Heat Burst Detection by a Temporally Fine-Scale Mesonet

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ABSTRACT

A heat burst which occurred at Sioux Falls, South Dakota, early in the morning of 11 August 2007, took place in close proximity to both the KFSD WSR-88D and to privately owned mesonet sensors which record data in 1-min increments. The event began with the decay of a thunderstorm, when precipitation a few hundred meters AGL descended to the ground and was immediately followed by the heat burst. Two mesonet sensors 2-km apart reported a marked temperature increase rate, averaging 0.23°C min^{-1}. The barometric pressure fell at an average rate of 0.13 hPa min^{-1} during the combined precipitation–heat burst period. The rise and fall of temperatures corresponding with the heat burst concluded within 45 min.

1. Introduction

A heat burst is defined as a localized, sudden increase in surface temperature associated with a thunderstorm, shower, or mesoscale convective system (Johnson 1983; Glickman 2000). Such an event occurred at Sioux Falls, South Dakota, between 0700–0900 UTC (0200–0400 CDT) on 11 August 2007. With decaying thunderstorms over and south of the city, the National Weather Service (NWS) Automated Surface Observing System (ASOS) sensor located at the airport in northern Sioux Falls (KFSD) reported a marked rise and subsequent fall in the hourly temperature report, accompanied by a temporary shift in wind direction and an increase in wind speed, with gusts to 30 knots (Table 1).

The event was also documented by privately owned Texas Weather Instruments® sensors located at the Washington Pavilion of Arts and Sciences in central Sioux Falls (5 km south of the airport), and at Patrick Henry Middle School (7 km south of the airport). Observations from both sensors were transmitted over the Internet to the Iowa Environmental Mesonet (IEM), where they were recorded in 1-min increments. Archived and real-time IEM data are freely available online (http://mesonet.agron.iastate.edu/schoolnet/).

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Heat bursts arguably are not rare in South Dakota. A short-lived, minor heat burst occurred at the Sioux Falls airport during the afternoon before the case detailed in this paper (P. Schumacher, 2007, personal communication). Previous significant heat bursts that occurred in the state have been documented by Heitkamp and Holmes (1998), Harding (2000), and Johnson (2003), among others. Another heat burst was observed in Pierre on 20 June 1989, when the temperature rose from 30 to 40°C (86 to 104°F) in two hours (NCDC 1989). However, observations of these events involved data that were recorded in time increments of 5- to 60-min—a coarser temporal scale.

2. Pre-existing conditions

Numerous severe thunderstorms affected the Upper Midwest on the evening and night of 10 August 2007. The heat burst discussed herein was preceded by a cluster of thunderstorms that moved from west to east through central and extreme southern South Dakota. Those storms evolved into a line of severe storms that produced hail and high winds from 0300–0600 UTC along the eastern portion of the South Dakota–Nebraska border (Fig. 1).

No severe weather was experienced in Sioux Falls, itself, but the heat burst closely followed a brief period of light rainfall as these storms decayed. Because it occurred in close proximity to the KFSD radar, the precipitation was scanned at levels very near the surface. The composite reflectivity from the KFSD Weather Surveillance Radar-1988 Doppler (WSR-88D) radar at 0709 UTC (Fig. 2a) shows a moderate convective shower over southwestern Sioux Falls, moving toward the northeast due to the prevailing southwesterly flow aloft. At that time, the highest reflectivity values (≥30 dBZ) were found at the 1.3 deg elevation and above, at a height >200 m AGL; weaker echoes were located below. In the following volume scan (Fig. 2b) the precipitation moved toward the center of Sioux Falls, passing over the mesonet sites. Light rain (<0.254 mm or < 0.01 in.) was recorded in the tipping bucket gage at Washington Pavilion (which records precipitation in 0.01-inch increments) between 0700 UTC and 0709 UTC.

KFSD WSR-88D Level 2 data can be used to provide a three-dimensional view of the precipitation core for the same time periods (Fig. 3). At 0708 UTC there was a precipitation core suspended from 0.2 to 3.2 km AGL. The actual echo top was probably higher, but data at greater heights were lost due to the lack of sampling directly above the radar (i.e., the "cone of silence"). During the 0713 UTC volume scan, some of the aforementioned ≥30 dBZ core had descended and was detectable in the lowest elevation scan (0.05 km AGL), so precipitation may have been reaching the surface. By 0717 UTC, the precipitation core had noticeably diminished, and dissipated over Sioux Falls by 0721 UTC. The composite reflectivity (Fig. 4) indicated echoes ≥35 dBZ were no longer present at 0726 UTC over the mesonet stations in central Sioux Falls.

3. Satellite imagery

Coincident with the dissipation of the precipitation core, satellite imagery shows that the cloud tops were warming directly over Sioux Falls. GOES-12 was in a rapid scanning mode during the event (although not all images are shown here for the sake of brevity), and the 10.7-µm channel (i.e., the infrared channel) measured a cloud top brightness temperature of -55°C over Sioux Falls at 0645 UTC (Fig. 5a). By 0702 the cloud top had warmed to -50°C over the city (Fig. 5b), and at 0715 UTC the cloud top over Sioux Falls had reached -45°C (Fig. 5c)—just as the heat burst event was being detected at the surface (discussed in the next section below).

The localized region of cloud top warming was similar in appearance to the signature created by downbursts on satellite imagery noted in Conway et al. (1997). The low-level echo dissipation combined with desiccation of the surface air is further indication of descent (Johnson 1983). Desiccation was quantified, along with the temperature rise, by mesonet sensors at the surface.

