WISCONSIN TORNADO OUTBREAK OF 18 AUGUST 2005: AN EXAMINATION OF THE VIOLA, WISCONSIN TORNADO

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ABSTRACT

On the afternoon of 18 August 2005, the largest single day tornado outbreak in Wisconsin history unfolded to the surprise of many people. This tornado outbreak spawned 27 total tornadoes, including an F2 that struck the village of Viola, Wisconsin and an F3 that hit the city of Stoughton, Wisconsin. This case focuses on the former of the above mentioned tornadoes. The tornado that struck Viola, Wisconsin touched the lives of many and miraculously nobody was injured or killed despite the millions of dollars of damage done.

I. INTRODUCTION

At around 2030Z on 18 August 2005, a squall line associated with a low pressure system and cold front produced an isolated supercell that would later move into the village of Viola, Wisconsin less than 45 minutes later. This tornado, officially rated an F2 by the National Weather Service, created 3.6 million dollars in total damage and permanently scarred the rural community by destroying thousands of trees and damaging hundreds of homes and structures. Although there was no advanced warning, no injuries or loss of life were reported. This tornado was the first significant tornado that was produced that day by this system. In all, 27 tornadoes were reported, including an F3 tornado in Dane County that took one life. This case looks to examine the mechanisms that were in place that created the first tornadoes in Vernon and Richland Counties in southwest Wisconsin.

II. DATA AND METHODS

Various software suites and programs were used to analyze various data for this case. GEMPAK was utilized to analyze upper air data from the RUC and ETA models. GARP was also used to analyze upper air data in addition to surface observations, level II and III radar data and satellite data from the NOAA GOES East imager. The visible, water vapor and 10.7 infrared channel were selected for use from the GOES East imager for their significance in this case. The software program IDV (Integrated Data Viewer) was also used to examine level II NEXRAD reflectivity and velocity data from the NWS WSR-88D radar in La Crosse, Wisconsin (KARX) and Davenport, Iowa (KDVN) as well as satellite imagery from GOES East. In addition to analysis from software programs, the National Weather Service, National Climatic Data Center and Storm Prediction Center archives were all accessed for surface analysis, storm reports and watch and warning products.

III. SYNOPTIC OVERVIEW

Surface analysis at 0900Z, 18 August 2005 indicated a developing surface low pressure center over eastern South Dakota with an associated trough extending through the Panhandle region of Texas and Oklahoma. At 12Z, the low pressure center had moved into northwestern Iowa and a surface warm front was established, stretching from the low pressure center of 1003 millibars, across the state and extending into portions of north central Illinois. The low pressure center continued to move northeastward into southern Minnesota at 15Z and a cold front was beginning to develop over western Iowa and eastern Nebraska. By 18Z, the low pressure center had moved into southeastern Minnesota and the frontal structure became more defined. The warm sector of the storm, located in east central Iowa, was defined by temperatures in the mid 80’s with dewpoints in the low to mid 70’s. The low continued to move to the east northeast and deepened to 1002 millibars by 21Z [Figure 1]. The low was centered near La Crosse, Wisconsin and the warm front had moved through southwest and south central Wisconsin,

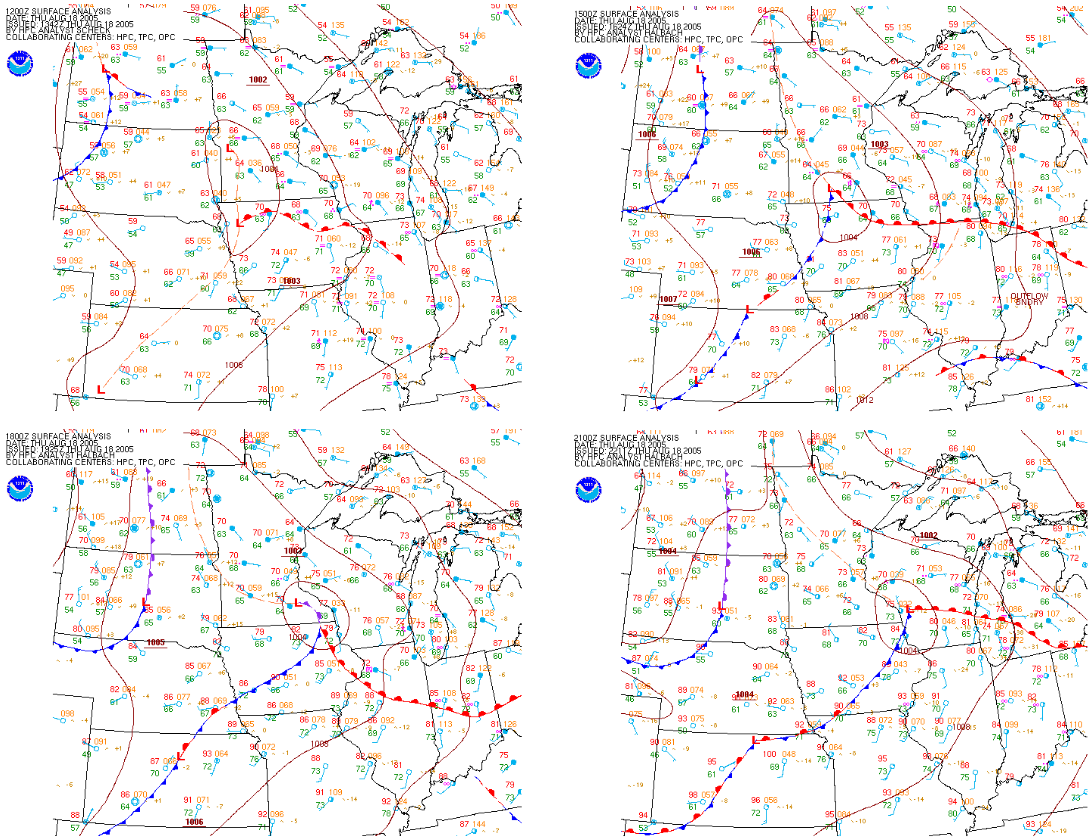

Figure 1: North Central surface analysis from the National Weather Service for 18 August 2005. Times shown; 12Z (upper left), 15Z (upper right), 18Z (lower left) and 21Z (lower right). Analysis shows developing frontal low pressure system and evolution.

