EXAMINATION OF A LONG-LIVED HEAT BURST EVENT IN THE NORTHERN PLAINS

Jeffrey S. Johnson

NOAA/National Weather Service Forecast Office
Rapid City, South Dakota

Abstract

Several heat bursts were observed across portions of northern Nebraska and southern South Dakota during the local morning hours of 30 July 2001. These heat bursts were noted by a marked increase in temperatures, decrease in dewpoint temperatures, pressure falls, and gusty surface winds. Due to the sparsity of surface observations in this region, only a few reports of this phenomenon were confirmed; however, the data that were collected indicate this event was unusual in that it persisted for over seven hours with a horizontal extent of at least 230 nm. Few events of this magnitude have been documented. It is significant to note that damaging surface winds were also recorded with this event, something rarely documented in association with heat bursts.

Familiarity with the environment conducive for heat bursts can help forecasters anticipate this type of event. This study examines the synoptic pattern and convective evolution that led to the heat burst activity. Observed and forecast soundings, radar and satellite imagery, wind profiler data, and surface observations are presented.

1. Introduction

During the morning of 30 July 2001, a series of heat bursts* was observed across portions of northern Nebraska and southern South Dakota (Fig. 1). The data that were collected indicate this event was unusual in that it persisted for over seven hours and extended at least 230 nm. Few events of this magnitude have been documented. It is significant to note that damaging surface winds were also recorded with this event, something rarely documented in association with heat bursts (MacKeen et al. 1998).

Johnson (1983) suggested that heat bursts are essentially downbursts impacting on a stable layer near the ground. A heat burst occurs when air in the downburst descends past its equilibrium point and becomes warmer than its surroundings upon reaching the surface. Johnson et al. (1989) supported this hypothesis in their study. Although the exact physical mechanism that produces heat bursts remains unknown, they are usually associated with decaying areas of convective precipitation and nearly dry-adiabatic lapse rates in midlevels (MacKeen et al. 1998).

2. Data Collection

Due to the limited surface data available in the northern plains (few cooperative observers and little mesonet data), the details of the extent and severity of this heat burst episode are not fully known. Automated Surface Observing System (ASOS) observations and data from the ground-based Global Positioning System Integrated Precipitable Water Vapor (GPS-IPWV) demonstration network were used to help identify areas affected by the heat bursts. Only two of the ASOS stations that recorded heat bursts had 5-minute data archiving capability, and the data from one of these two stations were not available during this period. Thus, any variations in temperature or dewpoint temperature between the routine hourly observations are known only for one ASOS site. Additionally, ASOS uses the running 5-minute average ambient air temperature and dewpoint temperature to update the maximum and minimum ambient air temperature and dewpoint temperature (ASOS User's Guide 1998). Thus, it is likely that any temperature or dewpoint temperature spikes associated with these heat bursts were smoothed by ASOS algorithms. Data from the GPS-IPWV sites were available at 6-minute intervals.

Some of the most compelling data collected during this event were obtained from a Maximum Minimum Temperature System (MMTS) used by a cooperative observer. Since an MMTS collects and stores *instantaneous* maximum and minimum temperatures, it is probably the most representative source for a maximum heat burst temperature in this study.

3. Synoptic Pattern and Convective Evolution

a. Upper-air and surface analyses

The northern plains were under the influence of west-southwest flow aloft, between an upper trough across the Pacific Northwest and upper ridge extending from the southern plains into the upper Midwest (Fig 2a). A sur-

*These heat bursts were noted by a rapid increase in temperatures, decrease in dewpoint temperatures, pressure falls, and gusty surface winds.

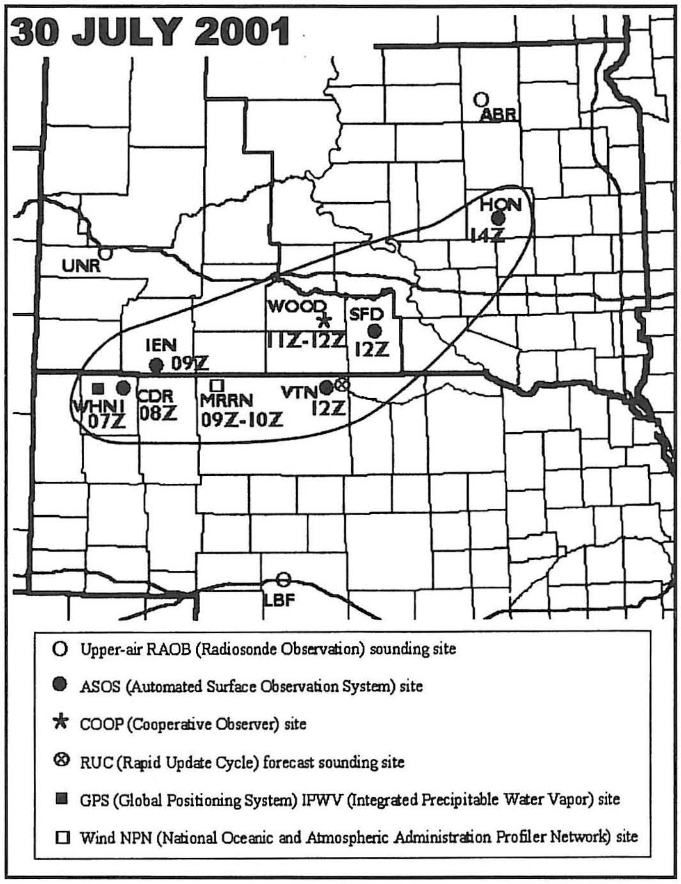

Fig. 1. Surface, upper-air, and profiler sites used to collect data and referenced in this paper are shown over South Dakota and Nebraska. Approximate times (Z) and the locations of observed heat bursts are enclosed within the solid line drawn around them.

