Assessment of the 18 August 2016 Severe Hailstorm in Great Falls, MT

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1. INTRODUCTION

On the early morning of 18 August 2016 a marginal and elevated supercell moved southeastward over Great Falls and produced hail up to ping pong ball-size. According to the Great Falls Tribune (2016), this hailstorm damaged many homes and vehicles in the city. During this event, the Storm Prediction Center (SPC) had forecast a marginal risk of severe thunderstorms for far-northern portions of north-central MT, along the Canada border. For the rest of the County Warning Area, including Great Falls, there was a risk of general thunderstorms. NWS Great Falls issued a severe thunderstorm warning at 06:33Z (12:33 AM MDT) 18 August 2016, 1-minute after the first report of severe hail. The warning remained in effect until 07:30Z 18 August 2016 and additional reports of severe hail were received through 06:50Z. Using archived mesoanalyses, surface analyses, model sounding data, and radar imagery, this study will assess the pre-storm environment and determine whether a proactive severe thunderstorm warning (i.e. one with positive lead time) could have been issued for this hailstorm.

2. SYNOPTIC AND MESOSCALE ANALYSIS

According to archived mesoanalysis data (SPC 2005) between 00:00Z and 06:00Z 18 August 2016, a 300 mb shortwave trough was approaching Great Falls from the west-northwest, while upper-level zonal flow was present over north-central MT (Figs. 1 and 2). At 500 mb, zonal flow also resided over north-central MT and the same shortwave trough was present upstream of Great Falls (not shown). A west-to-east-oriented 850 mb front moved from near the MT/Canada border at 00:00Z to near Great Falls and east-central MT by 06:00Z (Figs. 3 and 4). The same figures show enhanced gradients in 850 mb temperature and dew point, which denote the location of the front. As shown in Fig. 5, weak convergence along this 850 mb front had overspread Great Falls and vicinity by 06:00Z. This convergence along the 850 mb front likely contributed to the development of convection over and near Great Falls.

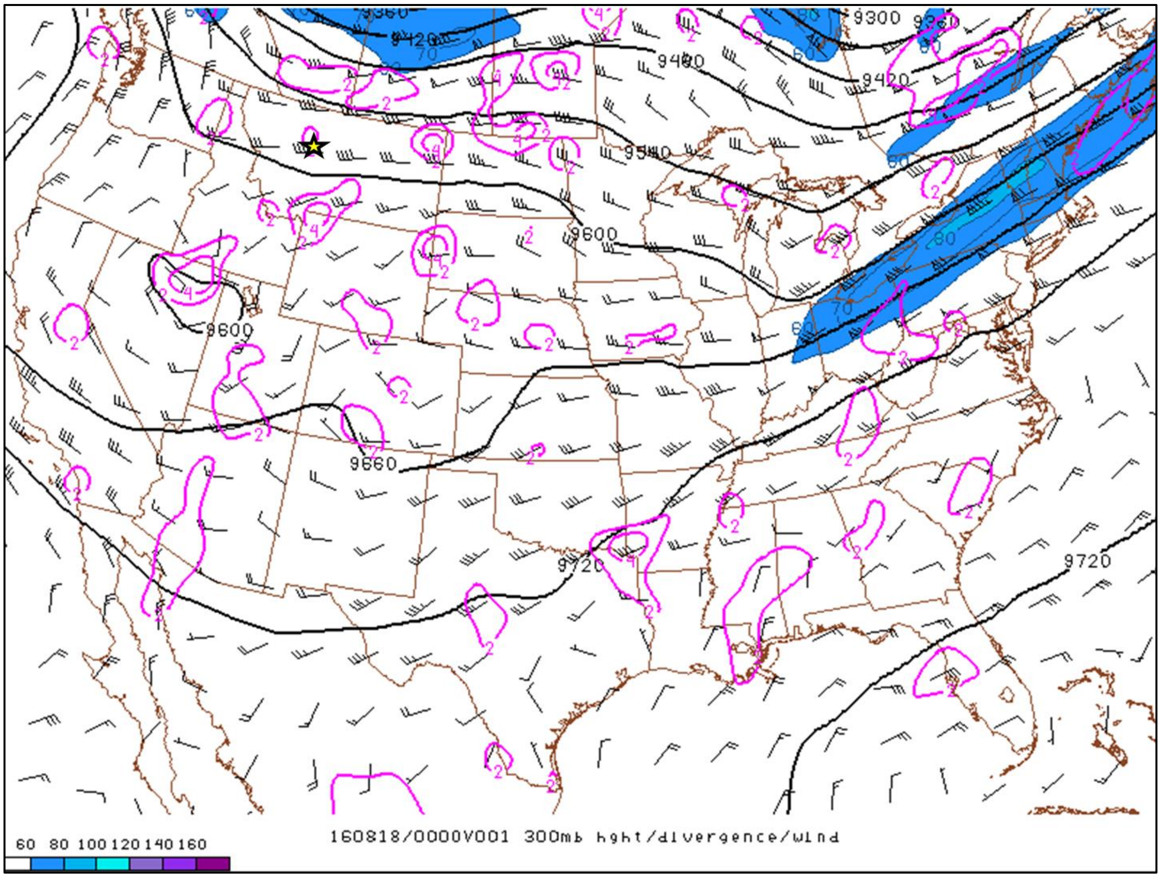


Fig. 1: 00:00Z 18 August 2016 mesoanalysis depicting 300 mb heights (m MSL), winds (kt), and divergence (s^{-1}). The yellow star denotes the approximate location of Great Falls.

