PICTURE OF THE MONTH

Hailstorm Damage Observed from the *GOES-8* Satellite: The 5–6 July 1996 Butte–Meade Storm

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20 February 1997 and 18 July 1997

1. Introduction

Late in the evening of 5 July 1996, a supercell thunderstorm developed near the Montana–Wyoming–South Dakota border and moved to the southeast across western South Dakota. This storm was particularly notable for its persistent combination of large hail and extremely strong winds, which caused almost complete vegetative defoliation and destruction within a 120-km-long path. So extensive was the impact of the storm (especially in Butte and Meade counties of South Dakota) that the vegetation scar was visible for over a month on *Geostationary Operational Environmental Satellite-8* (*GOES-8*) visible satellite imagery. This article briefly describes the nature of this extreme local storm event (hereafter referred to as the Butte–Meade storm) and the conditions responsible for creating the satellite-observed damage swath.

2. Discussion

The *GOES-8* visible satellite images from before (28 June) and after (15 July) the 5–6 July 1996 Butte–Meade storm illustrate the surface damage from this event (Fig. 1). The damaged areas are apparent in the 15 July image as a narrow light band, indicating where the vegetation (primarily range grasses) had been killed. These areas stand out in contrast against the ambient vegetation that was still green (darker in the black and white image) at the time. The area most severely damaged by the Butte–Meade storm extended along a 120-km-long, 7–11-km-wide swath from near Belle Fourche Reservoir (Butte County) through central Meade County. Damage surveys within the affected area indicated that most all rangeland grass and crops were dead, killed by a combination of large (>5 cm) hail and strong (estimated at greater than 50 m s^{-1}) winds that not only destroyed the standing plants, but also disturbed the soil to the point that roots were exposed and severely impacted. Where trees existed within this path, most leaves were stripped and branches less than 1 cm in diameter were snapped off. In several locations, standing crops were reduced to barren soil with the damaged vegetation effectively ''tilled'' under by the pounding of the hailstones. Residents within the storm path reported an eerie silence for several days after the storm, as most insects and birds were killed. In addition to the vegetative losses, other significant damage and weather reports included the following:

- Scores of sheep, cattle, and horses killed. Thousands of livestock injured by wind-driven hail. On one ranch, 56 horses were killed.
- Tennis-ball-sized hail with winds estimated at over 50 m s^{-1} in many locations.

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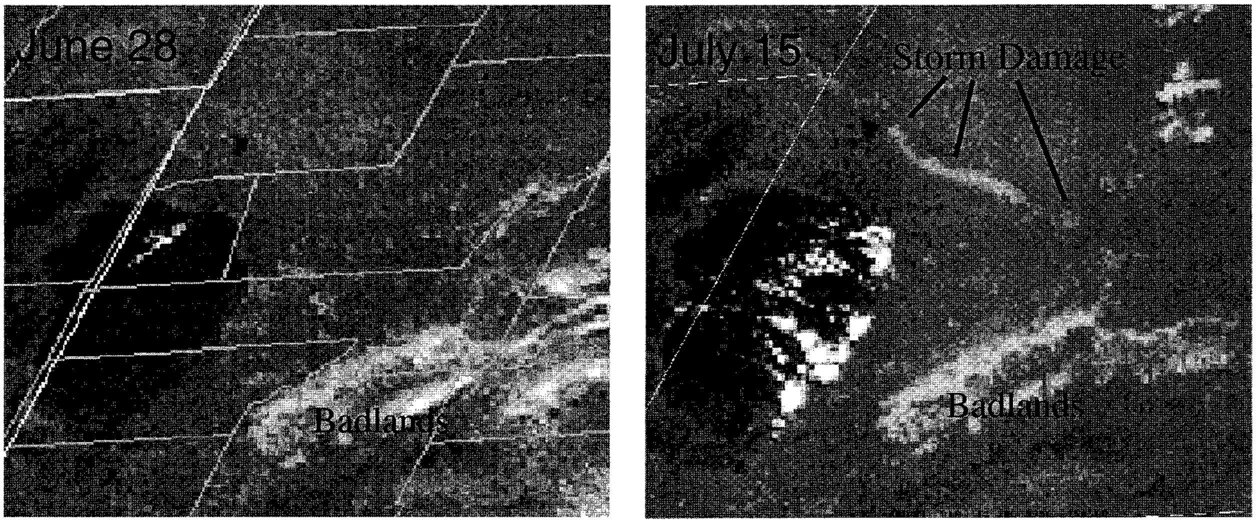

FIG. 1. *GOES-8* visible satellite images taken before (left) and after (right) the 5–6 July 1996 Butte–Meade storm, illustrating the region of storm damage in western South Dakota.