bringing warm temperatures in the mid 80's and dewpoints in the mid 70's. The cold front at this time extended from the low pressure center through central Iowa where it became a stationary front extending through central Kansas. South to southwest winds were observed ahead of the storm in the warm sector, while northwesterly winds were observed behind the cold front. The southerly winds ahead of the system provided for surface moisture transport in to southwest Wisconsin, as some dewpoint observations over eastern Iowa were in the upper 70's after the passing of the surface warm front [Figure 2]. The wind shift appeared to be the greatest change associated with the cold front, as temperatures ranged in the low 80's over Iowa with a slight dewpoint drop as well.

The 850 millibar analysis showed an area of strong temperature advection over Iowa stretching into southwest Wisconsin at 12Z. This advection was at the base of a geopotential minimum extending from the prairie provinces of Canada southeastward into northern Iowa. By 18Z the geopotential field had a local minimum associated with the surface low pressure over southern Minnesota. Winds at this level were also out of the southwest and much stronger than at the surface, indicating the presence of vertical speed shear and weak directional

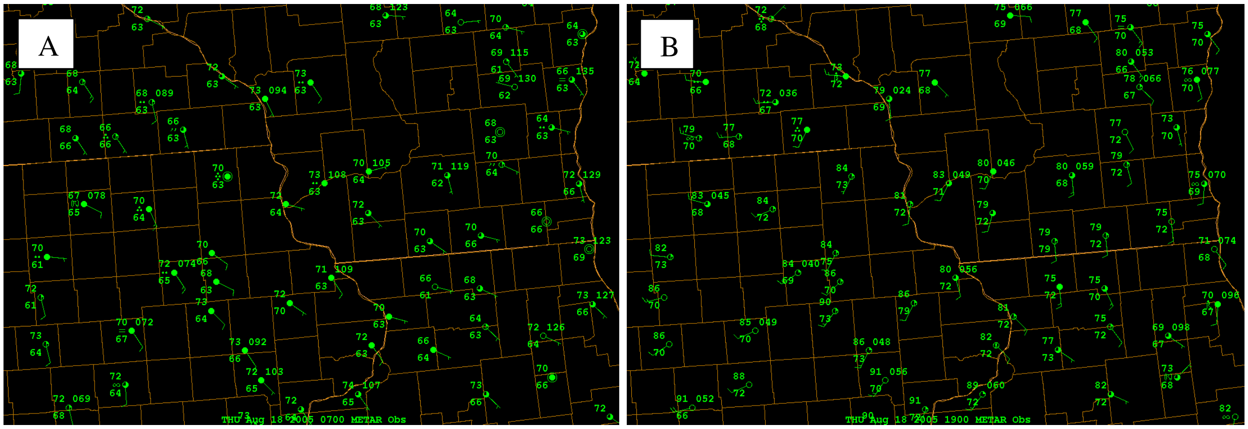

Figure 2: GARP surface observations taken at A) 0700Z and B) 1900Z, 18 August 2005 showing the increase in surface dewpoint temperatures (F) after passage of MCC and warm front due to residual high theta-e and moisture transport from central Iowa.