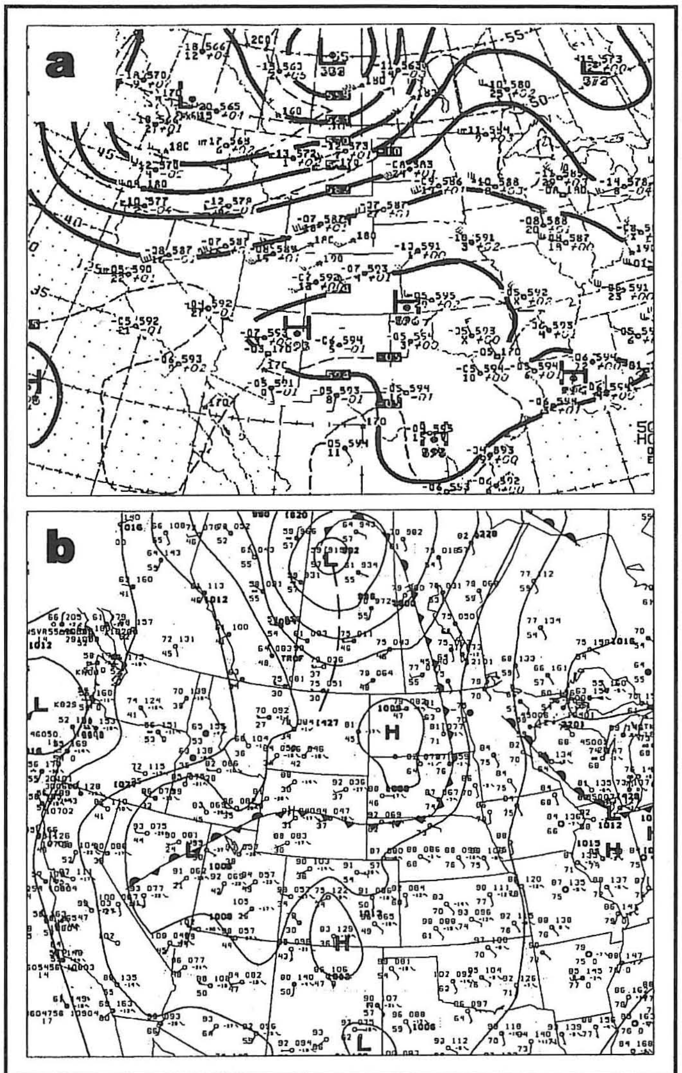

Fig. 2. Standard 500-mb chart (a) and surface chart (b) valid 1200 UTC 30 July 2001. (a) 500-mb geopotential height contoured every 60 m (b) Mean sea level pressure contoured every 4 mb. Standard station model format is shown in both charts.

face front was located across northern Nebraska (Fig 2b). The 1200 UTC 30 July 2001 NWS/Rapid Update Cycle (RUC) 3-hour forecast sounding near Valentine, Nebraska (VTN) (Fig. 3a) showed upper-level moisture, a deep dry layer below with near dry-adiabatic lapse rates, and a shallow surface-based inversion. This profile was also observed in the 1200 UTC RAOB (radiosonde observation) soundings from North Platte, Nebraska (LBF) and Rapid City, South Dakota (UNR) (Figs. 3b, c). These soundings are similar to those heat burst soundings presented in Fig. 10 of Johnson (1983). These soundings also appear to resemble "onion soundings" (Zipser 1977) that are characteristic of post-squall regions; however, the physical processes that lead to their formation, most notably the surface-based inversion, are different. The 1200 UTC sounding from Aberdeen, South Dakota (ABR) (Fig. 3d) showed a deeper inversion and more moisture aloft, which is an environment less favorable for heat bursts. Incidently, no heat burst activity was observed this far north.

Large Downdraft Convective Available Potential Energy (DCAPE) values were present in each sounding, with a minimum of 1200 J kg^{-1} observed on the ABR sounding and a maximum of 1950 J kg^{-1} observed on the UNR sounding. Values in excess of 1000 J kg^{-1} are usually favorable for strong downdrafts, while values over 2000 J kg^{-1} are rarely observed (Jeffrey Craven 2003, personal correspondence). However, the extent of the role DCAPE plays in heat burst occurrences is unknown. The use of DCAPE in estimating downdraft *strength* has been debated because it violates parcel theory; primarily, the entrainment of environmental air into the downdraft changes the θ_e of parcels (Gilmore and Wicker 1998).

b. Convective evolution

Convection initiated near the surface front across western Nebraska shortly after 0600 UTC on 30 July 2001. A mesoscale convective system (MCS) soon developed and moved east-northeast across northern Nebraska and southern South Dakota. The MCS decayed a few hours after sunrise as it moved into northeastern Nebraska and eastern South Dakota.

