

ANALYSIS OF THUNDERSTORM HAIL FALL PATTERNS IN THE SEVERE HAIL VERIFICATION EXPERIMENT

Kiel L. Ortega, Travis M. Smith and Kevin A. Scharfenberg

Univ. of Oklahoma/CIMMS and NOAA/NSSL

1. Introduction

An extensive overview of the Severe Hail Verification Experiment (SHAVE) can be found in Smith et al. (2006) in these proceedings. This paper represents a preliminary comparison of the SHAVE hail reports to storm evolution and type, and a preliminary comparison to multi-radar reflectivity and hail algorithm swaths.

Several near-storm environment (NSE; derived from hourly RUC model runs) variables were obtained for in the area where the storms formed. Quality-controlled SHAVE hail verification swaths were viewed using Google Earth (<http://earth.google.com>) along with temporal maxima (swaths) of reflectivity at lowest altitude and maximum expected size of hail (MESH) from multi-radar reflectivity grids. These two grids were used by SHAVE almost exclusively to determine where to call. Summary of the case dates, storm type and NSE variables can be found in Table 1.

2. Cases

2.1 20060621

SHAVE collected data on two supercells that moved across Republic, Cloud and Clay Counties in Kansas on 21 June 2006. SHAVE began data collection on the Republic County storm around 2230 UTC. The storm initiated in central Cloud County and quickly moved to the northeast. About the time the storm began to cross

the Cloud/Republic county line, the storm slowed down and maximum expected size of hail (MESH) values greatly increased. The storm, at times, would show signs of rotation on radar, however the rotation was not persistent from scan to scan nor was it very strong.

As seen in Figure 1, the initial hail fall was narrow. As the storm moved through southeast Republic County, the hail report swath widened, as well as the low level reflectivity maximum reflectivity area. As the storm moved further on and eventually out of Republic County, the low level reflectivity weakened coincident with maximum reported hail sizes. The MESH swath combined with the low level reflectivity swath seems to have worked well (in post-event analysis) to estimate intensity and extent of the hail fall.

The second storm of the day formed in a line of cells that grew to the southwest of the Republic County storm. This storm quickly grew and moved to the southeast away from the other cells. SHAVE began making calls into this storm around 2315 UTC. The storm looked very impressive with 60 dBZ echoes observed as high as 14km above radar level and a broad weak echo region (WER) on its southeastern flank. This storm had an assortment of reported maximum hail sizes where SHAVE first began calling, unlike the Republic storm which had only tennis- to baseball-sized hail near the beginning of its reported hail swath (Figure 2). The storm slowly moved to the southeast and just after entering Clay County the storm had

Date	MUCAPE (J kg^{-1})	0-6 km shear (m s^{-1})	0°C Altitude (km)	-20°C Altitude (km)	Max Hail (mm)	Storm Type
20060621	3000-4000	20	4.6	7.2	70	Clustered supercells
20060622	1500-2000	20	4.5	7.4	32	Clustered storms
20060701	2000	35	4.4	7.4	76	Isolated supercell
20060727	2000-2500	10	4.2	7.8	44	Tornadic supercell

Table 1: Summary of cases and associated NSE variables and storm types. The 0° and -20°C levels are used in the hail diagnosis algorithm (see Witt et al. 1998)

