P3.18 Mobile Mesonet Observations of an Intense RFD and Multiple RFD Gust Fronts in the May 23 Quinter, Kansas Tornadic Supercell during TWISTEX 2008

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1. INTRODUCTION

There are many unresolved issues regarding tornadogenesis in supercells. One question that has received recent attention in the research community is the role of the rear-flank downdraft (RFD) and rear-flank downdraft gust front (RFDGF) in tornadogenesis. TWISTEX 2008 (**T**actical **W**eather **I**nstrumented **S**ampling in/near **T**ornadoes **Ex**periment) was a field experiment designed to collect near-surface data in and near tornadoes. One of the project objectives was to document the kinematic and thermodynamic environment in the vicinity of the RFDGF, and to try to determine the RFD/RFDGF's contribution to low-level mesocyclogenesis, tornadogenesis and tornado maintenance.

On 23 May 2008, three TWISTEX mobile mesonet stations (denoted as M1, M2, M3) intercepted a tornadic supercell south of Quinter, KS. Teams followed the storm north as it cycled, and collected high-resolution data across the RFDGF and within the RFD near Quinter just prior to, and during the development of a mile-wide tornado. Of specific interest, the mesonet sampled a very strong internal RFD surge boundary that was temporally related to the formation of the large tornado. The complex evolution of this storm will be discussed, with a focus on the characteristics of the boundaries associated with the storm as measured with the mobile mesonet during a half hour period from 21:30 – 22:00 UTC.

2. May 23, 2008 STORM EVOLUTION OVERVIEW AND DATA COLLECTION

Data was collected with an array of three mobile mesonet stations similar in design to those described by Straka et al. (1996) using updated versions of equipment wherever possible. Atmospheric variables were sampled every 2 seconds, and the data was quality controlled using criteria similar to Markowski et al. (2002) and bias corrected prior to analysis. Each variable sample was then averaged over a 6 second period to remove very small timescale fluctuations. Unless otherwise noted, all data plots shown for the May 23 case are averaged data. In addition to the measured atmospheric quantities, several derived variables were calculated including θ_v and θ_e, and departures of these variables from their prestorm environment values (θ_v' and θ_e'). Since surface observing stations are very widely spaced in western Kansas, pre-storm environment values were calculated from average mesonet measurements taken east of the storm tens of minutes before storm intercept.

In order to try to gain some understanding of the two-dimensional structure in the RFD region of the storm, time–space conversion was applied in a manner similar to Markowski et al. (2002). In order to perform the time-space conversion, one must assume the storm is in 'steady-state' for some specified period of time. The position of the mesonets can then be plotted relative to the storm creating a quasi-2D view of the atmosphere. Since radar data was available about every 5 minutes, time-space conversion was done over a five minute period with full appreciation that it was highly unlikely that the storm was in 'steady-state' for 5 minutes. Thus, as one views data points further from the center time of the time-space conversion, the analyzed fields become less certain. Storm motion for the time-space conversion was calculated from the average motion of the mid-level mesocyclone (as identified in the KGLD velocity fields) over a 10 minute period from 22:36 – 23:45 UTC.

The storm of interest in this study developed along a dryline in western Kansas, and the mesonet teams intercepted the storm at approximately 21:25 UTC 3 miles south of Quinter. At this time the storm was producing a tornado 3-4 km west of the mesonet location. Teams followed the storm north toward Quinter while the first tornado appeared to dissipate as the teams approached I-80. The team locations relative to the storm features as seen by the Goodland radar are shown in Figure 1. At 21:36 UTC the storm had a well defined hook echo and low level mesocyclone with a potentially tornadic circulation embedded within it. The mesonet teams could not see a well defined tornado at this time due to poor contrast and limited visibility to the northwest as the teams passed through the western residential area of Quinter. By 21:41 UTC, M1 and M2 had proceeded northward past Quinter while M3 stopped on the north side of Quinter. An extremely large mesocyclone was visible to the north/northwest of M1's position. The Goodland radar still indicated a well defined low-level mesocyclone, but now with several potential smaller circulations embedded within it.

