P32 ASSESSING THE IMPACT OF THE NOCTURNAL TRANSITION ON THE LIFETIME AND EVOLUTION OF SUPERCELL THUNDERSTORMS IN THE GREAT PLAINS

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1. INTRODUCTION

The stabilizing and cooling of the boundary layer during the nocturnal transition leads to a series of thermodynamic and kinematic changes in the atmosphere, creating a challenging environment for forecasting the evolution of supercell thunderstorms. The primary environmental change that occurs during the nocturnal transition is a cooling of the boundary layer, in approximately the lowest kilometer the atmosphere, starting shortly after sunset and continuing until sunrise (Stull 1988). Limited forecasting-based research exists regarding precisely how supercells evolve during the nocturnal transition; there are numerous dynamic and thermodynamic changes that occur in and around the supercell, and complex interactions exist between the storm and these changes.

The governing dynamics of supercell thunderstorms have been well covered through various research studies (e.g., Lemon and Doswell 1979; Davies-Jones 1984; Rotunno and Klemp 1985). The numerous environmental factors that impact the strength, development and severe weather production of supercells are well-known, including vertical wind, moisture and temperature profiles (Thompson et al 2003); the nocturnal transition acts to modify these thermodynamic and kinematic aspects of the environment. The concern of this research is to determine how these modifications will affect the evolution of supercells. During the nocturnal transition, there are four possible evolutions for an originally isolated supercell: 1) dissipation, 2) merge with other supercells, MCS or other convective cells, 3) grow upscale to a larger form of convection, or 4) maintenance either through becoming elevated or remaining surface-based (Billings and Parker 2003; Nowotarski et al 2011; Davenport and Parker 2015).

Previous studies assessed several environmental scenarios similar to those seen during the nocturnal transition. Nowotarski et al. (2011) conducted a study on the impacts of surface layer stabilization on supercell structure and lifetime. Their findings included evidence that most supercells were still able to persist despite surface inhibition and still ingest surface parcels in all but the most extreme stable cases. Strong dynamic lifting of parcels to their levels of free convection (LFCs) from the updraft was hypothesized to allow supercells to persist. Going a step further, Coffer and Parker (2015) simulated the early evening transition by increasing low level wind shear due to a low level jet. Enhanced low level and mid-level vorticity within the storm were observed due to the increasing low level shear, strengthening nonlinear dynamic lifting, thus allowing for easier lifting of stable low-level parcels. Davenport and Parker (2015) furthered this area of research through the use of base state substitution (Letkewicz et al. 2013) to simulate the stabilizing of the boundary layer over time. Through parcel trajectories, their results showed that surface parcels were still able to be ingested for a time, even with strong CIN; eventually surface parcel inflow was entirely cut off with further increasing CIN.

Building upon these previous studies, this research aims to further knowledge of how the nocturnal transition's environmental modifications impact supercells and how this eventually leads to the evolution of supercells. Ultimately, this research hopes to improve forecasting of supercells during the nocturnal transition.

2. DATA AND METHODOLOGY

Using the SPC Severe Thunderstorm Event Archive, possible cases were flagged based on severe weather production (hail, wind, or tornado) from 0000 to 0500 UTC. The time period of 0000-0500 UTC was chosen to represent the nocturnal transition, as this time period encompasses several hours after sunset. A total of 289 possible cases were flagged in the Great Plains from March-June, 2006-2016. The flagged cases were then investigated further to confirm whether these storms were indeed supercells; this was performed using a combination of WSR 88-D level 3 data including: the Mesocyclone Detection Algorithm (MDA), reflectivity, and velocity data. In order for a confirmed supercell to be included in this study, it was required to be isolated (i.e. disconnected from other convection) with a precipitation-free inflow region at 0000 UTC. The result of this process was a total of 171 supercells that were utilized this study.

In order to better predict the how supercells will evolve during the nocturnal transition, the confirmed supercells were classified based on their evolution from 0000 UTC to 0500 UTC. 0000 UTC to 0500 UTC (1800 CST - 2300 CST) was the chosen time period as it captures the time of most rapid environmental change during sunset. The ultimate purpose of this classification is to discover differences in the environments between the categories of dissipation, merging, upscaled and maintained supercells (Fig. 1), in order to increase forecasting skill during this time frame. Determining the evolution type for each supercell was done using the following criteria. A supercell was selected as a dissipation event if the cell remained isolated and ceased displaying supercellular characteristics before 0500 UTC. A supercell that lost the MDA flag for multiple consecutive

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scans, or a supercell that no longer had discernable mid-level rotation or a bounded weak echo region, was considered to have dissipated. If the suspected dissipating supercell was positioned far from a radar, a combination of the above and any stop in hail reports was used to determine dissipation. Upscale cases were selected if the supercell grew into a larger form of convection that was not pre-existing. A merger type was selected if the isolated supercell collided with other supercells, or a larger feature, such as a squall line. The distinguishing feature between upscale and merger categories is that merger was selected if the merged cells then dissipated or if the supercell interacted with a pre-existing feature. Maintained cases were chosen if the supercell remained isolated and continued to exhibit supercell characteristics through 0500 UTC. A total of 91 dissipation cases, 20 maintained cases, 15 merger and 45 upscale cases were identified.

