CENTRAL REGION
APPLIED RESEARCH PAPERS
NO. 8

September 1992

NATIONAL WEATHER SERVICE CENTRAL REGION SERIES OF
CENTRAL REGION APPLIED RESEARCH PAPERS (CRARP)

The NWS Central Region Applied Research Paper (CRARP) series is an informal medium to compile and distribute a small part of the on-station research efforts being performed by the operational personnel of the Central Region. As the National Weather Service becomes more involved in using high technology to sample, describe, and forecast the weather, this medium has been made available to encourage the transfer of useful knowledge and skills to other NWS offices. Many times on-station research efforts and case studies are only circulated locally due to the time and effort required to put the study into "publishable" form (both text and graphic). The following CRARP compilations are a vehicle to distribute scientific and operational information to other NWS offices without forcing the authors to perform the time-consuming work typically required to "pretty up" the figure.

The first three were published as Technical Memoranda: (1) CR 88 "Central Region Applied Research Papers 88-1 through 88-7," (2) CR 97 "Central Region Applied Research Papers 97-1 through 97-6," and (3) CR 99 "Central Region Applied Research Paper 99-1 through 99-7." Central Region Applied Research Papers Nos. 3 and 4 were a first attempt at starting a new series numbering system. However, due to an editorial error, CRARP No. 6 served as the beginning point for accurately reflecting the numbering for this series.

NWS CR 88	Central Region Applied Research Papers 88-1 through 88-7, May 1988.
NWS CR 97	Central Region Applied Research Papers 97-1 through 97-6, July 1989.
NWS CR 99	Central Region Applied Research Papers 99-1 through 99-7, November 1989.
CRARP No. 3	Central Region Applied Research Papers 3-1 through 3-7, July 1990.
CRARP No. 4	Central Region Applied Research Papers 4-1 through 4-5, December 1990.
CRARP No. 6	Central Region Applied Research Papers 6-1 through 6-7, May 1991.
CRARP No. 7	Central Region Applied Research Papers 7-1 through 7-4, November 1991.

TABLE OF CONTENTS

CRARP 8-6

"On The WSR-88D, Verification and the Audio Spectrum Analysis of Sferics" written by Mark E. Ewens, WSO Fargo, North Dakota

CENTRAL REGION APPLIED RESEARCH PAPER 8-1

DIGITAL RADAR'S 3-D LOOK AT A TORNADO PRODUCING STORM MERGER

James M. Frederick
National Weather Service Office
Concordia, Kansas

1. Introduction

Computer generated radar products, such as those available from RADAP II and the WSR-88D, provide an enormous opportunity to look at thunderstorm evolution as never before. Digital radar data is currently available from several RADAP sites and provides an excellent opportunity to get acquainted with WSR-88D type products.

RADAP products are gridded alphanumeric data similar to these run on AFOS that can be overlaid with local maps. Sometimes looking at a series of numbers and letters can be a little tedious. A contoured graphic is a more "user friendly" medium. There has not been much work in developing AFOS or PC application programs to analyze RADAP data and produce locally contoured maps. This idea led to this attempt to do a storm case study showing the beauty of digital radar using simple analysis.

2. Description of Data

Since RADAP data has four dimensions (time, azimuth, range, and magnitude), a simple 3-D time series could easily show the evolution characteristics of a thunderstorm. An interesting case of a thunderstorm merger which produced a small tornado occurred near WSMO Monett, Missouri (UMN). RADAP data does a good job in depicting the evolution of the storms. A window of data from the storm was smoothed (using the simple 9-point method) and displayed using 3-D. Echo tops and VIL (Vertically Integrated Liquid) products were chosen for analysis, as their data was the most reliable at the storm distance.

Figure 1 is the automatically produced RADAP intensity, tops, and VIL products that were output every 12 minutes. They illustrate how busy the radar was that night. It is difficult to quickly pick out the most intense individual cells. In most cases it was necessary to draw contours on the products in order to distinguish between cells. VIL products were best at showing cell distinction (Fig. 1).

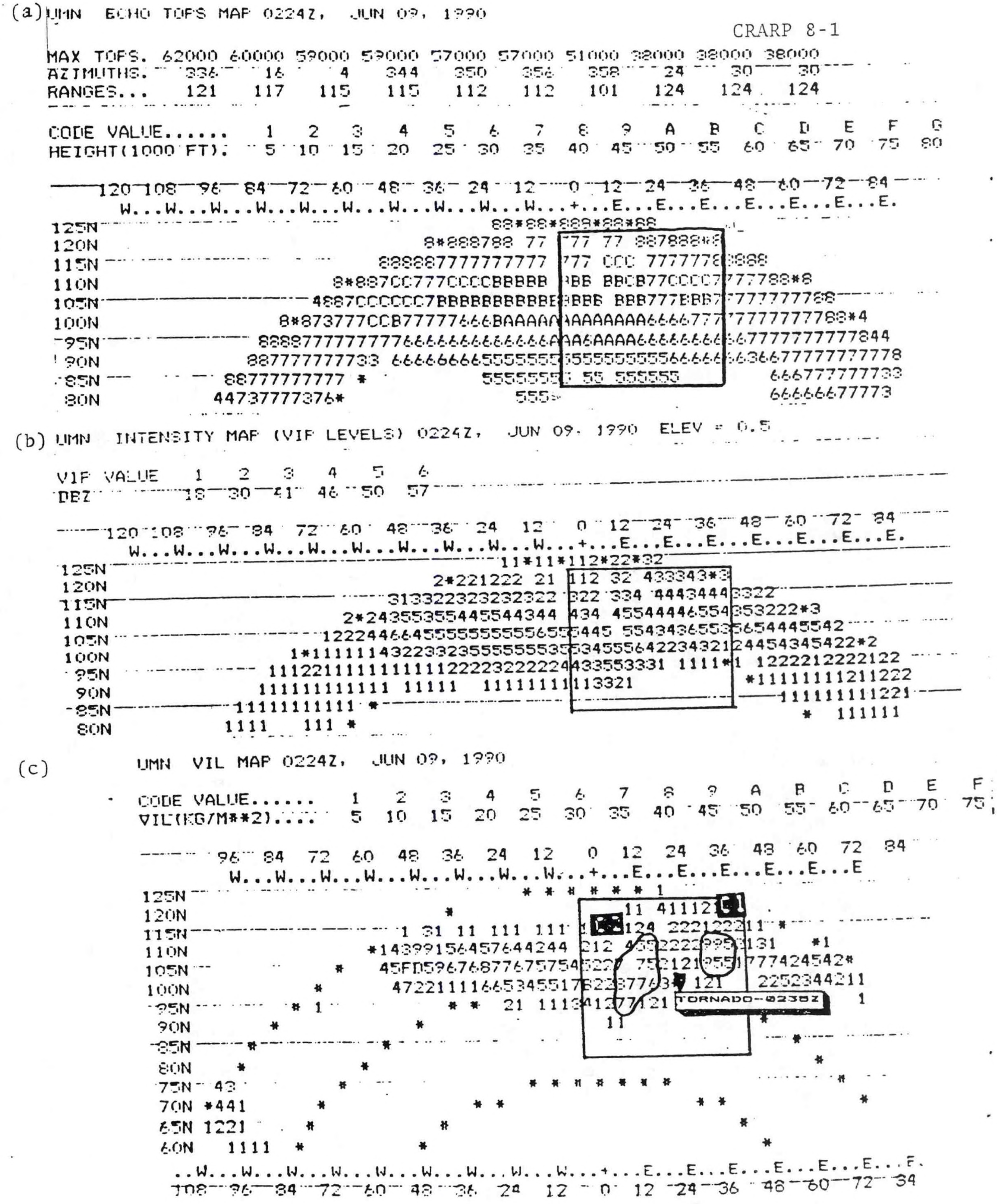


FIG. 1

Figure 1. (a) Echo top, (b) intensity, and (c) VIL maps from Monett, Missouri radar at 0224Z, June 9, 1990.

3. Synoptic Features

June 8, 1990 was a very active severe weather day across much of eastern Kansas and Missouri. A stationary front extended from an occluded low over the Great Lakes across central Missouri and into northern Kansas. Low level moisture was abundant with dew points in the 70s. Upper level diffluence and a cold pocket at 500 mb were all coming together to create the fertile grounds for storm development. A large cluster of thunderstorms developed from Emporia, Kansas, to St. Louis. Numerous reports of severe weather were received across central Missouri including a small tornado near Windsor (12 miles south of Sedalia, Missouri) at 0235Z (June 9).

There were some very large persistent storms in the complex along with numerous short-lived but potent ones. Individual cell movement was difficult to determine. Some of the storms remained stationary or redeveloped to the southwest while others moved east at 15 to 20 mph. There seemed to be quite a few cell mergers going on as the entire area of thunderstorms moved through Missouri.

4. Analysis

The boxed area in Figure 1 is the area analyzed in the 3-D plots. The 3-D plots (Fig. 2) are situated so that the southwest part of the storm is in the left rear and the northeast part is in the right front of the plot. So, from the back of the box to the front is west to east. The time range is from 0212Z to 0300Z with the reported tornado occurring at 0235Z. The vertical scale for TOPS extends to 60,000 ft and to 60 KG/M^2 for VIL. CELL 1 is the eastern most cell at 0212Z, and CELL 2 is the approaching cell (labeled in Fig. 1 VIL as C1 and C2, and in Fig. 2 VIL at 0212Z as CELL 1 and CELL 2).

CELL 1 had developed less than an hour before 0212Z and had shown little movement. CELL 2 was nearly 2 hours old and had moved about 50 miles eastward from south of Kansas City. The TOPS and VIL figures show these two distinct cells. Both cells had TOPS of around 60,000 ft, but CELL 1's max top was a little broader. CELL 2 had the higher VIL (40 KG/M^2) and larger low level core than CELL 1 (VIL 35 KG/M^2).

Twelve minutes later (0224Z) CELL 1 moved slightly eastward, broadened its low level core and increased its VIL to 45 KG/M^2. CELL 2 moved about the same as CELL 1 and its VIL remained the same. TOPS on both were still around 60,000 ft.

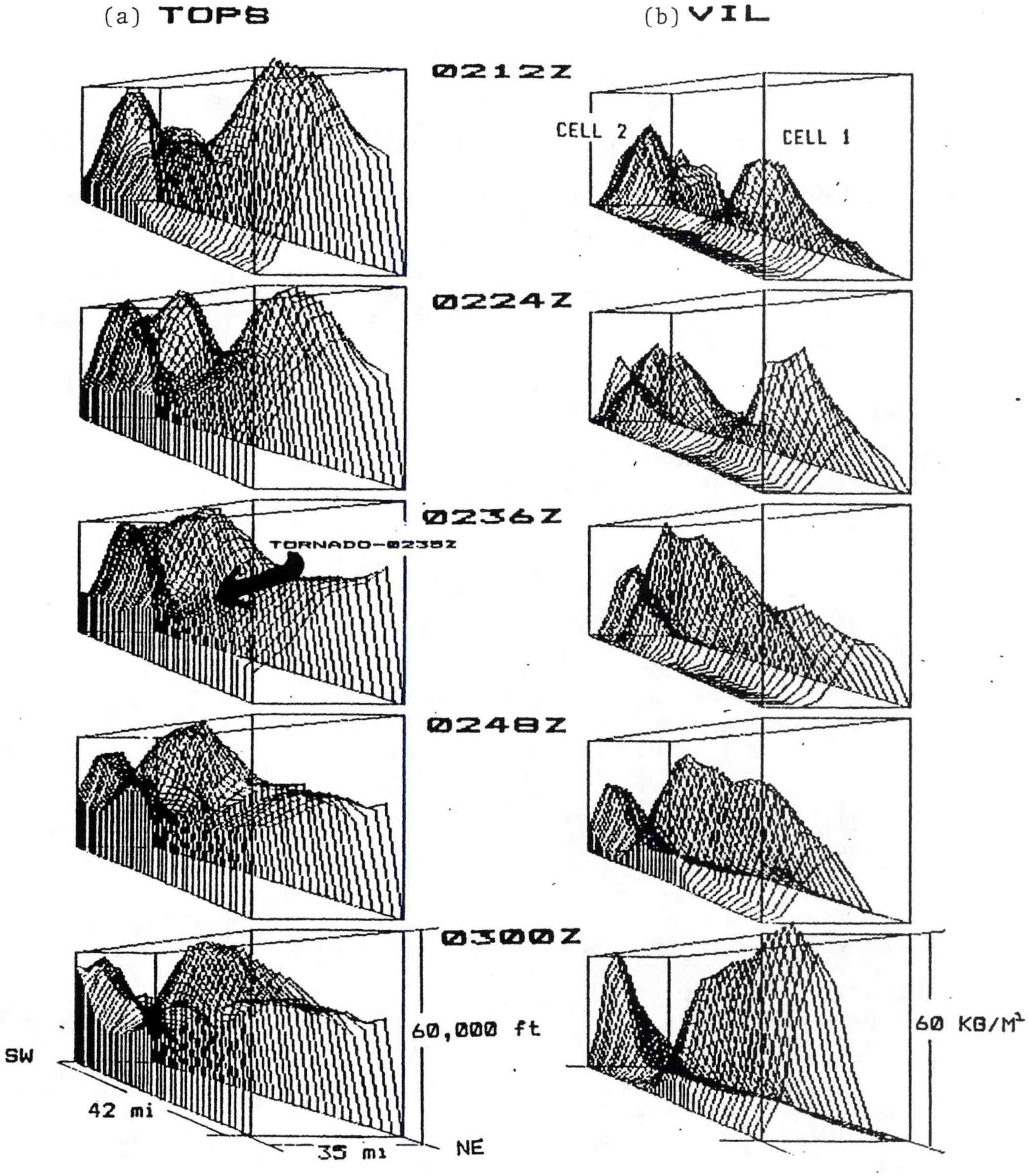


Figure 2. 3-D displays of (a) echo tops and (b) VIL from 0212Z until 0300Z on June 9, 1990.

CELL 1 (at 0236Z) appeared to have collapsed or moved eastward. The storm then had a max top between where CELL 1 and CELL 2 were at 0224Z with a broad summit still around 60,000 ft. A wide area of flattened tops from 35 to 40 thousand feet is left where CELL 1 was at 0224Z. VIL increased dramatically to 55 KG/M^2 and had a peak just to the east of CELL 2's peak VIL. The arrow shows the approximate location of the reported small tornado.

At 0248Z, part of the storm's top appeared to have given way and the overall VIL also lessened. The max top was 55,000 ft with a max VIL of 45 KG/M^2. The max top was in about the same location as before and the wide area of flattened tops was nearly unchanged. The VIL peak shifted eastward and elongated.

The storm appeared to again pulsate at 0300Z as the overall VIL increased tremendously with a peak at over 60 KG/M^2 and the storm moved eastward. The max top was nearly the same, with the overall height of the large area of flattened tops increasing. The VIL peak extended into the flattened tops suggesting a thick and deep, high VIP level core. Another strong storm continued to move in from the west (seen in the rear of the box). Shortly thereafter, the max top decreased to 50,000 ft with a small VIL core of 60 KG/M^2. The storm gradually diminished after that.

5. Discussion

There are several interesting things that occurred with this storm event, as shown by RADAP data from UMN. The reported tornado appeared to occur around the time and in the general location where the two cells interacted with each other. After the interaction and the short-lived tornado, VIL initially decreased then greatly increased. The rise in VIL implies greater rainfall rates from the storm. The thunderstorm lasted less than an hour after the merger with no further reports of severe weather.

6. Postscript

One purpose of this short note was to highlight the wonderful possibilities that exist with the use of digital radar. Looking at raw data in numbers and letters is tiresome, but graphically reproducing that data can be very enlightening. RADAP has been around since the mid-70s yet there are few application programs for manipulating this data. Simply animating RADAP maps on AFOS improves their usefulness greatly. Prior to the complete implementation of the WSR-88D radars it is clear that useful storm information can be derived from a careful analysis of RADAP data.

CENTRAL REGION APPLIED RESEARCH PAPER 8-2

A CASE OF SEVERE THUNDERSTORMS WITH DENSE FOG IN SOUTHEAST WYOMING

Michael S. Weiland
National Weather Service Forecast Office
Cheyenne, Wyoming

1. Introduction

During the evening of May 18, 1991, severe thunderstorms occurred in the extreme southeast corner of Wyoming. What made this event so unusual was the presence of stratus and dense fog in the area from mid afternoon through the evening. In the southeast corner of Wyoming, visibilities were reduced to as low as one-sixteenth of a mile (Fig. 1) and one to one and one-half inch diameter hail (Table 1) was reported. Of course with the rain and hail, visibilities and ceilings improved briefly, but quickly lowered after a thunderstorm passage.

In this paper, the author will briefly discuss the mesoscale and synoptic situations preceding and during this event.

2. Synoptic Discussion

During the day of May 18, 1991, diffluent south-southwest wind flow above 700 mb was in place over eastern Wyoming (Fig. 2). At the surface, high pressure was centered over southern Ontario at 12Z and a stationary front was located from southern Kansas to central Wyoming (Fig. 3). These surface features produced a moist southeast low level wind flow over eastern Wyoming and eastern Colorado during the day, with dew points in the lower to mid 50s (Fig. 4).

3. Mesoscale Discussion

An interesting situation existed over the area in the mesoscale. To the south of the synoptic scale stationary front, along a Greeley, Colorado, to Fort Collins, Colorado, line, mostly sunny skies prevailed until mid afternoon. To the north of the front, low clouds, fog, and cool temperatures were common. As seen on the maximum temperature chart for May 18, 1991, (Fig. 5) there was over a 20°C temperature difference between Cheyenne and the Greeley-Fort Collins area.

A very strong and moist southeast surface wind flow was over most of the area. In fact, in southeast Wyoming in the late afternoon and evening hours, some gusts were reported as high 50 mph. The surface winds produced convergence over the area, aiding in the thunderstorm development.

There exits almost a three thousand foot difference in the 35 miles from Fort Collins and Greeley (4500 ft) to the Cheyenne ridge (7500 ft) just south of Cheyenne. The observed gradient winds flowing up the terrain produced lift of about 5 m s^{-1}. More importantly, the surface boundary to about 9000 feet MSL was in an area about 25 miles wide. Convergence along the surface boundary produced upward vertical velocities estimated to be almost 20 m s^{-1} (Darkow, 1984).

By late afternoon, surface based lifted indices (Western Region TA, 1984) were between -3°C and -5°C just to the south of the boundary, and above zero to the north of the boundary (Fig. 6). The 00Z May 19, 1991 raob at Denver was not extremely moist, but did contain 131% of normal precipitable water (Figs. 7 and 8). Behind the stationary front was a moist, stable layer which was to a depth of 9000 feet MSL at 00Z at North Platte (Fig. 9). That 00Z North Platte raob had a lifted index of 6°C. However, lifting the 00Z Denver raob above 9000 ft, MSL over that stable layer produced a lifted index of almost -8°C.

4. Weather That Occurred

Thunderstorms developed over a small part of northeast Colorado between 00Z and 0030Z that evening (Fig. 10). The small area of thunderstorms moved north at about 25 kts and entered southeast Wyoming between 0100Z and 0130Z. Severe weather was first reported at 0055Z in Pierce, Colorado, where one-half inch to one and one-quarter inch hail fell (Storm Data, 1991). The storms continued to move north and were still present over southwest Wyoming and western Nebraska at 0430Z (Figs. 11, 12 and 13).

While over extreme southeast Wyoming, the storms produced hail in a 15 mile radius of Cheyenne between 0115Z and 0257Z (Table 1). In addition to the hail was very heavy rain. Each individual cell produced hail and rain which lasted ten minutes or less, but with continued development of thunderstorms on the south edge of the complex, several cells moved over the same area for repeat occurrences.