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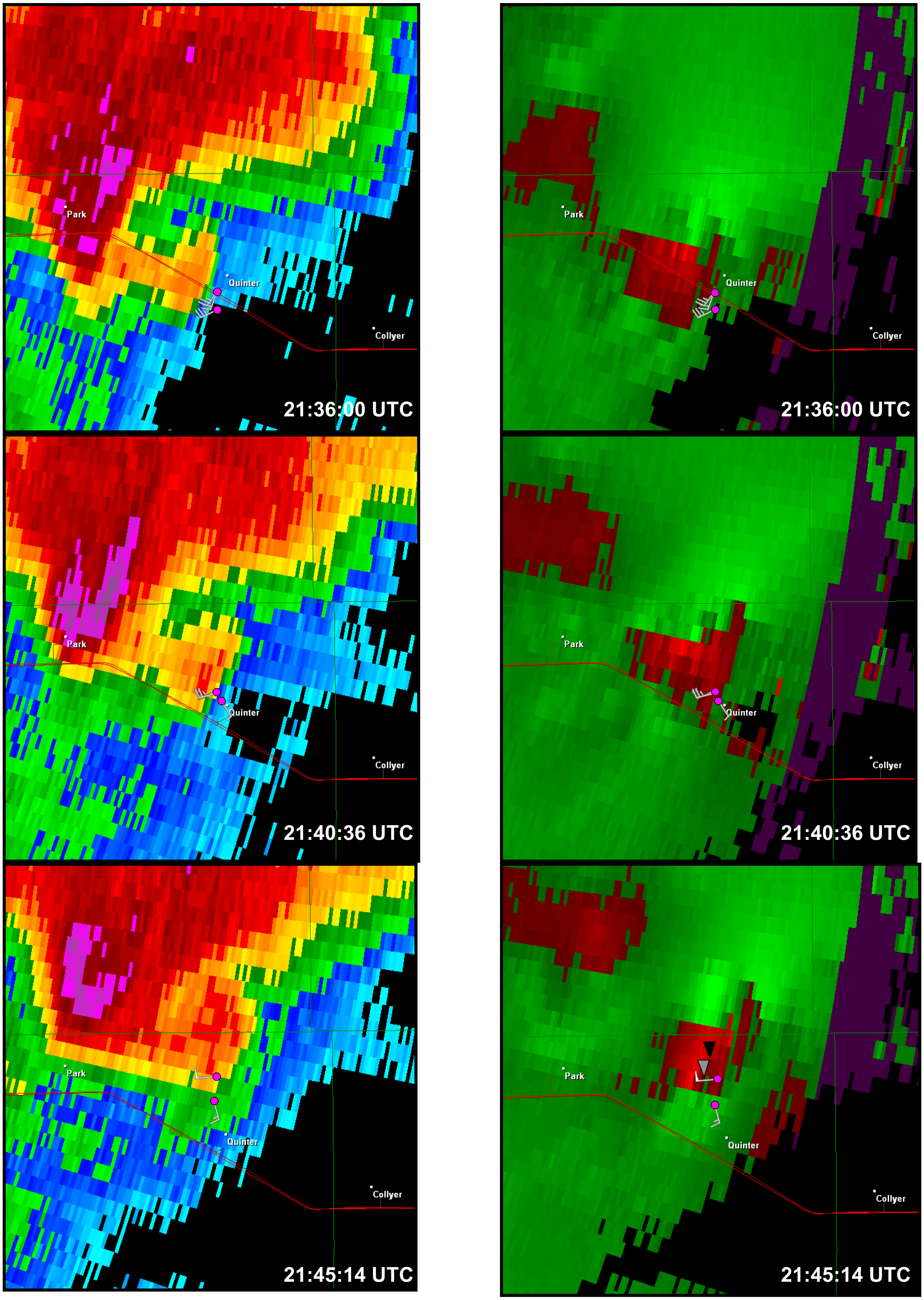

Fig. 1: Reflectivity (left) and Doppler velocity (right) from the KGLD radar on 23 May 2008 at 21:36:00 UTC (top), 21:40:36 UTC (middle) and 21:45:14 UTC (bottom). The positions of the mobile mesonet teams are shown as pink dots, and wind barbs denote the mesonet wind observations. The black triangle indicates the estimated position of the tornado at 21:45 UTC. The gray triangle indicates the estimated location of the upscale development of the tornado.