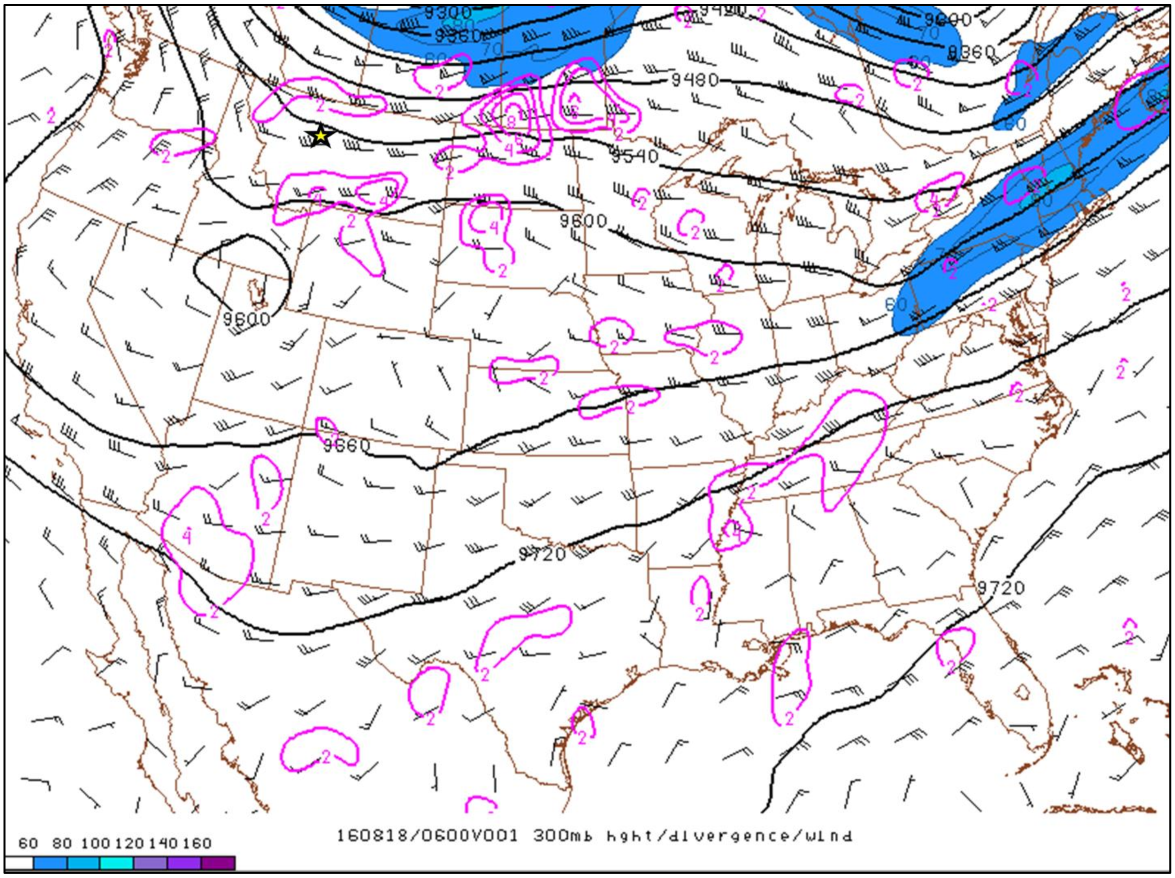


Fig 2: Same as in Fig. 1, except for 06:00Z 18 August 2016.

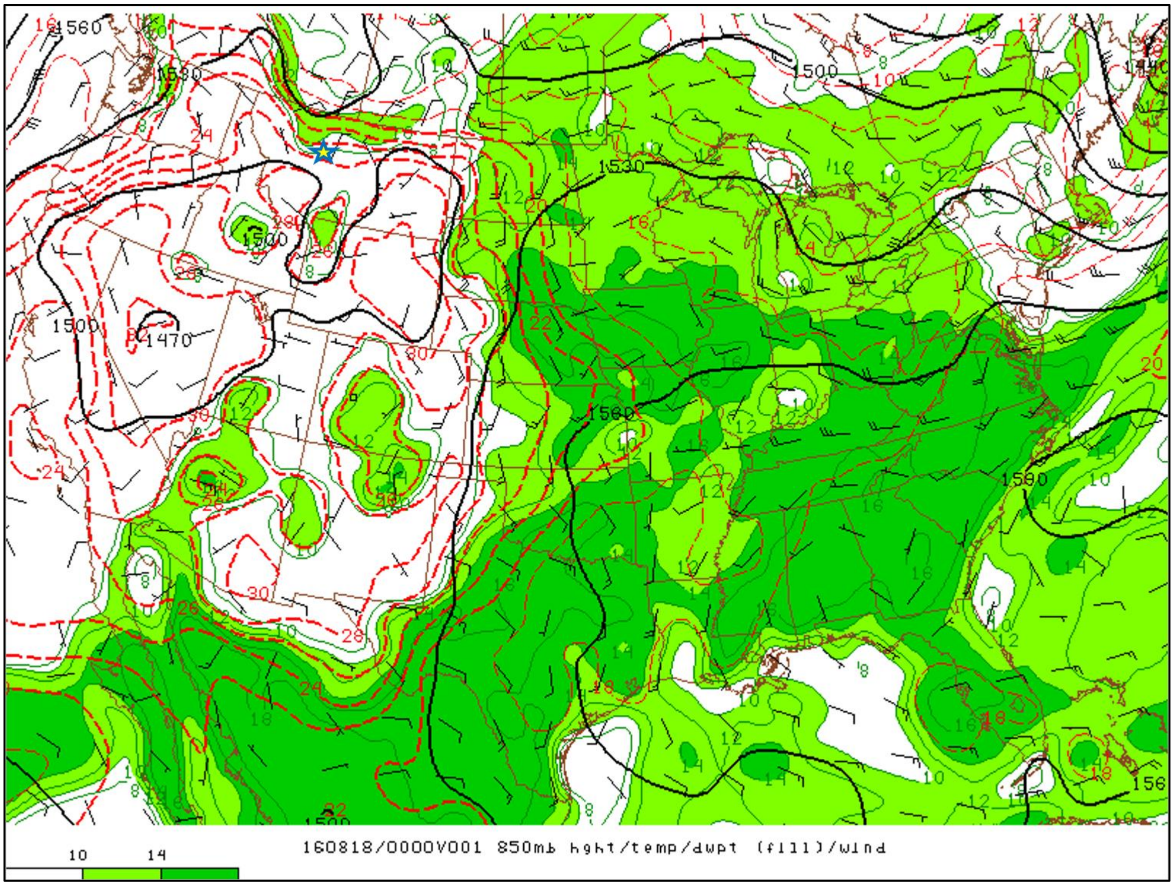


Fig. 3: 00:00Z 18 August 2016 mesoanalysis depicting 850 mb heights (m MSL), temperatures (°C), dew points (°C), and winds (kt). The yellow star denotes the approximate location of Great Falls.