4. One-minute sensor data

The mesonet station at Washington Pavilion was the first to detect abrupt changes in surface parameters, coinciding with the thunderstorm and its collapse. As the radar-indicated precipitation core descended to the surface, the barometer showed a strong pressure fall (Fig. 6a). At 0702 UTC the Pavilion barometer reading was 1012.87 hPa. However, during the weak thunderstorm the pressure fell 4.74 hPa in 18 min, reaching a local minimum of 1008.13 hPa at 0720 UTC. As the weak thunderstorm ended, the pressure fell another 1.36 hPa as the heat burst became more pronounced at this site.

The temperature at 0720 UTC was 25°C (77°F). It then rose sharply, reaching 31°C (88°F) at 0748 UTC, and 32°C (90°F) at 0808 UTC (Fig. 6b). The dew point also dropped sharply during the corresponding time periods, from 23°C (74°F) at the start of the heat burst to a minimum of 11°C (52°F) during the peak of the heat burst. The station's anemometer recorded a maximum wind gust of 21 m s^{-1} (41 knots) at 0720 UTC. Minor tree damage was reported.

Similar abrupt, fine-scale changes were detected in the 1-min data from the Patrick Henry sensors 2 km to the south-southeast. A sharp drop in pressure, 5.76 hPa, occurred between 0700 and 0747 UTC (Fig. 7a), and a wind gust of 16 m s^{-1} (31 knots) was recorded. Unlike at Washington Pavilion, light rain was not recorded by the sensor's rain gage. The temperature at Patrick Henry (Fig. 7b) rose 6°C (11°F) in 17 min, before returning to a pre-event reading by 0900 UTC. It appears there is a dry bias in the humidity sensor at Patrick Henry (approximately 5.6°C or 10°F), but the trace pattern itself follows the same trend as was observed at the Pavilion: a rapid decrease in dew point corresponding to the temperature rise during the heat burst itself.

When precipitation ended (0720 UTC), the rate of temperature change at Washington Pavilion was +0.19°C min^{-1} (+0.34°F min^{-1}) and at Patrick Henry was +0.27°C min^{-1} (+0.49°F min^{-1}). The rate of pressure fall was 0.14 hPa min^{-1} at Washington Pavilion and 0.12 hPa min^{-1} at Patrick Henry. While the pressure trends were relatively consistent between the mesonet stations, instrument calibration was suspect because initial barometric pressure readings at 0700 UTC were significantly different from the hourly reading at Sioux Falls airport (KFSD), and were not adjusted to mean sea level pressure. Otherwise, the temperature component of the heat burst event lasted approximately 45 min, but dew point values took longer to recover.

Rapid temperatures rises were also recorded on Davis Instruments® sensors at schools in nearby communities between 0700–0900 UTC (Fig. 8). The temperature rises were sharp in Colton (A), Baltic (B), Garretson (C), and Brandon (D), which were also under the area of rapid cloud top warming observed by satellite in Fig. 5. The rate of warming was not as pronounced farther southeast in Hills, MN (E). None of the surrounding communities had heat bursts of the same 5.6°C (10°F) magnitude as those observed in Sioux Falls.

5. Vertical profile

Sioux Falls is located more than 230 kilometers from the nearest radiosonde lauch site, midway between Aberdeen (KABR) to the north and Omaha–Valley (KOAX) to the south. The heat burst also occurred between balloon launches temporally, so observed sounding data for the event were not representative of the lower troposphere over Sioux Falls. Moreover, Tropospheric Airborne Meteorological Data Reporting (TAMDAR) aircraft data were not available over KFSD until 1300 UTC.

A sounding profile derived from the Rapid Update Cycle (RUC) 1-h forecast valid for Sioux Falls at 0700 UTC 11 August 2007 (Fig. 9) is somewhat "onion-shaped," with a shallow surface inversion and very dry air above 930 hPa. Shallow stable layers are conducive to penetration by thunderstorm downdrafts (Johnson et al. 1989; Horgan et al. 2007). Downdraft CAPE (DCAPE; Emanuel 1994) was 1433 J kg^{-1}, indicating the potential for strong rain-cooled downdraft flow. The mid-level lapse rate (between 700–500 hPa) was 8.9°C km^{-1}; between 700–600 hPa it was 9.8°C km^{-1} (dry-adiabatic). Heat bursts are usually associated with nearly dry-adiabatic lapse rates in mid-levels (Heinselman et al. 1998).

Based upon the RUC sounding and parcel theory, in order for the surface temperature to reach 32°C (90°F) at Washington Pavilion, an air parcel (mesoscale downdraft) from a minimum height of 907 hPa (0.912 km AGL) had to descend through its equilibrium point to the surface and warm at the dry-adiabatic rate to achieve the surface temperatures observed. Subject to the limitations of parcel theory, such a parcel descent would have to have sufficient momentum to overcome the positive buoyancy attained by descent through the stable layer (Bernstein and Johnson 1994).

6. Conclusion

Mesonet data at 1-min resolution are valuable for detecting heat burst activity, through the ability to observe temperature, humidity, and barometric pressure trends on a temporally fine-scale. In this case, the data showed that the onset of a steep pressure fall preceded the heat bust, commencing as a precipitation core aloft began its descent, and continuing through the resulting temperature increase.

It should be noted that data quality can be an issue with privately owned mesonet data, due to uncertainty about calibration and accuracy of measuring equipment. Despite this limitation, the widespread nature of this event and the consistent trends from station to station provide great confidence in its occurrence and impact.

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TABLES AND FIGURES

Table 1. Hourly station observations at the Sioux Falls ASOS (KFSD) for 0700 to 0900 UTC 11 August 2007.