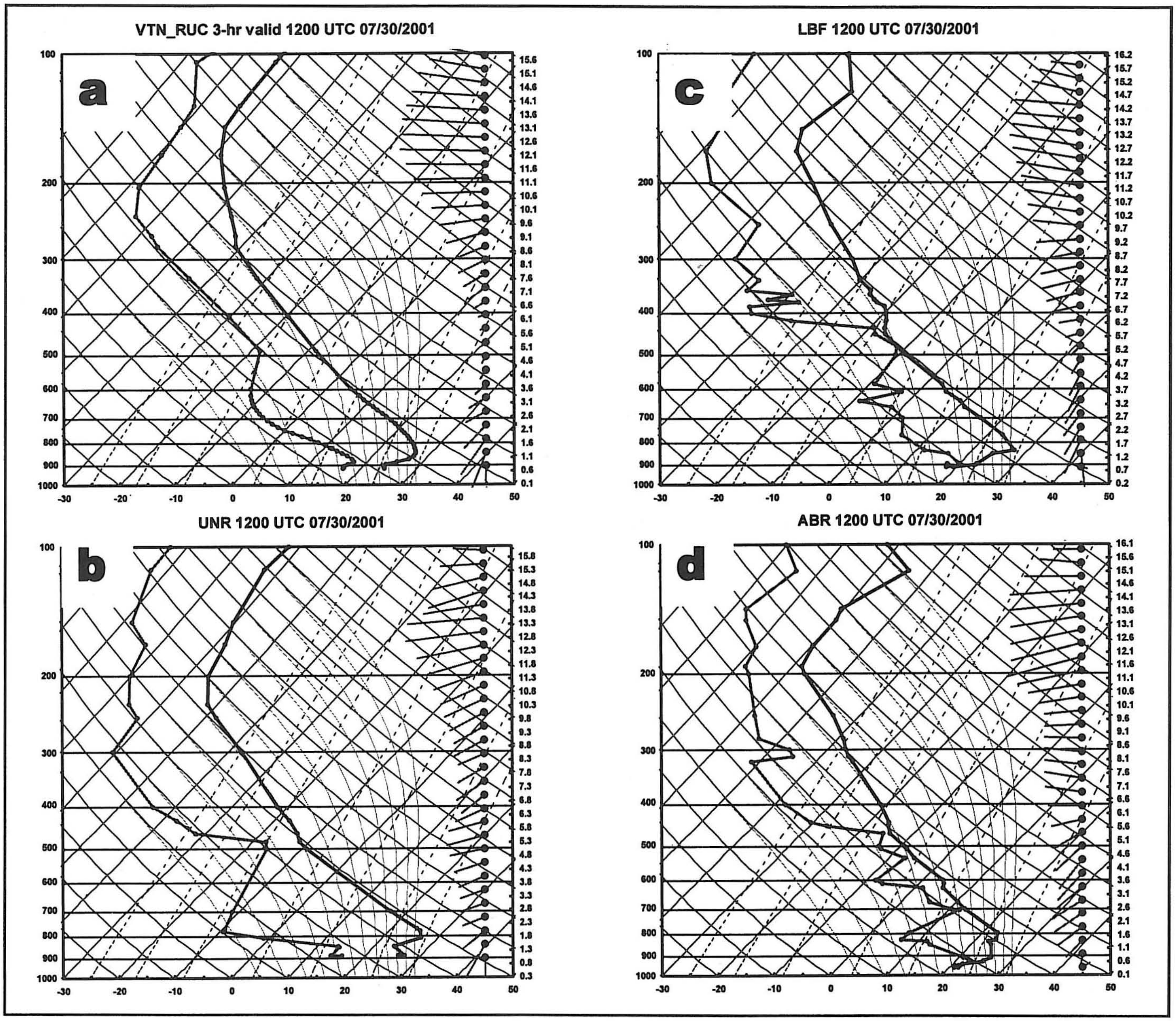

Fig. 3. The 3-hr RUC forecast sounding is plotted for (a) Valentine, Nebraska (VTN) valid 1200 UTC 30 July 2001, along with 1200 UTC RAOB soundings from surrounding upper-air sites at (b) Rapid City, South Dakota (UNR), (c) North Platte, Nebraska (LBF), and (d) Aberdeen, South Dakota (ABR).

4. Heat Burst Evolution

As stated earlier in this study, a series of heat bursts was observed across a broad area from northwestern Nebraska to eastern South Dakota between the hours of 0700 UTC and 1500 UTC on 30 July 2001. The observed heat bursts were located either near the north and west periphery of the anvil (as analyzed in satellite imagery), or beneath to just north of rapidly decaying thunderstorms. Additionally, no measurable precipitation (less than 0.01") was recorded at any of the heat burst sites. An ASOS site with augmented observations contained CBMAM OHD (cumulonimbus mammatus overhead) in the remarks during this event.

The first evidence of heat burst activity was recorded by the GPS-IPWV site at Whitney, Nebraska (WHN1) (Fig. 4), and the ASOS sites at Chadron, Nebraska (KCDR) and Pine Ridge, South Dakota (KIEN). Temperatures had cooled to around 24C (75F) during the mid to late evening hours. Between 0700 UTC and 0900 UTC, temperatures rose to around 29C (85F), relative humidities dropped rapidly from near 50% to around 35%, wind gusts to 24 m s^{-1} (47 kt) were observed, and pressure falls were noted. As the convection spread east-northeast, the GPS-IPWV site at Merriman, Nebraska (MRRN) (Fig. 4) observed the temperature warming to 32C (90F) before 1000 UTC, and the IPWV fell abruptly from 3 cm to below 2 cm. Spectral moment data (signal power and radial velocity) from the Merriman wind profiler shows the majority of hydrometeor returns above 700 mb, which would indicate that most of the precipitation evaporated in the deep dry layer in the mid-tropos-