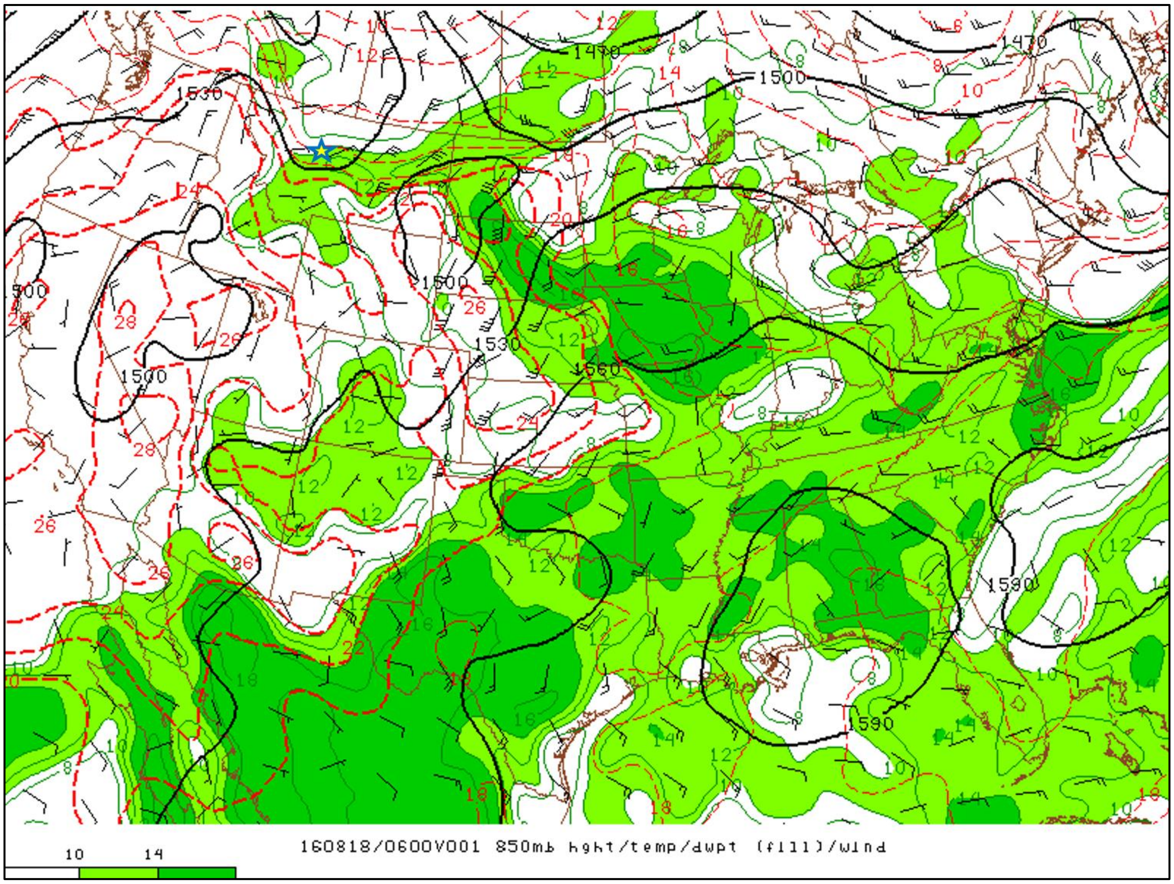


Fig. 4: Same as in Fig. 3, except for 06:00Z 18 August 2016. The yellow star denotes the approximate location of Great Falls.

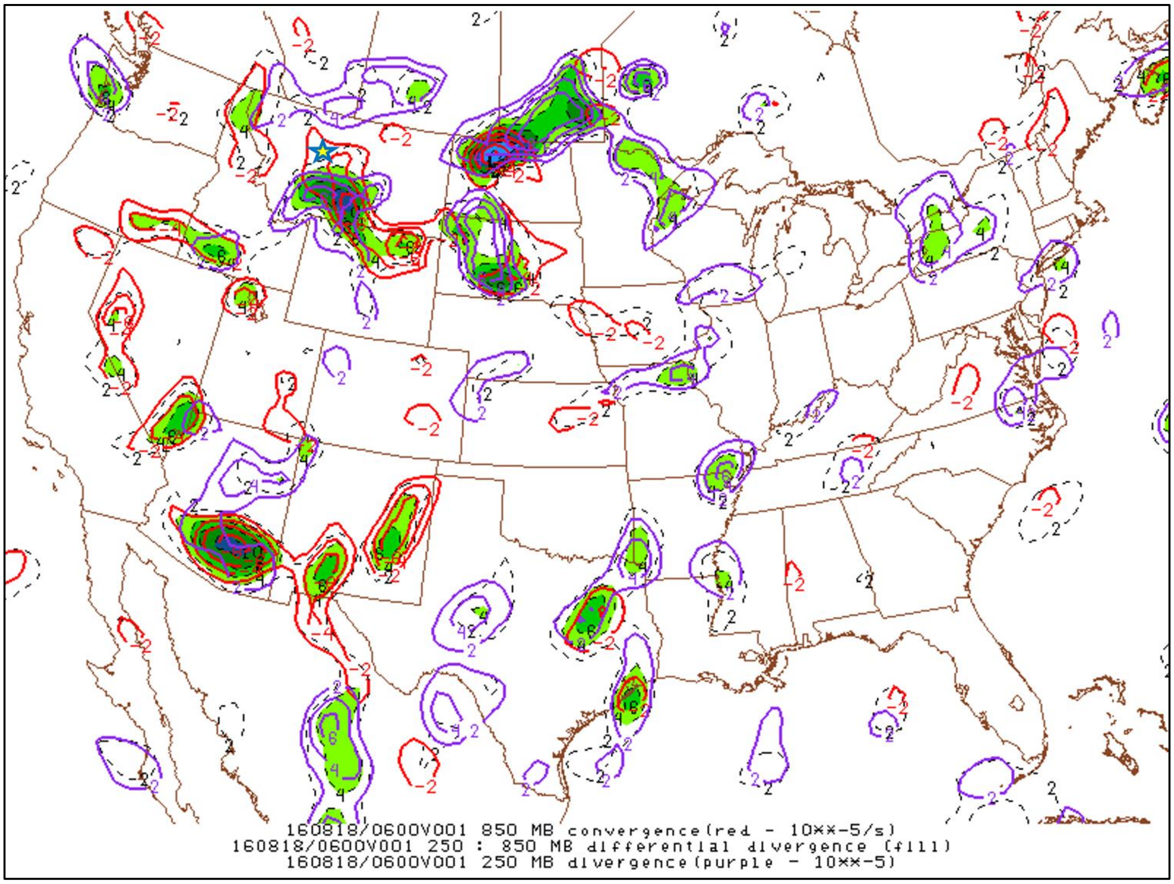


Fig. 5: 06:00Z 18 August 2016 mesoanalysis depicting 850 mb convergence (s^{-1}; red contours) and 250 mb divergence (s^{-1}; purple contours). The yellow star denotes the approximate location of Great Falls.

As shown in archived surface analyses (WPC 2017), a weak low pressure center drifted from northeastern MT toward southwestern ND between 00:00Z and 06:00Z 18 August 2016, while the accompanying cold front advanced southeastward and southward. However, the western portion of this front became stationary over southwest MT by 06:00Z 18 August 2016. The front likely stalled as it interacted with higher terrain along or near the Continental Divide. In addition, a surface ridge built south-southeastward from the AB prairies into north-central MT. With Great Falls located on the cool side of the surface front, one would expect any convection over and near the Great Falls area to be elevated (Figs. 6 and 7).