- Fist-sized holes from wind-driven hail on the *inside* wall of a house.
- Round bales of hay blown over a mile.
- Hundreds of telephone poles snapped.
- Greater than 200 000 acres (800 km^2) of private range and farmland destroyed, an additional 300 000 acres (1200 km^2) significantly damaged.
- Reports of hail 14–17 cm in diameter (central Meade County).
- Multiple reports of small buildings, automobiles, and farm/ranch equipment damaged and/or blown significant distances.

Figure 2 illustrates crop damage that was typical of that within the satellite-observed damage path.

The Butte–Meade storm developed within an environment of considerable instability (Fig. 3) with lifted indices from -6 to -10 and convective available potential energy from 2500 to 4000 J kg^{-1}. The vertical wind shear (Fig. 4) was such that it promoted supercellular processes (Weisman 1996), with a 0–3-km above ground level (AGL) storm-relative environmental helicity of 233 $m^2\ s^{-2}$ (Davies-Jones et al. 1990) and a bulk Richardson number of 29. Analysis of the Rapid City, South Dakota (KUDX), WSR-88D radar data in-

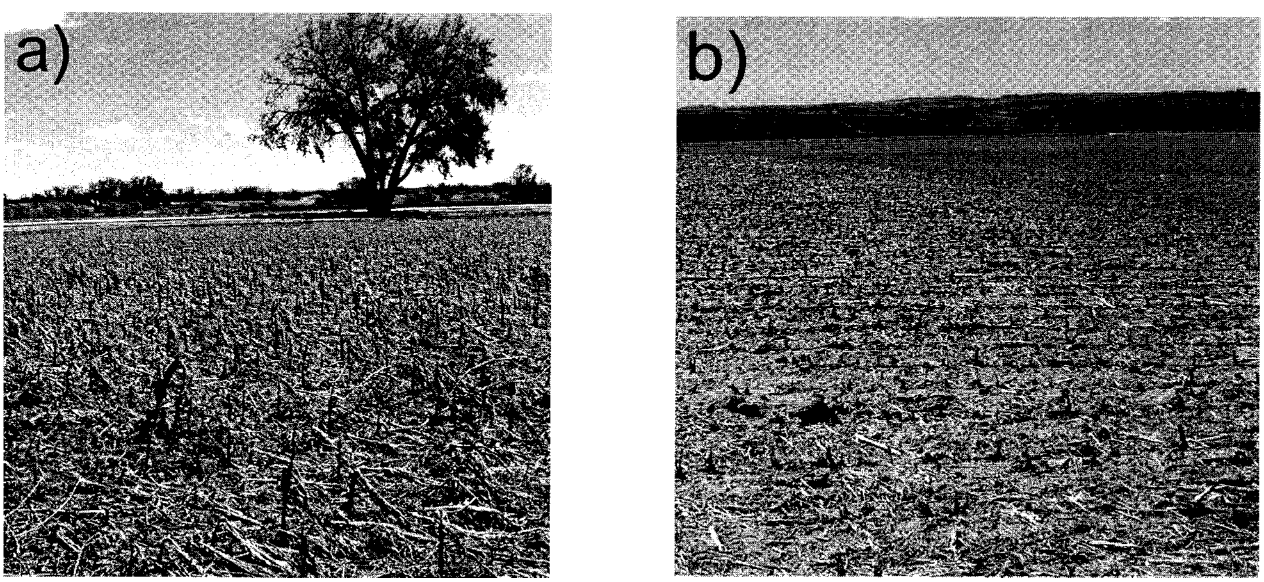

FIG. 2. Two photographs illustrating (a) moderate and (b) extreme damage to cornfields near and within the satellite-observed damage area (Butte County). The field illustrated in (a) had all corn plants shredded, with the remains of stalks standing up to 0.4 m high. Note the existence of leaves still on the tree in the background. The field illustrated in (b) was more severely impacted by the storm and exhibited little or no standing vegetation. Both cornfields had dense growth over 1 m high prior to the 5–6 July 1996 event.

