WESTERN REGION TECHNICAL ATTACHMENT
NO. 97-05
FEBRUARY 11, 1997

AN EXAMINATION OF AN OUTFLOW BOUNDARY AND THUNDERSTORM INITIATION ALONG THE CONTINENTAL DIVIDE OF NORTH-CENTRAL MONTANA FOR 11 JUNE 1995

Donald J. Emanuel - NWSFO Great Falls, MT

Introduction

During the late evening of June 11, 1995, thunderstorms rapidly developed along the Rocky Mountain Front west of Great Falls (Fig. 1). What made these storms unusual was their time of occurrence, speed of development, and strength. Nocturnal thunderstorm initiation is a relatively rare event in this area. This Technical Attachment (TA) will detail the genesis of these nocturnal storms as detected by the Great Falls Weather Surveillance Radar-1988 Doppler (WSR-88D) along with the interaction of outflow boundaries, drainage winds, and an intrusion of stratospheric potential vorticity on this storm.

Synoptic Pattern

The 500 mb chart from 1200 UTC 11 June showed an upper-level ridge axis over eastern Montana. By 0000 UTC 12 June, the axis had shifted to the Montana-Dakotas border (Figs. 2-3). This placed north-central Montana under southwest flow aloft, a favorable regime for summer convective activity. The convective indices from the 1200 UTC Great Falls sounding on the morning of 11 June indicated marginal stability over the area. Personal Computer Gridded Interactive Display and Diagnostic System (PCGRIDDS) analysis of the Eta model, as well as Skew-T/Hodograph Analysis and Research Program (SHARP) output, showed a Lifted Index (LI) value of zero°C and a Convective Available Potential Energy (CAPE) value of zero J kg^{-1}. Storm relative helicity in the lowest three kilometers (km) was a low 15 m^{2}s^{-2}. Dew point temperatures were in the 40 to 45 degree Fahrenheit range. The airmass west of Great Falls was destabilizing throughout the afternoon hours as indicated by the Great Falls sounding of 0000 UTC 12 June. PCGRIDDS and SHARP output indicated LI values of -2 to -3°C as well as a CAPE value of 754 J kg^{-1} and a helicity value of 105 m^{2}s^{-2}. Dew point temperatures were now in the lower 50s (^{0}F).

During the mid-afternoon of 11 June, WSR-88D radar at Great Falls showed a number of thunderstorms north and east of the city. At 2214 UTC, an outflow boundary became detectable on both base reflectivity and base velocity images. This outflow boundary originated from thunderstorms in eastern Choteau County and was not visible on radar until it reached Teton County (Fig. 4), northwest of Great Falls.

Atmospheric Dynamics

As this outflow boundary propagated westward, it began to interact with downslope winds originating off of the Rocky Mountain Front, as the area of rising terrain to the north and west of Great Falls is known. Figure 4A illustrates this area as noted by the returns to the west of the outflow boundary. These returns represent some of the higher peaks of the Rocky Mountain Front. The 0000 12 June sounding from Great Falls (Fig. 5) indicated strong southwesterly flow through the mid and upper levels of the boundary layer. Surface wind data from three sites located near the Rocky Mountain Front confirm the downslope winds as they all reported westerly winds throughout the evening. These downslope winds represent a drainage flow which has been shown to help initiate convection under favorable conditions (McCollum, Maddox, and Howard, 1995).

McCollum et al., has found that drainage winds can help initiate convection by providing a mechanism for lift. In this case, a convergence zone intensified as southwest drainage winds collided with northeast surface winds, originating from the outflow boundary (Fig. 4). Furthermore, research by Maddox has found that the presence of a dry adiabatic lapse rate within the lower atmosphere can help generate a greater response in the vertical motion field for parcels that are being acted upon and lifted by drainage winds (personal communication, Maddox). The 0000 UTC 12 June Great Falls sounding did show a fairly dry adiabatic lapse rate throughout the lower atmosphere (Fig. 5).

As stated previously, the airmass through which the outflow boundary propagated continued to destabilize. PCGRIDDS analysis of the 0000 UTC 12 June Eta model output indicated an axis of weak convergence through the surface to 700 mb layer. Additionally, weak divergence was occurring through the 400-300 mb layer (not shown).

Also indicated by the Eta model was a large area of isentropic potential vorticity. The concept of isentropic potential vorticity anomalies has been widely researched and documented (Bluestein, 1993). The mathematical foundation for their existence is beyond the scope of this TA. In general terms, the theory behind potential vorticity anomalies holds that they exhibit a specific circulation (much like an electric charge). Positive anomalies are associated with cyclones and negative anomalies with anticyclones. The values are expressed in terms of Potential Vorticity Units (1 PVU=$10^{-6}m^{-2}s^{-1}K\ kg^{-1}$).