Fig. 2. Video captures taken of the tornadoes associated with the mesocyclone north of Quinter. The tornado north of M1 (top), the tornado west of M1 (middle) and the large wedge tornado after the strong RFD punch (bottom). Top picture from video shot by M1. The middle and bottom pictures from video shot by Chris Collura, used with permission.

M1 observed a tornado develop ~2.5 km due north of its location at 21:41:53 UTC. This tornado at first had a multiple vortex structure, but evolved into a laminar funnel which moved north/northwest. During this time, a second larger tornado was located ~ 2-3 km west of the mesonet teams' positions (see Figure 2). Shortly after 21:44 UTC, the northern tornado suddenly dissipated, and blowing dust could be seen north of M1's location. Approximately 15 seconds later, M1 and M2 were hit by strong RFD winds well in excess of 70 kts. M1 drove into the ditch at 21:44:19 to avoid falling power lines. Eye witnesses reported seeing vortices along the leading edge of the RFD boundary, one of which passed over M2. M2, which was a half kilometer south of M1, recorded a pressure fall of 12 mb and measured a peak wind speed of 90 kts (103 mph) shortly before losing the anemometer (see Karstens et al., 2008). Several vehicles located between M1 and M2's positions lost windows due to flying debris. Coincident with the development of the strong RFD, the tornadic circulation to the west of M1 developed upscale into large wedge tornado, estimated to be a mile wide at its maximum extent. The Goodland radar scan at 21:45:14 UTC indicated that the low-level mesocyclone contracted in scale and was rotating more strongly as compared to the previous scan. A strong anticyclonic rotation signature also developed south of the mesocyclone. M1 and M2 measured strong RFD winds for 10 minutes as the large tornado moved off to the north. M1's wind speed for the time period M1 was in the ditch was corrected prior to analysis using overlapping observations with M3 which was parked on the road near M1 for a 10-15 minute period. M1's wind direction was also corrected based on its orientation in the ditch.

3. MOBILE MESONET OBSERVATIONS

Mobile mesonet teams intercepted the storm of interest at approximately 21:25 UTC 5 km south of Quinter. The teams attempted to move west to intercept the storm 3 km south of Quinter, but poor road conditions and rapid storm movement precluded the teams from deploying close to the storm. At this time, the storm was producing the first of several tornadoes approximately 3-5 km west of the team's location. At 21:32 UTC, the teams headed north toward Quinter to get into position to deploy closer to the storm which was moving north/northeast. As the teams moved northward, they encountered several boundaries as shown in Figure 3. M1 crossed the RFD boundary from the first tornado cycle at ~21:34 UTC, which was marked by a wind shift (ground relative) from south to southwest and a decrease in θ_e and θ_v of ~ 11 K and ~2.5 K respectively. At this time, there was still a strong ground-based circulation to the northwest of the teams' locations. At approximately 21:37 UTC, M1 entered the Quinter residential area and encountered periods of light to moderate rain. M1 exited the residential area and crossed the second boundary of sorts around 21:39 UTC, in which the winds shifted to a more westerly direction and the speeds increased. After crossing this feature, θ_e and θ_v continued to drop, but decreased more gradually than in the first RDF. The peak θ_e and θ_v deficits as measured by M1 and M2 at ~21:43 UTC were 17.5 K and 4.6 K respectively. Light rain and a few large hailstones (golf ball to baseball size) were observed falling and on the road as M1 and M2 proceeded north out of Quinter.

The final (and most significant) RFD boundary was encountered by M1 and M2 shortly before 21:44 UTC approximately 3 km north of Quinter. This internal RFD feature appeared to develop in conjunction with the upscale growth of the tornado that was ongoing northwest of Quinter. It was estimated that the initial measurements taken by M1 in this internal RDF surge were within 1 km of the developing larger tornado. The wind direction veered to a more westerly direction, and the wind speeds increased markedly with sustained winds in excess of 70 kts for a brief time after the