UTC	Temp °C (°F)	Dew Pt ° C (°F)	Wind (knots)	Pressure (hPa)	Sky
0700	25 (77)	19 (67)	S 9G18	1001.1	Thunderstorm with light rain
0800	31 (87)	12 (53)	W 13G30	1001.0	Clear below 12 kft
0900	26 (79)	14 (58)	S 8	1000.9	Clear below 12 kft

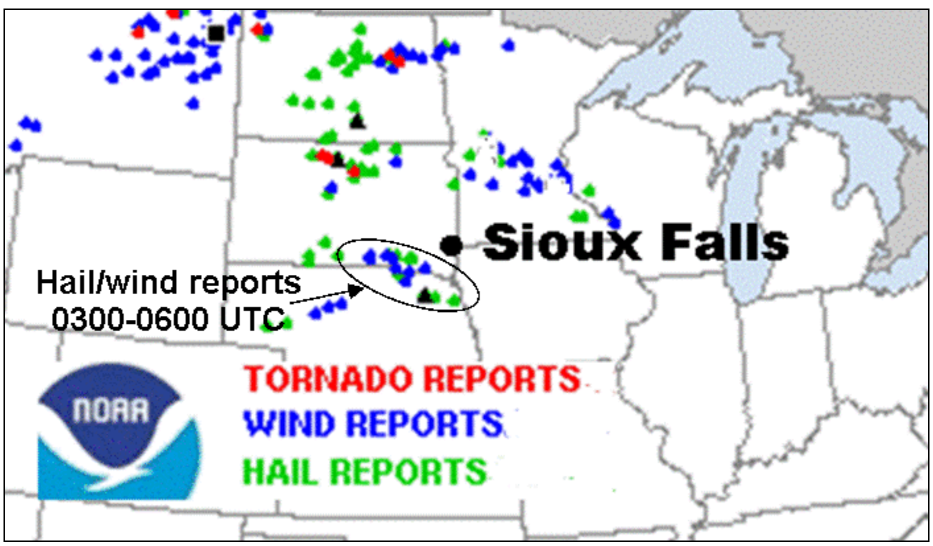

Figure 1. Storm reports from the NOAA Storm Prediction Center (SPC), 10 August 2007.

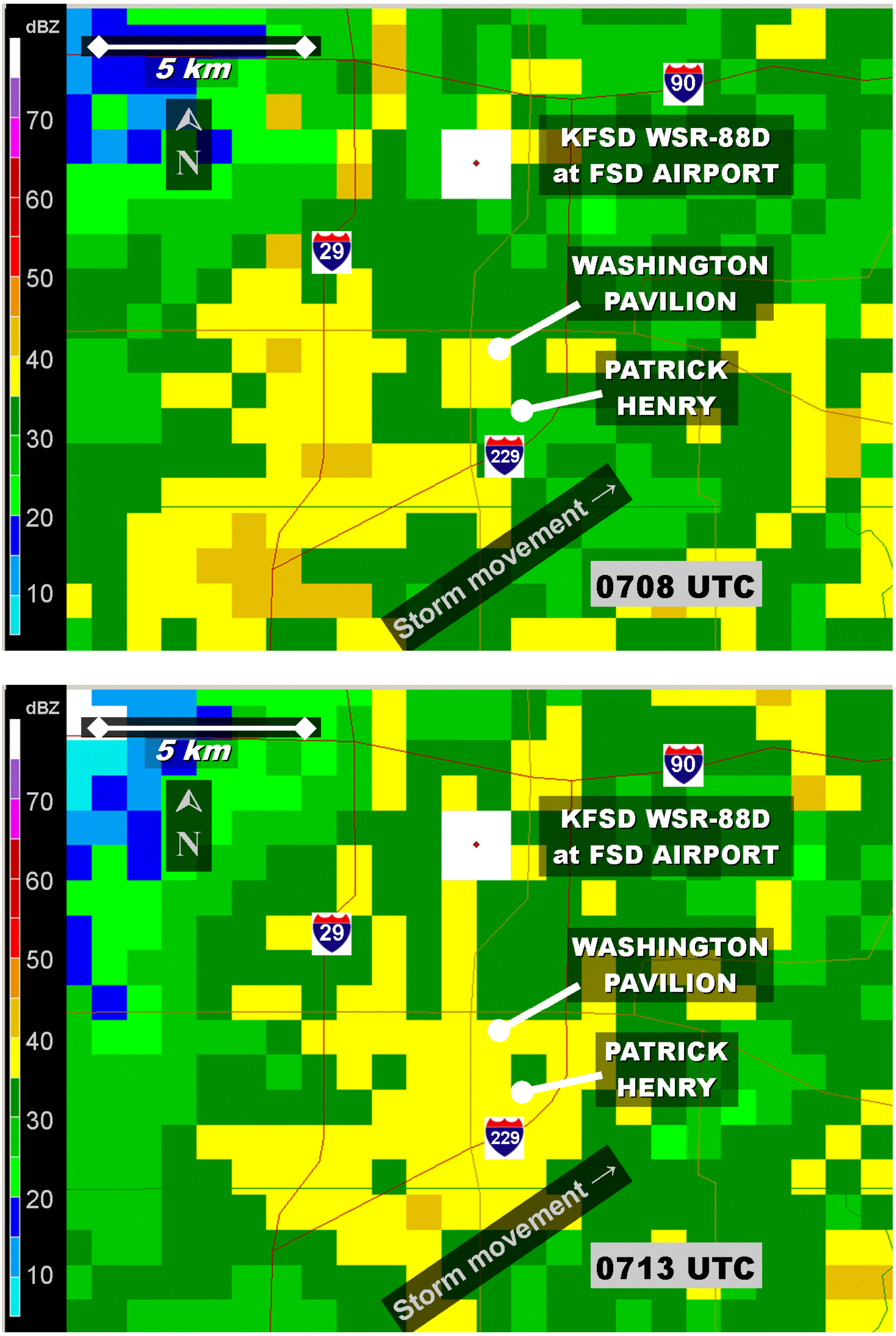

Figure 2. KFSD WSR-88D composite reflectivity data for (a) 0708 UTC 11 August 2007 in the top panel and (b) 0713 UTC 11 August 2007 in the bottom panel. The data are from the KFSD Level 3 archive. The white box in the upper-middle portion of the images represents the location of the KFSD WSR-88D.