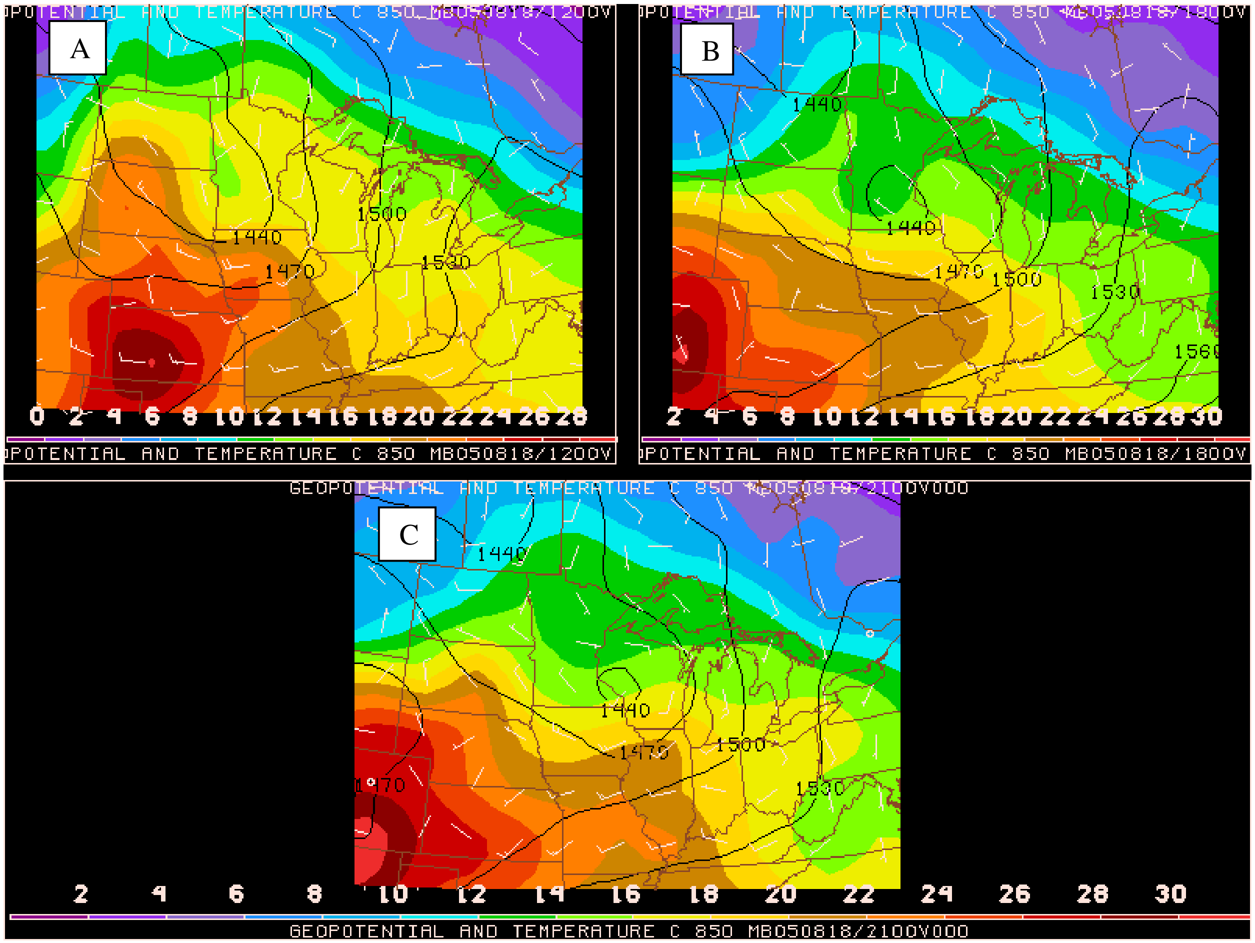

Figure 3: 850 RUC model analysis showing geopotental contours and filled contours of temperature from 18 August 2005 at A) 12Z, B) 18Z and C) 21Z. Analysis indicates WAA ahead of the low pressure at 12Z and a geopotential minimum over SW Wisconsin at 21Z.

shear over portions of south central Wisconsin, where surface winds were out of the south to southeast. At 21Z the geopotential minimum had pressed into far western Wisconsin with the associated warm air advection occurring farther to the east, over southeast Wisconsin as well as over Lake Michigan [Figure 3].

A shortwave trough was identified at 700 millibars and was echoed in the 500 millibar analysis. The shortwave was positioned over eastern South Dakota at 09Z and was associated with a strong vorticity maximum. The vorticity maximum and shortwave progressed to the east without losing intensity and was positioned over central Minnesota at 15Z. The shortwave and vorticity maximum were positioned slightly to the west of the surface low indicating a slight westward tilt with height of the system, indicating that the system was not weakening and possibly was strengthening. By18Z, about the time thunderstorm initiation that produced the first tornadoes, the vorticity maximum had weakened slightly and elongated over eastern Minnesota and western Wisconsin. The main axis of curvature, however, was located along a line from Minneapolis, Minnesota southeastward to Peoria, Illinois. At 21Z, the vorticity maximum had re-strengthened and the base of the shortwave had moved into extreme western Wisconsin. This ball of vorticity and associated curvature was located over the line of convection that spawned the tornadoes in Vernon County around 21Z [Figure 4].

The 250 millibar level showed a southwest to northeast oriented subtropical jet stretching from the Rockies to central Iowa at 12Z. The left exit region provided upper level divergence over northern Iowa which aided in the development of showers and thunderstorms that moved into southwest Wisconsin. The jet exit region pushed east of the area of focus by 18Z, but by 21Z, the exit region was positioned over southwest Wisconsin where thunderstorms were developing [Figure 5]. This provided necessary mass divergence at upper levels to allow for rapid and intense thunderstorm growth below.

Along with mass column divergence associated with the left exit region of the sub tropical jet, the surface low and associated fronts provided the required lift at the surface to initiate thunderstorm development over the area. This development was further aided by a vorticity maximum associated with a shortwave trough at 500 millibars and wind shear between the surface, out of the southwest, and at 500 millibars, out of the west. The combination of ample moisture, a strong lifting mechanism and positive vorticity advection by the thermal wind at mid levels created a synoptic situation that was favorable for the development of showers and thunderstorm. Why the storms spawned so many tornadoes is a question that cannot be answered by synoptics alone. In order to provide insight to this question, subtle mesoscale processes needed to be examined.