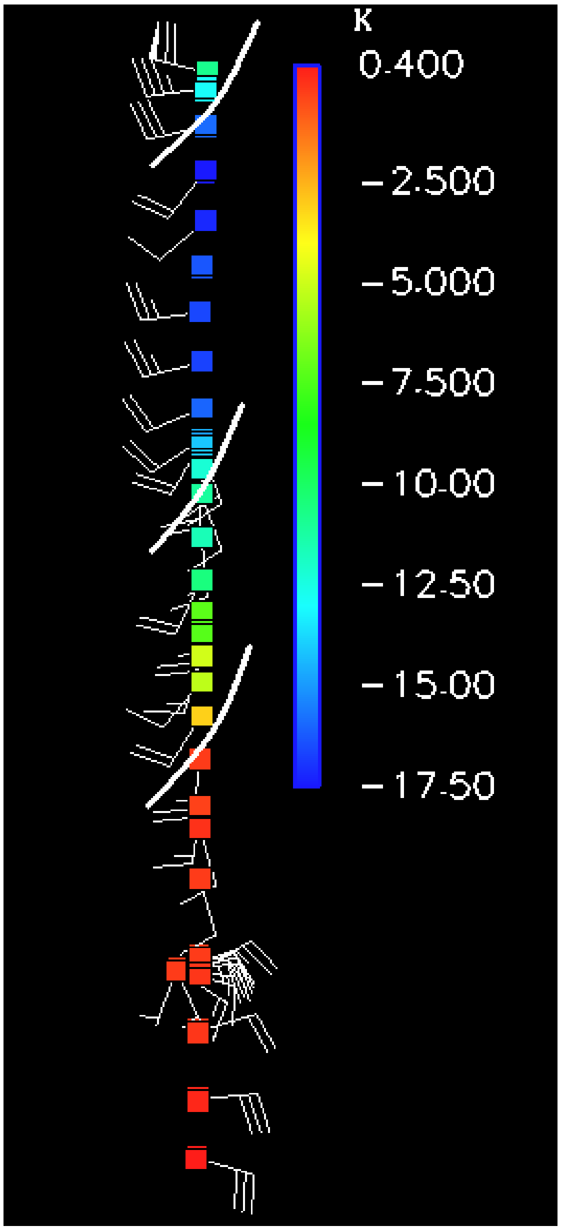

Fig. 3: M1 observation locations plotted every 30s between 21:30:00 UTC – 21:44:30 UTC. Colors denote the value of θ_e' (scale shown on right). Wind barbs denote the ground relative winds. The white lines denote the boundary crossings at 21:34, 21:39, and 21:44 UTC. Time increases from bottom to top. The distance covered by the observations is 7 km.

boundary passed. Winds were sustained between 40-50 kts for ~4 minutes following the passage of the internal surge boundary, and θ_e and θ_v increased markedly as shown in Figure 4. θ_e increased 13 K over a 3 minute period following the passage of the RFDB, and θ_v increased 2 K in the first minute, and then more gradually increased to values greater than the environmental values within 6 minutes of the passage of the RFDB. Note that there appears to be some periodicity to the fluctuations of θ_e and pressure in both M1 and M2's observations within the RFD (and in M3's observations when it joins M1 and M2 at their location) as shown in Figure 5. Since M1 is stationary throughout this time period (and M2 is nearly stationary within a half kilometer of M1), these fluctuations suggest that there may be some pulsing of the RDF, similar to what was seen in previous RDF observations (Finley and Lee, 2004).

To get some perspective of the horizontal structure of the RDF/RFDB, time-space conversion was performed on the data centered at two different times as shown in Figures 6 and 7. Prior to the development of the final intense RDF sampled by the mesonet teams, M1 and M2 passed through a weak low-level circulation as they enter the southern edge of the broader low-level mesocyclone as seen in Figure 6. The origin of this circulation is not known, but the area under and near the mesocyclone was clearly a vortex-rich environment, with one tornado developing ~ 2.5 km north of M1 at approximately 21:42 UTC, and a second tornado ongoing several km west of M1.