Once the supercells and the evolution types of each were confirmed, the associated environmental parameters were extracted. For this the Rapid Update Cycle (RUC) and the Rapid Refresh (RAP) numerical weather models were used (Benjamin et al. 2004; Benjamin et al. 2016). The RUC uses an isentropic-sigma hybrid vertical coordinate of 50 levels and horizontal grid spacing of 40 km, 20 km or 13 km, as it has been upgraded over time. The 20 km horizontal grid spaced RUC was used for 2005-2008 and the 13 km spacing was used from January 2009-May 2012. The hour zero analysis from the RUC was used for each hour from 0000 UTC to 0500 UTC. The RAP Model is used from May 2012-2016.

For each hour from 0000 UTC to 0500 UTC, a storm-relative upwind grid point in the inflow region of the supercell was selected based on the closest latitude and longitude point. At these grid points, a vertical profile was created using the 37 vertical pressure levels. Errors associated with RUC/RAP data were of similar magnitude to those in previous studies (Thompson et al. 2003). Once the corrected soundings were created, numerous environmental parameters were derived. The python library SharpPy was used for the calculations of all the thermodynamic and kinematic variables (Blumberg et al. 2016). The derived parameters included surface-based, mixed layer, and most unstable CAPE and CIN, 0-1 km SRH, 0-3 km SRH, 0-1 km bulk wind shear, 0-3 km bulk wind shear, 0-6 km bulk wind shear, effective SRH, effective bulk shear, the supercell composite parameter, Bulk Richardson Number (using MU CAPE) and the 700-500 mb lapse rate. The effective layer bounds used for the effective SRH and effective bulk shear was the same as in Thompson et al. (2003), with parcels of 100 J/kg > CAPE and -250 J/kg > CIN constituting the inflow layer.

3. RESULTS

a. Composite Profiles

To broadly assess differences in the inflow environment of each supercell classification type, a mean sounding was created for each evolution category on the 25 mb vertically spaced grid from the RUC/RAP. The average sounding was computed between the 975 and 100 mb levels; the 975 mb level was chosen as the base since the majority of cases had a surface pressure closest to this value. Profiles containing mean temperature, mean dew point, the MU parcel trace, and effective layer base and top at 0000 UTC and 0500 UTC were created for each classification (Fig. 2). Overall, as a result of nocturnal cooling, MU CAPE decreased on average for all categories; dissipation cases decreased by 56% (1507 J/kg), merger cases decreased 67% (1914 J/kg), upscale cases decreased 47% (1413 J/kg), and maintained cases decreased 37% (965 J/kg).

Composite 0-6 km wind profiles were also created for each classification at 0000 UTC, 0300 UTC and 0500 UTC (Fig. 3). In all four storm evolution types, increases in low and mid-level wind speeds are seen from 0000 UTC to 0500 UTC; the increasing southerly wind speed with time in all cases results in increasing low level shear and increasing SRH. The differences in depth of the low level southerly component, and subsequent influence on SRH, is possibly due to LLJs of varying intensity, a feature that will need to be investigated in further detail. Overall, the strongest kinematic difference among evolution types is evident by 0500 UTC: maintained and upscale cases contained much larger 0-3 km and effective SRH than the merger and dissipation cases.

b. Parameter Time Series

Time series of SB CAPE, ML CAPE and MU CAPE show the expected decreases in stability as the boundary layer cools, with SB CAPE having the smallest mean value of the three for all classifications (Fig. 4). Dissipation, merger, upscale and maintained saw the largest decreases for SB CAPE, followed by ML CAPE and MU CAPE. Since the ML and MU parcels include parcels above the layer of strongest surface cooling, this was expected as they are less dependent on surface cooling. Maintained cases exhibited the smallest rate of decrease for MU CAPE relative to other classifications (Fig. 4). The CAPE time series analysis indicates that SB CAPE plays little role in evolution since all classifications showed similar trends and mean values. The more elevated ML and MU parcels elucidate differences among classifications suggesting that the thermodynamic profile aloft plays a more crucial role than surface cooling.

SB and MU CIN time series describe a similar trend to the CAPE profiles. SB CIN showed rapidly increasing values with time in all classifications, the result of strong surface cooling. Conversely, MU CIN showed discrepancies between classifications; upscale and maintained cases MU CIN values remain quasi-steady with no significant change through 0500 UTC (Fig. 5). For both CIN and CAPE, MU parcel parameters yield the largest differences between classifications; maintained and upscale cases retain their MU environments far better than dissipation cases.

Storm-relative helicity values within the 0-1 km and 0-3 km effective layers showed only subtle differences between classifications in the temporal changes from 0000 UTC to 0500 UTC; effective layer SRH however showed the major differences. All classifications, except merger cases, show significant increases in 0-1 km and 0-3 km SRH by 0500 UTC; all classifications have similar mean values as well.

Effective SRH time series show significant differences between maintained / upscale and dissipation cases; dissipation sees 10% (18.5 m^2s^2) decrease while upscale and maintained cases see increases of 19% (36.5 m^2s^2) and 39% (84.2 m^2s^2) (Fig. 6). Since the effective layer SRH shows the greatest distinguishing capability of SRH parameters, the coupling of thermodynamics and kinematics is a key aspect of evolution during the nocturnal transition.

