

REVISITING THE SPENCER TORNADO OF 1998

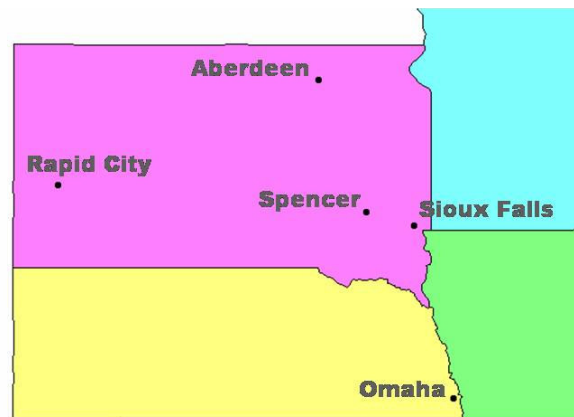
Jay Trobec

Chief Meteorologist, KELO-TV
Sioux Falls, South Dakota

[adapted from The Spencer, SD Tornado of 30 May 1998, presented by the author at the 23rd National Weather Association Annual Meeting in Oklahoma City, OK 19 October 1998]

Abstract

On 30 May 1998, a series of tornadoes formed over southeastern South Dakota. The strongest of these, one which would later be classified an F-4, swept through and destroyed the town of Spencer. Because it was the second-deadliest tornado of the 20th century in South Dakota, it deserves another look – with special attention to the way thermodynamic profiles evolved on the day of the event.



1. Introduction

Before the tornado, Spencer had been a town of 320 people located 45 miles northwest of Sioux Falls, South Dakota. It was a farming community, and many of the residents were elderly. The trees in town were mature and sturdy. The houses were mostly wooden frame construction. There was an old water tower in the center of town.

Figures 1a and 1b are video pictures of what parts of Spencer looked like in 1997. Nothing seen in these pictures existed after the tornado struck at 8:40 p.m. local time that Saturday in 1998.

Figures 2a and 2b are video pictures from the following day, Sunday 31 May 1998. That is the day news of the Spencer tornado appeared on most of the national broadcast networks.

The storm killed six people, and injured more than one hundred. Only six of Spencer's 190 buildings were spared total destruction. A few days after the tornado, volunteers searched for photographs and other family keepsakes, and then the area was bulldozed.

2. Preparations for the storm

Severe storms were already well anticipated one day prior to the tornado. The Storm Prediction Center (SPC) had placed eastern South Dakota in an area of moderate risk for severe weather development.

At the daily map briefing at WSFO (Weather Service Forecast Office) Sioux Falls, there was consensus that severe weather was going to occur in the area the next day. There was good model agreement about a strong surface low developing, and the moisture conveyor belt was in place. A jet streak was forecast to approach from the southwest. Additional staff was placed on-call for weekend duty at the weather service.

The WSFO issued a strongly worded special statement that evening, warning of the potential for severe weather the following day.

The morning of the Spencer tornado, there were severe thunderstorms in the northeastern corner of South Dakota. These thunderstorms resulted in warnings being issued between 4:00 and 7:00 a.m. CST (0800 UTC-1200 UTC) by WSFO Aberdeen. The storms occurred about one hundred miles northeast of Spencer, and preceded the tornadoes by 14 hours. Outflow from the old thunderstorms may have contributed to the Spencer tornado, but

any boundaries created were rather discrete. The SPC suggested that an early morning thunderstorm in NE Nebraska and western Iowa might have created mesoscale outflow that would affect the Spencer supercell (fig. 3). As the predawn thunderstorms fired up, WSFO Sioux Falls issued another special statement on the NOAA weather wire:

TTAA00 KFSD 300937
SDZ038>040-050-052>071-IAZ001>003-012>014-020>022-031-032-MNZ071-072-
080-081-089-090-097-098-NEZ013-014-302100-

SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE SIOUX FALLS SD
435 AM CDT SAT MAY 30 1998

...MODERATE RISK OF SEVERE WEATHER TODAY...SOME THIS MORNING AND
SOME THIS EVENING...

SATURDAY SHOULD SHAPE UP TO BE AN ACTIVE DAY ACROSS SOUTHEAST SOUTH DAKOTA...NORTHWEST IOWA...SOUTHWEST MINNESOTA...AND NORTHEAST NEBRASKA. IT APPEARS THAT SEVERE WEATHER WILL COME IN TWO PUNCHES. THE FIRST IS EXPECTED TO OCCUR IN THE PREDAWN AND MORNING HOURS. A CLUSTER OF THUNDERSTORMS FED BY A MOIST AND UNSTABLE AIR FLOW OVER A NEARLY STATIONARY WARM FRONT ALONG THE SOUTH DAKOTA AND NEBRASKA BORDER WILL SLIDE FROM SOUTH CENTRAL THROUGH SOUTHEAST SOUTH DAKOTA BY MID MORNING. THE PRIMARY THREAT FROM THESE THUNDERSTORMS WILL BE LARGE HAIL AND DAMAGING WIND...AND A SEVERE THUNDERSTORM WATCH IS IN EFFECT FOR MUCH OF CENTRAL AND EASTERN SOUTH DAKOTA AND ADJOINING NEBRASKA UNTIL 10 AM CDT.

THE SUN IS EXPECTED TO EMERGE DURING THE DAY BEHIND THIS CLUSTER AS THE WARM FRONT MOVES SLOWLY NORTHWARD...WITH MUCH OF THE AREA EXPECTED TO HEAT INTO THE 80S BY LATE AFTERNOON...WITH AROUND 90 DEGREES FOR NORTHEAST NEBRASKA AND ACROSS MUCH OF NORTHWEST IOWA. AN AREA OF LOW PRESSURE WILL RIPPLE EAST ALONG THE FRONT AND MOVE INTO CENTRAL SOUTH DAKOTA THIS AFTERNOON AND EASTERN SOUTH DAKOTA THIS EVENING. ADDITIONAL THUNDERSTORMS WILL FIRE UP WITH THE APPROACH OF EVENING FROM CENTRAL TO NORTHEAST SOUTH DAKOTA...AND MAY BECOME SEVERE THIS EVENING WITH LARGE HAIL AND DAMAGING WIND WHILE SLAMMING ACROSS THE FOUR STATE AREA.

By 6 a.m. local time (1100 UTC), a surface low was located over central South Dakota, with Spencer and southeastern South Dakota in the warm sector. Dew points were already in the 60's °F (16-19 °C) in the Northern Plains, which is very unusual for an early morning in May (fig. 4).

Seven hours later, the daily Significant Weather Outlook issued by the Sioux Falls WSFO spelled out the severe threat:

```
SDZ038>040-050-052>071-MNZ071-097-098-IAZ001-NEZ013-310500-
AURORA-BEADLE-BON HOMME-BROOKINGS-BRULE-CHARLES MIX-CLAY-DAVISON-
DOUGLAS-GREGORY-HANSON-HUTCHINSON-JERAULD-KINGSBURY-LAKE-LINCOLN-
MC COOK-MINER-MINNEHAHA-MOODY-SANBORN-TURNER-UNION-YANKTON-LINCOLN-
PIPESTONE-ROCK-LYON-DIXON-
INCLUDING THE CITIES OF...BROOKINGS...CHAMBERLAIN...HURON...MITCHELL...
SIOUX FALLS...YANKTON...LUVIERNE...PIPESTONE...ROCK RAPIDS
1147 AM CDT SAT MAY 30 1998

FORECAST THROUGH MIDNIGHT:
THUNDERSTORMS ARE LIKELY TO REDEVELOP LATE THIS AFTERNOON OR EARLY
THIS EVENING.

* SIGNIFICANT WEATHER:
SEVERE WINDS (GUSTS EQUAL TO OR GREATER THAN 58 MPH)
LARGE HAIL (EQUAL TO OR GREATER THAN 0.75" DIAMETER)
TORNADOES POSSIBLE
```

3. Upper air analysis

Conditions in the middle to upper troposphere were favorable for severe weather development.

250 mb level - Even at this synoptic scale, the flow and wind barbs seem to be pointing at Spencer. The 12z analysis (fig. 5) shows a tight gradient in the heights between 10680 and 10720 meters. This thin band shows strongest SW winds along the southern California coast (120 knots at Edwards Air Force base), but strong winds prevail right through the southwestern US. A plot of the jet streak (fig. 6) suggests that South Dakota will be in the left-front quadrant of the jet streak later in the day, a good setup for vertical motion and severe development. A large path of jet speed winds greater than 75 knots is already in place the morning of the event.

The jet stream has flattened by 0000 UTC (fig. 7) and the core of the jet streak (> 100 knots) runs from Salt Lake City (SLC) east-northeast toward the South Dakota-Nebraska border. Again, the setup is "aiming" just south of Spencer.

500 mb level - The analysis of the 12z map (fig. 8) from the morning of the tornado shows a strong SW flow. This will bring dry cT air into the mid-levels of the atmosphere over South Dakota. The gradient of height contours is tight, showing the strength of the flow.

Winds in excess of 50 kts are already being measured at Salt Lake City and Riverton, WY (RIW).

