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Rainfall Totals from the Hermosa Flash Flood of 17 August 2007

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ABSTRACT

During the evening of 17 August 2007, heavy rain over north-central Custer County produced a flash flood in Hermosa, South Dakota. At 0000 UTC on the 18th, an intense thunderstorm developed along the eastern foothills of the Black Hills in central Custer County and remained stationary for at least 2 hours. Southeasterly low-level winds fed moist air into the storms causing heavy rain to fall in and around Hermosa. By 0300 UTC, approximately 20 mi^2 had received over 6 inches of rainfall, and over 10 inches of rain fell in a 1 mi^2 just west of Hermosa. The large amount of precipitation from this storm in such a short period of time caused flash flooding across north-central Custer County. According to the *Rapid City Journal*, the storm damaged 60 to 70 homes around the Hermosa area. At least a half-mile section of railroad tracks and the embankment, as well as several roads and vehicles, were damaged. This paper details the meteorological conditions present for this event as well as the rainfall totals gathered after the event.

1. Introduction

On 17 August 2007 an area of severe thunderstorms developed over southwestern South Dakota. There were several storms which produced very large hail on this day; the two most notable were a storm that developed around Piedmont, South Dakota, and a series of storms that developed around Hermosa, South Dakota. Only the Hermosa storms will be discussed here due to the flash flooding that occurred that evening. The purpose of this paper is to document the meteorological conditions, rainfall amounts, and National Weather Service (NWS) products disseminated throughout the course of this flash flood event.

2. Meteorological Conditions

2.1 Upper-Level Analysis

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A look at the 300-mb chart from 1200 UTC 17 August (Fig. 1) indicates west-northwesterly flow aloft with a weak upper-level ridge over eastern Montana and eastern Wyoming. By 0000 UTC 18 August (Fig. 2) a shortwave trough moving through the flow had flattened the ridge causing the flow at 300 mb to turn more westerly. This shortwave helped in the initiation of convection that evening and can be seen in all of the analyses to follow. A similar picture is seen at 500 mb with the flow turning from westerly at 1200 UTC 17 August (Fig. 3) to southwesterly at 0000 UTC 18 August (Fig. 4). Again, the ridge was flattened by 0000 UTC as the wave moved across western South Dakota.

At 700 mb a pressure ridge was present across the northern Plains with the axis stretching from northeastern Montana to eastern Kansas. At this level, strong southerly flow was evident with speeds of 25 to 40 knots as indicated by the Rapid City, South Dakota (KUNR) sounding observations at 1200 UTC 17 August (Fig. 5) and 0000 UTC 18 August (Fig. 6). Again the shortwave trough was evident as it moved across eastern Wyoming and western South Dakota. At 850 mb the flow was more meridional with high pressure over the Midwest and low pressure over the northern Rocky Mountains (Fig. 7). Southerly flow was evident across South Dakota and Nebraska (Figs. 7 and 8).

The KUNR sounding at 1200 UTC 17 August (Fig. 9) indicates a deep layer of southerly flow from the surface to approximately 600 mb: an approximate depth of 300 mb. At 0000 UTC 18 August (Fig. 10) the layer of southerly flow extended to the termination of the sounding at 500 mb producing a 400-mb-deep layer. This south to southeasterly flow allowed very moist air (dew points were in the 60s and 70s °F across Nebraska) to advect into southwestern South Dakota. This deep layer of southerly flow can also be seen on the velocity-azimuth display (VAD) wind profile (VWP) (Fig. 11) through 12,000 feet, which is at approximately 650 mb.

The precipitable water value from KUNR at 0000 UTC 18 August (Fig. 12) of 1.41 inches was 189 percent of normal, and indicated that a very moist air mass had moved into western South Dakota. This observation was higher than the mean value for August by more than two standard deviations and approached the maximum values observed at Rapid City from 1948 to 2000 (Fig. 13).

2.2 Surface Analysis

At 2100 UTC 17 August (Fig. 14) a surface low pressure center was located over eastern Wyoming with a stationary front draped across western South Dakota and into northeastern Nebraska. By 0000 UTC 18 August (Fig. 15) the low pressure center drifted into southwestern South Dakota and by 0300 UTC (Fig. 16) the stationary front had pushed south extending from extreme southwestern South Dakota through southeastern Kansas. Prior to convective initiation, the surface temperatures across southwestern South Dakota were well into the 90s °F (Fig. 17) while north of the stationary front temperatures were only in the 60s °F. Dew points in the 60s °F extended from west-central to south-central South Dakota (Fig. 18).

2.3 Discussion

The combination of a deep layer (300 mb) of south to southeasterly flow and the compact shortwave trough approaching the area provided ample moisture and lift to initiate convection on 17 August 2007. The precipitable water value of 189 percent of normal is well above the 142

percent average that Maddox et al. (1979) found in his summary of western flash flood events. Maddox et al. (1980) categorized flash flood events in the western United States into four categories. This event fits into the Type II category as it corresponds well with the synoptic pattern including westerly winds aloft and observed precipitable water values of around 70 to 75 percent of the maximum for that time of year.

Doswell et al. (1996) put together a comprehensive list of ingredients to assist the forecaster in flash flood situations. The analysis above is consistent with the factors they reviewed including deep moist convection and sustained high rainfall rates which are described in the following section.

3. Observations

3.1 Radar Estimates

At 2330 UTC 17 August the first storm cell developed west of Hermosa (Fig. 19). This cell had moved past Hermosa by 2350 UTC. Another smaller cell developed at 2350 UTC and moved past Hermosa by 0015 UTC. At that time the main cell was beginning to develop west of Hermosa. This cell developed reflectivities in excess of 70 dBZ (Fig. 20) and remained nearly stationary west of Hermosa until 0100 UTC concentrating an area of precipitation with high rainfall rates directly over the area that would soon be flooded. Exacerbating the situation, at 0100 UTC the area around Hermosa began to fill with echoes (Fig. 21) and these echoes remained over this same area until about 0245 UTC. The final wave of showers for the evening crossed Hermosa from about 0300 to 0330 UTC.

Precipitation estimates generated from the KUDX radar data using a convective Z-R relationship ($Z=300R^{1.4}$) indicated an area of 2 inches or more of rain fell from Custer to Red Shirt to approximately 10 miles north of Hermosa (Fig. 22). An area of 36 mi^2 centered around Hermosa received 5 to 6 inches of rain according to this estimate. When looking at the radar-estimated precipitation using a tropical Z-R relationship ($Z=250R^{1.2}$), the area that received greater than 2 inches of rain increased slightly and the maximum rainfall detected increased from 5 to 6 inches to 8 to 9 inches just north of Hermosa (Fig. 23). Because of the poor performance of the tropical Z-R relationship it will not be discussed further in this paper.

3.2 Rainfall Reports

In the weeks following the flood, the United States Geological Survey (USGS) approached the NWS to ensure rainfall amounts were documented. The USGS provided the NWS with a list of rainfall reports that were collected from the general public with their flood survey. The NWS contacted the individuals, visited most of their locations, and documented the rainfall and rain gage data. These reports, combined with existing rainfall reports, were used to produce an isohyetal map of the storm rainfall (Fig. 24). According to the available rainfall data, a maximum storm value of 10.50 inches of rain fell five miles west-northwest of Hermosa. An area of approximately 20 mi^2 received at least 6 inches of rain, while an area of about 1 mi^2 received at least 10 inches of rain.

Table 1 is a listing of the data that were collected through the cooperative efforts of the USGS, NWS, and the help of the general public. Most of the rain fell during a period from 5:30 pm to 8:30 pm (MDT).

3.3 Comparison of Radar Data with Rainfall Reports

Comparing the isohyetal map with WSR-88D radar data, two conclusions can be made. First, the areal coverage of the WSR-88D radar-estimated precipitation was close to the isohyetal map created from observed rainfall reports. However, the major difference was in the rainfall totals as the storm total precipitation values produced by the radar using the convective Z-R relationship were grossly underestimated. Figure 25 shows the radar-estimated storm total precipitation with the isohyetal rainfall amounts as an overlay. Storm total radar precipitation estimates near Hermosa use a 1 km by 2 km grid system. The large grid size combined with an averaging algorithm over the radar bin is most likely responsible for the underestimation of the rainfall.

4. Comparison to Other Heavy Rain Events

Storms of this nature are not unheard of in the Black Hills area of western South Dakota. Several storms producing rainfall in excess of 6 inches have occurred in recent history including the following: 14 June 1996 where 14.6 inches of rain fell near Piedmont, South Dakota; 7 August 1999 in which 7 inches of rain fell near Custer, South Dakota; and 5 May 2007 where more than 6 inches of rain fell over the Badlands National Park.

One may draw comparisons to the 9 June 1972 flood of Rapid Creek in Rapid City, South Dakota in which almost 15 inches of rain fell northwest of town causing Canyon Lake Dam to fail and 238 people to lose their lives. This event had some similar features including the placement of a surface low across eastern Wyoming and a stationary front draped across western South Dakota. Some of the differences between these two events include the placement of the upper-level ridge farther east in 1972, much lighter winds aloft in 1972, an easterly orographic lift component more prominent in 1972, and, in conjunction with these, the duration and areal extent of the heavy rainfall was much larger in 1972 with more than 6 inches of rain falling over a 300 mi^2 area versus a 20 mi^2 area in 2007 west of Hermosa. Much more detailed information concerning the 9 June 1972 flood can be found in Schwarz et al. (1975).

5. Chronology of NWS Products

Table 2 lists the products issued by the National Weather Service in Rapid City, South Dakota, concerning the flood potential and ongoing flood concerns for the night of 17 August 2007. Over 48 hours before the flash flood and continuing through Friday, heavy rainfall was highlighted as a possibility in the hazardous weather outlook. A flash flood warning was issued for central Pennington County and northeastern Custer County 11 minutes before any reports of flash flooding occurred. A flash flood statement and a local storm report were issued during the event relaying reports from law enforcement. In all the statements issued by the National Weather Service, Hermosa was included in the list of impacted locations.

6. Summary

In summary, the following statements can be made from the analysis of these storms. First, very moist air was present with dew points in the upper 60s and lower 70s across Nebraska. Southeasterly low-level winds of 20 to 40 kts fed this moist air into western South Dakota where severe thunderstorms developed. The precipitable water percent of normal value was consistent with studies done by Maddox et al. (1979, 1980) indicating very moist air was present the night of 17 August 2007 with a potential for flash floods. Second, thunderstorm cells moved over the Hermosa area during a four-hour time frame, with the heaviest rain falling in about an hour. Finally, the radar rainfall estimation provided good areal coverage, however total rainfall amounts were underestimated. The underestimate of the radar precipitation seems to be largely due to the averaging algorithm used in the WSR-88D and the localized amount of heavy rain.

References

Doswell, C. A., H. E. Brooks and R. A. Maddox, 1996: Flash flood forecasting: an ingredients-based methodology. *Wea. Forecasting*, **11**, 560-581.

Maddox, R. A., C. F. Chappell and L. R. Hoxit, 1979: Synoptic and meso-α scale aspects of flash flood events. *Bull. Amer. Meteor. Soc.*, **60**, 115-123.

—, F. Canova and L. R. Hoxit, 1980: Meteorological characteristics of flash flood events over the western United States. *Mon. Wea. Rev.*, **108**, 1866-1877.

Schwarz, R. K., L. A. Hughes, E. M. Hansen, M. S. Petersen and D. B. Kelly, 1975: The Black Hills-Rapid City flood of June 9-10, 1972: a description of the storm and flood. *Geological Survey Profession Paper*, **877**, 1-47.

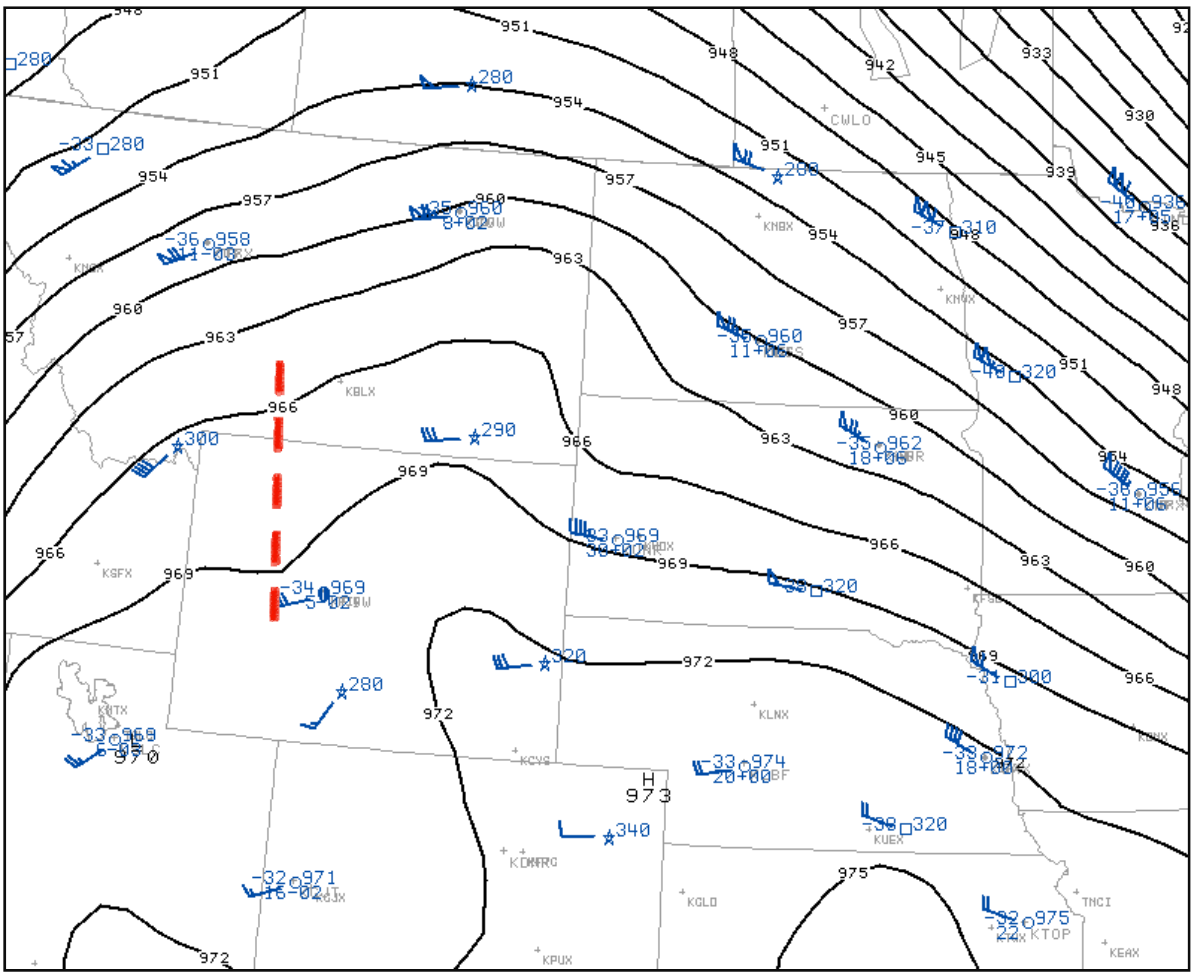

Figure 1. 300-mb analysis from 1200 UTC 17 August 2007. Height contours at 30-dam intervals with station plot in standard notation. Red, dashed line denotes shortwave trough location.