5. Summary

The synoptic and mesoscale situations of the rare coincident occurrence of dense fog and large hail was given in this paper. The combination of a significant surface boundary, strong and moist southeast flow over the boundary, and an unstable air mass above the stable layer produced the observed weather. Then strong upward vertical motion over a short distance enabled the warmer and unstable air to the south of the boundary to be forced over the boundary and produce the thunderstorms and not disturb the stable layer and fog.

6. Acknowledgements

The author would like to thank Charles Esmeier, OIC at WSMO Alliance, for providing radar observations and overlays for this event.

7. References

Darkow, G. L., 1984: Basic Thunderstorm Energetics and Thermodynamics, *Thunderstorm Morphology and Dynamics*, University of Oklahoma Press, Norman, OK, 63-64.

National Weather Service, 1984: Convective Stability Indices, Western Region Technical Attachment 84-14, NWS Western Region, Scientific Services Division, Salt Lake City, UT.

____________, 1991: Daily Weather Maps, May 13-19 1991, National Weather Service, National Meteorological Center, Climate Analysis Center, Washington, DC.

National Oceanic and Atmospheric Administration, 1991: Storm Data, May 1991. NOAA, National Environmental Satellite Data and Information Service, Asheville, NC.

Table 1. Severe local storm reports for southeast Wyoming on May 18, 1991.

LOCAL STORM REPORT...CORRECTED
NATIONAL WEATHER SERVICE CHEYENNE WY
1045 PM MDT SAT MAY 18 1991

...MAY 18 1991...

TIME	*COUNTY*	*REPORT*
715 PM	LARAMIE	5 E CHEYENNE 3/4 INCH DIAMETER HAIL.
800 PM	LARAMIE	10 SE CHEYENNE 1 INCH DIAMETER HAIL.
815 PM	LARAMIE	FUNNEL CLOUDS SOUTH SIDE OF CHEYENNE.
900 PM	LARAMIE	NORTHEAST CHEYENNE 52 MPH WINDS.
900 PM	LARAMIE	SOUTHEAST CHEYENNE 55 MPH WINDS.
850 PM	LARAMIE	10 WEST CHEYENNE ON INTERSTATE 80...1 INCH DIAMETER HAIL.
857 PM	LARAMIE	12 WEST CHEYENNE ON INTERSTATE...1 1/4 INCH DIAMETER HAIL AND MINOR FLOODING.

```
CYS SA 1050 E250 BKN 6F 144/54/51/1514/012
CYS RS 0953 5 SCT 5F 148/54/52/1215G19/012
CYS SP 0937 M5 OVC 5F 1316G20/012/CIG RGD OCNL BINOVC OVHD
CYS SA 0850 M2 OVC 4F 139/55/54/1416G23/011/ 00200 16//
CYS SA 0750 M2 OVC 5F 142/55/54/1316G23/011/ 98268
CYS SA 0650 M2 OVC 4F 140/56/55/1418G20/011/LE40
CYS SP 0648 M2 OVC 4F 1420G27/011
CYS SA 0550 M2 OVC 11/2L-F 139/56/56/1318G27/011/R26VVNO/ 11005 16//
 59
CYS SP 0506 M2 OVC 11/2L-F 1325G30/010/R26VVNO
CYS SA 0452 W1 X 3/4L-F 144/56/56/1317/011/R26VVNO
CYS SP 0424 W1 X 3/4L-F 1421G26/011
CYS SA 0350 W1 X 1/16L-F 152/54/54/1512G20/012/R26VVNO TE33 MOVD N
CB MOVD N REL020
CYS SP 0334 W1 X 1/16L-F 1315/012/R26VVNO TE33 MOVD N CB OCNL LTGIC
NW-N MOVG N
CYS SP 0305 -X M1 BKN 35 OVC 1/8TRW-F 1120G28/006/R26VVNO F9 T FQT
LTGICCC OVHD MOVG N CB ALQDS MOVG N PCPN VRY LGT
CYS RS 0250 -X M2 BKN 35 OVC 1/2TRW-F 135/54/54/1316G30/007/R26VVNO
F3 T OCNL LTGICCC OVHD MOVG N CB ALQDS MOVG N PCPN VRY LGT/ 30202
CYS SP 0237 -X M2 BKN 35 OVC 1TRW-F 1213/007/R26VVNO F2 T OCNL
LTGICCC OVHD MOVG N CB NE-OVHD-SW MOVG N
CYS SP 0223 -X M5 BKN 35 OVC 2TRW-F 1415G24/007/R26VVNO F2 T E MOVG
N OCNL LTGICCCCG SE CB NE-SW MOVG N
CYS SA 0150 W1 X 1/16TRW-F 131/53/53/1118/005/R26VVNO TB20 E MOVG N
CB NE-SE MOVG N AB20E23 HLSTO 1/2 RB20
CYS SP 0132 W1 X 1/16TRW-F 1315/008/R26VVNO T E MOVG N AE23 HLSTO
1/2 CB E MOVG N
CYS SP 0121 W1 X 1/16TRW-AF 1215/008/R26VVNO TARB20 E MOVG N HLSTO
1/2 CB E MOVG E
CYS SA 0050 W1 X 1/16F 131/53/53/1214G21/005/R26VVNO
CYS SP 0017 W1 X 1/2F 1220G25/007/R26VVNO
CYS SP 0009 W2 X 1F 1313G21/007/R26VVNO
CYS RS 2350 W2 X 3F 133/55/53/1213/007/ 60700 59
CYS SA 2250 M6 OVC 10 134/56/52/1319G26/007/LE20
CYS SP 2214 M5 OVC 4L-F 1415G24/009
CYS SP 2200 W1 X 11/2L-F 1315G20/009/R26VVNO
CYS SA 2150 W1 X 1/2L-F 145/53/52/1515G22/009/R26VVNO LB43
OR
CYS SP COR 2144 W1 X 1/2L-F 1416G27/009/RVVNO
CYS SP 2144 W1 X 1/2L-F 1416G27/009
CYS SP 2131 -X M2 OVC 3F 1316G26/009/F2
CYS SP 2120 M5 BKN 16 OVC 10 1417/009
```

Figure 1. Surface aviation weather observations (SAO) for Cheyenne, WY from 2120 UTC May 18 to 1050 UTC May 19, 1991.

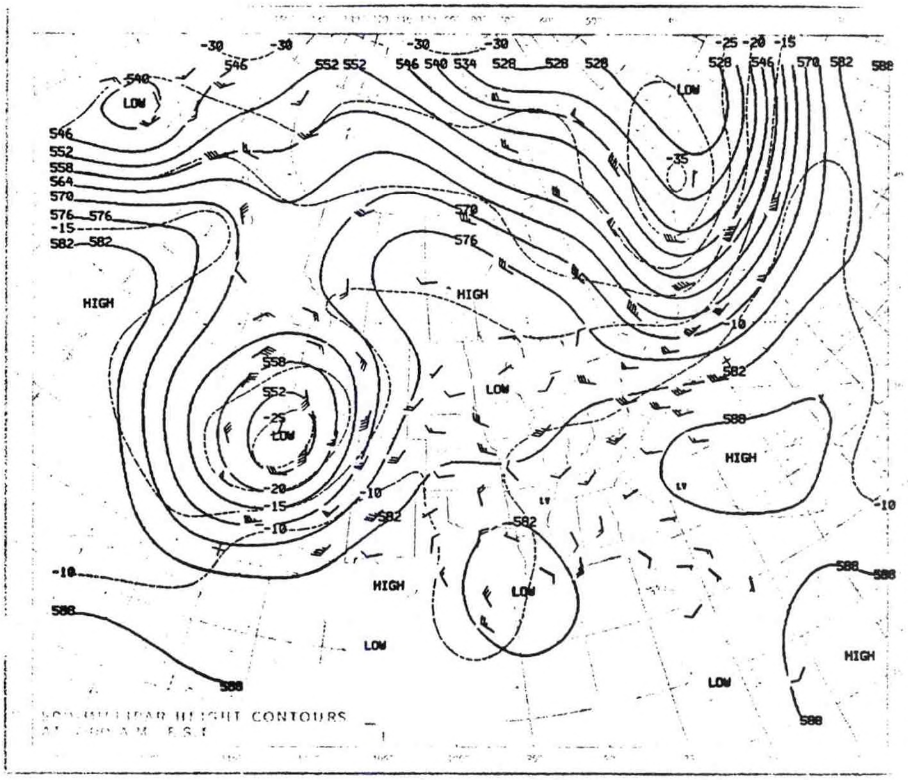


Figure 2 500 mb chart for May 18 1991 12z
(Daily Weather Maps)