The upscale evolution of the second tornado was temporally coincident with the development of the strong RFD surge, which can be seen in more detail in Figure 7. Note that M3 (which is 3.2 km south of M1 at the start of the 5 minute period, and ~0.5 km south of M1 at the end of the period) is south of the RFD boundary throughout the 5-minute time period. M3 measured 30-40 kt easterly storm-relative winds through the second half of the period, indicating a strong anti-cyclonic vortex sheet existed along the southern side of the RFD. Observations from M3 and M1 taken while M3 was within ~0.5 km of M1 (but still south of the RDF) were used to calculate vertical vorticity and divergence between M3 and M1 locations, yielding values of -0.066 s^{-1} and -0.047 s^{-1} respectively. Given the strong horizontal shear and convergence along the southern side of the RDF it would not be surprising to see significant shearing instabilities develop, and M3 reported a small tornado (anticyclonic) moving from west to east between M3's and M1's locations at ~21:47 UTC. M3 finally crossed the boundary at ~21:48:30 a few hundred meters south of M1/M2, and pulled up next to M2 at ~ 21:50 UTC.

It is also interesting to note that while M1 and M2 first encountered the strong RFD push at ~21:44 UTC, all mesonet teams (once M3 crossed the RFD boundary) were clearly within the RFD air mass through 21:54 UTC. During this period, the storm was moving north-northeast at 30-40 mph. Yet throughout

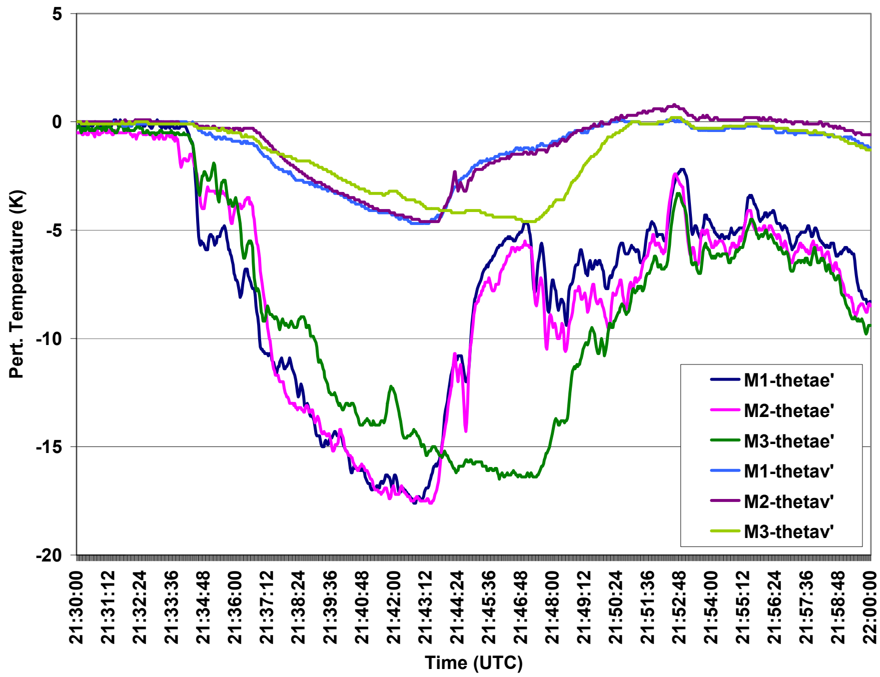

Fig. 4: Time series of θ_v' and θ_e' measured by each of the three mobile mesonet stations over a half hour period between 21:30 – 22:00 UTC. M1 boundary crossings occurred at approximately 21:34, 21:39, and 21:44 UTC.

