16.6 A PRELIMINARY INVESTIGATION OF SUPERCELL LONGEVITY

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1. INTRODUCTION

Supercells [as originally termed by Browning (1962)] arguably represent the most organized and longest-lived form of isolated deep moist convection. Their longevity derives from both a *persistent rotating updraft* that enhances vertical motion, and an *updraft–downdraft configuration* that generally prevents precipitation from falling through the updraft (Browning 1977; Weisman and Klemp 1986)—both of which, in turn, are dependent on the vertical wind shear.

Not surprisingly, part of the supercell definition includes persistence, namely, that the storm's circulation persists for at least 30–45 minutes (Moller et al. 1994). In some cases, a supercell may persist in a quasi-steady manner for several hours, and in extreme cases, the lifetime of a supercell may extend well beyond 4–5 hours (e.g., Paul 1973; Browning and Foote 1976; Warner 1976). These long-lived supercells can produce significant severe weather along the majority of their paths, and on occasion, they generate a devastating combination of large hail and damaging winds (e.g., Klimowski et al. 1998).

Since these longest-lived supercells are relatively rare, anticipating them in advance presents a perplexing forecasting challenge. Although modeling studies have shown a potential relationship between vertical wind shear and supercell longevity (Weisman and Klemp 1982; Droegemeier et al. 1993, 1996; Gilmore and Wicker 1998; Bluestein and Weisman 2000), observational documentation of this is generally lacking. Furthermore, other modeling studies have shown that the lifted condensation level (LCL) height may be related to supercell longevity (e.g., McCaul and Cohen 2000), but again little observational documentation exists to support or refute this claim. Other factors, such as boundaries and storm mergers, may also act to either enhance or limit the lifetime of a supercell. No solid relationships have emerged from the above studies, which leaves unsolved the problem of why some supercells persist for several hours.

In the current study, we present preliminary findings from an investigation of supercells that persisted in a quasi-steady manner for greater than 4 h. Specific attention was given to sounding parameters as well as the large-scale environment. For comparison purposes, we also examined shorter-lived supercells to determine if the environmental signals were the same or different from their longer-lived counterparts.

2. DATA AND METHODS

Several data sources were utilized in order to gather samples of our arbitrarily defined long-lived (> 4 h) and short-lived (< 2 h) supercells. [Those supercell events which had mean lifetimes between 2 and 4 h were not the focus of this study.] First, a literature search produced five cases of long-lived supercells (Paul 1973; Browning and Foote 1976; Warner 1976; Wade 1982; Pence and Peters 2000). We required clear graphical and/or written evidence of supercells that persisted for > 4 h in these documents. For example, the Lahoma, OK supercell (Conway et al. 1996) was not considered long-lived because it was unclear whether or not the supercell persisted for > 4 h *before* it evolved into a bow echo. Therefore, if there was any doubt whether or not a supercell's lifetime exceeded 4 h, the case was discarded, even though the supercell may have become a bow echo with a total *storm* lifetime (supercell plus bow echo) much greater than 4 h.

The primary source of supercells came from radar data that were archived by the authors from previous studies across the northern High Plains (NHP) (Klimowski and Hjelmfelt 1998; Bunkers et al. 2000). These data were reviewed for both long- and short-lived supercells, and they have been updated with supercell events collected from 2000 to 2002. Furthermore, radar data were also collected (as described in the next paragraph) for long-lived events across the United States that were observed in near-realtime. The average lifetime of all supercells was used to determine if an event was short-lived. For example, if three supercells occurred near a sounding with lifetimes of 1.0, 1.5, and 2.5 h, this was included as a short-lived supercell event since the average lifetime of all storms was 1.67 h (this occurred on three occasions). Additionally, left-moving supercells were not considered for the short-lived cases.

Lastly, the historical severe weather report database was interrogated [using the software of Hart and Janish (1999)] to graphically examine spatial and temporal characteristics of severe storm reports from 1996 to 2000 across the United States. If there was a consistent progression of relatively isolated reports on a given day (suggestive of a long-lived supercell), 2-km resolution 0.5-degree mosaic radar data for the United States were then acquired from the Cooperative Program for Operational Meteorology, Education and Training (COMET) archive of the Weather Surveillance Radar-1988 Doppler (WSR-88D). These data were subsequently examined for the presence of long-lived supercells, and some short-lived supercells were also acquired. For the archived radar data in which velocity data were not available (mainly the 2-km mosaic data), the determination of a supercell was based either on prior documentation (see previous paragraph), or else well-known reflectivity characteristics (i.e., hook echo, inflow notches, tight reflectivity gradient on inflow side, deviant motion).