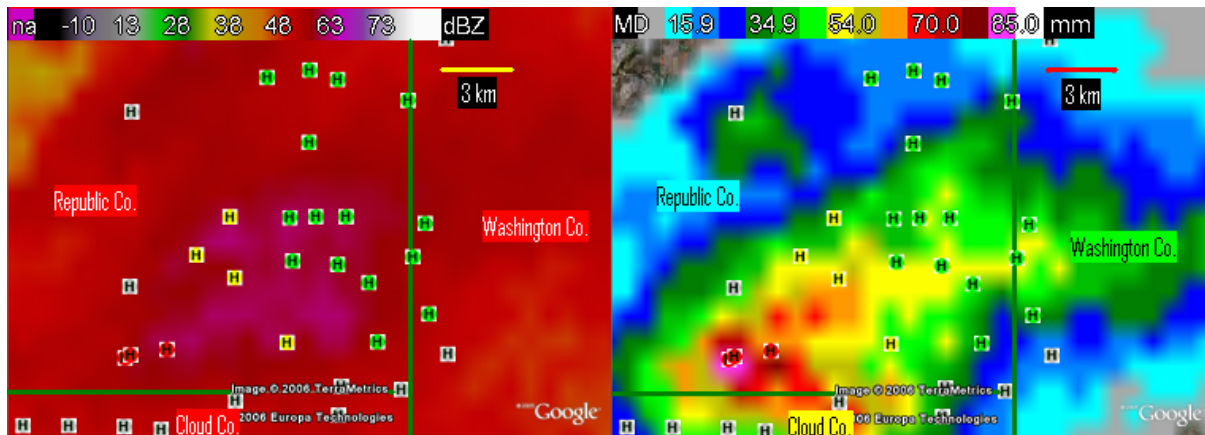


Figure 1: Reflectivity at lowest altitude (left) and MESH (right) swaths for the Republic County storm. The hail reports ('H' icons) are color coded by report size: grey-no report; green-hail up to 25 mm; yellow-hail up to 50 mm; red-hail up to 76 mm. The heavy green lines are the county boundaries. Swaths valid from 2230 UTC 21 June 2006 to 0000 UTC 22 June 2006.

become a cluster.

2.2 20060622

About this time the reported maximum hail size decreased, even though MESH estimates were nearly the same (Figure 3). It is interesting that the Cloud/Clay County storm produced a wide swath of MESH greater than 85 mm (Figure 3), yet there were no SHAVE reports larger than 44 mm in the swath (with the exception of the 76 mm report at the very start) while the Republic County storm had several reports near 76 mm. The Republic County storm had fewer other cells around it than did the Cloud/Clay County storm. Even though the Cloud/Clay County storm had higher reflectivities and higher MESH, the Republic County storm seems to have produced the larger hail.

SHAVE made one of its most impressive (with respect to length) cross sections on this day. Three separate cells, all part of a line of thunderstorms over western Kansas, were tracked over three counties. The hail verification swath was 120 km long, except for a 16 km gap. The first storm of the swath formed over northeast Rush County around 2100 UTC. This storm was slow moving and isolated for most of its life, and had weak rotation. Weak cells had been present around the storm for most of its life, however around 2200 UTC a cluster of storms formed around the SHAVE-followed storm; by 2230 UTC, a line had formed consisting of these storms and others that had moved in from the north. As the SHAVE-followed storm moved to the southeast, it either re-strengthened or a new cell formed on the outflow as low level reflectivity and MESH intensified over southern Rush County (see Fig. 4) around 2230 UTC. This storm weakened just before reaching the Rush/Pawnee County line and turned to the left. At 2320 UTC the outflow boundary was running southwest to northeast across Pawnee County and new storm formed along it in northeast Pawnee County. This storm moved on to the southeast and consisted of new cells that initiated along the outflow boundary. By the time the storm had crossed the Pawnee/Stafford County line, the outflow boundary was far ahead of the line and no new cells formed.

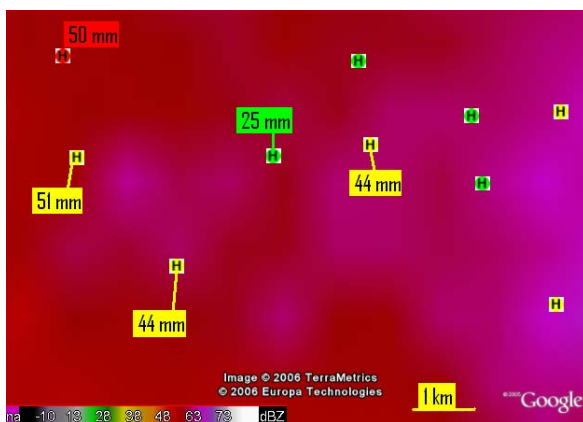


Figure 2: Start of the reflectivity at lowest altitude swath for the Cloud/Clay County storm showing a wide range of reported maximum hail sizes.