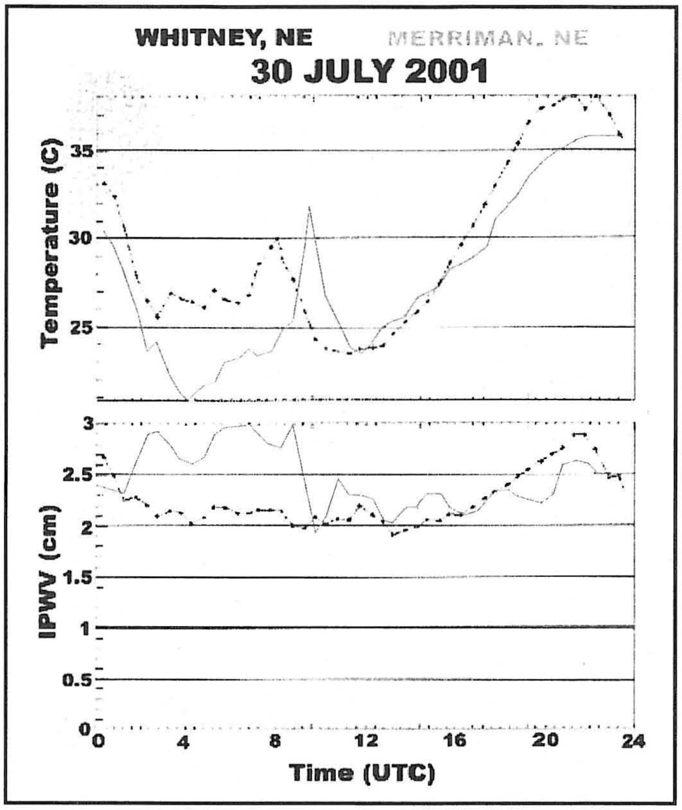

Fig. 4. Time series of temperature and Integrated Precipitable Water Vapor (IPWV) from 30 July 2001 for Whitney, Nebraska (bold) and Merriman, Nebraska. Temperature is in degrees Celsius (C) and IPWV is in centimeters (cm). Some 6-minute temperature data have been incorporated into the traces to show the maximum recorded temperatures at both sites.

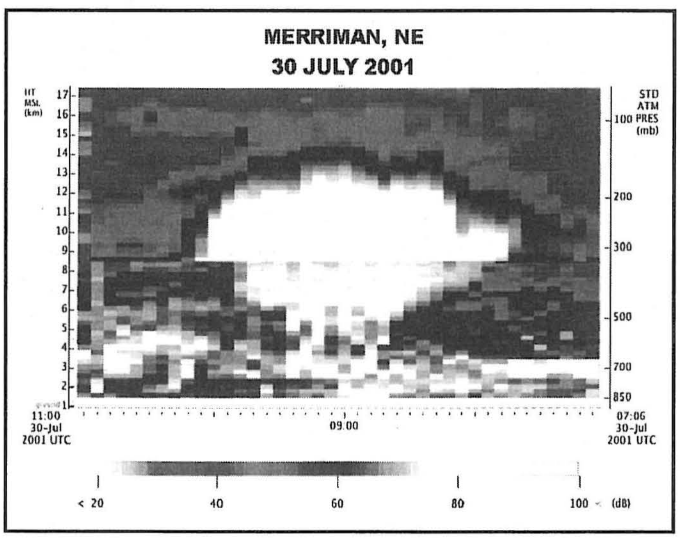

Fig. 5. Signal power in decibels from 30 July 2001 for the Wind Radar Profiler at Merriman, Nebraska.

phere. However, it cannot be determined from the signal power (Fig. 5) how much if any precipitation reached the surface due to contamination below 700 mb (Johnson 2003). These recorded heat bursts were located just north of the more intense radar echoes and under the overhanging anvil (Fig. 6).

Similar effects were then recorded at the Valentine, Nebraska (KVTN) and Winner, South Dakota (KSFD) ASOS sites (Fig. 7), as well as by an NWS cooperative observer at Wood, South Dakota. Of significance was a temperature of 38C (101F) measured by an MMTS at the Wood cooperative site sometime between 1100 UTC and 1200 UTC, which was the warmest temperature recorded during the event. As previously mentioned, this *instantaneous* temperature was some of the most compelling data collected. The observer also reported damaging winds around this time. At KVTN, the temperature rose to 32C (90F), winds gusted to 22 m s^{-1} (43 kt), and the relative humidity dropped to 22%. At KSFD, the temperature rose to 33C (92F), winds gusted to 28 m s^{-1} (56 kt), and the relative humidity fell to 22%. The Winner police department reported a snapped power pole from these winds. These heat bursts were located beneath or just north of rapidly decaying thunderstorms (Fig. 8).

As the MCS continued its eastward movement, additional heat burst activity was noted. Heat burst activity was recorded as far east as Huron, South Dakota (KHON) (Fig. 7). Between 1350 UTC and 1425 UTC the temperature at KHON rose 8C (15F), the dewpoint temperature fell 7C (13F), and winds gusted to 19 m s^{-1} (38 kt). By 1450 UTC the temperature fell 5C (9F) and the dewpoint temperature rose 5C (9F). Cloud cover likely minimized the diurnal influence in this temperature/dewpoint fluctuation. Figure 9 shows the rapid warming of cloud top temperatures during this time which is typical of decaying or weakening thunderstorms.

5. Damaging Winds

Although the exact cause of damaging winds during this event remains unclear, an interesting observation was made. Of the other heat burst events discussed in this study that did not contain significant or damaging winds, soundings indicated that winds near the top of the boundary layer were generally of the magnitude of 10 to 20 kt (5 - 10 m s^{-1}). In the heat burst event of 30 July 2001, 1200 UTC soundings (and the 3-h forecast sounding near VTN) for UNR and LBF reveal 35 to 45 kt (18-23 m s^{-1}) winds near the top of the boundary layer (similar to the 22-23 May 1996 event, MacKeen et al. 1998). Even more revealing is wind data from the profiler at MRRN (Fig. 10), where a low level jet of 55 kt (28 m s^{-1}) was measured at 0800 UTC and 0900 UTC near the top of the boundary layer. It is hypothesized that the velocity of the downdraft in combination with the mixing of winds throughout the boundary layer led to the damaging winds observed at the surface. A downdraft impinging on a stable surface layer may not have sufficient buoyancy to impact the surface with damaging results without the additional momentum provided by the strong winds near the top of the boundary layer.

