Evolving Dominant Charge Structures in West Texas on 4 June 2012

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ABSTRACT: On 4 June 2012 isolated storms initiated within range of the West Texas Lightning Mapping Array (LMA) and grew upscale into a mesoscale convective system (MCS). Part of the MCS remained over the West Texas LMA and Southwest Oklahoma LMA domains until it dissipated overnight. Initial storm cells developed within a relatively dry mid-level environment and were observed to contain a mid-level positive charge and predominantly negative intracloud (-IC) flashes. Only storms with this charge structure were observed for the first 40 minutes of convection. However, later storm cells and multicellular clusters, both further east in deeper moisture and within areas that had previously been moistened by convection, were primarily observed to contain a mid-level negative charge and +ICs at upper levels in each cell. Both -IC and +IC dominated storm cells were observed simultaneously for at least 90 minutes during this transition. As this case involves many storm cells of differing charge structures over a relatively long period, it will be used to examine the utility of existing models of electrification and microphysics processes in predicting the influence of environmental controls, including temperature and moisture, on the resulting charge structure.

INTRODUCTION

One of the goals of the Deep Convective Clouds and Chemistry Experiment (DC3) field campaign in the spring and summer of 2012 was to improve our understanding of the dependence on storm electrification and lightning flash rates on other storm parameters. Of interest to this goal is how the local environment can impact the polarity of lightning in a storm, as changes in polarity may drive changes in the vertical distribution of lightning channels and therefore in mono-nitrogen oxide (NO_x) sources.

Changes in the environment could drive changes the overall storm charge structure through the dependence of noninductive charging in the mixed phase region (0°C to -40°C) between collisions of graupel and ice crystals on their relative vapor diffusional growth rates, in which the fastest growing particle gains a net positive charge, leaving the other particle with a negative charge [*Baker et al.*, 1987; *Mitzeva et al.*, 2005]. At warm temperatures with high supercooled liquid water content in the mixed phase region, the graupel (ice crystal) is expected to charge positively (negatively), while cold temperatures with little supercooled water can cause the graupel to charge negatively. As the graupel and the ice crystals separate under gravity, it is expected that, in a more moist environment, with a faster depletion of supercooled liquid water, more negative charging of graupel at mid-levels in the storm will occur, resulting in negative charge dominating the mid-levels as discussed by *Bruning et al.* [2014]. The converse is that a slower depletion of supercooled liquid water in the mixed phase region as typically associated with a drier environment will result in more positively charged graupel and a more dominant positive charge region at mid-levels. The Oklahoma-Texas DC3 domain provides the opportunity to examine concurrent storms in close proximity with different charge structures [*Sullivan et al.*, 2013].

Observational studies have shown that storm polarity does vary with the environment. Statistically it has been seen that storms with a high production of positive cloud-to-ground (CG) flashes are more likely

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to occur in regions of relatively large equivalent potential temperature (theta-e) gradients while storms with a high production of negative CG flashes occur in regions with large average theta-e values [*Carey et al.*, 2003], indicating that these storms are different both electrically and environmentally. Case studies have also shown that storms with a large rate of positive CG flashes often occur in environments which are relatively dry in the low to mid-troposphere [*Carey and Buffalo*, 2007] and these storms have more low-precipitation characteristics than their counterparts producing more negative CG flashes [*Branick and Doswell*, 1992; *Curran and Rust*, 1992], but not always [*Bluestein and MacGorman*, 1998]. It has been observed that the characteristics of the CG flashes associated with a storm can change when the storm crosses a mesoscale boundary [*Gilmore and Wicker*, 2002], and similarly, that storm cells which initiate on a weak cold front can have different inferred charge structures than adjacent cells which initiate on an outflow boundary [*Weiss et al.*, 2008].

METHODOLOGY

A convective case during the afternoon and evening of 4 June 2012 in the Lubbock, Texas area was chosen for analysis. The charge structures of storms in this event were inferred by subjective flash-by-flash analysis of the West Texas Lightning Mapping Array (WTLMA) data within 100 km of the center of the network [*Mazur*, 2002; *Coleman*, 2003; *Wiens et al.*, 2005]. Special attention was paid to updraft regions of the storms as inferred from KLBB and KAMA WSR-88D radars, visualized through WDSS-II (Warning Decision Support System – Integrated Information) [*Lakshmanan et al.*, 2007], where we expect there to be less impact from horizontal transport and mixing of hydrometeors on the observed charge structures than further away from the updraft. The CG flash polarities were also noted from the National Lightning Detection Network (NLDN) data. The surrounding environment was interrogated using archived Storm Prediction Center (SPC) analysis, GOES and Aqua satellites, archived model output for DC3, West Texas Mesonet surface observations, the nearest environmental soundings (at Midland and Amarillo, Texas) and North American Regional Reanalysis (NARR). The Texas Tech University Weather Research and Forecasting model (TTU-WRF) ensemble was one of the model outputs examined in detail. The TTU-WRF ensemble was run with version 3.3 of WRF, 4 km grid spacing, 37 vertical levels and no cumulus parameterization, so clouds were explicitly modeled.