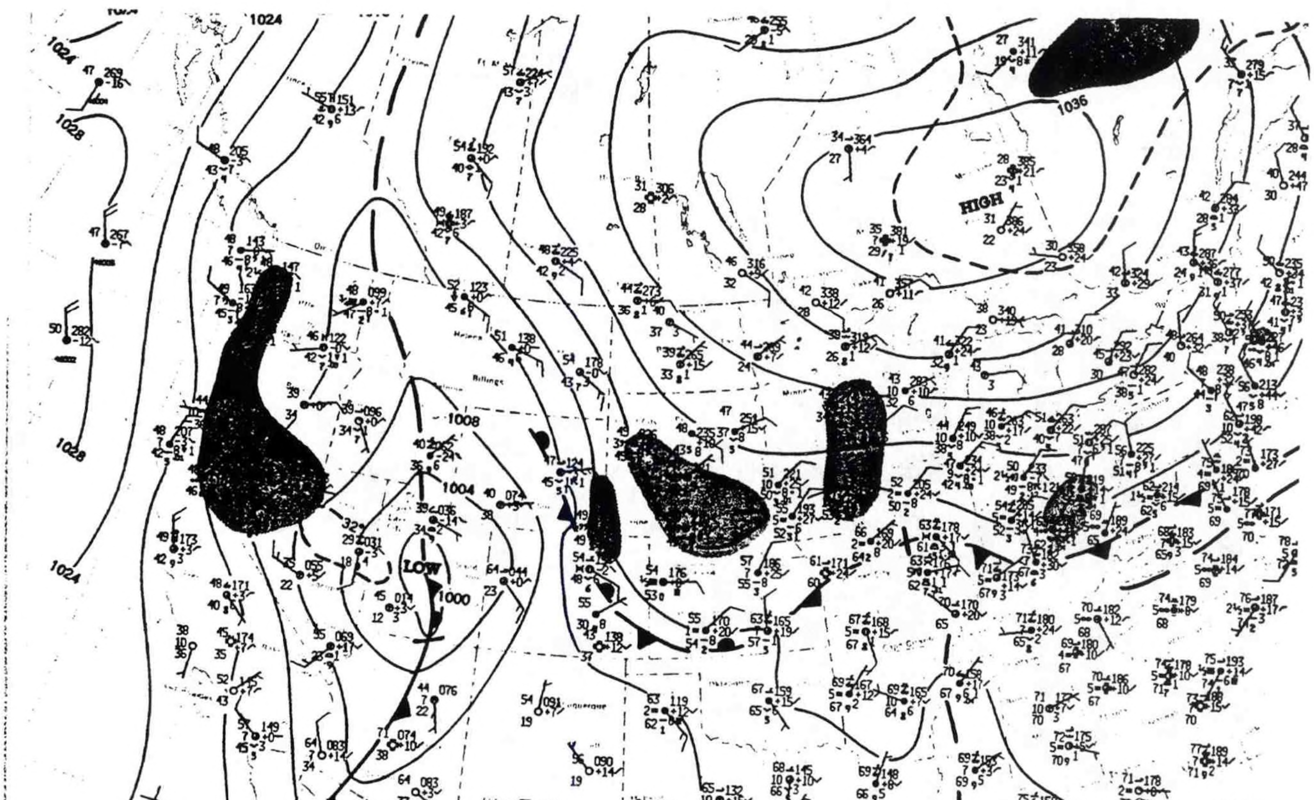


Figure 3 Surface chart for May 18 1991 12z
(Daily Weather Maps

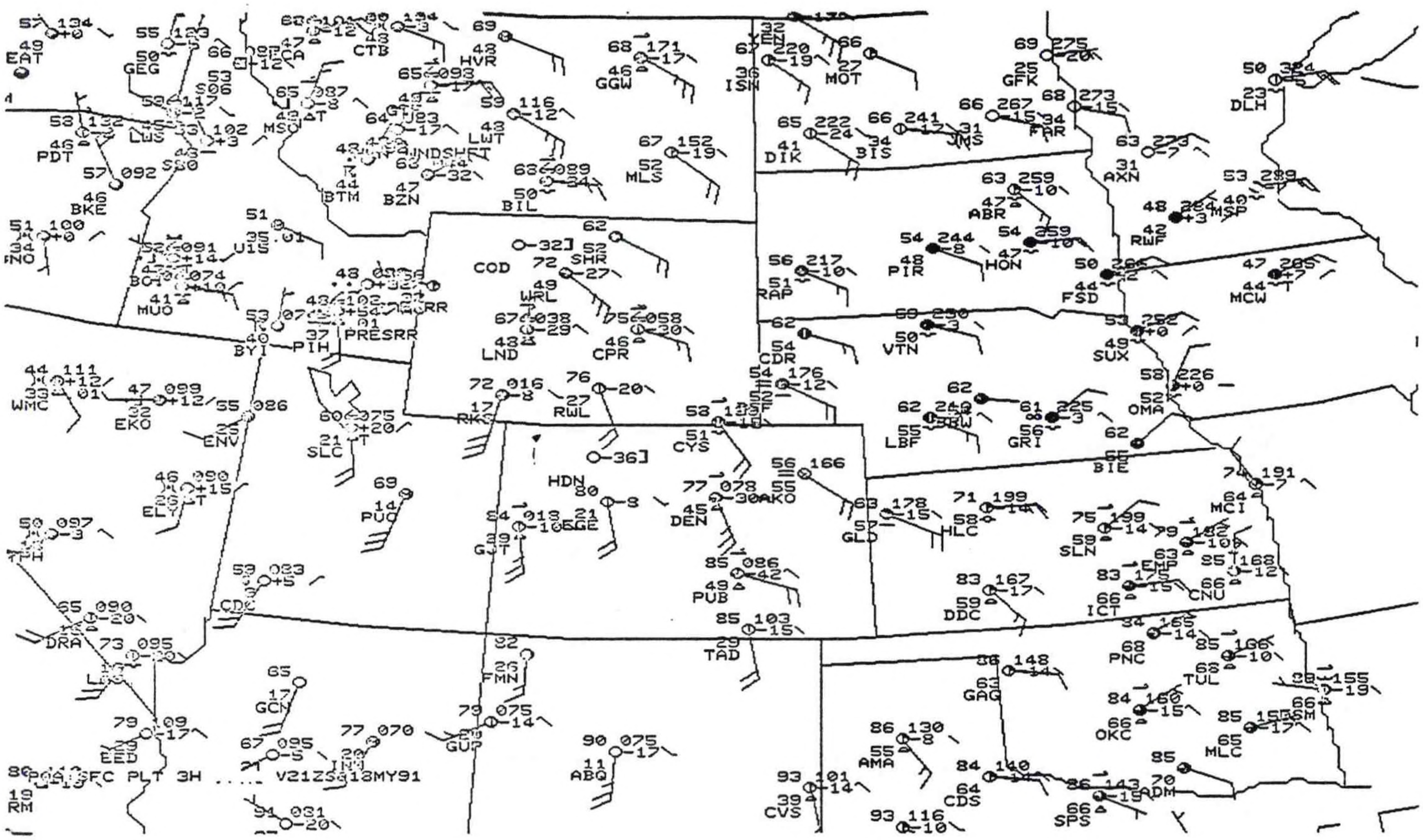


Figure 4 Surface Plot May 18 1991 21z

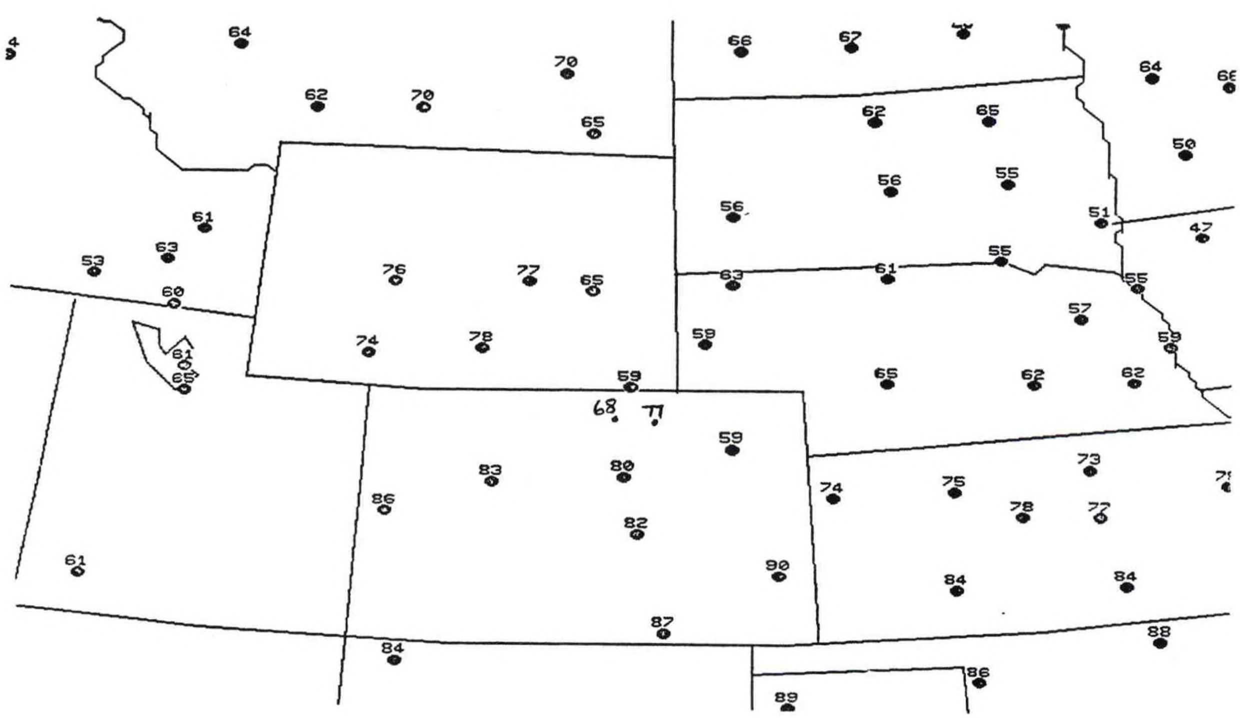


Figure 5 Maximum Temperature Chart for May 18 1991

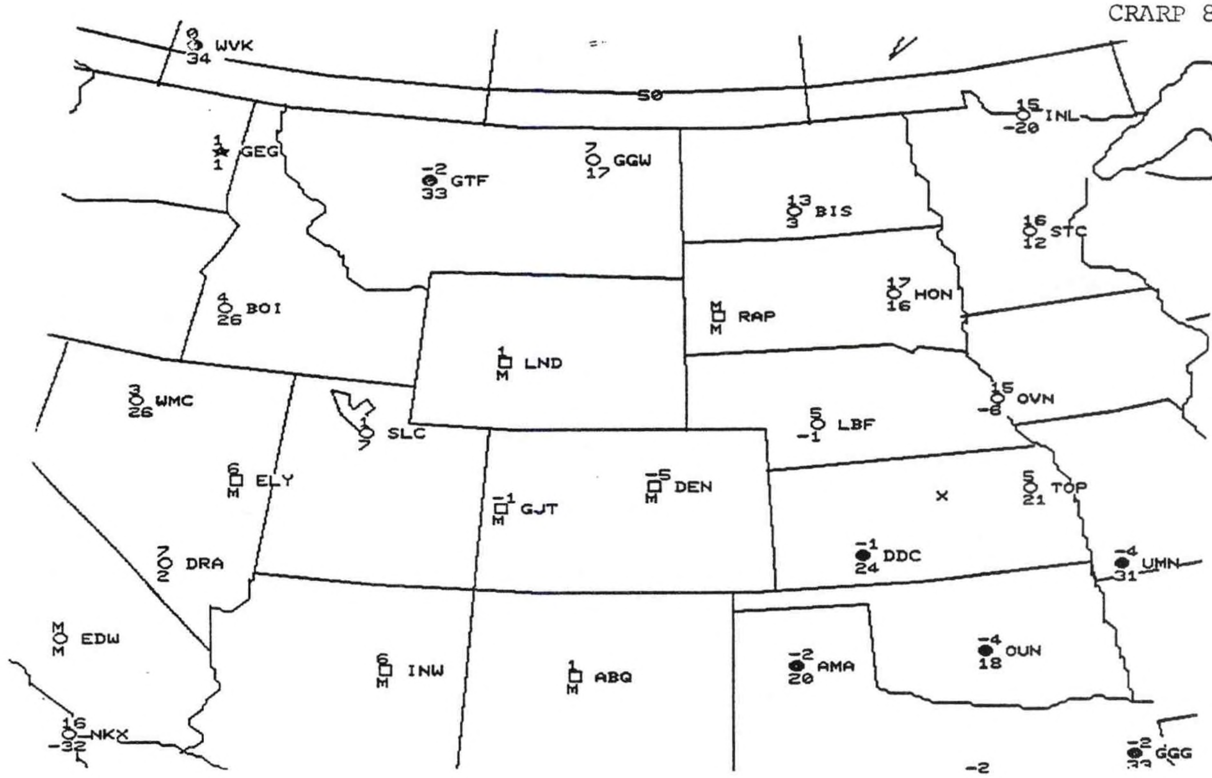


Figure 6 Lifted Index/K Index Chart May 19 1991 00z

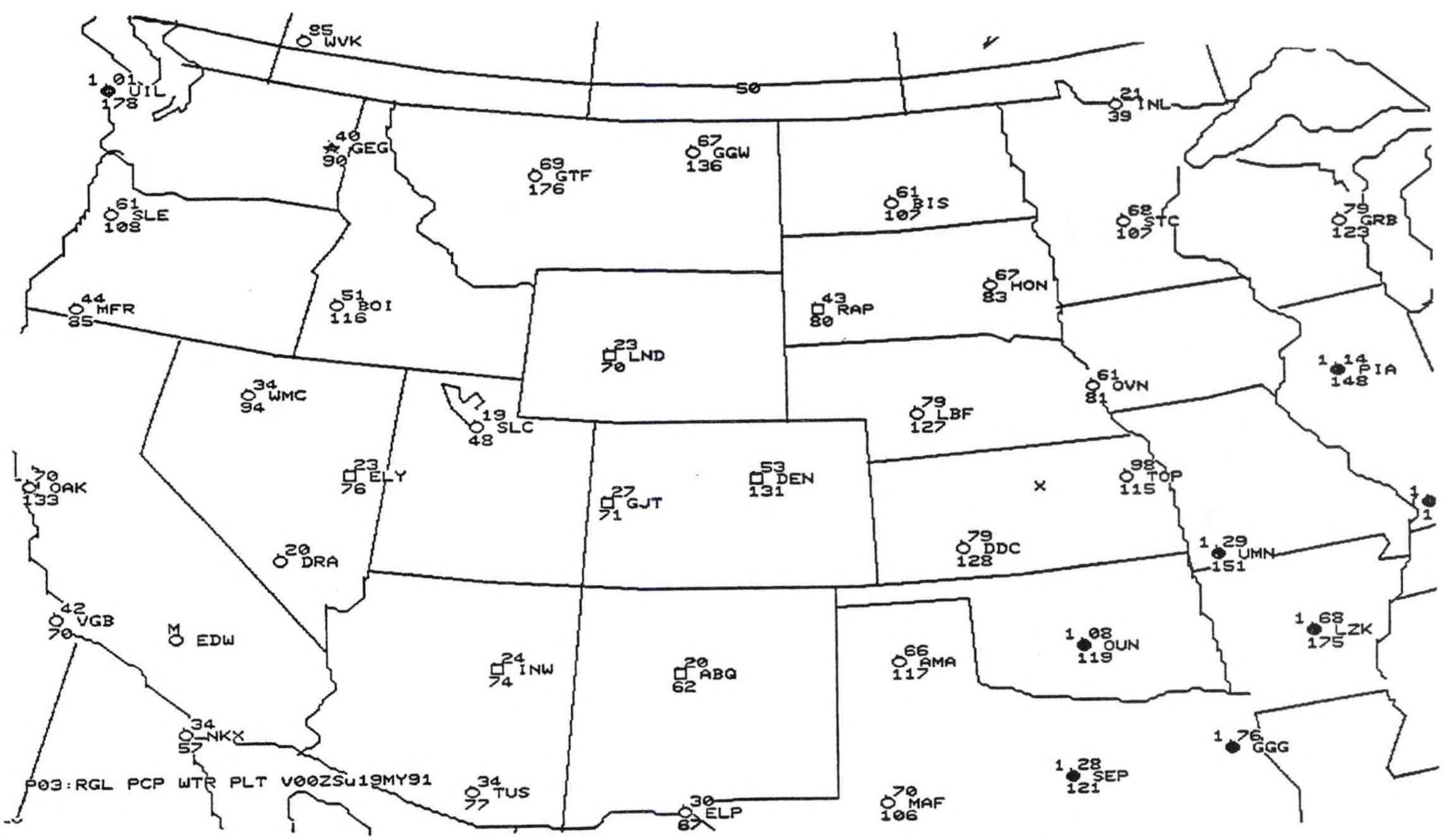


Figure 7 Precipitable Water Chart May 19 1991 00z

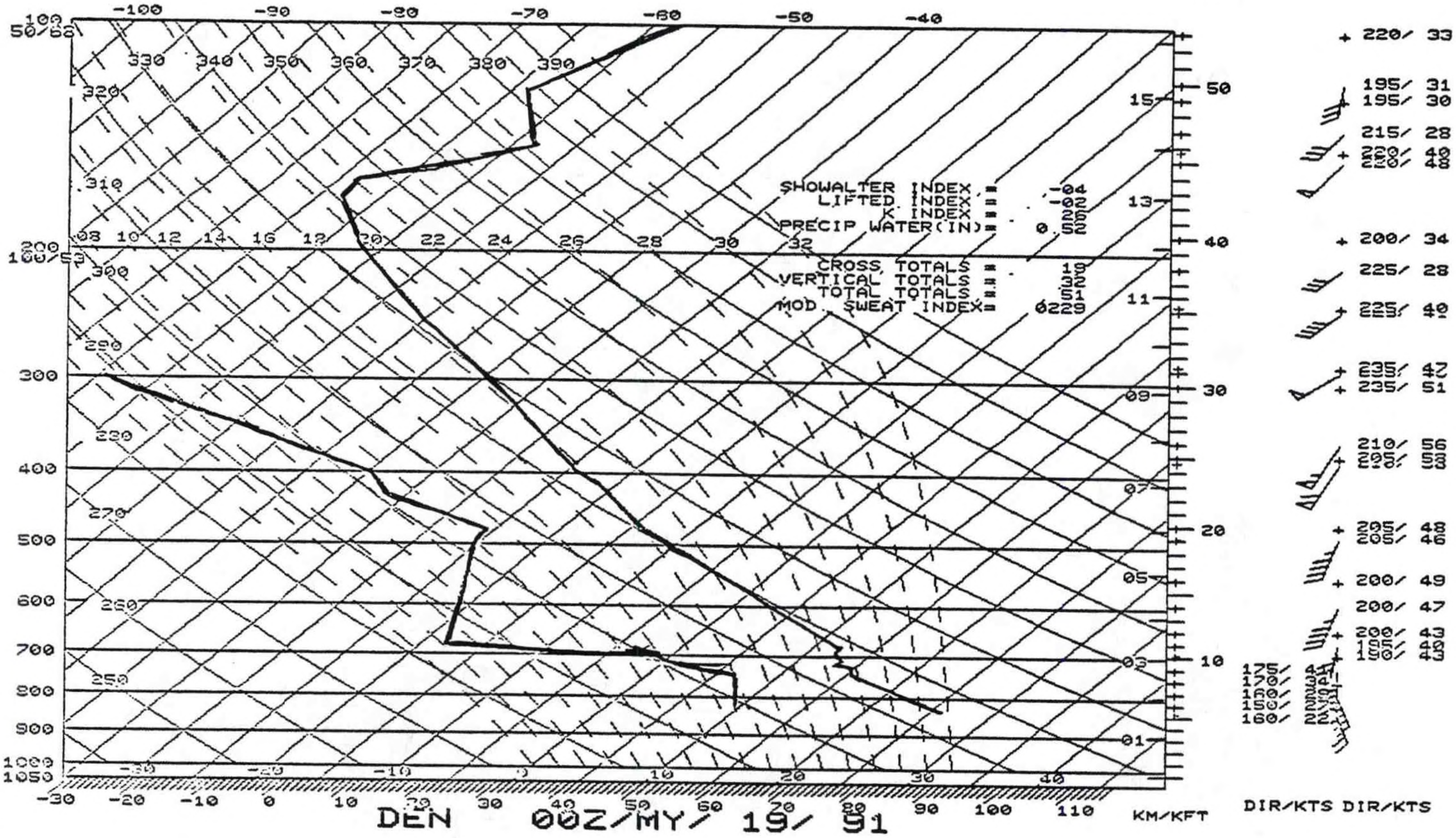


Figure 8 Denver raob May 19 1991 00z

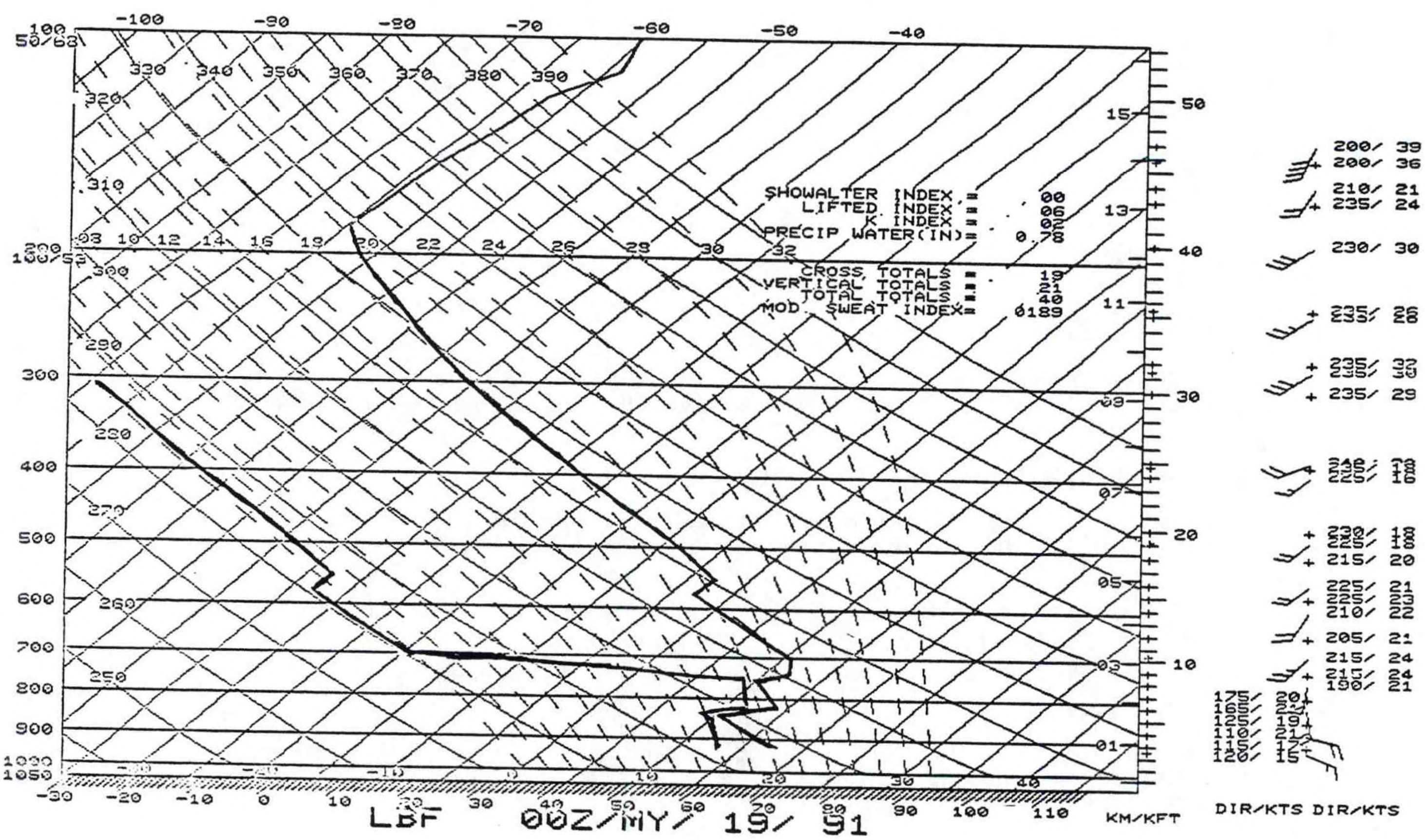


Figure 9 North Platte raob May 19 1991 00z

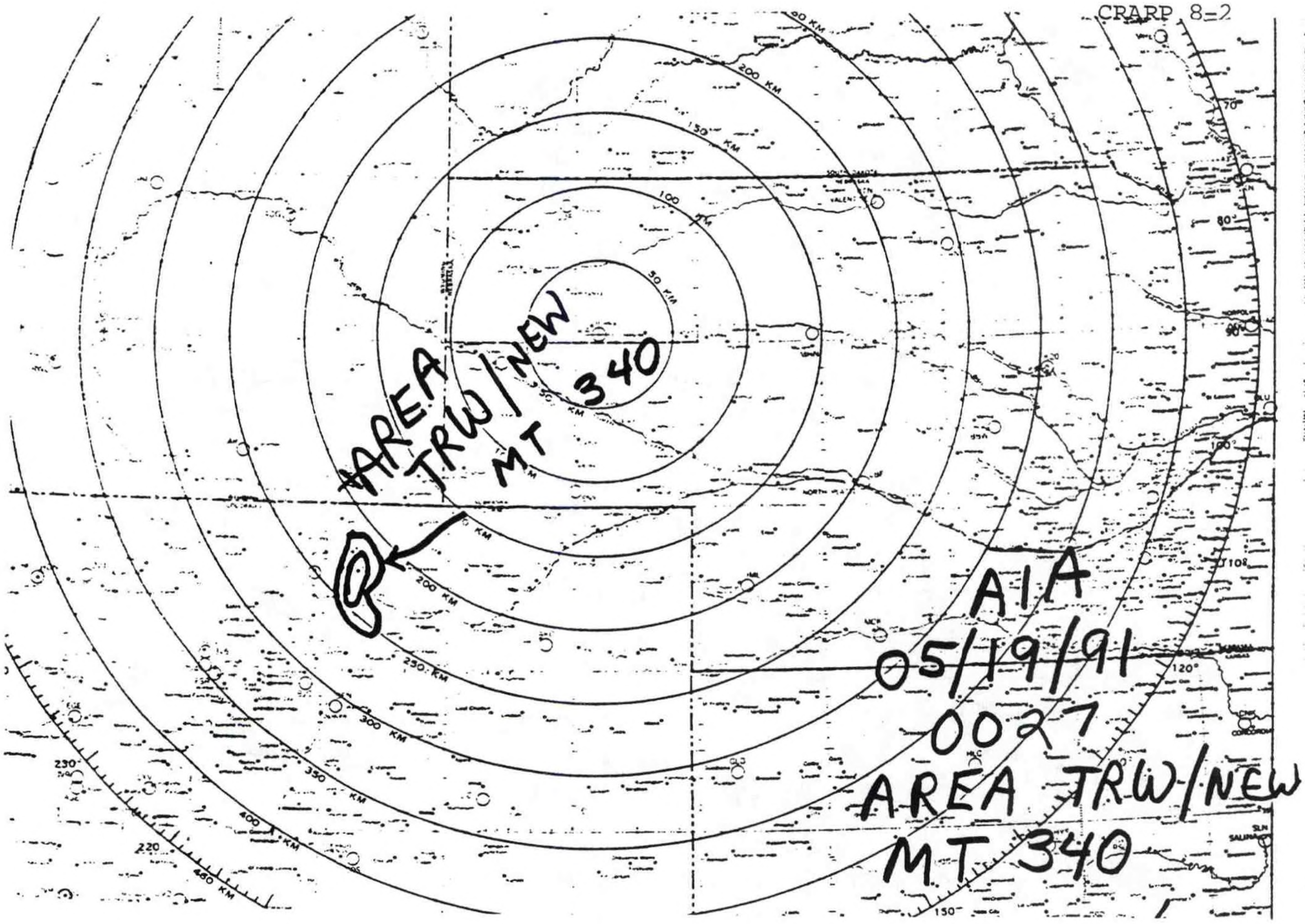


Figure 10 Alliance radar overlay May 19 1991 0027z
X marks Cheyenne

AIA RADAR OBS

MAY 18, 1991

!AIA 2325 PPINE=

MAY 19, 1991

!AIA 0027 AREA 3TRW/NEW 232/105 220/140 30W MT 340 AT 227/125
^QI1 RI9=

!AIA 0125 CELL TRWXA/+ 228/115 D20 C1825 MT 490 HAIL 228/115
AREA 3TRW+A/+ 270/120 212/110 50W C1825 MT 400 AT 242/100 HAIL 242/100
^OG9 PI31 QI52=

!AIA 0158 SPL CELL TRWXA/+ 234/105 D5 C1825=

!AIA 0235 SPL AREA 5TRWXA/+ 230/55 249/135 58W C1825 MT 440 AT 242/118
TOP 440 AT 238/95 HAIL 242/118 HAIL 238/95
^OI3 PH551=

!AIA 0258 SPL CELLS TRWXA/+ 242/110 D5 MT 500 247/105 D7 TOP 500 C1820
VIP 5 TO 280=

!AIA 0325 AREA 5TRW+/- 273/45 252/140 60W C1820 MT 400 AT 247/100
^NH131 OG9031 PH23=

!AIA 0430 CELLS TRW++/+ 259/80 D5 MT 400 286/50 D7 TOP 400 C2120
AREA 5TRW-/- 330/55 266/105 75W C2120 MT 390 AT 290/70
^MH114 NI41=

