P10.18 *ORIGINS OF THE GRANITE FALLS, MN TORNADO, JULY 25, 2000 REVISITED*

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1. INTRODUCTION

On July 25, 2000 an F4 tornado occurred at Granite Falls, Minnesota around 23:20 UTC (6:20 PMCDT). Both WSR-88D radar imagery from MPX (Chanhassen, MN, located about 100 miles to the east), along with visible and IR GOES satellite imagery show that a storm interaction or merger occurred between a supercell on the south end of a squall line moving east and a second band of convection on the leading edge of left mover rapidly splitting off from a supercell that first developed in extreme eastern South Dakota about 43 nautical miles due west of Granite Falls between 2210 UTC and 2225 UTC. The interaction occurred between 2247 UTC and 2302 UTC while the response to storm merger became evident between2302 UTC and 2315 UTC on GOES IR data when a spike occurs in the overshooting storm top of the supercell near Montevideo at 2315 UTC. GOES IR data displays a rather dramatic collapse of the supercell top between 2315 UTC and 2325 UTC during the time of the Granite Falls tornado. It appears that during the 20 minute time period leading up to the storm merger, storm-relative inflow for the supercell approaching near Montevideo, MN (about20 miles northwest of Granite Falls) was greatly enhanced due to the advancing left mover along with the outflow on the leading edge of the left mover over the border between Yellow Medicine, Lincoln and Lyon Counties. An accelerated influx of warm and moist air likely developed into the right rear flank of the supercell near MVE as the inflow wedge between the two convective systems was gradually pinched off. This in turn led to an updraft pulse into the supercell and the observed intensification of its overshooting top. Associated with the overshooting top was an arching environmental vortex tube that originated at ~24,000ft and arched to ~34,000ft. As the inflow wedge pinched off, support for the updraft was rapidly cut off and the storm top collapsed suddenly between2315 UTC and 2325 UTC leading to the Granite Falls tornado; note the warming of the storm top from a range of –55ºCto –60ºC to a range of –38ºC to –47ºC over this time span. In addition to the above, we also believe that enhanced mid-level flow (i.e. at 10K to 20K aboveground level) from the left mover southwest of the supercell near MVE may have dynamically performed the same role of a supercell rear flank downdraft and may have been the catalyst for strong mesocyclogenesis in the boundary layer making a storm of the magnitude of Granite Falls possible.

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2. ADDITIONAL DATA

Using 0.5º elevation WSR-88D (MPX) radar data, (A) the mean speed (22 kts) and direction (290º)* for the supercell over Lac Qui Parle County was estimated between 2232 UTC and 2302 UTC by following the area of tightest reflectivity gradient on the southwest flank of the storm cell (i.e. near the probable location of the storm updraft) and (B) the mean speed (42 kts)** and direction (260º)** of cell movement, on the east side of the left mover described above was estimated between 2242UTC and 2257 UTC up to the approximate time of cell merger.

* an aerial survey of storm motion out of Lao Que Parle county Minnesota was from 295º.

** reflectivity returns for 0.5º and 1.5ºelevation averaged between 25 and 35 dbz and were 35 to 45 dbz for 20minutes leading up to storm merger (representing a layer between 5 kft above ground level and 27 kft aboveground level).

3. ARCHING VORTEX LINES IN NUMERICAL MODELS OF SUPERCELLS AND MERGERS OF SUPERCELLS.

The modeling of storm mergers clarifies the sequence of events observed in the Granite Falls storm merger. As the modeled storms merge (Fig. 1 - 3) the left mover of the southern storm moves north into the right mover of the northern storm. The first response to the merger is the development of convection in the mid levels and the development of a mid level mesocyclone. The arching vortex lines (in white) associated with the mid level mesocyclone can be seen in Fig. 4. Subsequent development of precipitation and an associated gust front generate vortex lines near the surface that are captured by the updraft and tilted into the vertical. The code of the numerical weather-modeling tool called ARPS (The Advanced Regional Prediction System) was modified to produce two storms. Numerous simulations of storm mergers were performed. The storms merged but did not always produce strong low-level rotation. However with the proper relative positioning of the storms, and storms in the correct phase of their life cycle, the mergers lead to strong low-level rotation. This rotation was linked to arching vortex lines formed near the surface along a bulge were gust-fronts of the two storms merged. As the vortex lines lifted over the gust-front they were captured by a low level updraft and stretched up through the storm. Precipitation or evaporatively cooled downdrafts appeared to pin down the ends of the arching part of the vortex lines to the ground.

The downdrafts surrounded the backside of the main updraft tower of the storm.

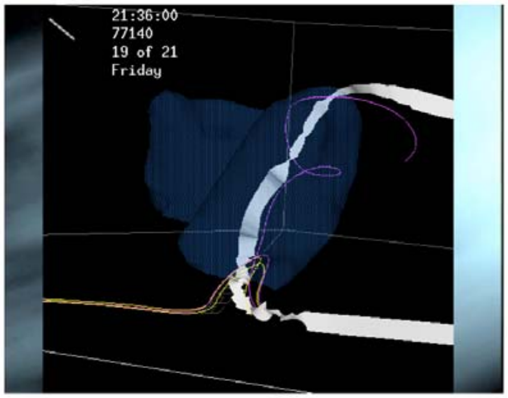


Fig. 1 Above is a single storm with arching vortex lines: The blue is the 20m/s updraft isosurface. The white ribbon is a streamline. The colored lines are the arching vortex lines.