OBSERVATIONS

Storms initiated just before 1920 UTC along a line of cumulus visible on satellite along a weak surface pressure trough associated with an east-west oriented decaying stationary front. The most significant surface temperature and dew point differences (3°C and 9°C respectively) remained north of the initial region of convection (see Figure 1), with cooler and more moist conditions further north. There was a slight west to east difference in surface dew points of approximately 3°C with the most moist air in the eastern region of convection, but the exact location with respect to the convection could not be determined given the spacing of the mesonet stations. No organized pattern was seen in the surface theta-e values. At low to mid-levels in the troposphere there was a moisture (6°C) and temperature difference (3°C) between New Mexico and Oklahoma, with drier air and warmer temperatures to the west, as shown by all upper-level analyses at the time period of initiation. The 0000 UTC run of the TTU-WRF was one of the few models to accurately predict the extent of the storms' initiation, although it displaced them slightly to the south of their actual initiation locations. It showed an extension of moisture from the Red River southwestward in the pre-storm environment, creating a gradient of relative humidity at 700 mb from northwest to southest in the region of at least 10% across a 35 km distace (see Figure 2). The 700 mb level was below the expected cloud base of 3.5 km MSL based on both the Amarillo and Midland soundings.

Initial storm cells were relatively discrete with slow westward movement, due to very weak upper level winds. By 2040 UTC new cells developed along the outflow from the original cells, which slowly moved south and eastward along the outflow. These cells formed a ragged line by 2310 UTC and continued to grow upscale, eventually leaving the WTLMA domain. The inferred charge structure in each active storm updraft showed little to no change with time (excluding during storm dissipation). However, storms had different charge structures depending on their locations. Generally, the storms could be arbitrarily grouped into four primary regions by storm morphology and dominant charge structures (see Figures 3 and 4).

Region I

Region I, on the western side of the domain, was the first with storms. They began just before 1920 UTC. The storms were discrete in nature and dominated by a mid-level positive charge and negative intracloud (-IC) flashes at upper levels. The only exception was a cell which initiated under the remains of a previous cell. The western-most storm became multicellular and moved westward out of the domain by 2100 UTC, maintaining the mid-level positive charge. This western-most cluster also contained a less active lower negative charge region and did produce a handful of +CG flashes throughout its lifetime.

Region II

In the northern portion of the domain (Region II) discrete storms initiated by 2000 UTC. This region contained many short-lived storm cells (radar reflectivity lasted less than 15 minutes) with low flash rates and a variety of charge structures. The cells in Region II which had better inflow and more orgainzed updrafts, therefore lasting longer, were dominated by mid-level positive charge and -IC flashes at upper levels. These longer lasting storms were on the northern extent of the convection within the WTLMA domain, where the surface temperatures were lower and moisture content higher than they were in Region I, even though they had a similar mid-level positive charge. The northwestern-most storms which initiated around 2130 UTC propagated northwestward along their outflows and moved out of the domain by 2300 UTC, maintaining their mid-level positive charge (see the northernmost cluster in Figure 4). The storms in Region II did not produce many CG flashes while within the WTLMA domain.

Region III

In the eastern side of the domain (Region III) discrete storms initiated around 2010 UTC. The storms in this region were relatively quick to cluster and were dominated by a mid-level negative charge and +IC flashes at upper levels. The western-most storm in this region (which initiated by 2020 UTC and can be seen in Figure 3) was long-lived, quick to intensify, and contained the highest flash rates of the discrete cells. It began to propagate along its outflow after 2100 and contained an active lower positive charge region. Throughout its lifespan this storm produced many -CG flashes. However, the storm immediately to its west, in Region II, contained a mid-level positive charge, even though the updrafts of these two storms were only separated by 10 km. This Region II storm only lasted from 2030 UTC until 2100 UTC, when it was overrun by the western Region III storm.