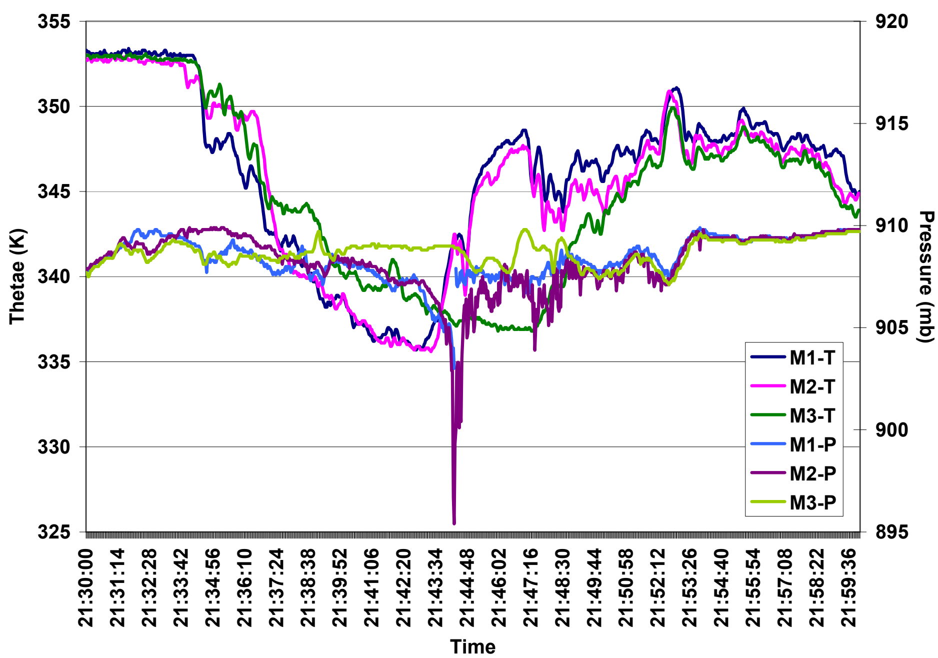

Fig. 5: Time series of θ_e and pressure as measured by each of the three mobile mesonet stations over a half hour period between 21:30 – 22:00 UTC. M1 boundary crossings occurred at approximately 21:34, 21:39, and 21:44 UTC. A strong vortex along the RFDB passed over M2 at ~21:44:15 UTC.