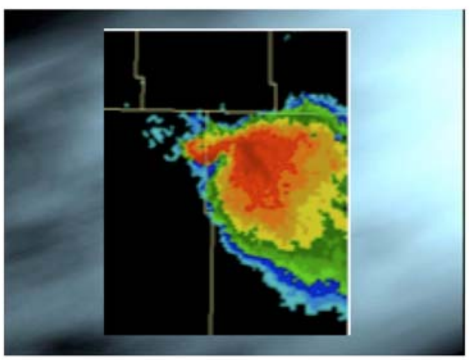


Fig. 2 Radar image of counter rotating vortices associated with a tornadic North Dakota storm of July 18, 2004 (Grafenauer 2005).

3.1 Storm merger

The following frames (Fig. 3-5.) show a two-storm run that produces a merger. The simulations were done with ARPS and use the Del City, May 20, 1977 sounding. The storms are placed in a 67 km by 67 km grid positioned at (18, 48) and (48,18). The following frames show the cold pools merging and the development of counter rotating vortices in the region where the two storms merge. These are not at the surface rather these are associated with environmental vorticity.

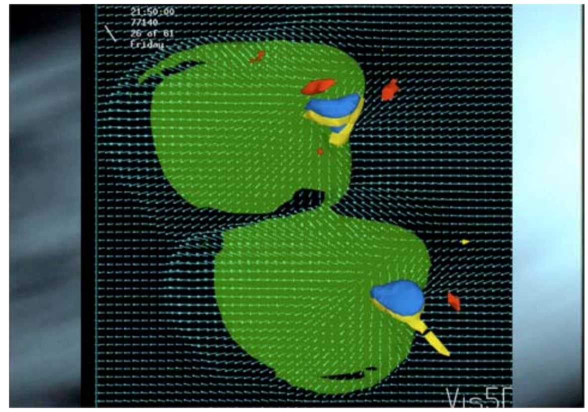


Fig. 3. Time 21:50. The green isosurfaces represent cold pools of 299 K and the red isosurfaces represent negative vertical vorticity of $0.01 s^{-1}$, yellow positive vorticity $0.01 s^{-1}$; blue updraft, 20m/s. The aqua vector field represents the surface wind field.

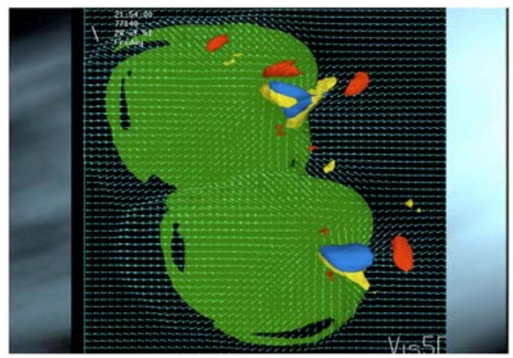


Fig. 4. Time 21:54. Same as Fig. 3.

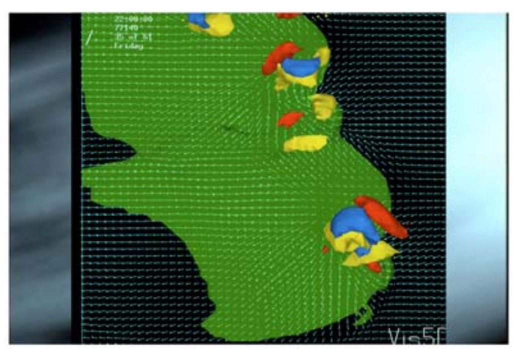


Fig. 5. Time 22:08. Same as Fig.3.

3.2 Arching vortex lines

The following frames (Fig. 6-8) show the development of low-level vorticity along the bulge where the gust fronts of the two storms merge. The viewer is looking from the northeast to the southwest, at the arching vortex lines lifting over the new bulge in the gust front. The time is same as in FIG. 5.

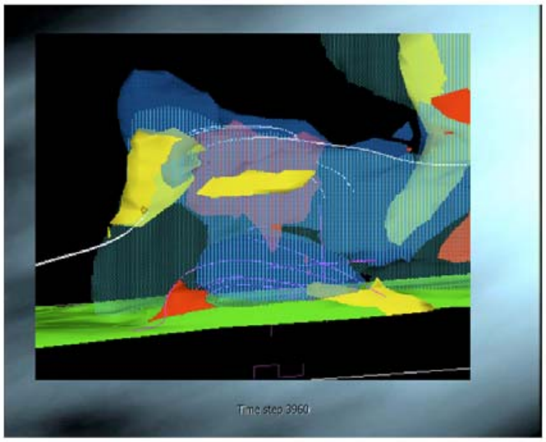


Fig. 6. Isosurfaces: yellow, positive vorticity 0.005/s; red, negative vorticity; blue updraft, 10m/s; light blue, rain mixing ratio 2g/kg. Vortex lines : white, environmental; red, baroclinic.