Figure 4 shows that the low-altitude reflectivity swath and MESH swath were not sufficient for distinguishing if hail was falling at the surface. A major feature of these swaths is that as time went on, the hail fall became more sporadic. As shown in Figure 4, as the storm approached Stafford County the ability to draw a

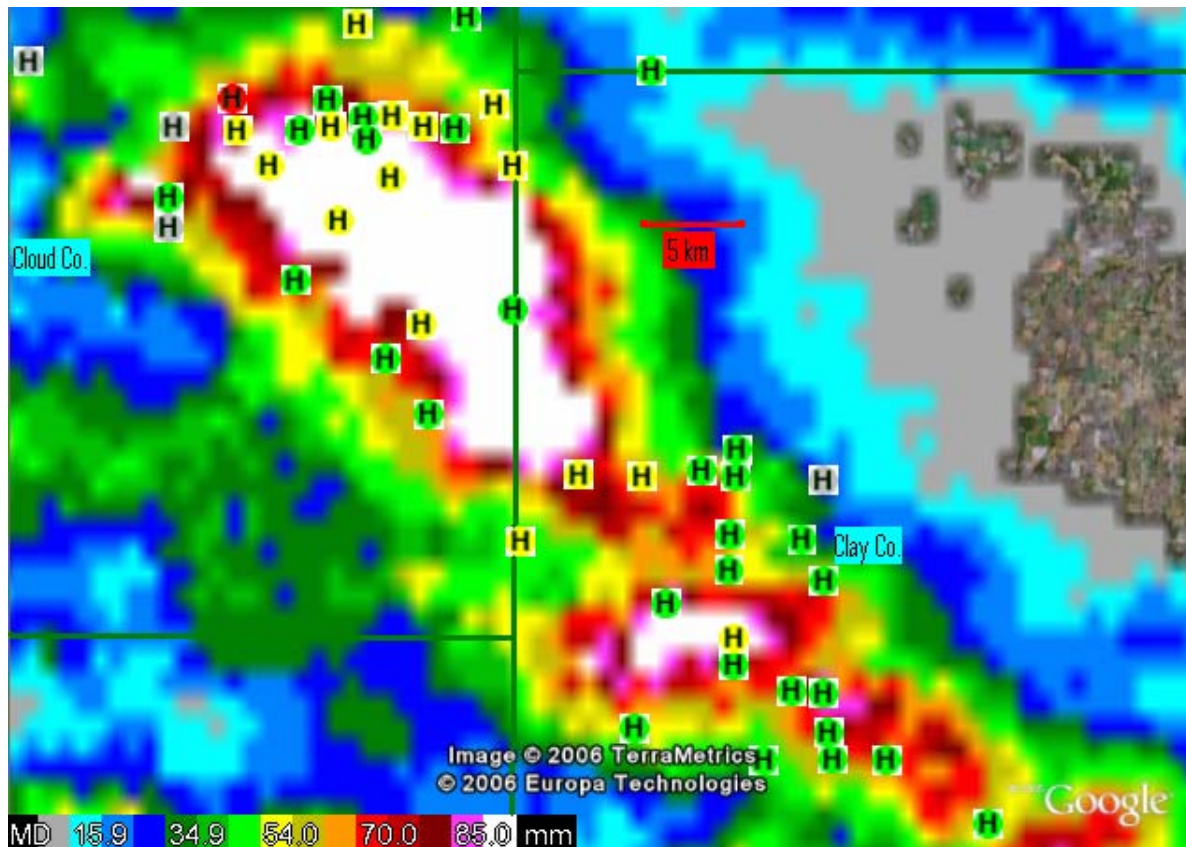


Figure 3: MESH swath for the Cloud/Clay County storm with hail reports (as in Fig. 1). Swaths valid from 2345 UTC 21 June 2006 to 0200 UTC 22 June 2006.

hail or no hail line, even using the SHAVE verification swath, becomes difficult.

2.3 20060701

One of the most impressive storms studied during SHAVE was the Oconto County, WI hail storm on 1 July 2006. Shown in Figure 5, this storm exhibited great examples of a bounded weak echo region (BWER; Marwitz 1972) and three-body scatter spike (TBSS; Lemon 1998) during its life. SHAVE obtained an estimated maximum hail size report of 76.2 mm and according to preliminary reports from the Green Bay National Weather Service office, estimated maximum hail size along the storm path was 101.6 mm. The hail caused extensive damage in Oconto County.

The Oconto storm started around 1940 UTC in central Langlade County. SHAVE began tracking the storm about 20 minutes later with 2 no hail reports in extreme southeast Langlade County. The storm began to intensify (Figure 5) just before entering Oconto County. During its life in Oconto County, the storm showed moderate rotation on radar, a hail spike and a large WER or BWER. Maximum reflectivities were

generally at or above 70 dBZ in the mid-levels of the storm.