Figure 11 Alliance radar observations

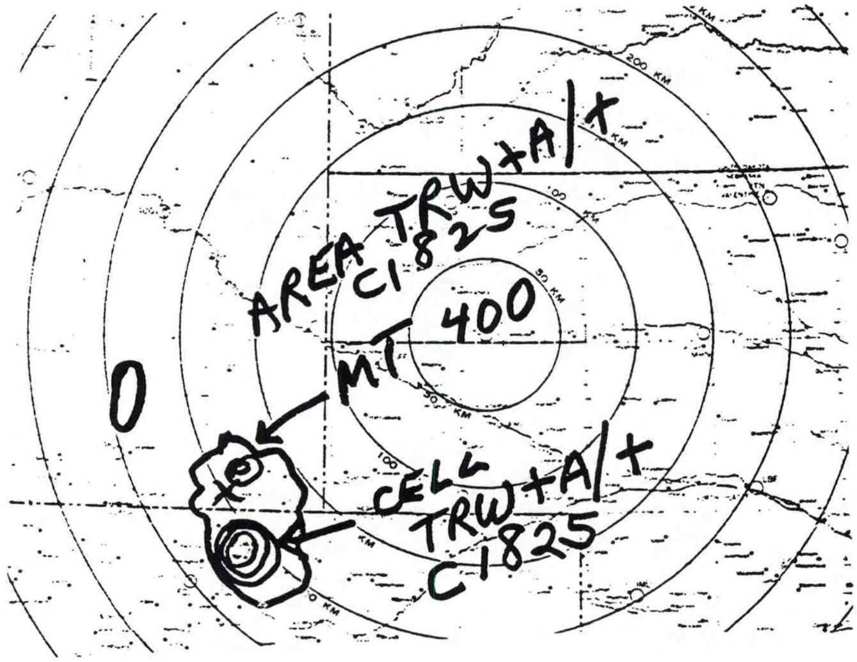


Figure 12 Alliance radar overlay for May 19 1991 0125z
X marks Cheyenne

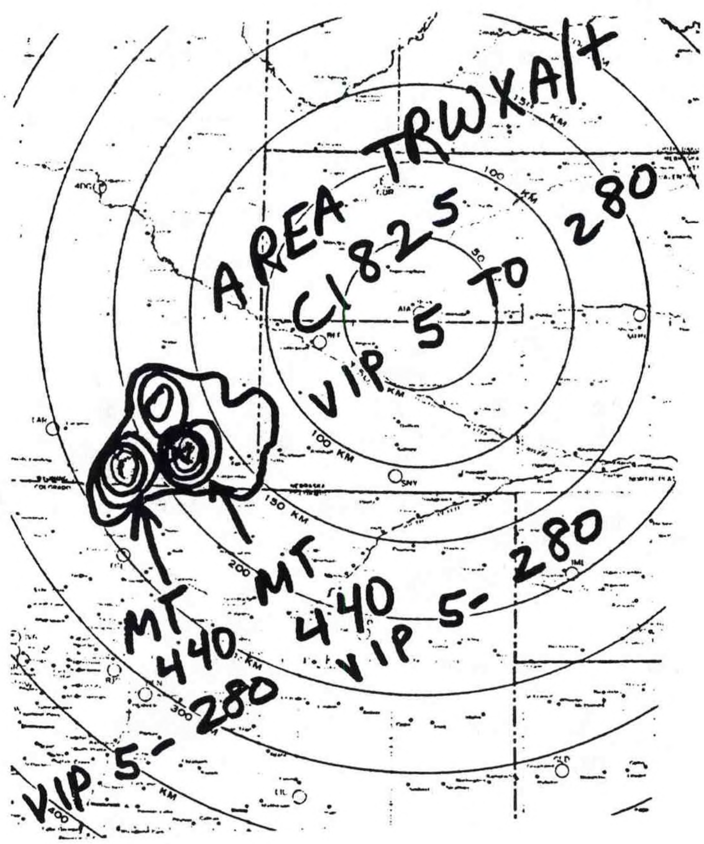


Figure 13 Alliance radar overlay for May 19 1991 0230z
X marks Cheyenne

CENTRAL REGION APPLIED RESEARCH PAPER 8-3

FLASH FLOOD EVENT IN NORTHEAST MINNESOTA AND NORTHWEST WISCONSIN SEPTEMBER 5-6 1990--A BACKWARD PROPAGATING MCS

Carol Christenson
National Weather Service Office
Duluth, Minnesota

1. Introduction

In the past few years, forecasters have been putting more emphasis on using theta-e[1] analysis in forecasting mesoscale convective systems (MCSs) and the heavy rainfall and flooding that can occur with them. Backward (westward) propagating MCSs often move along the gradient of the theta-e ridge toward higher values (Robinson and Scofield 1990). This paper will show that a flash flood event that occurred over northeastern Minnesota and northwestern Wisconsin was caused by a backward propagating MCS that regenerated along and followed the 850 mb theta-e ridge

The worse flooding in over a decade occurred in northeastern Minnesota and northwestern Wisconsin during the night of September 5-6, 1990 (Fig. 1). Over ten inches of rain fell in northeastern Carlton County where damage was estimated at 1.4 million dollars. Campers were evacuated from Jay Cooke State Park for fear of a dam failure and the park was eventually closed due to culvert washouts. The flooding rains were preceded by severe weather, including baseball size hail and damaging winds. The National Weather Service Office in Duluth (WSO DLH) recorded continuous thunder from 0241Z CST September 6--almost ten hours of thunderstorms.

2. History

The morning of September 5 was marked by rain, drizzle, and dense fog over northeastern Minnesota that lasted into the early afternoon. Scattered showers had developed over north-central Minnesota by late morning. By late afternoon, showers and a few weak thunderstorms had formed a line across northeastern Minnesota and moved southeast into more unstable air.

---

[1]Equivalent potential temperature (theta-e) is the potential temperature that a parcel of air would have if all its moisture were condensed out and the resultant latent heat used to warm the parcel. Conditional instability can be expressed in terms of theta-e (Holton 1979).

At 2042Z, the storms had reached severe limits in northern Aitkin County, Minnesota, where baseball-size hail was reported. As the severe storms moved southeast across east-central Minnesota into northwestern Wisconsin, they left a trail of damage. Two-inch hail was reported in western Carlton County and trees were uprooted by strong winds just northwest of Duluth. Numerous trees were blown down in the northwestern Wisconsin counties of Washburn and Burnett.

By about 0400Z, the thunderstorms had decreased in intensity and were no longer considered severe; however, they were causing tremendous amounts of rain. The radar operator at WSO DLH noticed the storms were moving over the same areas that had received severe weather earlier. The WSO DLH began issuing flash flood warnings, early September 6, for Carlton and southern St. Louis Counties in Minnesota and Douglas County in Wisconsin. Warnings for Carlton and Douglas Counties had to be extended because the storms continued to redevelop and move over the same areas in a train effect (Berkowitz 1988). The line of storms extended in a northwest to southeast line from northern Aitkin County in Minnesota to Douglas and Bayfield Counties in Wisconsin.

3. Synoptic situation:

At 1200Z September 5, a surface stationary front was over southern South Dakota through northern Iowa and Illinois. During the day, the front pushed northward as a warm front and a meso low formed over eastern South Dakota (Fig. 2). The air mass was unstable along and north of the surface boundary. As shown by the positive area, considerable convective instability existed on the 0000Z St. Cloud sounding (Fig. 3). The SHARP Workstation computed the CAPE at St. Cloud to be 4767 J/Kg. The CAPE may have been significantly greater than this value, since the effect of virtual temperature was not included in the calculation. The Lifted Index at 500 mb decreased from -2 at 1200z September 5 to -9 at 0000Z September 6. During the same time period, Totals rose from 44 to 50 and the SWEAT INDEX increased from 238 to 368.

The high values of theta-e were a good indicator of the presence of conditional instability and moisture across northeast Minnesota and northwest Wisconsin. Analyses of 850 mb theta-e for this event (Figs. 4a-4b) were derived using the PC-THETAE computer program. The 850 mb theta-e ridge (maximum value of 343 °K) at 1200Z September 5 was broad and extended from eastern Montana through central Minnesota into northwest Wisconsin. By 0000Z September 6, the theta-e ridge (maximum value of 346 °K) had increased in amplitude and was positioned across northern Minnesota and extreme northwest Wisconsin.

The abundant moisture in the atmosphere was evident on many other products. The precipitable water analysis showed that a ridge of over 1.50 inches was over Minnesota and western Wisconsin at 0000Z September 6. South of the front, surface dew points were in the 70s, while north of the fronts dewpoints rose from the middle 50s in the morning into the middle 60s in the afternoon.

At 850 mb (not shown) a closed low was over western Nebraska with strong warm advection into much of Minnesota, except in the far northwest. A 30 knot low level jet from Kansas through central Minnesota provided a significant source of moisture and warm advection which enhanced and focused the destabilization process. As noted in Maddox (1983) and Cotton et al. (1989), the low level jet appears to be a strong influence on larger MCSs, especially when it occurs on the southwest flank of the MCS as it did in this case.

The 500 mb circulation exhibited a zonal west to east flow at 35 knots over northern Minnesota. A large high pressure area covered almost all of the lower 48 states. At 0000Z September 6, a weak vorticity maximum was over western North Dakota, but there was little positive vorticity advection (PVA). This is consistent with Maddox (1983), who notes that PVA plays only a minor role in large MCS development, while temperature and moisture advections are the most important factors.

Easterly surface winds north of the front combined with the low level jet and 700 mb westerlies to create good directional shear. However, there was very little shear above 700 mb. Maddox (1983) found that MCSs tend to occur on the anticyclonic side of a westerly jet stream. In this case there was a 300 mb jet streak of 70 knots over the Northern Plains into extreme northern Minnesota. It is important to note that the upper level winds were nearly parallel to the surface front. Maddox et al. (1979) describes this type of wind field as the most conducive for the formation and longevity of an MCS.

Maddox et al. (1979) also found that many MCS flash flood events are preceded by severe weather as did the one in this study. The severe weather occurred near the intersection of the low level jet and the mid-level jet just south of the upper level jet streak and just north of the surface warm front in the most favorable wind shear zone. As the storms moved into an area of weaker wind shear they decreased in severity. Maddox (1980) found that on occasion an MCS will form when the cool outflow boundary generated from earlier thunderstorms acts to strengthen the surface front, which increases both convergence and vertical velocity. This is likely what generated the MCS in this case.

By studying the satellite photos (Figs. 5a-5c) and mentally overlaying the 0000Z September 6 theta-e analysis (Fig. 4b), one can see that this MCS did propagate westward along the theta-e ridge. This is supported by the flash flood warning and statements issued that night, as well as by the precipitation reports. They indicate that this is where the heaviest and longest-lasting rain occurred. As Robinson and Scofield (1990) and Maddox (1980) conclude, this is toward the area with the greatest instability, the maximum low level (inflow) winds and warm air advection, and weaker upper level winds. These are the most vital conditions that are usually present for an MCS to form and thrive.

4. Summary

The flooding rains of the night of September 5-6 occurred on the cool side of a warm frontal boundary. A cool outflow boundary from earlier convection, a low level jet bringing warm air over the frontal boundary, and overall weak wind shear all played a role in the formation of an MCS. The storms regenerated upstream along the 850 mb theta-e ridge toward higher theta-e values. For many hours the thunderstorm cells passed over the same area and caused flooding over parts of northeastern Minnesota and northwestern Wisconsin.

Like other flash floods in recent years, in particular the Minneapolis flash flood of 1987 (Schwarz et al. 1990) and the Iowa flash flood of 1989 (Robinson and Scofield 1990), this one was caused by an MCS that was backward-propagating along the 850 mb theta-e ridge. At the time of this event, forecasters at WSO DLH were not fully aware of the importance of the theta-e ridge. Since that time, an AFOS graphic of 850 mb theta-e plots (NMCGPH89A) has been made readily available. Forecasters at WSO DLH use it extensively now, not only to assess the heavy rain potential, but also for forecasting general convective activity.

5. Acknowledgements

Thanks to Jim Christenson, Pete Hill, and Dave McGinnis of WSO DLH who worked that night and reviewed the manuscript. Also, thanks to Rich Naistat and Steve Eddy of WSFO MSP for their help, Glenn Lussky of MSP for his editing and comments, Terry Schoeni of NSSFC and Rich Kessler of CWSU MSP for satellite photos.

6. References

Berkowitz, D. S., 1988: Radar Hydrology, NWS Training Center Publication.

Cotton, W. R., M. S. Lin, R. L. McAnelly, and C. J. Tremback, 1989: A Composite Model of Mesoscale Convective Complexes, Mon. Wea. Rev., 117, 765-783.

Holton, J. E., 1979: An Introduction to Dynamic Meteorology, New York: Academic Press, 319 pp.

Maddox, R. A., 1983: Large Scale Meteorological Conditions Associated with Midlatitude Mesoscale Convective Complexes, Mon. Wea. Rev., 111, 1475-1493.

___________, 1980: Mesoscale Convective Complexes, Bull. Amer Meteor. Soc., 61, 1374-1387.

___________, C. F. Chappell, and L. R. Hoxit, 1979: Synoptic and Meso-Scale Aspects of Flash Flood Events, Bull Amer. Meteor. Soc., 60, 115-123.

Robinson, J. and R. Scofield, 1990: Backward Propagating Mesoscale Convective Systems (MCSs) and Flash Floods, Satellite Application Information Note 90/6, Satellite Applications Laboratory, NESDIS, Washington, DC.

Schwarz, B. E., C. F. Chappell, W. Togstad, and X. Zhong, 1990: The Minneapolis Flash Flood: Meteorological Analyses and Operational Response, Weather and Forecasting, 5, 3-21.

Scofield, R. A. and J. Robison, 1990: The "Water Vapor Imagery/Theta-E Connection" With Heavy Convective Rainfall, Satellite Applications Information Note 90/7, Satellite Applications Laboratory, NESDIS, Washington, DC.

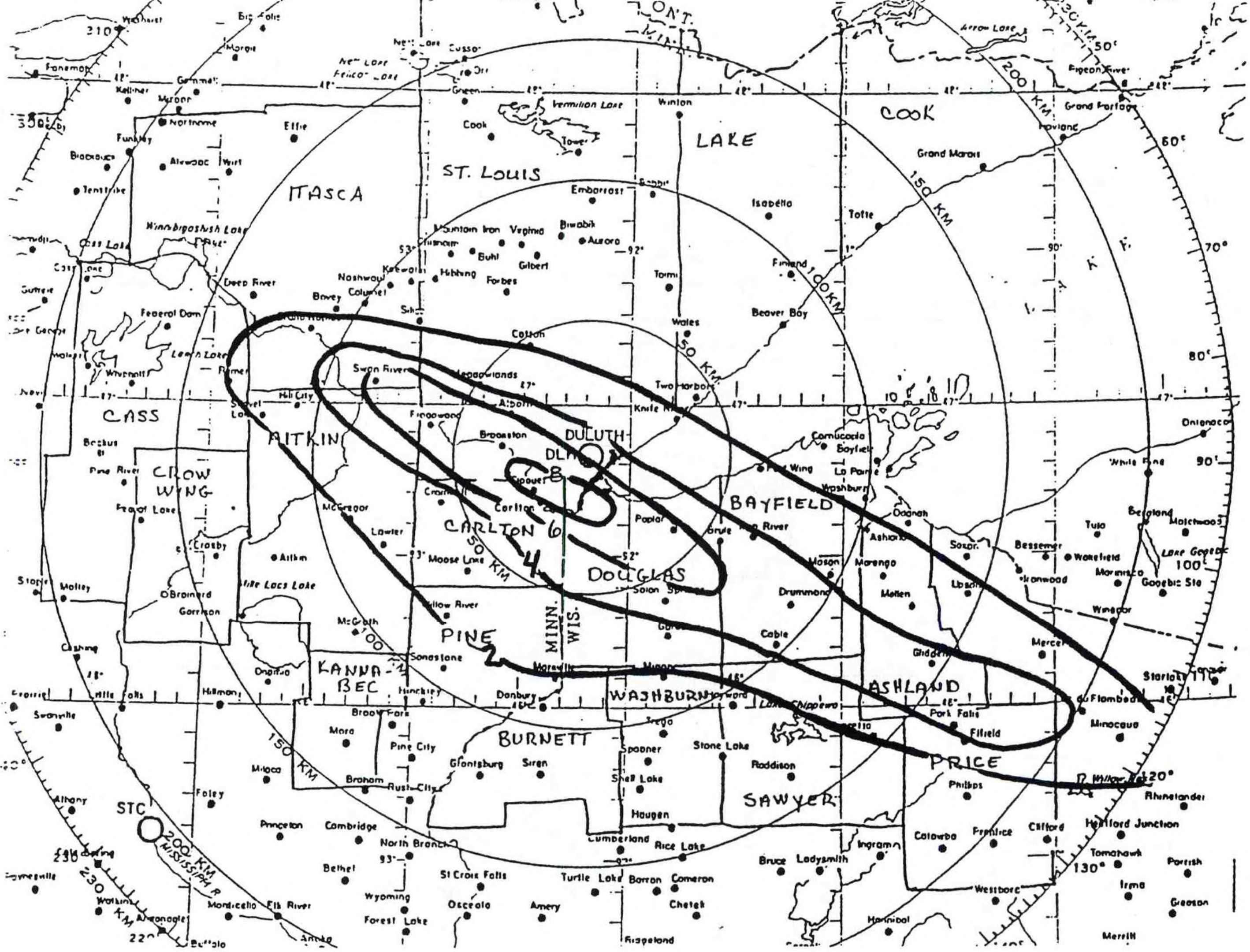


Fig. 1. 24 hour precipitation amounts (inches) from 1200Z September 5 to 1200Z September 6, 1990. Data includes more than 40 reports from the NWS and MN DNR, State Climatology Office.

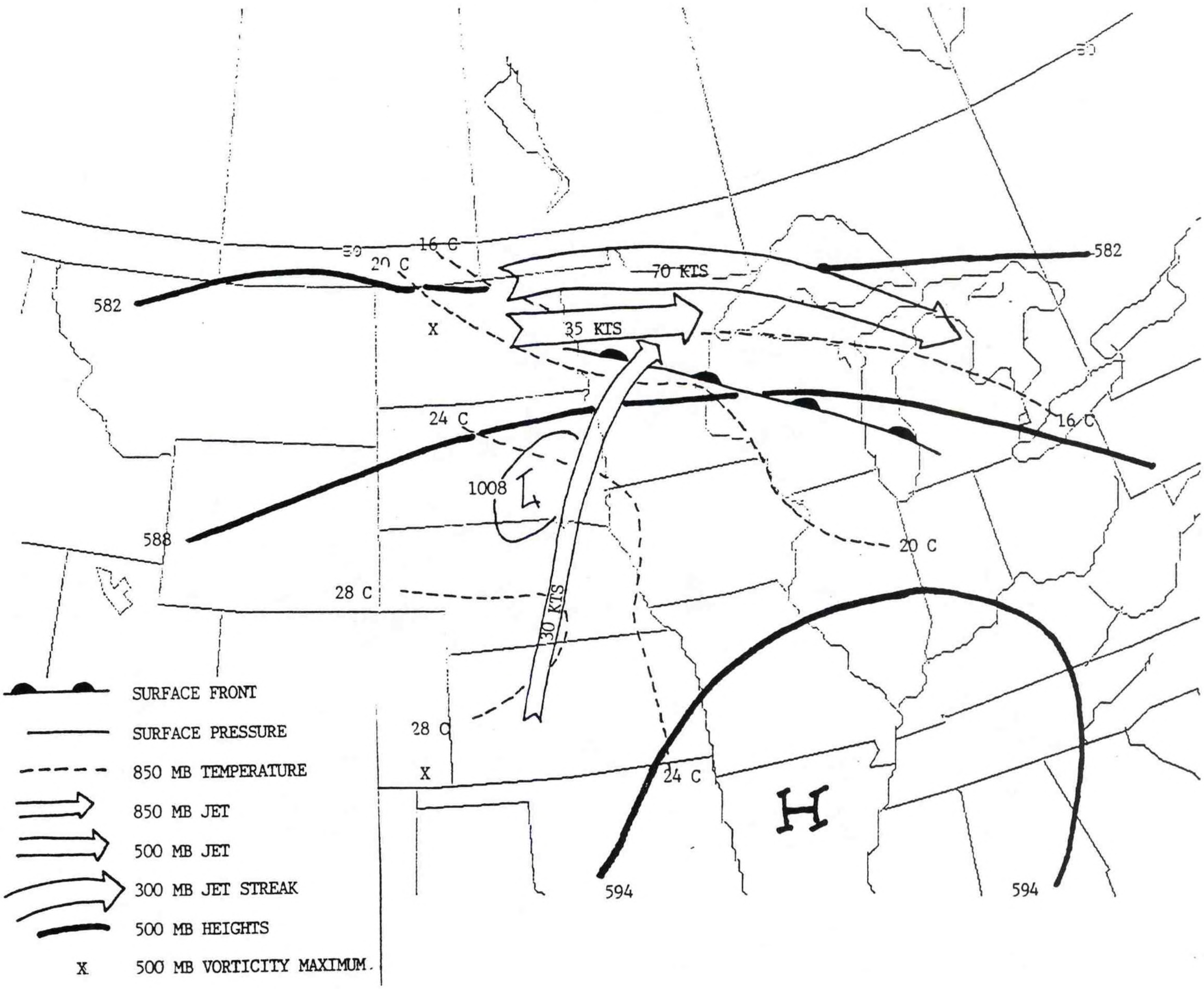


Fig. 2. Composite chart for 0000Z September 6, 1990.