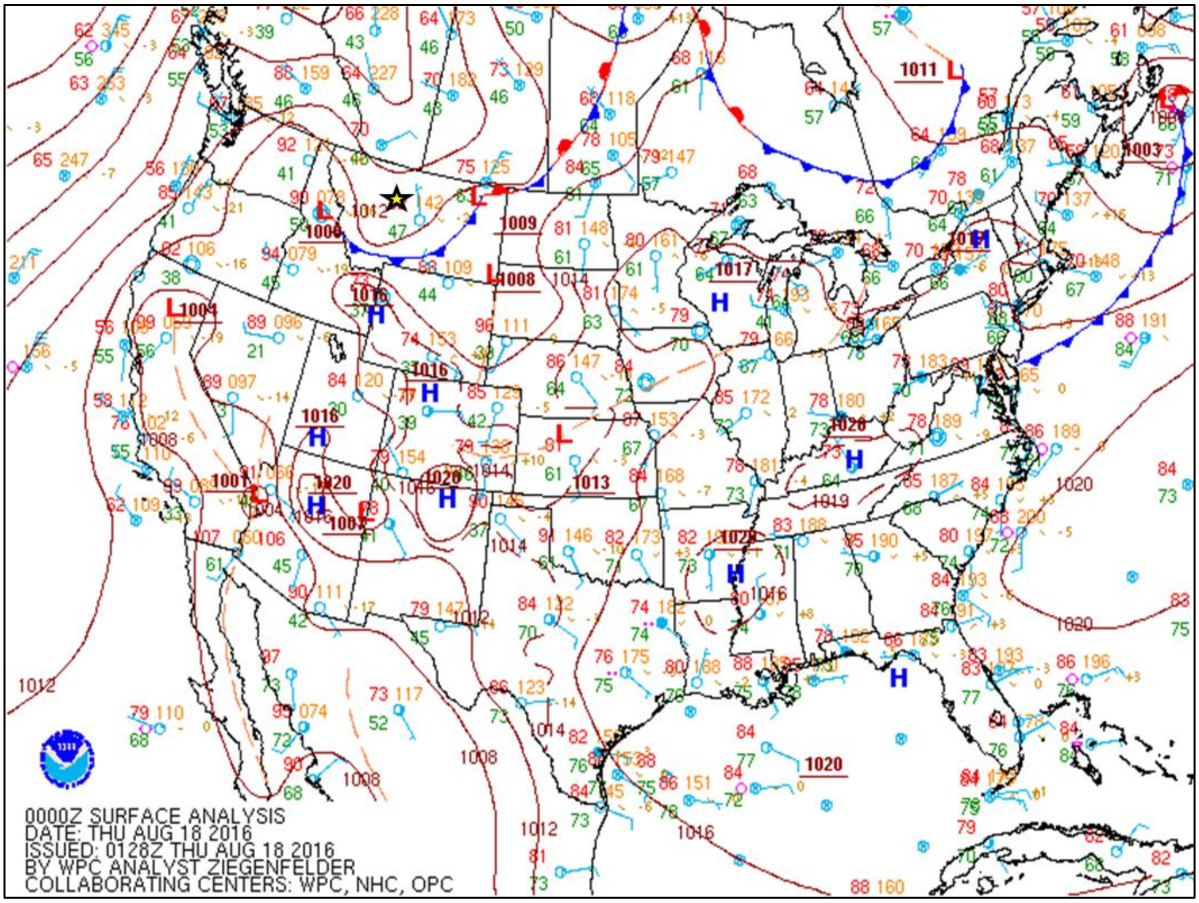


Fig. 6: 00:00Z 18 August 2016 surface analysis. The yellow star denotes the approximate location of Great Falls.

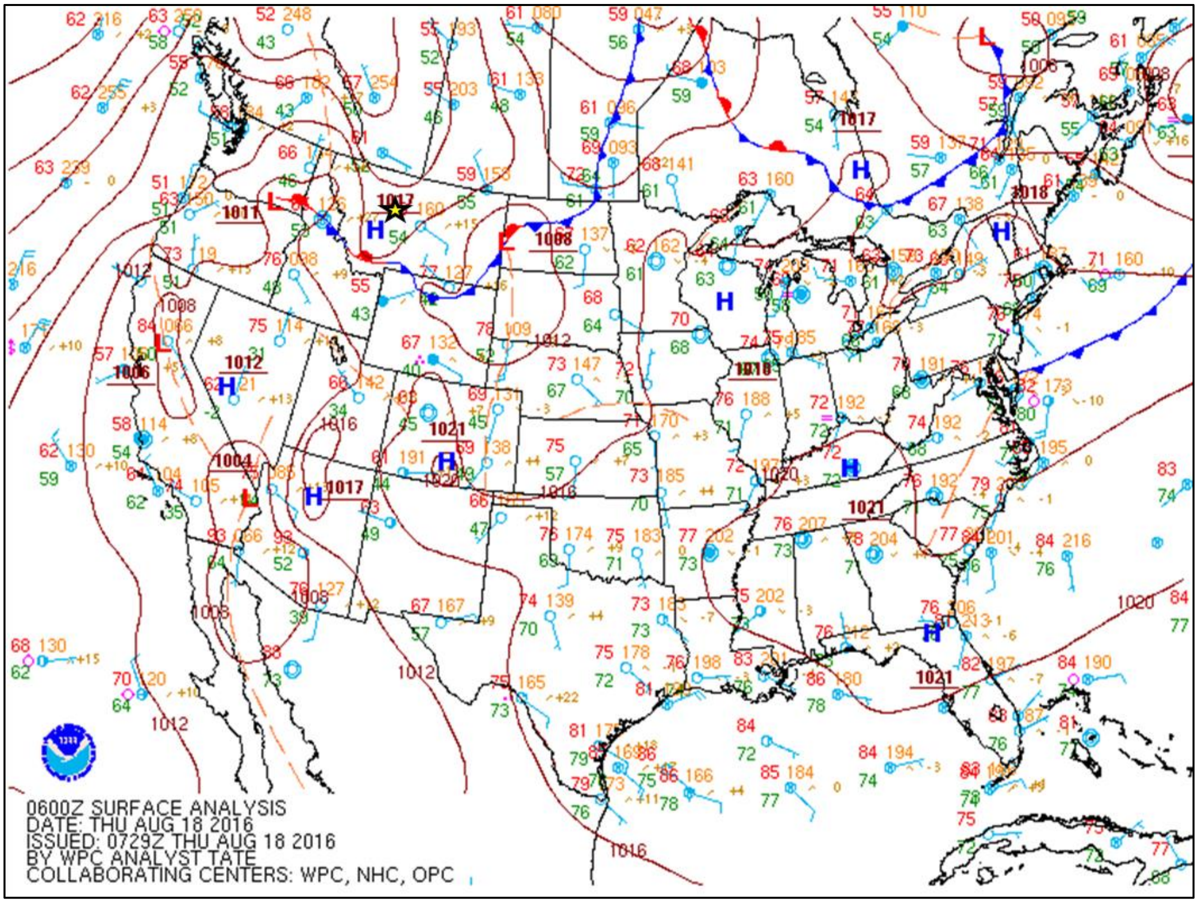
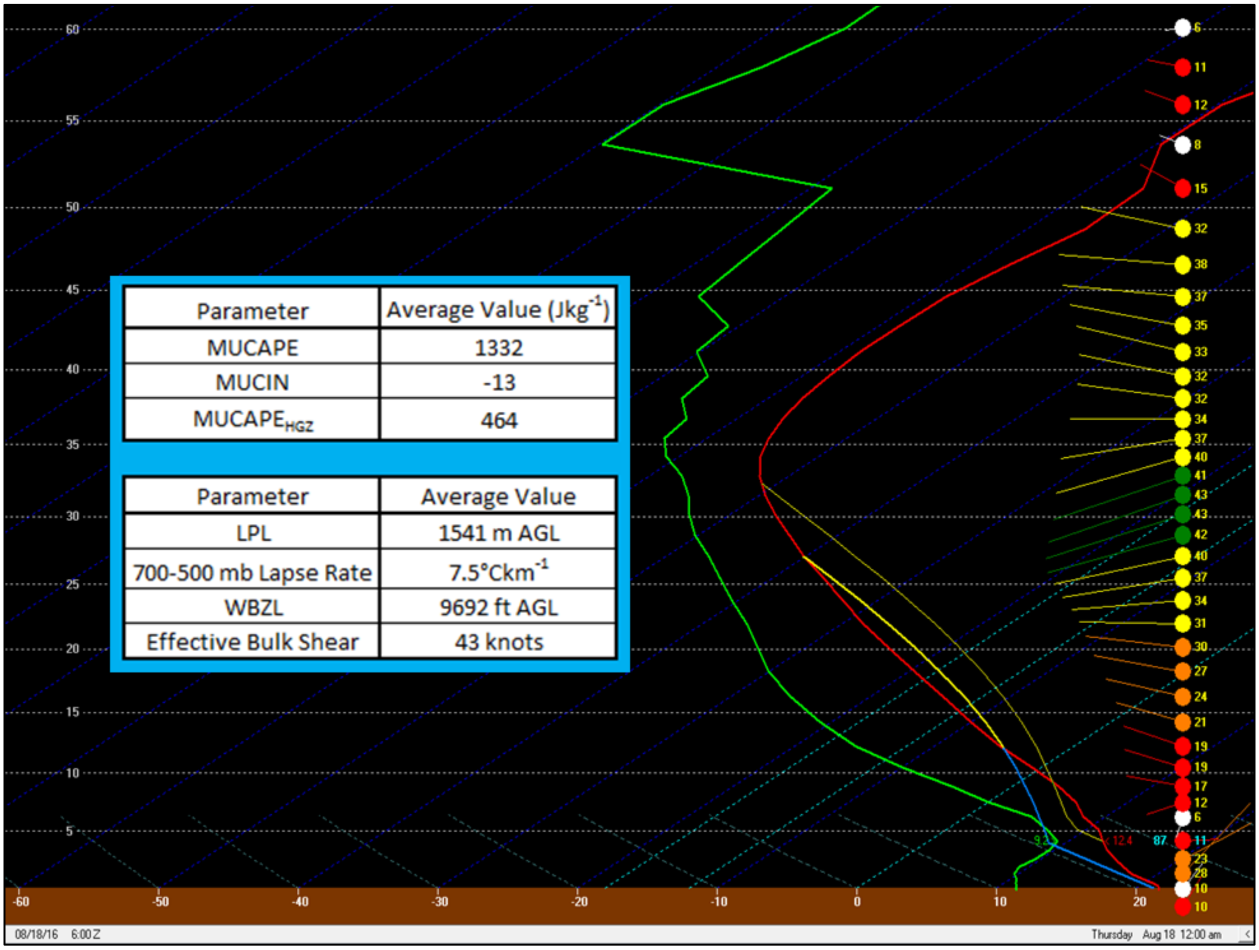