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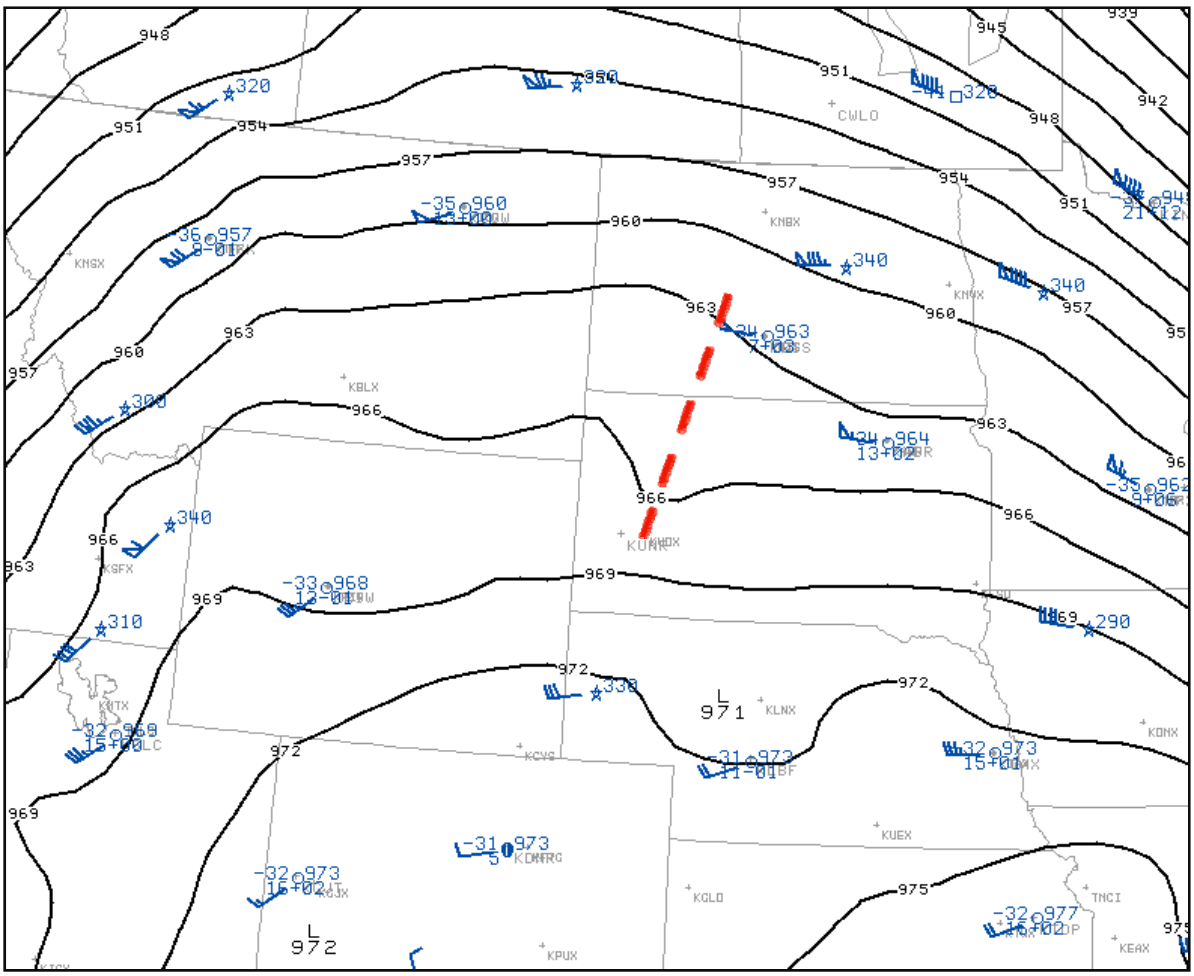

Figure 2. Same as Fig. 1, except analysis from 0000 UTC 18 August 2007. [Note the 0000 UTC Rapid City sounding did not reach 300 mb (Fig. 10).]

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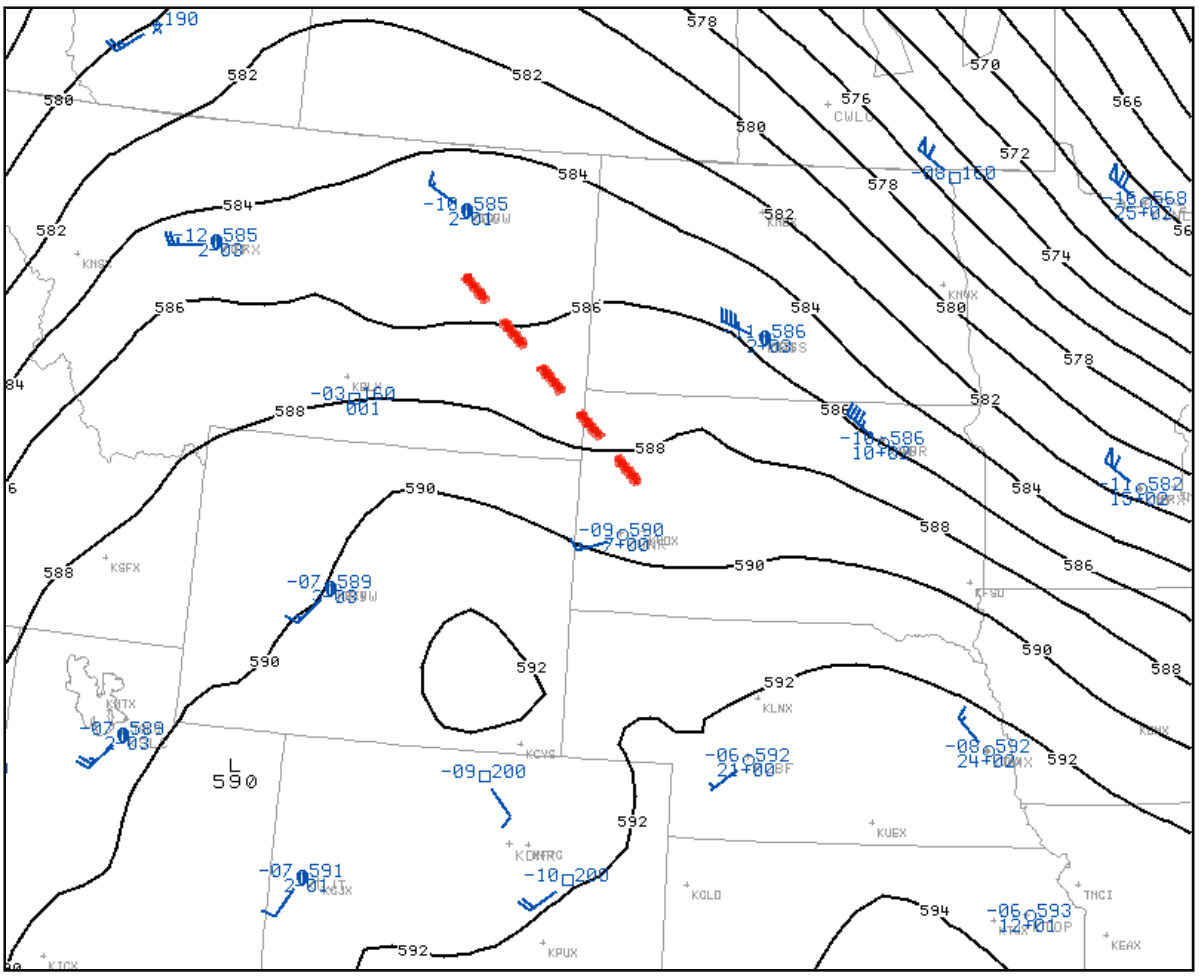

Figure 3. 500-mb analysis from 1200 UTC 17 August 2007. Height contours at 20-dam intervals with station plot in standard notation.

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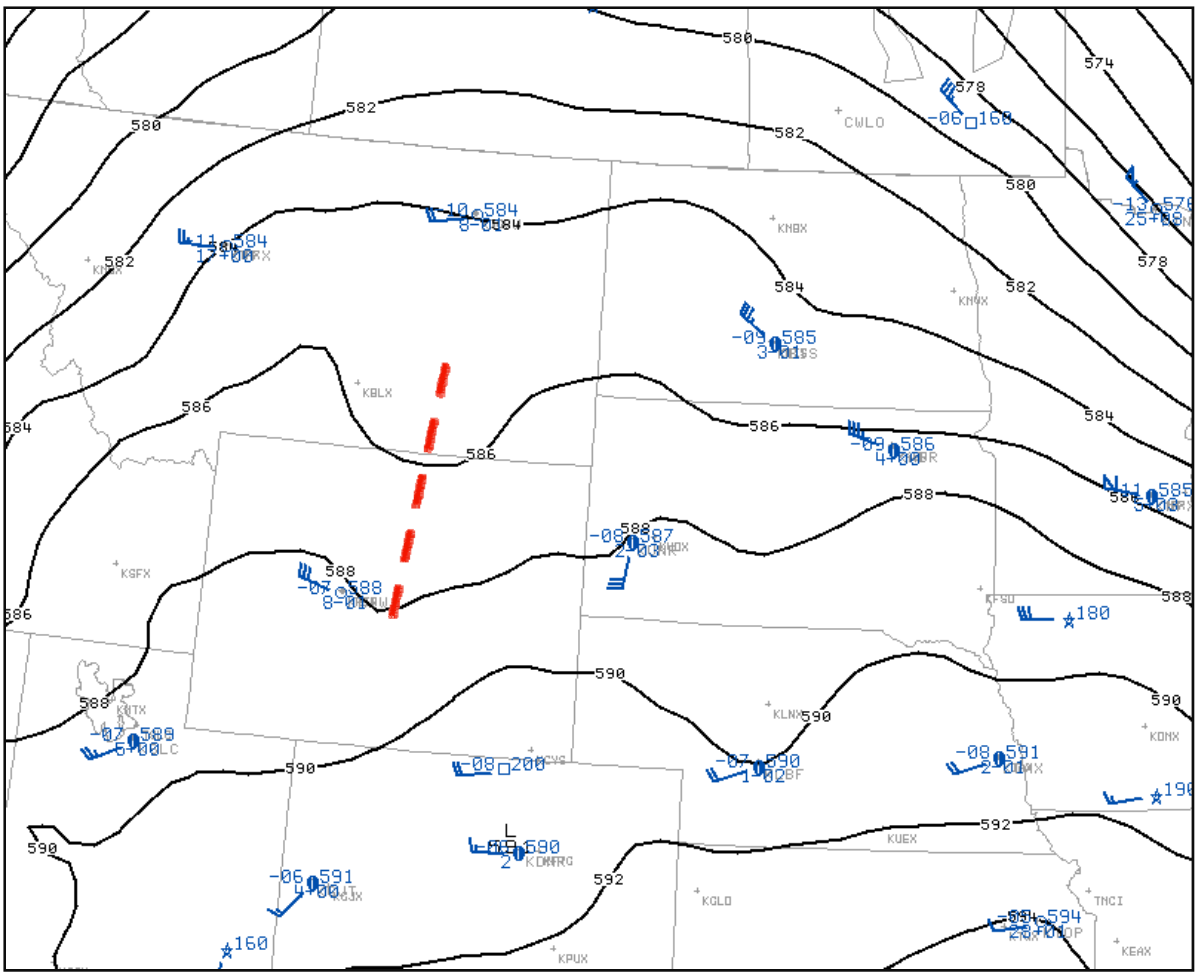

Figure 4. Same as Fig. 3, except analysis from 0000 UTC 18 August 2007.

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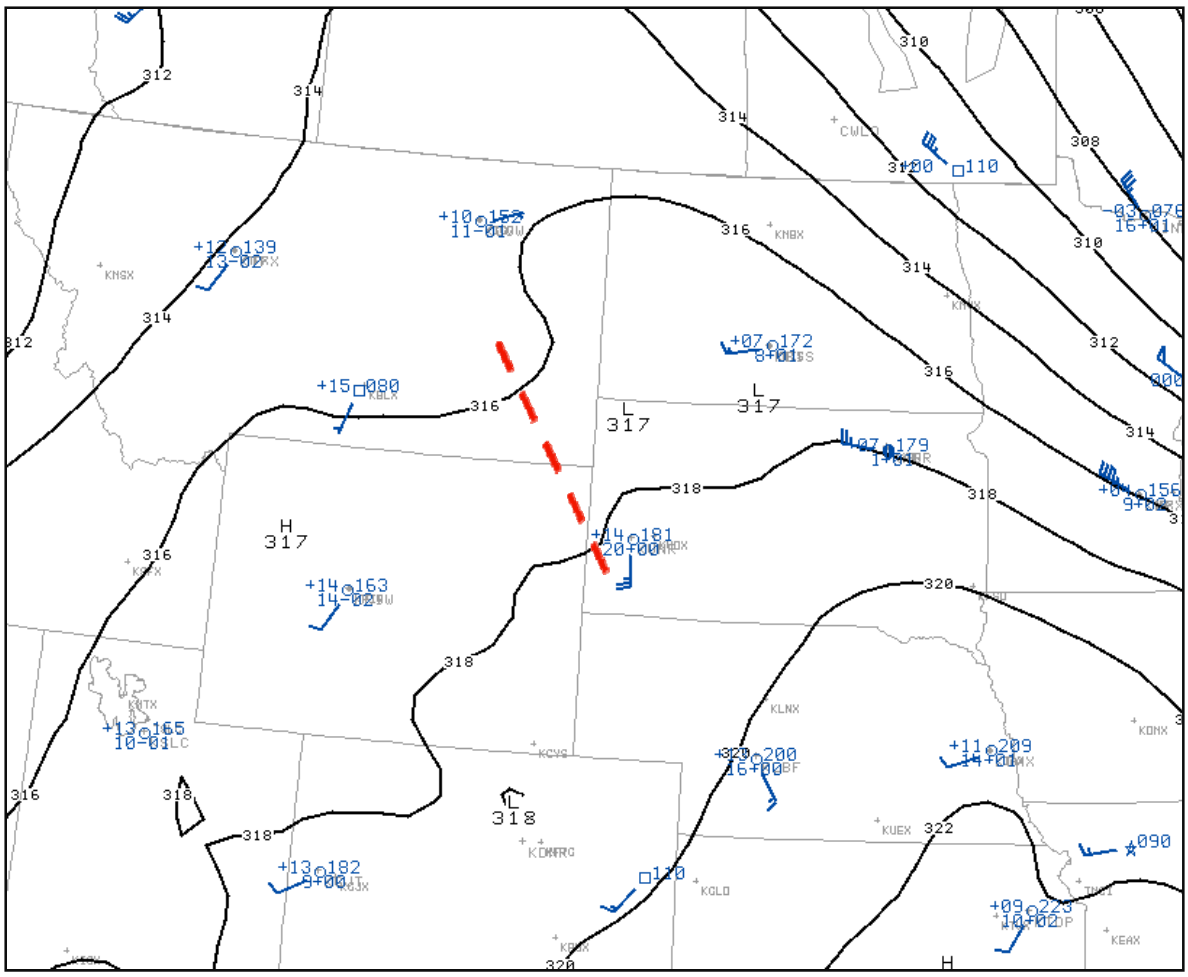

Figure 5. 700-mb analysis from 1200 UTC 17 August 2007. Height contours at 20-dam intervals with station plot in standard notation.