As with the 0-1 and 0-3 km SRH, bulk shear magnitudes within the 0-1 km, 0-3 km, 0-6 km layers showed similar mean values and trends across the classifications; effective layer shear revealed greater initial differences at 0000 UTC and in trends with time. Dissipation, merger and upscale cases had significant decreases in 0-6 km shear, in agreement with the composite hodographs; maintained cases see a slight, but not significant, decrease. The mean values for 0-3 km shear were never statistically different from 0000 UTC at any hour for any classification; only maintained cases show an increase in mean hourly values with time. In contrast, all four classifications types had significant increases in 0-1 km shear, occurring at 0200 UTC for dissipation, upscale, and maintained cases, and at 0300 UTC for merger cases. Between 0000 and 0500 UTC, 0-1 km wind shear increased by 65% (9.8 m/s), 62% (12.5 m/s), 65% (11.3 m/s), 65% (11.4 m/s), for dissipation, merger, upscale, and maintained cases, respectively.

Effective bulk shear magnitude decreases were significant for dissipating cases from 0300 UTC to 0500 UTC; no other classification showed significant change in effective shear through 0500 UTC. Unlike effective SRH or 0-1 km shear, mean effective shear did not increase with time for any classification, indicating that the LLJ may not be affecting the top of the effective layer. Since effective SRH is calculated through integrating over the depth of the layer, the LLJ's impact is included; the shear magnitude only measures the difference in wind between the top and bottom of the layer.

The analysis of the time series of each parameter show several important themes. Notably, dissipation cases tend to have the least favorable environments for supercell maintenance, including the largest increase MU CIN, the quickest occurring decrease in MU CAPE, no significant increase in effective SRH and a significant decrease in effective shear. Physically, this implies that dissipating supercells have weakening updraft velocities from both increasing MU CIN and decreasing MU CAPE. Decreasing MU CAPE would weaken stretching of the updraft and with no increase in SRH to help offset this, the vertical pressure perturbation gradient force (VPPGF) from the updraft would weaken. In contrast, maintained supercells tend to see increasing effective SRH, constant MU CIN and MU CAPE. This implies that the VPPGF should remain steady from continuing updraft stretching and rotation.

c. Cumulative Statistical Comparisons

The significance of the time series tests is not transitive (i.e., effective SRH for maintained cases saw a significant increase with time while dissipation cases did not; but it is still not certain if dissipation and maintained cases have significantly different effective SRH). Therefore to test if a parameter for a classification is significantly different from another classification, Kolmogorov-Smirnov (KS) tests for each parameter's total distribution and Student's T-test on the distribution's means were performed (e.g., testing the difference between the cumulative 0000-0500 UTC SB CAPE distributions for maintained versus upscaled cases). A total of six comparisons were performed between the four classifications to test for significance at the 95% level and all environmental parameters were tested.

Dissipation and upscale cases had statistically significant differences for many parameters, both thermodynamic and kinematic, including MU CIN, MU CAPE, supercell composite parameter (SCP), effective SRH, and effective bulk shear. The mean values for these parameters are more favorable for supercell maintenance in the upscale cases compared to the dissipating cases. Additionally, upscale cases contain constant MU CAPE through the 0000-0500 UTC time frame, so there is retained elevated instability available for the parcels that are lifted to their LFCs. The more favorable MU CIN values also allow for ample lifting to the LFC and thus utilizing the elevated CAPE. Dissipation cases see no significant increase in effective shear or effective SRH relative to upscale cases, and along with more unfavorable MU CIN, this implies that dissipation cases fail to reach a balance between inhibition and updraft strength.

Dissipation versus merger cases show more differences in thermodynamic quantities. CAPE differences are substantial, with dissipation cases on average containing SB, ML and MU CAPE values at least 300 J/kg *more* than merger cases; the dissipation MU CAPE mean value was 511 J/kg greater than merger cases. However, merger cases have the more favorable kinematic parameter mean values; 0-1 km, 0-3 km SRH and 0-1 km shear had mean values that were 69 m^2s^2, 84 m^2s^2, and 7 m/s greater, respectively.

Dissipation versus maintain cases show differences in kinematic quantities, SCP, and Bulk Richardson Number (BRN); notably, there were no purely thermodynamic differences, indicating the importance of strong kinematics in sustaining supercells during the nocturnal transition. The maintained cases contained larger mean values for all kinematic parameters, with the largest difference in means for effective SRH, where maintained cases on average had 107 m^2s^2 more SRH. The BRN mean for maintain cases of 34 is in a more favorable range for supercells, while dissipation cases are borderline with a mean of 48. Surprisingly, given the differences seen in MU CIN for the time series data, MU CIN was not statistically significant when comparing the total distributions.

Upscale versus merger cases show significant differences in all CAPE values, where more favorable values are seen for upscale cases; SB, ML and MU CAPE were on average larger by 570 J/kg, 432 J/kg, and 657 J/kg, respectively. Significant kinematic parameters show slightly more favorable environments for merger cases. A difference in means of 40 m^2s^2 for 0-1 km SRH and 4 m/s for 0-1 km shear is not likely to be physically significant, and thus potentially less useful for forecasting.