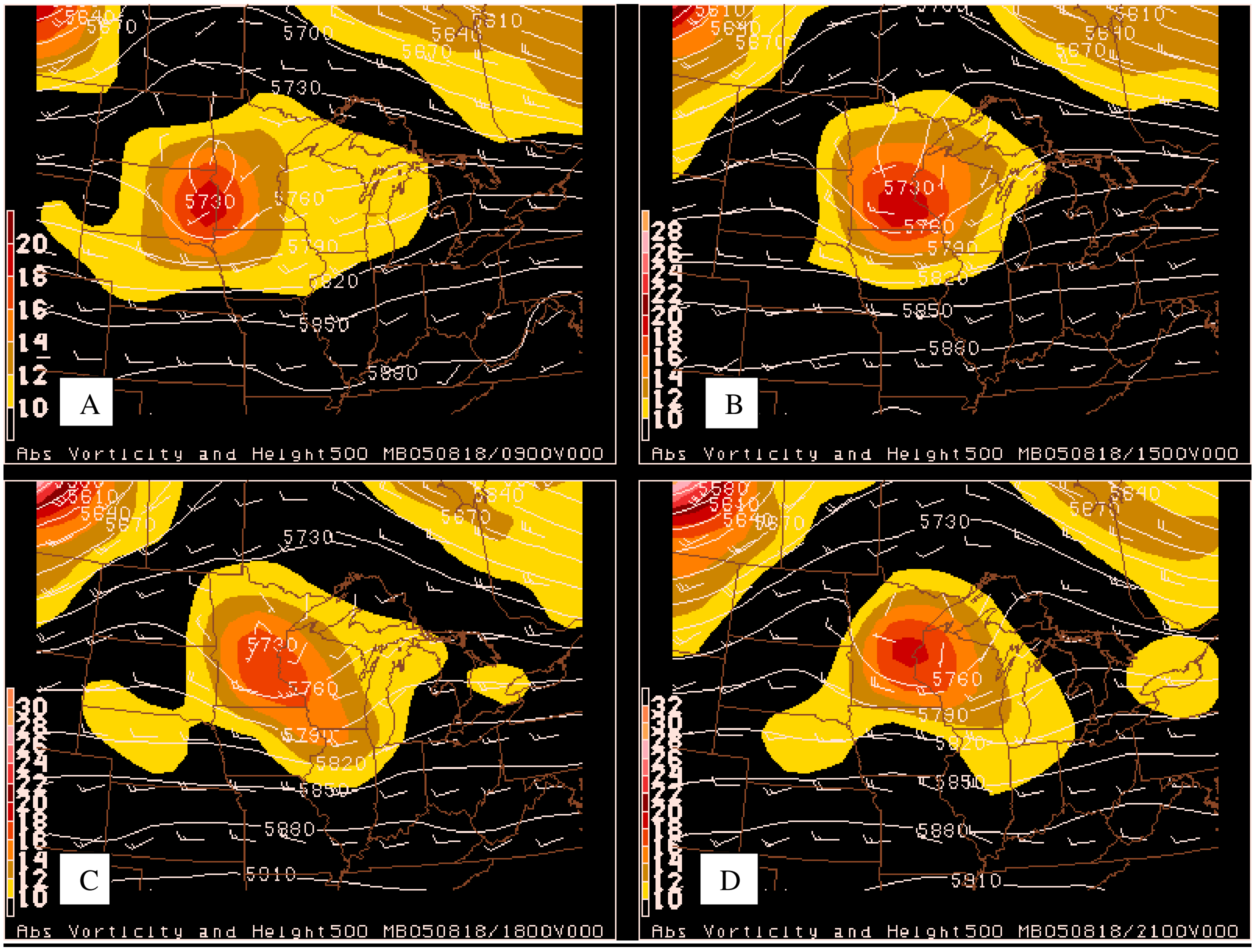

Figure 4: 500mb geopotential and filled contours of absolute vorticity from 18 August 2005 at A) 09Z, B) 15Z, C) 18Z and D) 21Z. The reader will note positive vorticity advection over southern Wisconsin during thunderstorm development at 18Z and 21Z.

IV. MESOSCALE ANALYSIS

The precursor to the severe weather event was an MCC that developed over the western border between Minnesota and Iowa, and moved into the tri-state area (southeast Minnesota, northeast Iowa and southwest Wisconsin) by 08Z. This complex strengthened and organized into a bow echo that produced severe thunderstorm winds in Lafayette County in southwest Wisconsin around 1230Z [Figure 6].

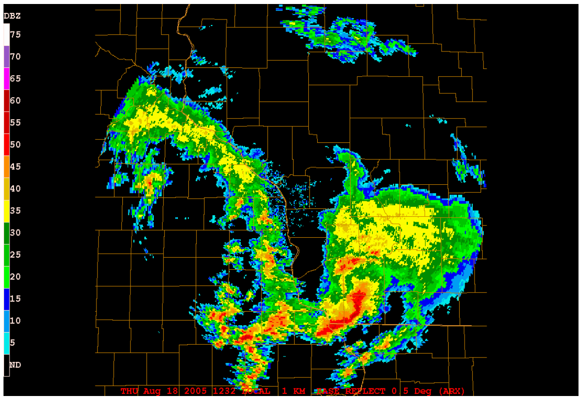

Figure 6: NEXRAD radar base reflectivity from the National Weather Service Radar in La Crosse, WI (KARX) showing the eastward propagating thunderstorm complex and bow echo over Lafayette County at 1232Z, 18 August 2005.

This thunderstorm complex moved out of the area along the warm front by 15Z and in its wake left moist soil and eventually clear skies. Surface observations taken over the tri-state area indicated a spike in dewpoint temperature after the passing of this complex. This spike was attributed to evaporation due to clear skies and surface warming, in addition to the warm frontal passage that brought about a southwesterly flow drawing warm moist air into the area from eastern and central Iowa. Because this event took place in mid-August, large corn fields over central and eastern Iowa typically produce large quantities of atmospheric moisture due to evapotranspiration. This phenomenon was more than likely responsible for the flux of moisture into the area after the passing of the warm front [Figure 2].

Another key surface forcing mechanism was the presence of an outflow boundary caused by the departing MCC. This outflow boundary was positioned ahead of the cold front and was associated with high theta-e and mixing ratio values remaining from the departing thunderstorms Figure 7].