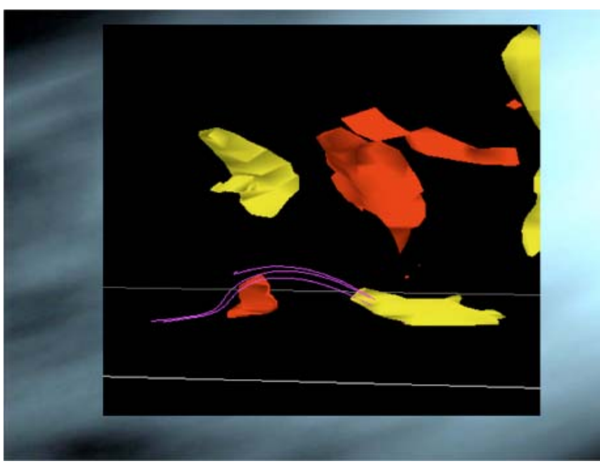


Fig. 7. Same as Fig. 6.

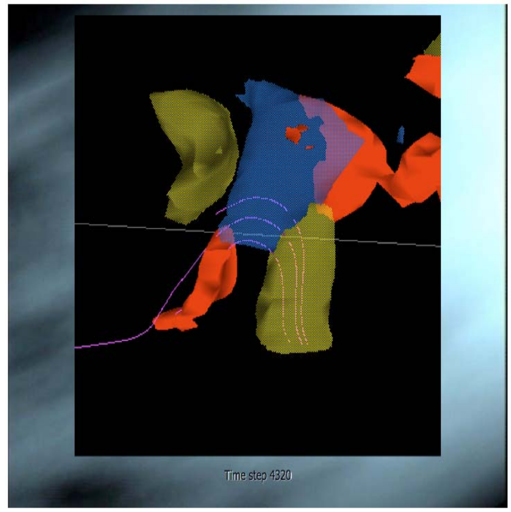


Fig. 8. Same as Fig. 6, except blue updraft, 20m/s, no precipitation.

4. GRANITE FALLS SET UP.

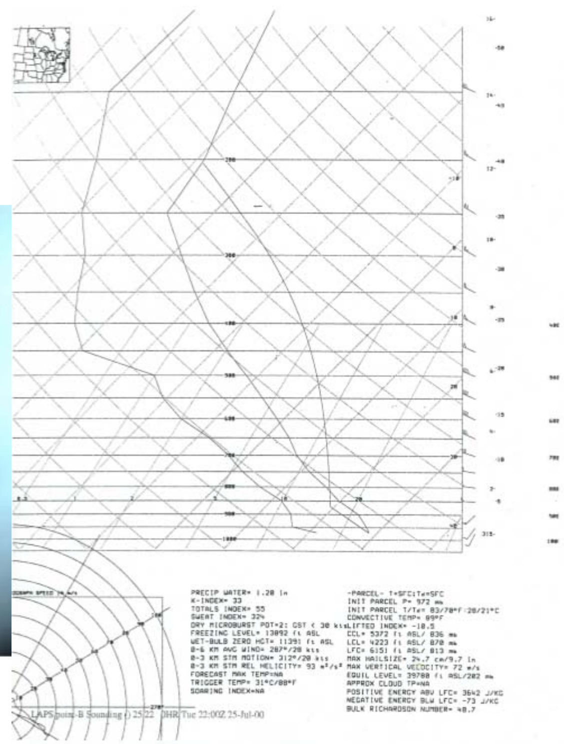


Fig. 9 LAPS point-B sounding taken at 2200Z, 44.81ºLatitude, -95.58º Longitude.

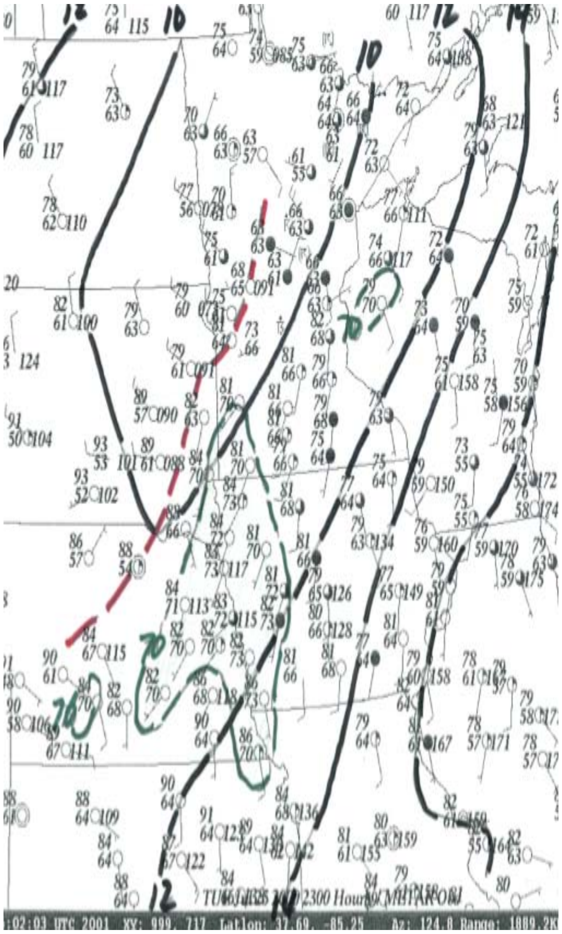


Fig. 10. 2300Z SURFACE

Severe thunderstorm watch number 619 was issued at 444 PM CDT Tuesday, July 25 2000 for portions of Southern Minnesota and Eastern South Dakota effective from 515 PM until 10:00PM CDT. This watch included the Granite Falls area.