The low-altitude reflectivity and MESH swaths (Figure 6) are quite narrow swaths and worked well for distinguishing where hail was falling. While the 21 June 2006 case, where MESH area greater than 85 mm (depicted in white) was 10 km across, the MESH area greater than 35 mm is only 6-7 km across in this case. However, the 3rd storm on 22 June 2006 had a MESH area greater than 35 mm 8 km wide, yet its largest hail report was not more than 25 mm. These differences probably exist due to the weighting of reflectivity by relative height in the hail diagnosis algorithm (Witt et al. 1998). While the storms exhibited similar vertical reflectivity patterns, the differences in the 0°C and -20°C (probably more heavily dependent on the -20°C height) heights caused the large differences in the algorithm's hail estimates.

2.4 20060727

Another interesting SHAVE case occurred on 27 July 2006 in Lac qui Parle County, MN. A supercell formed in the northern part of the county and became tornadic

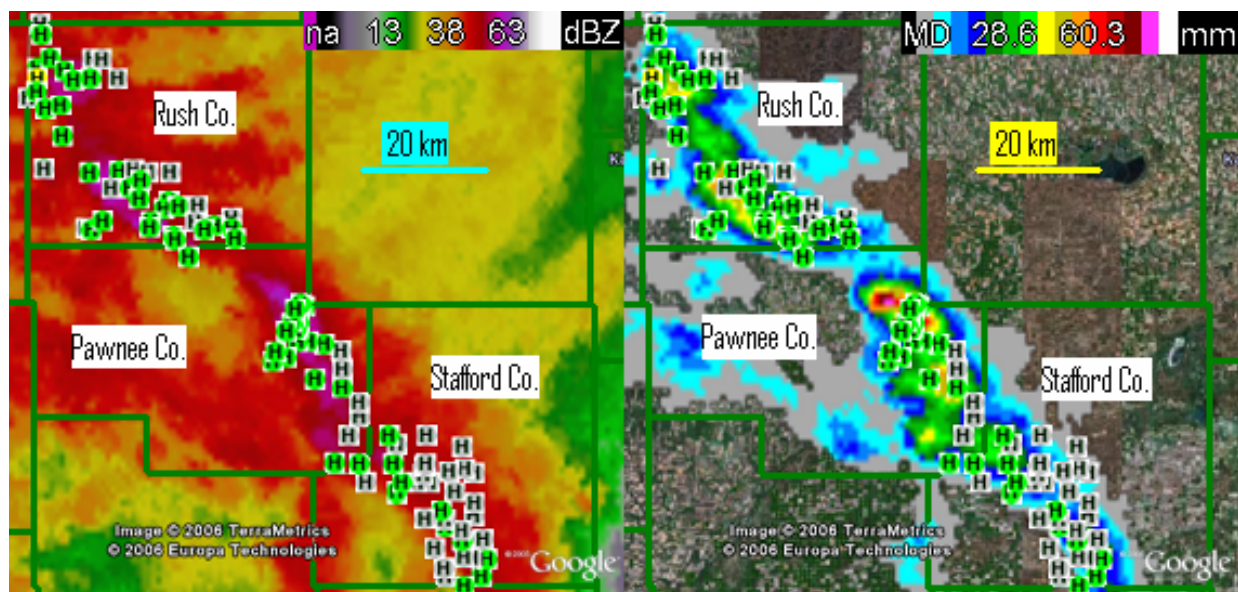


Figure 4: As in figure 1 for the Rush/Pawnee/Stafford County storm. Swaths valid from 2145 UTC 22 June 2006 to 0145 UTC 23 June 2006.

later in the southern part of the county and dissipated not long after the tornado. SHAVE began to collect data on this storm not long after initiation. Figure 7 shows the low level reflectivity and MESH swaths. These provided excellent guidance on the presence of hail at the surface. Note that the largest hail (yellow icons) reports width began to spread out near the time of the tornado.

3. Remarks

As seen from these four cases, hail fall is highly dependent on storm type and environment. These cases show that even using environmental data in hail diagnosis algorithms can still lead to inaccurate predictions of hail size. The major factor, illustrated by these cases, between similar algorithm predictions and differences in the observed maximum hail is storm isolation. The 22 June 2006 case shows that use of MESH and low level reflectivity grids do not always lead to a definite area of where hail did or did not fall. The case also shows that use of these grids are not suited to characterize the size of the hail fall, as other cases had similar MESH and low level reflectivity with much larger hail.