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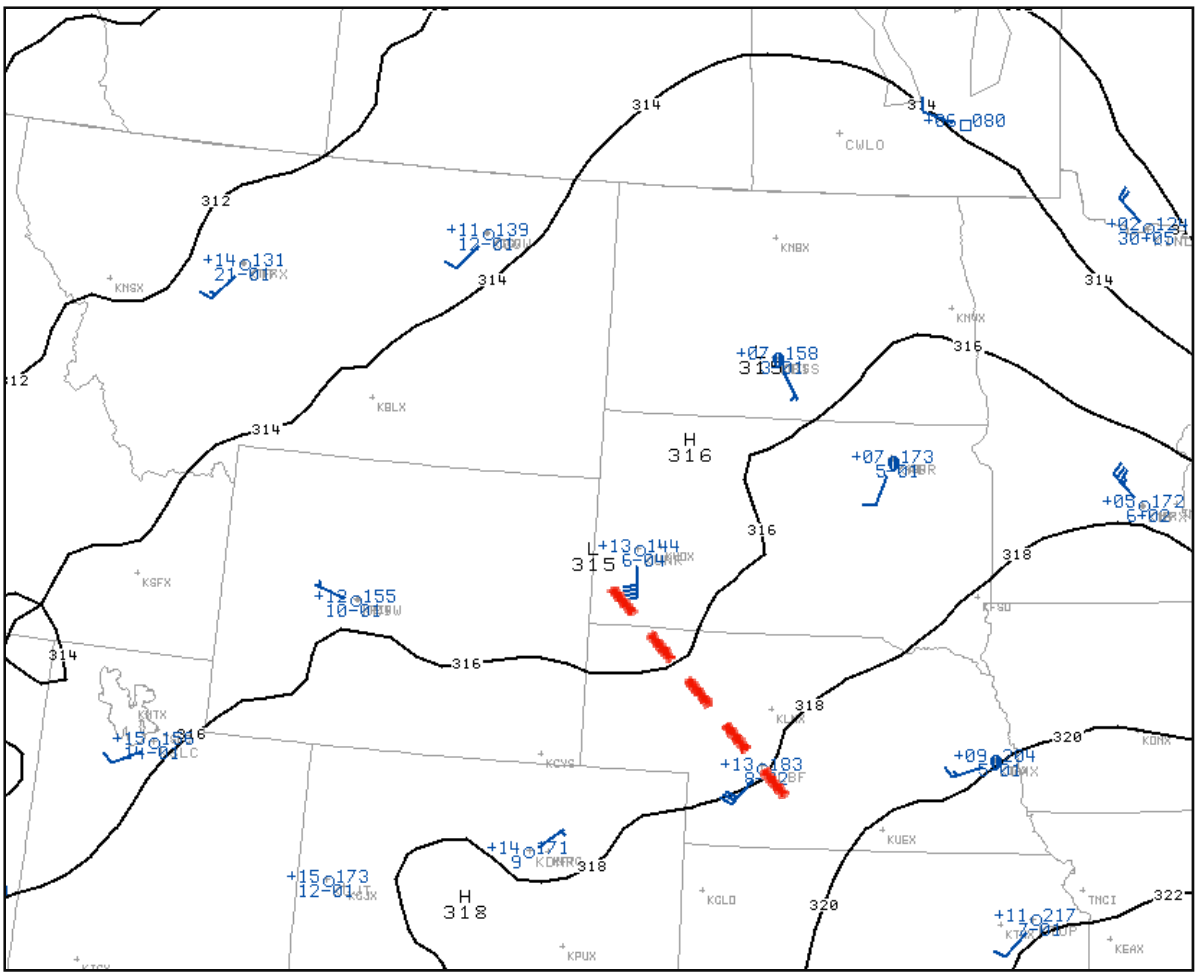

Figure 6. Same as Fig, 5, except analysis from 0000 UTC 18 August 2007.

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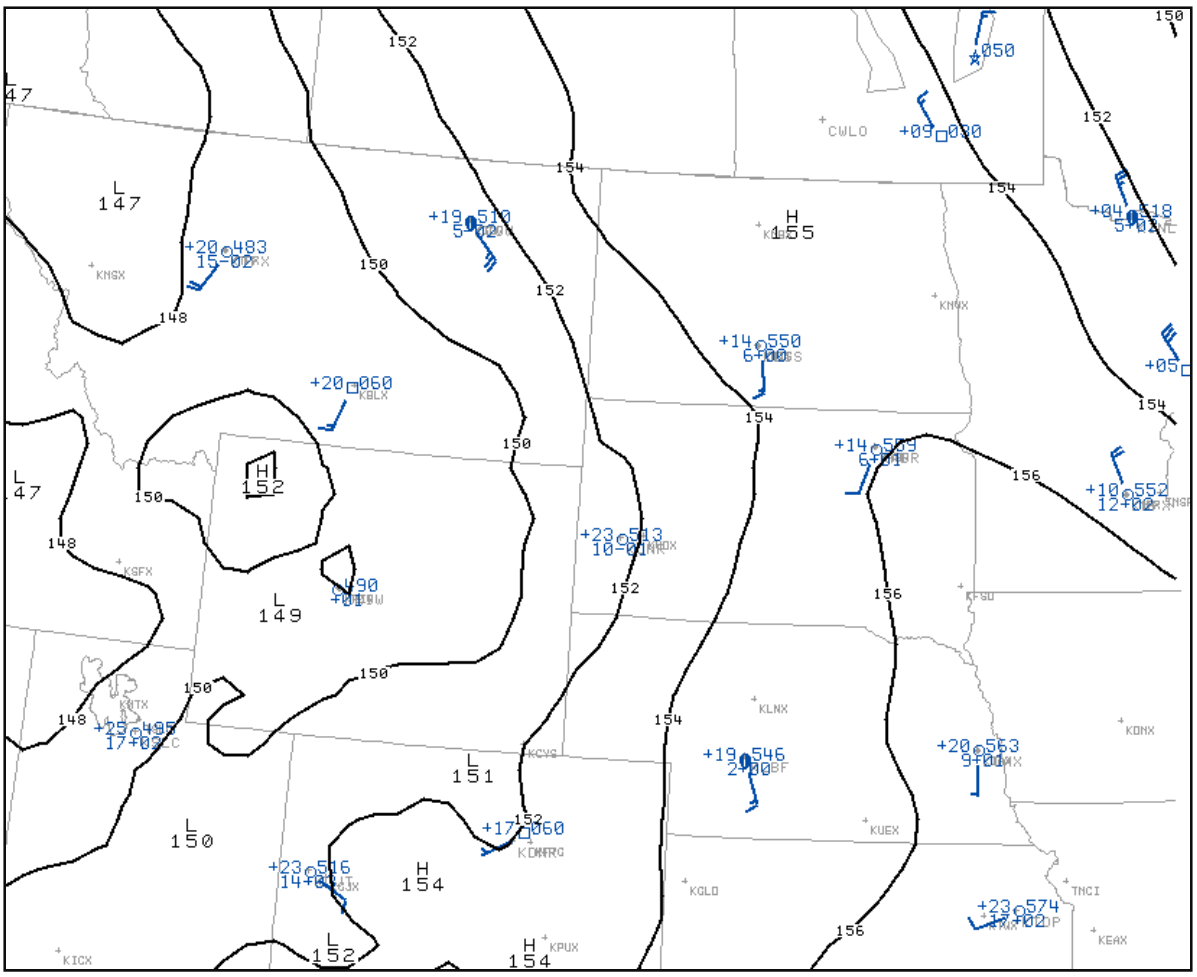

Figure 7. 850-mb analysis from 1200 UTC 17 August 2007. Height contours at 20-dam intervals with station plot in standard notation.

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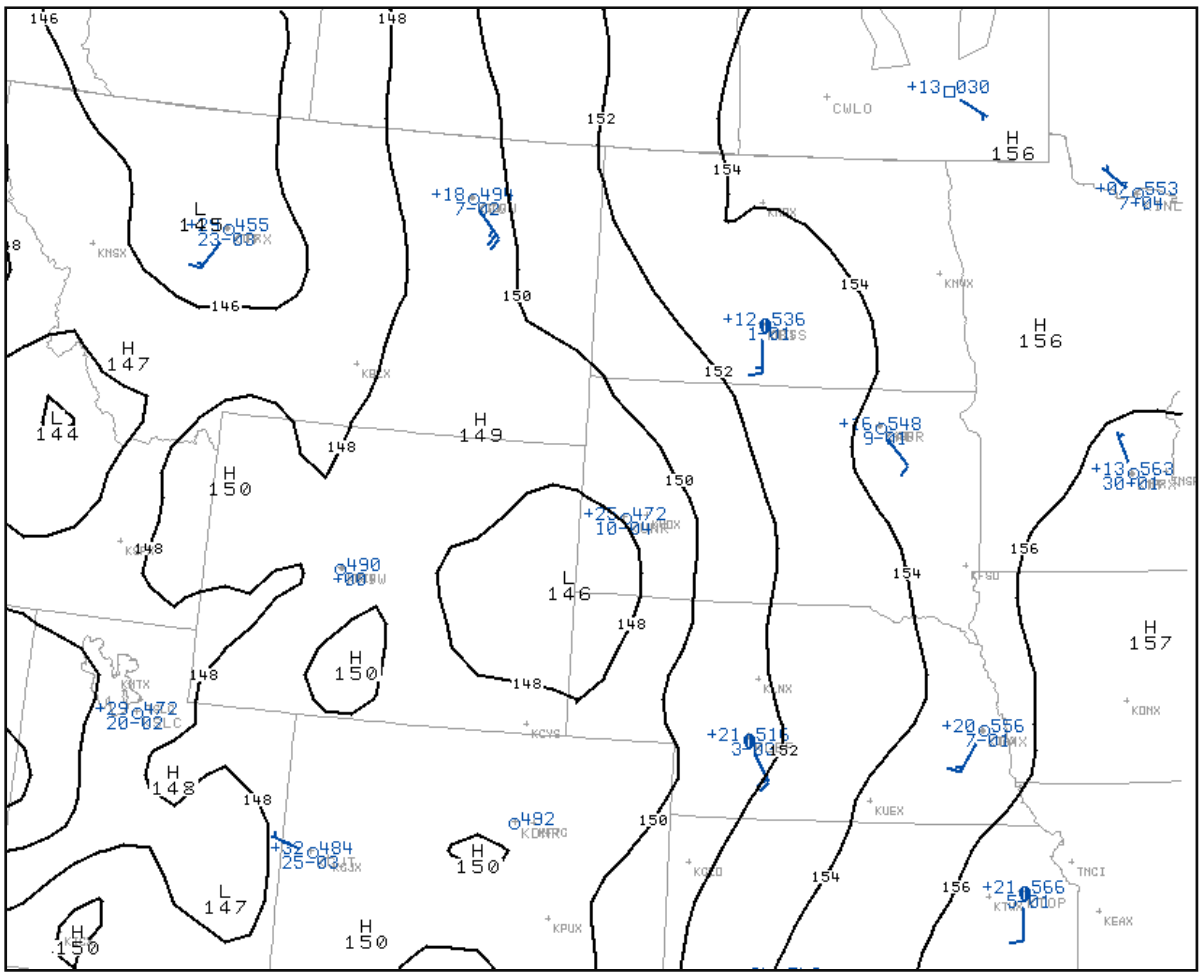

Figure 8. Same as Fig. 7, except analysis from 0000 UTC 18 August 2007.