Fig. 7: Same as in Fig. 6, except for 06:00Z 18 August 2016.

In order to assess the pre-storm environment, the values of relevant convective parameters were obtained from NAM12 and RAP13 model soundings for Great Falls using NSHARP and then averaged. In addition, MUCAPE within the hail growth zone ($\mathrm{MUCAPE_{HGZ}}$) was calculated for the NAM and RAP soundings using BUFKIT and then averaged. All model data were initialized at 00:00Z 18 August 2016. In addition, all convective parameter values were obtained from 06:00Z 18 August 2016 model soundings, which represented the pre-storm environment approximately 30-minutes before the first severe hail report from the thunderstorm.

As shown in Fig. 8, MUCAPE was moderate, MUCIN was weak, and the lifted parcel level (LPL) was situated within an elevated effective inflow layer. In turn, this effective inflow layer was co-located with the convergence along the 850 mb front shown in Fig. 5. Thus, the 850 mb front was likely the primary lifting mechanism that triggered this elevated thunderstorm. Hail growth zone CAPE of at least 400 $\mathrm{Jkg^{-1}}$ is favorable for severe hail production (WDTD 2016). For this event, $\mathrm{MUCAPE_{HGZ}}$ was supportive of severe hail production and wet bulb zero level (WBZL; NWS 2009) was favorable for severe hail to survive its fall to the surface (Fig. 8). The same figure shows effective bulk shear was 43-knots, indicating a favorable kinematic environment for supercells. In addition, 06:00Z 18 August 2016 mesoanalysis data depicted a supercell composite parameter (SCP) value of approximately 2 over and near Great Falls (not shown), with a 20-knot Bunkers supercell storm motion vector directed toward the south-southeast. As stated before, this severe hailstorm was a marginal and elevated supercell that advanced generally southeastward. According to archived reflectivity (not shown), this storm moved to the right when compared to the forward motion of nearby thunderstorms. The majority of elevated right-moving supercells are associated with SCP values greater than 1 (Thompson et al. 2004).



Parameter	Average Value (Jkg^{-1})
MUCAPE	1332
MUCIN	-13
$MUCAPE_{HGZ}$	464

Parameter	Average Value
LPL	1541 m AGL
700-500 mb Lapse Rate	7.5°Ckm^{-1}
WBZL	9692 ft AGL
Effective Bulk Shear	43 knots

Fig. 8: 06:00Z 18 August 2016 RAP sounding for Great Falls in BUFKIT and average values of convective parameters from NAM and RAP soundings. The average height of the base (top) of the effective inflow layer (not shown) was 355 m AGL (3039 m AGL).

3. RADAR CHARACTERISTICS OF THUNDERSTORM AND WARNING PERFORMANCE ASSESSMENT

The most basic radar signatures for severe hail detection are reflectivity (Z) of at least 60 dBZ at -20°C and -30°C within a thunderstorm and storm-top divergence ΔV of at least 70 knots. The aforementioned reflectivity signature within a thunderstorm implies the presence of golf ball-size or larger hail within a relatively-strong updraft and the upper-reaches of the hail growth zone. This, in turn, causes the probability of severe hail at the surface to increase dramatically since hail of such size rarely melts considerably before reaching the ground. Storm-top divergence $\Delta V \geq 70$ knots implies the presence of a sufficiently-strong updraft for severe hail production (WDTD 2016, personal communication). Storm mode is also an important consideration when forecasting maximum hailstone size for a severe thunderstorm or tornado warning (Blair et al. 2017). In regard to supercells, a midlevel mesocyclone exhibiting rotational velocity (V_{rot}) ≥ 30 knots for $\geq$ 15-minutes will likely produce maximum hail $\geq$ 2.00” in diameter. Marginal supercells (e.g. those with 20 knots $\leq V_{rot} < 30$ knots for the midlevel mesocyclone) tend to produce maximum hail in the range of 1.25” to 2.00” in diameter. Dual-pol radar data can further inform the potential of severe hail. Severe hail with little rain (e.g. a lofted severe hail core) typically yields $Z > 55$ dBZ, ZDR < 1 dB, CC of 0.95 to 0.97, and KDP < $1°\mathrm{km}^{-1}$ (WDTD 2016, personal communication).