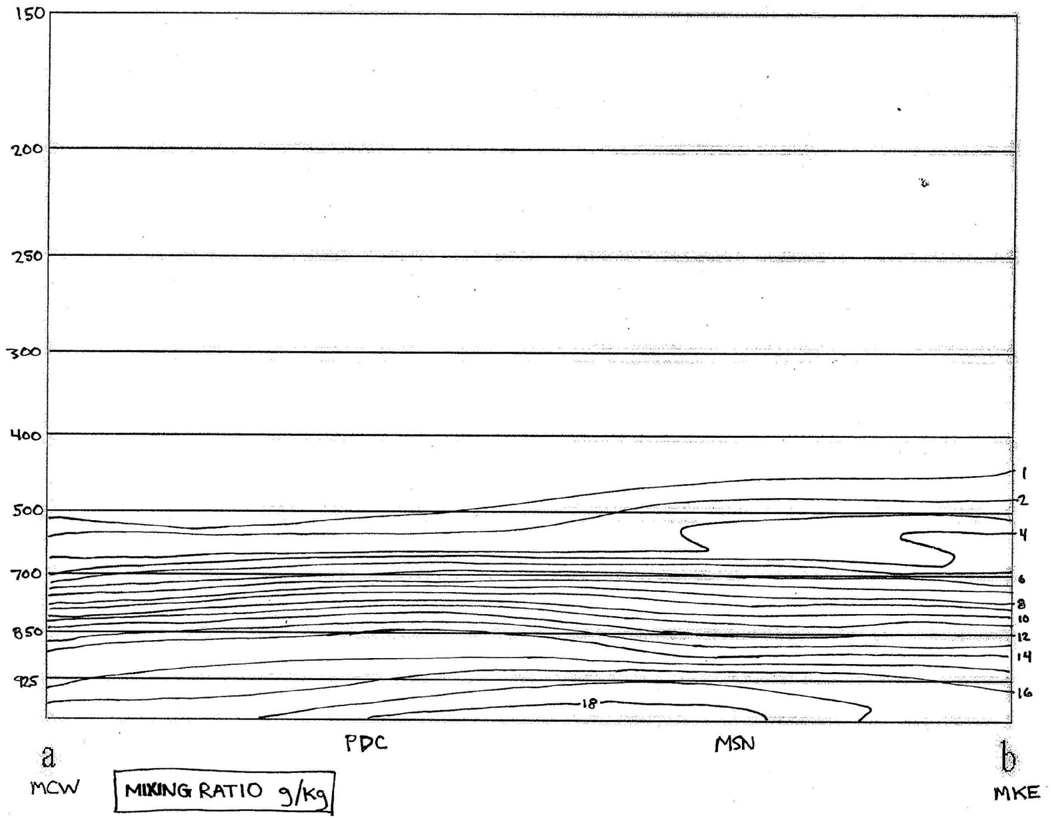

Figure 7: Hand drawn cross section from Mason City, Iowa to Prairie Du Chien, Wisconsin to Madison, Wisconsin to Milwaukee, Wisconsin at 2100Z, 18 August 2005 showing mixing ratio in the area of thunderstorm development.

Portions of this area of high theta-e and high mixing ratio air were positioned over Vernon and Richland Counties, precisely where the storms became tornadic [Figure 8]. As the cold front approached, winds from the southwest pushed the outflow boundary and associated theta-e maximum to the east and aligned with the cold front. This outflow boundary also helped to accentuate the surface convergence present

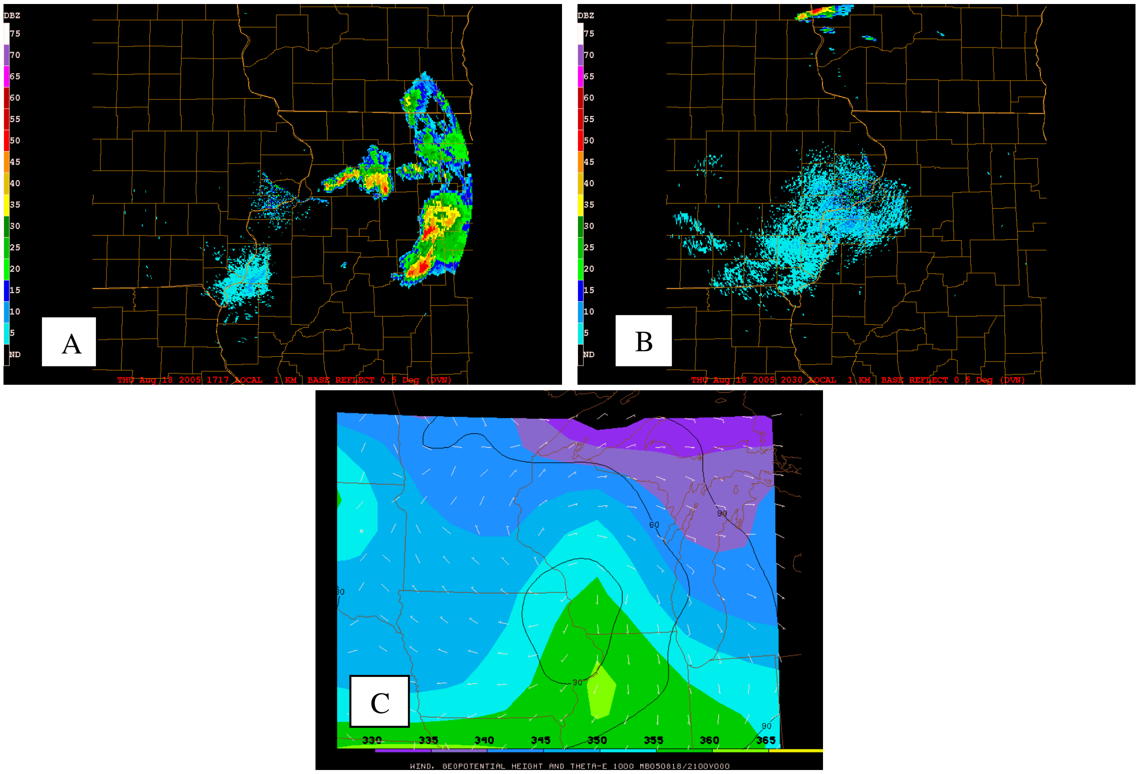

Figure 8: 8A shows developing outflow boundary from departing MCC near National Weather Radar site in Davenport, Iowa (KDVN) at 1717Z. 8B shows outflow boundary stretching from the radar site to central Crawford County, WI and developing showers and storms south of the main cell structure at the top of the image at 2005Z. 8C shows surface winds and filled contours of theta-e being advected into the area of thunderstorm development at 21Z

ahead of the developing low [Figure 9].