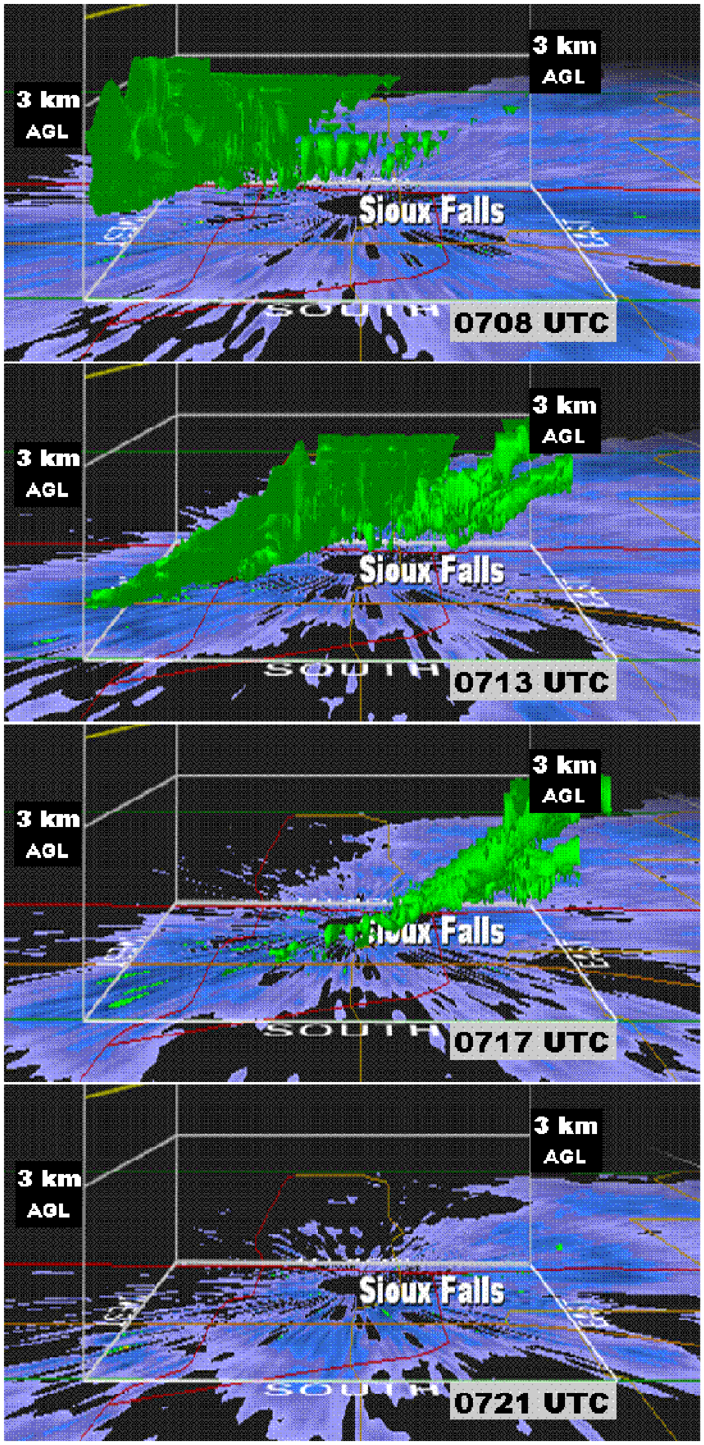

Figure 3. Base reflectivity three-dimensional representation using KFSD WSR-88D Level 2 data valid 0708–0721 UTC 11 August 2007. Reflectivity values ≥35 dBZ are depicted in green. Cube dimensions are 12 km on each side.