Twelve hours later, just before the touchdown of the Spencer tornado, the 0000 UTC (31 May 1998) soundings showed the SW flow into the area remained strong. The 500 mb temps over South Dakota were still -12°C to -14°C . The pool of cold air was in contrast to the hot temperatures at the surface, and the steep lapse rate provided great vertical acceleration for parcel ascent. Winds at 500 mb did strengthen by 0000 UTC, with a large area of 50+ knots over the upper Midwest (fig. 9). Fifty knot flow at that level is often a precursor to tornado development in the Northern Plains.

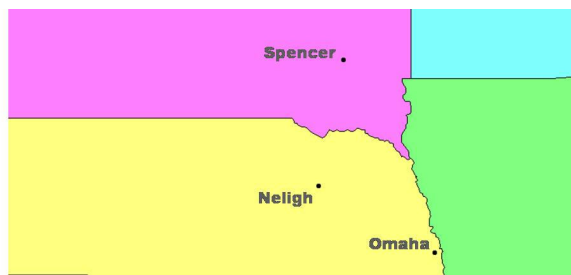
850 mb level - On the 1200 UTC map (fig. 10), southeastern South Dakota is clearly experiencing significant warm air advection on the morning of the tornado. The area is in the exit region of the trough in pressure contours, and is in a place where the isotherms are crossing the isohypses in a nearly perpendicular fashion. The 850 temperature gradient is significant upstream, with 17°C at North Platte, NE (LBF) and 27°C a short distance away at Dodge City, KS (DDC).

By 0000 UTC (fig. 11) the warming of the day has strengthened the warm air advection. The 30°C isotherm has reached into northern Kansas, and the 25°C line is now running through the middle of Nebraska. These lines are again perpendicular to the height contours. WAA is also setting up over Iowa and Illinois, which experienced severe weather the following day.

4. Soundings and profilers

Spencer is not very close to any of the radiosonde launch locations. The closest are ABR-Aberdeen (too far north of the warm front) and RAP-Rapid City (to the west, in a much different air mass behind the cold front). The most applicable sounding is OAX (Omaha-Valley), because although it is 155 miles SE of Spencer, it was the nearest sounding sampling the warm sector air mass (fig. 12).

Like Spencer, OAX had SE winds at the surface, veering with height. Besides directional shear, speed shear is evident, with wind speeds reaching 100 knots at the 200 mb level. Dew point depressions at the 700 mb to 500 mb level show the dry, continental tropical (cT) air that intruded the column, further destabilizing the air mass.



Here are the parameters derived from the special 1800 UTC balloon launch from OAX, along with generally accepted interpretations:

Convective Available Potential Energy (CAPE): 3343 J/kg (very unstable-significant potential energy).

K-Index: 31 (60-80% probability of thunderstorms).

Total Totals (TT): 56 (numerous thunderstorms, scattered severe, scattered tornadoes)

Convective Inhibition (CINH): -5 J/kg (minimal, little heating or convergence required to break cap).

Lifted Index (LI): -10 C (very unstable-heavy to strong thunderstorm potential).

While the OAX lifted index was -10, the GOES-8 satellite sounder data derived over the Spencer area indicated an LI of -12 °C to -15 °C at 2346 UTC, as well as a significant Total Precipitable Water (TPW) of 46-48 mm at that same time (CIMSS, 1998).

A better source for wind data would have been the wind profiler located at Neligh, Nebraska. Unfortunately, there was apparently an equipment malfunction the day of the Spencer tornado.

But after looking at wind data from around the Midwest, it appears that the nose of the low-level jet associated with the synoptic scale cyclone was well to the east, over the state of Iowa. The Slater profiler in central Iowa detected 35 knot winds at the 850 mb level from 2200 UTC through the hour after the Spencer tornado. Those winds were from a southwesterly direction.

5. Surface analysis

At 1 p.m. central standard time (1800 UTC) the surface low was located near Pierre (PIR), where the pressure had fallen 0.7 mb in the last hour, to 1001.3 mb (fig. 13). A frontal boundary separates temperatures in the 70's (°F) to the north from temps in the 80's (°F) farther south. A dry line is forming in the panhandle of Nebraska, as evidenced by a dew point of 48 °F at Chadron (CDR) and of 35 °F at Alliance (AlA). This dry line will drift east during the day and be the focusing mechanism for severe weather.

By 3 p.m. (2000 UTC) Alliance, Chadron, Pine Ridge (IEN), Scottsbluff (BFF), and Sidney (SNY) all have dew points in the 30's (°F), while the rest of Nebraska has dew points in the 60's to low 70's (°F). Meanwhile, a tongue of moist air has brought dew points of 70 °F to Winner (SFD) and Chamberlain (9V9) in south central South Dakota (fig. 14).

The 2200 UTC map (fig. 15) shows some thermal changes starting to take place. At Rapid City (RAP), winds have become northwesterly at 35 mph, and the temperature has dropped ten degrees in one hour due to the apparent cold front passage. Meanwhile, daytime solar heating is taking place, as SFD and 9V9 have both exceeded the 90 °F mark. Surface air pressure in Pierre has dropped to 999.1 mb.

The dry line continues its easterly drift on the 0000 UTC 31 May 1998 map (fig. 16). It has already passed SFD and ANW, where the dew points have dropped suddenly (22 °F in two

hours at ANW, even though the air temperature has remained the same). By this time, a squall line of thunderstorms has already formed in central through south central South Dakota. Like the surface low, they will drift in an east-southeasterly direction.

The 0200 UTC map (fig. 17) is the closest time period to the Spencer touchdown. The surface low has sagged just to the west of Spencer (west of Mitchell, station MHE). The dry line has pulled through O'Neill (ONL), dropping its dew point by 22 °F in two hours. MHE is also feeling the effects of the dry line/cold front, with a temperature drop and dew point drop of 7 °F since the previous map. The triple point is now only a few miles from Spencer. The town is experiencing baroclinicity from the dry line/front, and tornadoes are starting to form to the west.

6. Radar imagery

The closest WSR-88D radar to Spencer is at Sioux Falls airport (FSD). It was in precipitation mode, with volume scans completed approximately every five minutes.

The 88-D picked up the mesocyclone when it was north of Mitchell. A shear marker [radar image 1] on the storm relative velocity product at lowest tilt angle, shows the area with a maximum wind speed (with storm motion factored out) of 82 knots. Twenty-eight minutes later [radar image 3], the same product was tracking two mesocyclones, with the one north of Farmer, directly NW of Spencer, clocked at 122 knots. The next volume scan [radar image 4] shows the 88-D's tornado vortex signature algorithm was triggered by the meso just outside Spencer. By this time, warnings had already been issued. The touchdown in Spencer occurred about ten minutes later [radar images 7 and 8].

The base reflectivity series [radar images 9-16] shows an interaction between storms that may have provided a significant trigger for the Spencer tornado. The first image [radar image 9] shows a meso cyclone north of MHE, with a hook echo apparent [radar image 10]. But farther west there are three cells (more are visible if you use a composite of other radars in the area) in a squall line. As time goes along, the squall line moves east faster than the meso cyclone near MHE. In fact, when the meso near MHE forms a rear flank downdraft, the

existing squall line merges with it. This merger may be the reason for the F -4 to strike Spencer.

Because of "radar myopia," it would have been easy to neglect the importance of the squall line of thunderstorms because the operator would have been paying more attention to the bigger mesocyclone near Spencer. Warnings had been issued several minutes before the merger, but this interaction seems to have kicked the mesocyclone into violent tornado status.

7. Alerting the public

Zone public forecasts issued during the day for the Spencer area consistently mentioned the risk of severe weather. At 3:50 p.m. local time, the SPC issued a Tornado Watch which included Spencer and southeastern South Dakota.

A Tornado Warning was issued for northern Hanson County (adjoining Spencer, which is located along the county line) at 8:12 p.m. Another Tornado Warning was issued

for northern McCook County (Spencer area) at 8:32 p.m. KELO-TV, the dominant television station in the state, broadcast that warning and showed a lowest-level tilt picture from its own Doppler radar which clearly indicated a hook echo suggesting

tornado presence. Using the station's extrapolation software, the on-air meteorologist said the tornado would be in Spencer around 8:42 [video clip].

Largely unknown to the WSFO, there were many professional storm chasers in the Spencer area at the time of the tornado. The weather service reports that with few exceptions, the chasers did not report what would have been valuable information (visual

confirmation of a tornado on the ground). The McCook County sheriff called in his sighting when the tornado was one mile west of town.

Several residents of Spencer reported seeing the warnings on television, but many of them failed to take cover. Some said they did not believe the warning because they did not

hear a civil defense siren. The siren did not sound because of a power outage caused by the storm.

The same supercell that created the Spencer twister also spawned other, less severe tornadoes as it moved southeast.

This is a map (adapted from Brian Smith, WSFO Omaha-Valley, NE) showing the path of touchdowns from five suspected tornadoes. Other than Spencer, the rest of the tornado damage was rated F-0 to F-2. Note that the paths are generally NW to SE, while most tornadoes in this region move SW to NE.

Downdrafts from these storms produced outflow boundaries that caused windstorm damage in southwest Minnesota and northwest Iowa later that evening. Similar synoptic conditions created severe thunderstorms in other parts of the Upper Midwest the remainder of that night. But by far the strongest of the storms was the one that destroyed the town of Spencer.

8. Conclusions

1. it was not not diurnally favored... 8:40 pm
2. low level jet not in play... too far east

References

CIMSS (Cooperative Institute for Meteorological Satellite Studies), cited 1998: 30 May 1998 – Tornado outbreak in South Dakota [currently available online at <http://cimss.ssec.wisc.edu/goes/misc/980530.html>].