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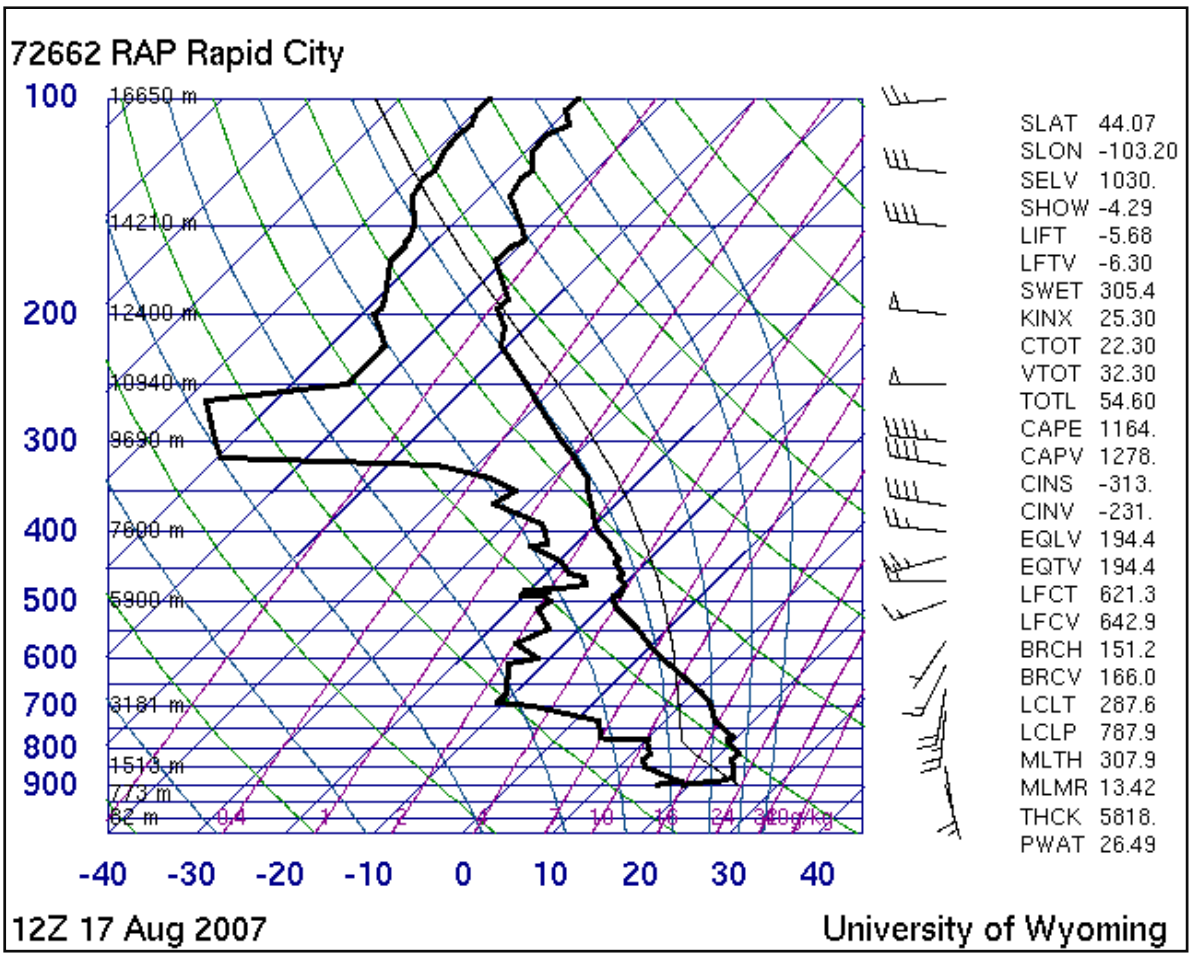

Figure 9. 1200 UTC 17 August 2007 KUNR upper-air sounding. (Courtesy of University of Wyoming, http://weather.uwyo.edu/upperair/sounding.html)

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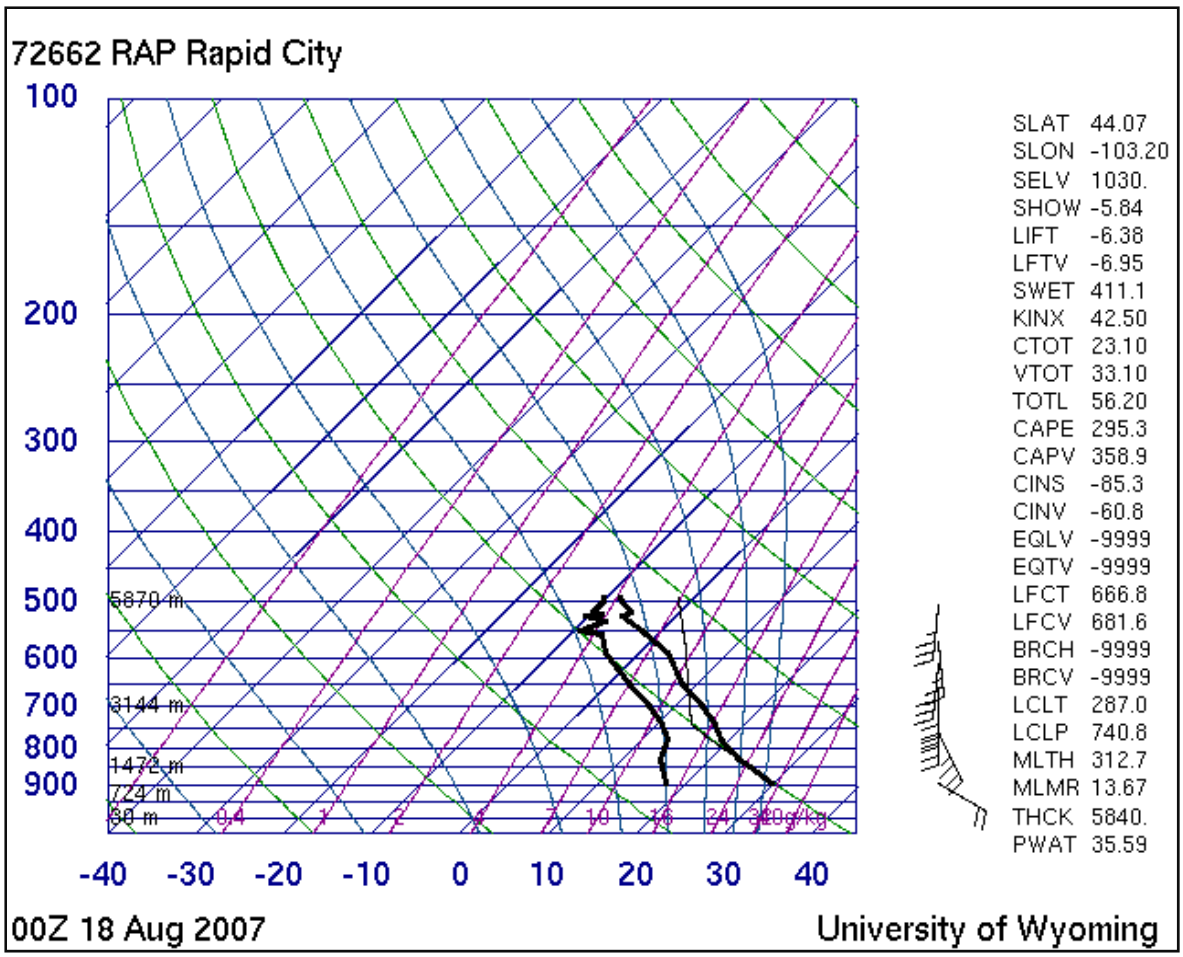

Figure 10. Same as Fig. 9, except for 0000 UTC 18 August 2007.

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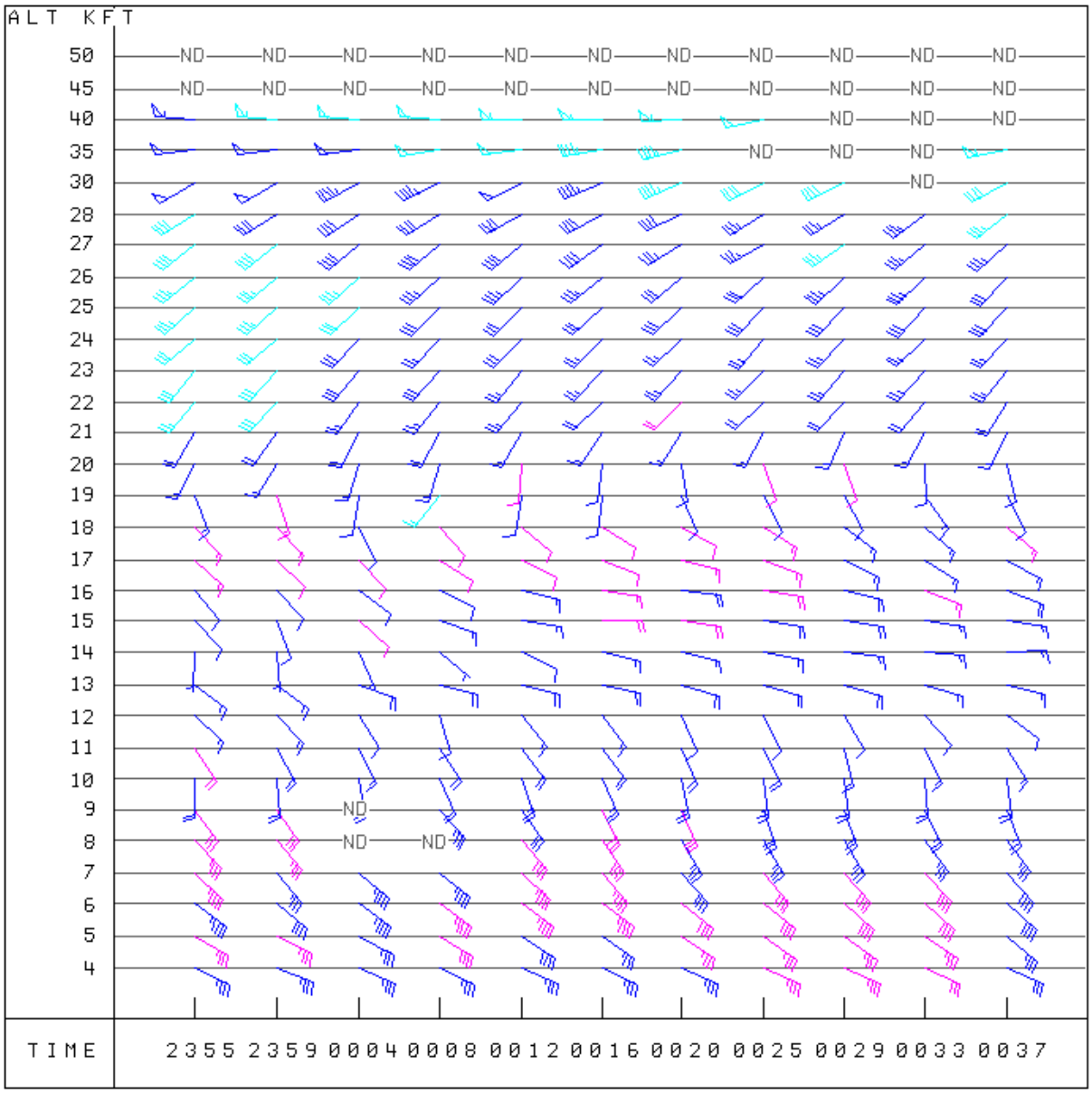

Figure 11. KUDX VWP from 2355–0037 UTC. X axis is time and the Y axis is height in thousands of feet MSL.

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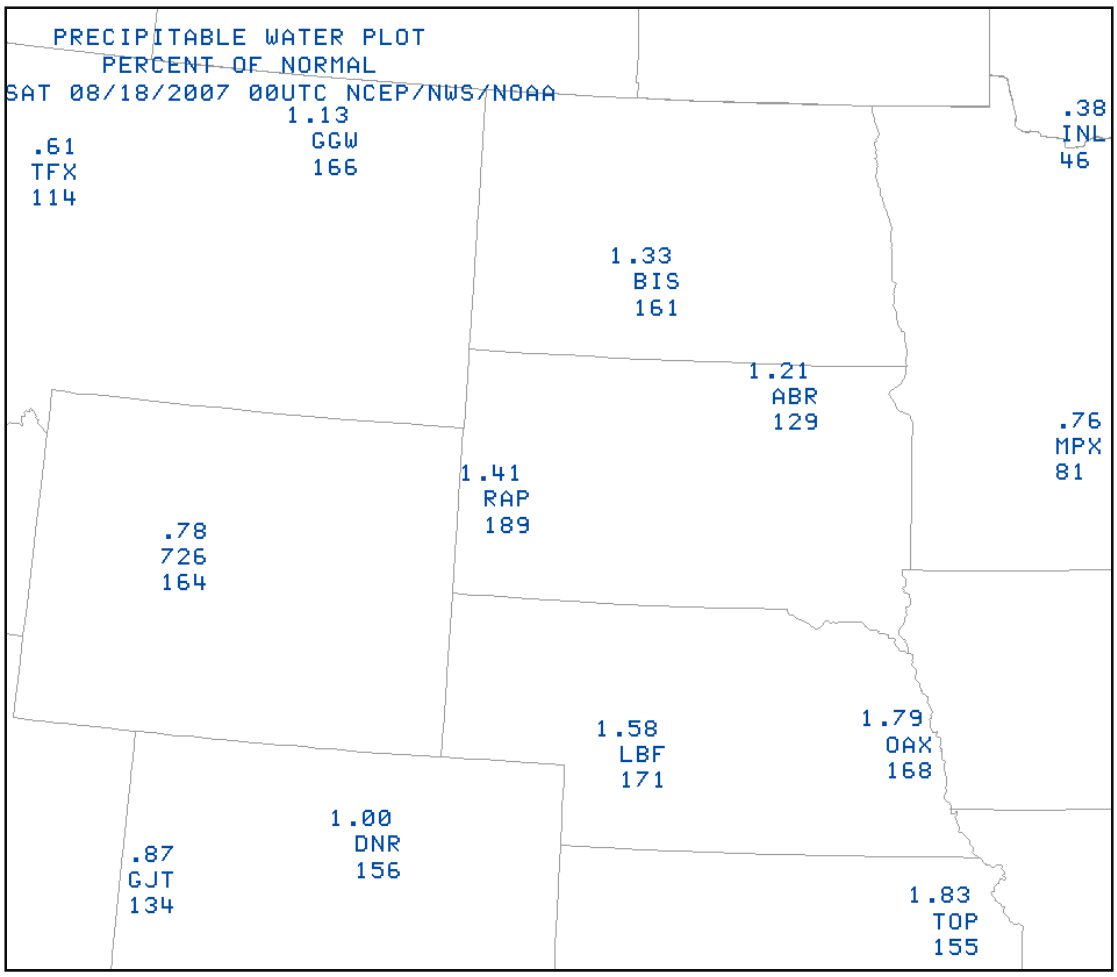

Figure 12. Precipitable water at 0000 UTC 18 August 2007. Top number is the precipitable water value (in inches) while the bottom number is the percent of normal.