Region IV

The southern portion of the domain, Region IV, contained storms which initiated on the outflows of the storms in Regions I and III, starting just before 2040 UTC. These storms, like those in Region III, were dominated by mid-level negative charge, +IC flashes at upper levels and had flash rates comparable to the western-most discussed storm in Region III. This region did have some variability in charge structures between 2100 and 2130 UTC as the storms transitioned from discrete to multicellular. However as they transitioned from multicellular clusters to a somewhat linear system, the charge structure stabilized, being dominated by mid-level negative charge and +IC flashes at upper levels. At this point they system did have an active lower level positive charge region and some -CG flashes near the leading edge, which became more frequent as the storms moved eastward, while CG flashes of both polarities were observed in the trailing stratiform region. The storms slowly moved eastward and out of the region. Convection which initiated in the overturned air several hours after these storms moved out of the domain also contained this mid-level negative charge region and +IC flashes at upper levels.

CONCLUSIONS

The 4 June 2012 case in the WTLMA domain showed significant variability in charge structures of contemporaneous storms in close proximity, particularly between the discrete convection which initiated in Regions I and III. Region I, on the western side of the domain, was dominated by a mid-level positive charge layer while Region III, on the eastern side of the domain, was dominated by a mid-level negative charge layer. Most of Region I did have slightly drier conditions at the surface than Region III, which could cause different available liquid water contents in their mixed-phase regions, which could provide the expected result as discussed by *Bruning et al.* [2014] and correspond with some of the previous observations on CG polarity [*Branick and Doswell*, 1992; *Carey and Buffalo*, 2007]. However, this does not explain why the long-lived storms in Region II (with more surface moisture) had the same polarity as the storms in Region I (with less surface moisutre). The modeled humidity at 700 mb did show a difference in moisture which approximately lined up with the analyzed regions. The driest air in the domain at 700 mb corresponds with Region I and and parts of Region II, in which the long-lived cells were dominated by positively charged mid-levels. The moist air at 700 mb corresponds with parts of Region III and Region IV, in which the long-lived cells were dominated by negatively charged mid-levels. Based on the relative growth rate of hydrometeors in the mixed phase we would expect that drier conditions would be associated with enhanced positively charge graupel at mid-levels and vice versa, which could imply based on the current analysis that the below cloud-base environment can cause a significant modification on the properties of the parcels entering the cloud. The modeled nature and depth of this moist layer will be further examined in the near future along with its mechanisms for formation and possible errors in its location.

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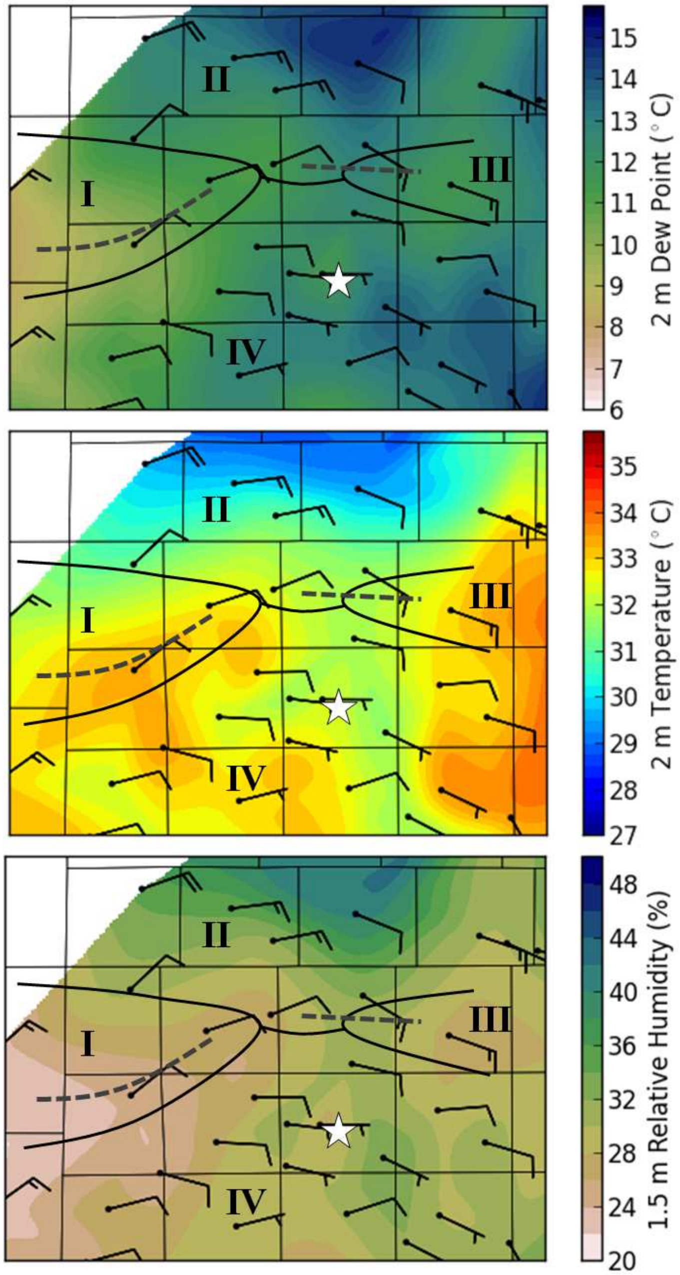