Analysis of the 300-200 mb layer from 1200 UTC 11 June showed values of +3 PVUs across northern Montana with values of +2 PVU stretching from west-central Montana to the southwest corner of the state (Fig. 6). Researchers agree that potential vorticity values greater than 1.5 PVU are usually associated with air of stratospheric origin (Bluestein, 1993). By 0000 UTC 12 June, the area of +3 PVU had moved further south and east (Fig. 8). This would indicate that stratospheric intrusion of potential vorticity had occurred in this area. Analysis of the 1200 UTC Great Falls sounding from 11 June showed the tropopause at a height of 10.4 km MSL. By 0000 UTC 12 June, the tropopause was at 10.9 km MSL, indicating the intrusion had lessened somewhat, as corroborated in Figs. 6-9.

The depth of these stratospheric intrusions must also be considered. The depth of penetration is somewhat dependent upon the static stability of the layer. Low static stability , i.e., an unstable lapse rate, would allow a larger penetration than if the atmosphere were more stable. PCGRIDDS analysis of the 850-400 mb layer from 0000 UTC 12 June showed a static stability value of 7.0^{0} C km^{-1} over the area west of Great Falls (Fig. 10). By 0600 UTC, this rather unstable lapse rate remained in this same area.

Additional analysis of 0000 UTC 12 June data offered a few more clues. Wind data from 250 mb showed the core of the jet streak/stream to be moving across southern Montana (Fig. 11). Isohypsic data from the same level indicated divergence was occurring, as quantified by PC GRIDDS data. At 200 mb, the data suggested positive vorticity advection (PVA) was occurring in the presence of a weak short wave (not shown).

Thunderstorm Morphology

The outflow boundary reached the area of consideration around 0045 UTC 12 June. Convection initiated in southwest Teton County around 0130 UTC and began to intensify. Thunderstorms developed by 0200 UTC with reflectivities quickly reaching 56 dBz. For several hours the storms maintained reflectivities of 55 to 60 dBz as they moved east across north-central Montana (Fig. 12). No severe weather was reported with these thunderstorms as they produced generally brief heavy rain and small hail.

The southern end of the outflow boundary was less conspicuous on radar imagery and difficult to discern. It seemed likely that convection was initiated along the southern edge of the boundary due to combined effects of evening drainage flows and the instability of the airmass due, in part, to the stratospheric intrusion of potential vorticity. Once convection initiated at the boundary's southern end, it developed rapidly. New thunderstorms developed west of Great Falls around 0500 UTC with a maximum reflectivity of 47 dBz and vertically integrated liquid water content (VIL) values of 27 k gm^{-2}. Echo tops were fairly constant at 38000 feet above ground level (AGL). By 0607 UTC, a second thunderstorm developed five miles west of Great Falls. This storm closely followed the track of the first while rapidly intensifying. Echo tops for this second storm reached 40000 feet AGL, a rather impressive height given the time of day. Hail measuring 3/4" was reported at the NWS office at 0622 UTC (Fig. 13). Reflectivities remained in the 60 to 64 dBz range as the storm moved rapidly northeastward, dissipating several hours later over eastern Montana. No additional severe weather was reported after these storms moved beyond the Great Falls area.

Summary

The importance of the interaction of mesoscale factors, such as the outflow boundary with the leading edge of the downslope winds, contributing to the initiation of convective activity cannot be overstated. As illustrated by this TA, an outflow boundary can serve as an efficient trigger when it encounters and interacts with the proper conditions. The proper conditions, however, can be subtle at times and very difficult to interpret. An unusual event, such as the one discussed in this TA, can sometimes be anticipated if all available data is utilized. This may involve data not normally examined by forecasters. Possibilities such as intrusions of stratospheric vorticity, the changing of static stabilities within a layer, or the interaction of drainage winds should all be considered and may help explain the "unexplained" event.

Acknowledgments

The author would like to thank David Bernhardt and Dr. Robert Maddox for their helpful comments and suggestions in preparing this TA.

References

Barnes, S. L. and B. R. Colman, 1994: Diagnosing an operational numerical model using q-vector and potential vorticity concepts. *Weather and Forecasting*, **9,** 85-102.

Bluestein, H. B., 1993: *Synoptic-Dynamic Meteorology in Midlatitudes, Vol. II.*, Oxford University Press.

McCollum, D. M., R. A. Maddox, and K. W. Howard, 1995: Case study of a severe mesoscale convective system in central Arizona. *Weather and Forecasting*, **10**, Amer. Meteor. Soc., Boston, 643-665.

