NOAA Technical Memorandum NWS WR-221

UTILIZATION OF THE BULK RICHARDSON NUMBER, HELICITY AND SOUNDING MODIFICATION IN THE ASSESSMENT OF THE SEVERE CONVECTIVE STORMS OF 3 AUGUST 1992

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I. INTRODUCTION

On August 3, 1992, a severe thunderstorm developed during the early evening hours over north-central Montana (Fig. 1). The severe thunderstorm dropped baseball-size hail, causing extensive damage to homes, vehicles, and crops. An F0 tornado and one report of wind damage was also reported.

When assessing the threat of severe weather, forecasters typically ask the question, "What type of storm structure can be expected"? One way to forecast storm type is through the use of the Bulk Richardson Number (BRN) as defined by Weisman and Klemp (1982, 1984). The BRN involves a relationship between storm type, wind shear, and buoyancy and is especially useful in determining isolated supercell development. This study examines the conditions that led to the initiation of the severe convection, forecasting the location of severe weather, and assessing the type of storm structure using the BRN. The role of helicity and sounding modification is also examined.

II. COMPOSITE ANALYSIS

Johns and Doswell (1992) note that composite analyses, prepared daily by the forecasters at the SEvere Local Storms (SELS) unit of the National Severe Storms Forecast Center (NSSFC), are a useful technique in observing those meteorological parameters necessary for the development of severe local storms. From the composite chart, wind, moisture, and temperature patterns at various levels in the atmosphere can be visualized. Also, these patterns can be compared to the orientation of the static stability fields at a given time. The SELS forecaster uses the chart to help define and delineate areas in which severe thunderstorm development is most likely.

The composite analysis (Fig. 2) valid at 1200 UTC on 3 August showed several features conducive to the generation of severe thunderstorms. A north-south oriented stationary surface front extended from east of Cut Bank, Montana (CTB), through Great Falls (GTF) and southeast through Billings (BIL). Surface dew points were 50°F or greater over much of Montana east of the Continental Divide. At 850 mb, southeasterly low-level winds of 25 knots prevailed across eastern Montana. Also at the 850 mb level, a thermal ridge extended from southern Alberta through western Montana and continued south into western Utah. Progressing upward to the 700 mb level, a positively tilted short-wave trough was located across southern Alberta and into the northeast portion of Washington state. At 500 mb, a low pressure trough and associated cold pool of air was situated over southeast British Columbia. Across eastern Washington state, northern Idaho, and western Montana, a mid-level wind maximum (500 mb) of 35 knots was observed. Diffluence was also noted at 500 mb over northwest Montana. The 300 mb upper-air chart showed a strong jet maximum located over eastern Washington state illustrated by the observed 95 knot wind at Spokane (GEG). Lifted Indices (LI) of zero or less were observed from west-central Montana southwest into Idaho. Specifically, the 1200 UTC sounding at GTF indicated an LI of -1.

By 0000 UTC on 4 August, conditions had become more favorable for severe convection across Montana. The composite analysis (Fig. 3) at 0000 UTC showed several parameters converging across southern Alberta and north-central Montana. The surface frontal boundary was located east of a line from Lethbridge, Alberta (YQL) to GTF and extended south to Bozeman, Montana (BZN). Surface dew points remained above 50°F across portions of central and eastern Montana with dew points greater than 55°F across north-central Montana. The southeasterly jet maximum of 25 knots at 850 mb remained across eastern Montana, as did the thermal ridge over southern Alberta, western Montana, and into western Utah. The positively tilted short-wave trough at 700 mb was propagating east across western Manitoba and north-central Montana. Warming temperatures in the lower layers of the atmosphere combined with cooling aloft associated with the thermal trough at 500 mb advecting eastward, resulted in steepening lapse rates across north-central Montana. This contributed to a more favorable environment for severe convection by increasing potential instability. A 50 knot mid-level jet was also apparent moving across the central portions of Montana. The upper-level jet maximum at 300 mb, previously located over eastern Washington state, was now over western Montana (the 0000 UTC 4 August GTF sounding indicated a 79 knot wind at the 300 mb level). The jet maximum helped to create favorable speed shear north of the jet axis, and the left front quadrant of the jet maximum was placed across north-central Montana. McGinley (1986) and others note that this region is favorable for enhancing upward motion through the ageostrophic secondary circulation.

Through the use of the composite charts (Figs. 2 and 3), the forecaster is now aided in visualizing the changing dynamic and thermodynamic structure of the atmosphere. This can help in narrowing down a region favorable for strong or severe thunderstorm development. In this particular case, the composite charts indicated north-central Montana as the area most conducive to severe weather.