Figure 1: . West Texas Mesonet dew point temperature (above) and temperature (middle) at a 2 m height and relative humidity (below) at a 1.5 m height observations at 1800 UTC. The solid black lines mark the separation between the discussed regions. The dashed grey lines represent the initial lines of convection. For reference, the white star indicates the location of Lubbock, TX.

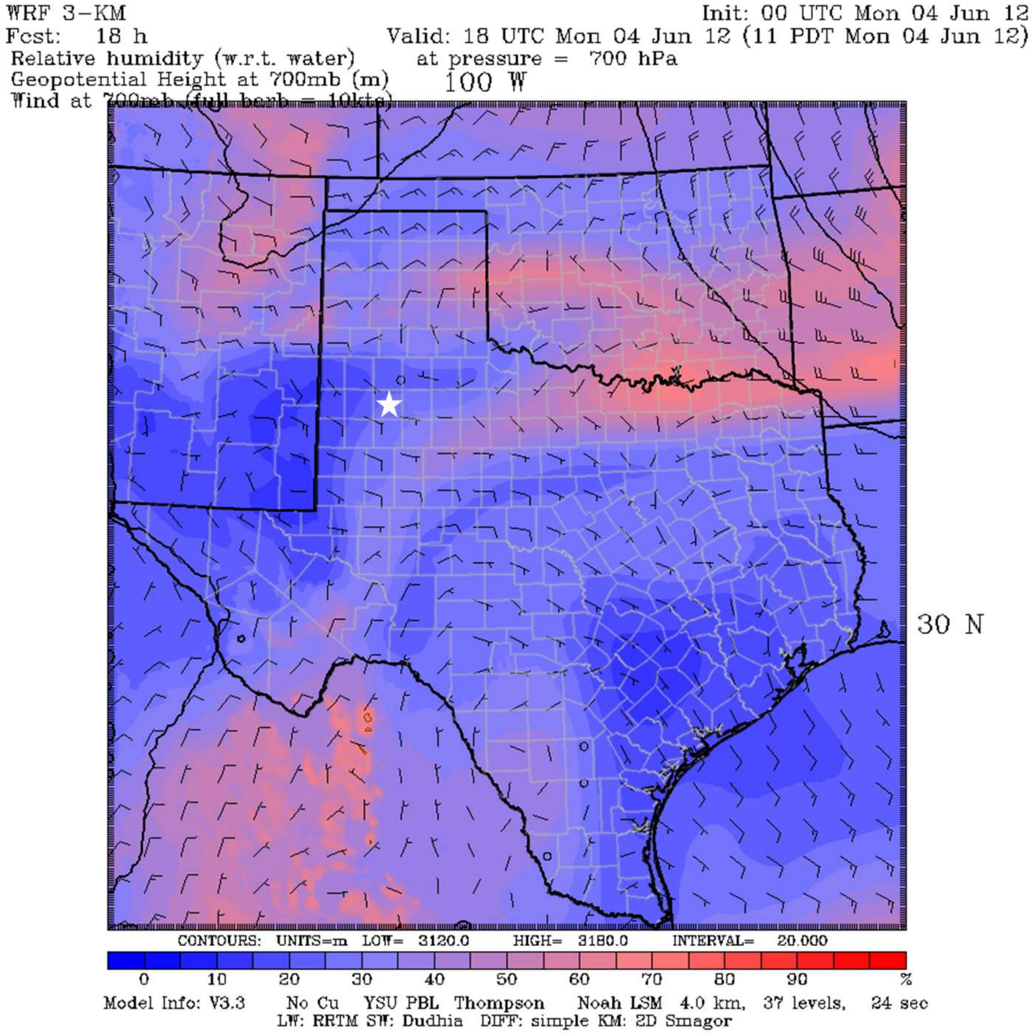

Figure 2: Average relative humidity at 700 mb at 1800 UTC from 4 km TTU-WRF ensemble initialized at 0000 UTC, 3 June 2012. For reference, the white star indicates the location of Lubbock, TX.