Observed soundings were obtained for both the long- and short-lived supercell events, with the requirement that the radiosonde was released ahead of, or along, the supercell's path, and that it was within 4 h of the event. For the soundings that were furthest in space/time from the supercell event, surface data in the vicinity of the storm were used to modify the sounding. Due to the unavailability of observed soundings in some instances (i.e., the storm was not close in time/space to a sounding site), Rapid Update Cycle (RUC) analysis soundings were utilized for four of the supercell cases. Finally, synoptic-scale maps at either 1200 or 0000 UTC were analyzed to determine the presence of fronts, instability axes, and lines of forcing; however, only a portion of these data have been analyzed at the time of this writing.

3. RESULTS

3.1 *Observations of the long-lived supercells*

Based on the preliminary data, most of the long-lived supercells tracked to the east or southeast (Fig. 1). There was a bias toward a southeast direction over the NHP (where most

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of the cases have been collected), although the data are too limited to assert that this is a common feature of long-lived supercells in general. The fact that there were only six storms with a northerly component to their motion, and none with a northeast to north component, is intriguing. No long-lived supercells have been discovered in the mountainous western United States, but some have occurred as far north as Alberta and Saskatchewan. Also of interest, there were no long-lived left-moving supercells in the dataset (although there were a few noted with lifespans of 2–3 h).

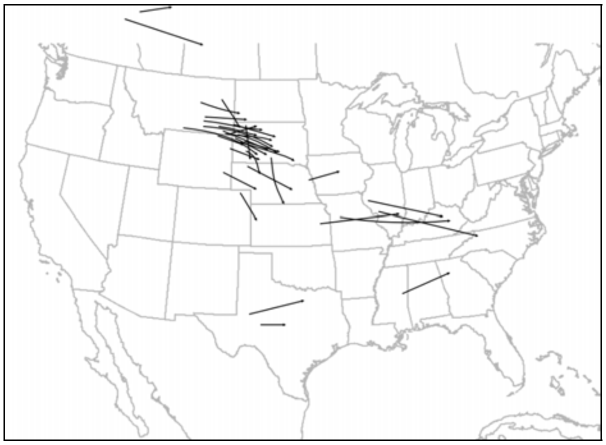

Fig. 1. Storm tracks for supercells that persisted for > 4 h. The tracks were plotted by following the centroid of the storm on the 0.5-degree reflectivity images. The tip of the arrow indicates where the supercell ended.

An examination of the radar data revealed that most (88%) of the long-lived supercells were quite isolated, and on several occasions, there were no other storms within 100–200 km. In a few instances, there were two or three distinct long-lived supercells in relatively close proximity for a majority of their lifetimes. It was common to observe the supercells transition from CL to HP, consistent with the findings of Moller et al. (1994). About one-third of the supercells experienced a cycling or regeneration in which a new mesocyclone developed within the same storm, or the storm experienced some discrete development (Browning 1977; Burgess et al. 1982). This appears to be a relatively common feature of these longer-lived storms.

The hourly distribution of the long-lived supercell occurrences matched very closely to the diurnal cycle of convection, with a peak occurrence at 0100 UTC and a minimum at 1100 UTC. The average beginning time of the long-lived supercells was 2200 UTC, typically lasting 6.5 h until 0430 UTC. But in a few cases, there were long-lived elevated supercells that persisted well past 0600 UTC.

Severe hail (≥ 1.9 cm) was common to all of the long-lived supercells, with many of them producing large hail along a substantial portion of their path. The severe hail was accompanied by severe wind (≥ 26 m s^{-1}) in 75% of the cases, sometimes producing extensive damage (e.g., Klimowski et al. 1998). Fifty-eight percent of these storms produced tornadoes, although only 10% of them were significant tornadoes (F2 or greater). It is suspected that this higher percentage of tornado occurrence with the long-lived supercells is due, in part, to the greater likelihood of these storms interacting with a favorable environment because of their longevity.