5. RADAR IMAGES FROM KMPX (WATADS) AND KFSD (GRlevel 2 Analyst).

The following images show the split of cell [35] from cell [81] (Fig. 11, 12) and the lead-up to the merger of cell [35] and cell [66] (Fig. 12 to 20). Initial split shown is of a right moving supercell, cell [81], shedding left mover, and cell [35]. There was a sequence of left movers shed by cell [81]. Two of which were involved in tornado production. Cell [35] as it merges with cell [66], and a cell produced later (see section 6). The result of the merger of cells [35] and [66] was the Granite Falls tornado. It had a nine mile path and was on the ground from 2257-2325 UTC.

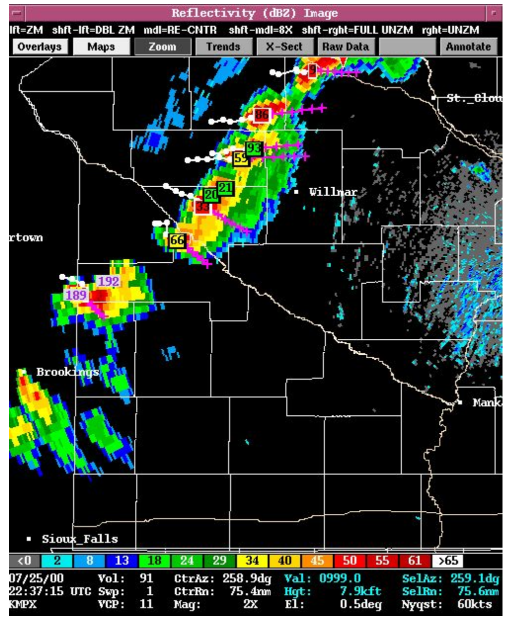
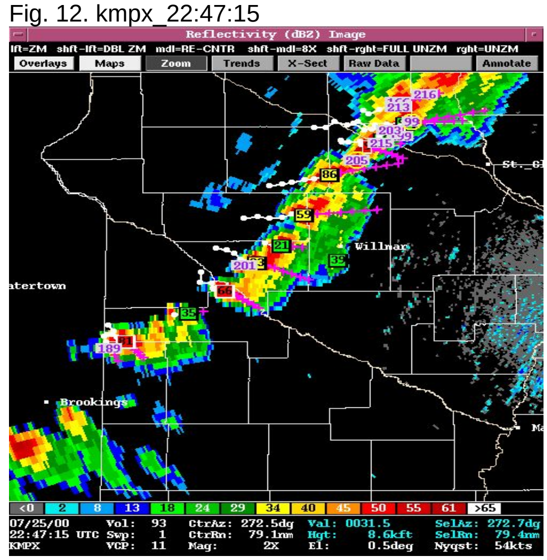


Fig. 11. kmpx_22:37:15. The merger of the Granite Falls storm (cell [66]) and the left mover (cell [35]) can be seen in the sequence of radar images below.

Fig. 12. kmpx_22:47:15



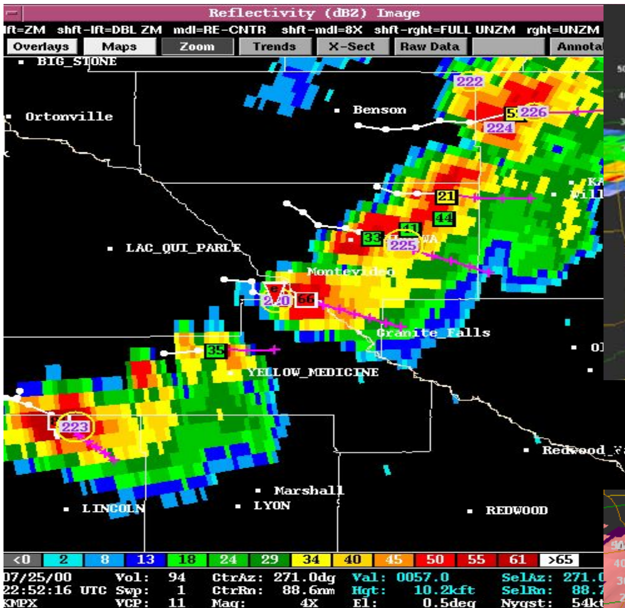


Fig. 12. kmpx_22:52:16

The overshooting top (Fig. 13) created an arching environmental vortex tube above cell [66] (Fig. 12), whose axis was normal to the unidirectional shear at 24,000ft. This can be seen on the kfsd_20000725_2251 radar image (not shown here) using GRlevel2 vorticity tools. The tube appears to have originated at 24,000ft and arched to about 34,000ft. As the overshooting top collapsed the vortex tube dissipated. The tornado icon [e] in the Watads image above (Fig. 12) was likely due to the Watads algorithm's detecting the arching vortex tubes. The new convection between the two merging cells appears to have initiated in response to lift at the base of the southern end of the arching vortex tube. (See the speck between the two cells in Fig. 13.) The new cell forms (Fig. 14.) as the two storms gust fronts (cold pools) interact. The coincidence of the overshooting tops and the gust front interaction, suggests a possible connection between the two events.