Thaler, E., 1995: Isentropic analysis and IPV, *COMAP Notes class 95-1.*

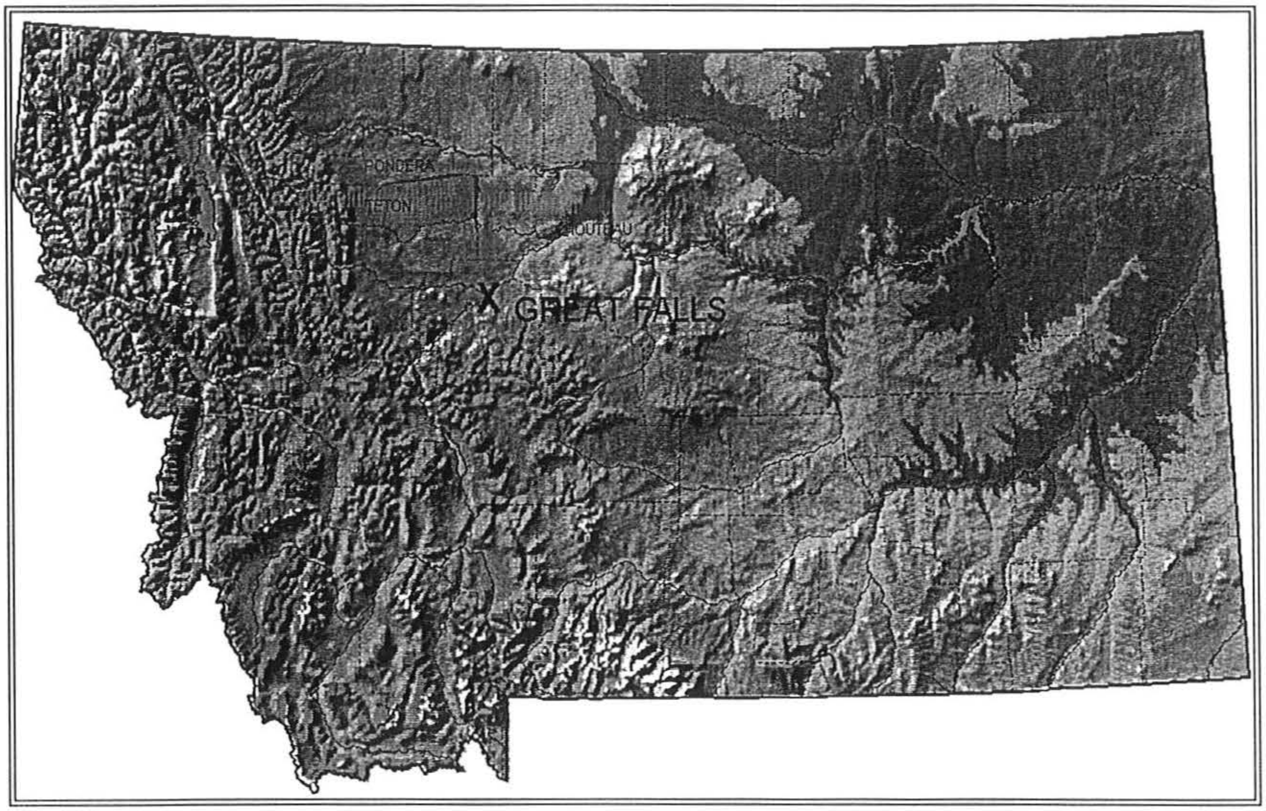

Fig. 1 Montana Topographic Map

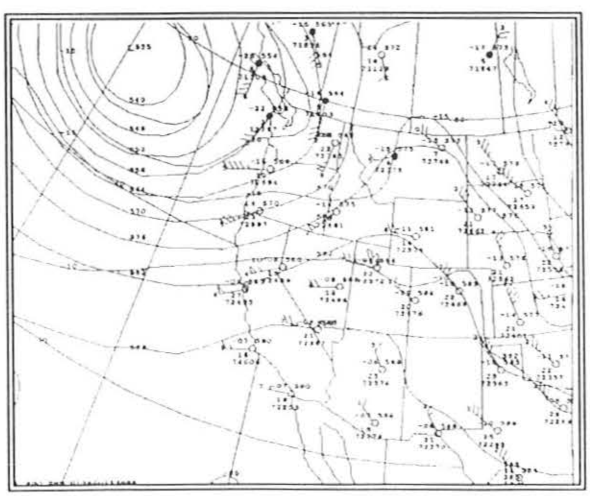

Fig. 2 500 mb Height Analysis
12Z June 11, 1995

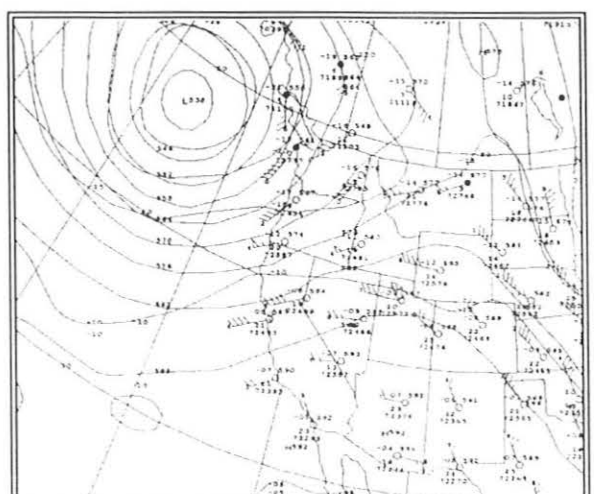

Fig. 3 500 mb Height Analysis
00Z June 12, 1995

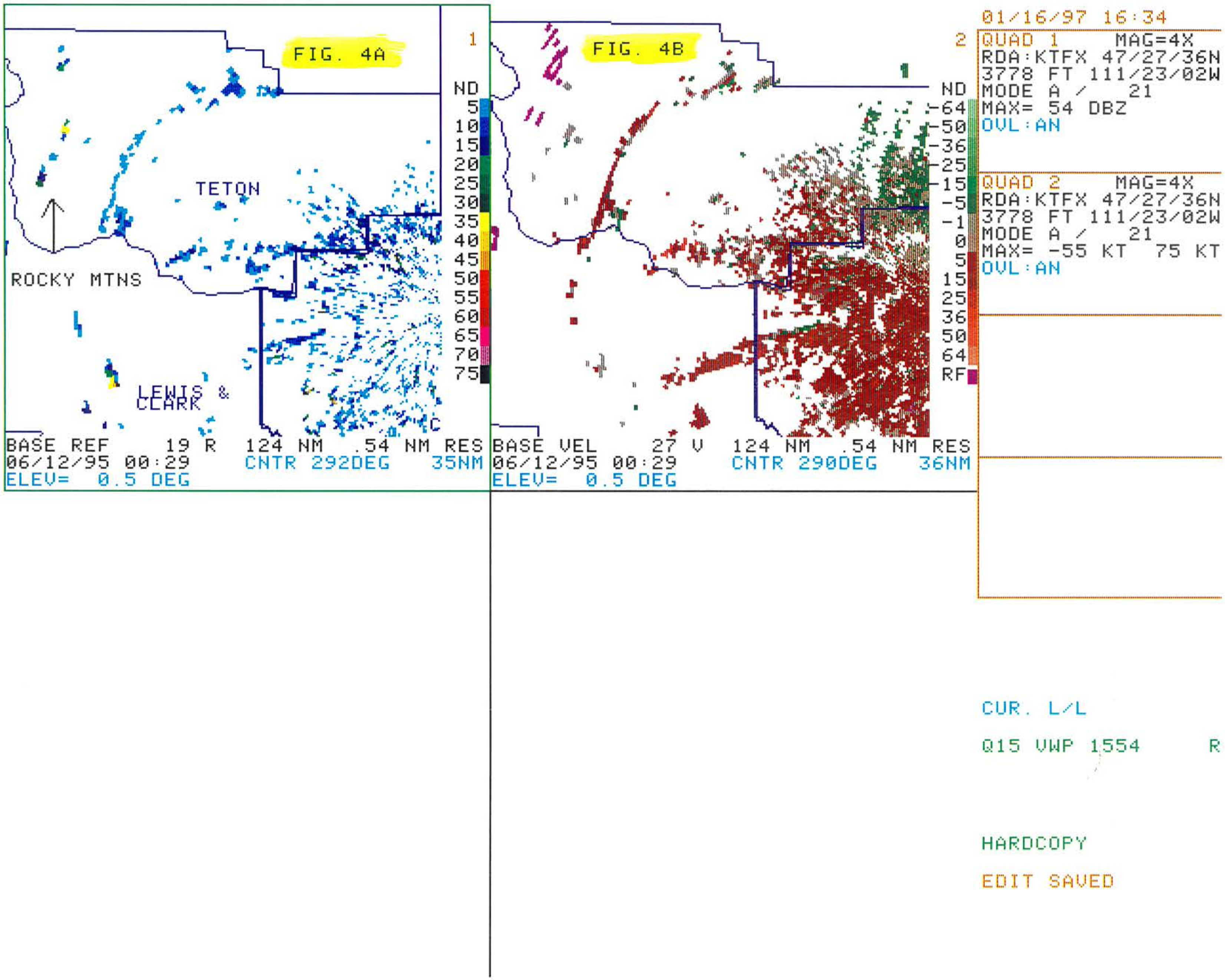
FIG. 4A
FIG. 4B
01/16/97 16:34
QUAD 1 MAG=4X
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
MODE A / 21
MAX= 54 DBZ
OVL:AN
QUAD 2 MAG=4X
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
MODE A / 21
MAX= -55 KT 75 KT
OVL:AN
TETON
ROCKY MTNS
LEWIS & CLARK
ND 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
ND -64 -50 -36 -25 -15 -5 -1 0 5 15 25 36 50 64 RF
BASE REF 19 R 124 NM .54 NM RES
06/12/95 00:29 CNTR 292DEG 35NM
ELEV= 0.5 DEG
BASE VEL 27 V 124 NM .54 NM RES
06/12/95 00:29 CNTR 290DEG 36NM
ELEV= 0.5 DEG
CUR. L/L
Q15 VWP 1554 R
HARDCOPY
EDIT SAVED