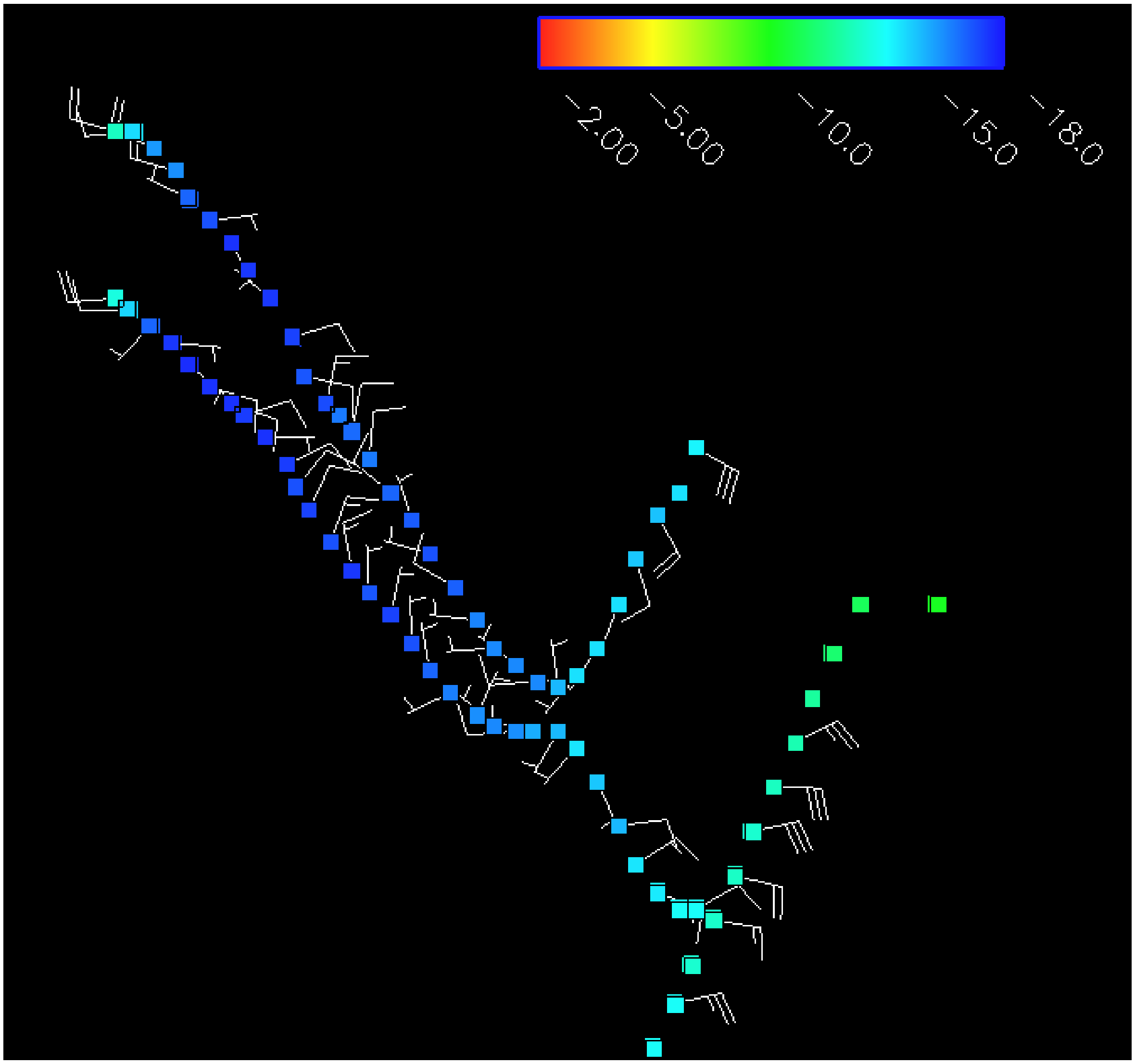

Fig. 6: Time-space conversion over a 5 minute period centered at 21:41:30 UTC. Mesonet data are plotted every 10 s. The wind barbs depict the storm-relative wind in knots. The color on the mesonet positions shows the value of θ_e' in degrees Kelvin (scale in the upper right corner). M1 and M2 are the northernmost measurement stations. Only a portion of the M3 measurements are shown. Most stations without a wind staff had wind data removed in the quality control.

the 10-minute time period, the southern boundary of the RFD appeared to remain almost quasi-stationary. M3 was northbound out of Quinter ~ 3 km south of M1//M2 at the time M1 and M2 encountered the strong RFD surge, yet M3 didn't cross the RFD boundary until it was within a few hundred meters of M1 which was stationary through the time period. Since the storm propagated northward 8-11 km during the 10 minute period (depending on the storm motion chosen), this indicates an 'upscale' growth in size of the RFD outflow as measured at the surface during the 10-minute period.

4. SUMMARY AND DISCUSSION

We have presented some preliminary analysis of the mobile mesonet data collected in the RFD region of a strong tornadic supercell near Quinter, Kansas on May 23, 2008. Three mesonet teams collected data in the RFD region of the storm through several tornadic cycles. The RFD sampled toward the end of the first tornadic cycle was cold relative to the environment, with a decrease (relative to the environment) in θ_e and θ_v of ~11 K and ~2.5 K respectively. The second boundary sampled was encountered as the mesonet teams passed through the southern edge of the low-level mesocyclone. After crossing this boundary, θ_e and θ_v continued to decrease to the coldest values measured in the 30 minute period analyzed (perturbations of -17.5 K and -4.6 K respectively). Yet in this "supposed" cold low-level environment, two tornadoes developed within 3 km of the mesonet stations. The third boundary sampled was the leading edge of a strong internal RFD surge which appeared to be associated with the upscale development of an ongoing tornadic circulation, and was sampled at fairly close range within 1 km of the tornadic circulation. θ_e and θ_v increased rapidly behind the RFD boundary, with θ_v eventually exceeding the environmental values (θ_e deficits increased to about -5 K) suggesting that the air within the RFD had little negative buoyancy and was very likely potentially buoyant. Additional work is underway to calculate proximity soundings to more accurately gage the potential buoyancy of the low-level air surrounding the tornado. However, the results presented here suggest that early in the tornado lifecycle, the RFD needs to be sampled in close proximity to the tornado to accurately gage the thermodynamic properties of the RFD.