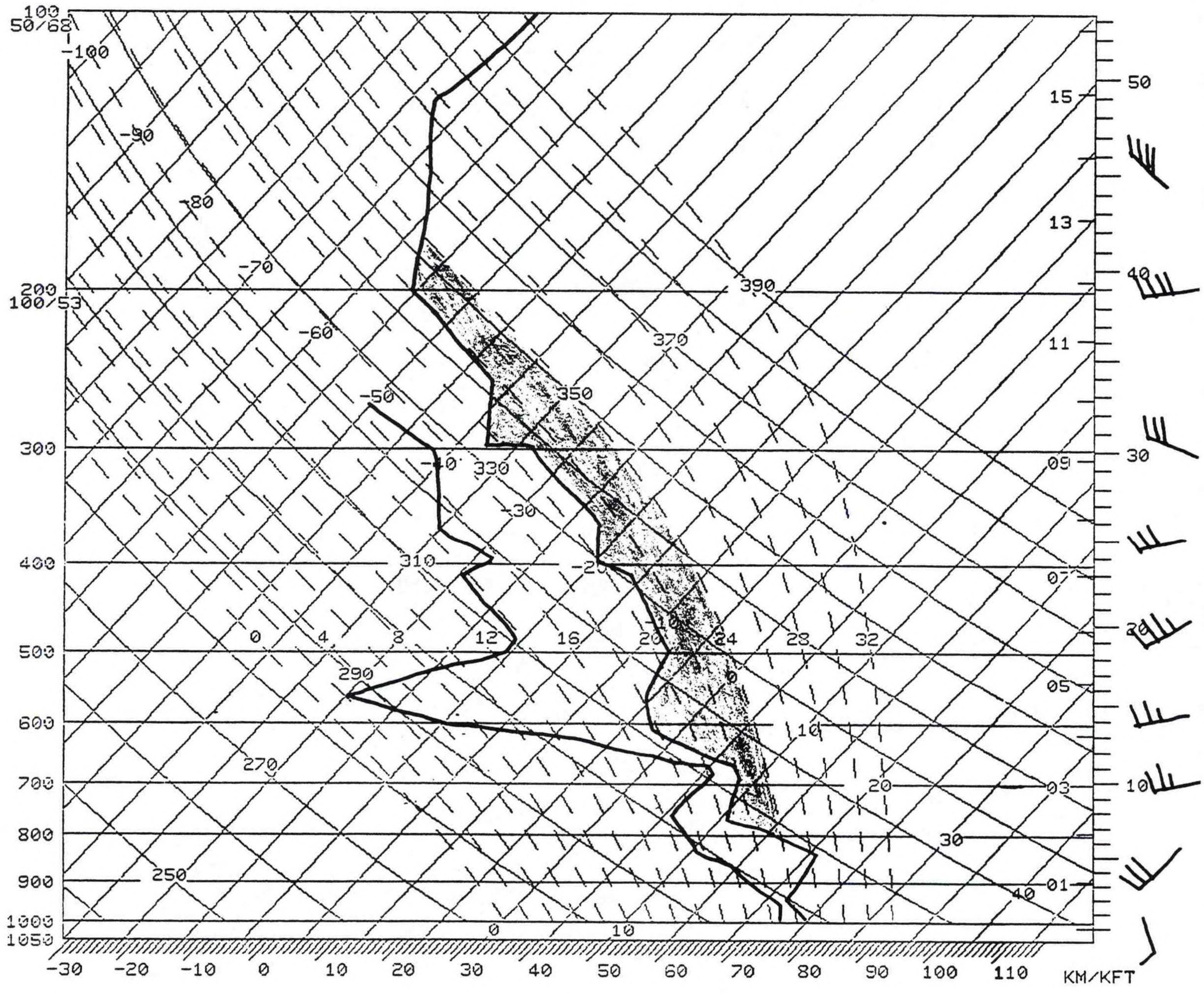


Fig. 3. 0000Z September 6, 1990 for St. Cloud MN. Shaded area is positive bouyancy area.

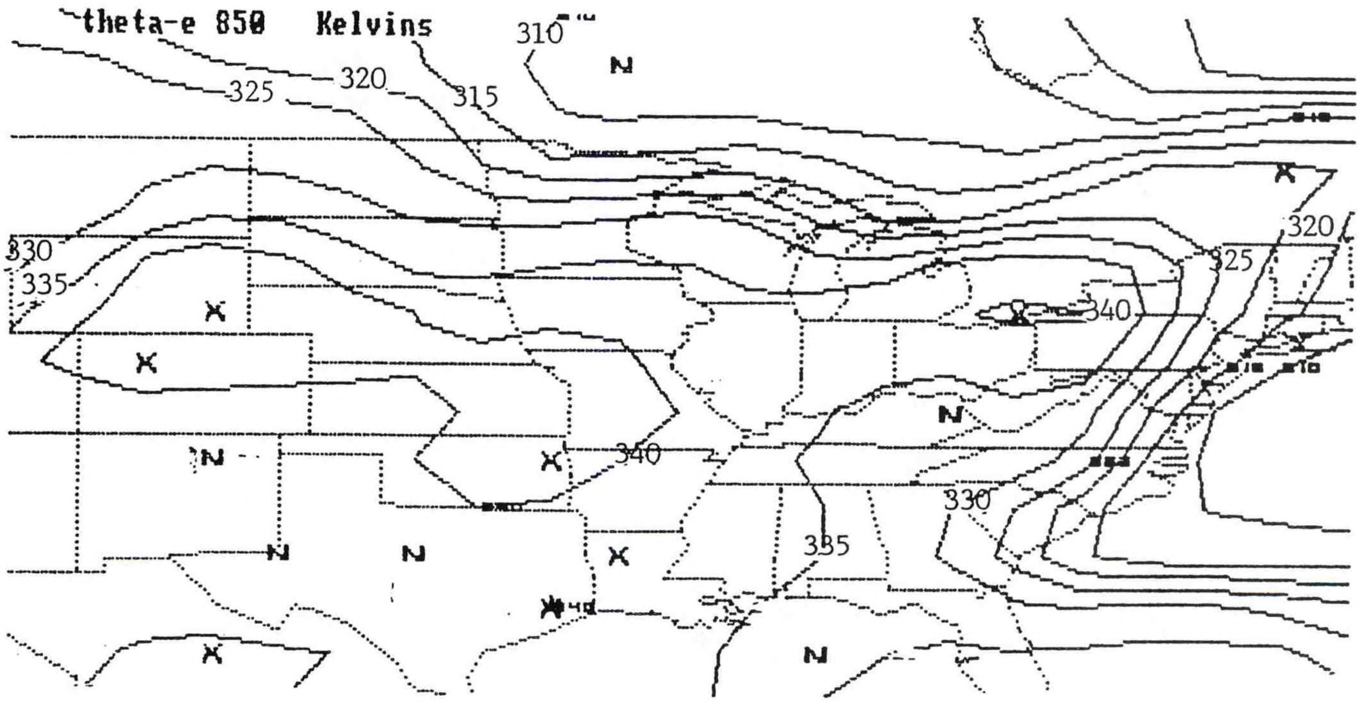


Fig. 4a. 850 mb Theta-e analysis for 1200Z September 5, 1990.

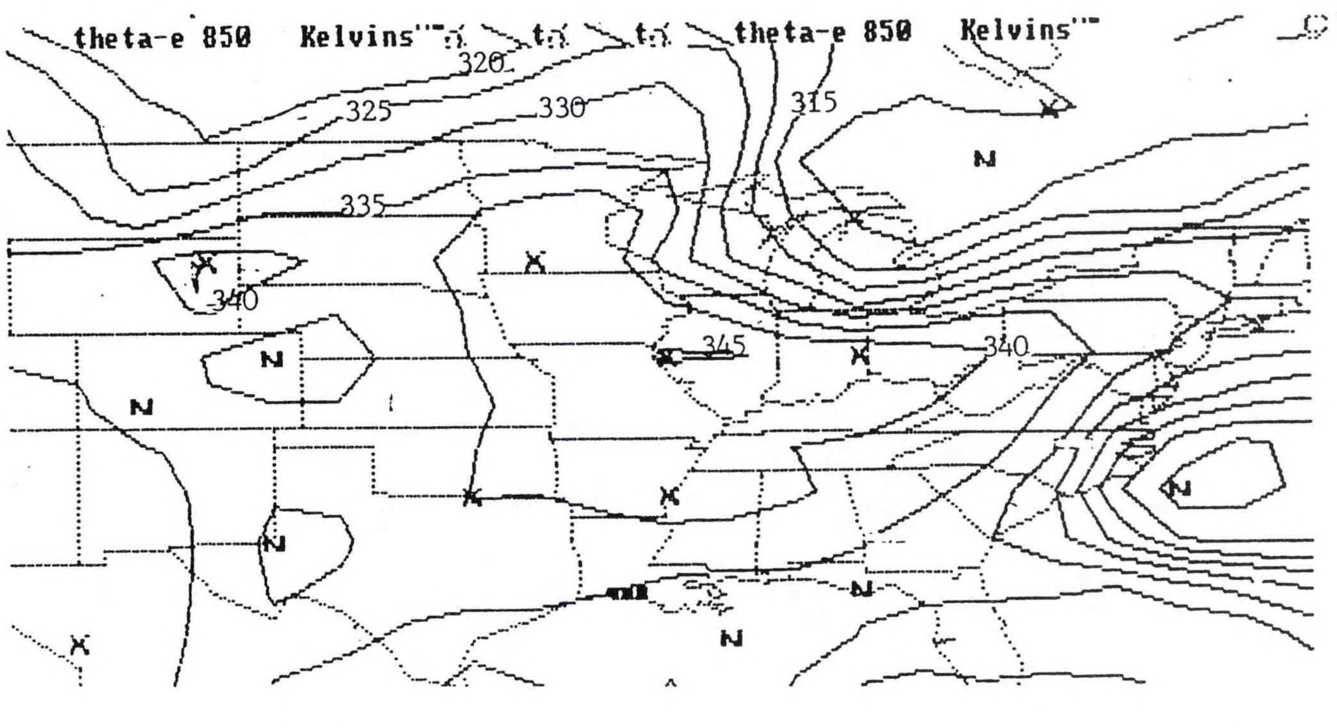
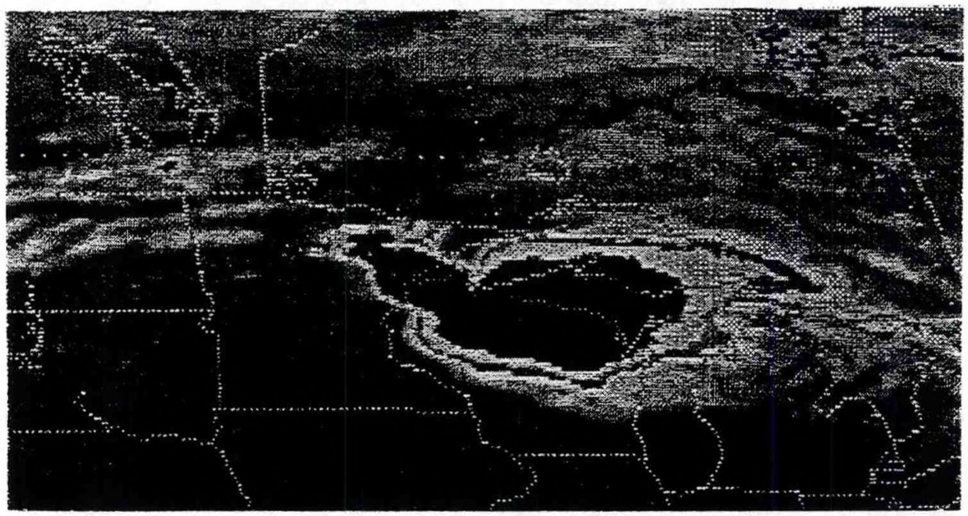


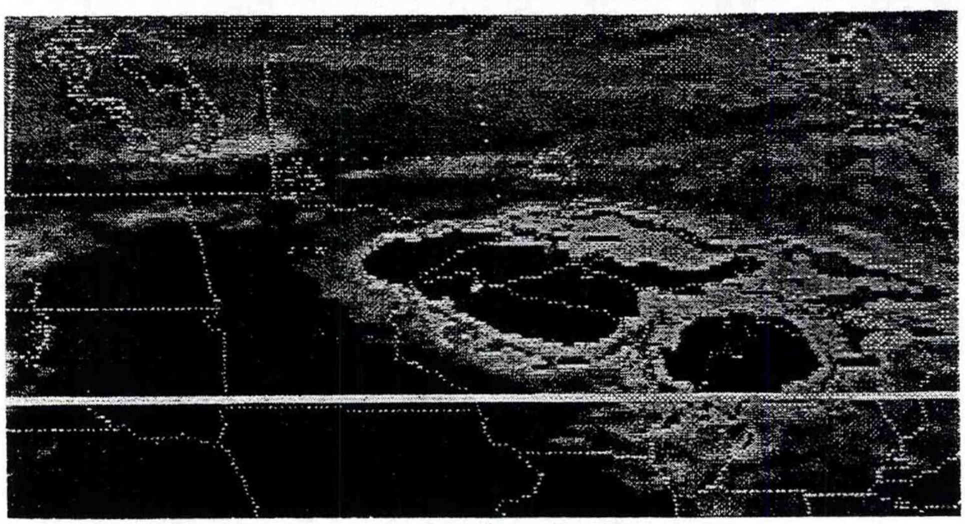
Fig. 4b. 850 mb Theta-e analysis for 0000Z September 6, 1990.

5a. 0001Z

5b. 0401Z



5c. 0801Z



Figs. 5a-5c. Time series of IR satellite imagery from September 6, 1990.

CENTRAL REGION APPLIED RESEARCH PAPER 8-4

AN ANALYSIS OF ISOLATED YET VIGOROUS CONVECTIVE DEVELOPMENT IN NORTHEAST IOWA

Paul A. Collar
National Weather Service Office
Waterloo, Iowa

1. Introduction

During the evening hours of June 18, 1991, a small cluster of thunderstorms developed in north-central Iowa along the Iowa/Minnesota border. A small tornado formed near New Hampton as the thunderstorms expanded southward. The thunderstorms also produced golf ball to tennis ball size hail. The event was characterized by strong mesoscale forcing in an overall weak synoptic scale setting. This paper will overview the factors that led up to the development of severe convection.

2. Synoptic Discussion

2.1 Surface

At 0000Z a wind shift boundary extended from northwest Wisconsin through extreme southeast Minnesota into north-central Iowa (Fig. 1). The pressure gradient over the Upper Midwest was very weak, producing light surface winds. Thus, convergence along the surface boundary was weak. Temperatures either side of the front were in the middle 80s. Across northeast South Dakota and central Minnesota temperatures were in the 70s. The most noticeable feature on the surface chart was the wind shift boundary signaled the start of some drier air moving into northwest and north-central Iowa.

2.2 850 MB Analysis

The 0000Z 850 mb chart showed an area of high pressure over Iowa (Fig. 2). The wind field was weak and low-level warm advection was absent. With these unfavorable conditions, one could conclude that severe convection chances were minimal. However, the 850 mb moisture field illustrated that the environment was sufficiently moist for severe convection with dew points around 10 °C. A moist axis extended from east-central Minnesota into central Iowa. The best moisture, however, was wrapped up in the circulation of a low in the Gulf states and was being shunted westward into the central plains with the help of the ridge in Iowa. A sustained inflow of moisture at 850 mb was not occurring prior to the onset of convection.

2.3 700 mb Analysis

The 0000Z analysis at 700 mb (Fig. 3a) showed an elongated ridge of high pressure that extended from the southern plains through Iowa into the Great Lakes. The strongest wind field was northwest of Iowa with a 30-35 knot jet maximum from North Dakota into Minnesota. The southern edge of a trough in Canada was located Dakota/Minnesota border. There was some drying behind this feature (Fig. 3b), however, dry air intrusion into northeast Iowa appeared minimal. In fact, it appeared that moisture advection was in progress. There was a band of dry air that was being brought southwestward around the periphery of the high with maximum drying occurring just south of Iowa and in the Great Lakes. However, a forecast discussion from Milwaukee/Sullivan (Fig. 4) noted a dry punch moving into Iowa as noted then on water vapor imagery.

2.4 500 MB Analysis

The 0000Z analysis at 500 mb (Fig. 5) illustrated that Northern Iowa was under the influence of a 35 to 40 knot jet. A stronger segment of the jet (50 knots) was moving through Montana and the Dakotas. A key feature at this level was the 35 to 40 knot westerly jet moving through the Dakotas and Minnesota which turned southwest at Green Bay signaling the presence of a wave of energy moving through the region. This wave extended southward from low pressure north of Lake Winnipeg. The jet segment moving through the Dakotas split slightly upon approaching Iowa signaling the presence of weak diffluence. Upon further inspection, moisture was being advected eastward with the jet; height falls were occurring in northern Minnesota with 10-30 meter rises over most of the midwest. Temperatures at this level were sufficiently cool for severe convection with readings between -10 and -13 °C.

2.5 300 MB

The 0000Z 300 mb analysis (Fig. 6) showed that Northern Iowa was not situated in a favorable jet quadrant for severe weather (left front or right rear). The more suggestive dynamics were focused from Montana through the Dakotas into Northern Minnesota in conjunction with an 85 knot jet stream. However, some diffluence in Northern Iowa was suggested by the wind regime in southern Minnesota and western Iowa.

3. Mesoscale Analysis Using the ADAP Fields

Given the weak synoptic-scale features of this environment, a detailed analysis of the mesoscale fields is a must to isolate the areas most prone for convective development. Analyses from the ADAP program suggested that convective weather was possible over northeast Iowa on this day.

At 0000 UTC, the parcel lifted index panels showed extreme instability over northeast Iowa with values of -6 to -8 at 500 mb (Fig. 7) and -11 to -13 at 300 mb (Fig. 8). The area showed a capping strength of 1 °C, hence a lid on convection was not present. The moisture flux convergence field (Fig. 9) showed a divergence/convergence couplet extending from south-central Minnesota through central Iowa. This was also in a region of maximum surface mixing ratio (Fig. 10).

4. The Storms

Convective development took place shortly before 0001Z along the Iowa/Minnesota border 20 miles northwest of Decorah. These storms had become VIP 5 by 0115Z with maximum tops reaching to 42000 feet (Fig 11). The cells propagated southward and at 0203Z a hook echo was detected 35 miles north of Waterloo, or about 5 miles north of New Hampton. A small tornado touched down in the New Hampton vicinity shortly thereafter. The tornado was short lived and caused no damage. Between 0115Z and 0240Z there were reports of golf ball to tennis ball size hail in a corridor that extended from 50 miles north to 30 miles north of Waterloo.

5. Summary

This storm situation falls well short of what would be considered an "outbreak". However, it highlights the subtleties that contribute to summertime severe local storms. Many variables for severe storm formation were missing (the low-level jet, strong speed maxima, warm air advection, and a sharp cold front). The main ingredients for this event were 1) extreme instability, 2) an approaching wind shift boundary, 3) dry punch evidenced by water vapor imagery, 4) surface moisture convergence, and lastly 5) upper diffluence.

6. References

Bothwell, Philip D., 1988: Forecasting Convection with the AFOS Data Analysis Programs, NOAA Technical Memorandum NWS SR-122.

Johns, Robert H. and staff of the National Severe Storms Forecast Center., 1986: Parameter Patterns and Other Considerations.

State Forecast Discussion: National Weather Service-Milwaukee (Sullivan), June 19, 1991 0002Z.