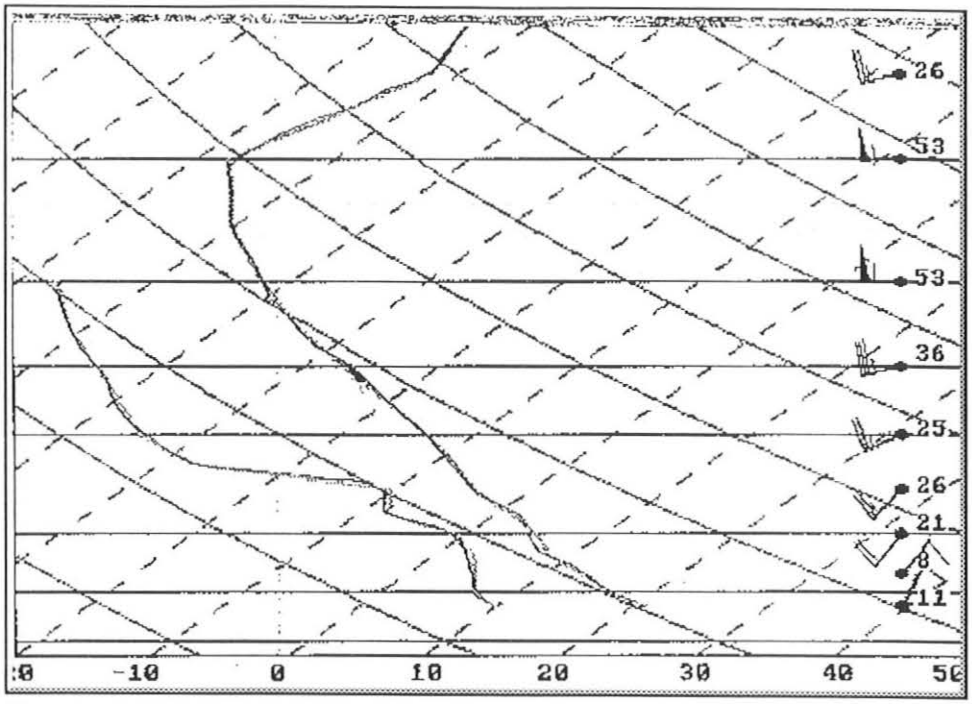

Fig. 5

Great Falls Sounding
00Z June 12, 1995

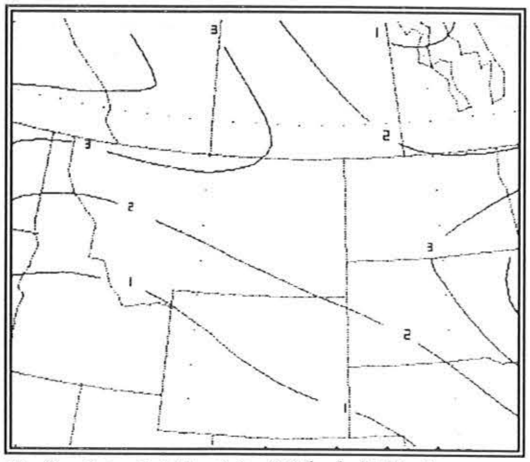

Fig 6: Potential Vorticity ($10^{-6}m^{-2}s^{-1}$ K kg^{-1})
300-200 mb
12Z June 11, 1995 Analysis

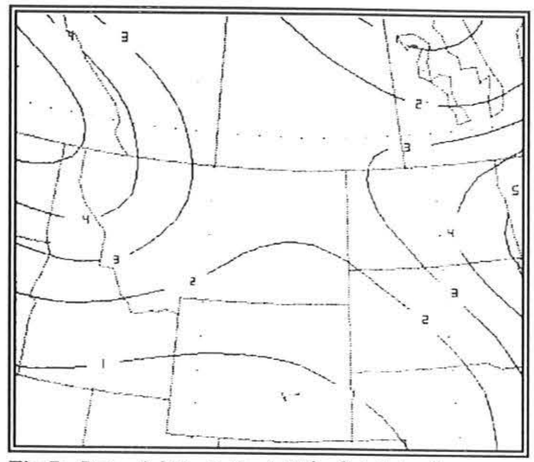

Fig 7: Potential Vorticity ($10^{-6}m^{-2}s^{-1}$ K kg^{-1})
300-200 mb
06 Hour Forecast

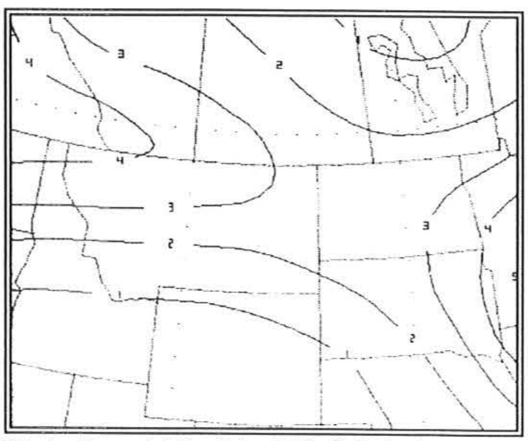

Fig 8: Potential Vorticity ($10^{-6}m^{-2}s^{-1}$K kg^{-1})
300-200 mb
00Z June 12, 1995 Analysis