Meteorologists at NWS Great Falls are able to analyze data from several Doppler radars when interrogating a storm (Fig. 9). Using the sampling tool and RAP13 standard environment package in AWIPS II, all-tilts data from the Missoula, MT Doppler radar (KMSX) were used to assess Z at -20°C and -30°C, storm-top divergence ΔV, V_{rot}, and any lofted severe hail core dual-pol signature. KMSX was the only useful radar for analyzing the upper-reaches of the thunderstorm because of the storm’s close proximity to KTFX and apparently the storm’s depth. Due to limited network bandwidth, CC data are not available in AWIPS II from the radars that neighbor KTFX, including KMSX. However, CC data are available in GR2 Analyst software. For each radar data frame and elevation angle, the location (i.e. latitude and longitude) that corresponded to the center of the pixel of strongest $Z > 55$ dBZ was found using the D2D points tool in AWIPS II. For simplicity, latitude and longitude were both rounded to the nearest hundredth of a degree. Using the CC display from KMSX in GR2 Analyst, the corresponding CC value was noted at the same location.

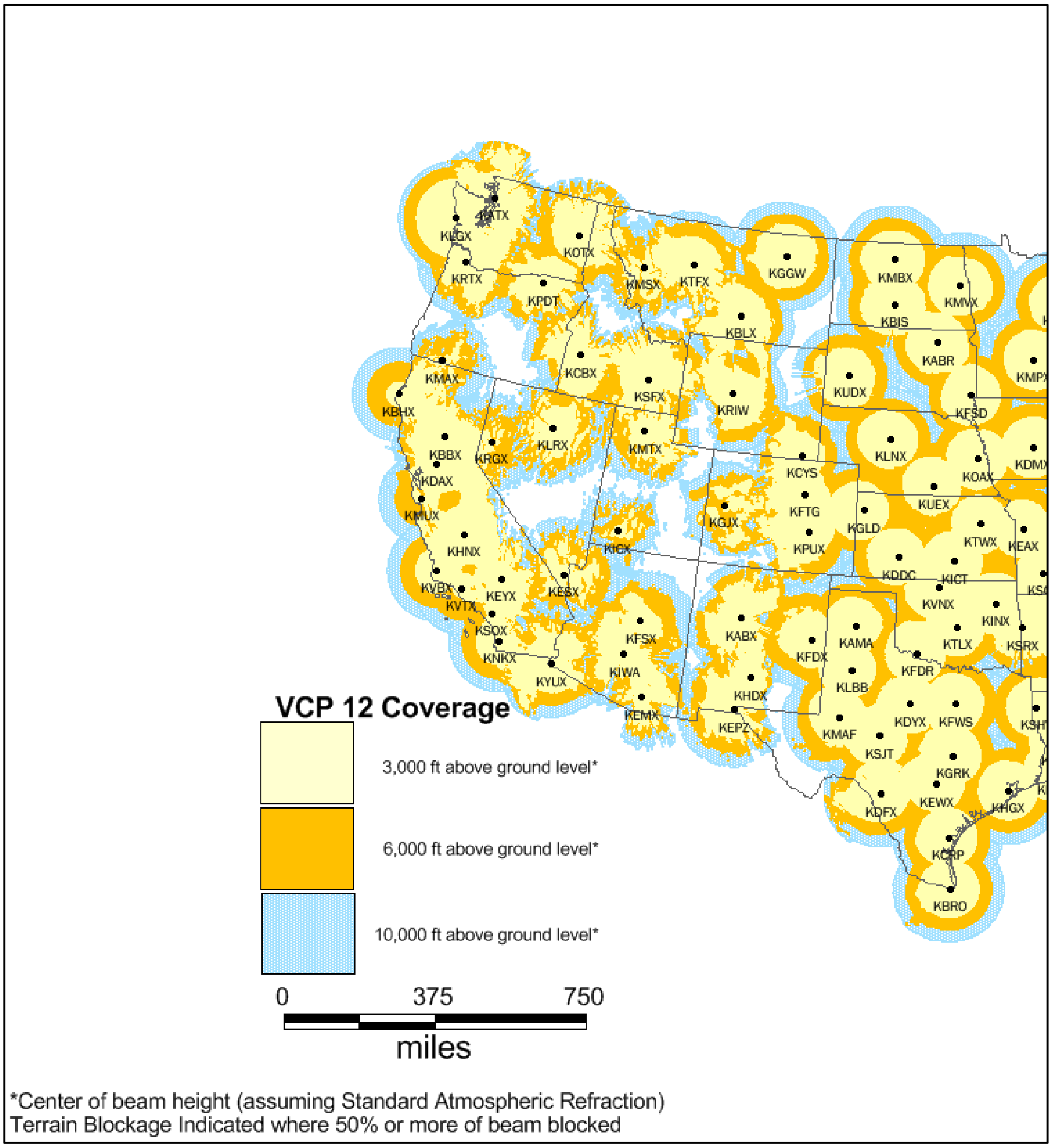
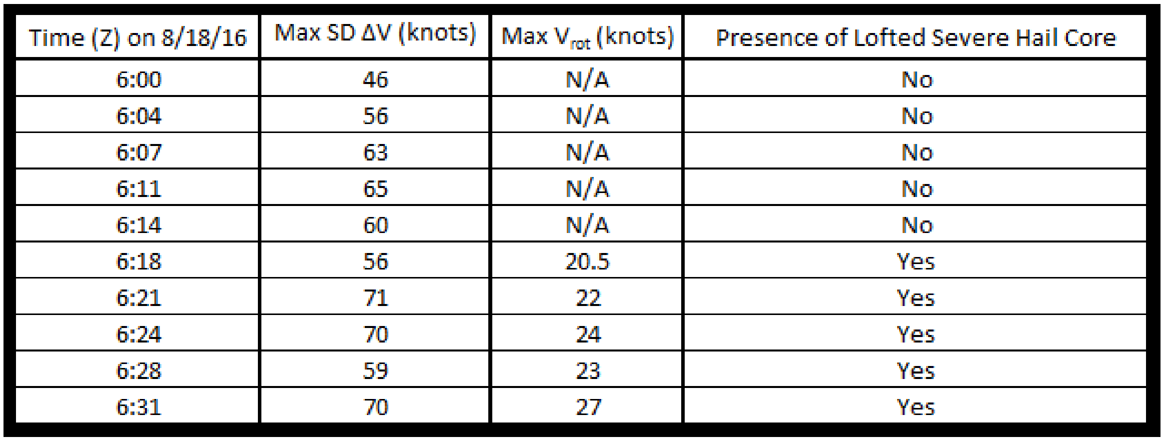