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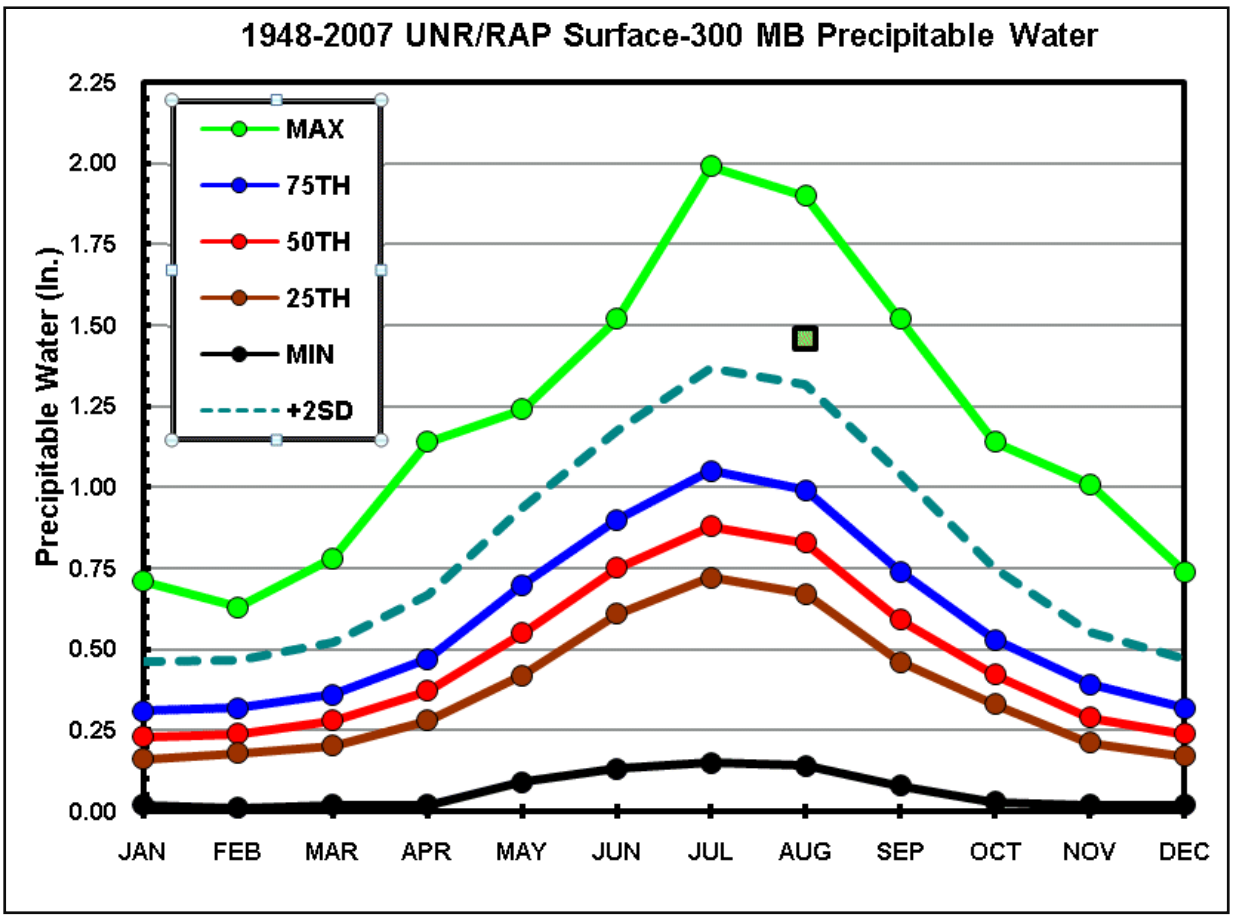

Figure 13. Precipitable water climatology for KUNR from 1948-2007. Max and min represent the maximum and minimum observed precipitable water values, respectively; while, 25th, 50th, and 75th represent each statistical percentage of the dataset with +2SD indicating two standard deviations from the mean. The green shaded square marks the value of 1.41 inches found on the 0000 UTC 18 August 2007 KUNR sounding.

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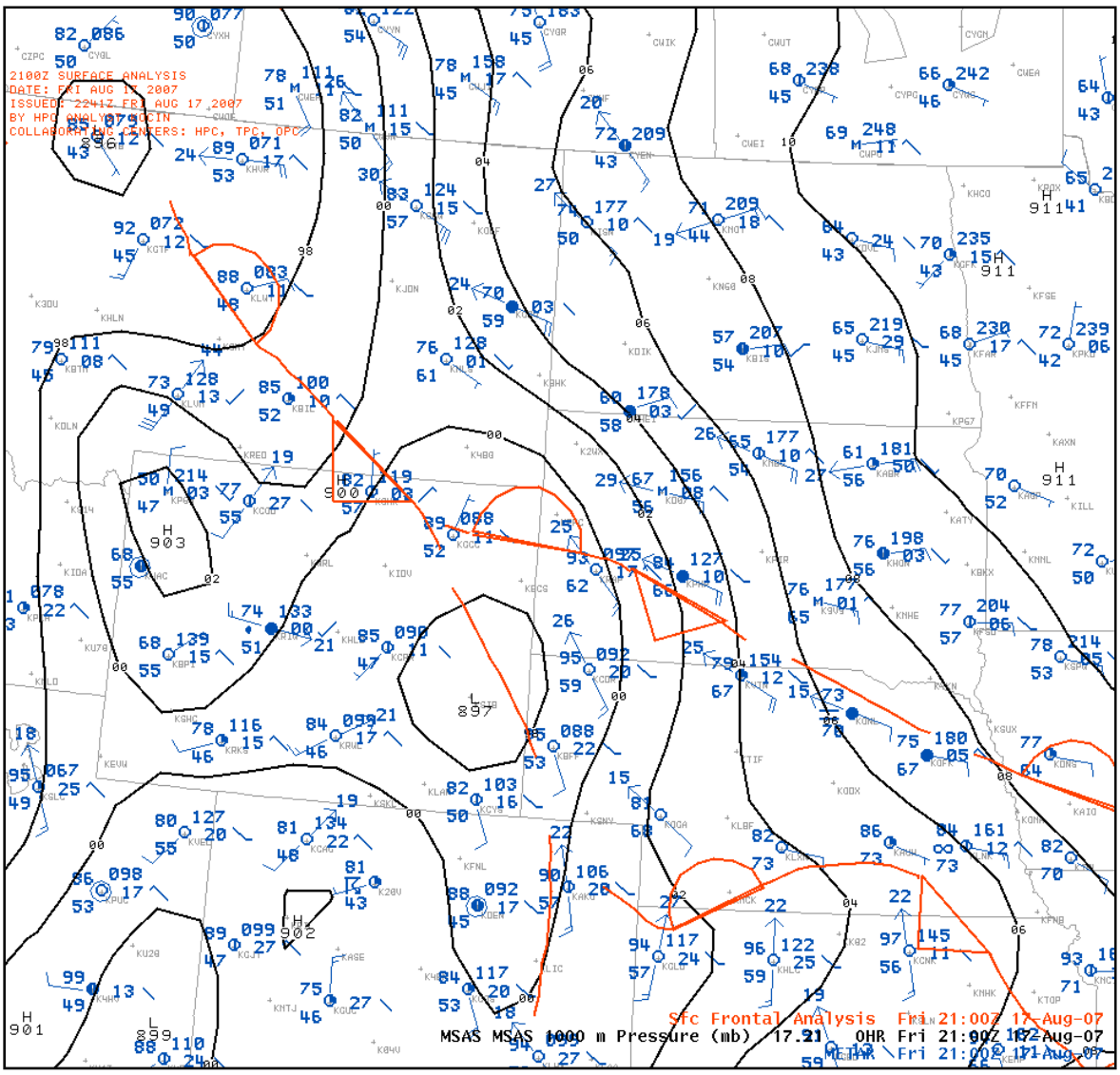

Figure 14. Surface analysis for 2100 UTC 17 August 2007. Pressure contours at 2-mb intervals with station plots in standard notation.

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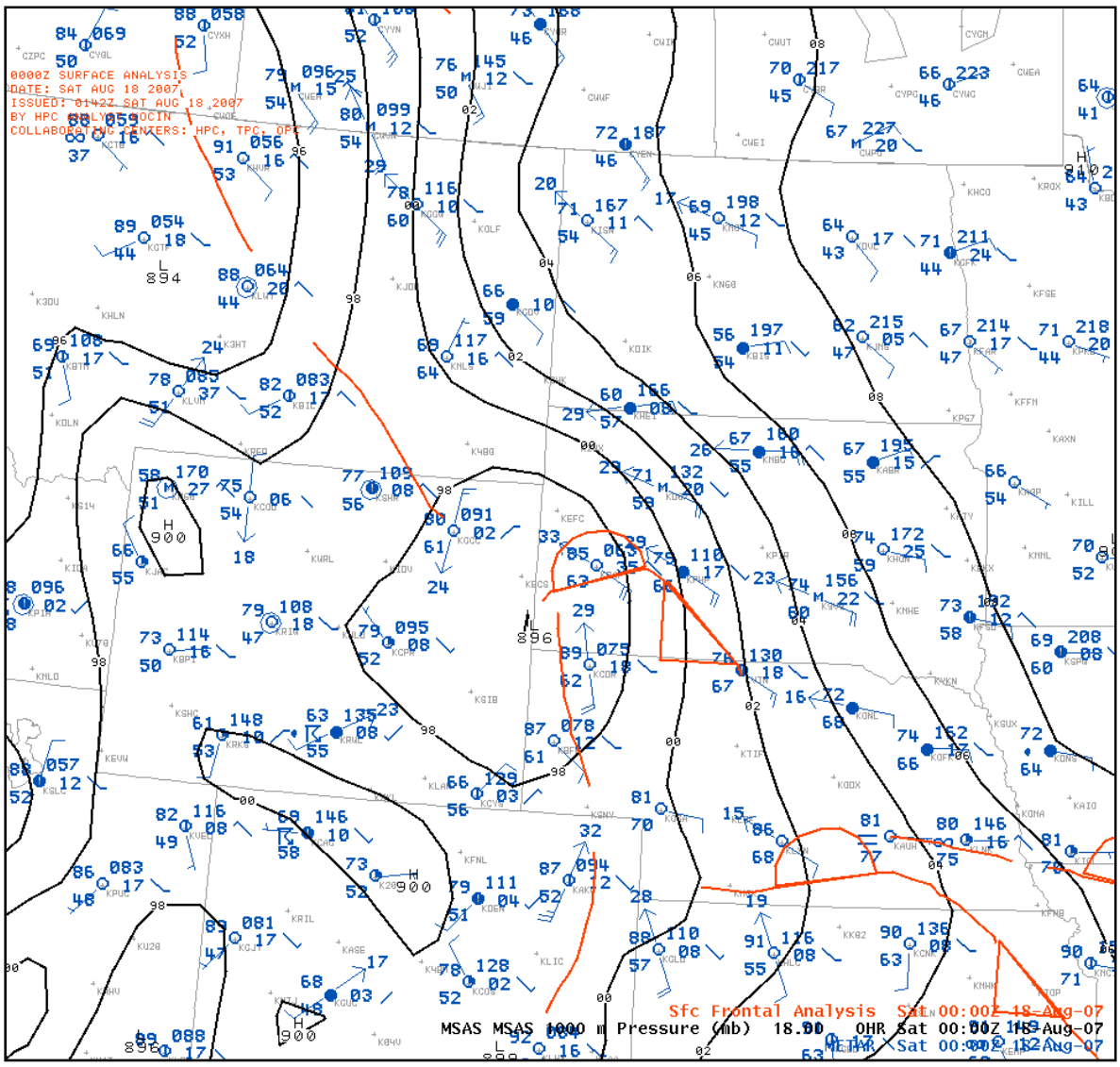

Figure 15. Same as Fig. 14, except analysis from 0000 UTC 18 August 2007.

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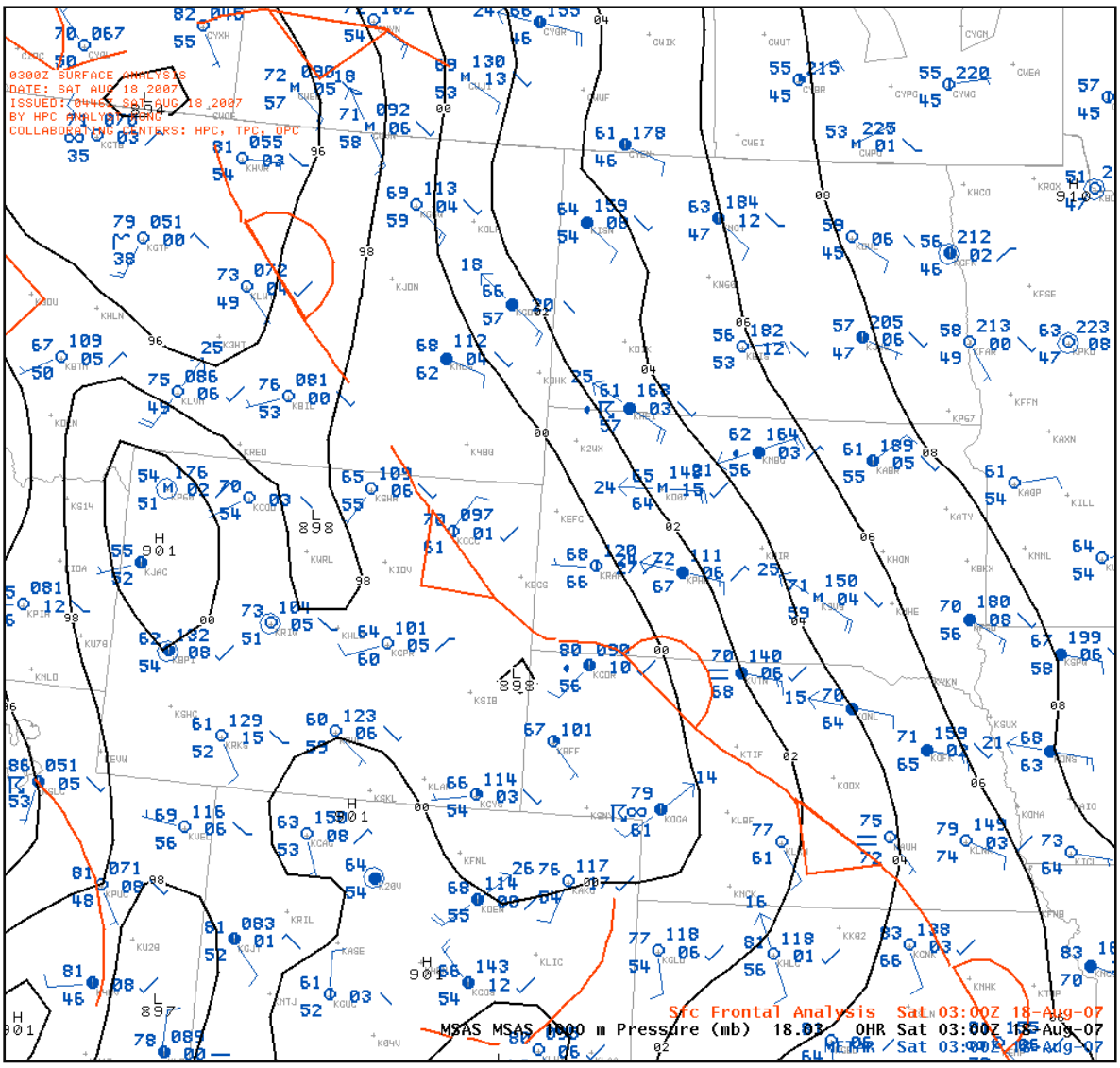

Figure 16. Same as Fig. 14, except analysis from 0300 UTC 18 August 2007.