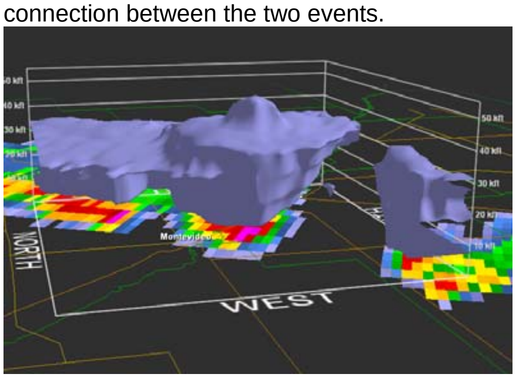
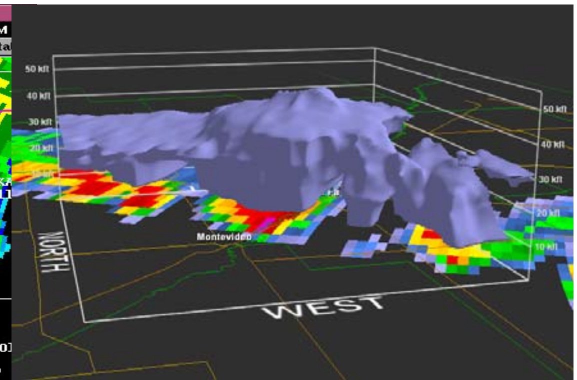


Fig. 13. kfsd_20000_2251



g. 14. kfsd_20000_2257

esponse to new cell lifting and stretching vortex es: couplet forms (top) and (bottom).

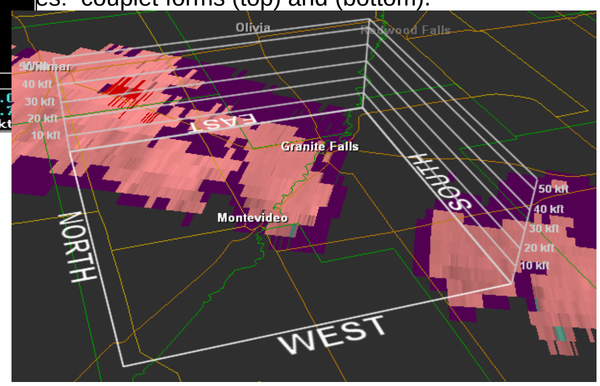


Fig. 15. kfsd_20000725_2251

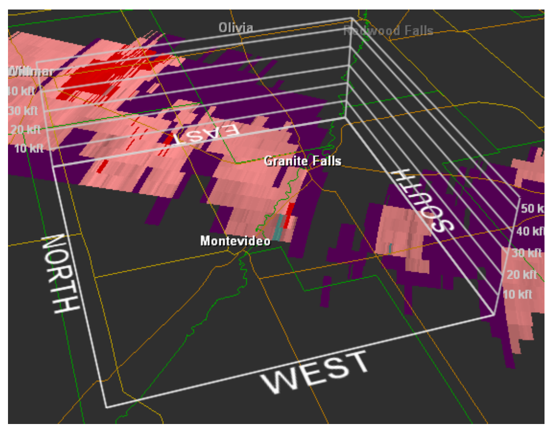


Fig. 16. kfsd_20000725_2257

The images below show the merger of the two cells.