About 70% of the long-lived supercells simply weakened or dissipated at the end of their lifetime. This may have been due to the storms traveling into a less favorable environment (e.g., more stable air mass), or perhaps the storm's outflow eventually undercut the updraft. In 20% of the cases, the end of the supercell's lifetime was signaled by a transition into a bow echo (Moller et al. 1994), which may have persisted for a few hours thereafter. The remaining long-lived supercells lost their identity after merging with other thunderstorms.

3.2 *Observations of the short-lived supercells*

By way of contrast, the short-lived supercells were associated with groups of storms much more frequently than the long-lived supercells (about 60% of the time). It may be that their relatively close proximity to other storms potentially limited their lifetime through adjacent storm interactions. The short-lived supercells consisted mostly of CL/HP storms, but identification of the HP storms tended to be more obvious than in the long-lived supercell dataset.

Just because a supercell is short-lived does not mean that the severe weather threat is diminished. In about one-half of these cases, the supercells were observed to evolve into a squall line or bow echo complex, often producing widespread severe winds. Additionally, there was a tendency for the short-lived supercells to be more numerous at any given time and location (when compared to the long-lived supercells). Their tornado production, however, was lower than for their long-lived supercell counterparts, with 34% of the events resulting in tornadoes (only 3% were significant tornadoes).

The demise of the short-lived supercells was equally split between (i) an evolution to an other convective mode (i.e., squall line or bow echo), and (ii) a gradual weakening or dissipation. Adjacent cell interactions played a significant role in the supercell transitions to other convective modes. Only about 10% of the short-lived supercells merged with other storms without evolving further (and thus losing their structure).

It is important to note that both the long- and short-lived supercell datasets are biased toward the NHP, where most of the archived radar data were readily available. The above observations are subject to change as more data are analyzed across the rest of the United States.

3.3 *Environments of the long- and short-lived supercells*

There was a large difference in the vertical wind shear between the long- and short-lived supercells, with much greater shear accompanying the long-lived supercells (Table 1, Fig. 2). The 0–4-km bulk shear for the long-lived supercell composite hodograph is 1.5 times that for the short-lived supercell composite (Table 1), and the 4–8-km shear for the long-lived composite is 2.4 times that for the short-lived composite. In fact, the 4–8-km bulk shear for the long-lived supercell composite hodograph is almost as strong as the 0–4-km bulk shear for the short-lived supercell composite. The stronger shear for the long-lived supercells also leads to double the storm-relative helicity (SRH) (Table 1). Although the 5-km storm-relative wind (SRW) was only slightly stronger for the long-lived supercells, the 8-km SRW was much stronger (20.5 vs. 12.1 m s^{-1}).

Table 1. Shear-related variables obtained from the composite hodographs in Fig. 2. SRH units are m^2 s^{-2}; others are m s^{-1}.

	Long-Lived Supercells	Short-Lived Supercells
0–4-km Bulk	23.1	15.8
4–8-km Bulk	13.5	5.6
0–8-km Bulk	36.6	21.3
0–3-km SRH	267	139
0–1-km SRW	18.1	14.2
0–3-km SRW	12.7	10.8
5–km SRW	11.7	9.5
8–km SRW	20.5	12.1

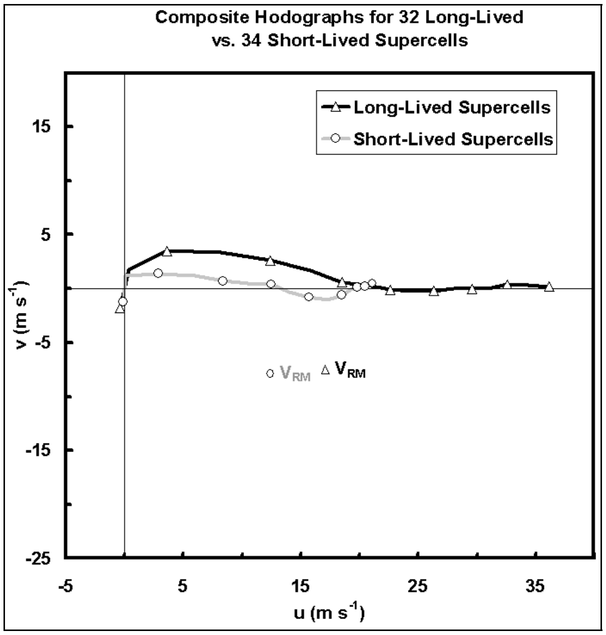

Fig. 2. 0–8-km composite hodographs and storm motions for 32 long-lived (open triangles) and 34 short-lived (open circles) supercells. Wind data are plotted every 500 m AGL, with labeling at 1-km intervals.