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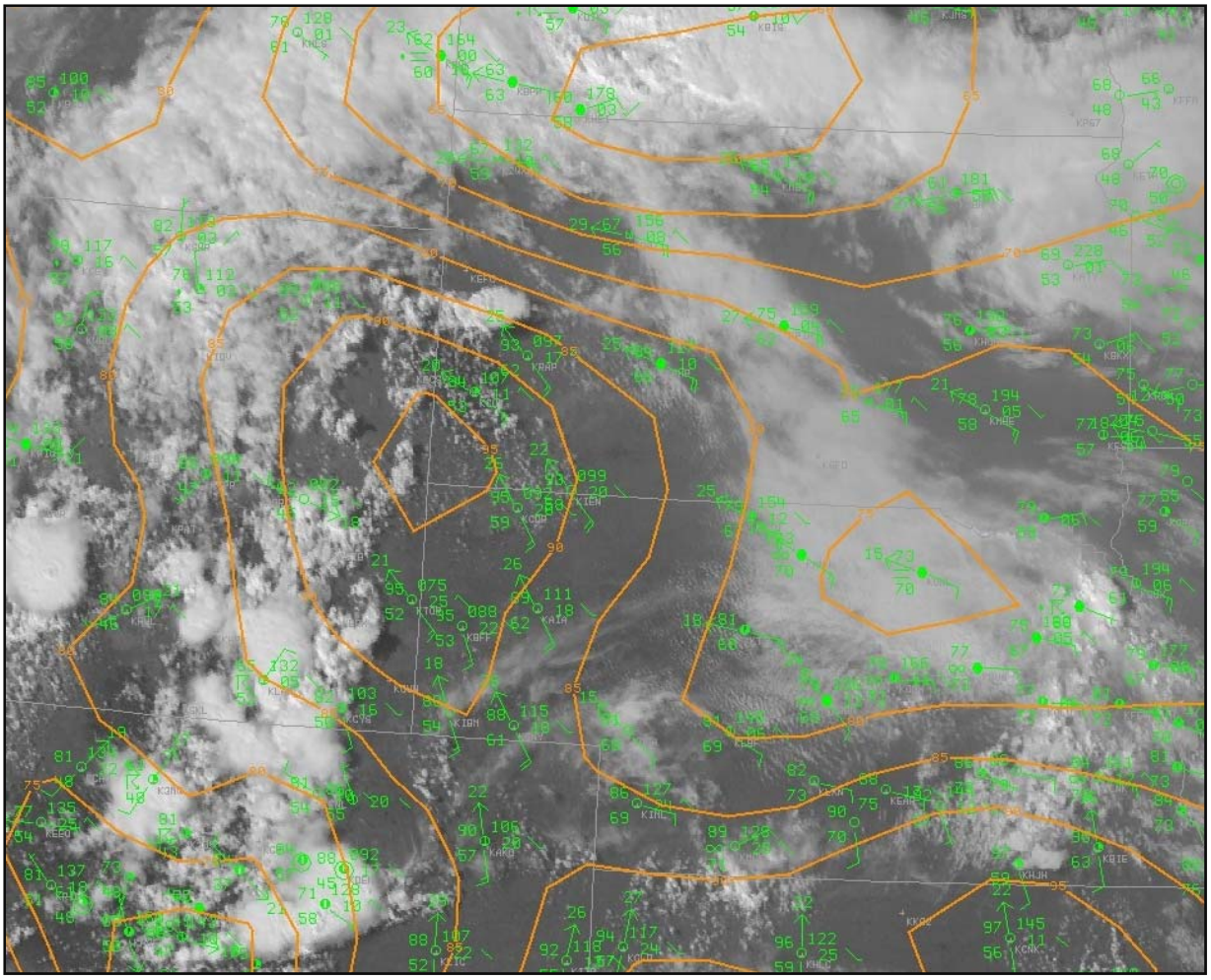

Figure 17. Visible satellite image valid 2115 UTC 17 August 2007, with the orange contours representing objectively analyzed temperatures valid at 2100 UTC with an interval of 5°F. Station plots in standard notation also are included (green).

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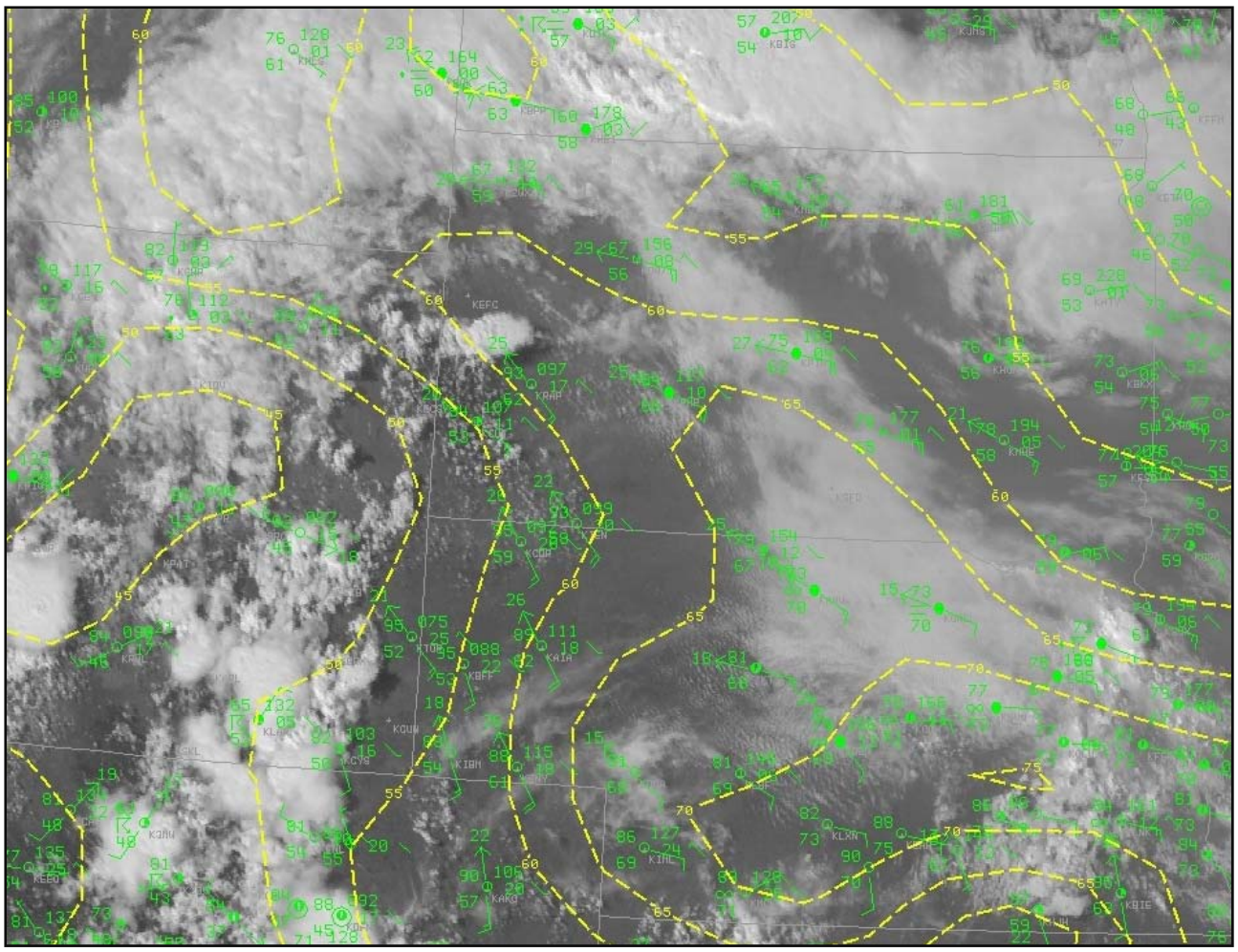

Figure 18. Visible satellite image valid 2115 UTC 17 August 2007, with the yellow-dashed contours representing objectively analyzed dew points valid at 2100 UTC with an interval of 5°F. Station plots in standard notation also are included (green).

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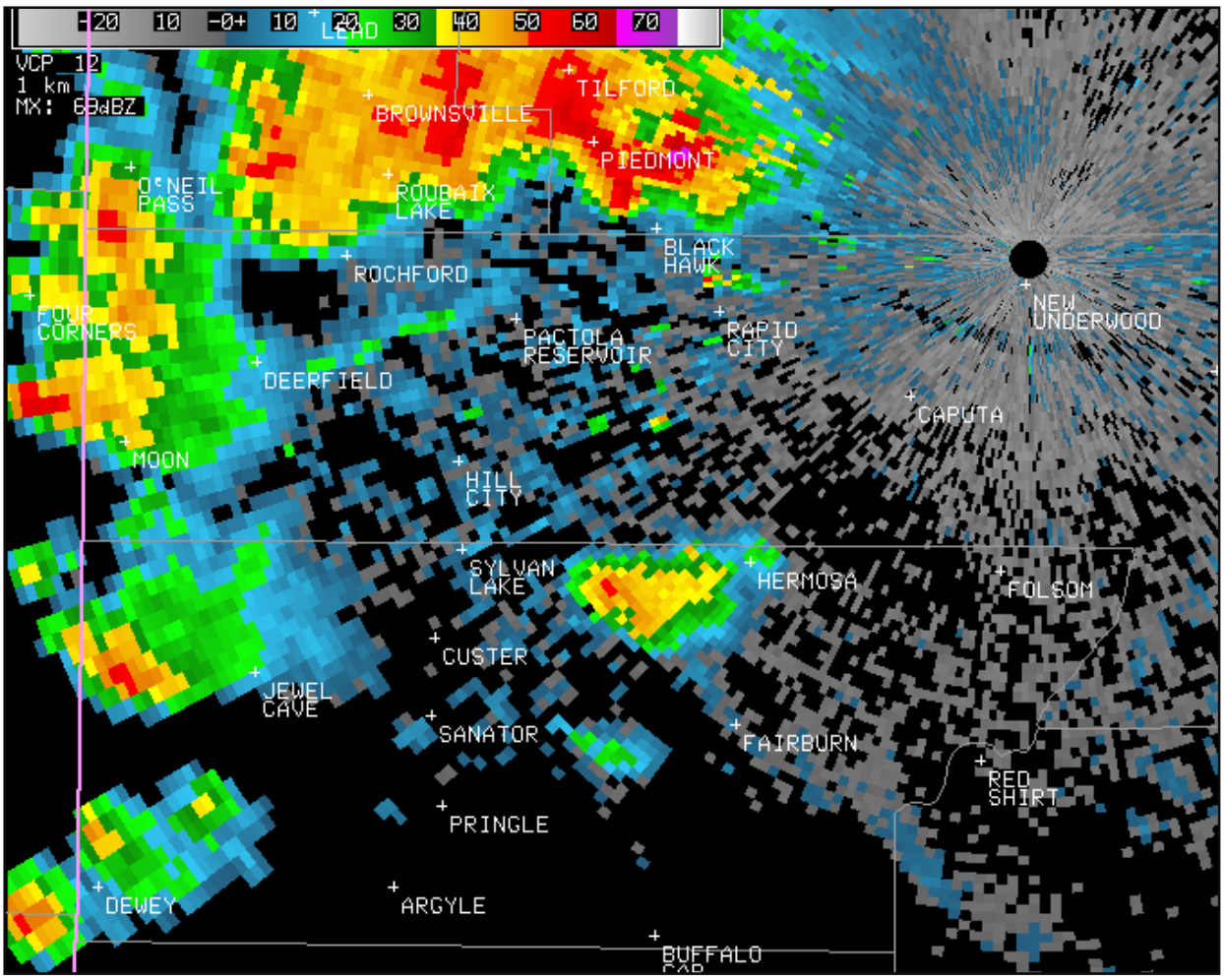

Figure 19. KUDX WSR-88D 0.5° reflectivity valid 2330 UTC 17 August 2007. Common cities are indicated in white while county boundaries are in gray and the South Dakota–Wyoming border is in pink. Hermosa is ~25 miles southwest of the KUDX radar, the latter of which is located just north of New Underwood, South Dakota.

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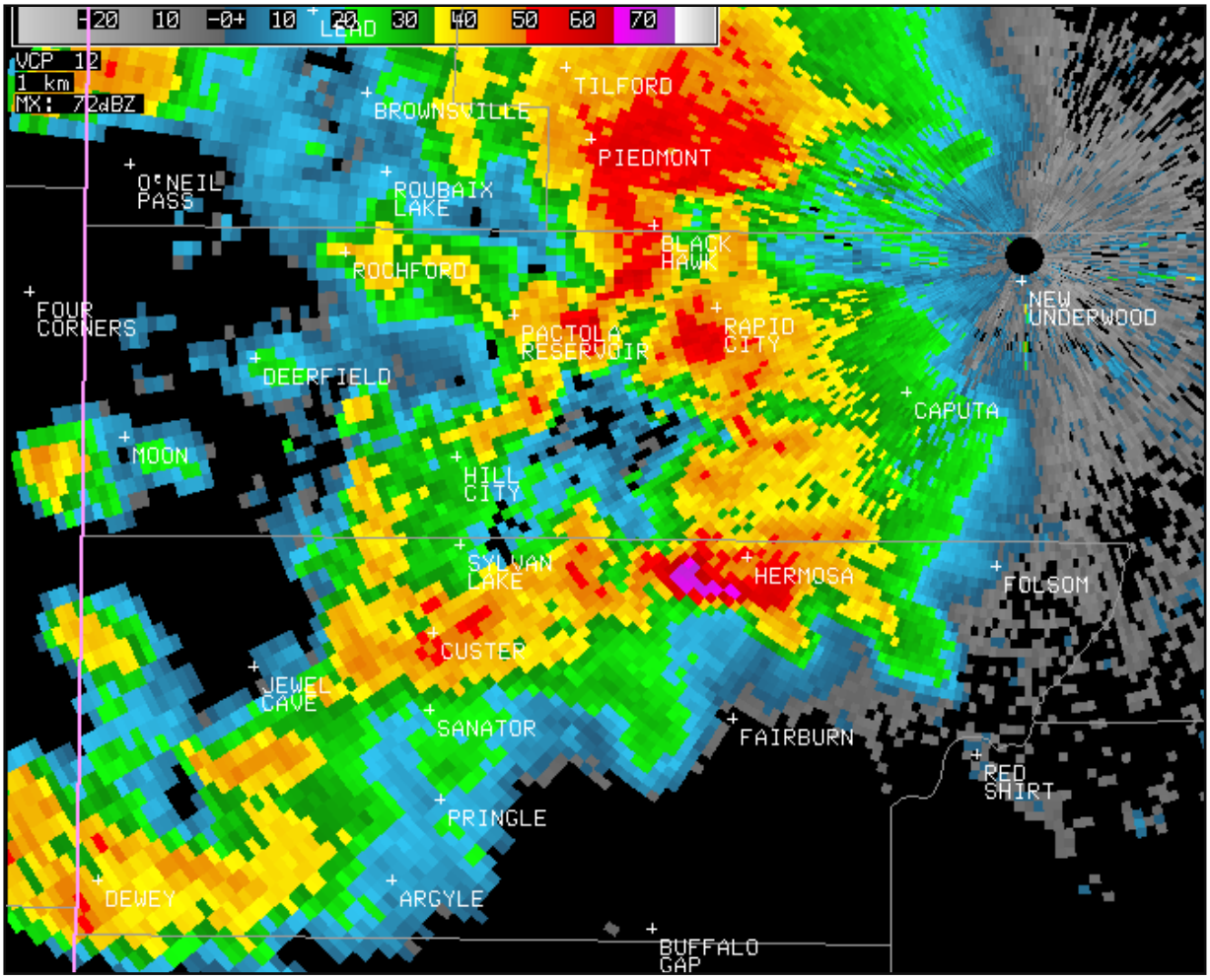

Figure 20. Same as Fig. 19, except valid 0025 UTC 18 August 2007.