III. SURFACE ANALYSIS

The 1800 UTC 3 August surface analysis (Fig. 4) showed dew points greater than 50°F extending from southern Alberta across central Montana with a 61°F dew point noted at YQL. A frontal boundary, east of the Continental Divide, extended from north-central to south-central Montana. By 0000 UTC, the front had moved east and was located just east of a line from YQL to GTF and south to BZN. This frontal boundary had similar characteristics associated with those of a Southern Plains dry line. Warm, dry air existed west of the surface boundary while a relatively cool, moist air mass prevailed east of the boundary. Dry air aloft and steep lapse rates aided in transferring momentum to the lower layers of the atmosphere which contributed to the eastward progression of this boundary, as well as strengthening the moisture gradient found along it. The dew point at GTF decreased 18°F during the six-hour period from 1800 UTC to 0000 UTC as dry northwesterly winds began to advance south along the east slopes of the Rocky Mountains. Between 1800 UTC and 0000 UTC, moisture pooled over north-central Montana and southern Alberta, as illustrated by the position of the 55°F isodrosotherm. As noted by Johns and Hirt (1987), increased low-level moisture contributes to greater positive buoyancy for a lifted parcel and lowers the level of free convection (LFC). This decreases the amount of dynamically induced lift necessary to initiate and sustain deep convection. The moisture gradient east of the Rocky Mountains continued to increase as noted on the 0000 UTC 4 August surface analysis (Fig. 5). A dew point difference of 16°F existed between GTF and HVR as the drier, low-level air continued to filter southeast along the Continental Divide.

The intrusion of drier air along the east slopes of the Rocky Mountains alerts the forecaster that this area has a decreased threat for the development of severe convection. Thus, the focal point of the operational meteorologist shifts to the area where the higher concentration of low-level moisture exists.

IV. THETA-E ANALYSES

A 700 mb theta-e ridge (Fig. 6) at 1200 UTC on 3 August extended from Edmonton, Alberta (WEG) to GTF and south to Lander, Wyoming (LND). Last (1992) pointed out that equivalent potential temperature (theta-e) analyses are useful in locating areas of high Convective Available Potential Energy (CAPE). A favored area for the formation of severe convective development, as noted by Campbell (1991), is along a theta-e axis. The 0000 UTC 4 August 700 mb theta-e analysis (Fig. 7) indicated the theta-e ridge axis had now shifted into eastern Montana, enhancing the potential for severe thunderstorms.

V. SOUNDING AND HODOGRAPH DATA

The 1200 UTC 3 August GTF sounding (Fig. 8) showed marginal instability with the Showalter and Lifted Indices both indicating values of -1. Mielke's (1979) local program for measuring CAPE, computed 1,920 J/kg of buoyant energy in the sounding. The GTF hodograph (Fig. 9) showed significant veering in the wind field and increasing speeds from the surface through 9,000 feet (MSL). This type of hodograph favors the development of cyclonically rotating, right-moving supercells (Doswell 1990).

The 0000 UTC GTF sounding on 4 August (Fig. 10) showed the atmosphere had stabilized in the past 12 hours as the lowest layers had dried considerably. This corresponded to the drier air found west of the frontal boundary. The Showalter and Lifted Indices were now +1 and +2, respectively. The threat for severe weather had now shifted east where the sharp dew-point gradient existed. The 0000 UTC GTF hodograph on 4 August (Fig. 11) showed a noticeable change in the structure of the wind field. Winds from the surface to about 8,000 feet (MSL) prevailed from the northwest compared to the previous 12 hours where a southerly component to the winds existed.

VI. BULK RICHARDSON NUMBER

Severe weather can result from any type of convective storm, however certain storm types are more likely to produce severe weather than others. Being able to determine what type of convective storm may result from a given environment can be a valuable tool in this assessment. One such tool, the Bulk Richardson Number (BRN), is a relationship between wind shear and buoyancy. Observations and research from Weisman and Klemp (1986) suggest the BRN can be related to a preferred storm type. The BRN (R) is expressed by:

$$R = \frac{B}{1/2U^2}$$

where B is the buoyant energy in the storm's environment (CAPE) and U is a density weighted mean measure of the vertical wind shear through a relatively deep layer (0-6 km AGL). Lazarus and Droegemeier (1990) point out that the BRN is a bulk measure of the ambient shear and does not account for detailed aspects of the wind profile, particularly low-level veering. The results obtained by Weisman and Klemp, in their numerical studies of convective storms, noted that for unsteady, multicellular storm growth, values of R were greater than 30. For isolated supercellular storm growth, values of R ranged between 10 and 40.

Weisman and Klemp (1986) note that although the magnitude of R may indicate a preferred cell type to be favored in a given region, it does not necessarily provide an indication to the severity of that convection. An example of this is an environment with small buoyant energy ($B < 1000\ m^2/s^2$) and moderate 0-6 km wind shear ($4 \times 10^{-3}\ s^{-2}$). The value of R may be well within the range for supercell development, and a forecaster would then expect some of the convective storms to have the steadiness and propagation characteristics of supercell storms. However, since other factors are also important for severe convective development, one cannot be assured that given the existence of a supercell, severe weather will occur (Johns and Doswell 1992). Also, an environment with large buoyant energy ($B > 3500\ m^2/s^2$) and moderate 0-6 km wind shear may be characterized by a relatively large value of R, yet produce tornadoes or large hail with a relatively unsteady, or cyclic storm.