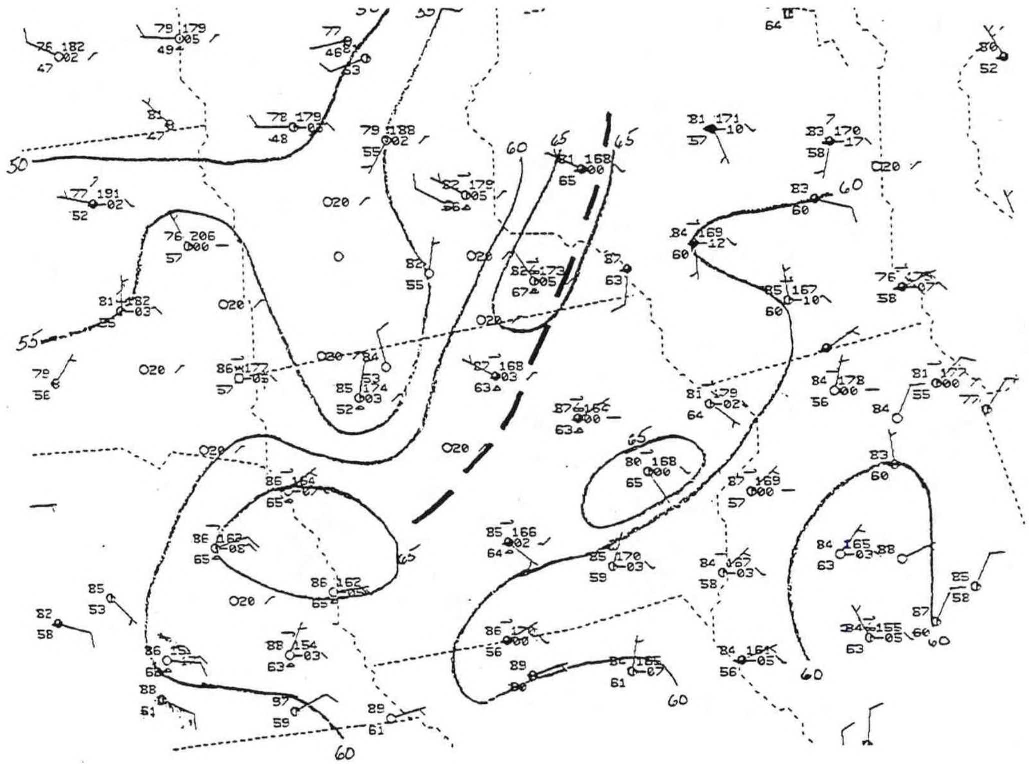


Fig. 1. Surface Map at 0000Z June 19, 1991 (Isodrosotherms every 5 °F) (wind shift indicated by dashed line).

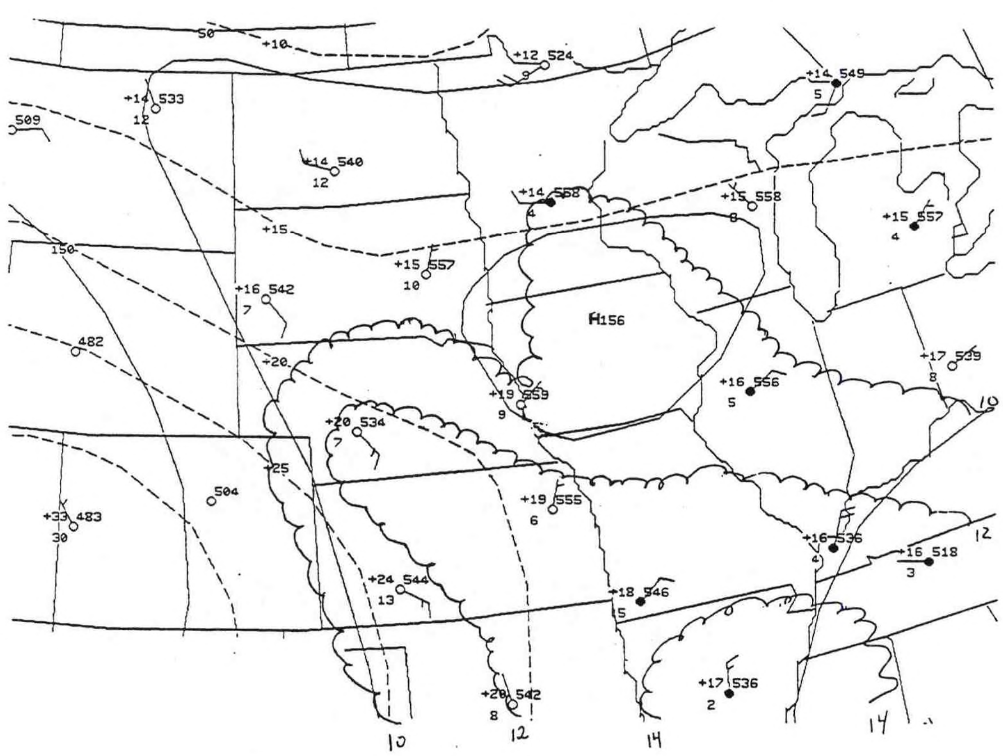


Fig. 2. 850 mb map at 0000Z June 19, 1991 (Isodrosotherms scalloped for every 2 °C starting at 10 °C).

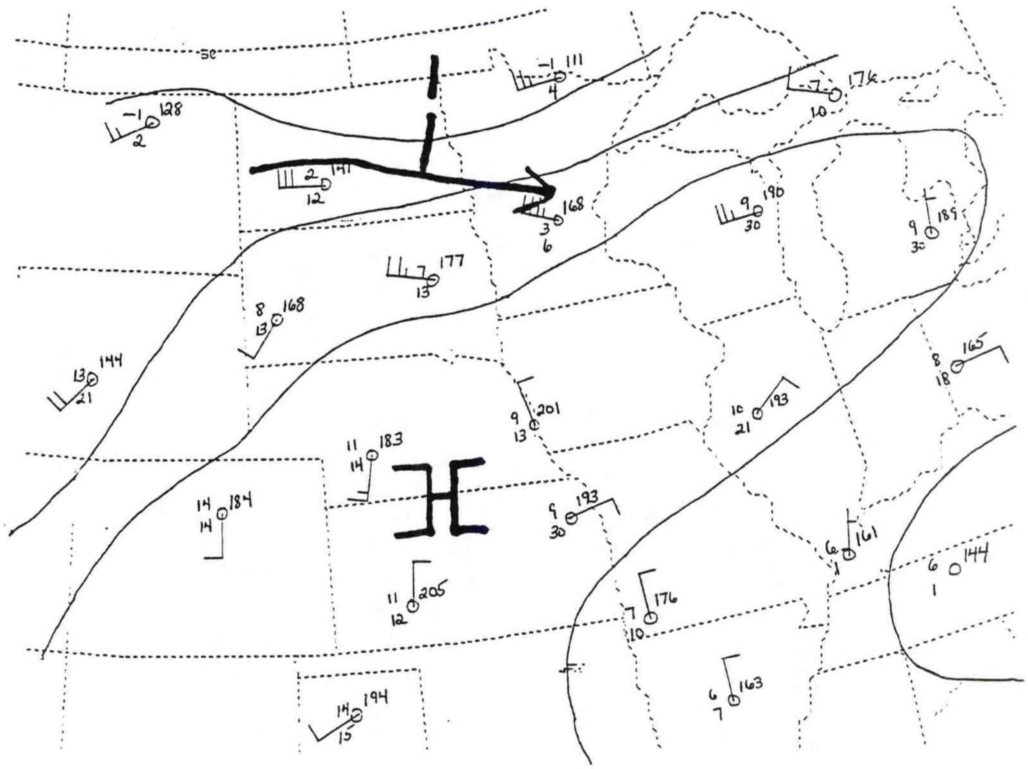


Fig. 3a. 700 mb map at 0000Z June 19, 1991 (dashed line represents short wave) (arrow representing jet-max).

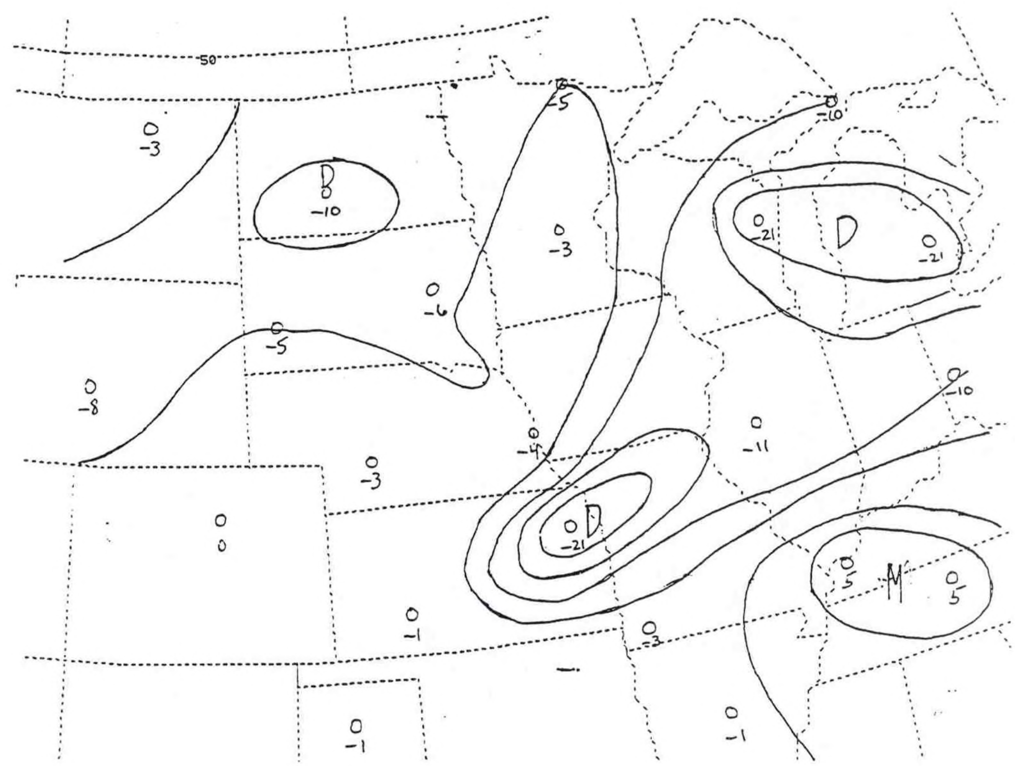


Fig. 3b. 700mb moisture analysis at 0000Z June 19, 1991 (isodrosotherms every 5 °C).

ZCZC MKESFDMKE
TTAA00 KMKE 190216

WATER VAPOR LOOP ON SWIS SHOWS NICE DRY PUNCH WORKING ACROSS IA INTO WI. THIS IN COMBO WITH COLD MID LEVEL TEMPS (REF STC H7 TEMP +3)...WK WND SHFT LINE AND DIFFLUENT H3 FLOW...JUST ENOUGH TO SET A FEW TSTMS OFF IN NRN IA. ADAP/MESO PROGRAM ALSO OUTLINING SW WI WITH POTENTIAL. WIL INCLUDE SML CHC RMNDR OF NITE IN THE SW/S-CNTRL WI AS FEW TSTMS MAY DRIFT IN THERE. WSO/S HAVE DISCRETION WHETHER OR NOT THEY WANT TO MENTION IN LCL.

OTHERWISE LTL OR NO CHGS.

.WI...NONE
STUREY

Fig. 4. Milwaukee/Sullivan State Forecast Discussion June 19, 1991 0002Z.

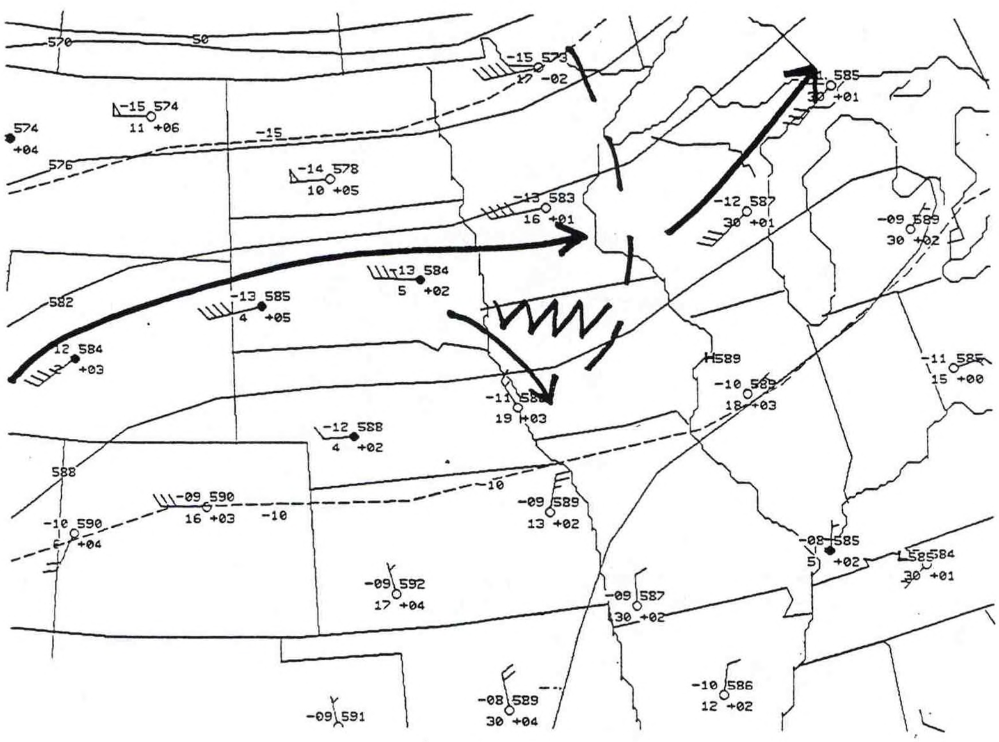


Fig. 5. 500 mb map at 0000Z June 19, 1991 (arrows correspond to jets, zig-zags to diffluence and dashed line represents short wave).

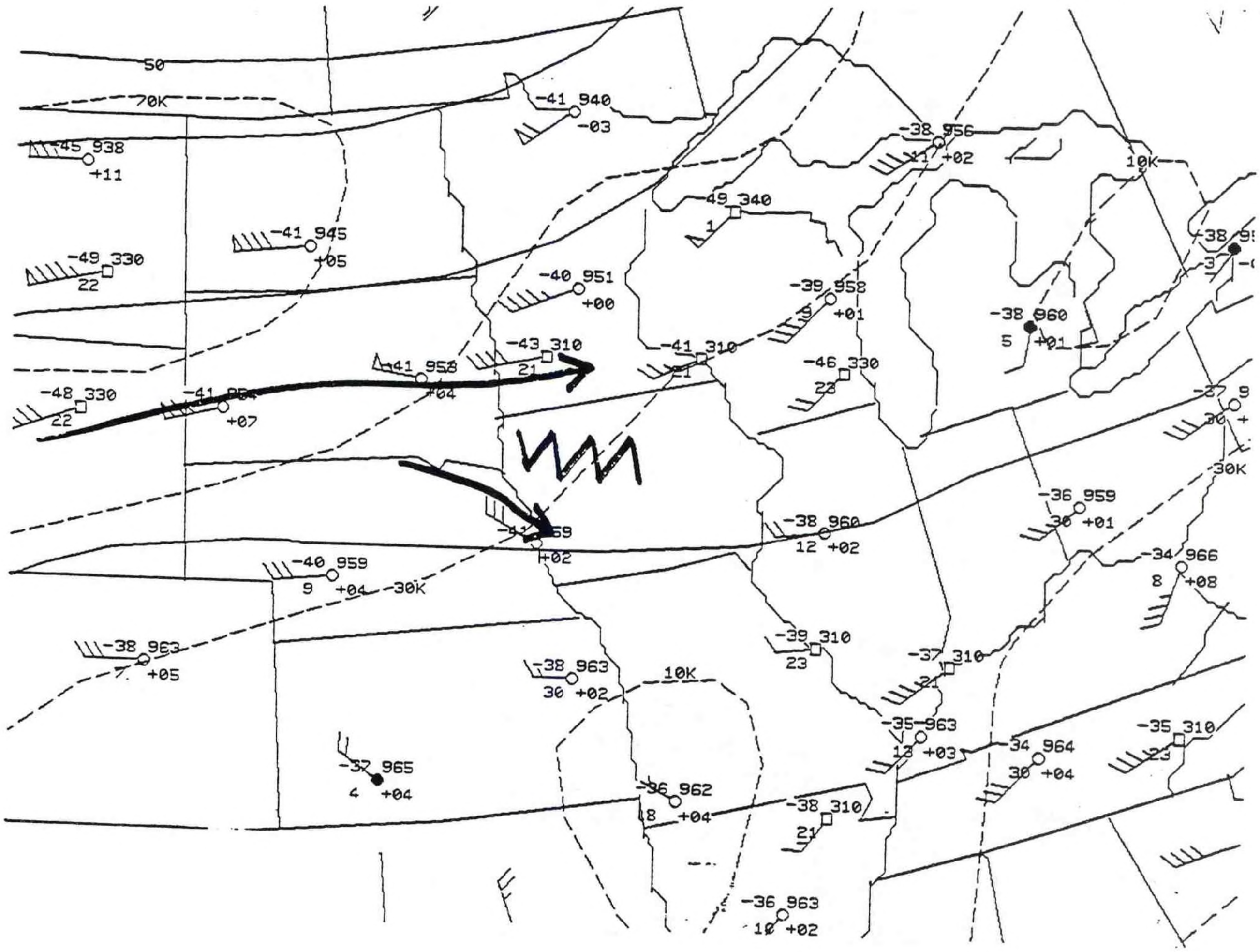


Fig. 6. 300 mb map at 0000Z June 19, 1991 (axis of diffluence represented by zig-zag) (arrows represent jets).

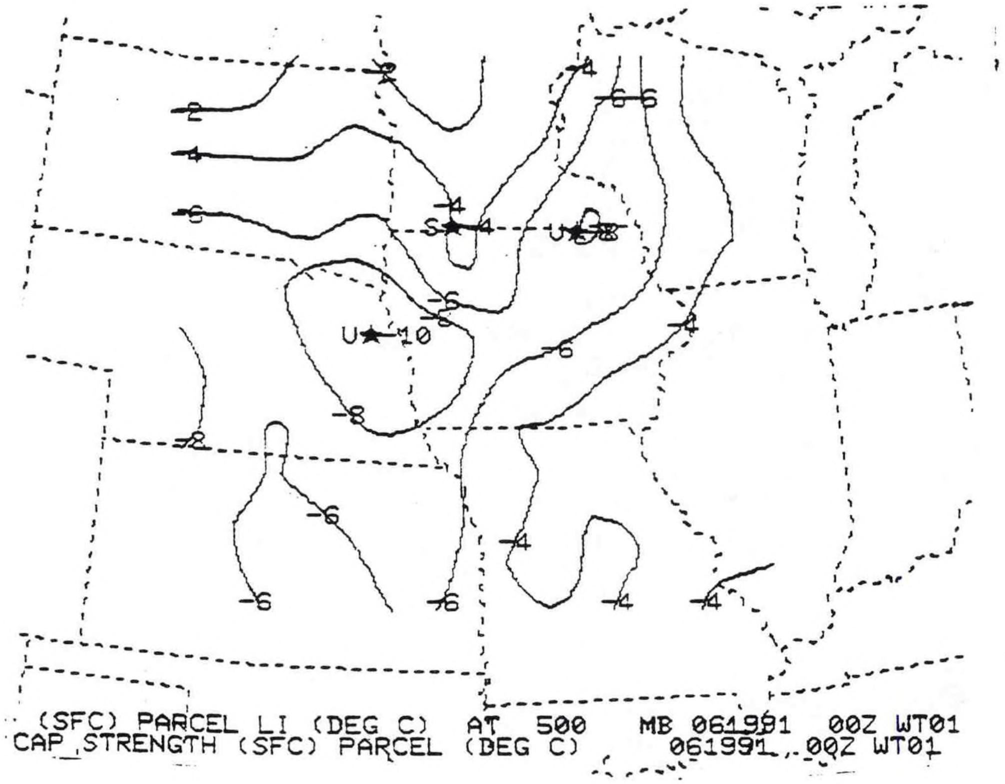


Fig. 7. Parcel Lifted Index at 500 mb 0000Z June 19, 1991.