The above results are consistent with previous studies. For example, Weisman and Klemp (1982, 1984) found that increasing the vertical wind shear over a relatively deep atmospheric layer has an organizing effect on modeled convection (up to a point were it is detrimental). Gilmore and Wicker (1998) found that stronger midtropospheric winds can promote supercell longevity in the presence of midtropospheric dryness. Droegemeier et al. (1993) suggested that storms forming in environments with large SRH are longer-lived than those in environments exhibiting less SRH. And Brooks et al. (1994) and Rasmussen and Straka (1998) reported that weak mid- to upper-level SRW was associated with more rapidly evolving supercells, and that stronger flows promoted longer-lived storms. Finally, the composite hodograph for the short-lived supercells represents the lower end of the vertical wind shear spectrum for supercell thunderstorms (e.g., Bunkers 2002).

An important question that arises from the above results is whether or not the upper-level shear is more important than the SRH (and hence the low-level shear) in determining supercell longevity. In an attempt to answer this question, contingency tables were constructed for the 4–8-km bulk shear and the 0–3-km SRH. From these tables, it is apparent that the 4–8-km bulk shear performed somewhat better than SRH at indicating the long-lived supercells when compared to the short-lived supercell dataset (Table 2). The 4–8-km bulk shear optimal value of 10 m s^{-1} resulted in a probability of detection (POD) = 83%, false alarm rate (FAR) = 26%, and critical success index (CSI) = 64%. By way of comparison, 21 of the 59 events were misclassified when using the optimal SRH value of 200 m^2 s^{-2}, resulting in a POD = 63%, FAR = 34%, and CSI = 48%.

These results are not surprising when considering the above studies. For example, even with high SRH, if the shear is not strong enough in the mid- to upper-levels, more precipitation falls near the updraft, thus creating a stronger downdraft and enhancing low-level outflow (Brooks et al. 1994; Rasmussen and Straka 1998). Accordingly, the 8-km SRW also did well at discriminating between the long- and short-lived supercells, with only 11 events misclassified using an optimal value of 15 m s^{-1} (Fig. 3). The 0–8-km bulk shear, which incorporates some measure of SRH into its calculation (although it does ignore the turning of the shear vectors), performed better than all of the above measures at 30 m s^{-1}, with a POD = 87%, FAR = 13%, and CSI = 76% (e.g., Fig. 3). In agreement with these observations, Droegemeier et al. (1993) presented modeling results in which the 0–3-km SRH was 200 m^2 s^{-2} for a particular case (*of a circular hodograph*), but the resulting storm displayed multicell/supercell characteristics, and was relatively short-lived. Accordingly, the corresponding 0–8-km bulk shear was 0 m s^{-1}, with an 8-km SRW of 10 m s^{-1}. In summary, the analysis of long-lived supercell wind environments indicates that the wind shear must be sufficiently strong over a relatively deep layer—supporting both strong storm rotation and limited interference between the updraft and downdraft.

Table 2. Contingency tables for long-lived supercells using the a) 4–8-km bulk wind shear with 10 m s^{-1} as a discriminator, and b) 0–3-km SRH with 200 m^2 s^{-2} as a discriminator.

a) 4–8-km bulk shear		Forecast		
		Yes	No	Total
Observed	Yes	25	5	30
	No	9	20	29
	Total	34	25	59

b) 0–3-km SRH		Forecast		
		Yes	No	Total
Observed	Yes	19	11	30
	No	10	19	29
	Total	29	30	59