Upscale versus maintain cases show significant differences for BRN and MU CAPE, as well as other kinematic parameters. Maintained cases see greater statistically significant, but likely not physically significant, values for 0-3 km shear and SRH; mean differences were only 2 m/s and 41 m^2s^2. Conversely, BRN mean values were 42 and 25 for upscaled and maintained; a physically and statistically significant difference. So in this case, the upscale cases are being influenced by the larger CAPE values and smaller 0-3 km and effective shear.

Maintained versus merger cases show statistical differences in both thermodynamic and kinematic parameters, with maintain cases showing smaller MU CIN, SB CIN and greater SCP values. Since merger events require the presence of a linear convective feature, it was expected that maintained events would have would generally more favorable supercellular environments. SB CIN and MU CIN both were significantly smaller for maintained cases and no significant differences in any CAPE parameters were found. Merger cases did see a slightly larger mean 0-1 km shear value of 27.9 m/s versus 23.7 m/s for maintained; this is not quite large enough to make a physical difference.

d. Hourly Statistical Comparisons

Parameters for different classifications are now compared on an hourly basis (e.g., comparing dissipation versus maintained case's 0100 UTC values of effective SRH). The KS and Student's T-test were then used to test for significant differences. Table 1 shows parameters that were significant under *both* the KS test and T-test and table 2 shows those are significant under only the T-test. The differences seen between classifications support the trends seen in the time series analysis. Dissipation and merger events see no significant parameters, under both the KS test and T-test, on an hourly scale; a sharp contrast to the cumulative comparisons. Few significant differences are also present when comparing maintained and upscaled events, as only one significant hourly parameter was present (BRN) at 0300 UTC when both statistical tests were applied (Table 1). Given that BRN should increase as convection evolves into a multicellular form, it was expected that BRN was larger and significantly different for upscale cases.

Maintained versus merger events only see significant differences at 0500 UTC between effective shear and MU CIN (Tables 1-2); this was expected based on the results of the previous section, as well as the need for maintained supercells to sustain updraft rotation with lower MU CIN and large effective SRH. Comparing upscale and merger events illustrates that MU CAPE is significantly different at 0400 and 0500 UTC, as well as MU CIN at 0500 UTC. Under only the T-test, BRN is now seen to be significant for multiple hours between upscale and maintain cases. The Supercell Composite Parameter (SCP) also was shown to be a significant parameter under only the Student's T-test (Table 2). With higher values of SCP and lower BRN values, the maintained supercells show stronger tendency towards retaining supercell characteristics, as expected.

Overall, the results suggest that a balance between the MU CIN and effective SRH is required to sustained isolated supercells. The environments for dissipation cases display rapid increases in MU CIN, too much for their effective SRH; less SRH decreases in the ingestion of streamwise vorticity and results in weaker lifting of parcels. Upscale cases also differ from dissipation supercells but is likely a result of cold pool lifting, where dissipation cases do not have the proper balance between shear and CIN in order to lift parcels to their LFCs.

The maintained and upscale cases yielded very similar environments, where both MU CIN and effective SRH are not statistically different. However, since the orientation of shear with respect to lifting mechanisms can help determine linear versus isolated convection developing, the 0-6 km shear differences were explored further (Fig. 7). Maintained cases are seen to have the largest change in 6 km winds from 0000 to 0500 UTC; upscale see little change in 6 km winds. This difference in 6 km winds could be playing a role in keeping the deep layer shear more favorable for isolated convection through 0500 UTC in maintained cases; this idea will need to be explored further in future research.

4. CONCLUSIONS

In order to assess how the environmental changes associated with the nocturnal transition impact supercell thunderstorm evolution and lifetime, inflow proximity soundings from the RUC/RAP between 0000 UTC and 0500 UTC were collected for Great Plains supercells occurring over a span of 10 years. Each supercell was classified based on its evolution from 0000 UTC to 0500 UTC as either: dissipating, merging with another convective feature, growing upscale or maintenance (Fig. 1). A plethora of environmental parameters were calculated from the proximity soundings and then statistical differences between the classifications were assessed.

Surface-based and mixed layer parameters were not statistically different for all comparisons, implying that changes in the elevated environment play a more important role. Only minor and/or physically significant differences were found when comparing upscale, maintained, or dissipation to merger cases. Large differences in effective SRH and MU CIN yielded the most useful skill when distinguishing maintained versus dissipating supercells (Figs. 5-6). A balance between updraft rotation maintenance and environmental inhibition is necessary for maintained supercells, where large MU CIN can be overcome with sufficient effective SRH and MU CAPE. Dissipation cases also exhibit higher MU CIN values, indicating that even elevated convection is unlikely once the BL stabilizes. Similarly, upscaled and dissipating supercells showed significant differences in MU CIN and effective SRH. Purely kinematic parameters such as 0-3 km SRH were less useful in distinguishing classifications, which is likely due to the interplay between thermodynamic and kinematic changes in the atmosphere. This is also perhaps why the effective layer SRH and effective bulk shear, provided the most skill, since they are function of both these types of environmental changes.

a. Future Work

The next steps in this research aim to create more robust statistical comparisons, distinguish upscaled and maintained supercells more accurately and ultimately create a skillful and universal forecast tool. In order to create a more a representative climatology, increasing the sample size is necessary; the goal is to expand the domain to include 2004 and 2005 since those years are also included in the SPC event archive. Increasing the small number of maintained and merger cases is a priority as it will increase confidence in the statistical results. Multiple linear regression will also be performed using a small number of the most physical and statistically important parameters; decision trees will be created from these results to provide a forecasting tool.