National Weather Service, Sioux Falls, SD (WSFO-FSD), NOAA Weather Wire 1998: Special Weather Statement and Severe Weather Outlook, 30 May 1998.

- NOAA Hydrometeorological Prediction Center (NOAA-HPC), 1998: Daily Weather Map. [archive maps available online at <http://www.hpc.ncep.noaa.gov/dwm/dwm.shtml>].
- NOAA Storm Prediction Center (NOAA-SPC), cited 2003: Preliminary Local Storm Reports. [Available online at <http://www.spc.noaa.gov/climo/>].
- Rasmussen, Erik N. 2003: Refined Supercell and Tornado Forecast Parameters. *Weather and Forecasting*. Vol. 18, No. 3, pp. 530–535.
- Thompson, Rich, cited 2003: Explanation of SPC Severe Weather Parameters. [Available online at <http://www.spc.noaa.gov/sfctest/s2/>].
- Wakimoto, Roger M., Hanne V. Murphey, David C. Dowell, Howard B. Bluestein: The Kellerville tornado during VORTEX: Damage survey and Doppler radar analyses, 2003. *Monthly Weather Review*, Vol. 131, Iss. 10, pg 2197.
- Wolf, Ray A., 2000: Observations of a tornadic and non-tornadic circulation near the KDVN WSR-88D associated with the 18 June 1998 squall line. Preprints, *20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., pg 7.2.



Fig. 1a. 1997 video picture of Spencer, as seen from Interstate 90 one mile south of town (KELO-TV).

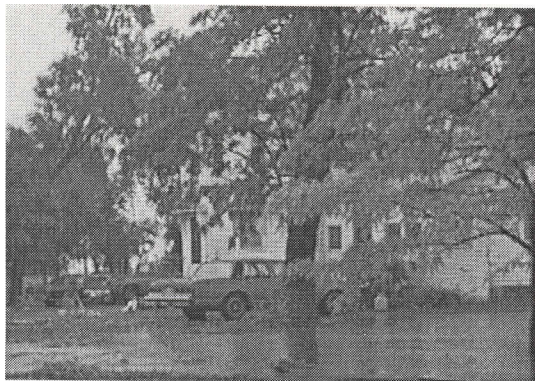


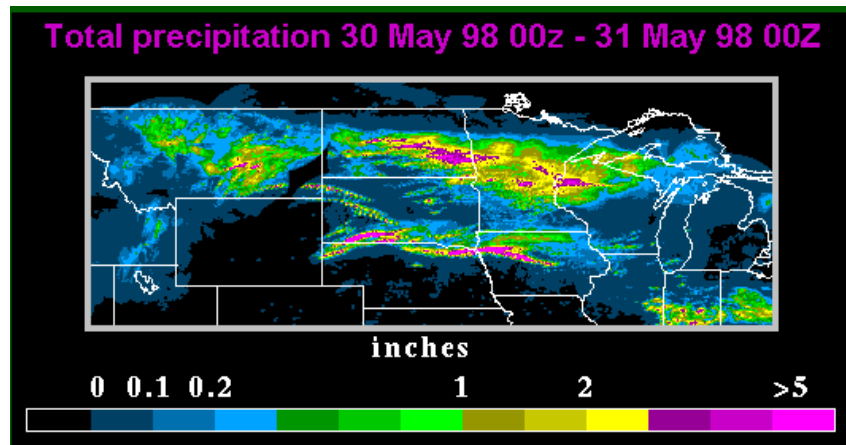
Fig. 1b. Typical homes and foliage in Spencer before the tornado (KELO-TV).



Fig 2a. Aerial view of Spencer, after the tornado (KELO-TV).



Fig. 2b. Signature photo of downed water tower, 31 May 1998 (KELO-TV).



North-central US 24-hour precipitation from 00Z May 30 (7 pm CDT May 29) to 00Z May 31 (7 pm CDT May 30). Note that this would not include the Spencer supercell. Two prominent streaks of precipitation are mapped near the NE/SD border. The western one, across the Pine Ridge area near Chadron NE, is associated with passage of several thunderstorms during the evening of the 29th. [Those storms evolved from low-precipitation (LP) supercells which formed near the dryline, near the WY/NE border, on May 29.] Wet ground in this area appears to have temporarily hampered the vertical mixing and eastward progress of a small part of the dryline on May 30. This is evident in the [much higher surface dew points at CDR and IEN sites at 17Z](#) (non CDT), after the westerly wind shift elsewhere associated with the dryline.

The eastern streak was created by the morning/early afternoon [supercell across northeast NE and IA](#). This storm produced an outflow boundary which may have influenced mesoscale conditions leading to the Spencer tornado. Rainfall data and map scale courtesy NASA.

Fig. 3. SPC precipitation map indicating wet ground over much of southern South Dakota in the hours preceding the Spencer tornado. (Available online at <http://spc.noaa.gov/misc/spencer/rainmap.htm>)

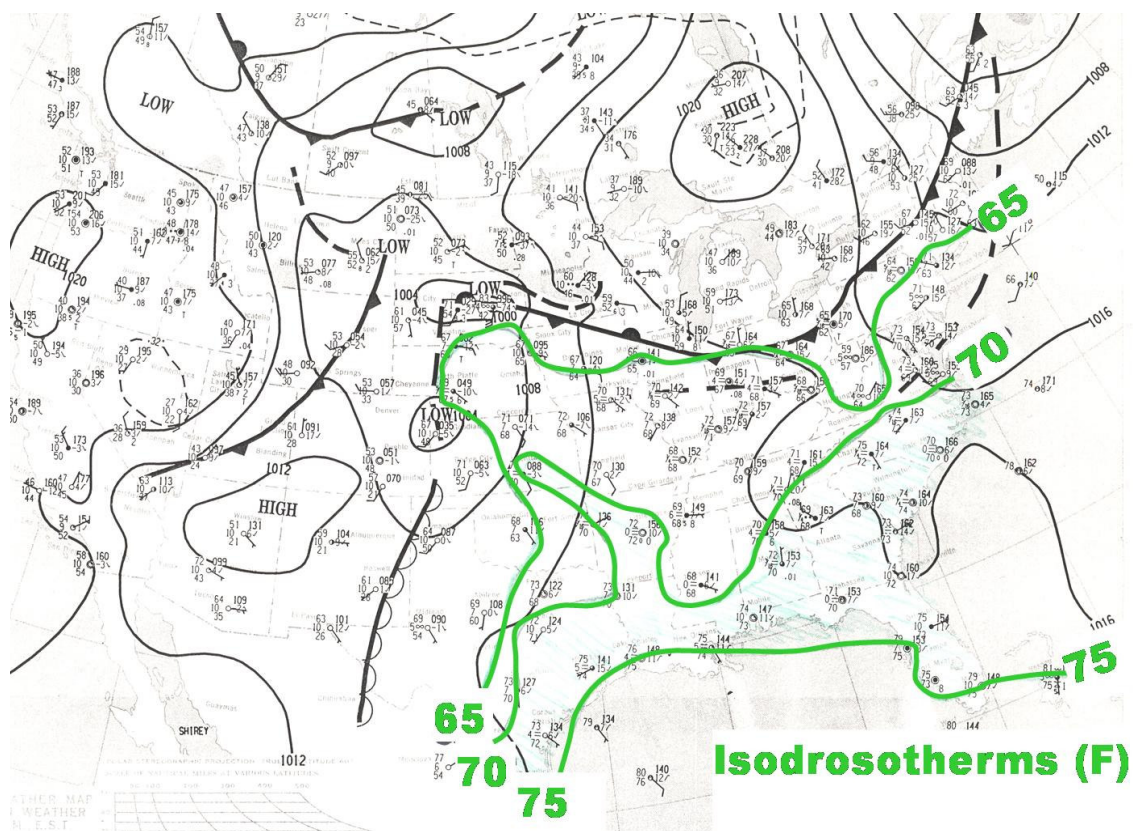


Fig. 4. Hand analysis of dew points ($^{\circ}\text{F}$) on Daily Weather Map, 1200 UTC 30 May 1998. Note the moisture tongue streaming into the surface low over central South Dakota.