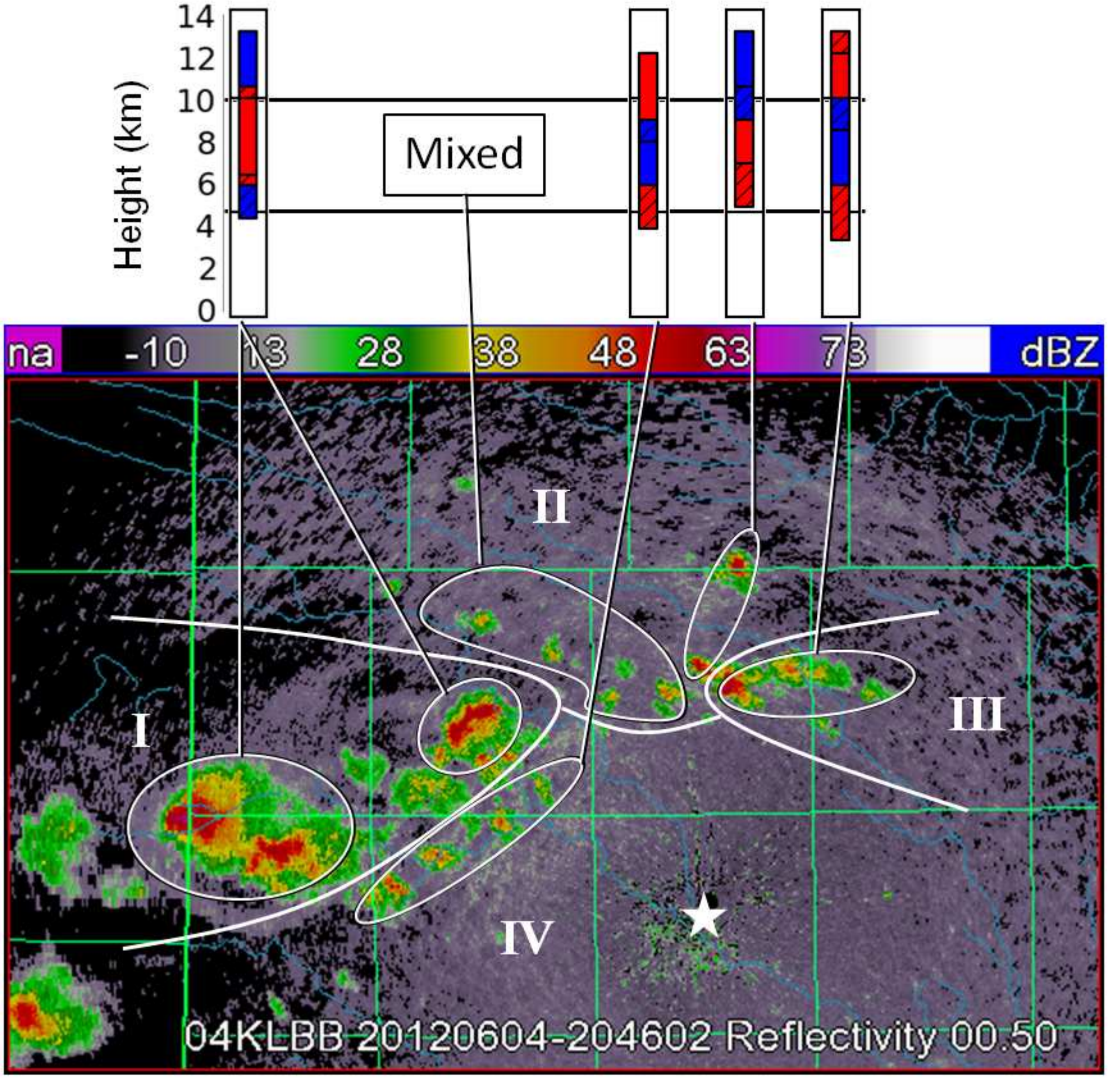

Figure 3: Reflectivity from the lowest tilt of the KLBB WSR-88D at 2046 UTC with the inferred charge structures by height (MSL) for active updrafts in the circled regions. The solid horizontal lines on the charge plot represent the environmental 0°C and 40°C levels at 0000 UTC. The red (blue) regions represent heights dominated by positive (negative) charge, with the hatched regions indicating heights with some variability between storms in the region or with time, notably the possible non-existence of a lower charge region in some storms or early in the lifecycle of a given storm as infered from the WTLMA. For reference, the white star represents the location of Lubbock, TX.