Strong shear and convergence were measured along the southern side of the RFD boundary with vertical vorticity and divergence values on the order of -0.05 s^{-1}. A weak anticyclone tornado was observed along this boundary. If equally strong cyclonic shear existed along the northern portion of the RFD boundary

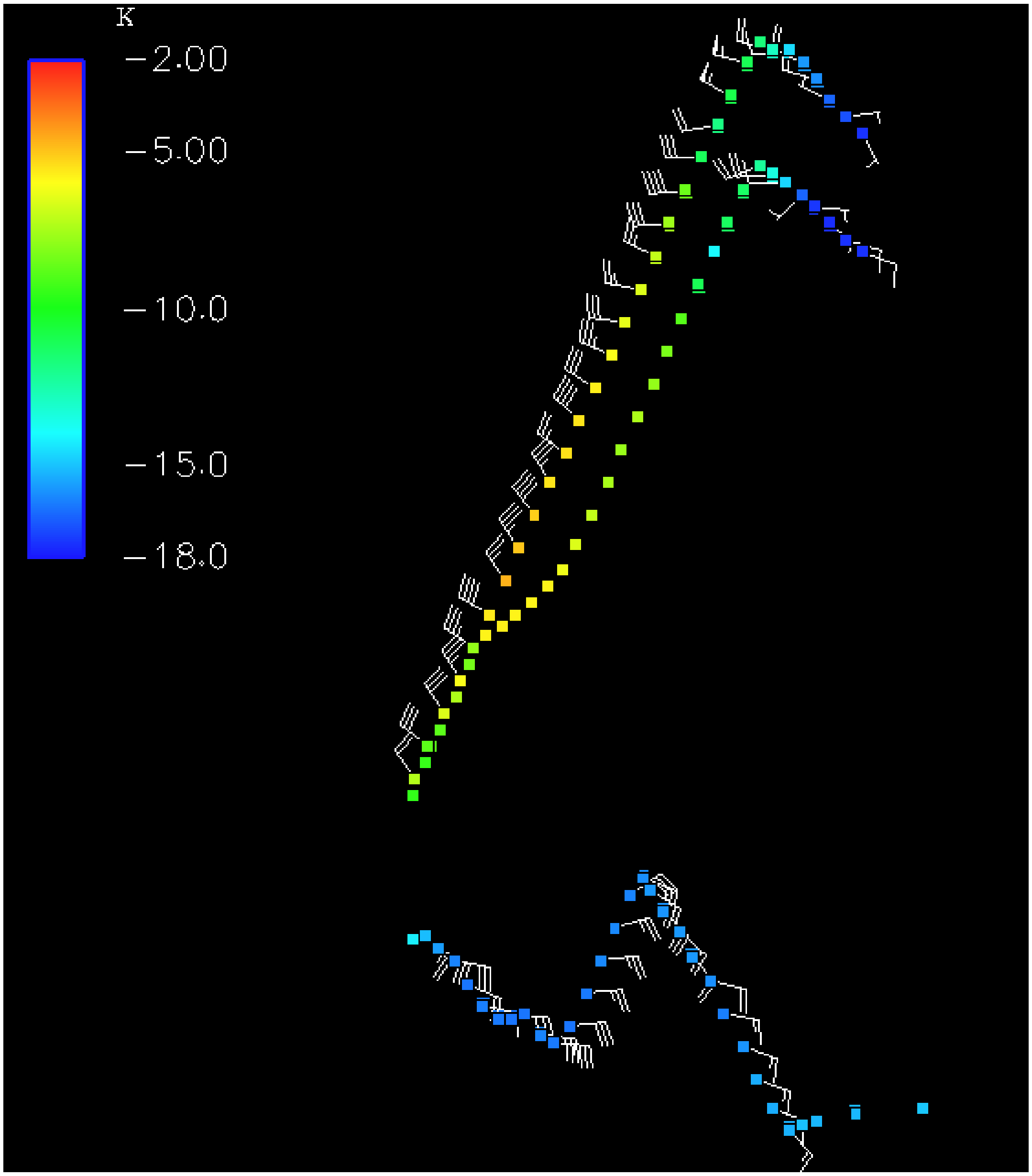

Fig. 7: Time-space conversion over a 5 minute period centered at 21:45:30 UTC. Mesonet data are plotted every 10 s. The wind barbs depict the storm-relative wind in knots. The color on the mesonet positions shows the value of θ_e' in degrees Kelvin (scale in the upper left corner). Note the sharp increase in θ_e' as measured by M1 and M2 (two northernmost stations) in the strong RFD.

and this air were feeding into the tornado, the RFD boundary could be a significant source of positive vertical vorticity for the tornado and/or low-level mesocyclone, as well as a possible source for 'seed vortices' which develop through shearing instabilities along the boundary.

5. ACKNOWLEDGEMENTS

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