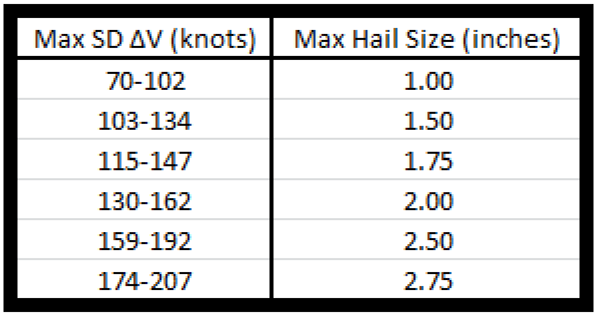
Fig. 9: Map of NWS Doppler radar coverage below 10,000 feet AGL for the western U.S. and vicinity. NWS Great Falls meteorologists analyze data from the four MT Doppler radars and the Pocatello, ID radar (KSFX).

Table 1 shows the trends in maximum storm-top divergence ΔV (SD ΔV), maximum V_{rot}, and the presence of a lofted severe hail core detected by KMSX. These trends span 06:00Z (approximate time at which the convective cell initiated northwest of Great Falls) to 06:31Z 18 August 2016, which was the last available scan from KMSX before the first report of severe hail in Great Falls. Note that $Z \geq 60$ dBZ at -20°C and -30°C was never sampled within the storm and is excluded from Table 1. KMSX began detecting a marginal midlevel mesocyclone and lofted severe hail core by 06:18Z, and sufficiently-strong SD ΔV for severe hail by 06:21Z. Given favorable trends in dual-pol data, maximum SD ΔV, and maximum V_{rot} were present, in tandem, by 06:24Z 18 August 2016, a severe thunderstorm warning for quarter-size to half dollar-size hail could have been issued, providing those affected with at least eight-minutes of lead time. These forecast hail sizes are based on the findings of Blair et al. (2017) and WDTD guidance (Table 2). Table 3 shows all the severe hail reports from the supercell, while Figures 10 through 12 depict the storm's structure around the time at which the warning should have been issued.



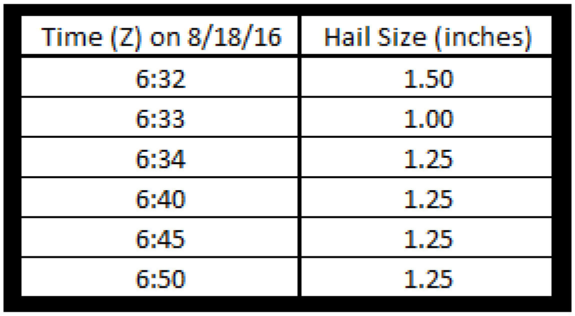
Time (Z) on 8/18/16	Max SD ΔV (knots)	Max V_{rot} (knots)	Presence of Lofted Severe Hail Core
6:00	46	N/A	No
6:04	56	N/A	No
6:07	63	N/A	No
6:11	65	N/A	No
6:14	60	N/A	No
6:18	56	20.5	Yes
6:21	71	22	Yes
6:24	70	24	Yes
6:28	59	23	Yes
6:31	70	27	Yes

Table 1: Trends in maximum storm-top divergence ΔV (Max SD ΔV), maximum rotational velocity (Max V_{rot}), and presence of lofted severe hail core from 06:00Z to 06:31Z 18 August 2016 according to data from KMSX.



Max SD ΔV (knots)	Max Hail Size (inches)
70-102	1.00
103-134	1.50
115-147	1.75
130-162	2.00
159-192	2.50
174-207	2.75

Table 2: WDTD guidance for forecasting maximum hail size given maximum storm-top divergence ΔV (SD ΔV).



Time (Z) on 8/18/16	Hail Size (inches)
6:32	1.50
6:33	1.00
6:34	1.25
6:40	1.25
6:45	1.25
6:50	1.25

Table 3: Observed severe hail reports from the supercell as it impacted Great Falls.

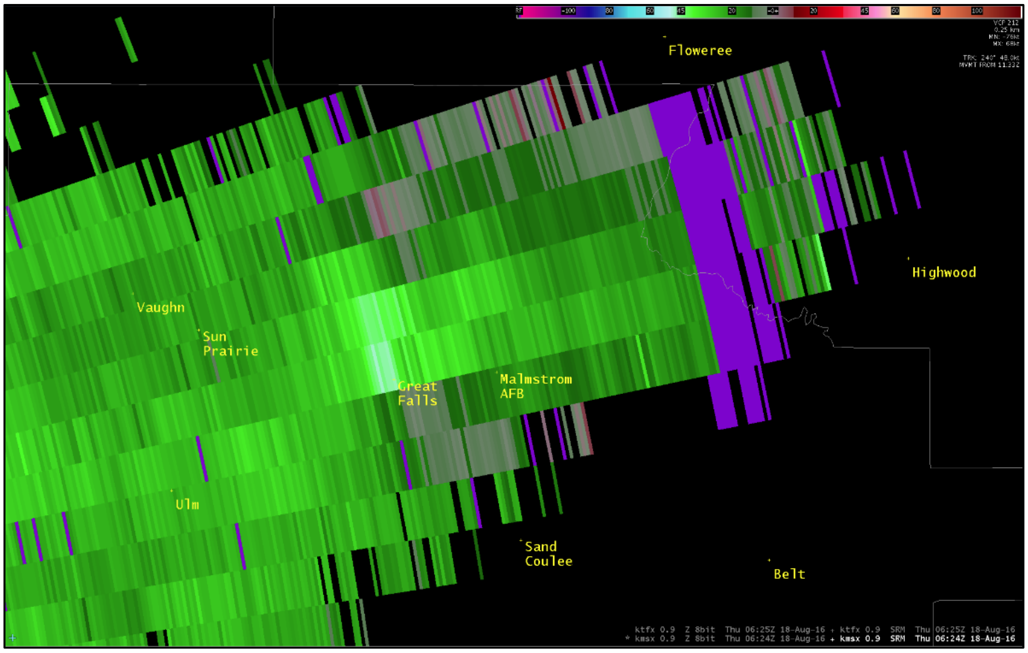


Fig. 10: 06:24Z 18 August 2016 0.9° storm-relative radial velocity from KMSX when the weak mesocyclone was situated over Great Falls. KMSX is west-southwest of the storm and north is toward the top of the image.