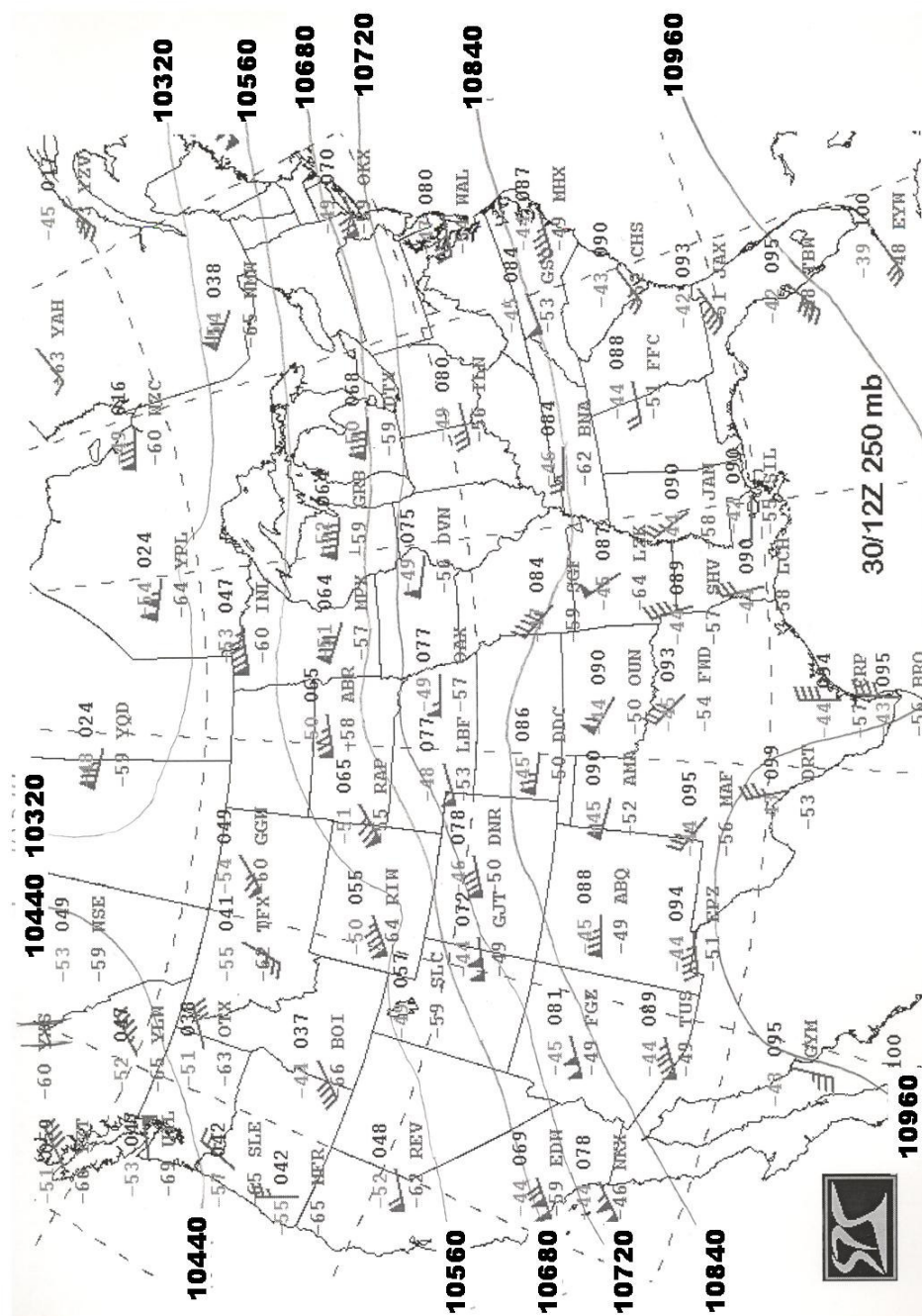


Fig. 5. Hand analysis of 250 mb heights, in meters, 1200 UTC 30 May 1998.

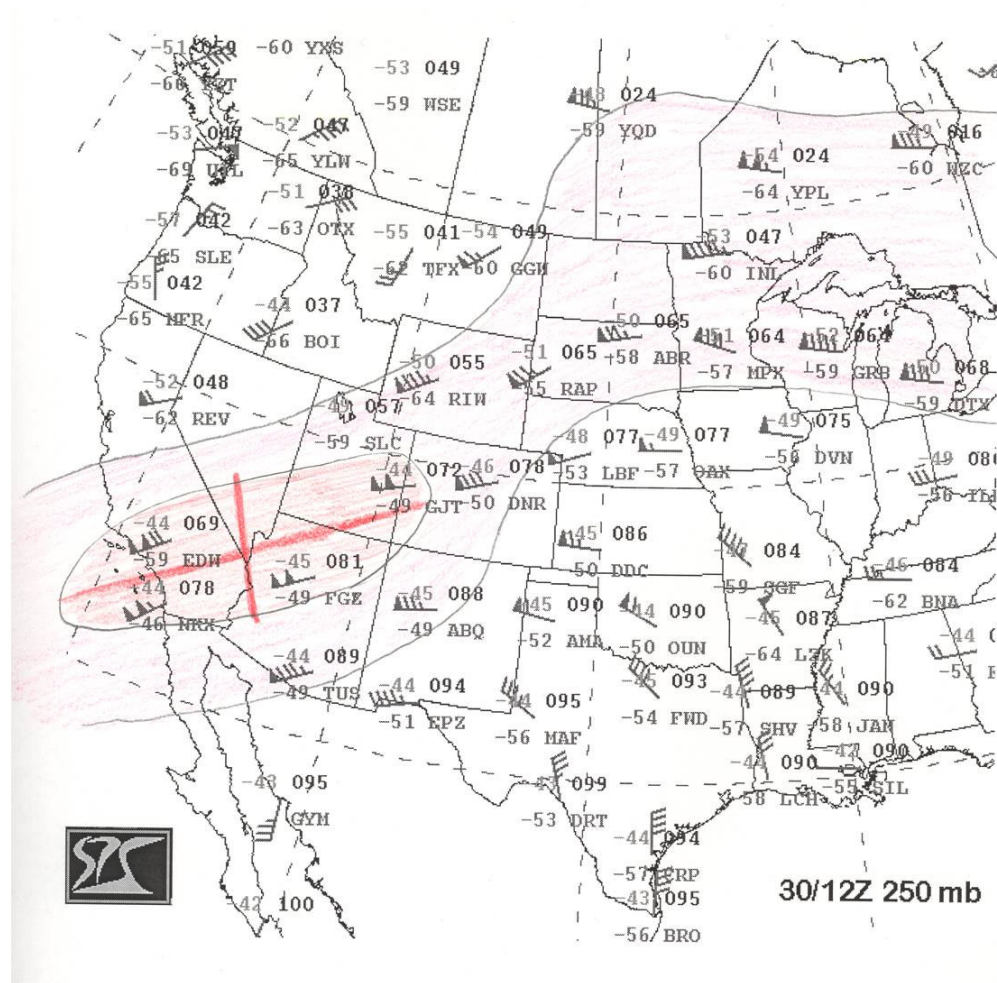


Fig. 6. Hand analysis of 250 mb winds, in knots, 1200 UTC 30 May 1998. Winds in excess of 100 knots are highlighted.

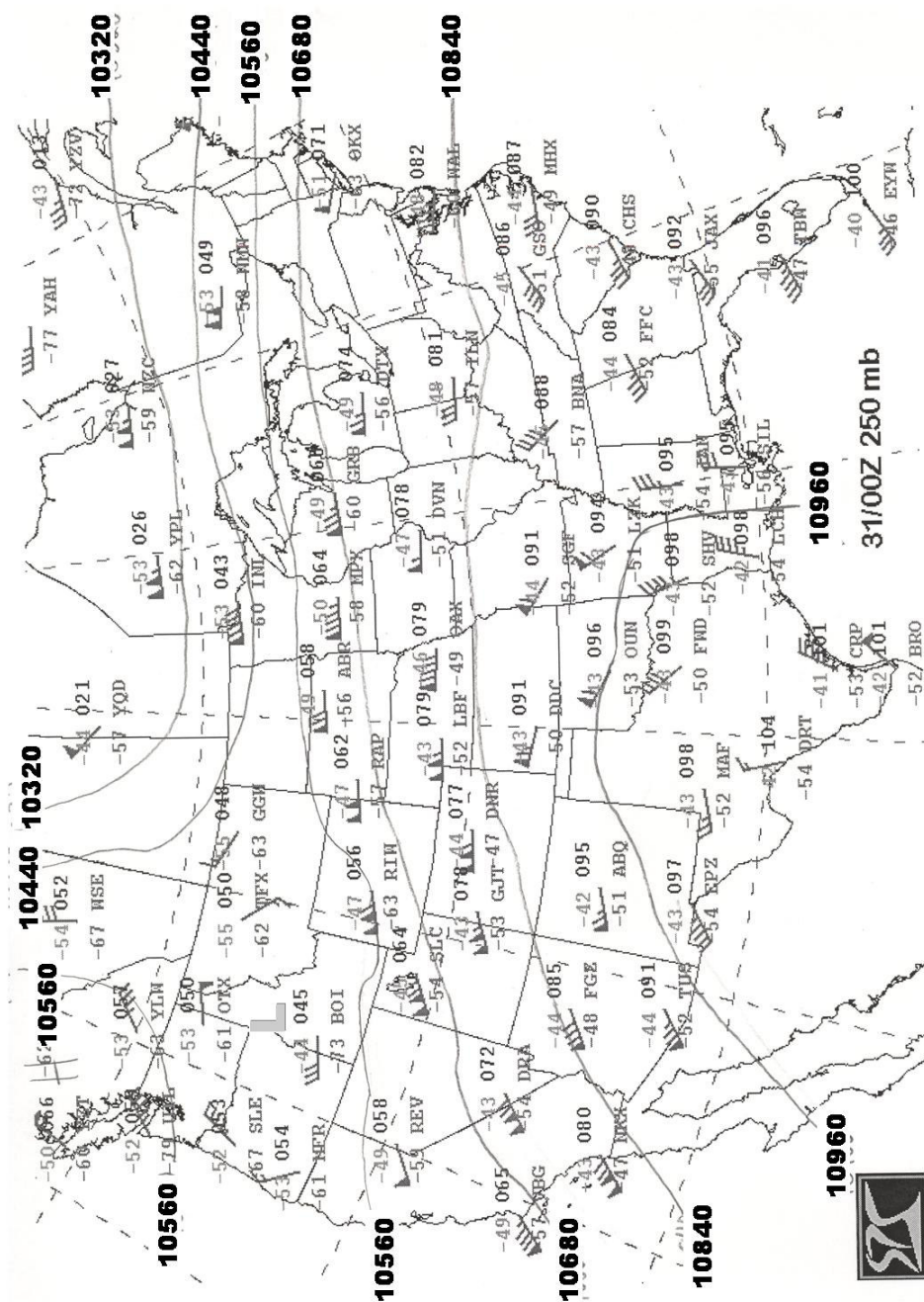


Fig. 7. Hand analysis of 250 mb heights, in meters, 0000 UTC 31 May 1998 (one hour before the Spencer tornado).