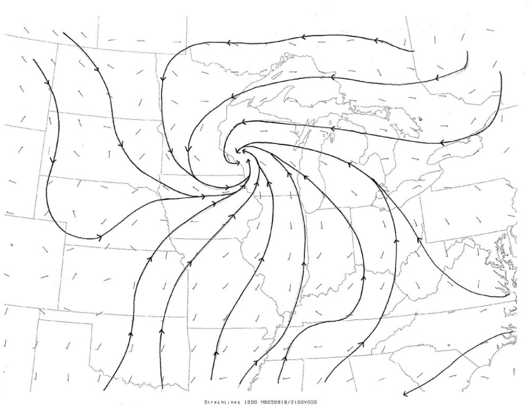

Figure 9: Hand streamline analysis at 1000 millibars at 2100Z, 18 August 2005.

This surface convergence helped to force mass into the area and thus helped to create vertical motion. This convergence was echoed at the jet level as divergence aloft.

Aloft, dry air had positioned itself over the region and subsequently over the moisture rich boundary layer. Satellite imagery as well as model derived sounding data verified the presence of dry air aloft. The dry air aloft provided a small cap that allowed for the boundary layer to heat and moisten throughout the day. This situation created a sounding favorable for the explosive development of thunderstorms [Figure 10]. As the cap broke in the presence of the advancing cold front, moist warm air was able to convect upward explosively, creating rapidly developing, and rotating, thunderstorm in the presence of directional shear at mid to low levels.

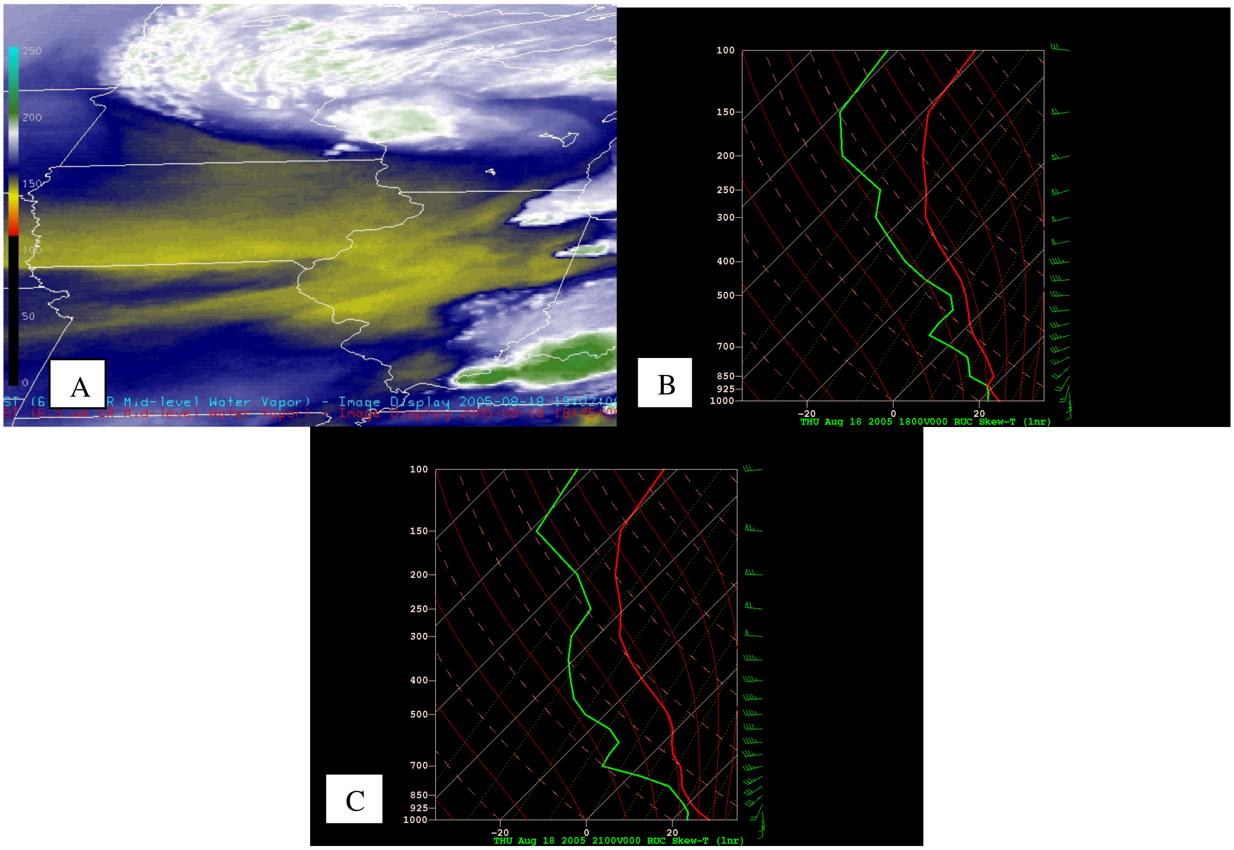

Figure 10: 10A) GOES East mid-level water vapor channel at 4km resolution depicting dry air at mid levels at 1845Z, 18 August 2005. RUC model derived soundings depicted at 18Z and 21Z for figures B and C respectively showing weak cap and dry air aloft.

In order to produce strong, long lasting thunderstorms, shear needed to be present at low and mid levels. Strong speed shear was observed over the region between surface winds and winds at 850 millibars. Surface winds were observed around 5 knots while winds at 850 millibars were around 15 knots. This speed shear is critical in the production of thunderstorms and allows for the production of slantwise convection necessary for maintaining an updraft and a downdraft in a thunderstorm. This speed shear helped form the initial pre-frontal squall line over far southeast Minnesota that pushed into areas of western Vernon County Figure 11].