Defining a sunset relative nocturnal transition as the five hours after local sunset, rather than 0000 to 0500 UTC, and then rerunning the statistical tests shown is planned work. This would eliminate any potential bias associated with the time period chosen and varying months used (i.e. a supercell that occurs in late June would generally have more favorable conditions at 0000 UTC than one occurring in early March).

Additional investigation into the maintained supercells to determine whether or not they became elevated is also planned to further assess the difference between maintenance and upscaled supercells. Since elevated convection tends to limit tornado development due to a very stable BL, looking into the temporal distribution of tornadic vortex signatures or tornado reports could also be beneficial.

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	0000	0100	0200	0300	0400	0500
Dissipate to Upscale	-	-	-	Eff. SRH SCP SFC CIN	Eff. SRH SCP MU CIN	MU CIN
Dissipate to Maintain	MU CAPE	-	-	Eff. SRH Eff. Shear	Eff. SRH Eff. Shear	Eff. SRH Eff. Shear SCP MU CIN
Dissipate to Merger	-	-	-	-	-	-
Maintain to Upscale	-	-	BRN	-	-	-
Maintain to Merger	-	-	-	-	-	Eff. Shear MU CIN
Upscale to Merger	-	-	-	-	MU CAPE	MU CAPE MU CIN

Table 1. Hourly tests for significance for entire dataset. Listed parameters were significant at 95% confidence level for both the KS test and T test for the corresponding comparison, a dash (-) indicates that no parameters were significant for that hour.

	0000	0100	0200	0300	0400	0500
Dissipate to Upscale	-	-	Eff. SRH	Eff. SRH Eff. Shear SCP MU CIN SFC CIN	Eff. SRH Eff. Shear SCP MU CIN	Eff. SRH Eff. Shear SCP MU CIN
Dissipate to Maintain	MU CAPE BRN	BRN	Eff. SRH Eff. Shear SFC CIN	Eff. SRH Eff. Shear SFC CIN	Eff. SRH Eff. Shear BRN MU CIN	Eff. SRH Eff. Shear SCP MU CIN
Dissipate to Merger	-	-	700-500mb LR	-	SFC CAPE MU CAPE	SFC CAPE MU CAPE
Maintain to Upscale	MU CAPE	-	BRN	BRN	BRN SCP	BRN SCP
Maintain to Merger	-	-	-	-	SCP MU CAPE ML CAPE SFC CAPE	Eff. Shear MU CIN Eff. SRH MU CIN SCP MU CAPE ML CAPE
Upscale to Merger	-	-	-	SFC CAPE ML CAPE MU CAPE	SFC CAPE ML CAPE MU CAPE SCP	SFC CAPE ML CAPE MU CAPE MU CIN

Table 2. Hourly tests for significance for entire dataset. Listed parameters were significant at 95% confidence level for only the Student’s T test for the corresponding comparison, a dash (-) indicates that no parameters were significant for that hour.

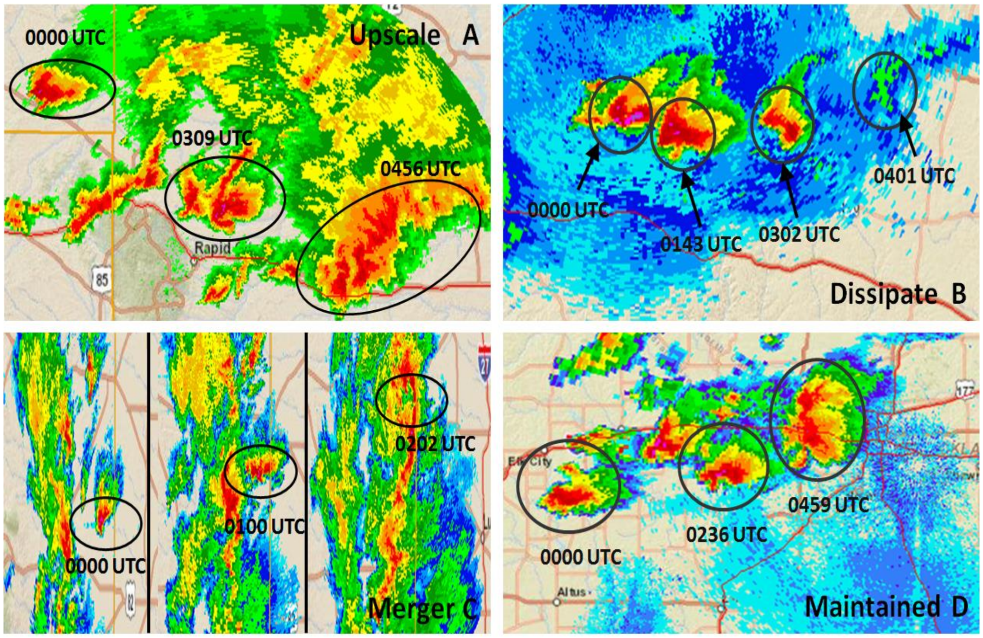

Figure 1. Panel a) shows an example upscaled supercell case with three scans overlayed. Panel b) shows an example dissipating case with four scans overlayed. Panel c) shows a merger case at 0000 UTC, 0100 UTC and 0200 UTC. Panel d) shows a maintained case with three scans overlayed. The supercell in question is circled for each evolution type.

