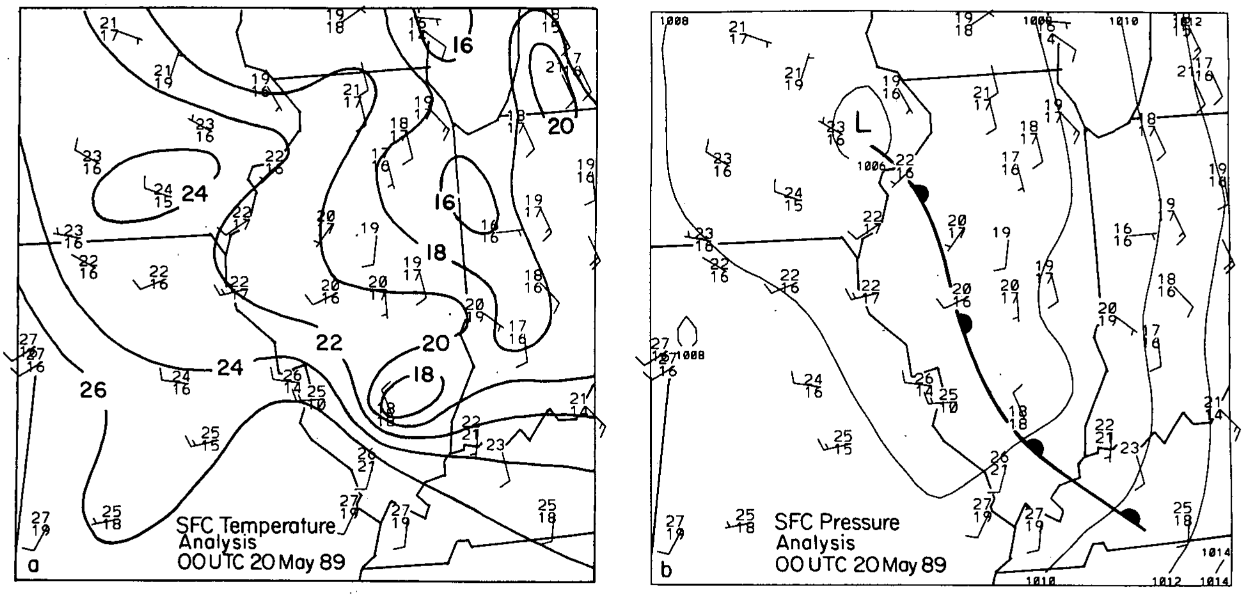

FIG. 1. Surface analyses at 0000 UTC 20 May 1989. At the station locations the temperature is plotted above the dewpoint (°C). Wind speeds are in meters per second, with a long barb indicating 5 m s^{-1}. (a) Temperature analysis. Contours are temperatures in degrees Celsius. (b) Pressure and frontal analysis. Contours are sea level pressures in millibars.

slot until after 1700 CDT; later than the time of maximum solar heating. 3) The low pressure center associated with the comma cloud remained shallow, and its large-scale upward vertical motion field was correspondingly weak. 4) Finally, since the general dry-slot convection observed on 19 May 1989 was not intense and showed no tendency toward linear organization, it is apparent that the destabilization processes outlined by Carr and Millard (1985) were not vigorous.

In summary, both the KWS and D95 postanalyses depict the low-level return of warmer air into the region where the Bement storm developed. Doswell has further isolated a surface intrusion of warm air into the dry-slot region. While Doswell's configuration does suggest that some convective storm development was still possible, the dry slot in the Bement case is not particularly unstable. Overall, the implied potential for severe weather development in east-central Illinois was low. We believe that very few operational forecasters would have categorized the 19 May 1989 environment as ''threatening'' in terms of tornadic potential.

3. The representativeness of the Peoria sounding

As noted in KWS, the applicability of the 0000 UTC Peoria (PIA) sounding to the immediate environment of the tornadic storm was questionable. During the preparation of KWS, we sought additional data with which to characterize the near storm wind field. The Flatland wind profiler, located within 5 km of the tornado track, was not in operation on the night of the storm (W. Clark 1992, personal communication).