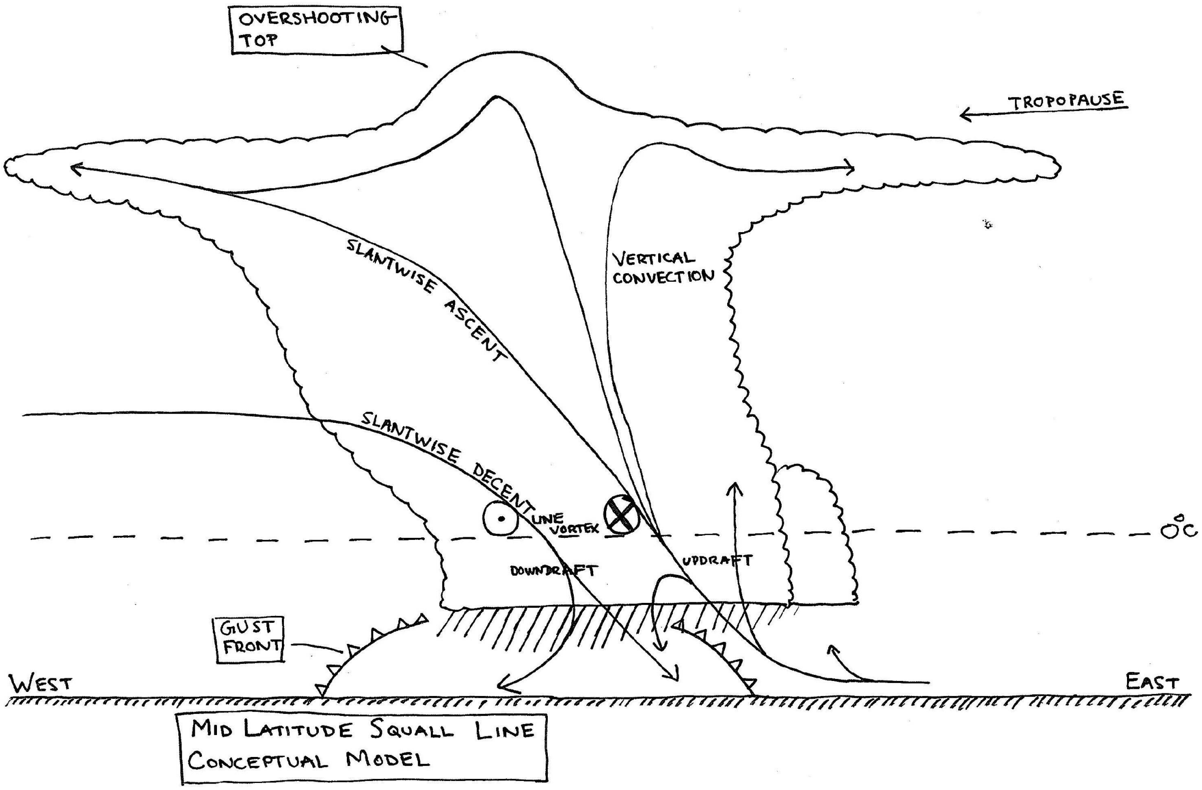

Figure 11: Hand drawn conceptual model of a mid latitude squall line present in this case. The reader will note the slantwise convection and vortex sheet.

This speed shear was also complimented by directional shear between 850 and 500 millibars. Winds out of the west at 500 millibars and winds out of the south-southwest at 850 provided sufficient shear to produce rotation, in the form of a mesocyclone, within the thunderstorms. The mesoscale formation was critical in preventing dynamic entrainment into the storm which would have weakened and killed the storm. Because there was directional shear at mid levels, dynamic entrainment was prevented and the supercells that had formed were allowed to last for a long duration.

As the thunderstorms moved into western Wisconsin, the bow echo squall line began to form into a singular supercell on the south side of the line at the time a weak tornado was reported at Esofea, Wisconsin at 2046Z. This supercell formation was likely caused by the vortex sheet associated with the squall line balling up at the south end, creating a mesocyclone. This small supercell spawned a larger supercell to its southeast and this cell became a right moving supercell. This right movement was favored by the marginal helicity values identified by the NWS sounding from Davenport, IA at 12Z.

As the new supercell moved away from the line, the southern end of the squall line dissipated and the supercell became more intense. Radar imagery began to show signs of a hook echo or embryo curtain [Figure 12]. This indicated that the mesocyclone associated with the thunderstorm was drawing precipitation around the south side of the storm. A velocity scan verified a mesocyclone in the same vicinity as the hook and using basic trigonometric methods, the mesocyclone was calculated to reach over 8800 meters up from the surface. Located within the embryo curtain were high values of radar reflectivity indicating that large hail also accompanied this storm and was indicative of a very strong updraft, manifest in the tornado and mesocyclone.

The strength of the mesocyclone was indicated by the long life of this supercell. Because of the strong rotation of the mesocyclone, an inertial wall was created that prevented dynamic entrainment of dry air into the storm. As the storm moved out of the Richland County area, it weakened leaving millions of dollars worth of damage in its wake.