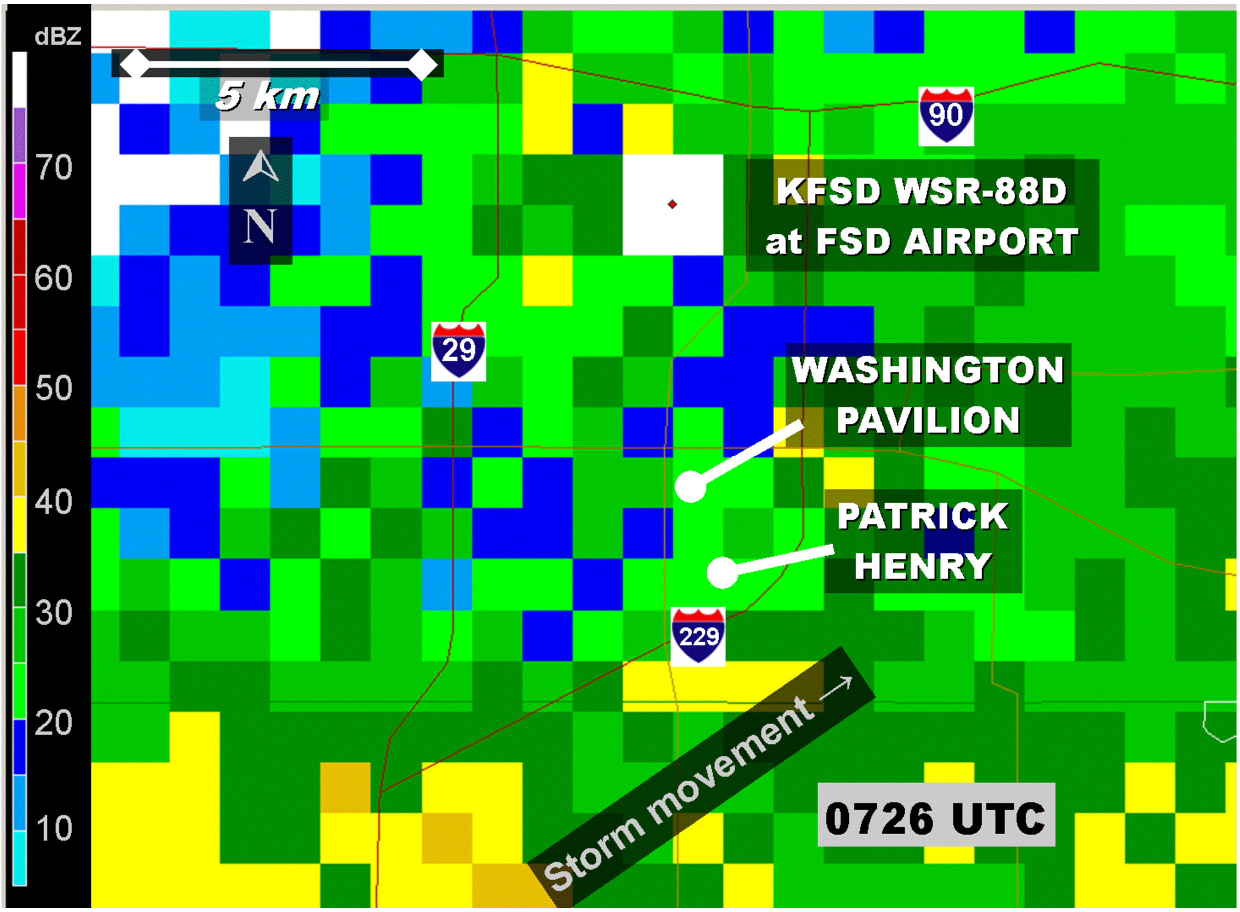

Figure 4. As in Fig. 2, except for 0726 UTC 11 August 2007. The white areas in the northwestern portion of this image indicate reflectivity <5 dBZ.