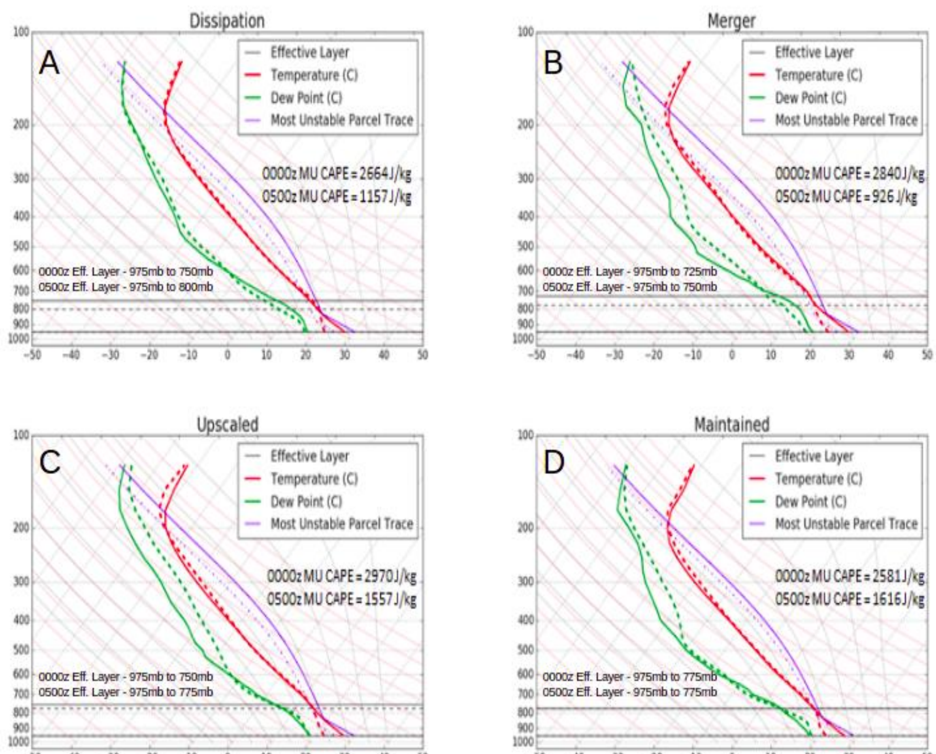

Figure 2. Mean composite sounding for each classification. Solid lines are for mean values at 0000 UTC, dashed lines for 0500 UTC, with panel A, B, C and D for dissipation, merger, upscale and maintained respectively. Effective Layer top is the last parcel in the profile with > 100 J/kg CAPE and > -250 J/kg CIN.

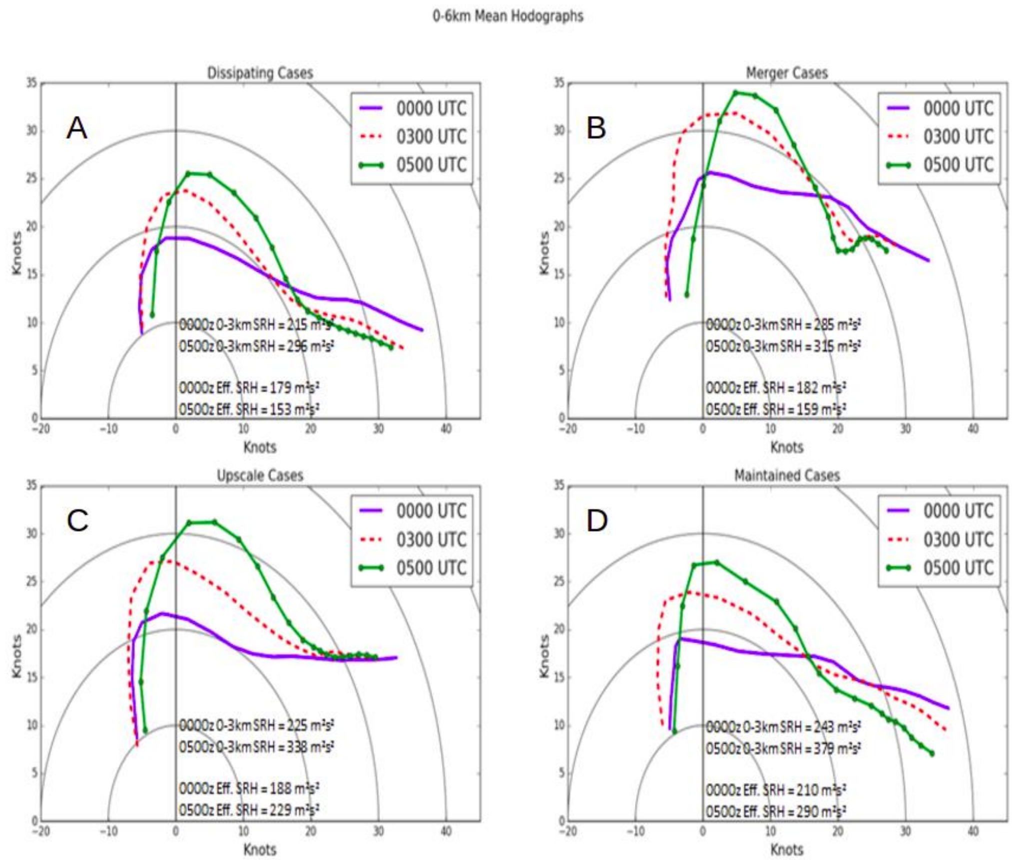

Figure 3. 0-6 km mean composite hodographs at 0000 UTC, 0300 UTC and 0500 UTC for dissipation (A), merger (B), upscale (C) and maintained cases (D).