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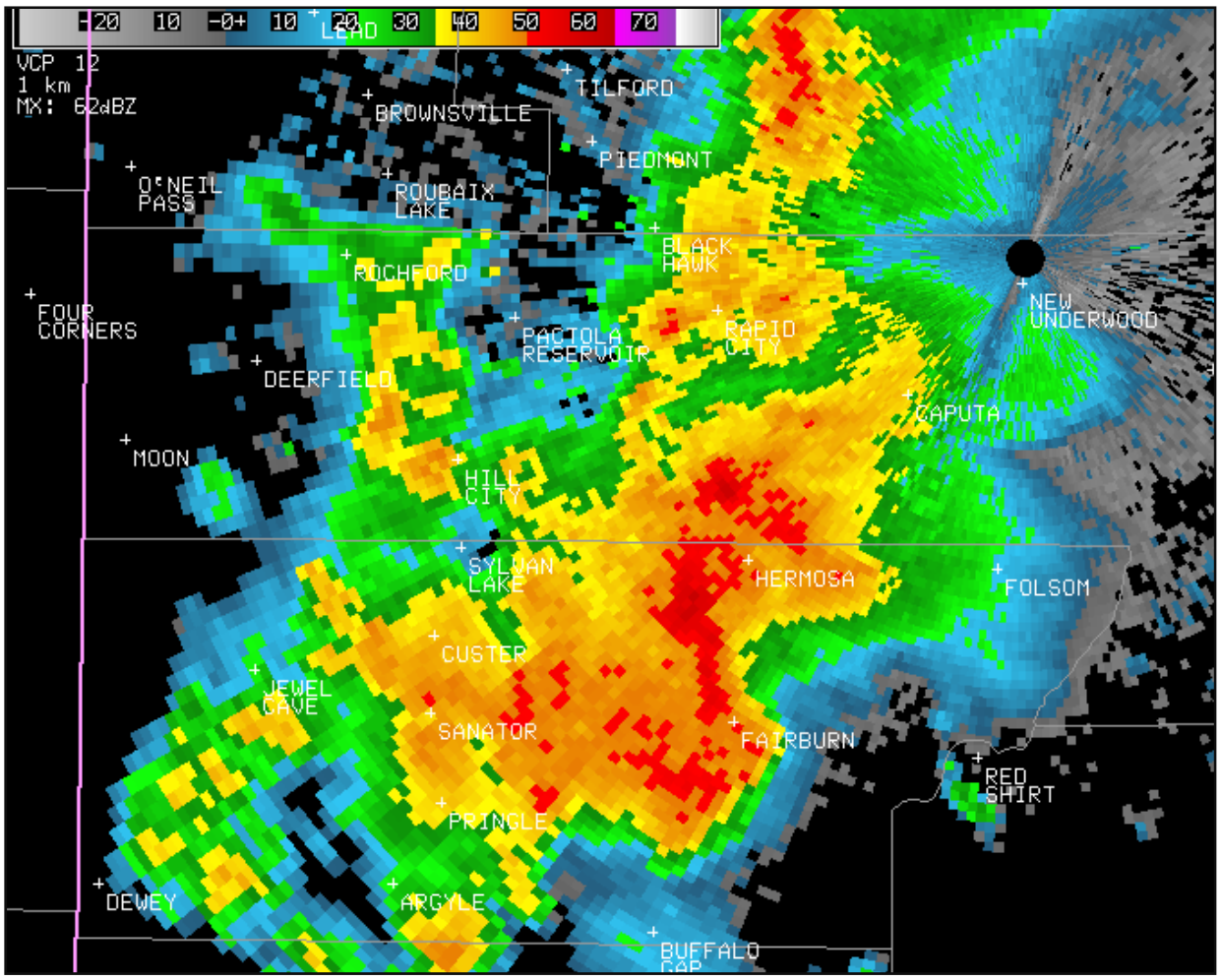

Figure 21. Same as Fig. 19, except valid 0119 UTC 18 August 2007.

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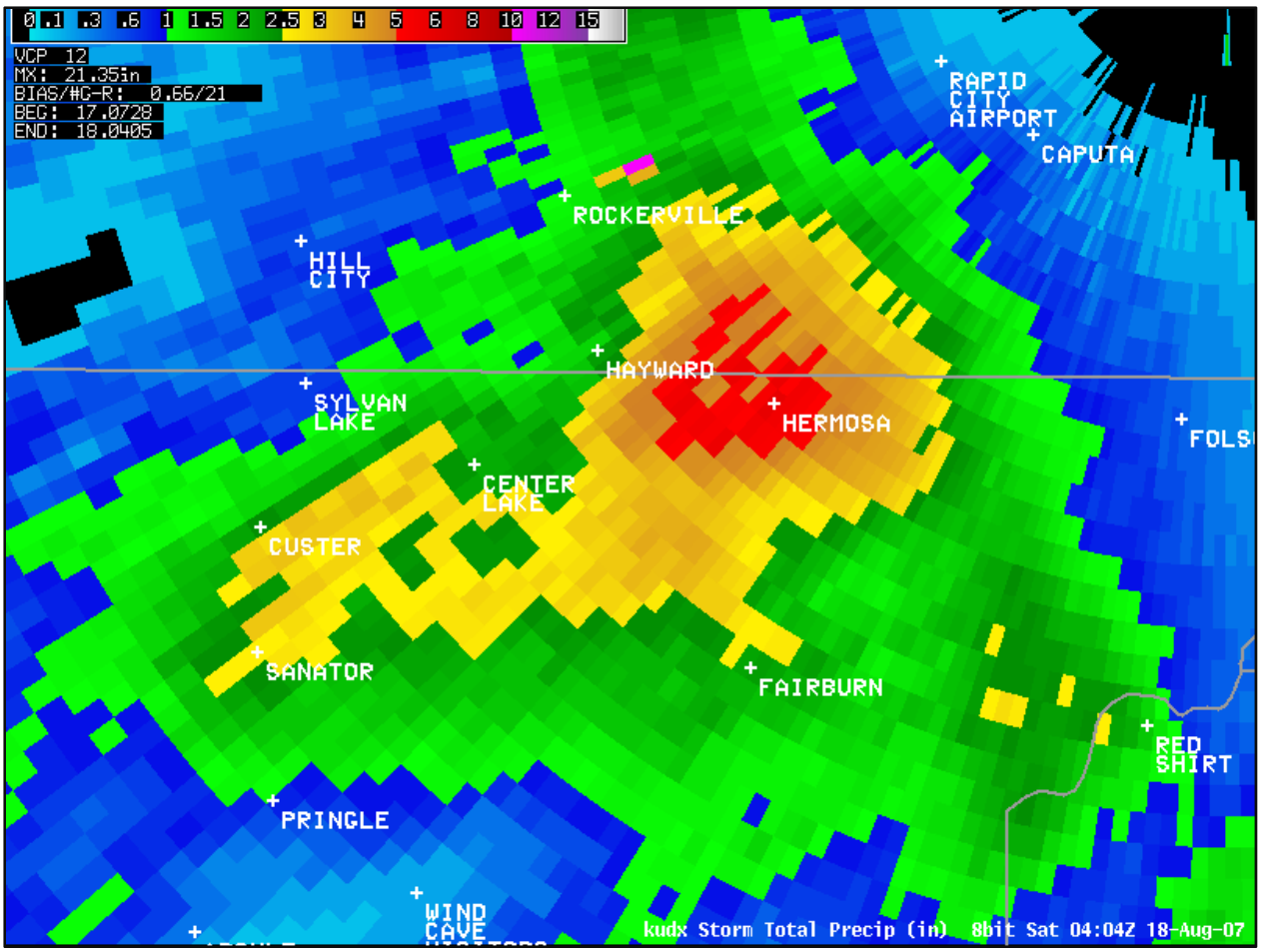

Figure 22. Same as Fig. 19, except radar-estimated precipitation in inches using a convective Z-R relationship ($Z=300R^{1.4}$). Note the maximum precipitation amounts of 5 to 6 inches in the Hermosa area.

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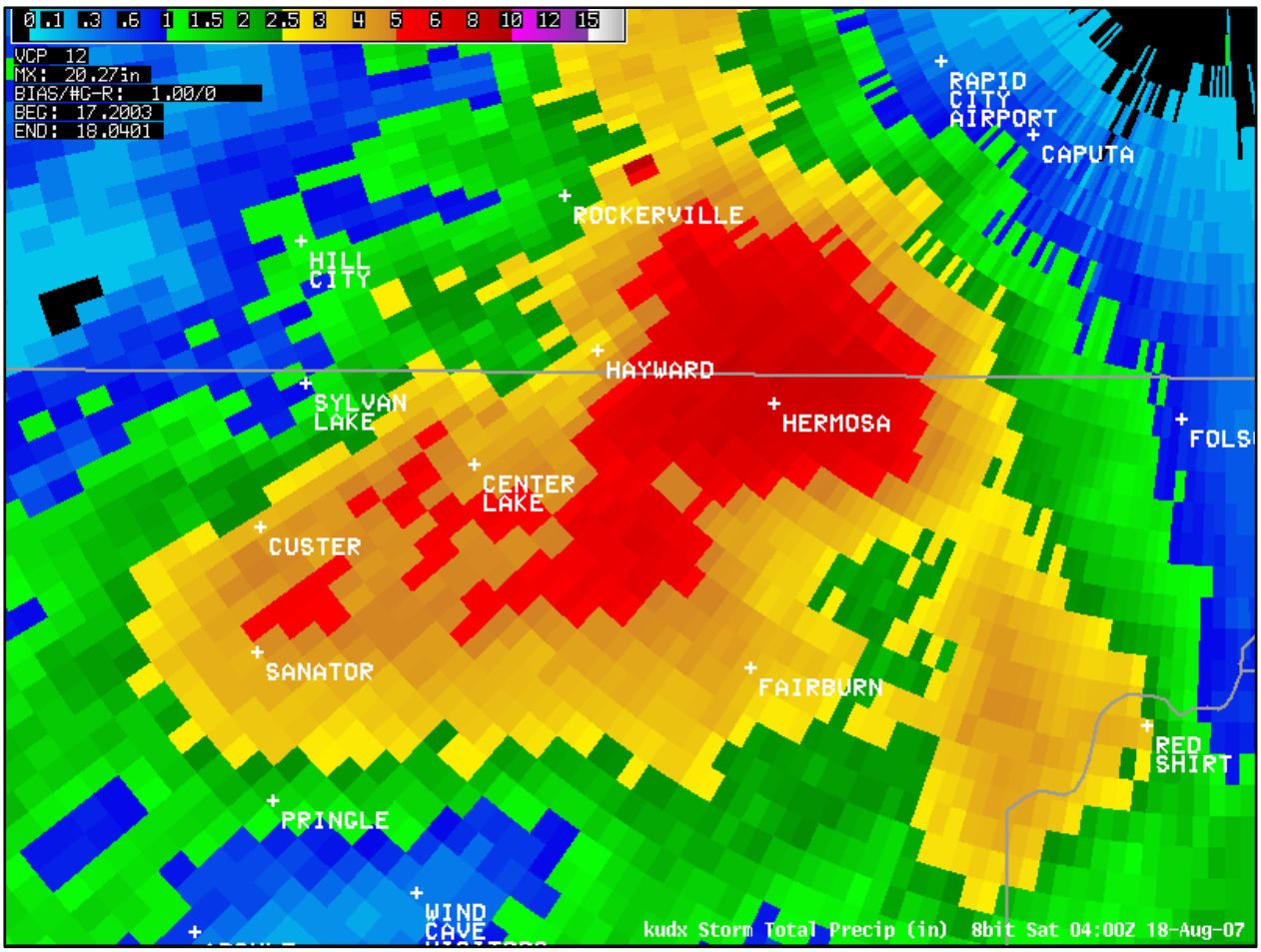

Figure 23. Same as Fig. 19, except radar-estimated precipitation using a tropical Z-R relationship ($Z=250R^{1.2}$).