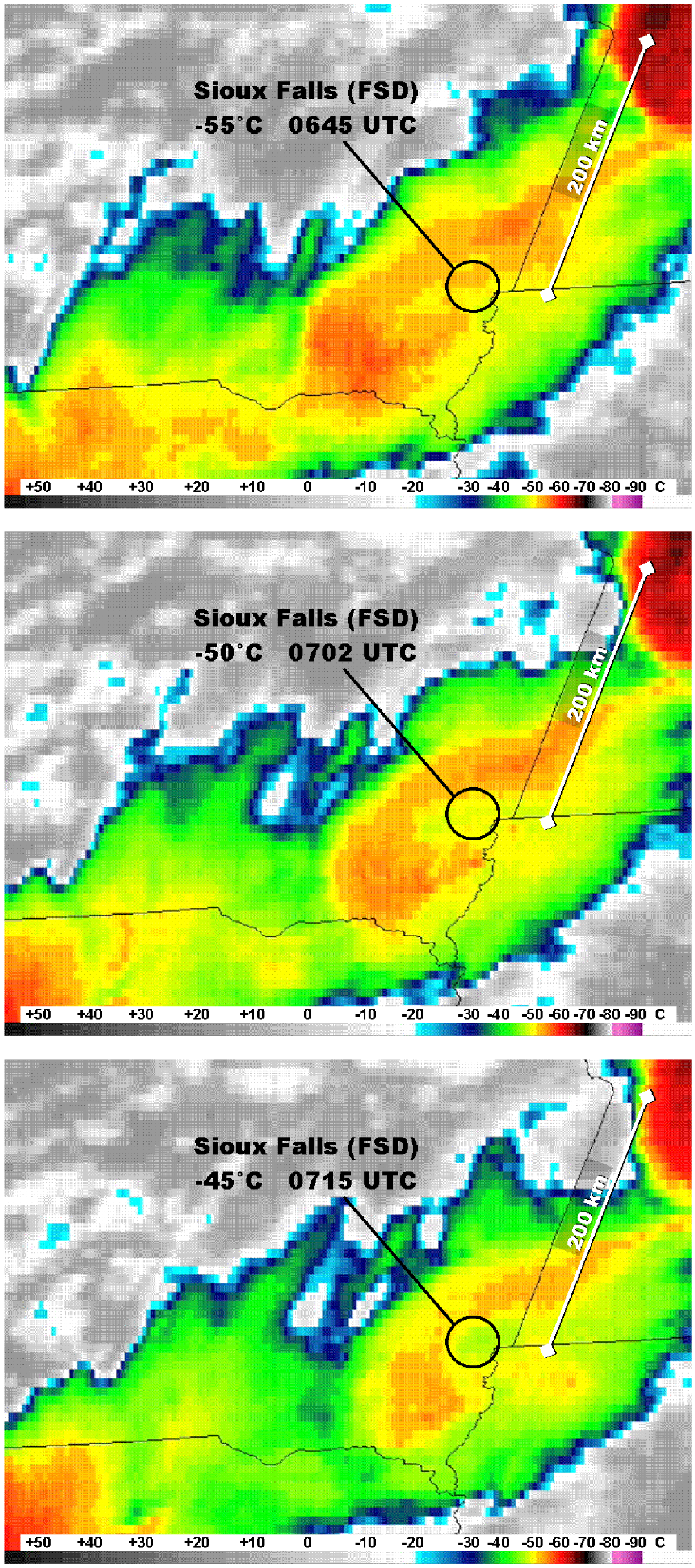

Figure 5. GOES-12 satellite 10.7-µm channel (infrared) images on 11 August 2007 for (a) 0645 UTC in the top panel, (b) 0702 UTC in the middle panel, and (c) 0715 UTC in the bottom panel.

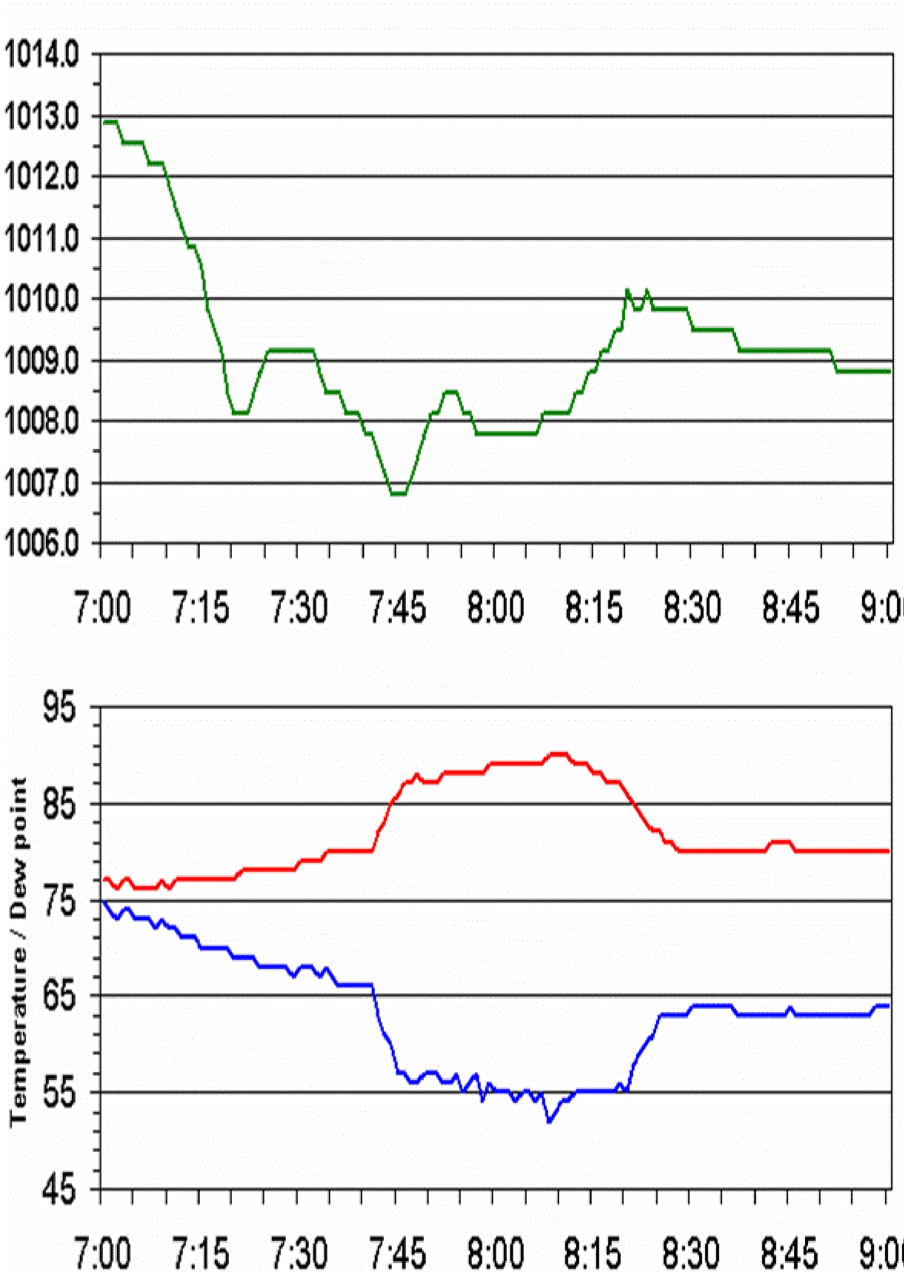

Figure 6. (a) In the top panel, 1-min barometric pressure trace at Washington Pavilion in Sioux Falls, SD, on 11 August 2007. (b) In the bottom panel, temperature (red line) and dew point (blue line) in °F during the same time period (images in °C were not available). Time stamps are in UTC along the abscissa.