6. Conclusion

The heat burst episode of 30 July 2001 was unique in several ways. Both the temporal and spatial scale of this event was among the largest yet documented and, as far as the author can determine, is one of only a few documented cases to contain damaging winds. However, the severity and total extent of this particular event is

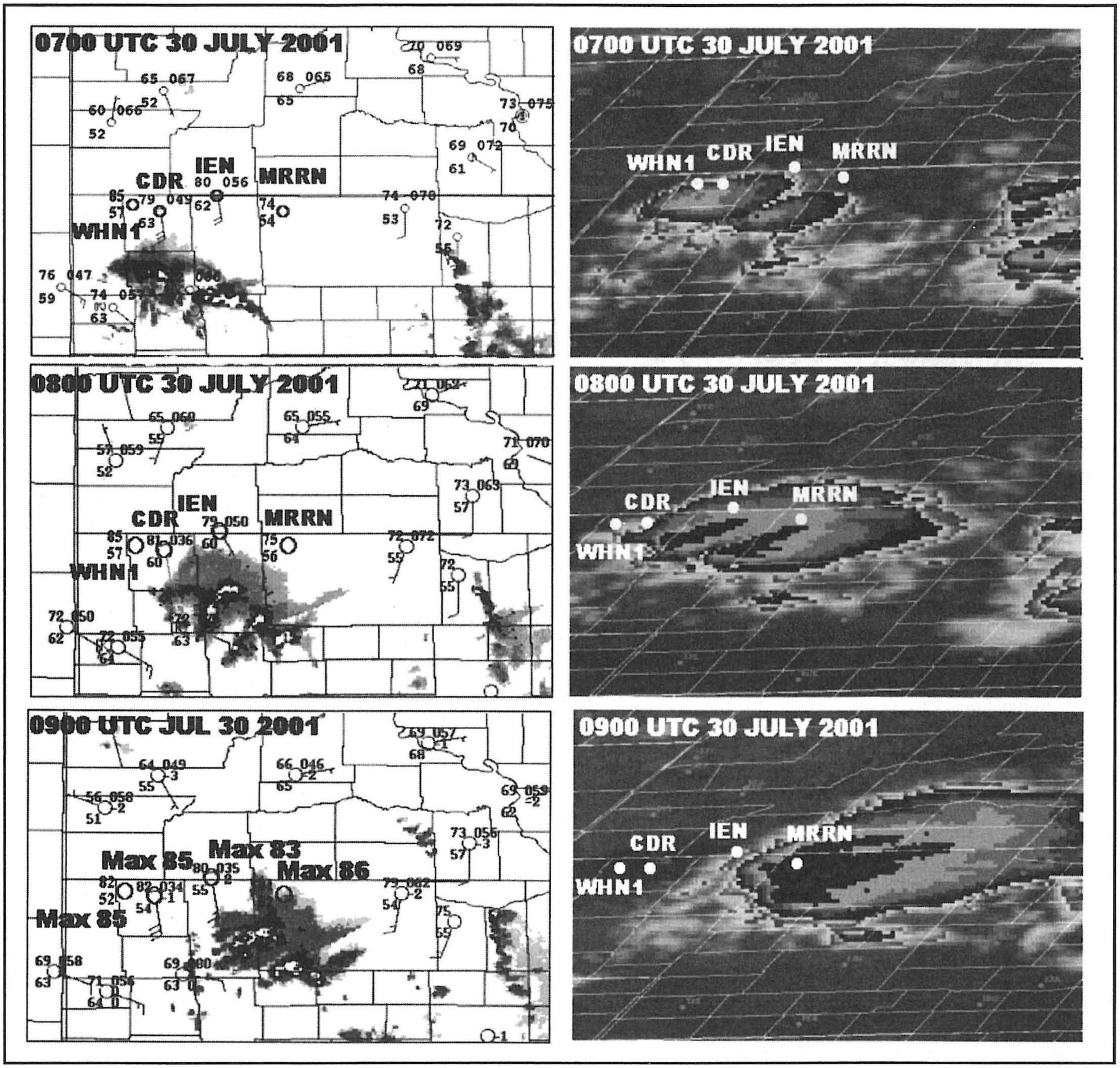

Fig. 6. Base Reflectivity, Surface Observations, and Infrared Satellite Imagery for 0700 UTC, 0800 UTC, and 0900 UTC 30 July 2001. As the trailing anvil collapses (warms), note the rise in temperatures (°F) and sudden drop in dewpoint temperatures (°F) at Whitney, Nebraska (WHN 1), Chadron, Nebraska (CDR), Pine Ridge, South Dakota (IEN), and Merriman, Nebraska (MRRN).

unknown due to the limited surface data available across the northern plains and the limitations of ASOS.

It has been shown in several studies that a sounding consisting of upper-level moisture, a deep dry layer below with near dry-adiabatic lapse rates, and a shallow surface-based inversion is the most likely environment in which heat bursts occur. What makes the heat burst environment a fairly rare event is not entirely clear; however, Johnson et al. (1989) suggest that such a situation is favored when an MCS develops in relatively hot, dry conditions, as was the case on 30 July 2001.

Knowing the environment conducive for heat bursts can help forecasters anticipate this type of event. Also, having more surface observations and profiler data in real time would aid the forecaster in tracking such events and forecasting their evolution. Even though ASOS algorithms have their limitations with regard to recording heat burst data, ensuring 5-minute data are available to forecasters should be made a priority. Also, it is the author's recommendation that all ASOS data be archived for every site to aid the research community.