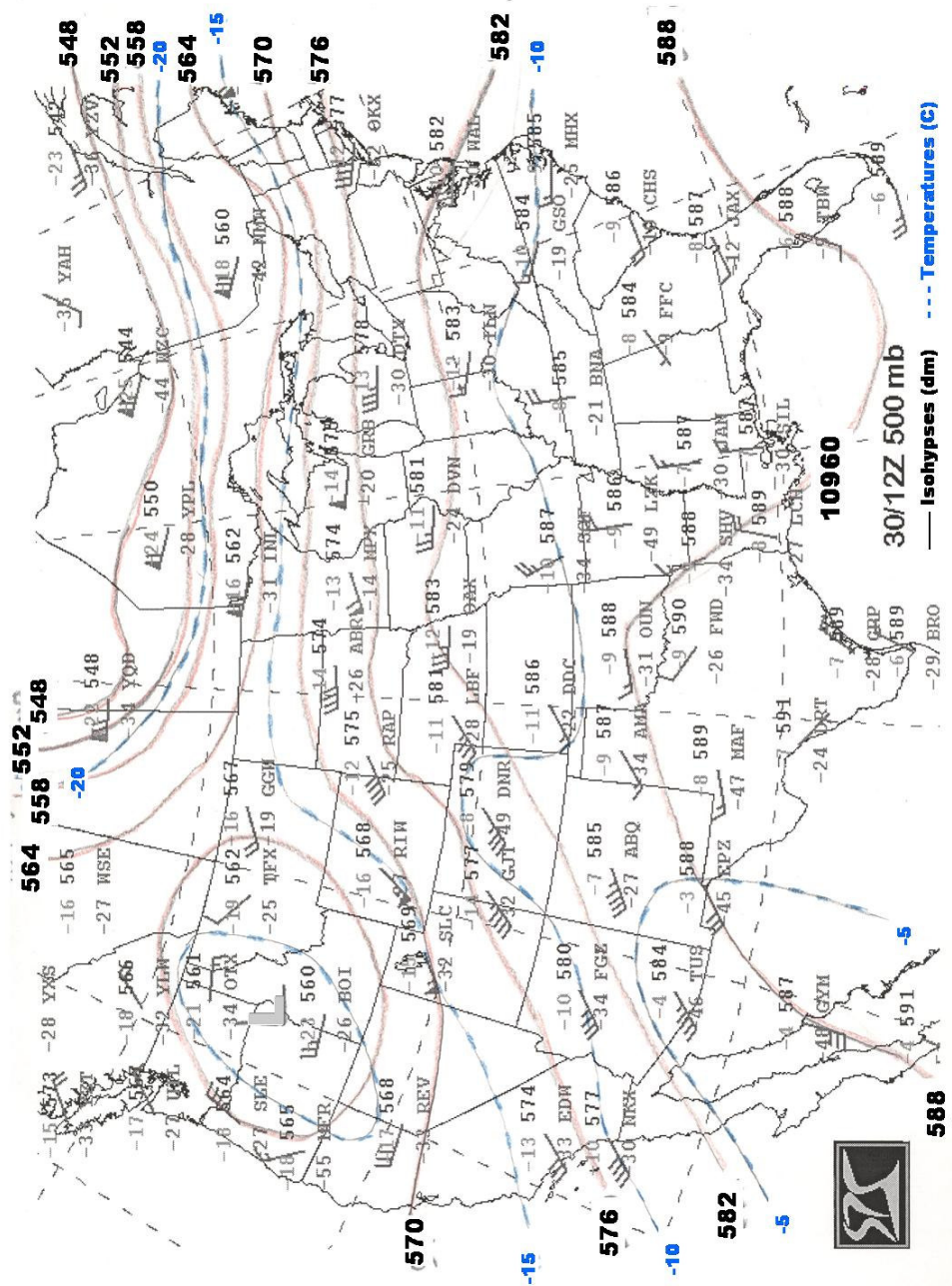


Fig. 8. Hand analyzed 500 mb map, effective 1200 UTC 30 May 1998. Heights are solid lines, temperatures are dashed.

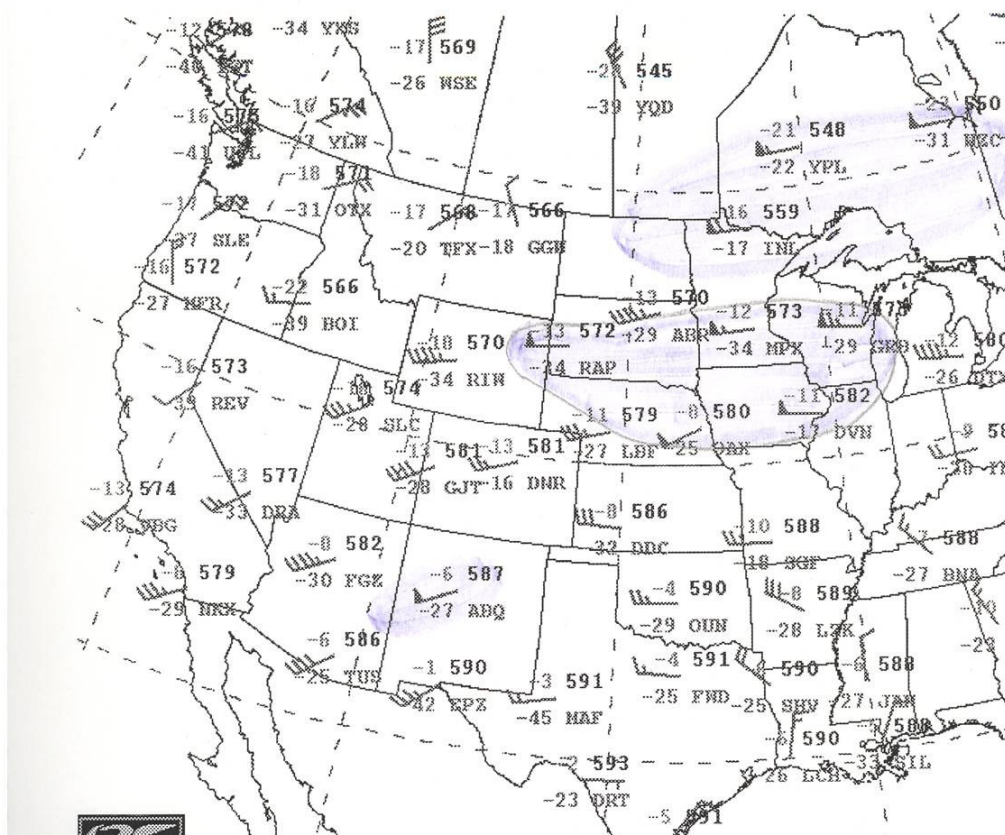


Fig. 9. Hand analysis of 500 mb wind flow, 0000 UTC 31 May 1998.

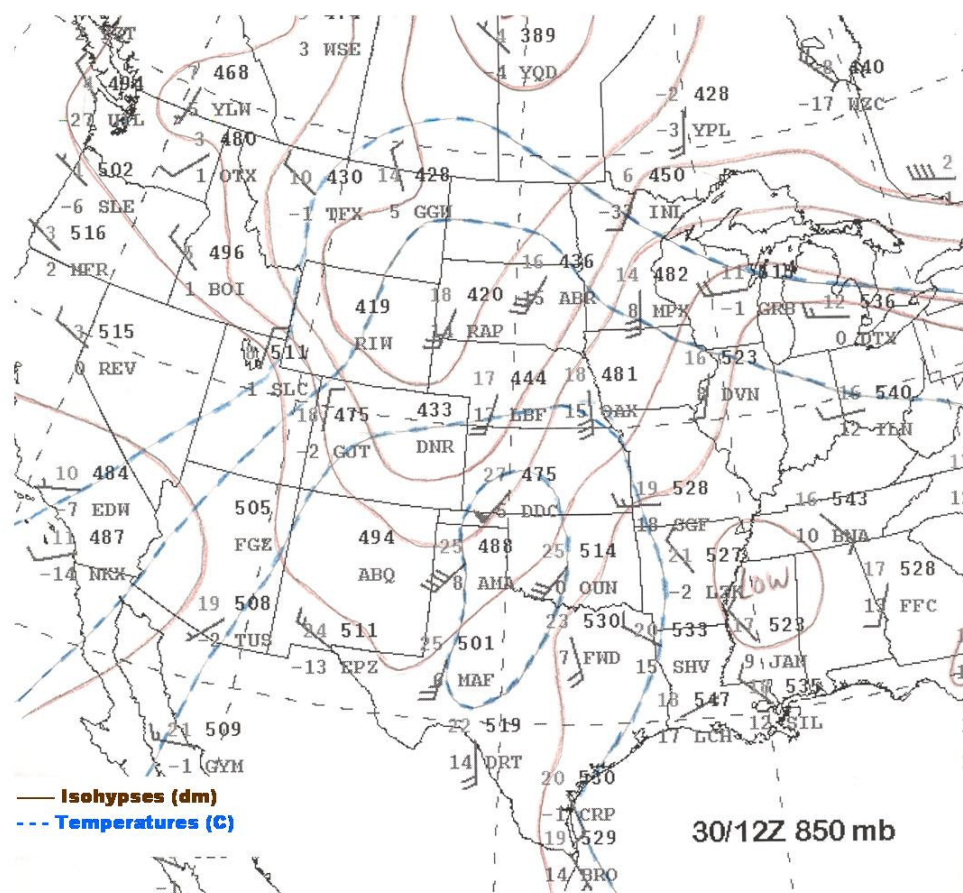


Fig. 10. Hand analysis of 850 mb heights and temperatures, 1200 UTC 30 May 1998.