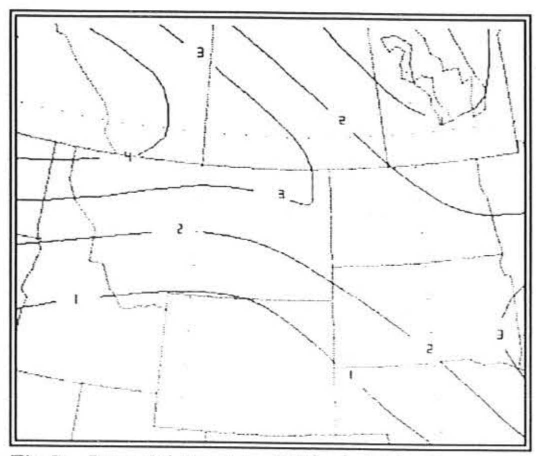

Fig 9: Potential Vorticity ($10^{-6}m^{-2}s^{-1}$K kg^{-1})
300-200 mb
06 Hour Forecast

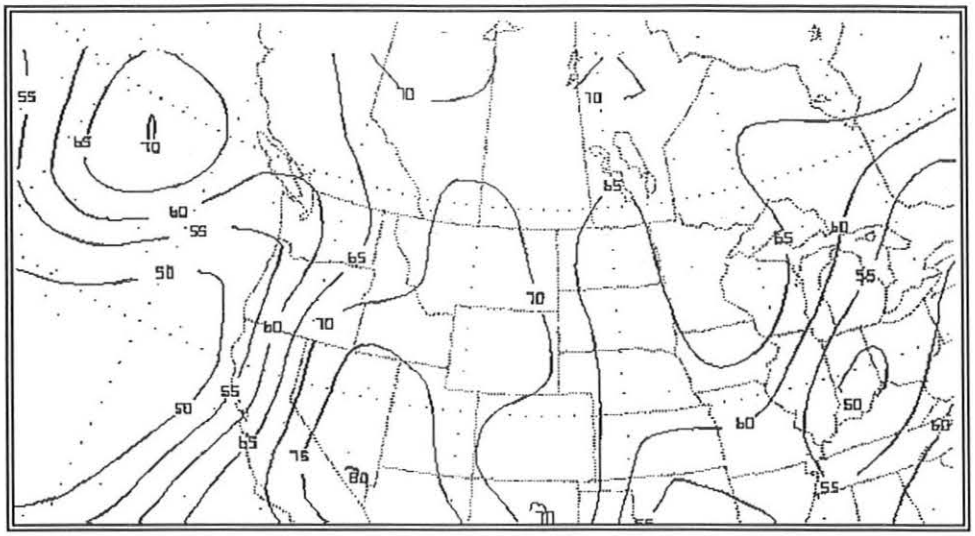

Fig. 10 Static Stability ($^{0}C\ km^{-1}$)
850-400 mb Layer
00Z June 12, 1995

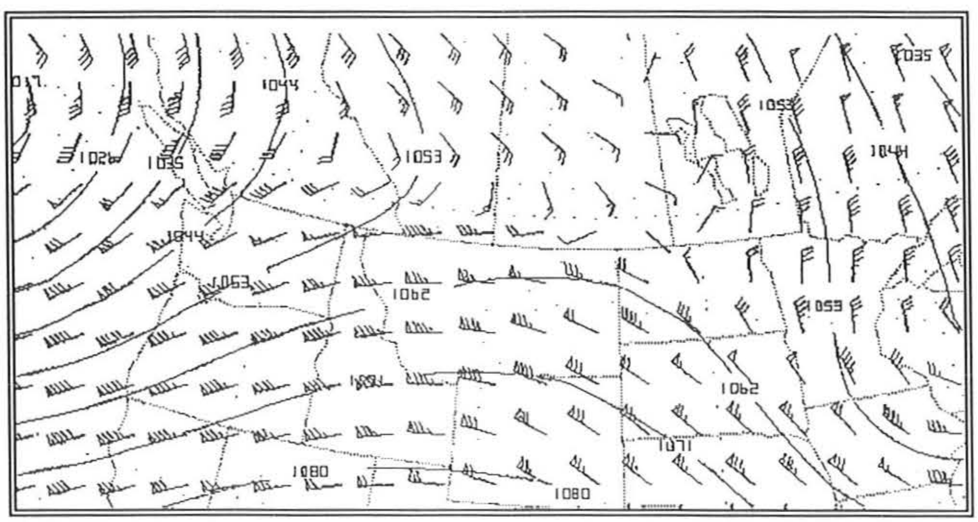

Fig. 11 250 mb Height and Wind Field
06Z June 12, 1995

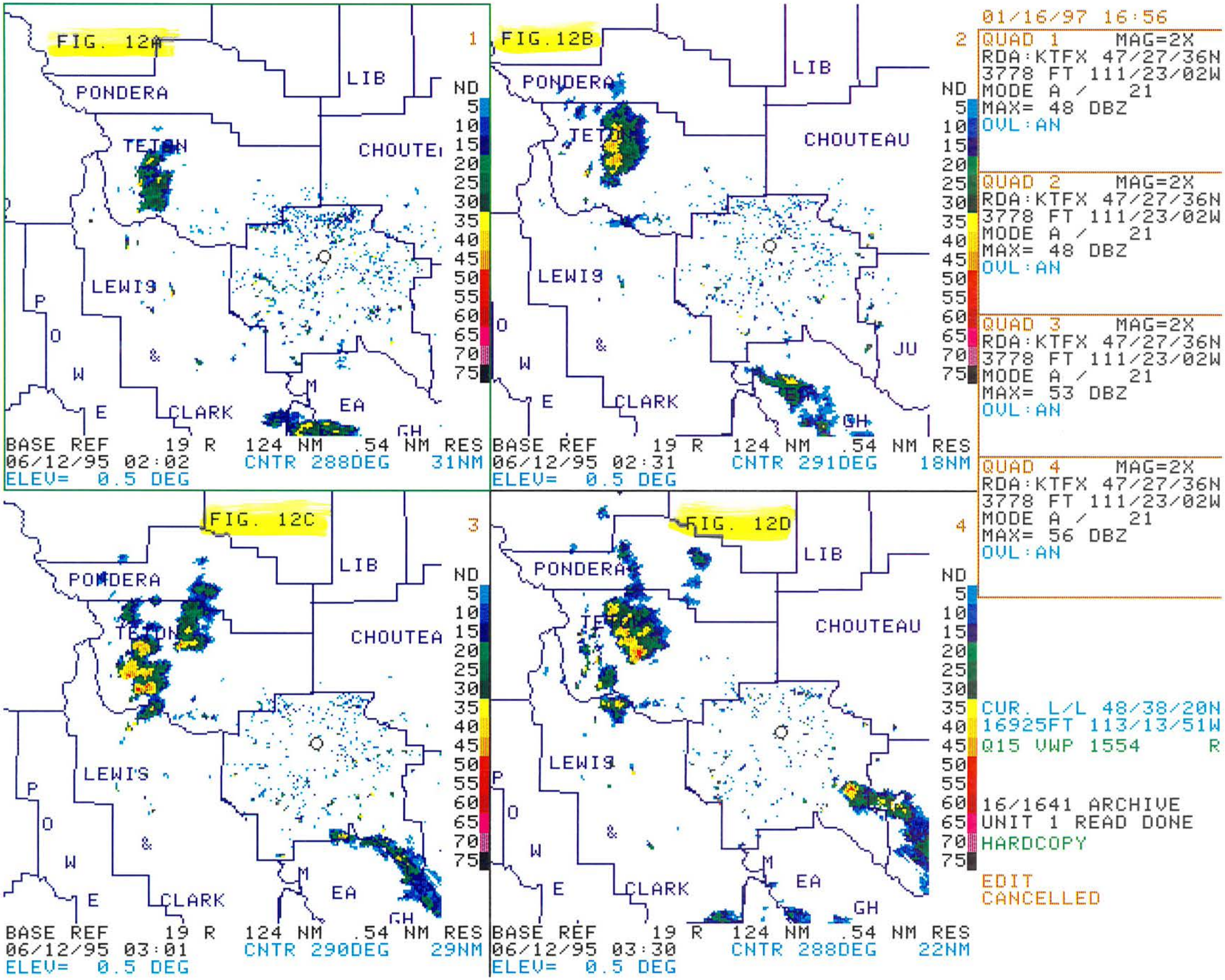
FIG. 12A
1
PONDERA
TETON
LIB
CHOUTE
LEWIS
P
O
W
E
&
CLARK
M
EA
GH
ND 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
BASE REF 19 R 124 NM .54 NM RES
06/12/95 02:02 CNTR 288DEG 31NM
ELEV= 0.5 DEG
FIG.12B
2
PONDERA
TETON
LIB
CHOUTEAU
LEWIS
O
W
E
&
CLARK
JU
EA
GH
ND 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
BASE REF 19 R 124 NM .54 NM RES
06/12/95 02:31 CNTR 291DEG 18NM
ELEV= 0.5 DEG
01/16/97 16:56
QUAD 1 MAG=2X
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
MODE A / 21
MAX= 48 DBZ
OVL:AN
QUAD 2 MAG=2X
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
MODE A / 21
MAX= 48 DBZ
OVL:AN
QUAD 3 MAG=2X
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
MODE A / 21
MAX= 53 DBZ
OVL:AN
QUAD 4 MAG=2X
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
MODE A / 21
MAX= 56 DBZ
OVL:AN
FIG. 12C
3
PONDERA
TETON
LIB
CHOUTEA
LEWIS
P
O
W
E
&
CLARK
M
EA
GH
ND 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
BASE REF 19 R 124 NM .54 NM RES
06/12/95 03:01 CNTR 290DEG 29NM
ELEV= 0.5 DEG
FIG. 12D
4
PONDERA
LIB
CHOUTEAU
LEWIS
P
O
W
E
&
CLARK
M
EA
GH
ND 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
BASE REF 19 R 124 NM .54 NM RES
06/12/95 03:30 CNTR 288DEG 22NM
ELEV= 0.5 DEG
CUR. L/L 48/38/20N
16925FT 113/13/51W
Q15 VWP 1554 R
16/1641 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
EDIT
CANCELLED