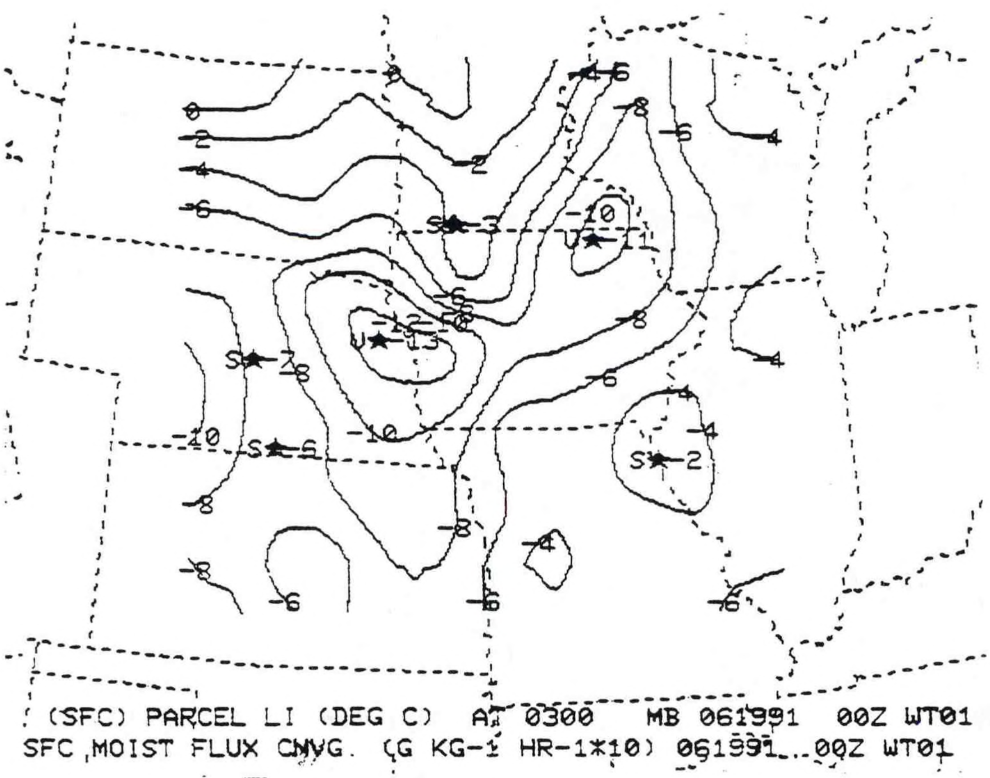


Fig. 8. Parcel Lifted Index at 300 mb 0000Z June 19, 1991.

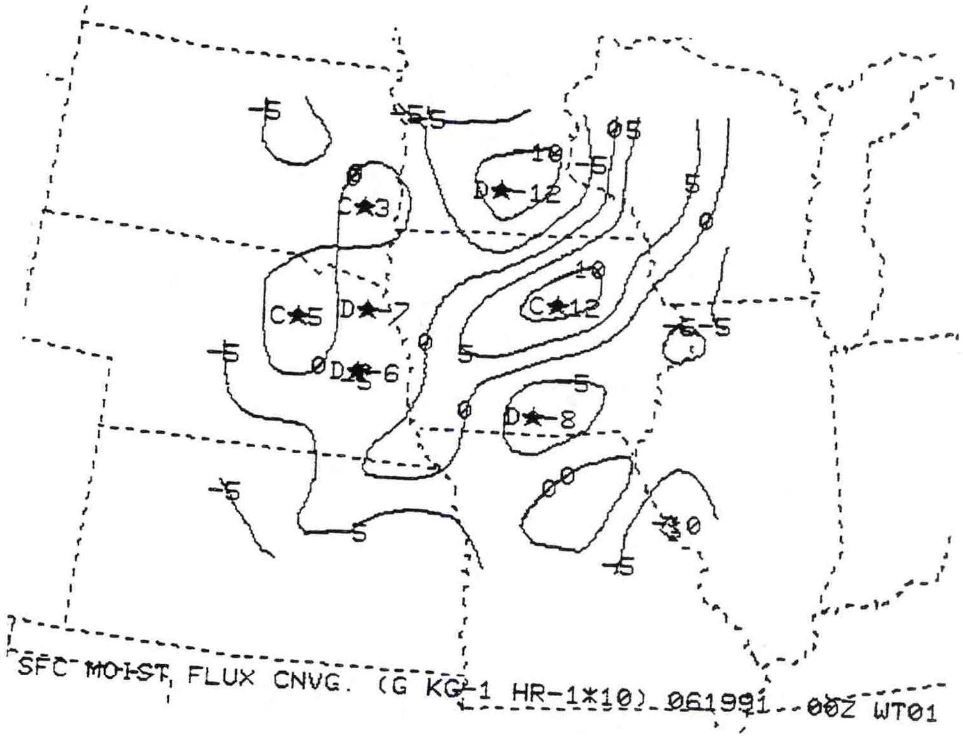


Fig. 9. Surface Moisture Flux Convergence 0000Z June 19, 1991.

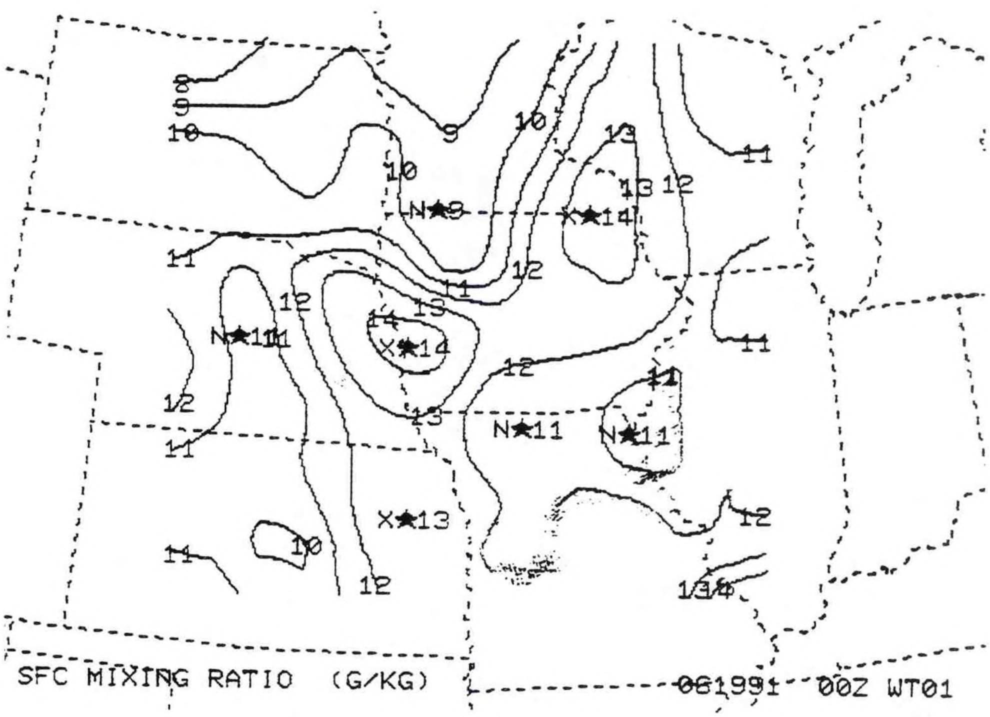


Fig. 10. Surface Mixing Ratio 0000Z June 19, 1991.

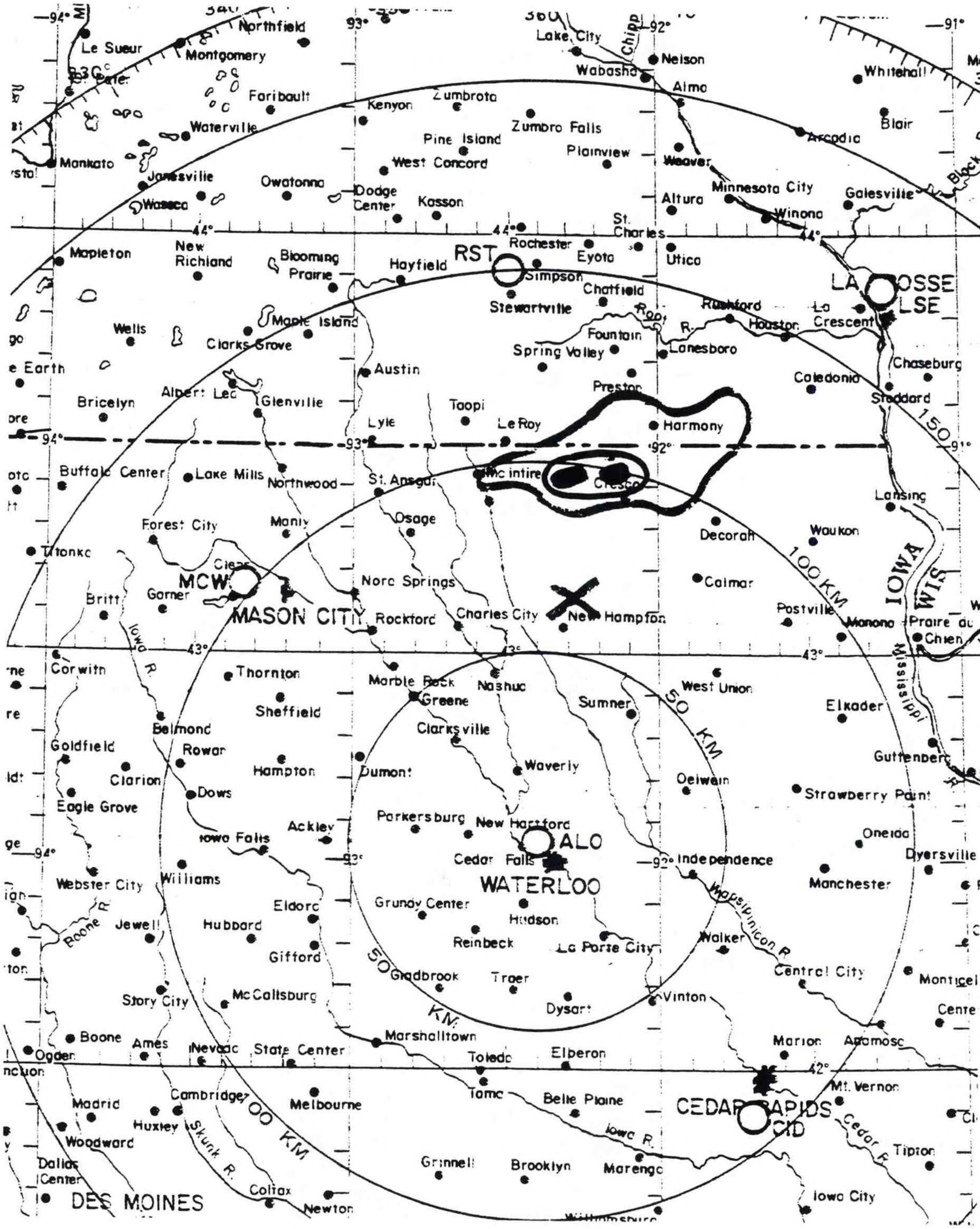


Fig. 11. Radar analysis showing VIPS 1-3-5 at 0115Z June 19, 1991 and location of hook echo at 0203Z.

CENTRAL REGION APPLIED RESEARCH PAPER 8-5

RELATIONSHIP BETWEEN LIGHTNING STRIKES AND SEVERE CONVECTION IN WESTERN WYOMING

Michael S. Weiland
National Weather Service Forecast Office
Cheyenne, Wyoming

1. Introduction

Severe thunderstorm detection over western Wyoming can be a difficult task. This is primarily due to a lack of weather radar coverage in that part of the state. In past years, most Warnings for western Wyoming have been issued after the fact. The probability of detection (POD) is quite low for the western part of Wyoming. In fact, the POD for the west half of the state in 1991 was only .125.

Recently, severe storm detection has improved some with the use of lightning and satellite data. In addition, application programs such as SHARP (Hart and Korotky 1991) and ADAP (Bothwell 1986) have improved prediction of severe thunderstorms. However, much improvement is needed for the National Weather Service to effectively meet the goal of timely and accurate Warnings for Western Wyoming.

During the past few years, much work has been done on the use of the lightning data. A number of papers have discussed the relationship between cloud-to-ground lightning strikes and the various types of severe convective weather. This paper will try to determine if the use of near real-time lightning data can improve on severe thunderstorm detection in data and population sparse western Wyoming.

2. Methodology

Severe convective weather occurrences over the west half of Wyoming were obtained (Storm Data 1988-1991). The years examined were from 1989 to early June of 1991. During that time period, there were 32 separate severe convective events in western Wyoming. Lightning data was obtained from the AOS computer in Boise, Idaho, which archives the ALDS (Automatic Lightning Detection System) data (Rasch and Mathewson 1984). However, due to various AOS computer problems, only 22 of the 32 events had useful information.

The lightning data from the AOS computer was obtained for a fifteen minute time period on either side of the time of the severe event. In addition, a thirty-mile radius of the severe event was defined to attempt to catch all of the significant cloud-to-ground lightning strikes. This data included all lightning strikes along with their location and time (in seconds) within the specified time and area. Both negative and positive cloud-to-ground strikes were included. The information from the AOS computer is also used to create the WLS (and other) AFOS graphics that are distributed every 30 minutes.

3. Data

The 22 severe weather events that were reported in western Wyoming between 1989 to early June of 1991 were broken down into types of event. The categories are: tornadoes, hail, thunderstorm winds and heavy rain. Each category was broken down into number of events, average duration of event and average cloud-to-ground strikes per event. Table 1 shows the results of the breakdown of the data.

<u>Table 1</u>

	Tornado	Hail	Winds	Heavy Rain
Number of Events	6	4	6	6
Average Duration (min)	2.0	12.7	14.1	85.0
Average C-G Strikes	10.1	12.4	21.6	78.3

Some of this data may be misleading. For example, five of the six tornado events had only two to five strikes. The other tornado event, just east of Riverton on July 9, 1989, had 44 strikes. For hail, most events had between 10 and 25 strikes with one event only recording one cloud-to-ground lightning strike. And finally, for heavy rain, a flash flood event in Rock Springs had nearly 350 strikes in its duration, significantly increasing the heavy rain category average.

The frequency of the cloud-to-ground lightning strikes is also important to consider (Kane 1991). Kane showed that a peak in lightning frequency is a precursor to severe weather. Frequency of cloud-to-ground lightning strikes for each of the four types of events in this paper is shown in Table 2.

<u>Table 2</u>

	Tornado	Hail	Winds	Heavy Rain
Frequency (per minute)	.2	1.0	.7	1.1

To make the above data perhaps more realistic, the maximum and minimum strikes per category were deleted. The results are in Table 3.

Table 3

	Tornado	Hail	Winds	Heavy Rain
Number of events	4	2	4	4
Average C-G Strikes	3.7	19.0	22.0	26.7
Frequency (per minute)	1.9	1.5	1.6	3.2

The most significant event during this study was the flash flood that occurred near Rock Springs on July 12, 1989. Most of the lightning data was available for this event. In order to check to see if the frequency or duration is the most important element, at least in heavy rain events, a breakdown of cloud-to-ground lightning in five minute increments was made for the Rock Springs event. This information is in Table 4.

Table 4

Time (UTC)	C-G Lightning Strikes
2300-2305	23
2305-2310	21
2310-2315	37
2315-2320	27
2320-2325	8
2325-2330	18
2330-2335	20
2335-2340	12
2340-2345	7
2345-2350	8
2350-0000	Missing
0000-0005	23
0005-0010	19
0010-0015	13
0015-0020	20
0020-0025	15
0025-0030	16
0030-0035	25
0035-0040	9

The heaviest rainfall with this storm occurred between 2305 and 2320 UTC. It was during that time the amount of cloud-to-ground strikes was at one of the highest levels. However, high five minute cloud-to-ground strikes also were noted throughout the duration of the storm.

4. Discussion

Numerous research has been done on cloud-to-ground lightning strikes in the past 10 years. Part of this research deals with the near real-time lightning strikes as they relate to various types of severe convective weather. For example, the most frequent cloud-to-ground lightning is often found on the leading edge of the precipitation core (Holle and Maier 1983). This would go along with research which states that updraft penetration to the -20°C level is critical for significant cloud-to-ground lightning strikes (Kieltyka and Torrence 1985). If more water is transported to this level, lightning activity will intensify. This transport of water is dependent on the strengths of the updrafts (Western Region Technical Attachment 1986).

With the nearly three years of data studied for western Wyoming, several items concerning cloud-to-ground strikes and their relationship to severe weather become evident. Data shows a pattern with the greater cloud-to-ground strikes being associated with heavy rain producers. The difference between heavy rain and flash flood producing storms is the duration of the storm as well as its movement. Both of which can be obtained by use of satellite imagery and the various lightning graphics. The other types of severe weather are not as definite in this relationship, with the exception of a minimum of strikes with tornadic storms.

Previous discussion showed that the more water that is available at the -20°C level, the more strikes. This would seem to correspond most closely with heavy rain producing cells. The Rock Springs flash flood of 1989 was discussed earlier. This event had 342 strikes during its lifetime. Mosher and Lewis (1990) stated in their study on operational use of lightning data that there appears to be a relationship between lightning frequency and rainfall rates. This look at some western Wyoming storms seems to verify that statement.

5. Summary

Cloud-to-ground lightning data was examined to determine its usefulness in helping to identify severe convection over western Wyoming. While the data was limited, the study for the three-year period seems to suggest that the higher cloud-to-ground strike producing thunderstorms tend to be heavy rain/flash flood producers in that part of the country. The events in this study are probably too small to be any statistical inferences and much more study needs to be done in the use of lightning data. The relative importance of lightning frequency and duration of the storm is still uncertain. Both appear to play a large role during a heavy rain event in western Wyoming. It is hoped that improvement on the use of lightning data and satellite imagery will aid in more timely and accurate detection of severe weather in data sparse western Wyoming.

6. Acknowledgments

The author would like to thank Mr. Joel Tannenholz of WSFO Boise, Idaho, for his help in obtaining the lightning data.

7. References

Bothwell, Philip A., 1986: Meso Data Analysis, Southern Region Technical Attachment. Notes 1-7.

Hart, J.A. and W.B Korotky, 1991: The SHARP Workstation - V1.50, A Skew T/Hodograph Analysis and Research Program for the IBM and Compatible PC Users Manual, NOAA/NWS/NWSFO Charleston, WV 62 pp.

Holle, R.L. and M. W. Maier, 1983: Radar Echo Heights Related to Cloud-to-Ground Lightning in South Florida, Preprints 12th Conference on Severe Local Storms, pp 330-333.

Kane, Richard J., 1991: Correlating Lightning to Severe Local Storms in the Northeastern United States, Weather and Forecasting, Vol. 6, No.1 pp 3-12.

Kieltyka, F. and J. Torrence, 1985: 20 Below Celsius...A Number to Remember, Eastern Region Technical Attachment, July.

Mosher F. R. and J. S. Lewis, 1990: Use of Lightning Location Data in Severe Storm Forecasting, Preprints 16th Conference of Severe Local Storms: Conference on Atmospheric Electricity.

Rasch, G.E. and M. Mathewson, 1984: Collection and use of Lightning Strike Data in the Western U.S. During Summer 1983, NOAA Technical Memorandum WR-184.

U.S. Department of Commerce: Storm Data, May 1989-June 1991.

Western Region, 1986: Characteristics of Lightning, Technical Attachment 86-18, April.