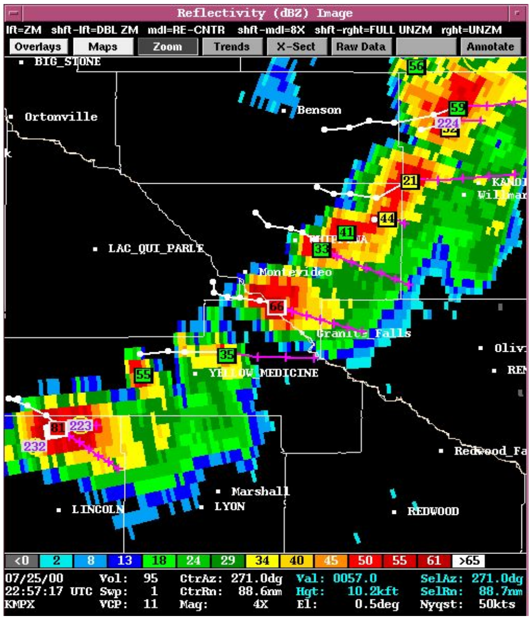


Fig. 17 kmpx_22:57:17

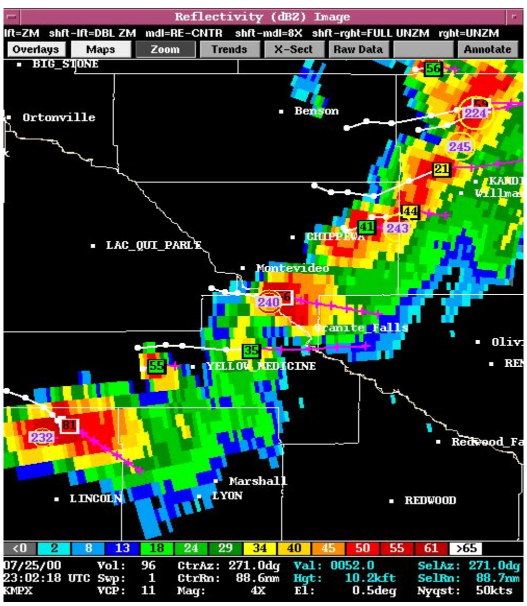


Fig. 18 kmpx_23:02:18

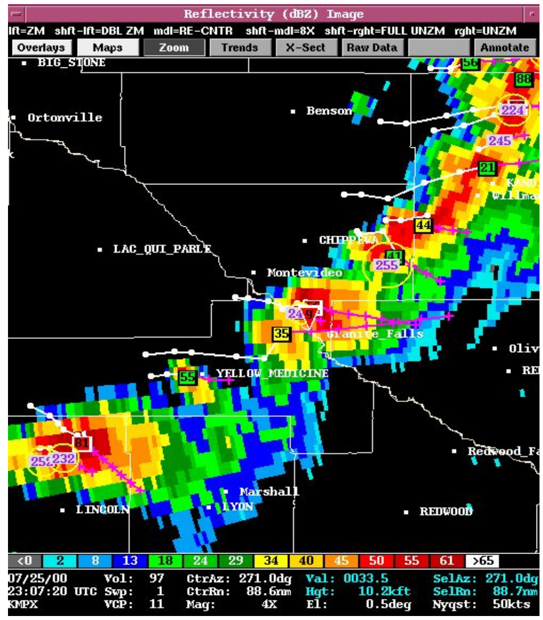


Fig. 19. kmpx_23:07:00. Anti cyclonic hook (above the “c” in Yellow Medicine) at the southern end of the left mover (cell [35]) and the tornado icon [g] indicate possible arching of vortex lines along the lead edge of the left mover (cell [35]).

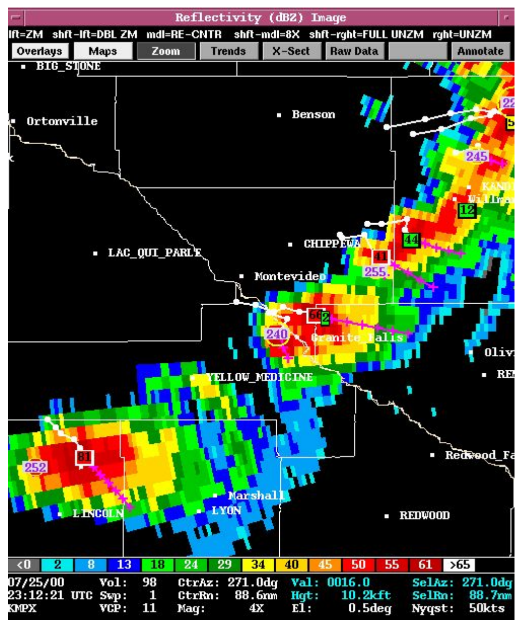


Fig. 20 kmpx_23:12:21. In the image above the mesocyclone [240] and the anticyclonic inflow notch (above the n in Yellow Medicine) are moving closer together, suggesting merger of the ends of the arching vortex lines and an occlusion of the mesocyclone. This is near the time tornado was in granite Falls.

5.1 Overshooting Storm tops

As the inflow wedge pinched off, support for the updraft was rapidly cut off and the storm top collapsed suddenly between 2315 UTC and 2325 UTC leading to the Granite Falls tornado; note the warming of the storm top from a range of –55ºCto –60ºC to a range of –38ºC to –47ºC over this time span.

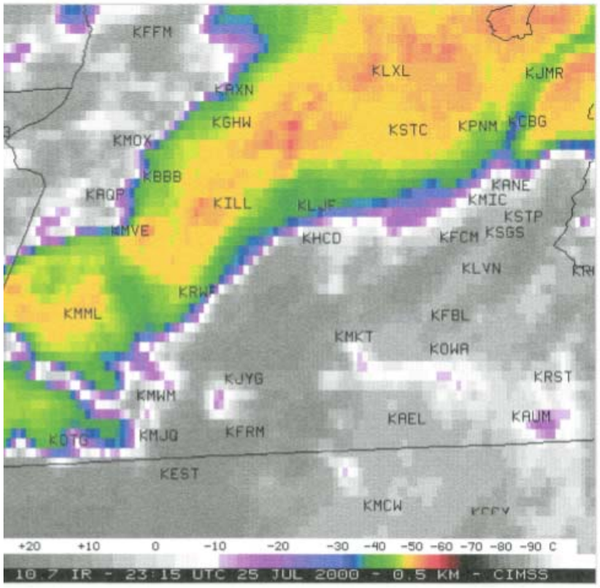


Fig 21. Goes image of overshooting top of Granite Falls storm 23:15 UTC. (Orange east of KMVE)