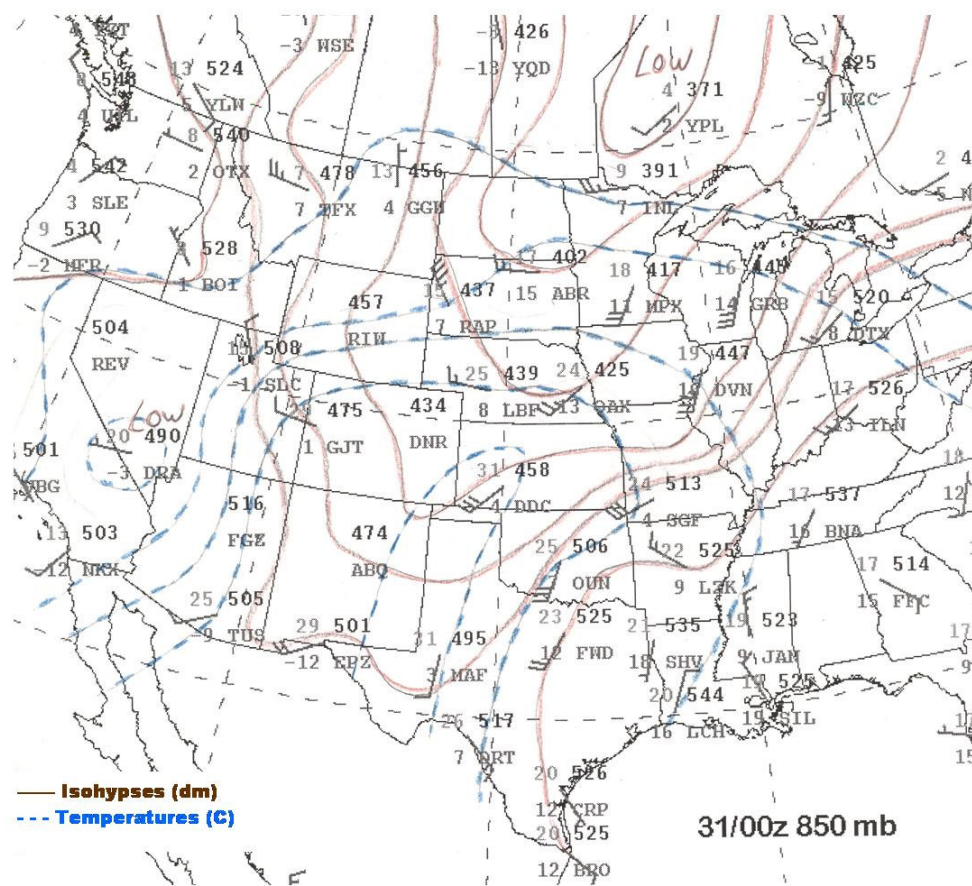
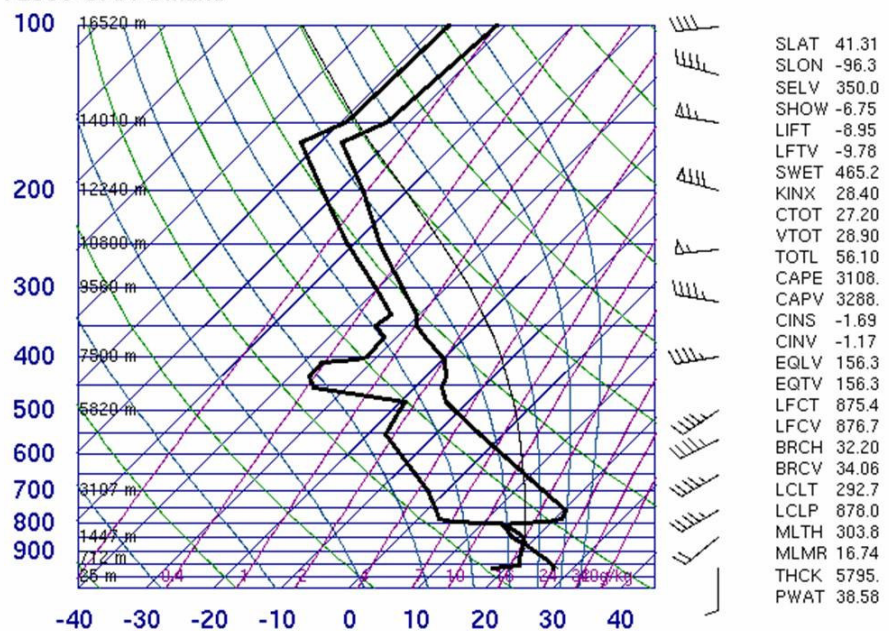


Fig. 11. Hand analysis of 850 mb heights and temperatures, 0000 UTC 31 May 1998.

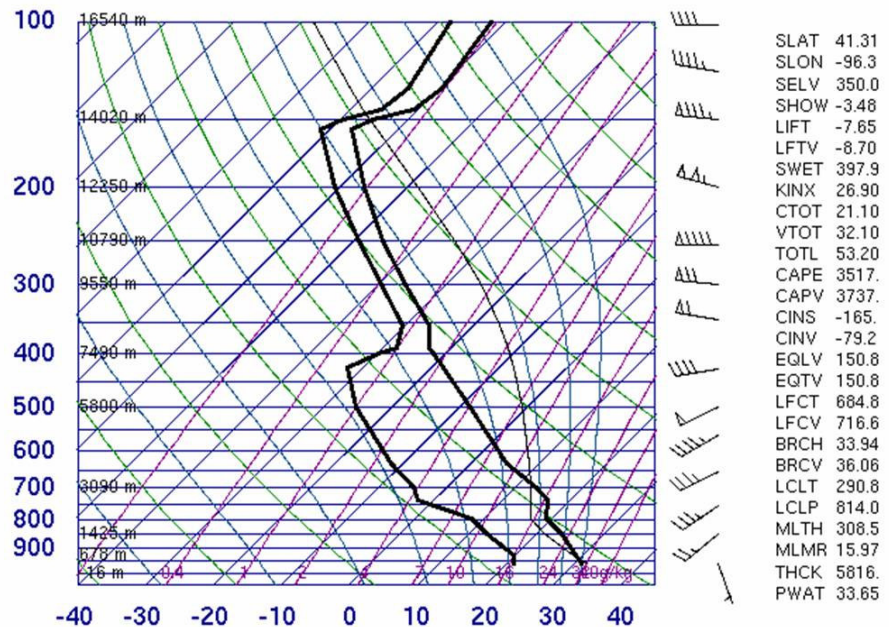
72558 OAX Omaha



18Z 30 May 1998

University of Wyoming

72558 OAX Omaha



00Z 31 May 1998

University of Wyoming

Fig. 12. Skew T -log p display of balloon soundings from Omaha, 1800 UTC 30 May 1998 and 0000 UTC 31 May 1998. (University of Wyoming archives, available online at <http://www.weather.uwyo.edu/upperair/sounding.html>)