CENTRAL REGION APPLIED RESEARCH PAPER 8-6

ON THE WSR-88D, VERIFICATION, AND THE AUDIO SPECTRUM ANALYSIS OF SFERICS

Mark E. Ewens
National Weather Service Office
Fargo, North Dakota

1. Introduction

The current methodology of verifying severe thunderstorm and tornado warnings has several shortcomings that will affect the rated efficiency of the Next Generation Weather Radar (WSR-88D). There will be instances where the warning verification efficiency (VE) (Grenier et al. 1986) will show little change between the old technologies and the new technologies. This, in turn, will not reflect the full impact new technologies will have in the Modernization and Associated Restructuring (MAR). An alternative verification procedure used at WSO Fargo during the Audio Spectrum Analysis of Sferics (ASA) experiment is described.

2. Restructuring and Verification

The National Weather Service (NWS) has begun a massive restructuring which will result in improved warning and forecast services to the Nation. On the forefront of this effort is the Weather Surveillance Radar-88 Doppler (WSR-88D), a Doppler radar with an impressive first year operational record.

There is much justification behind the deployment of this technology, including a) improve the Radar coverage across the Nation; b) improve the understanding of the atmosphere by detailing atmospheric processes on the storm scale as well as synoptic scale; c) replace an aging radar system, and d) improve the national warning program.

The present weather Radar system is comprised primarily of the WSR-57 and -74 series which are conventional (non-Doppler) Radars. In 1990, the current Radar technology (Central Region statistics) produced a False Alarm Ratio (FAR) of 67%, a Probability of Detection (POD) of 56%, and a Critical Success Index (CSI) of 26%. Comparatively, the Norman, Oklahoma Operational Test and Evaluation in 1990, which employed the operational NSSL Doppler, yielded significantly higher PODs and CSI with a much lower FAR.

Lightning data and satellite data are tools which may assist in the warning decision, but at present, it is data and techniques derived from the WSR-57 and -74 radars on which most warnings are based. Several problems have been identified using these techniques in the Northern Plains, particularly the WRIST technique (Lemon 1974; Ewens 1986, 1988, 1989). The WSR-88D appears to have overcome many of the problems in severe storm signature detection, but fundamental problems remain.

Warnings are verified using a technique based on the number of counties warned versus the number of counties for which severe weather is reported.[1] In areas with a population density that allows for easy storm verification, this will yield low FAR's, high POD's and CSI's. In rural areas, such as North Dakota and northern Minnesota, this is not the case. Roughly two-thirds of WSO Fargo's County Warning Area (CWA) fall into the rural[2] category. This is a major reason WSO Fargo has a low CSI and high FAR; the lack of population base to verify warnings (Hales, 1987).

It has already been demonstrated by Hales (1987) that the number of severe weather reports is directly proportional to the size of the population density in which the event occurs. Since the current Warning Verification Program (WVP) verifies a severe weather warning via the number of counties it covers (Donaldson et al 1975), the WSR-88D will likely show little improvement in rural states. The NWS Headquarters has stated, "No significant change is planned for the manner in which warnings are verified" in the -88D era (LFTAC Notes 1991). If this is true, then the WSR-88D will likely yield little increase in VE in many rural areas. It is apparent that a change in the verification program is needed.

---

[1]The additional stipulation that hail and wind reports be greater than 15 minutes apart and separated by 10 miles can hurt the verification scheme. This was evidenced when two separate warnings for a county in the Fargo County Warning area were verified by two distinct events, but this time/distance rule threw out one on the events.

[2]Rural is defined by the U.S. Census Bureau as a population density of less than 1000 people per square mile. Additionally, NOAA defines rural as an area or township with less than 8 non-farm families. Under either definition, most of northern Minnesota and virtually all of North Dakota are rural.

3. WSO Fargo's Severe Weather Season

The severe weather season in the Fargo CWA is generally short--from late May through early August. Many of the severe weather events occur in June through the first half of July, with a high percentage after 1000 pm CDT (0300 UTC) (Schaefer 1983, 1986; Sangster and Schaefer 1984, Ewens 1991). Few, if any, reports are received due to the late hour, therefore little verification of warnings. Many of the Sheriff offices in the Fargo CWA close at night, primarily due to manning considerations. The State Highway Patrol is also "stretched thin".

Typically, severe weather develops in the central or western Dakotas during the late afternoon (1500-1800 CDT) reaching the western sections of the Fargo CWA around of after 1800 CDT. Quite a few severe events occur with pulse severe thunderstorms, or severe storm lines/clusters. Most infrequent is the sustained supercell event (Maddox, 1980). While no hard statistics are available, local experience suggests that over 50% of the severe weather in the Fargo CWA is a result of the pulse event. For pulse events, it is almost impossible to warn in advance. They are generally short-lived (less than 1 hour). Several techniques are being developed at WSO Fargo to cope with this problem, however. Severe storm lines and clusters, as well as supercells, commonly exhibit life spans up to 6 hours, covering paths up to 400 km (200 nm). These events are relatively easy to warn. The peak occurrence of thunderstorms in the Northern Plains is between 100 am and 200 am CST (Schaefer 1983). In the Fargo CWA during 1990, the frequency of severe thunderstorms at night (after 2000 CST and before 0700 CST) versus day was 65% for night and 35% by day. These numbers are very representative for the 1991 season as well as past seasons (Ewens, 1991)

4. WSO Fargo NOWCASTING Severe Weather and the Audio Spectrum Analysis of Sferics Program

A program has been underway at WSO Fargo since 1986 designed to assist in issuing timely severe weather warnings. The Audio Spectrum Analysis of Sferics (ASA) (Ewens, 1988) combines specialized lightning detection equipment and Radar in an attempt to improve the warning program. It has been discovered that many severe thunderstorms (in the Fargo CWA) demonstrate a particular pattern in the audio spectrum power curve prior to becoming severe. In general, this lead time varies from 5 to 15 minutes, although longer lead times (up to 1/2 hour) have been observed. Negative lead times results have also been observed, but these have been the exception.

ASA works in this manner. A RF receiver, tuned to 500 kHz, is attached to a directional antenna located outside the WSO. The Radar operator has the ability to focus the antenna at a storm or cluster of storms. Inside, the audio output signal of the receiver is input to a micro-computer. A program breaks the audio signal down into its respective audio frequencies which are displayed in a bar graph format on a video screen. By observing the audio patterns, the Radar operator can determine when the thunderstorm is transitioning from non-severe to severe, then being able to issue a timely warning.

The NOWCASTING program, which will be tested this year, is a hybrid of the WSFO Minneapolis GenCon program (Graff, O'Malley 1974). The technique is designed to "get the jump" on when and where severe weather will next occur by plotting events on a local work map over time, and then extrapolating them forward one to two hours. This technique has had success in the past, and hopefully can be fine-tuned to further enhance the warning program.

5. Severe Weather Scenarios - Current Systems Shortfall

5.1 Scenario #1

A severe thunderstorm develops in a rural area and remains mostly in a rural area for several hours before crossing into a more densely populated area and weakening. Radar shows a "5 level" extending to 35,000 feet with echo maximum top 52,000. The evening (0000 UTC) equilibrium level (EL) for Huron, South Dakota was 48,700 feet with a maximum parcel level (MPL) of 53,000 feet. The ASA output shows the typical phase shift in the audio pattern associated with developing severe thunderstorms (Ewens 1986).

A warning is issued. This warning is for three counties - Sargent, Ransom and southern Cass (Fig. 1). Initially, no reports of severe weather are received from Sargent or Ransom counties due to the lack of available spotters. The storm traverses into southern Cass, where numerous reports of 1½-inch hail and 80 mile per hour winds flood the WSO. The warning is reissued for all of Cass county North Dakota and Clay county Minnesota. Due to the higher population densities, both counties verify. Radar shows that the storm remains severe, with maximum tops now over 55,000 and the "5 level" core nearly 40,000. A tight gradient in the DVIP has developed on the inflow side of the storm and the max top is shifting to the south-east. The ASA audio pattern suggests damaging winds or possibly a tornadic storm. Therefore, a warning is issued for Mahnomen and northern Becker counties and the WSO at International Falls issues a warning for southern Clearwater county including the Itasca State park. No event reports are received from Mahnomen or Becker counties, but State Park police in the Itasca State Park report 2-inch hail and numerous trees down. WSO Fargo issues a fourth warning for Hubbard County, which verifies, due to the higher population. The thunderstorm remains severe based on Radar and ASA signatures as it crosses into Cass County Minnesota, where WSO Duluth takes over.

For WSO Fargo, the score: 8 county warnings, 3 county verifications, FAR .63, POD .38 and CSI .24.

5.2 Scenario #2

A severe thunderstorm develops in southern Manitoba where Environment Canada issues several weather warnings based on Radar and observed events (Fig. 1). Although outside of the 230 km operational range of the Fargo WSR-74S, the thunderstorm appears as a large DVIP 5 level. Since the thunderstorm is outside of the ASA range, it is yet of little value. However, the Experimental National Lightning Detection System (AFOS call up LDS) shows an increase in ground strokes with this storm. Over 50 strikes have been reported in the last 15 minutes. Based on this, a warning is issued for Cavalier and Pembina counties of northeast North Dakota. As the storm races southeast at 50 knots, warnings are issued for Walsh and eastern Grand Forks counties. The Radar top is 47,000 feet and the "5 level" core is 30,000 feet; morning EL and MPL from International Falls are 38,500 and 47,000 feet, respectively.

No event reports are received from Cavalier or Pembina counties, but the city of Grafton in Walsh county receives 1-inch hail. Two-inch hail and winds of 75 knots strike the city of Grand Forks 30 minutes later. A warning is issued for Polk and Red Lake counties of northwest Minnesota based on an ASA audio large hail signature, Radar tops of 43,000 feet and "5 level" core of 28,000 feet. The storm weakens half way through the warning lifetime, turns left and is no longer considered a threat. The score: 6 county warnings, 2 county verifications; FAR .66, POD .33 and CSI .20.

6. Local Verification

Had the WSR-88D been available for the above scenarios, warnings may have been issued for sections of counties instead of whole counties (in some instances). However, the overall VE would remain unchanged due to the lack of verification. Under the current verification system, the old Doppler dilemma is now this: A warning without verification is a "bust", regardless of how good the equipment upon which the warning is based. The WSR-88D will likely prove accurate in detecting Northern Plains storms (after algorithm adjustments are made) as it has proven in the Southern

Plains storms. Yet the verification scheme which works well in Oklahoma or Missouri will, and has, fallen short in the Dakotas, Montana, northern Minnesota and other rural states. In this regard, the WSR-88D will not lead to improvement in warning verification.

The WSO Fargo has had an aggressive verification/follow-up program for several years. A staff member is tasked with "bird dogging" warning verification after the fact, while everyone tries to get warning verification in real-time. Yet due to the rural nature of the CWA, the above scenarios are not at all uncommon. The official POD for WSO Fargo for the last six years has averaged 56%, indicating a high likelihood of warning verification. A local verification program which verifies WSO Fargo warning for warning, shows a higher POD/CSI and consequently lower FAR than the official national scores indicate. It is this technique of a warning for warning verification which was employed by Ewens (1989) to verify the ASA program.

In this verification scheme, a warning issued using the ASA technique was deemed a "hit" (FAR 0, POD/CSI 1) if severe weather occurred anywhere in the warning area during the valid time of the warning, regardless of how many counties were involved. This technique was used for two reasons; 1) the forementioned population density problem and 2) the relatively gross nature of the equipment used in the ASA program. The directional antenna has an effective reception width of approximately 15 degrees. In cases where several intense, potentially severe storms are clustered, it falls to the Radar signature normally used to determine severity. There lies a catch. The classic signature(s) (Lemon 1980) are often missing from Northern Plains storms, while others have all the signatures but never produce any reported severe weather. Therefore, the ASA technique may point to thunderstorms that are not displaying severe weather signatures on Radar. Using the Warning for Warning technique, the resultant 1991 WSO Fargo FAR was .56; the POD .80 and the CSI .35.

6.1 Scenario #3

Consider the following event. At 1230 CDT the Radar operator and severe weather coordinator decide a severe thunderstorm warning is needed for several counties. The office is using the Quick Warn technique developed at Topeka Kansas. Therefore the warning is immediately placed on the NOAA Weather Radio (NWR) by the Radar operator. The severe weather coordinator calls the necessary warning points on the NAWAS as the public service forecaster prepares the AFOS version using GWARN. However, AFOS crashes at 1233 CDT and has to be fully rebooted. AFOS is back in service at 1236 CDT and the warning finally typed and GWARN run at 1239 CDT.

A cooperative observer reports one-inch hail and 65 mile an hour winds with the suspect thunderstorm, having started at 1236 CDT. GWARN finishes and the official dissemination time is 1240 CDT - fully 10 minutes after the warning decision was made. The warning is, technically, a "bust".

It is our proposal that the time of dissemination, for verification purposes, be the time the warning is issued on the NWR (for offices using Quick Warn) and/or NAWAS. Several warnings have been considered "busts" for this reason - that the time on the AFOS warning was after the verifying event.

7. Recommendations/Conclusions

It is often argued that the current warning verification program has significant problems. Persons involved in warning verification, at all levels (local, regional, NSSFC, national), are aware of difficulties with warning verification (Livingston, 1992). The author suggests a new verification rating be added to the current suite, that is the Warning-for-Warning criterion. It has been shown that the VE will increase using this technique. Further, all warnings verified under the old system should be reverified and this verification scheme employed to acquire a base line to support the improvements the WSR-88D will bring to the entire WVP.

The author suggests that dual verification be employed during the MARD period to develop a base line. This system would allow for open comparison of the two techniques (county warning vs warning for warning), showing where weaknesses lie in both. Furthermore, the issuance time of a warning for verification purposes should be the time of dissemination over NWR (for offices using Quick Warn), or other means of initial distribution. The AFOS time should not be used in these instances.

There is no argument that the WSR-88D will provide better storm detail. Simply put, the WSR-88D will not improve the VE in many rural areas under the current plan. The NWS should take another look at the schemes used presently and the schemes planned for the MARD and beyond.

8. References

Akulow Jr., Mike, 1992: The Topeka "Quick Warn" NOAA Weather Radio Method, Central Region Technical Attachment 92-01.

Donaldson, R. J., R. M. Dyer and M. J. Kraus, 1975: An objective evaluator of techniques for predicting severe weather events, Preprints, AMS Ninth Conference on Severe Local Storms, Norman, Oklahoma, 395-402.

Ewens, Mark E., 1986: Using a Locally Developed SFERICS Unit as a Complement for Weather Radar: Test Results Spring/Summer 1985, Central Region Technical Attachment 86-2.

____________, 1988: The Audio Spectrum Analysis of SFERICS, National Weather Association 12th Annual Conference, Denver, Colorado.

____________, 1989: On the Operational Use of the Audio Spectrum Analyzation of Sferics in Relation to Severe Weather: 530 kHz, Central Region Technical Attachment 89-13.

____________, D.M. Morin, 1991: Local Verification Statistics.

Graff, J. V., O'Malley, D., 1974: Detecting and Predicting Severe Thunderstorms Using Radar and SFERICS, NOAA Technical Memorandum NWS CR-55.

Hales, J. E., 1987: An Examination of the National Weather Service Severe Local Storm Warning Program and Proposed Improvements, NOAA Technical Memorandum NWS NSSFC-15.

Lemon, L. R., 1980: Severe Thunderstorm Radar Identification Techniques and Warning Criteria, NOAA Technical Memorandum NWS NSSFC-3.

Line Forecasters Technical Advisory Committee (LFTAC) Final report: 1991 pg 12.

Livingston, R.L., 1992: Personal communication.

Maddox, C., 1980: Mesoscale Convective Complexes, Bulletin of the AMS, 61, 1374-1387.

Sangster, W., Schaefer, J., 1984: Nocturnal Thunderstorms, Central Region Technical Attachment 84-10.

Schaefer, J., 1983: The Time of Summer Thunderstorms, Central Region Technical Attachment 83-9.

__________, 1986: Nocturnal Thunderstorms, Sometimes Known as Mesoscale Convective Complexes (MCCs), Central Region Technical Attachment 86-19.

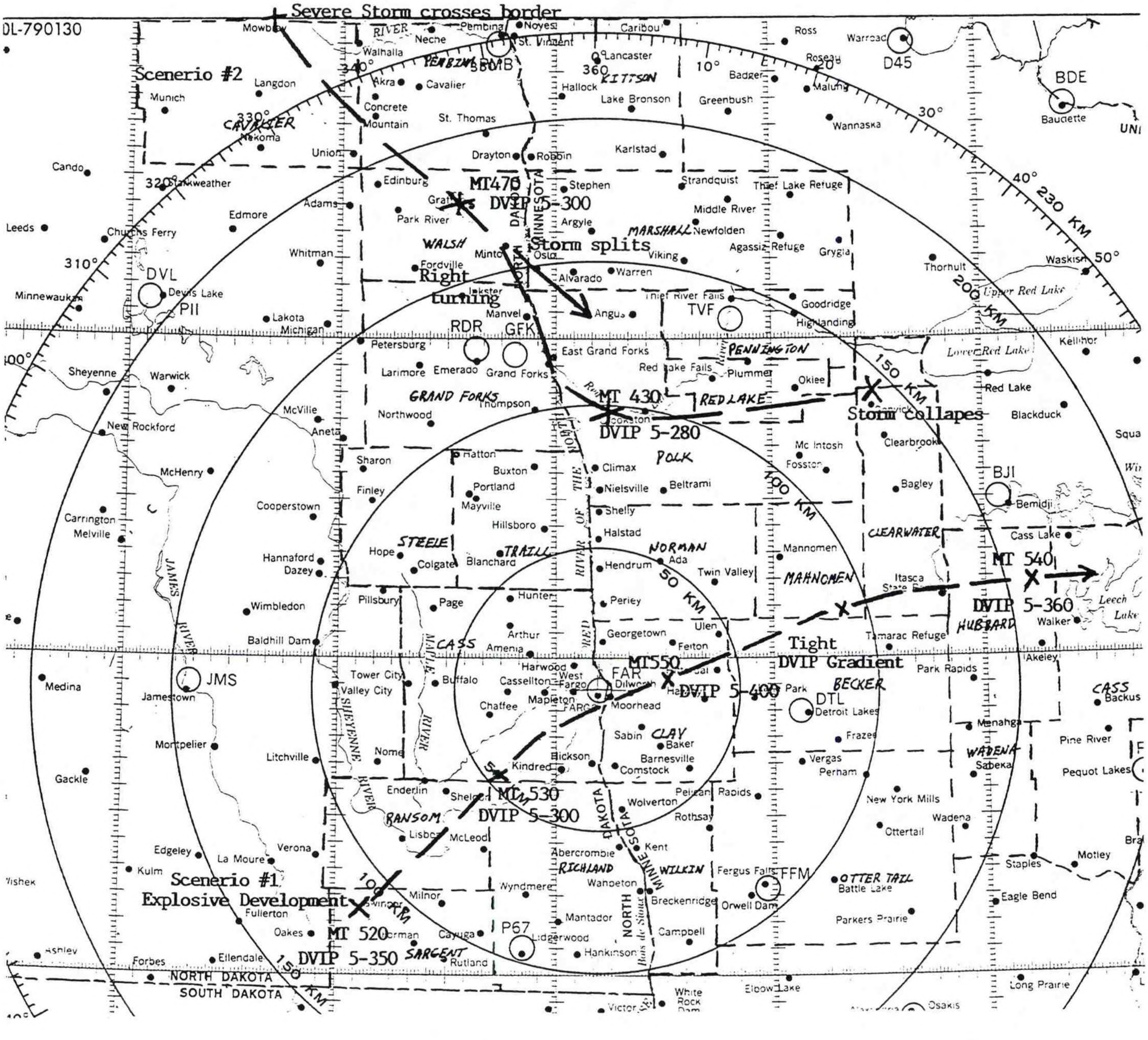


Fig. 1 Tracks of severe thunderstorms discussed in Scenarios 1 and 2.