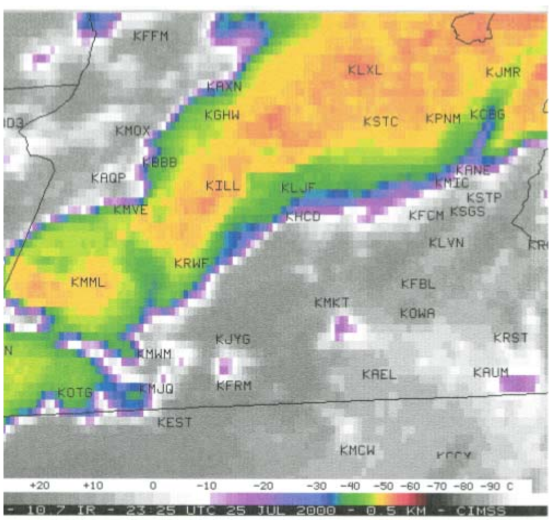


Fig. 22. Goes image of collapse of top of Granite Falls storm 23:25 UTC. (Green east of KMVE)

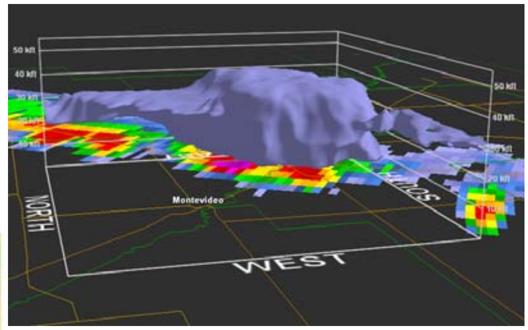


Fig. 23. Pre-overshooting. kfsd_20000725_2308

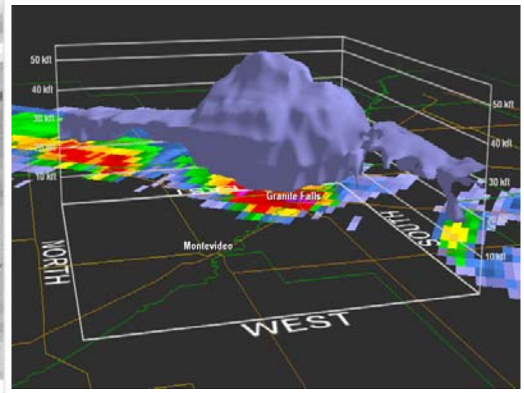


Fig. 24. Overshooting top.kfsd_20000725_2314

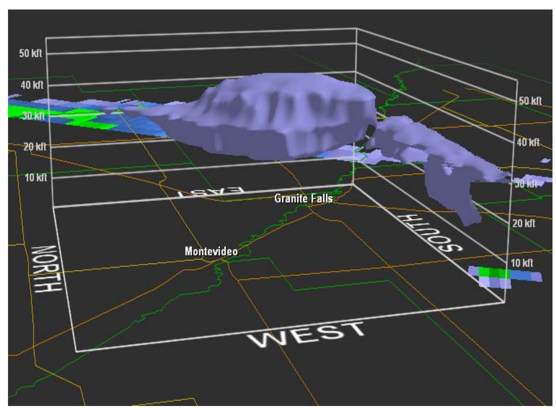


Fig. 25. Collapsed top. kfsd_20000725_2320

6. WEAK TORNADO ON THE LEAD EDGE OF A LEFT MOVER: The next three images, Fig. [26]-[28] (from three successive volume scans) show arching vortex lines on the lead edge of a left mover about to split off of the supercell (cell [81], mesocyclone [261]). This is the south moving storm (cell [81]) that earlier produced the left mover (cell [35]) that merged with the Granite Falls storm. The first two show the northern cyclonic end of the arching vortex line and the last shows the southern end of the arching vortex line.

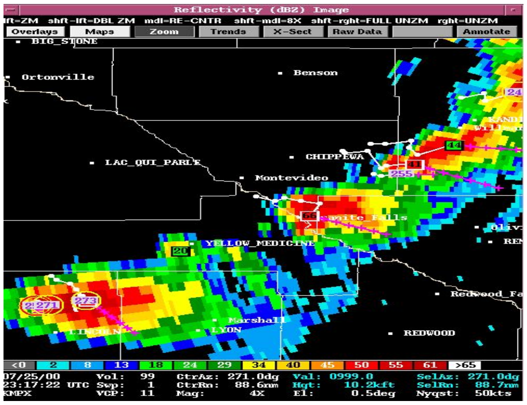


Fig. 26. kmpx_23:17:22. Cyclonic hook at the east end of cell [81].