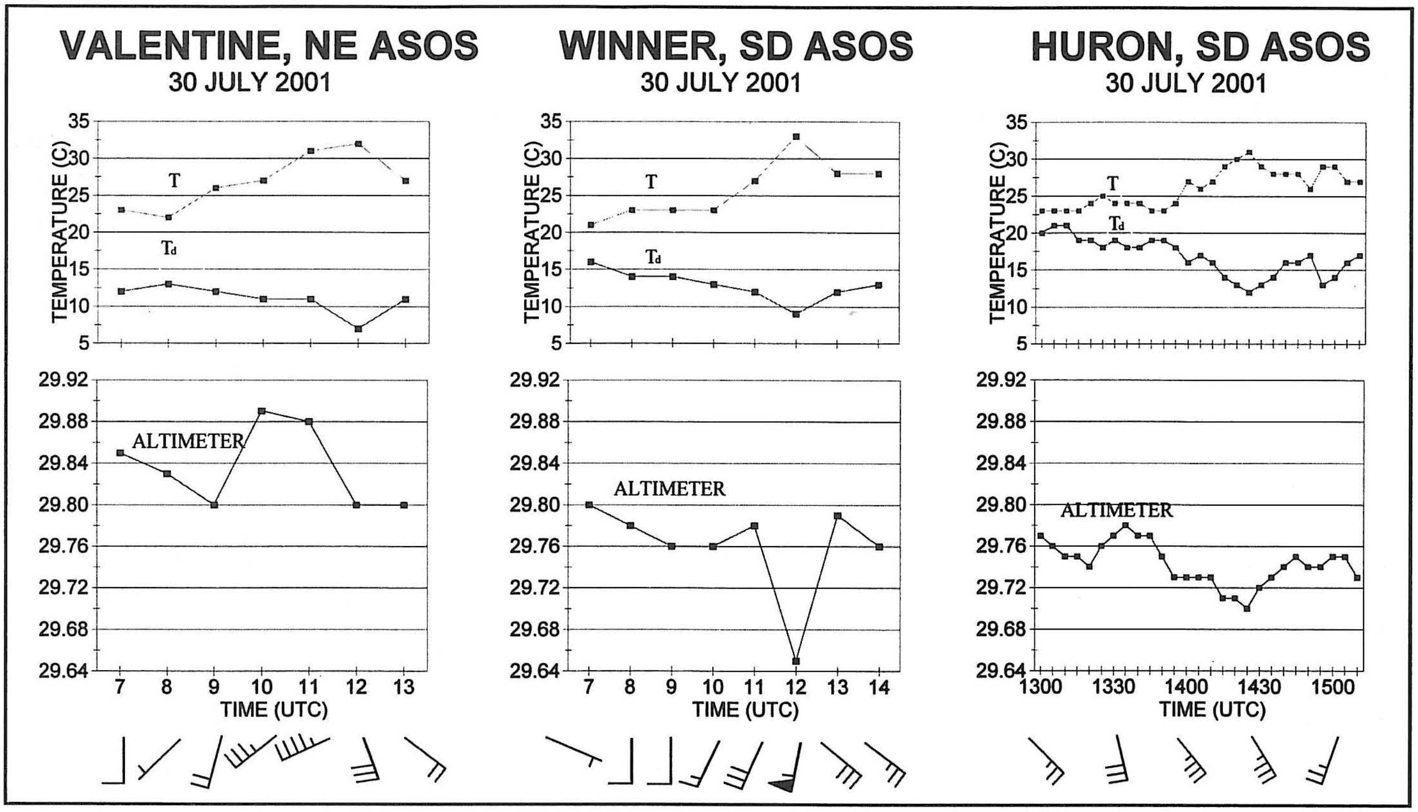

Fig. 7. Time series of temperature, dewpoint temperature, altimeter, and peak wind from 30 July 2001. Temperature and dewpoint temperature are in degrees Celsius (C), altimeter is in inches of mercury, and wind barbs are in knots. The 5-minute ASOS data were only available for Huron, South Dakota.

Acknowledgments

I would like to thank Dr. Brian Klimowski and Matthew Bunkers for their direction and review of the material, and to the reviewers (Jeffrey Craven, Carolyn Kloth, Dennis Rogers) for their excellent comments and subsequent improvements to the manuscript. Dennis Rodgers and Douglas van de Kamp greatly enhanced this research by providing GPS-IPWV observations and profiler data, and Jeffrey Craven shared his experience using DCAPE in an operational setting. Base reflectivity and infrared images were provided by UCAR-COMET and NOAA/NCDC.

Author

Jeffrey Johnson is a meteorologist with the National Weather Service (NWS) Forecast Office in Rapid City, South Dakota. He has also worked at the NWS offices in Great Falls, Montana, and Jacksonville, Florida. His primary interests include case studies that directly apply to operational forecasting as well as programming applications. Prior to employment with the National Weather Service, Jeffrey was a meteorologist for American Airlines in Fort Worth, Texas. He earned his B.S. in meteorology from Texas A&M University in 1995. He can be reached at Jeffrey S. Johnson, NOAA/NWS Weather Forecast Office, 300 East Signal Drive, Rapid City, South Dakota 57701-3800; E-mail: Jeffrey. Johnson@noaa. gov

References

ASOS User's Guide, March 1998, 11-14.

Gilmore, M.S., and L.J. Wicker, 1998: The Influence of Midtropospheric Dryness on Supercell Morphology and Evolution. *Mon. Wea. Rev.*, 126, 943-958.

Johnson, B.C., 1983: The Heat Burst of 29 May 1976. *Mon. Wea. Rev.* 111, 1776-1792.

Johnson, J.S., 2003: Signal Power and Radial Velocities from 30 July 2001 at Merriman, NE. [Available online at http://www.crh.noaa.gov/unr/edusafe/jj/031003.htm].

Johnson, R.H., S. Chen, and J.J. Toth, 1989: Circulations Associated with a Mature-to-Decaying Midlatitude Mesoscale Convective System. Part 1: Surface Features - Heat Bursts and Mesolow Development. *Mon. Wea. Rev.*, 117, 942-959.