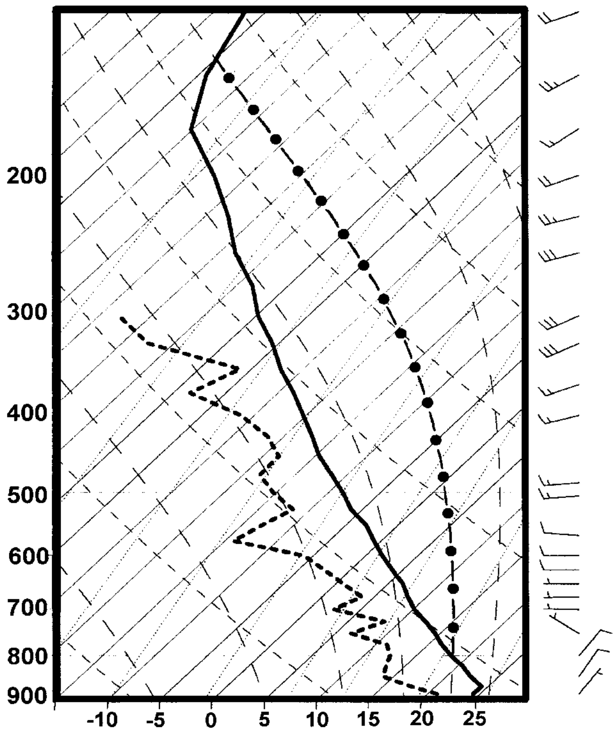

FIG. 3. Skew *T*–log*p* diagram representing the temperature (solid line), moisture (dashed line), and wind profile over Rapid City at the time of the storm (0500 UTC 6 July). Horizontal axis is temperature (°C); vertical axis is pressure (mb). The wind is given along the right edge, with a full barb representing 10 m s^{-1}. The 0000 UTC Rapid City sounding was modified with (0500 UTC) surface data and VAD wind profile data from the KUDX radar for this figure.

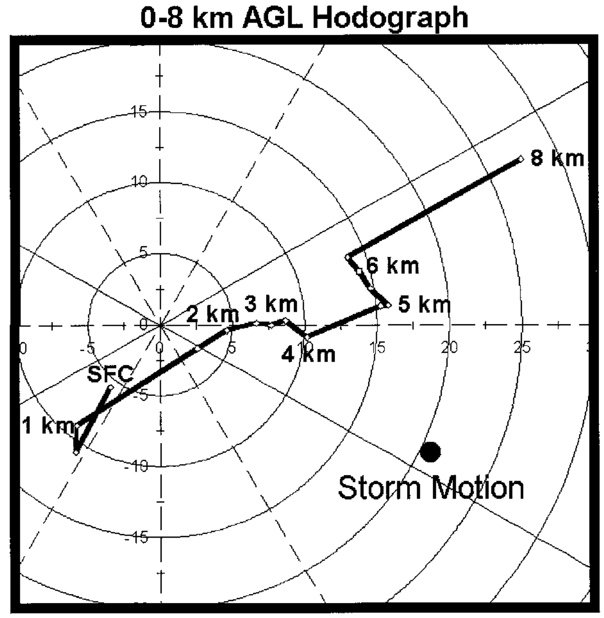

FIG. 4. Hodograph of the winds from the 0000 UTC Rapid City sounding, modified in the low levels with 0500 UTC surface data and KUDX radar VWP data. Horizontal and vertical axes are in meters per second. Numbers along the hodograph line are heights in kilometers AGL.

dicated that this event was a high-precipitation (HP) supercell (Moller et al. 1990), and appeared to be of similar magnitude, and shared the general characteristics of other extreme HP events in the literature (Cummine et al. 1992; Moller et al. 1990; Fujita and Wakimoto 1981; Inglish 1990; Smith 1993 and Janish et al. 1996). Three 0.5° PPI (plan position indicator) base reflectivity scans from the KUDX radar during the period that the storm was over the area of the satellite-visible damage are shown in Fig. 5. As this figure illustrates, the low-level reflectivity structure remained quasi-steady during this period, with a prominent inflow notch on the eastern side of the storm as it moved to the east–southeast at approximately 20 m s^{-1}. Through the most intense phase of the storm (0508–0602 UTC) maximum reflectivities of 73–77 dB*Z* were observed, with maximum 0.5° radial velocities (inbound) of about 35 m s^{-1}. Though the storm moved rapidly, large rainfall amounts (10–15 cm) were reported along and near the damage path. There was one report of a tornado with this event, though no striking tornado signatures were observed in the reflectivity or velocity data.

The relationship between the satellite-observed vegetation scar and the reported surface damage is indicated in Fig. 6. Reports of hail greater than 5 cm are indicated by filled circles, and the region of F1 or greater wind damage is enclosed by the thick line. The shaded regions indicate storm-damaged areas visible from the GOES visible satellite imagery. Storm damage data were acquired from visitation to the site, an areal flight survey, and numerous calls to the affected area. Most of the observed wind damage was caused by exceptionally strong straight-line winds from the northwest. Analyses of the damage reports indicated that the areas of the greatest vegetative destruction occurred where the largest hail and greatest wind were coincident. For this case, it appeared that hail greater than 5 cm in diameter, with surface winds approaching 50 m s^{-1} was sufficient to generate much of the satellite-visible hail damage visible in Fig. 1.