The SHAVE data allows for the hail fall patterns to be compared to storm evolution. The Oconto County storm showed that local maxima in the maximum hail size occurred after large three-body scatter signatures and maxima in mid-level reflectivities appeared. The Lac qui Parle County storm showed that around the time of a tornado the largest hail began to widen. The 21 and 22 June 2006 cases showed great examples of hail fall patterns as storms became more clustered with time.

The SHAVE verification data provides for unique set of observations due to the high spatial and temporal resolution. Future work with the SHAVE dataset should look closely at issues such as storm isolation and storm environment with respect to the maximum reported hail size. The SHAVE dataset can also be used to

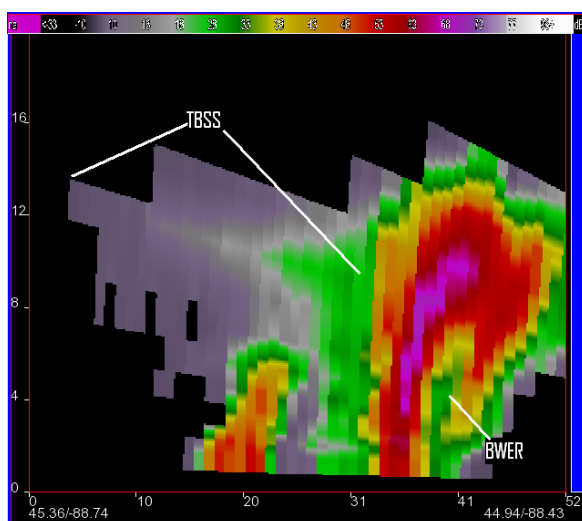


Figure 5: Vertical cross-section of the Oconto County storm showing a TBSS and BWER. This cross section was taken just as the storm approached the Menominee/Oconto County line. Scale at the bottom is in kilometers.