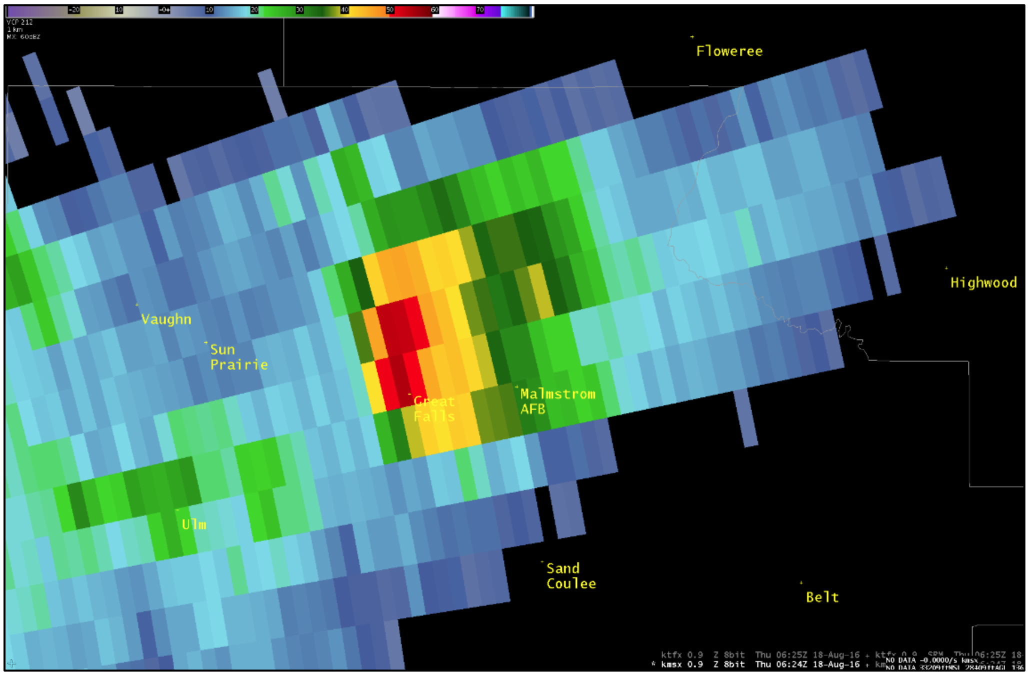


Fig. 11: Same as in Fig. 10, except 0.9° base reflectivity from KMSX is shown.

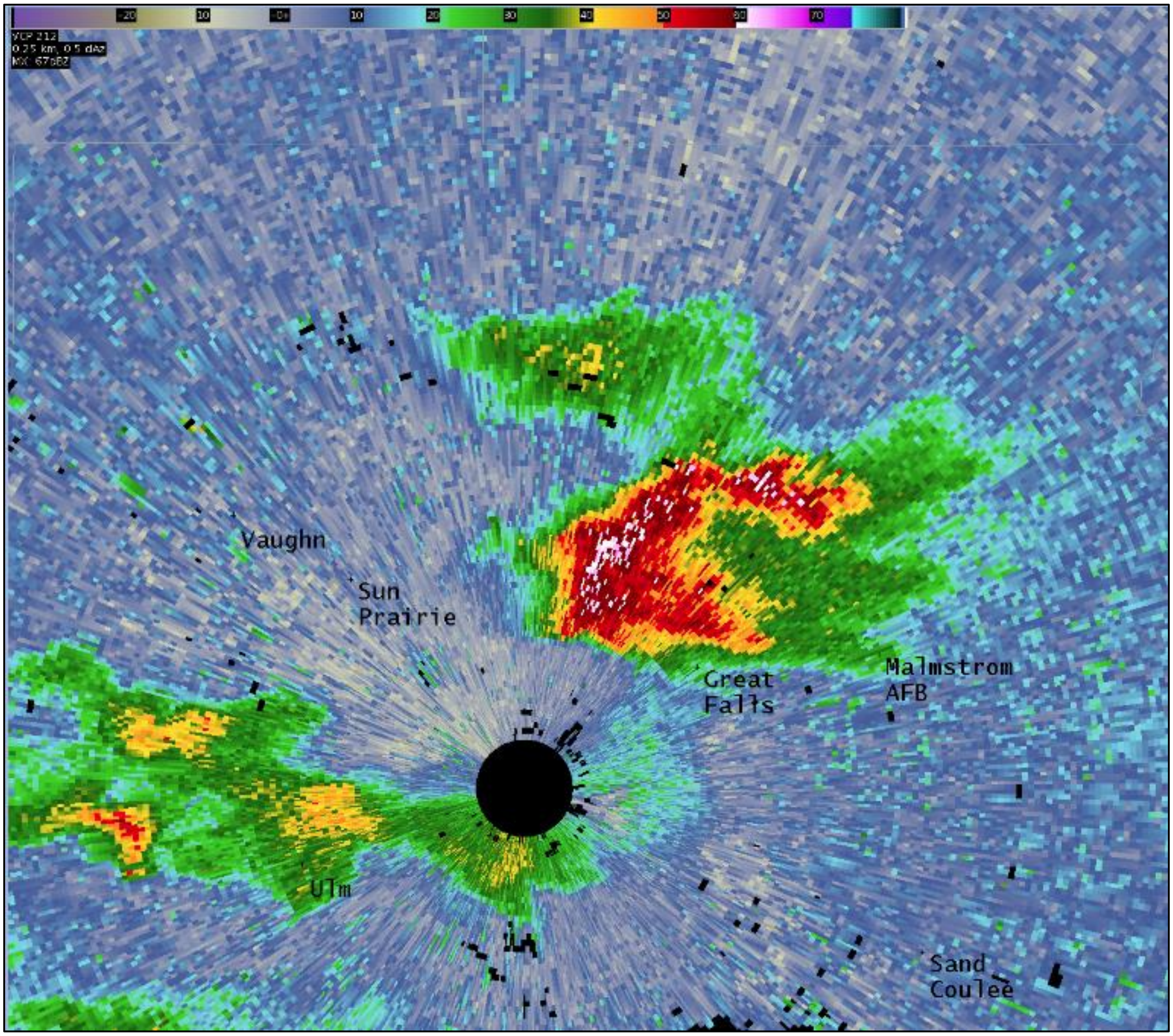


Fig. 12: 06:25Z 18 August 2016 0.5° base reflectivity from KTFX as the supercell neared Great Falls.

4. CONCLUSION

A proactive severe thunderstorm warning could have been issued for this supercell-related hailstorm and would have provided at least eight-minutes of lead time. Due to the storm's close proximity to KTFX and apparently the storm's depth, KMSX was the only Doppler radar that would have provided the warning forecaster with important severe hail signatures found in the upper-reaches of a thunderstorm. These signatures include trends in storm-top divergence ΔV and the lofted severe hail core dual-pol signature. This underscores the need to analyze data from multiple radars when interrogating a thunderstorm, especially when the storm is close to the radar and thus its upper-reaches are not being sampled.

5. ACKNOWLEDGEMENTS

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