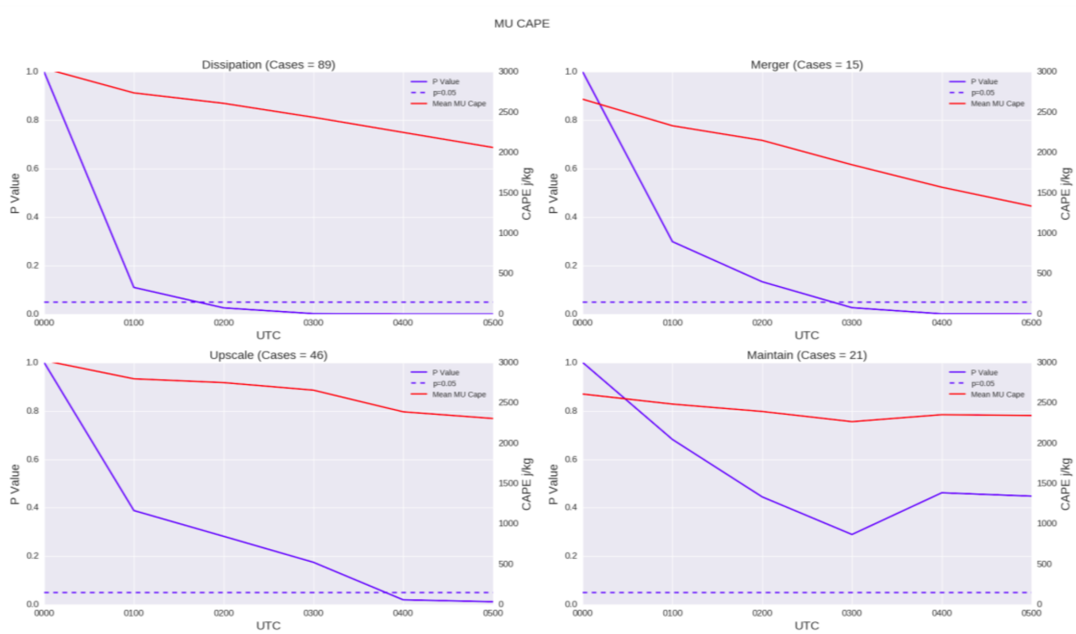

Figure 4. Time series for mean hourly MU CAPE (red). Blue line shows the p-value under the Student's T-test comparing that hour to hour zero. Dashed blue line is the level significance of 95%.