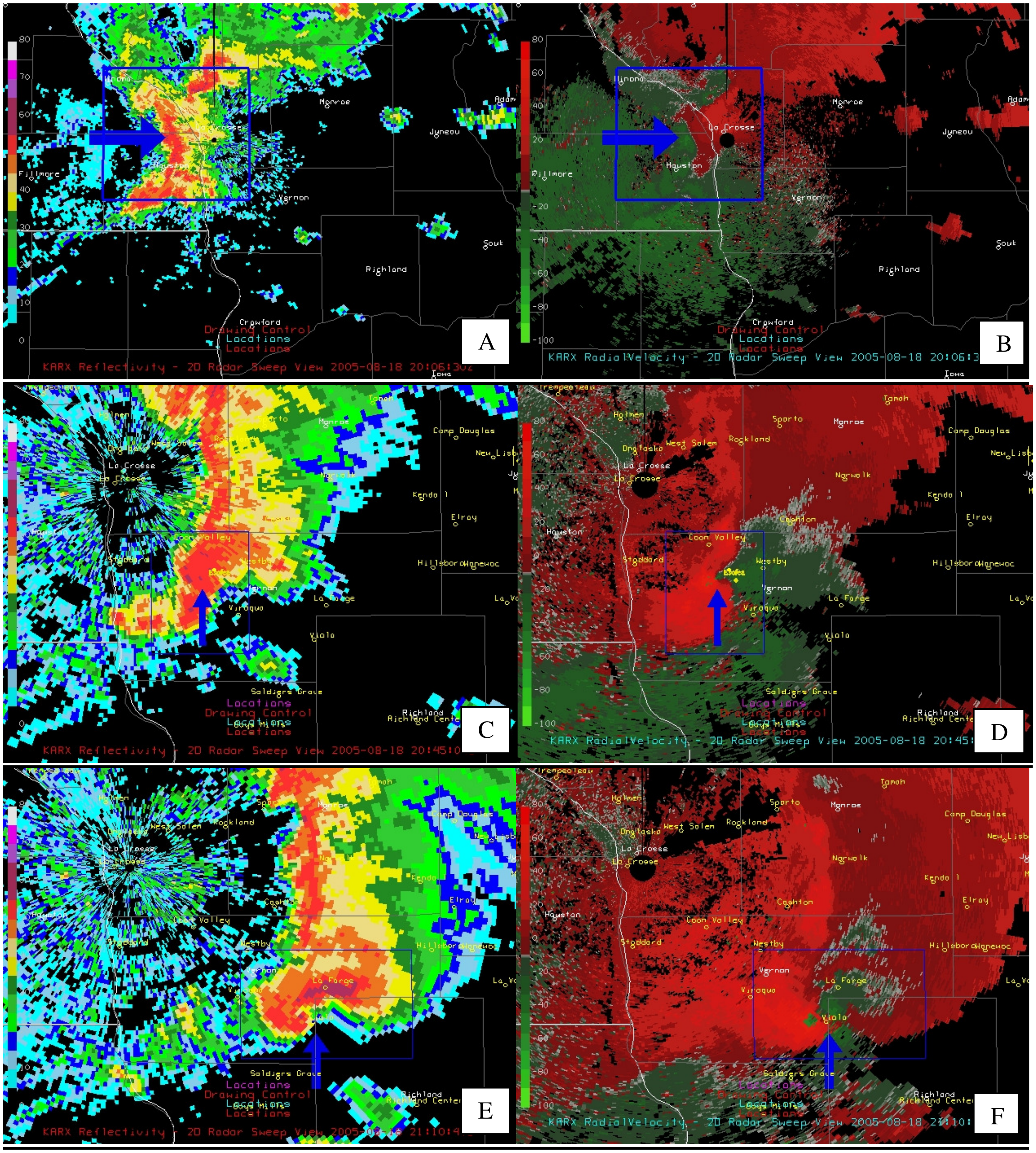

Figure 12: Figures 10 A and B show KARX base reflectivity and base velocity respectively. Blue boxed region indicates bow echo and arrow indicates an area of strong downdraft as indicated by radar at 2006Z. Figures 10 C and D show the same line of thunderstorms begin to spawn a right moving thunderstorm at eh south side of the line caused by the balling of line vortex near Esofea, Wisconsin. Base reflectivity and velocity are shown respectively. Figures 10 E and F show mature hook echo with hail core positioned over La Farge, Wisconsin indicating reflectivity upwards of 60dBz and a strong mesocyclone with velocity scale folding near Viola, Wisconsin respectively.

V. CONCLUSION

The system responsible for the tornado that struck Viola, Wisconsin on 18 August 2005 was a developing low pressure system associated with a mid level shortwave and vorticity maximum. This system created a MCC that moved over the area during the early morning hours of 18 August. This complex provided an outflow boundary for lift and high moisture content at the surface. Dry air aloft provided a weak cap that allowed the surface to heat due to daytime heating, and to moisten due to southwesterly winds transporting moisture into the area. Once primed, the combination of the cold front and outflow boundary provided the necessary force to break the weak cap and produce strong rapidly developing thunderstorms.

As the cold front advanced to the east, a squall line developed ahead of the front. As the squall line moved to the east, it encountered an area of enhanced theta-e at the surface as well as mid level directional shear. This allowed for the vorticity sheet associated with the squall line to ball up at the southern end of the line creating a supercell thunderstorm that ravaged the village of Viola.

Severe weather indices taken from Davenport, Iowa, just ahead of the cold front at 00Z, 19 August indicated surface based CAPE values near 3000 with CIN values of -13. In addition to the favorable thermodynamic values, helicity at 18Z was at 206, indicating strong shear in the environment. Because the ingredients for tornadic thunderstorms were marginal, few people saw the outbreak that materialized coming. In fact, the supercell that created the tornado in Viola was not issued a warning for until after the tornado had struck the village by the National Weather Service in La Crosse, Wisconsin.

Overall, the tornado that struck Viola, Wisconsin came as a surprise to forecasters and citizens alike. Although the tornado caused significant damage, it was the first of many and led forecasters downstream of this tornado to provide warnings well in advance of the other tornadoes that would develop that day.

VI. ACKNOWLEDGEMENTS

My biggest thanks goes to Professor Steve Ackerman, Mark Kulie and Pete Pokrandt for providing me with the necessary satellite, radar, and upper air data necessary for this case. Another special thank you goes to President Michael Geary of the Village of Viola for providing me with photos and eye witness accounts of the tornado and damage accounts. Without these people, this case study would have not been possible. Thank you.

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