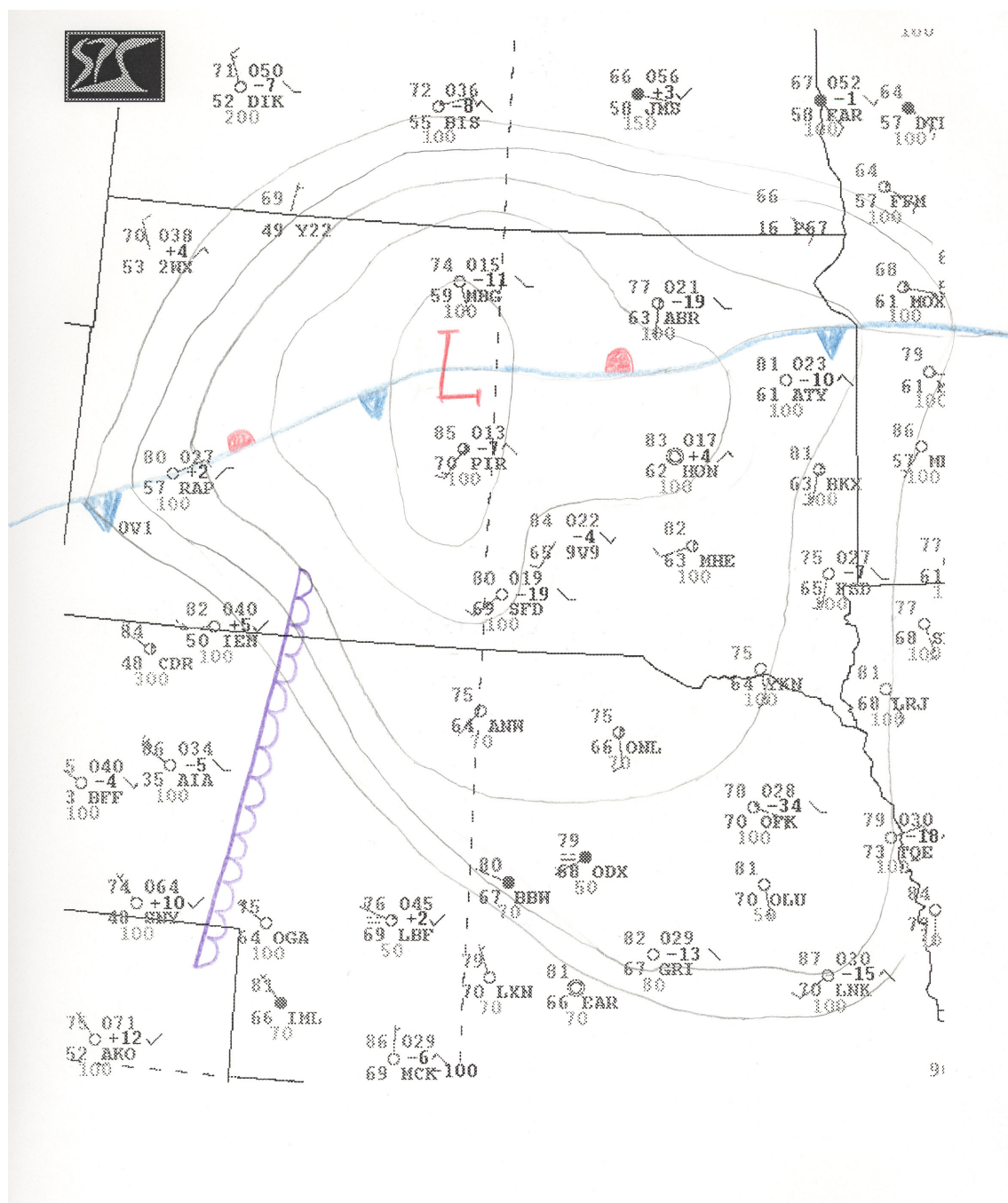


Fig. 13. Hand surface analysis, 1800 UTC. Note dry line in the panhandle of Nebraska. Spencer is approximately 25 miles (40 km) east of Mitchell (MHE).

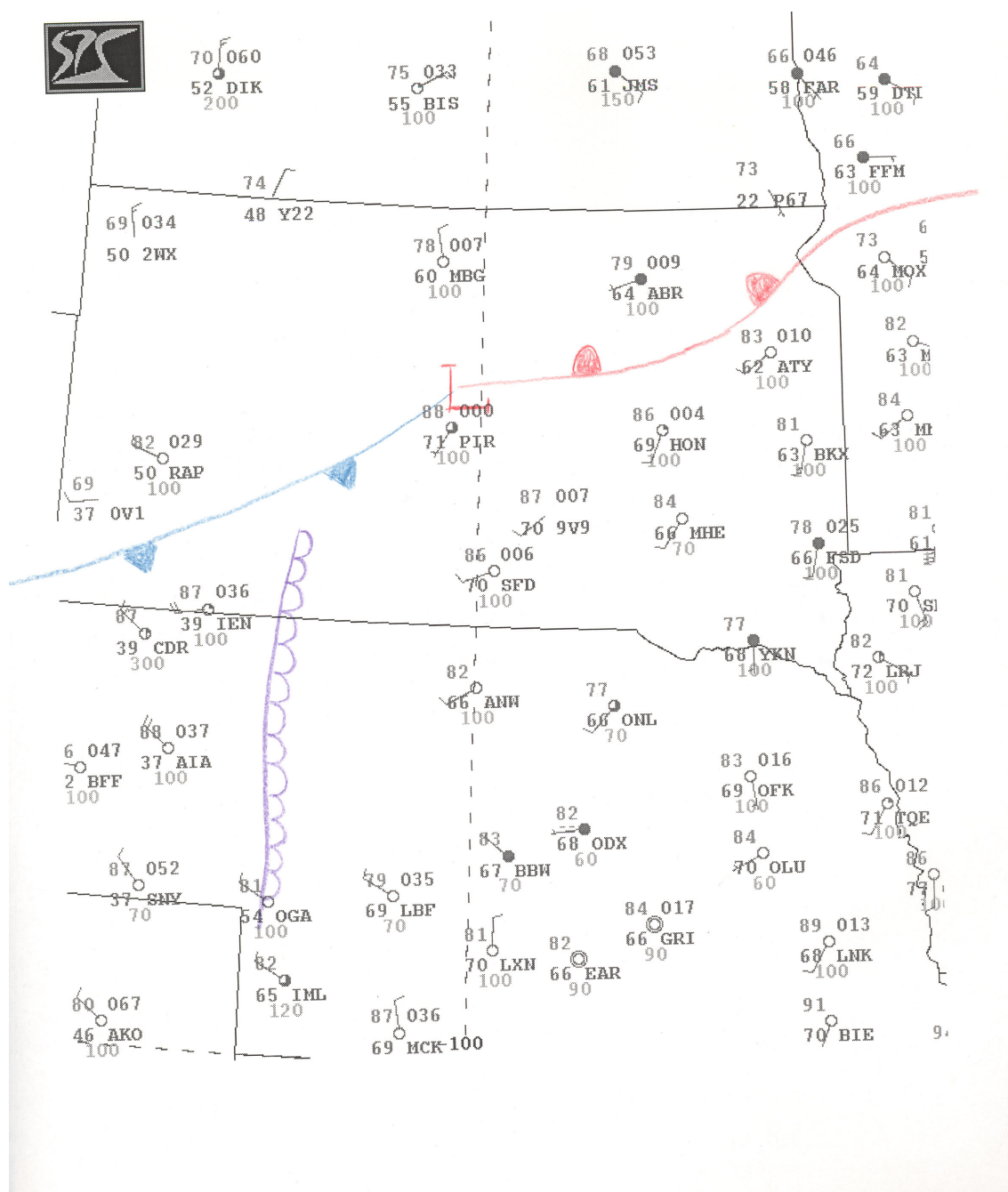


Fig. 14. Hand surface analysis, 2200 UTC. Dry line is progressing east.