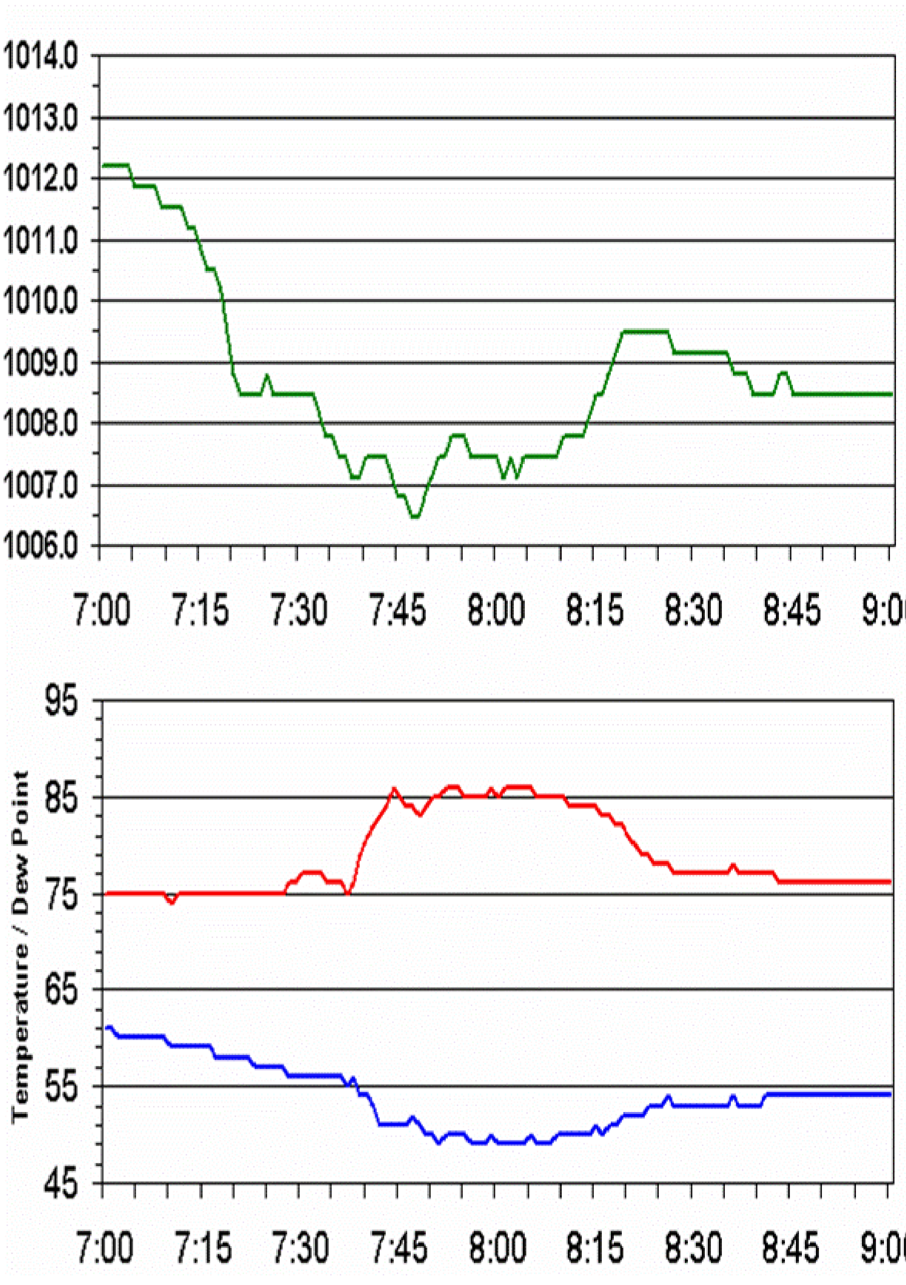

Figure 7. Same as Fig. 6 except for Patrick Henry School in Sioux Falls, SD.