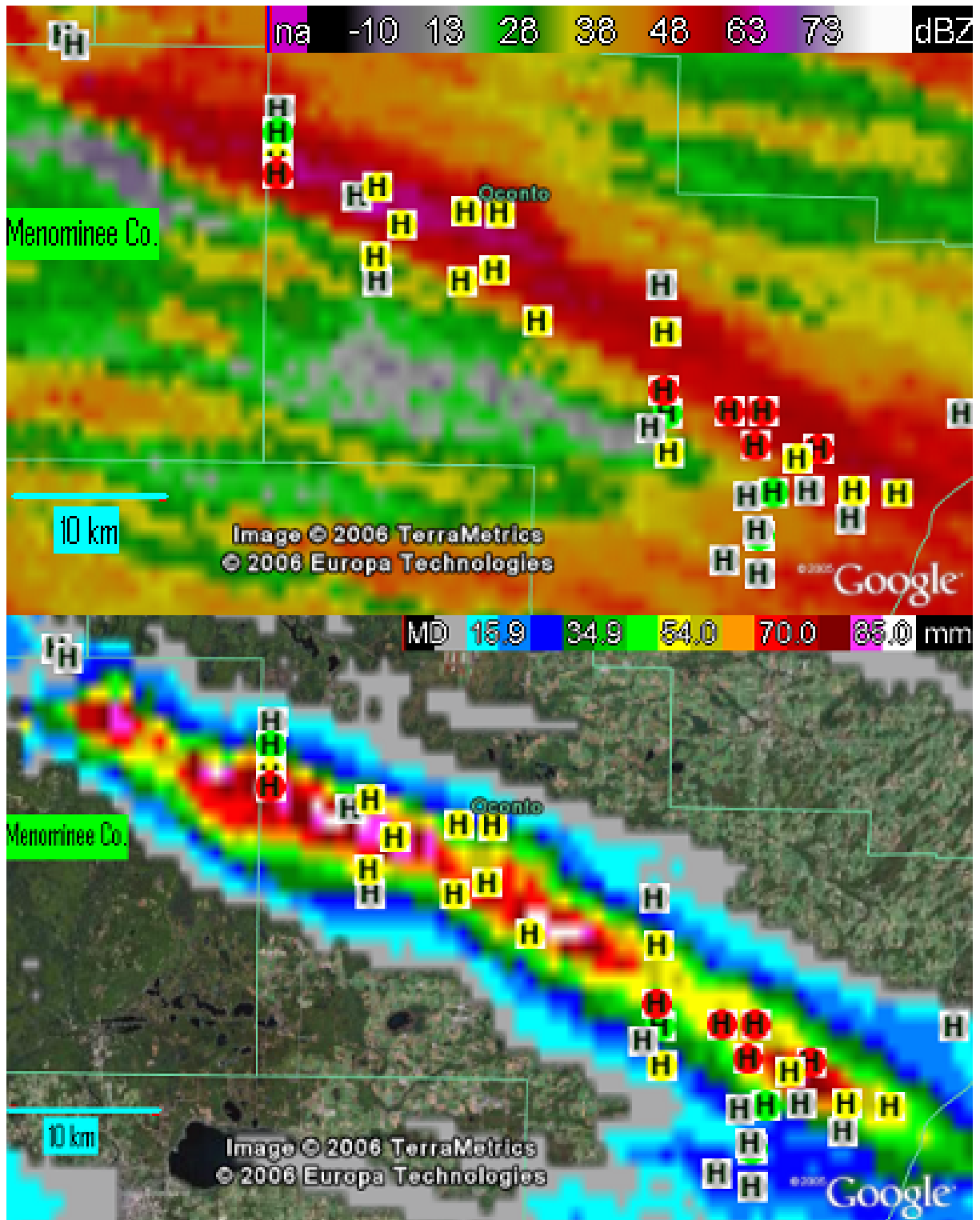


Figure 6: Same as figure 1 except for the Oconto County storm. Swaths are valid from 2030 UTC 1 July 2006 to 2200 UTC 1 July 2006

determine the distribution of reports given a combination of reflectivity and MESH values. These distributions can be applied to the development of

probabilistic warnings or verification grids for probabilistic warnings.

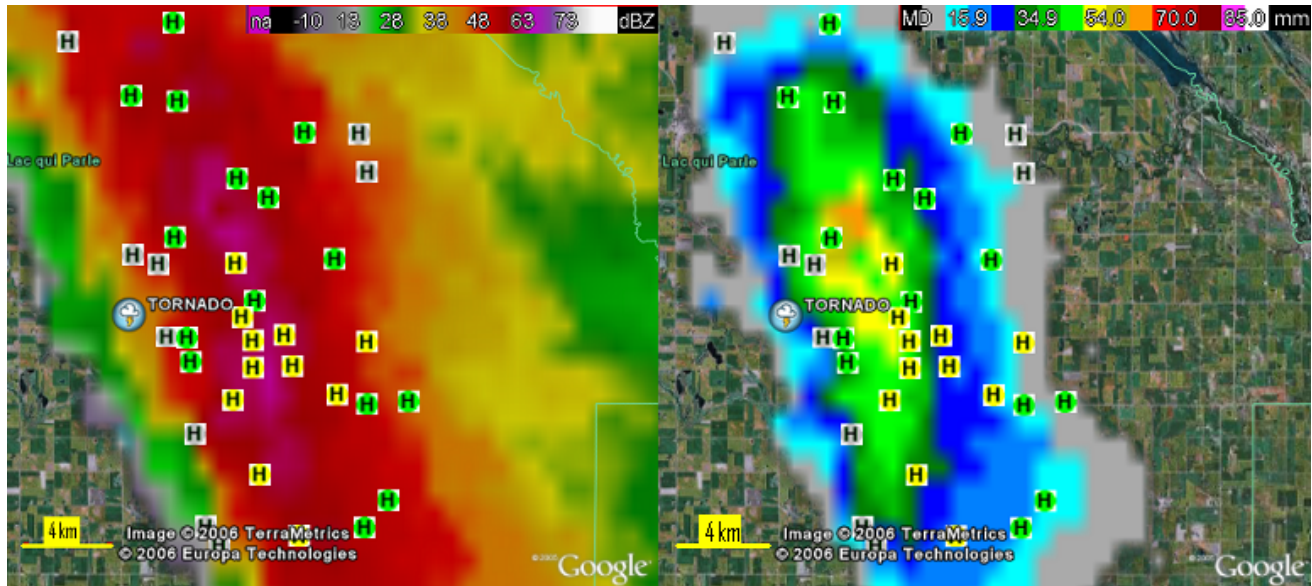


Figure 7: As in Figure 1 except for the Lac qui Parle County storm. Swaths are valid from 0015 UTC 28 July 2006 to 0130 UTC 28 July 2006

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