Mackeen, P., D.L. Andra, and D.A. Morris, 1998: The 22-23 May 1996 Heatburst: A Severe Wind Event. Preprints, *19th Conference on Severe Local Storms*, 14-18 September 1998, Minneapolis, MN, 510-513.

Zipser, E.J., 1977: Mesoscale and Convective-Scale Downdrafts as Distinct Components of Squall-Line Structure. *Mon. Wea. Rev.*, 105, 1568-1589.

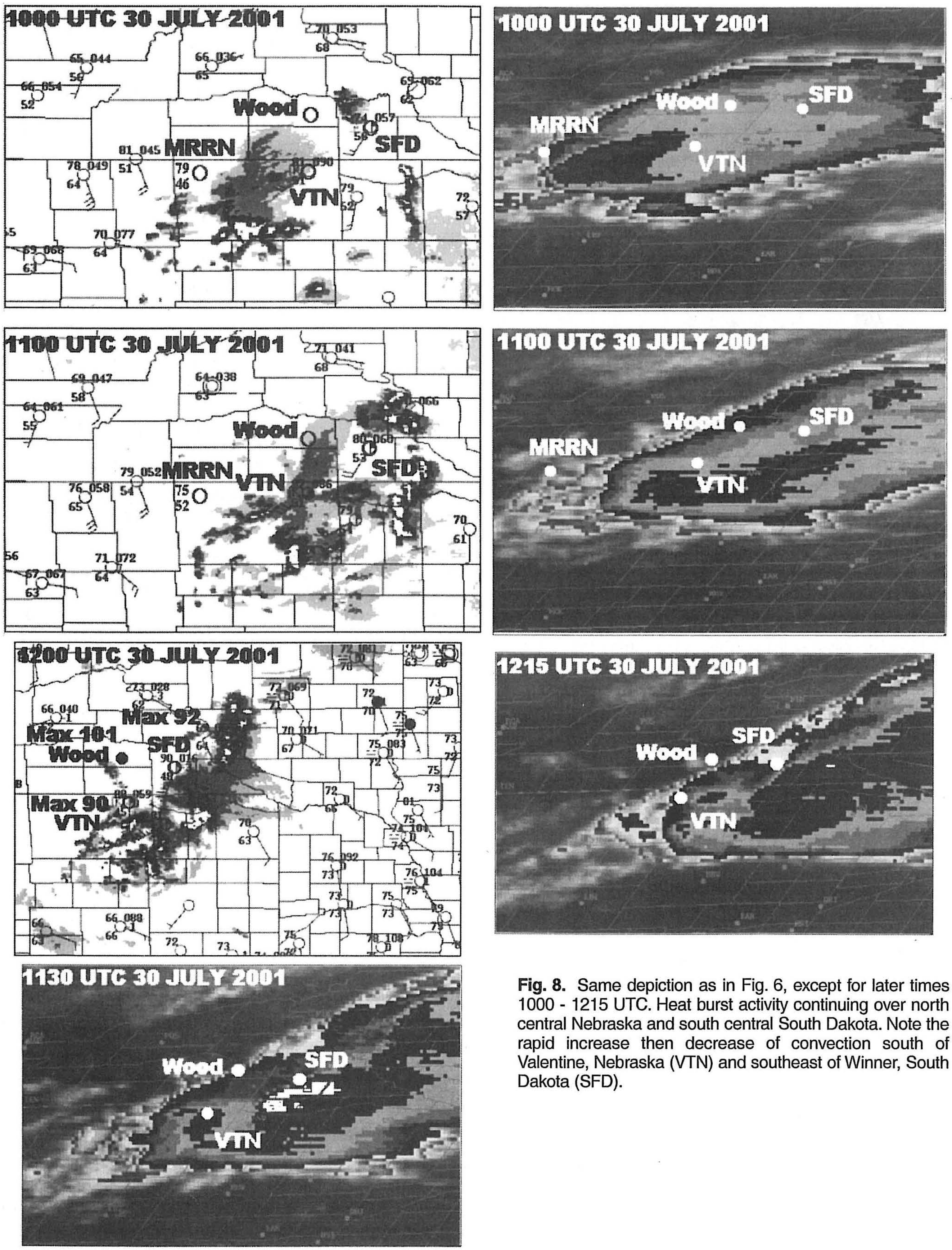

Fig. 8. Same depiction as in Fig. 6, except for later times 1000 - 1215 UTC. Heat burst activity continuing over north central Nebraska and south central South Dakota. Note the rapid increase then decrease of convection south of Valentine, Nebraska (VTN) and southeast of Winner, South Dakota (SFD).