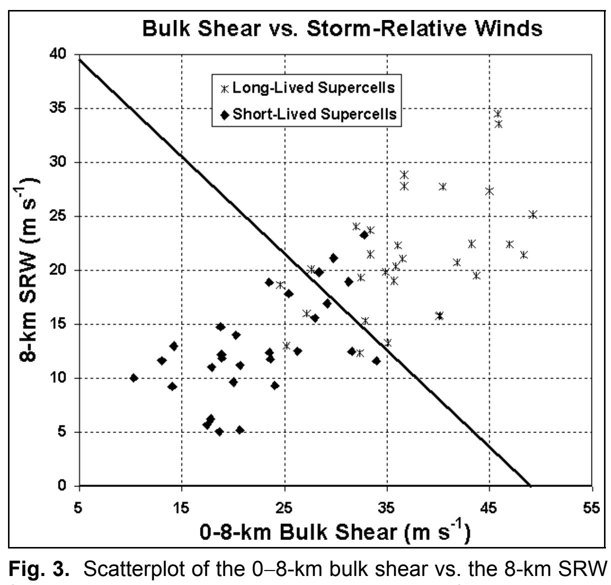

Fig. 3. Scatterplot of the 0–8-km bulk shear vs. the 8-km SRW for the long-lived (asterisks) and short-lived (filled diamonds) supercells. The diagonal line is a suggested partition between the two datasets.

The thermodynamic parameters were not as revealing between the long- and short-lived supercell partitions (Table 3). The best discriminator among these was the bulk Richardson number (BRN)—also dependent upon shear. All but two of the long-lived supercells were associated with a BRN between 5 and 35, which is in very good agreement with Weisman and Klemp (1982, 1984). Some short-lived supercells were also associated with a BRN in this range, but there were also 13 cases with either larger or smaller values.

There was no difference in the mean buoyancy between the two environments, but it is interesting that the average convective inhibition (CIN) was smaller for the long-lived supercell dataset. Consistent with McCaul and Cohen (2000), the LCL and level of free convection (LFC) were lower, on average, in the environments of the long-lived supercells; however, this was not statistically significant.

Table 3. Average thermodynamic properties for the long- and short-lived supercells. The lowest 1000-m mixed layer (ML) was used to determine parcel ascent, applying the virtual temperature correction (Doswell and Rasmussen 1994).

	Long-Lived Supercells	Short-Lived Supercells
MLCAPE	1453 J kg^{-1}	1460 J kg^{-1}
MLCIN	-46.8 J kg^{-1}	-75.0 J kg^{-1}
MLBRN	14	26
MLLCL	1456 m	1686 m
MLLFC	2204 m	2593 m
θ_e Difference	25.3 °C	23.1 °C
RH	55%	55%

3.4 *Environmental and external influences*

Just as important as the vertical wind shear is to supercell longevity, there are a number of other factors which will affect, or limit, the longevity of a storm. Among others, these include (i) an inhomogeneous storm-relative distribution of moisture/instability, (ii) storm motion relative to fronts, dry lines, and short-wave troughs, (iii) thunderstorm outflow boundaries, (iv) topography, and (v) storm mergers.

Of the few cases analyzed in detail, observations suggest that the long-lived supercells had their shear-related motion (Bunkers et al. 2000) somewhat parallel to a moisture/instability axis, or along a boundary. If the shear-related motion was such that there was a significant angle to these features, the storm's lifetime was limited. For example, in some of the cases studied, the vertical wind shear was favorable for long-lived supercells (based on Fig. 3), but their motion was nearly perpendicular to a moisture/instability axis or front, and they dissipated or weakened "prematurely" in a more stable environment. Therefore, it appears that the strength of the deep-layer shear is a necessary, but not sufficient condition for long-lived supercells, and one must additionally forecast if the supercell will remain relatively isolated in a homogeneous region of favorable instability.

4. SUMMARY

Although this study is in its preliminary stages, some general comments can be made.

- The 0–8-km bulk wind shear is usually much stronger in the environments of long-lived supercells (when compared to short-lived supercells), leading to stronger 8-km storm-relative winds.
- Even though sounding parameters may be favorable for long-lived supercells, the large-scale environment and/or external factors may act to limit storm longevity.
- Long-lived supercells are relatively isolated (when compared to short-lived supercells).

5. ACKNOWLEDGMENTS

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