The storms that passed during the afternoon hours removed most of the clear air scatterers that would normally be detected by the CHILL radar. Thus, we did not initially attempt to develop a hodograph based on the velocity–azimuth display (VAD) technique (Browning and Wexler 1968). Prompted by D95, the radar data were reexamined. It was found that by 1905 CDT, portions of the upper-level ''blow off'' from the tornadic storm had drifted over the CHILL site (the storm core was at a range of approximately 30 km at this time). The VAD analysis domain was restricted to ranges less than 20 km. While a visual inspection of the radial velocity plan position indicator (PPI) data in this domain did not show any obvious flow disturbances due to storm-top divergence, the presence of such velocity contamination cannot be ruled out. The flow within 2 km of the surface was least impacted by any storm top outflow. The VAD domain contained weak (<25 dBZ), mainly nonprecipitating echo. The azimuthal coverage of this echo remained incomplete, and considerable ground clutter was present at the lower elevation angles.

In an effort to define the near-storm wind profile, the 1905 CDT PPI data were subjected to VAD analysis. During this processing, gates were rejected if their radial velocities were under 1 m s^{-1} (presumed ground clutter). To allow an accurate sine wave fit to the radial velocities observed around a constant range ring, the maximum azimuthal gap between accepted gates was restricted to 90°. Typically, 75–200 gates were available around each of the analysis rings, with the acceptable gate count generally increasing with height. The observed radial velocity azimuthal distribution of these gates generally fell within ±2 m s^{-1} of the modeled sinusoid.

The VAD-based wind profile for the 0–3-km AGL layer is shown in Fig. 2. It is apparent that the winds in this profile are generally from the southwest at speeds mostly less than 10 m s^{-1}.

In both KWS and D95, it was recognized that the observed PIA wind profile required modification to better reflect the tornadic storm environment. The modified hodograph proposed in D95 as well as the "plausible" profile referred to in KWS have also been plotted on Fig. 2. As expected, all three of these hodographs (VAD, D95, and KWS) show wind directions that are backed significantly with respect to the PIA sounding. The profile proposed in D95 contained the strongest low-level southerly wind component.

Doswell correctly states that the storm-relative environmental helicity (SREH, Davies-Jones et al. 1990) implied by his hodograph modification is 144 $m^2 s^{-2}$ for the surface to 3-km AGL layer. The actual storm inflow layer depth certainly varies from case to case (Johns and Doswell 1992). One "standard" for the SREH computational depth is the 0–2-km AGL value used in a characterization of the environments observed near strong tornadoes (Fig. 20 of Johns and Doswell 1992). When the first 2 km of the two proposed hodographs are considered, the SREH value for the Doswell profile falls to 95 $m^2 s^{-2}$, while the plausible hodograph referred to in KWS yields 90 $m^2 s^{-2}$. The SREH from the VAD wind profile is only 37 $m^2 s^{-2}$. Clearly, uncertainties exist in all three of these storm environment hodographs. However, there is no indication that the 0–2-km SREH in the Bement storm environment exceeded 100 $m^2 s^{-2}$.

The second major parameter characterizing the storm environment is the magnitude of the convective available potential energy (CAPE, Weisman and Klemp 1984). Doswell's CAPE evaluation (~1200 J kg^{-1}) relies heavily on the Paducah, Kentucky (PAH), 0000 UTC thermodynamic data (D95 Fig. 6). But the PAH sounding was released ahead of the active squall line that was producing severe weather over western Indiana (KWS Fig. 2). It has long been recognized that the convective processes in squall lines quite rapidly deplete buoyant energy (Fritsch et al. 1976). The existence of the persistent surface cool-air pool identified by Doswell in this case is a direct byproduct of the active release of convective instability in the squall line.

As noted by Doswell, the PAH surface conditions were not accurate reflections of the tornadic storm environment. Thus, the CAPE in the tornado environment was clearly less than the instability implied by the PAH sounding. However, as recognized in both D95 and KWS, the PIA 0000 UTC sounding was also a questionable representation of the tornado environment. The true CAPE value characterizing the tornadic storm probably fell between the overestimate at PAH (1200 J kg^{-1}) and the underestimate at PIA (~350 J kg^{-1}). The selection of a CAPE value from this range is obviously a critical issue. Given that the radar echoes behind the squall line in Illinois did not reach tropopause heights, we continue to believe that it is unlikely that the near-storm CAPE approached 1000 J kg^{-1}.