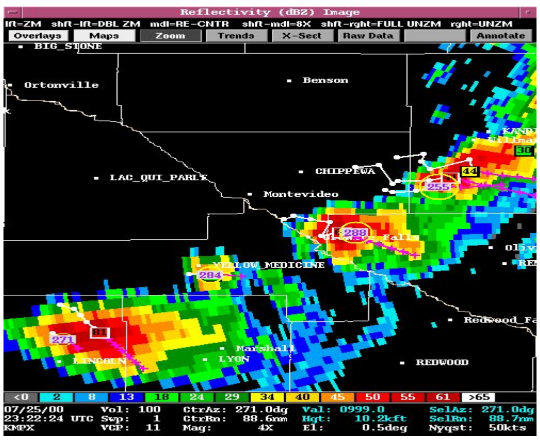


Fig. 27. kmpx_23:22:24. A weak tornado forms about the time of this image. The tornado was two miles northwest of Marshall, MN. (See SPC Storm Reports.)

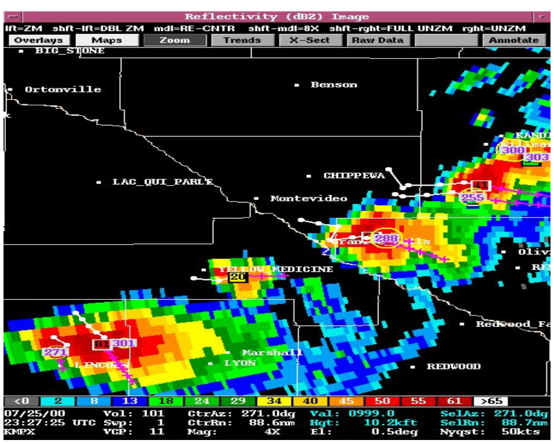


Fig. 28. kmpx_23:27:25. Anti-cyclonic hook at east end of cell [81].

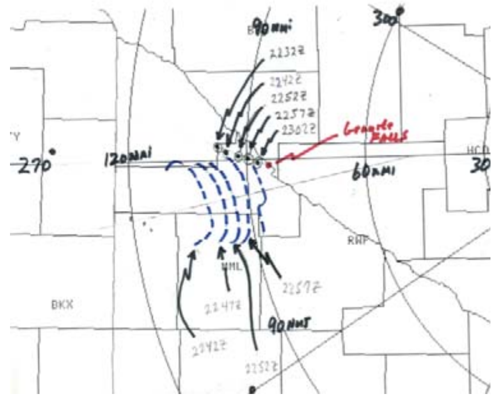


Fig. 29. Time series of the gust front of left mover (cell [35]) merging (blue dashed line) with southern end of the squall line (black dot or red dot).

7. CONCLUSIONS: The Laps point-B sounding given in Fig. 9, gives modest 0-3km SRH of $95km^2/s^2$ and an LCL of 4223 ft. These values are marginal for tornados (Davies 2006). Davies suggests strong tornados that form in environments with weak shear and/or high lifting condensation levels may be interacting with boundaries. The F4 magnitude of the Granite Falls tornado, suggests that the left mover's gust front interacting with the southern end of the squall line enhanced the tornado or its genesis. A subsequent weak tornado on the lead edge of the gust front of another left mover (Fig. 26-27) suggests that processes similar to those observed and studied in Atkins (2009) and Weisman (2003) may have been present. The speed of the left mover, 42kts, in the same direction as the surface winds of 10kts, in a high cape environment suggests lifting on the lead edge of the gust front. However the rapid development of the arching vortex lines does not seem to fit with the theories of these two papers.

We believe that the process discussed above associated with the left mover in Fig. 26-27, was also involved in the earlier merger (Fig. 29, Fig. 12, and Fig. 17-20) that produced the Granite Falls tornado. Arching vortex lines along the lead edge of the left mover in the earlier merger would have produced a cyclonic vortex at the north end of the gust front and an anticyclonic vortex at the southern end. This is consistent with the Radar images in Fig. 19-20. Also the distance between the two vortices is closing off as the merger proceeds is consistent with the rendering in Fig. 29
based on the radar data.

Conclusions: Mergers between left mover and supercell. Comparing the numerical simulations The Granite Falls storm merger and the Fig. 26-28 we hypothesize that

1) Merger should be such that the lead edge of the gust front of the left mover pushes under the main updraft tower of the supercell (from the warm inflow side of the storm).
2) As left mover approaches the supercell the interaction of their gust fronts creates a new cell in between.
3) New cell lifts vortex lines that are generated baroclinically along the lead edge of the left movers gust front.
4) If the cape is large, explosive updraft in the new cell yields rapid stretching of vortex lines.
5) Large magnitudes of low-level vorticity are created where the vortex lines turn upward. Pressure deficits in these areas lead to occlusion downdrafts.
6) Occlusion downdrafts pin down the ends of the arching vortex.
7) Tornado genesis rapidly follows.

3-7 above are the same as a mechanism for tornado genesis discussed in papers [M] and [S] below.

A similar situation may have been present in the July 18, 2004 tornado event in southeast North Dakota. Similar situations may have been present in bow echoes overtaking and merging with supercells.

Acknowledgements

Doug Dokken, Kurt Scholz. Luke Edholm, and Pat Shanahan were supported by NSF CSUMS grant DMS-0802959. We are grateful for assistance from David Porter and for the resources from the University of Minnesota Supercomputing Institute.

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