Assessing the Impact of the Nocturnal Transition on the Evolution and Lifetime of Supercell Thunderstorms in the Great Plains

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Introduction

The cooling and stabilization of the boundary layer during the nocturnal transition leads to a series of thermodynamic and kinematic changes in the low-level environment. This transition creates a challenging environment for forecasting the evolution of supercell thunderstorms, as it is not well understood how supercells respond to variations in their environment. During the nocturnal transition, there are four possible evolutions for an isolated supercell (Colman 1990; Billings and Parker 2012; Nowotarski et al. 2012; Davenport and Parker 2015): (1) Dissipation 2) Merge with other convection (e.g., supercells or MCCs); 3) Grow upscale to a larger form of convection 4) Maintenance (as elevated or surface-based convection)

The goal of this study is to increase skill in forecasting supercells during the nocturnal transition, thereby expanding our understanding of how supercells respond to kinematic and thermodynamic changes in their local environment.

Methods

Nocturnal supercell cases were identified using the Storm Prediction Center’s Severe Thunderstorm Event Archive from 2005 to 2016. Cases were limited geographically to the Great Plains of the United States during the months March – June. Isolated supercells at sunset (SS) were then classified based on their evolution from SS to SS +5 hours (Fig. 1).

157 isolated supercells were confirmed at SS:
● Dissipated (Fig. 1a) - 86
● Maintained (Fig. 1b) - 14
● Upscale (Fig. 1c) - 45
● Merger (Fig. 1d) - 12

Nocturnal supercell transition

Figure 1. Example of each nocturnal supercell classification

Rapid Update Cycle and the Rapid Refresh model hourly analyses were used from SS -1 to SS +5 for proximity soundings (at a single point) and to describe the mesoscale environment around the supercell. Numerous thermodynamic (e.g., CAPE, CIN) and kinematic (e.g., shear and SRH over a variety of depths) parameters were derived from the model output.

Results

● Mean sounding profiles and hodographs show low-level cooling and stronger low-level winds over time for all evolution types (Figs. 2-3)
   ○ Unlike other evolution types, maintained cases had virtually no change in the effective layer depth through SS +5, as well as the smallest decrease in MU CAPE (Fig. 2)
   ○ Mean hodographs were strongly curved, favoring right moving supercells, with clear development of the low-level jet over time
   Maintained and merger cases contained the largest SRH, favoring stronger and longer-lived supercells (Fig. 3)

Figure 2. Mean RUC/RAP soundings at SS -1 (solid line) and SS +5 (dashed line) for each evolution classification.

Figure 3. Mean hodographs at SS -1 (blue), SS +2 (dashed red) and SS +5 (dashed blue) for each evolution classification.

● The general synoptic setup is favorable for all supercell classifications, though a more amplified trough is evident in maintained and merger cases (Fig. 4)
● The mesoscale inflow environment contains significant spatial heterogeneity, with notable differences evident in MU CIN and effective SRH among all classification types (Fig. 5)
● Dissipating cases had the least favorable mean values and overall trends for supercell maintenance for the majority of parameters, including effective SRH, effective bulk shear, and MU CIN (Table 1, Fig. 6)

Figure 4. Mean RUC/RAP 500 mb height field for each classification at 0000 UTC.

Figure 5. Inflow grid of mean MU CIN change from SS to SS +5. Hashing indicates regions where change was significant (p-value < 0.05). Red dot indicates supercell location.

Table 1. Hourly comparisons between evolutions and the corresponding significant parameters (p < 0.05) based on the Two-Way Kolmogorov-Smirnov and Student’s T-tests.

● Comparing the distributions of all computed parameters among each pair of supercell classifications at each hour reveals numerous statistically significant parameters (Table 1). The most common discriminating parameters include shear and SRH in a variety of layers, supercell composite parameter (SCP), MU CAPE, and MU CIN.

Discussion and Conclusions

The strongest statistical signal was between maintained and dissipating supercells:
● Increasing MU CIN values, combined with decreasing MU CAPE, and steady effective SRH likely caused the dissipating supercells to no longer be able sufficiently lift parcels into the updraft
● These results indicate that a balance between MU CIN and effective SRH is likely needed sustain supercells through the nocturnal transition

Figure 7. Time series of mean effective SRH for dissipation (solid) and maintained (dashed), with the corresponding p-value at each hour.

The discriminatory power of effective SRH, MU CIN, and SCP (Table 1, Figs. 5-7) led to the development of a CIN-scaled Supercell Composite Parameter (CSCP; Equation 1). Effectively, SCP is lowered when MU CIN is present. This new parameter has skill in separating the various evolution types (Figs. 8-9).

Break the CSCP down into the contributions of each parameter (Fig. 8) shows the relative importance of effective SRH and MU CIN compared to CAPE and bulk shear. When comparing 0-1 km shear with CSCP (not a function of 0-1 km shear), strong forecasting skill is seen (Fig. 9).

Figure 8. Individual contribution of each term in the CSCP equation. Each box represents – one standard median deviation from the median.

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Figure 9. Phase space of CSCP and 0-1 km shear. Each box represents – one standard median deviation from the median.

CSCP = MU CAPE, Eff SRH, EB Shear, -25 J/kg
1000 J/kg * 5 m/s * 20 m/s * MU CIN
Equation 1. CSCP equation with MU CIN scaled term. The CIN-scaled term is equal to zero when MU CIN < -25 J/kg.