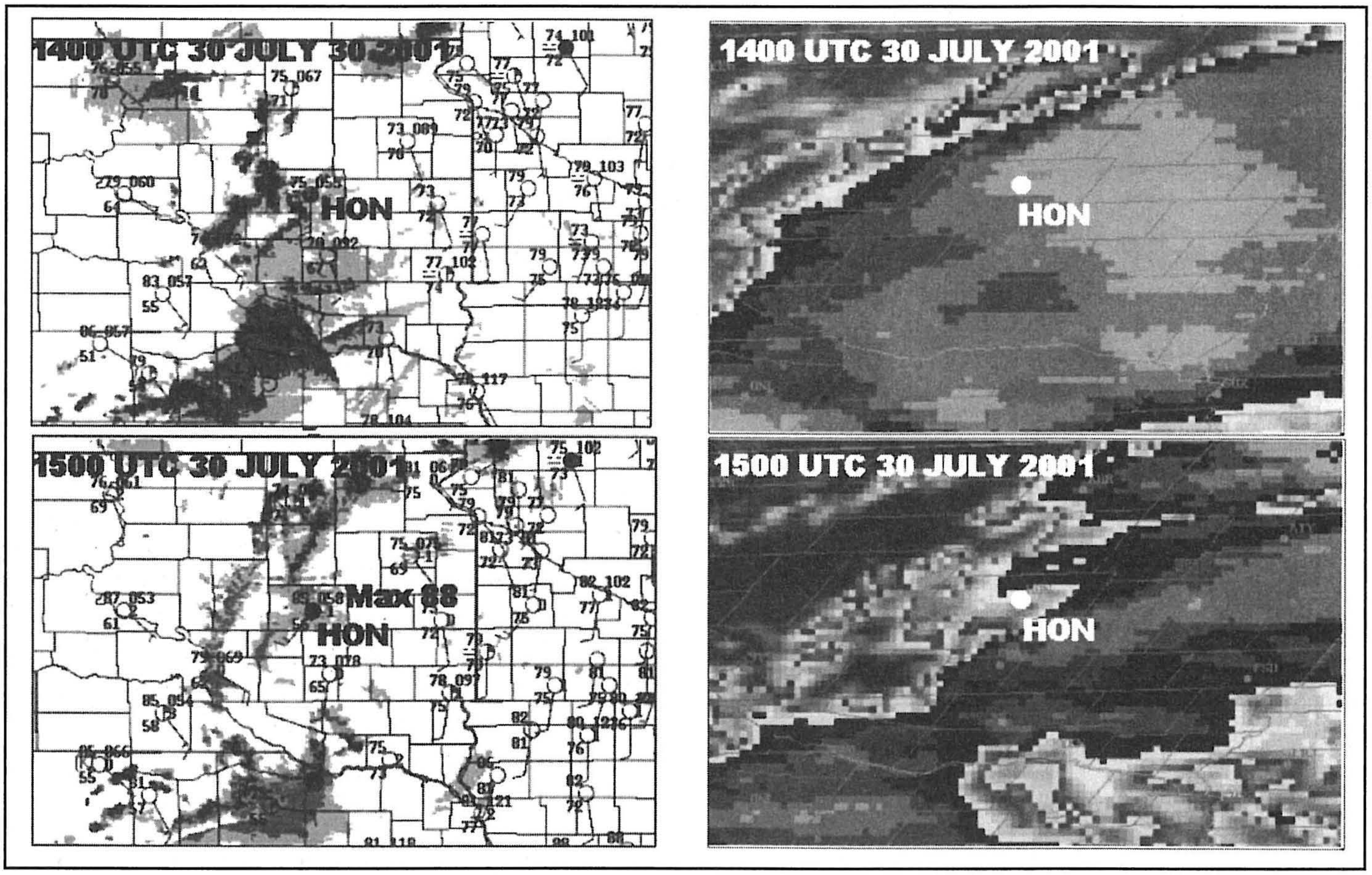

Fig. 9. Same depiction as in Fig. 6, except for 1400 - 1500 UTC. Heat burst activity near Huron, South Dakota (HON). The IR imagery shows the collapse (warming) of the trailing anvil near HON.

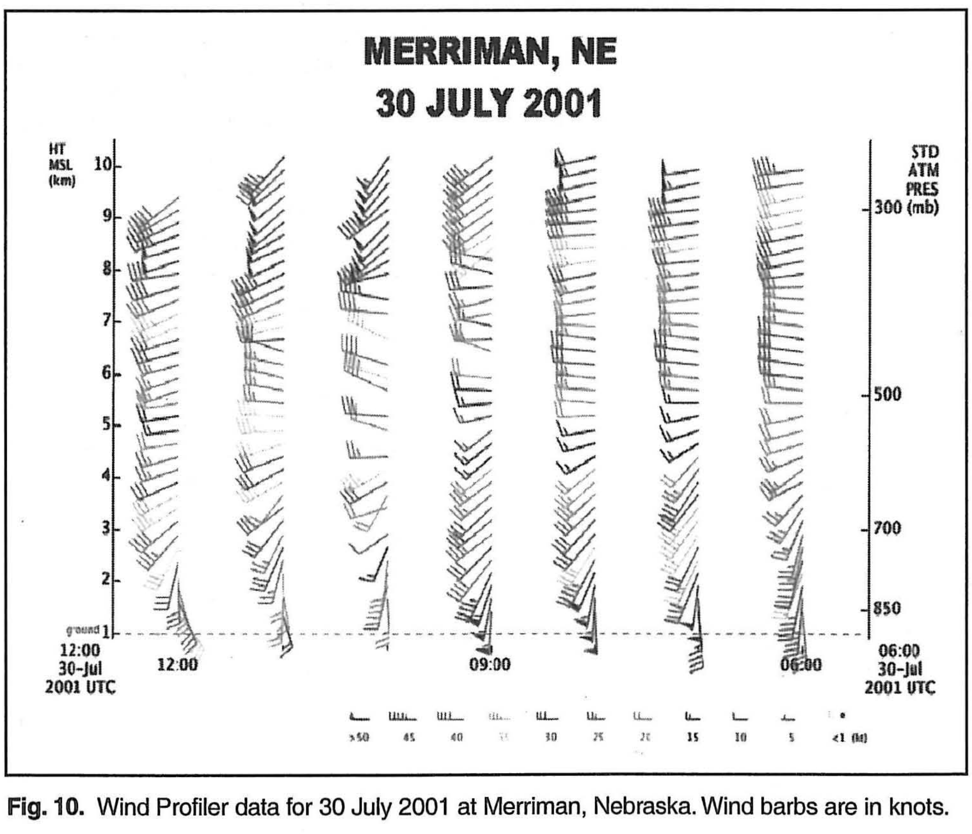

Fig. 10. Wind Profiler data for 30 July 2001 at Merriman, Nebraska. Wind barbs are in knots.