3. Conclusions

The satellite-observed hail damage presented here is not a unique observation. The authors know of several less spectacular examples that have occurred on the High Plains. From these data it appears that for such a feature to be observed in the GOES visible satellite imagery, over an area with similar surface characteristics (rangeland grasses, few crops), a combination of copious amounts of large hail (>5 cm) and very strong winds (>35 m s^{-1}) must occur. Of course, the visibility of such a feature will be strongly dependent on the condition of the ground cover. Regions of young, green rangeland grasses and crops (typical of what would exist in June or early July) would likely be most susceptible

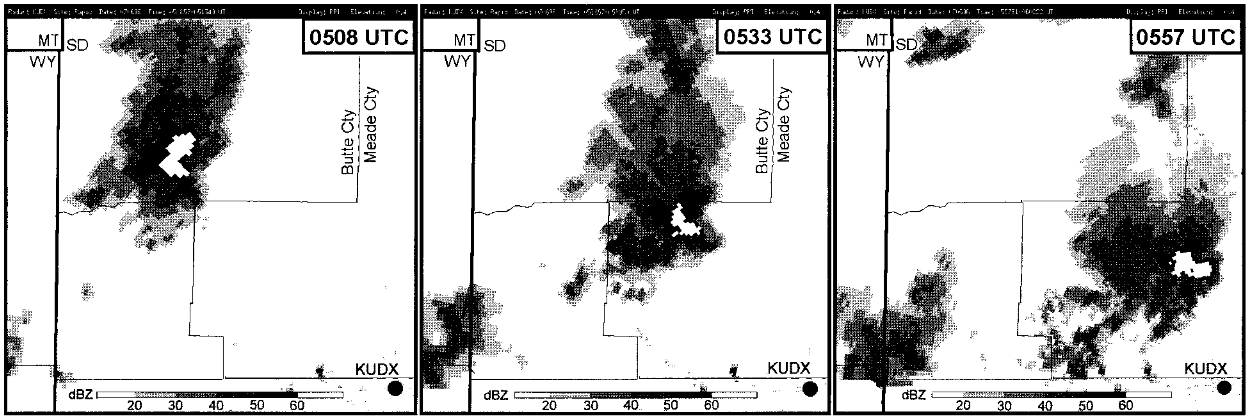

FIG. 5. Plots of the KUDX radar 0.5° reflectivity at 0508, 0533, and 0557 UTC. Reflectivity contoured every 10 dB*Z*, from 20 to 60 dB*Z*.

to this kind of observed damage. Later in the season, the High Plains typically experience significant browning (drying), which may obscure such a feature. It is hypothesized that where significant amounts of trees are present, this magnitude of satellite-observed damage may not be visible due to the darkening produced by the shadows from the defoliated trees.

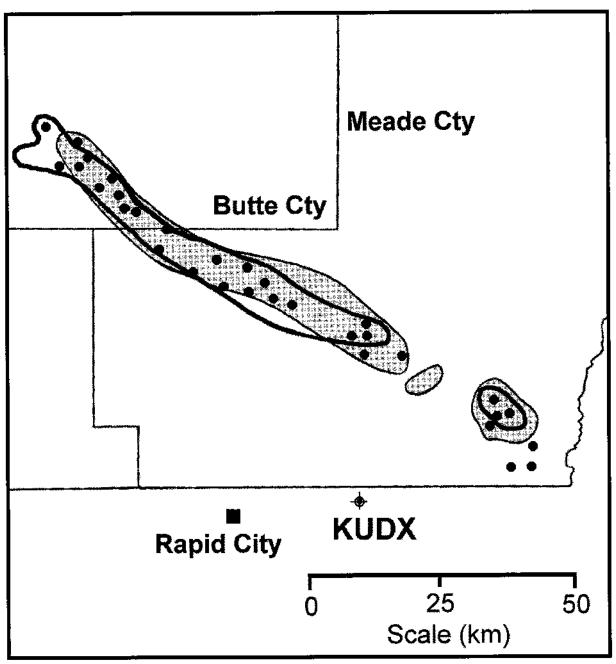

FIG. 6. Areal extent of the surface damage from the 5–6 1996 July Butte–Meade storm. Reports of hail greater than 5 cm are indicated by filled circles; the region encapsulating reports of F1 or greater wind damage is indicated by the thick line. The shaded areas indicate storm-damaged areas apparent in the *GOES-8* visible satellite imagery.

Acknowledgments. We are grateful to Kyle Carstens and Jay Searles (forecasters at the NWSO Rapid City) who first brought this feature to our attention. This research was supported in part by a COMET cooperative grant.

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