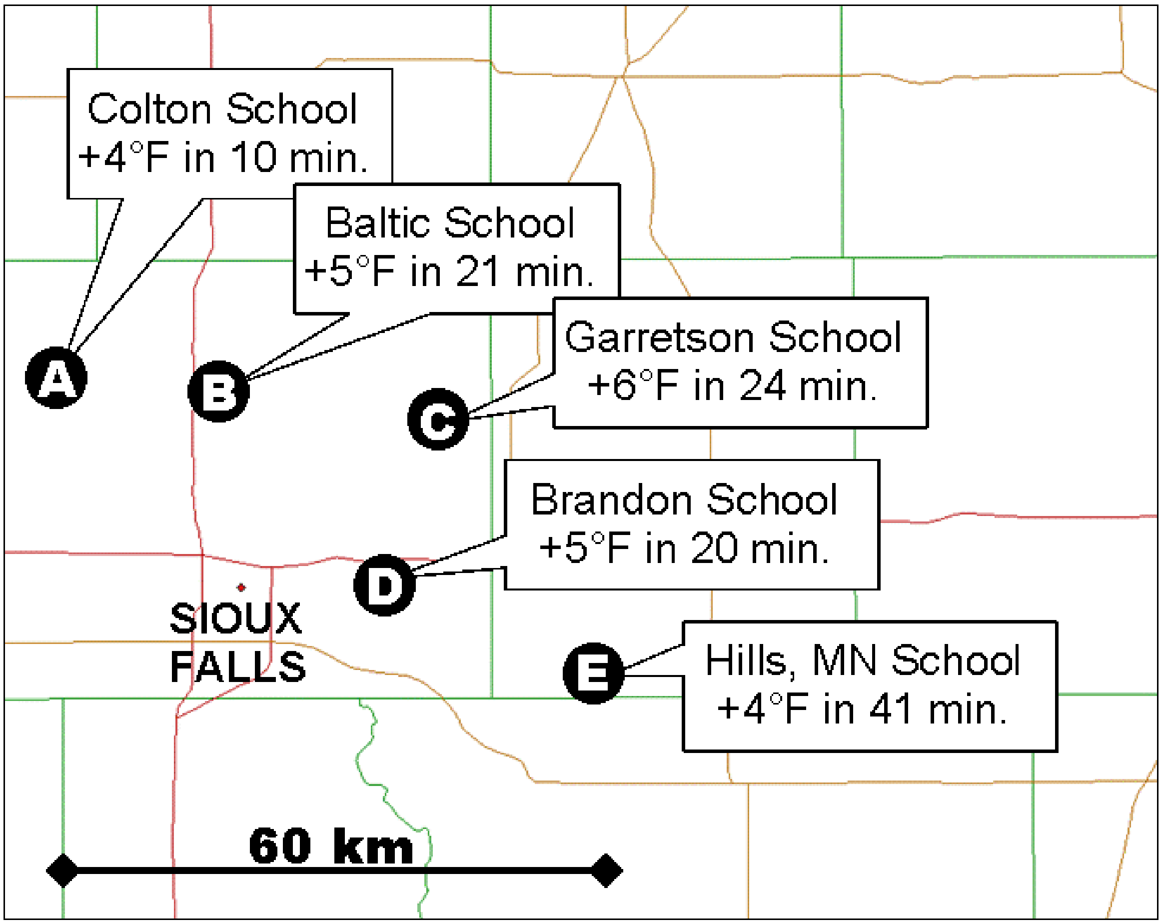

Figure 8. Map of mesonet stations near Sioux Falls, SD (KFSD, small red diamond), showing temperature increases over short time periods occurring between 0700–0900 UTC 11 August 2007.

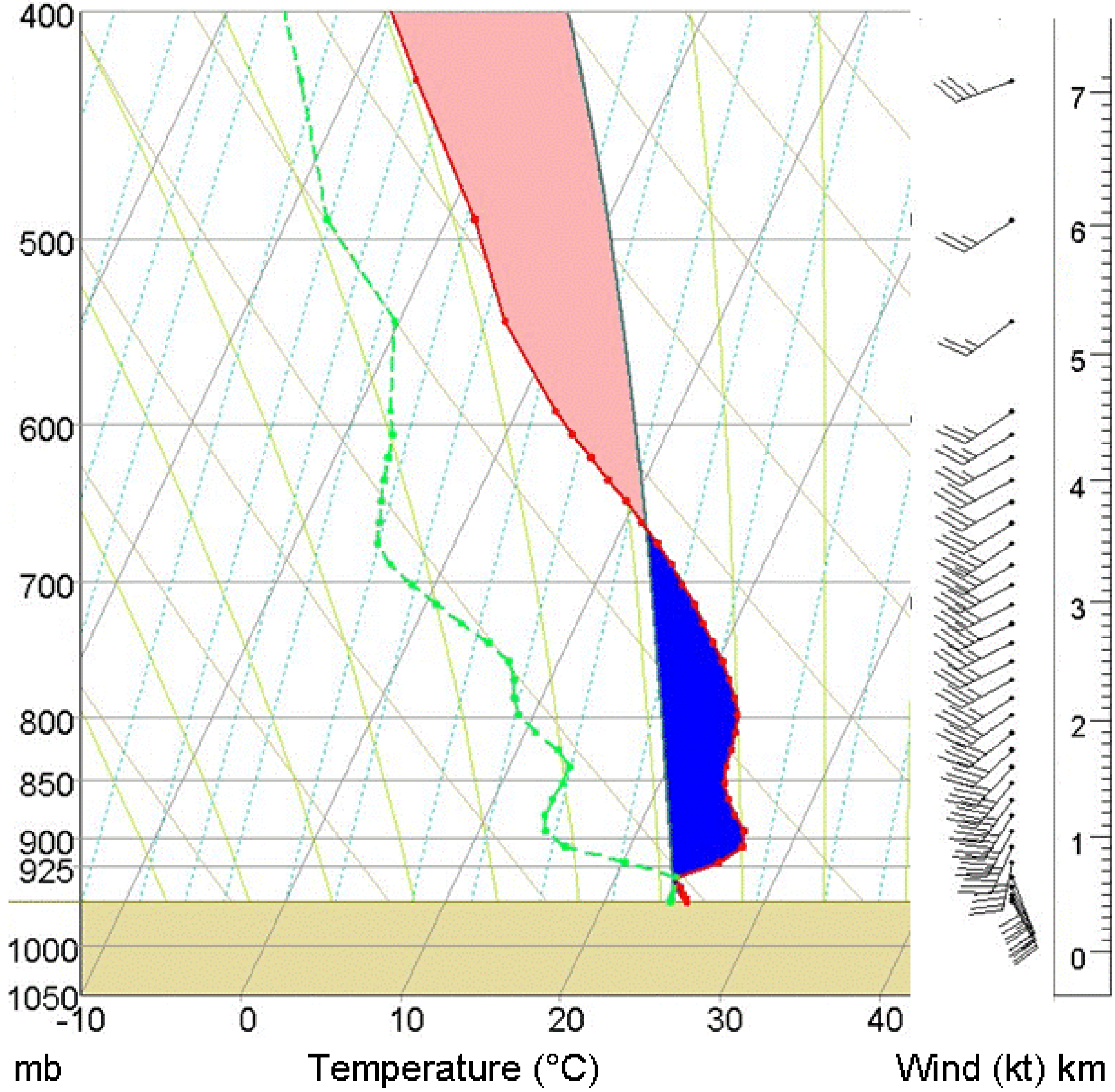

Figure 9. Skew-*T* log-*p* sounding diagram below 400 hPa from the 0600 UTC 11 August 2007 Rapid Update Cycle (RUC) 1-hr forecast, valid 0700 UTC. CAPE is shaded red, and CIN is shaded blue.