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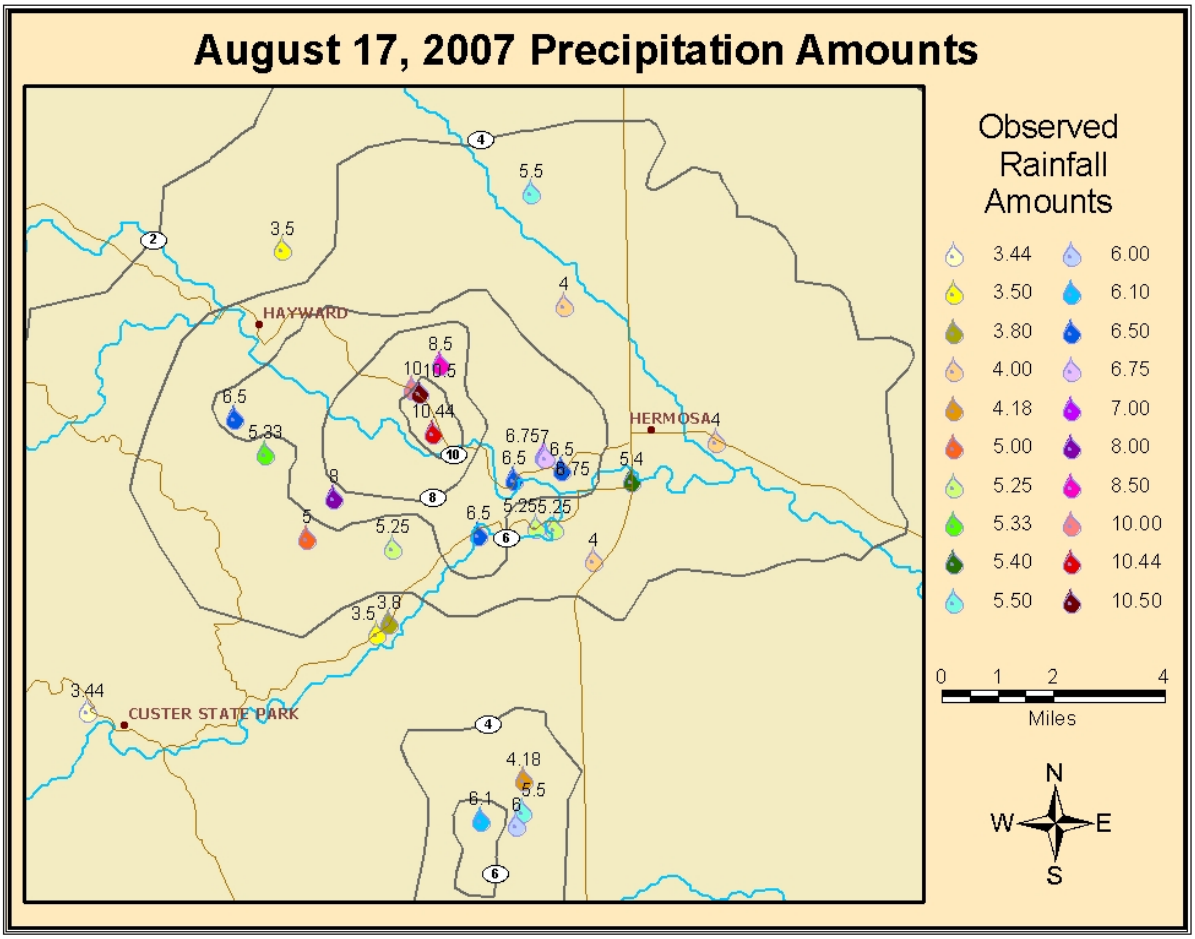

Figure 24. Rain gage precipitation amounts and contours for the 12-hour period ending at 0600 UTC 18 August 2007. Map is zoomed to a 15 x 15 mile square centered just west of Hermosa, South Dakota. Blue lines indicate rivers and streams and the brown lines indicated state highways.

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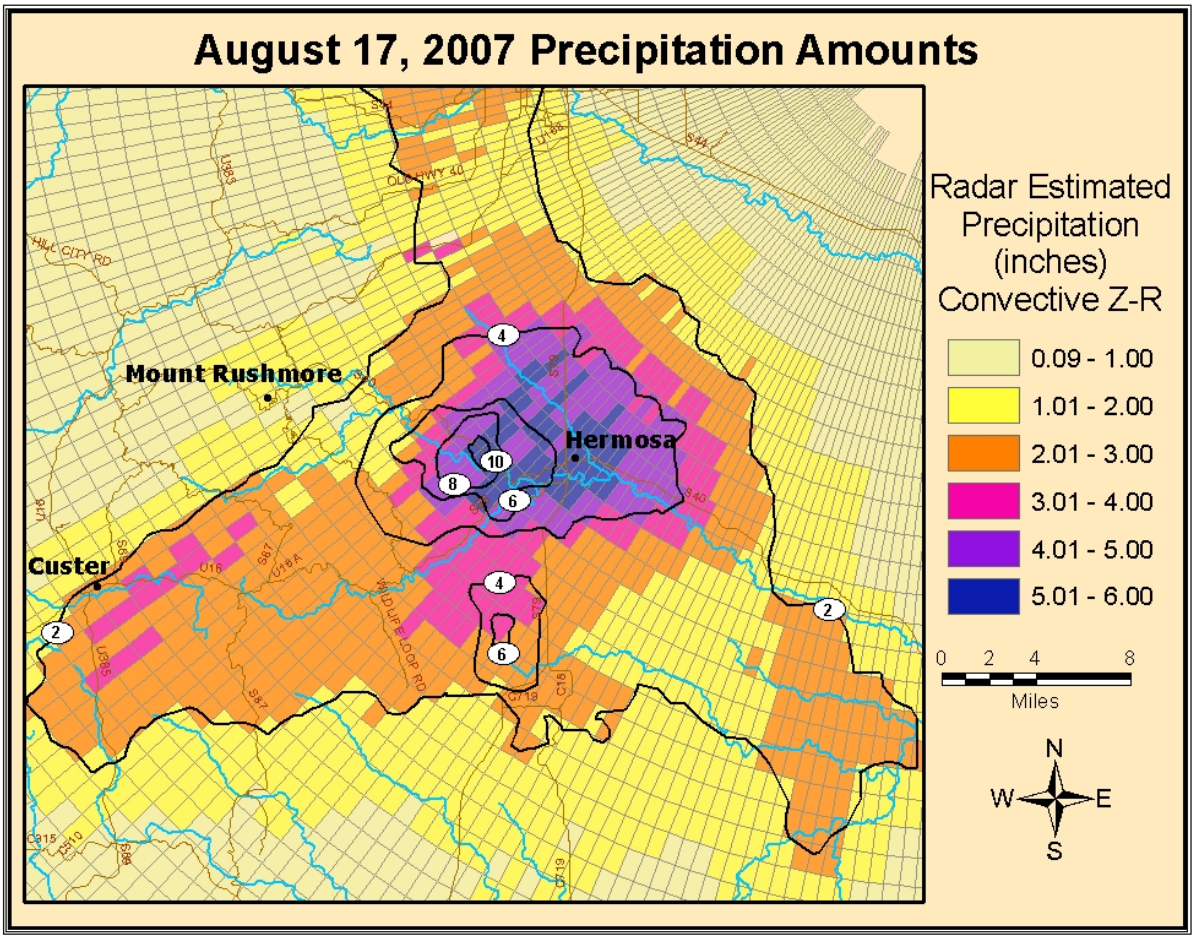

Figure 25. Same as Fig. 24, except rain gage precipitation contours overlaid on radar-estimated precipitation using the convective Z-R relationship. Brown squares indicate radar bin size.

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Latitude	Longitude	Total Rainfall	Rain Gage Type	Remarks
43.77028	-103.39639	3.44	4” plastic	
43.88968	-103.32298	3.50	Not Available	Could not be contacted, estimate is reasonable.
43.78888	-103.29167	3.50	Electronic	Davis Pro
43.79166	-103.28750	3.80	4” plastic	
43.87370	-103.22183	4.00	Not Available	Did not visit, estimate is reasonable
43.83730	-103.16800	4.00	Wedge	
43.80690	-103.21300	4.00	4” plastic	
43.75000	-103.24000	4.18	4” plastic	
43.81435	-103.31603	5.00	Not Available	
43.81600	-103.23360	5.25	5” cylinder	
43.81562	-103.22696	5.25	Wedge	
43.81127	-103.28545	5.25	Not Available	
43.83666	-103.33055	5.33	4” plastic	
43.82758	-103.19905	5.40	Not Available	Did not visit, estimate is reasonable
43.90325	-103.23293	5.50	Wedge	
43.74200	-103.24083	5.50	Electronic	Davis Pro
43.73829	-103.24302	6.00	5” cylinder	Amounts measured and dumped during rain
43.73994	-103.25554	6.10	Not Available	
43.83065	-103.22385	6.50	5” cylinder	Amounts measured and dumped during rain
43.82852	-103.24147	6.50	Wedge	
43.84602	-103.34125	6.50	Pint Jar	Amounts measured and dumped during rain
43.81432	-103.25447	6.50	4” plastic	Automated gage reported about the same amount
43.83435	-103.23062	6.75	8” cylinder	
43.83417	-103.22950	6.75	Electronic	
43.83400	-103.23000	7.00	5” cylinder	
43.82470	-103.30620	8.00	4” plastic	
43.85890	-103.26700	8.50	Not Available	Did not visit, estimate is reasonable
43.85258	-103.27728	10.00	4” plastic	
43.84118	-103.27008	10.44	4” plastic	
43.85176	-103.27446	10.50	4” plastic	

Table 1. Total rainfall for August 17 at miscellaneous gaging stations around Hermosa.

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Date	Time	Product	Comments
8/15/07 Wed	332 AM	Hazardous Weather Outlook	There is a chance of thunderstorms Friday and Friday night. Some storms have the potential to become severe...especially Friday afternoon and evening. Large hail...damaging winds...and heavy rainfall are all possible.
8/15/07 Wed	632 AM	Hazardous Weather Outlook	There is a chance of thunderstorms Friday and Friday night. Some storms have the potential to become severe...especially Friday afternoon and evening. Large hail...damaging winds...and heavy rainfall are all possible.
8/16/07 Thu	333 AM	Hazardous Weather Outlook	There is a slight risk for severe thunderstorms Friday...mainly in the afternoon and evening hours. The main threat for severe weather will be across western South Dakota and northeast Wyoming during the afternoon hours. Then the bulk of severe weather will shift toward the South Dakota plains Friday evening. Large hail...damaging winds...and locally heavy rainfall are all possible.
8/17/07 Fri	618 AM	Hazardous Weather Outlook	There is a slight risk for severe thunderstorms across all of northeast Wyoming and western South Dakota...mainly during the afternoon and evening hours...as an upper level system passes over the area. The main threat for severe weather will be across far western South Dakota and northeast Wyoming during the afternoon hours...then shift east across the South Dakota plains during the evening. Large hail...damaging winds... And locally heavy rainfall can be expected with the stronger storms.
8/17/07 Fri	709 PM	Flash Flood Warning	The national weather service in rapid city has issued a * Flash Flood Warning for... Central Pennington County in west central South Dakota... Northeastern Custer County in southwestern South Dakota... * Until 1015 pm MDT * At 703 pm MDT...Doppler radar indicated very heavy rain from a thunderstorm over the warned area. Flash flooding is expected in the area. * Locations impacted include... Hermosa... Caputa... Farmingdale... Rapid Creek east of Rapid Valley... Spring Creek... Battle Creek... Thunderstorms will continue over the area with another 3 inches of rain possible through 800 pm MDT. If you live along a stream or low lying area...move to higher ground immediately to save your life. Do not wait until the water gets higher.Never try to walk through fast moving water.

Date	Time	Product	Comments
8/17/07 Fri	722 PM	Flash Flood Statement	...A Flash Flood Warning remains in effect until 1015 pm MDT for Custer and Central Pennington Counties... At 719 pm MDT...Doppler radar continued to indicate very heavy rain over the warned area. Flash flooding will continue in the area. Law enforcement has reported Highway 40 was flooded 5 miles west of Hermosa. In the city of Custer...flooding was reported from the junction of Highways 16 and 385 to two miles east of town...north to Montgomery Street...and most of the south end of town. The Custer Airport has received 2.26 inches of rain so far. Thunderstorms will continue over the area with up to another 3 inches of rain possible through 900 pm MDT. Locations impacted include... Custer... Hermosa... Caputa... Farmingdale... Rapid Creek east of Rapid Valley... Spring Creek... Battle Creek... French creek... Custer State Park... If you live along a stream or low lying area...move to higher ground immediately to save your life. Do not wait until the water gets higher. Do not cross bridges or low lying spots covered by water. Vehicles can be swept away by only a foot or two of fast moving water...or the road may be washed out.
8/17/07 Fri	805 PM	Local Storm Report	0720 pm Flash 5 W Hermosa 43.84N 103.29W 08/17/2007 Flood Custer SD Law Enforcement Highway 40 was flooded. 0720 pm Flash Custer 43.77N 103.60W 08/17/2007 Flood Custer SD Law Enforcement Flooding was reported across most of Custer...from the junction of Highways 16 and 385 to 2 miles east of town...north to Montgomery Street...and most of the south end of town.

Date	Time	Product	Comments
8/17/07 Fri	900 PM	Public Information Statement	...Central and Southern Black Hills... Grizzly Bear Creek near Keystone 1.07 Mount Rushmore 1.23 Sheridan Lake / 8NE Hill City 1.29 Victoria Creek Dam 1.62 Battle Creek 5 se Hill City 1.77 Battle Creek near Hayward 2.18 Custer County Airport 3.05 Near Hayward 3.06 Custer State Park 11E Custer 3.44 Battle Creek near Hermosa 3.91 7 SW Hermosa 4.18
8/17/07 Fri	923 PM	Flash Flood Statement	...A Flash Flood Warning remains in effect until 1015 pm MDT for Custer and Central Pennington Counties... At 918 pm MDT...Doppler radar estimated over 5 inches of rainfall has fallen over parts of the warned area. Flooding will continue in the area. Law enforcement has reported that water is up to the bridge on Battle Creek between Highways 36 and 40 on the south end of Hermosa. Debris has been reported on the road. Battle Creek level is at 14.9 feet. Flood stage is 8.0 feet. The Creek should remain above Flood Stage until early morning as runoff continues. If you live along a stream or low lying area...move to higher ground immediately to save your life. Do not wait until the water gets higher. Do not cross bridges or low lying spots covered by water. Vehicles can be swept away by only a foot or two of fast moving water...or the road may be washed out.
8/17/07 Fri	1010 PM	Local Storm Report	0910 pm Flash 1 S Hermosa 43.83N 103.19W 08/17/2007 Flood Custer SD Law Enforcement Battle Creek flowing over Highway 79. Flood crest was 14.9 feet at 900 pm MDT.
8/18/07 Sat	1050 AM	Local Storm Report	1000 am Heavy Rain 7 W Hermosa 43.84N 103.33W 08/18/2007 m5.33 inch Custer SD NWS Employee

Table 2. Products issued by the National Weather Service 17 and 18 August 2007.

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