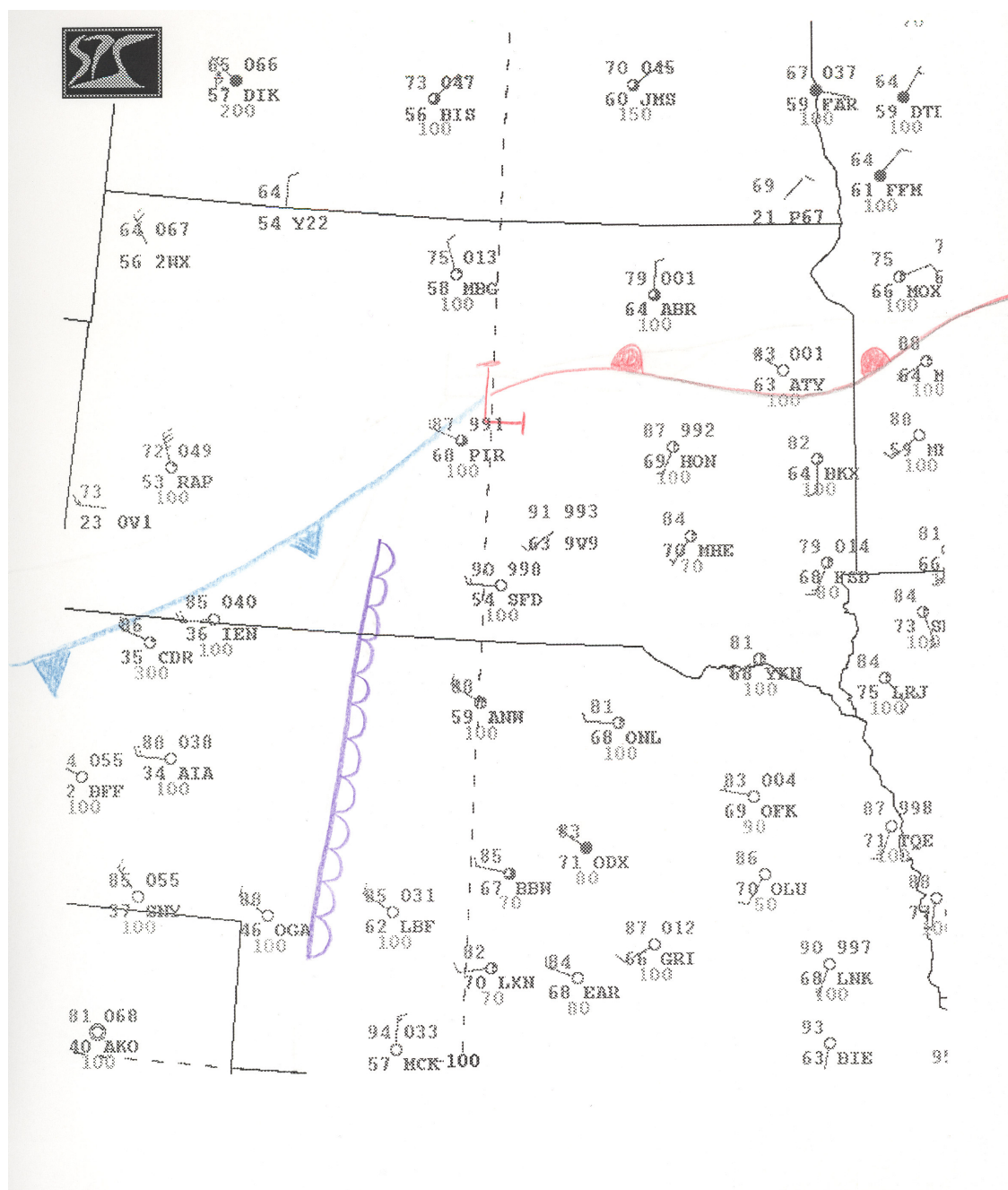


Fig. 15. Hand surface analysis, 2200 UTC.

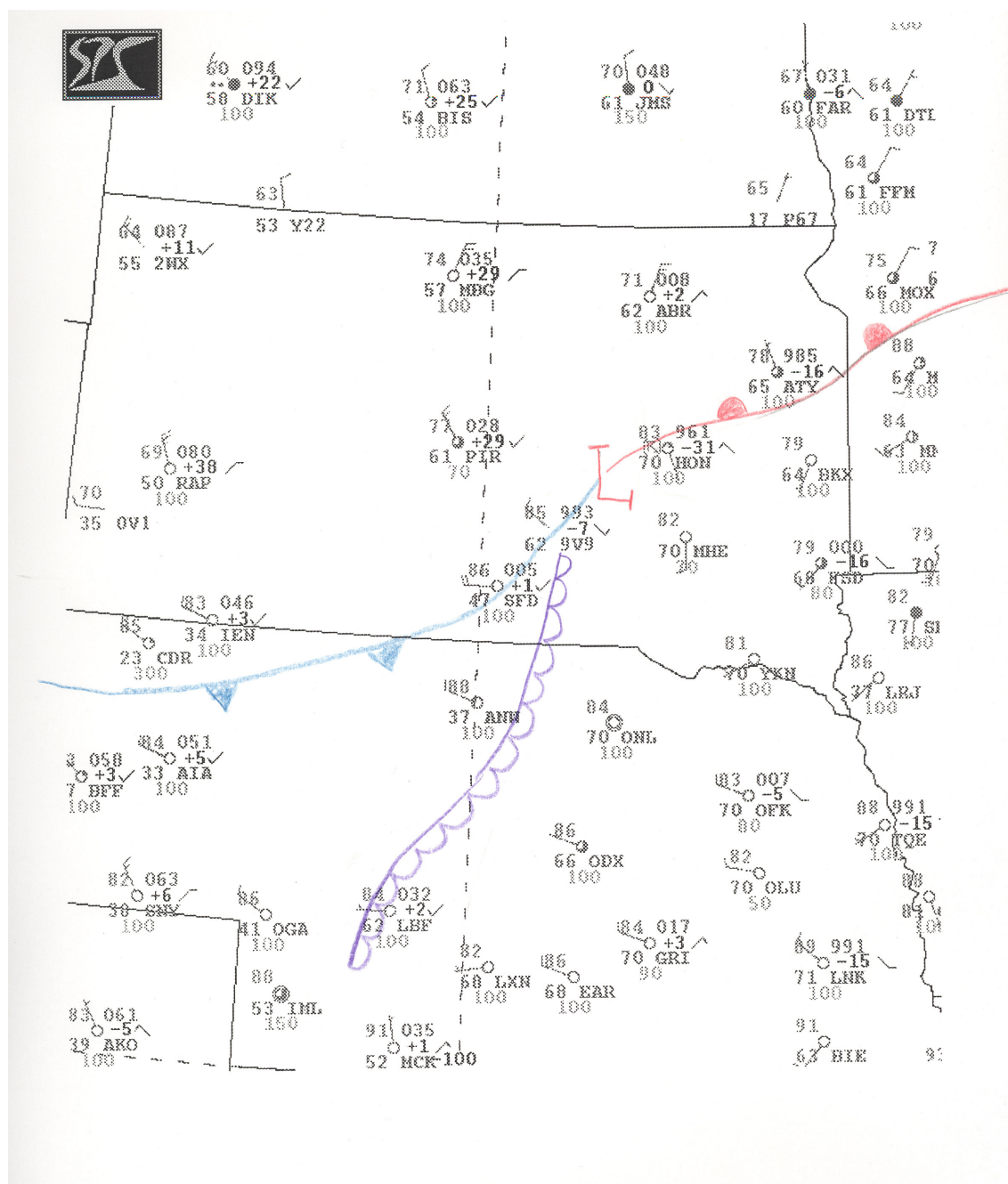


Fig. 16. Hand surface analysis, 0000 UTC 31 May 1998.

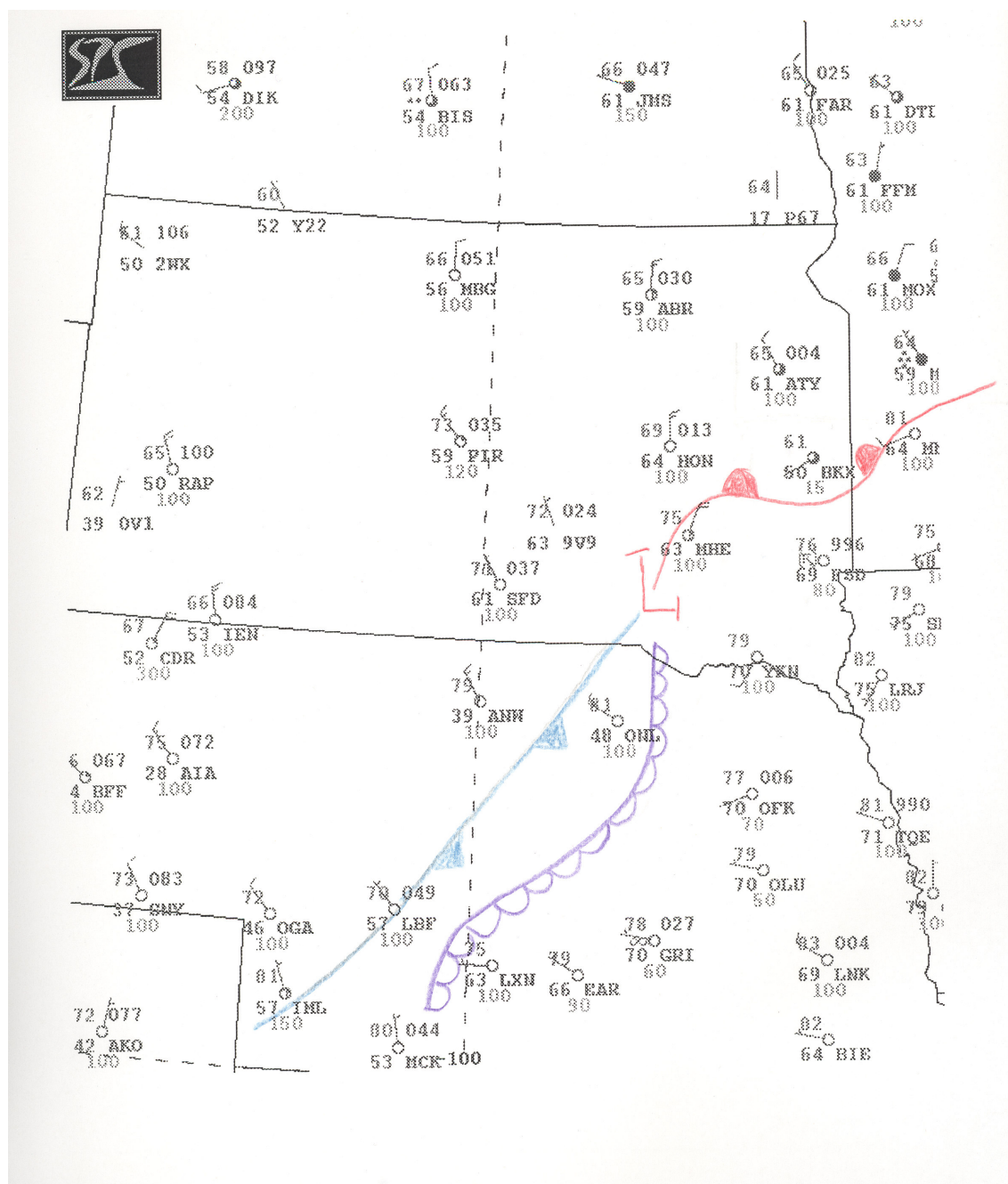


Fig. 17. Hand surface analysis, 0200 UTC 31 May 1998. These are the hourly observations immediately preceding the Spencer touchdown.