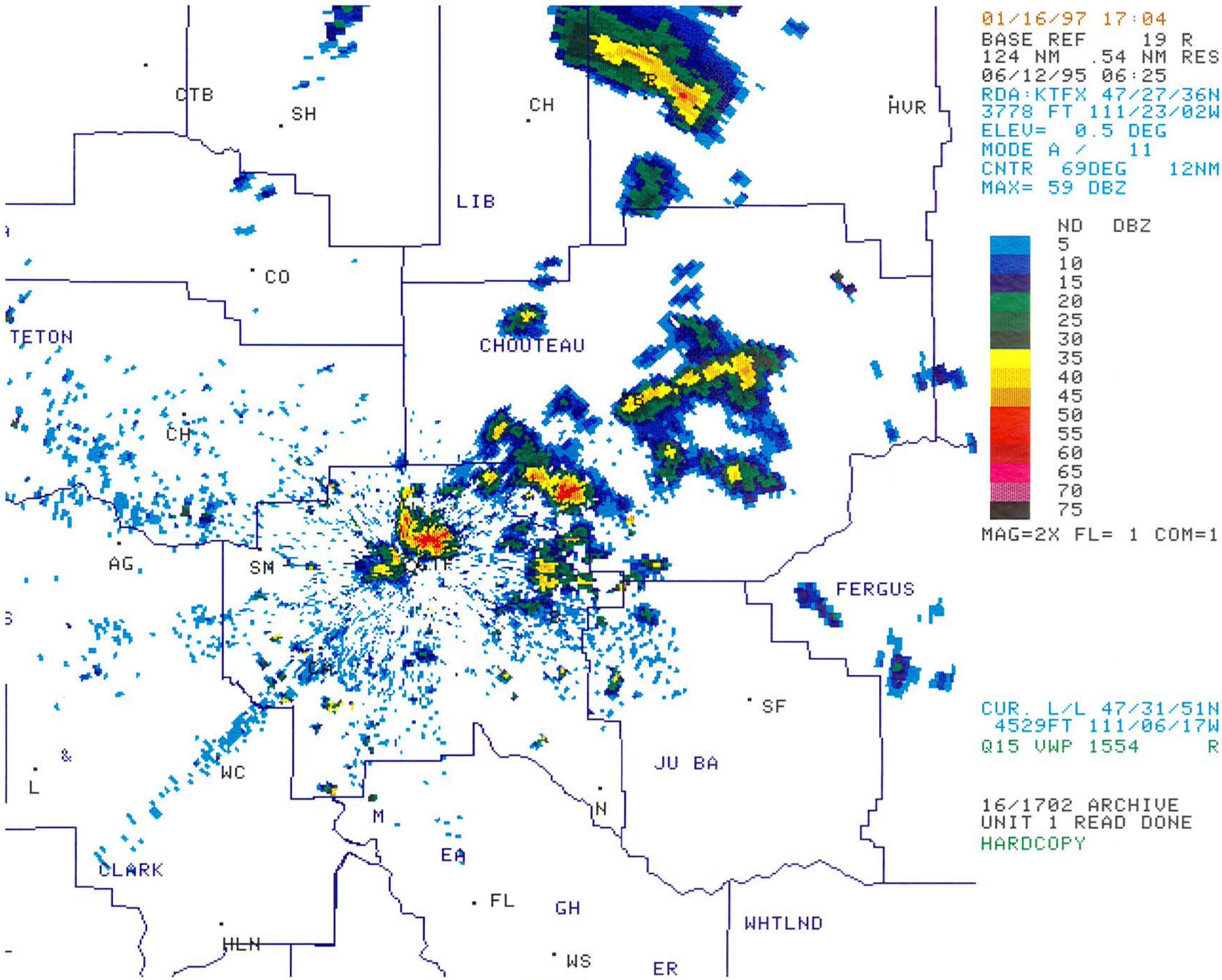
01/16/97 17:04
BASE REF 19 R
124 NM .54 NM RES
06/12/95 06:25
RDA:KTFX 47/27/36N
3778 FT 111/23/02W
ELEV= 0.5 DEG
MODE A / 11
CNTR 69DEG 12NM
MAX= 59 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=2X FL= 1 COM=1
CUR. L/L 47/31/51N
4529FT 111/06/17W
Q15 VWP 1554 R
16/1702 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
CTB
SH
CH
LIB
HVR
CO
TETON
CHOUTEAU
CH
AG
SM
FERGUS
SF
JU BA
WC
L
&
M
N
EA
CLARK
FL
GH
WHTLND
HLN
WS
ER

Fig 13