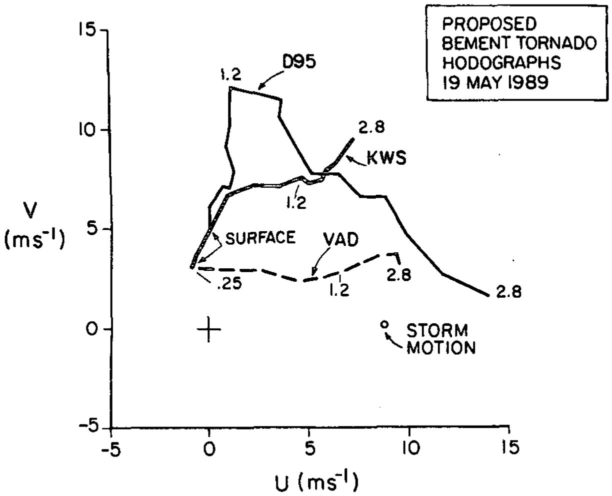

FIG. 2. Proposed Bement tornado environment hodographs. The curve marked "D95' is the wind profile suggested in Doswell's comment. The "KWS" profile is the "plausible" modification of the PIA 0000 UTC sounding referred to in Kennedy et al. (1993). The curve labeled VAD is based on a velocity–azimuth display (Browning and Wexler 1968) analysis of the CHILL volume scan starting at 1905 CDT. Selected heights are marked in kilometers above ground level.

Assuming that the Bement tornado environment is well represented by a CAPE ⩽1000 J kg^{-1} and a 0–2-km SREH of less than 100 $m^2 s^{-2}$, then this storm occurred below the envelope of greater than F2 tornadic environments depicted in Fig. 20 of Johns and Doswell (1993). This result is not unreasonable since the Bement tornado only produced F0–F1 damage. It is not our claim that environmental conditions outside of the Johns and Doswell (1993) envelope are by definition "nontornadic." However, it is apparent that the Bement tornado developed in a relatively low energy environment. Further discussion of the tornado threat level indicated by this storm's setting is included in the following section.

4. The atypical nature of the Bement tornado event

Doswell questions our use of the term "atypical" to describe the Bement tornado event. In particular, this question addresses two specific aspects of the case: 1) the radar and visual appearance of the storm's structure, and 2) the storm's environmental setting. We shall attempt to clarify these two related issues.

As documented in KWS, other than its small size, the echo evolution and visual appearance of the Bement tornado's parent storm exhibited well-known supercell characteristics. But these echo characteristics were not readily discernible unless the radar data were examined at high resolution. Our contention is that in practice, unless a forecaster was somehow motivated to examine the Bement storm echo in detail, its supercell characteristics could readily be overlooked. This would be especially likely if the general threat of severe weather were thought to be low. In this context, we take ''atypical'' to mean that the radar display had to be studied with greater than average effort to recognize the echo's supercell features.

We have characterized the storm environment as ''nonthreatening'' in the sense that the synoptic pattern did not imply a significant tornado threat. As noted in KWS, the guidance information issued by the National Severe Storms Forecast Center (NSSFC) indicated that the tornado threat had essentially ended in Illinois at the time when the Bement tornado developed. It is our belief that the setting in which this tornado occurred was atypical in the sense that many operational forecasters would not have anticipated the development of this tornadic thunderstorm (Moller and Ely 1985). Indeed, as Doswell states in D95 ''the current literature is not obviously helpful in characterizing situations like the Bement storm.''

As Doswell's comment indicates, if the possibility of severe weather development can be anticipated, then the likelihood of its timely detection is enhanced. We concur with this idea. Based upon his postanalysis, it is Doswell's contention that supercell formation was not out of the question on the evening of the Bement tornado. This idea is supported by the fact that a supercell storm structure was observed. But clearly, the evaluation of the severe weather threat depends upon how one chooses to apply the conventional observations to the storm's setting. Although the satellite data showed that the storm developed within a dry slot, little evidence of generalized dry-slot destabilization could be found. Also, Doswell relied heavily on the PAH sounding to characterize the storm environment. Due to the intervening squall line, we believe that use of the PAH sounding is unwarranted and results in a significant overestimate of the supercell potential in the Bement area. As the D95 analyses suggest, additional convective storm development in the wake of the departing squall line was possible. However, we continue to believe that in real time, operational forecasters would be unlikely to sense an important threat of severe weather development. This in no way is meant to discourage operational forecasters from attempting to diagnose the severe weather threat in situations that do not fit classical patterns. The utility of the presentations made in KWS and D95 is increased to the extent that they aid forecasters in identifying situations in which the severe weather threat is subtle.

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