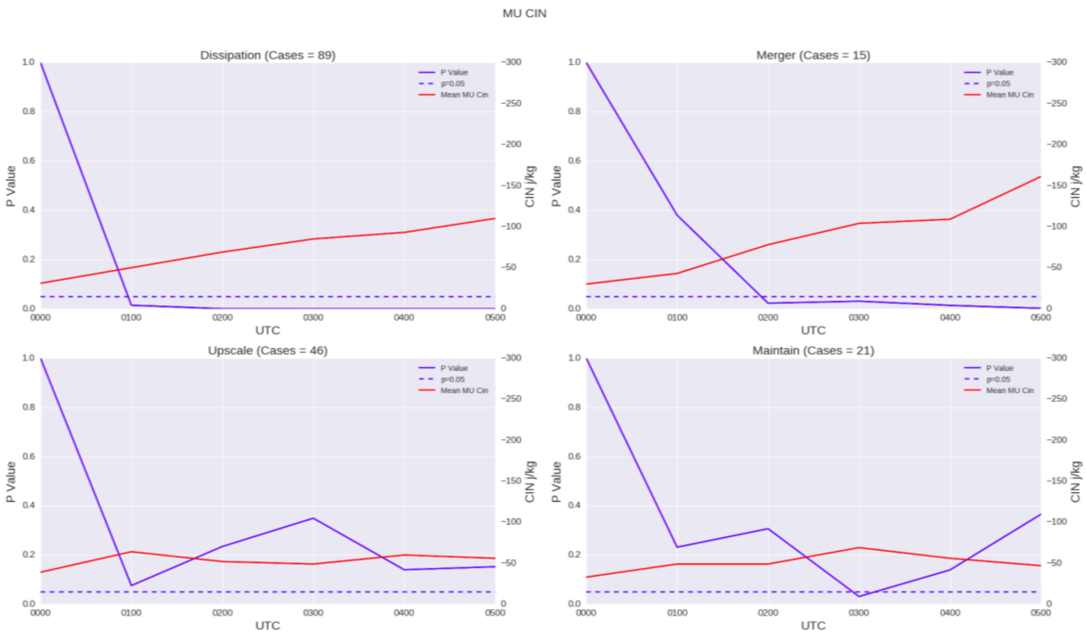

Figure 5. Same as figure 4, for MU CIN

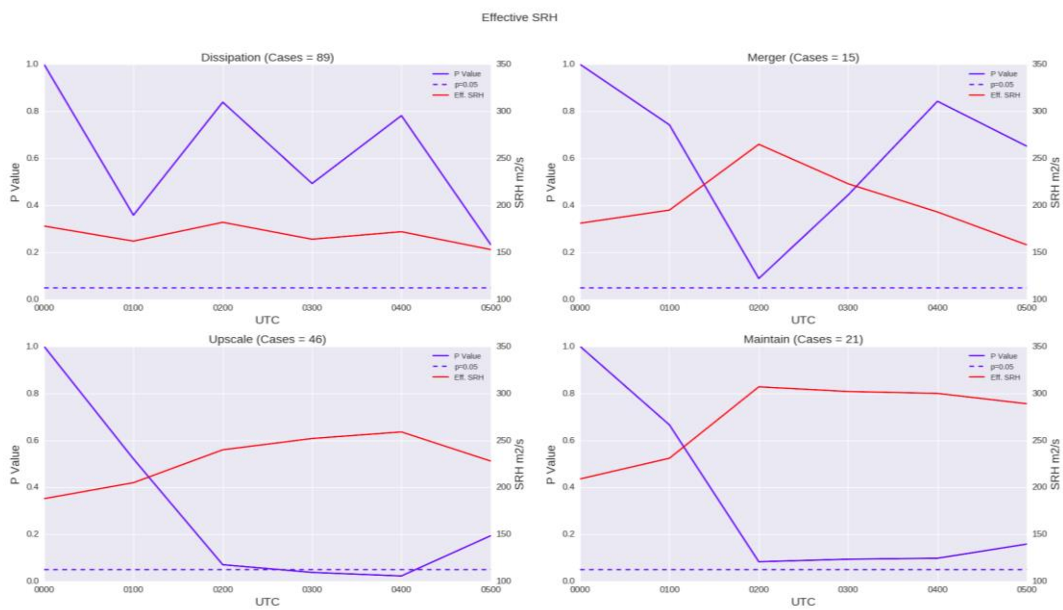

Figure 6. Same as figure 4, for effective SRH

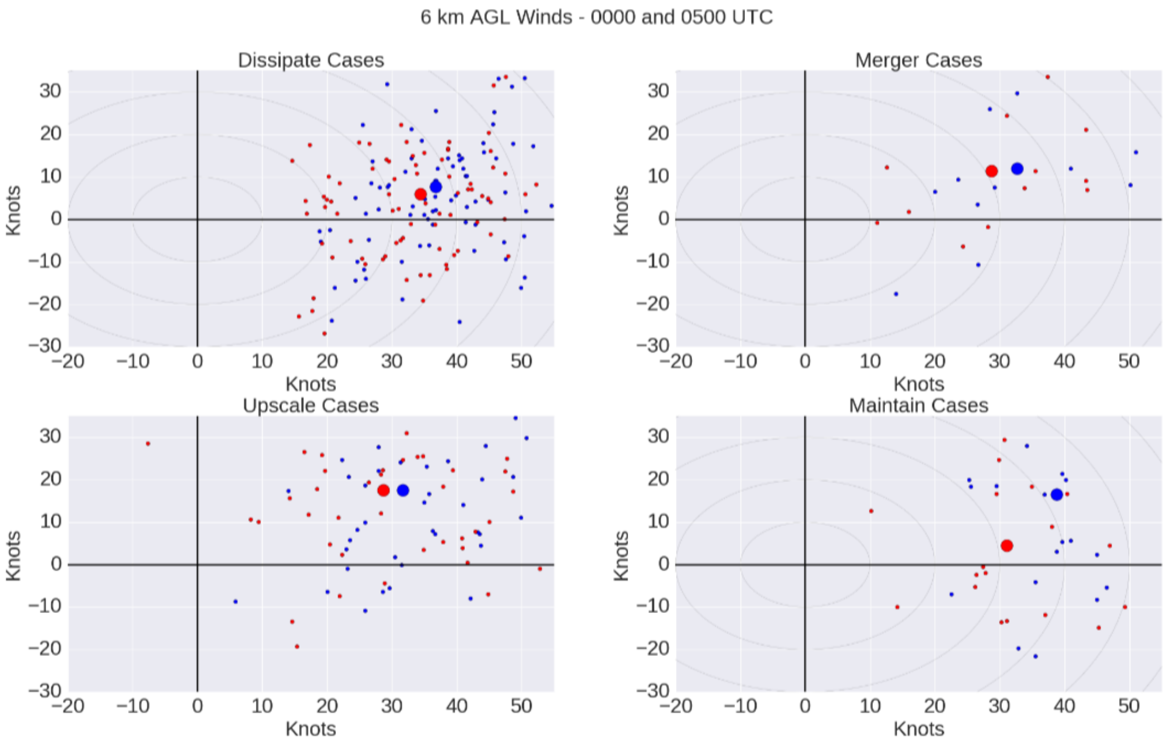

Figure 7. 0000 UTC (blue) and 0500 UTC (red) 6 km winds for each supercell cases. Larger points indicate the median value for that respective hour.