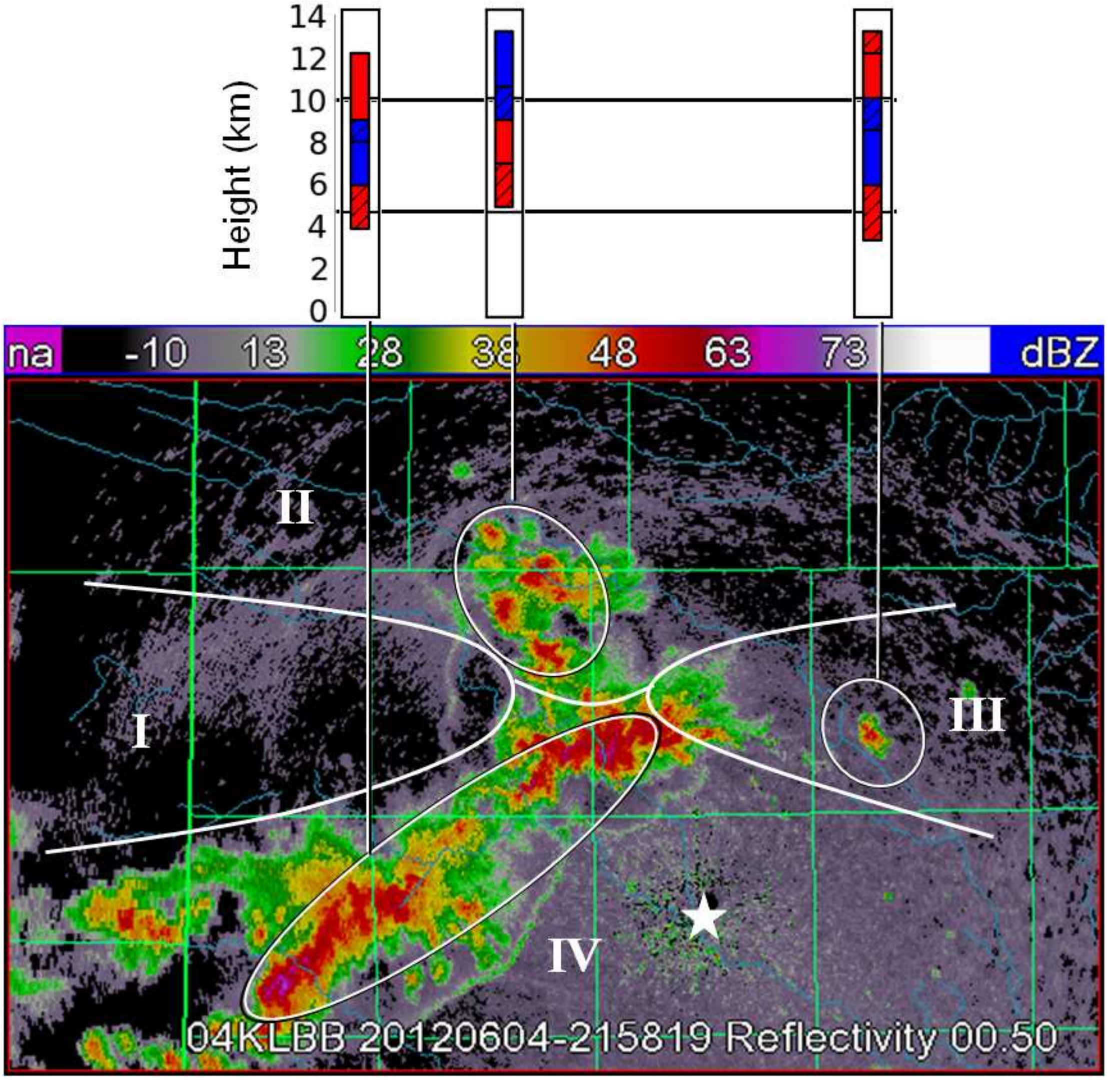

Figure 4: As in Figure 3 but at 2158 UTC.