In the case on 3 August, the 1200 UTC hodograph at GTF (Fig. 9) had an observed BRN value of 28 which is in the range determined by Weisman and Klemp for isolated supercell storm structure. As mentioned earlier, the buoyant energy at GTF was 1,920 J/kg and considerable wind shear was evident from the hodograph. This diagnosis can aid the forecaster in assessing not only if the threat of severe weather exists, but what type of storm structure will or should occur.

The 0000 UTC 4 August GTF hodograph (Fig. 11) indicated a BRN value of 2, which did not fit into either category of multicellular or isolated supercell storm type. The influence of the dry, low-level northwesterly winds along the east slopes of the Rocky Mountains significantly altered the buoyancy and wind shear terms of the BRN equation.

However, by modifying the low-level conditions (e.g., surface to 700 mb) of the GTF sounding to those near HVR in north-central Montana, a proximity sounding representing conditions near the area of possible severe weather can be constructed. This is achieved by substituting the surface data from HVR for GTF, and then interpolating values from the upper-air data at 850 mb and 700 mb. Through the substitution of these data, a modified HVR sounding and hodograph was constructed using the SHARP Workstation (Hart and Korotky 1991). The 0000 UTC 4 August modified sounding for HVR indicated a positive buoyant energy of 2170 m^2/s^2 (Fig. 12). The modified HVR hodograph (Fig. 13) produced a BRN of 24, which indicated an environment conducive for isolated supercell storm structure and development. Satellite photos (not shown) indicated that an isolated supercell developed over north-central Montana and moved south-southeast (330°). This movement was noticeably to the right of the 0-6 km mean wind (252°). This cell was responsible for the production of large hail and an F0 tornado.

VII. HELICITY

Although the BRN is a useful parameter, it is not as detailed of a predictor of storm rotation because it is a bulk measure and does not take into account details of the vertical wind profile. In recent years, special emphasis has been placed on the lowest 2 or 3 km of the atmosphere, usually below the level of free convection (LFC), which is considered the inflow layer into a convective storm. Storm relative helicity (Davies-Jones 1990) is an important parameter used to measure the potential storm rotation obtainable for a given environmental low-level wind field. Storm relative helicity (SRH) is the summation of the streamwise vorticity through the storm inflow layer and indicates the rotation potential of a thunderstorm updraft. In other words, air parcels flowing toward the updraft region of a thunderstorm spin about a horizontal vorticity axis. When lifted into the updraft, this axis is tilted and stretched into the vertical and develops a cyclonic rotation.

SRH is calculated on the SHARP Workstation as twice the area bounded by the hodograph between the storm inflow vectors at the top and bottom of the measured layer. SHARP uses an initial storm motion of 30 degrees to the right of the 0-6 km mean wind, and 75 percent of its magnitude (after Leftwich 1990) to get an estimate of the SRH. This would allow the forecaster an initial first guess as to the amount of SRH available in a given environment before the storms develop. Then, storm motion can easily be updated on the SHARP Workstation with the use of radar data, for example. In a study of 28 tornado cases, Davies-Jones (1990) found approximate ranges of 0-3 km (AGL) SRH corresponding to tornado intensity. For weak tornadoes (F0-F1), helicity values were between 150-299 m^2/s^2 while for strong tornadoes (F2-F3), helicity values ranged from 300-449 m^2/s^2. Violent tornadoes (F4-F5) produced helicity values greater than 450 m^2/s^2.

Calculations of SRH were made by using the modified hodograph in section 6 and modifying the observed storm motion. Storm motion, initially calculated by the SHARP Workstation, indicated a storm motion of 286 degrees at 14 knots and a SRH of 157 m^2/s^2 (Fig. 13). Using the observed radar data, a storm motion of 330 degrees at 15 knots was substituted for the SHARP Workstation storm motion. Given these modifications, the 0-

3 km SRH was 221 m^2/s^2 (Fig. 14) which is a considerable increase over the initial calculation of SRH. The increased SRH shows a greater rotation potential of the thunderstorm updraft.

VIII. CONCLUSIONS

Severe convection initiated as a result of several key parameters: low-level moisture ahead of a sharpening moisture gradient as a front moved east into the HVR area; low-level convergence and a 700 mb short-wave trough were present to provide dynamical forcing of the moist air; a thermal trough at 500 mb aided in destabilizing the atmosphere as mid-level cold air advection advanced into north-central Montana; the left front quadrant of a 300 mb jet maximum supported upward motion; and moderate values of buoyant energy existed. Composite analysis proved useful to graphically show all of the above features. This aided the forecaster in isolating north-central Montana as the area most favored for severe weather.

The Bulk Richardson Number was utilized to assess the predicted type of storm structure for this particular environment. Modifications made to the sounding and hodograph data using the HVR surface and low-level observations, via the SHARP Workstation, led to a more accurate assessment of potential buoyant energy and vertical wind shear in the convective area. Storm relative helicity provided even further information about the low-level inflow (0-3 km AGL) into a convective storm and its potential to generate cyclonic rotation and long-lived supercell thunderstorms.

The forecaster may want to consider modification of the surface and upper-air data features in close proximity to the severe weather threat area to derive a better representation of the near storm environment. As in the above case, this can be a very valuable tool to forecasters.

IX. ACKNOWLEDGMENTS

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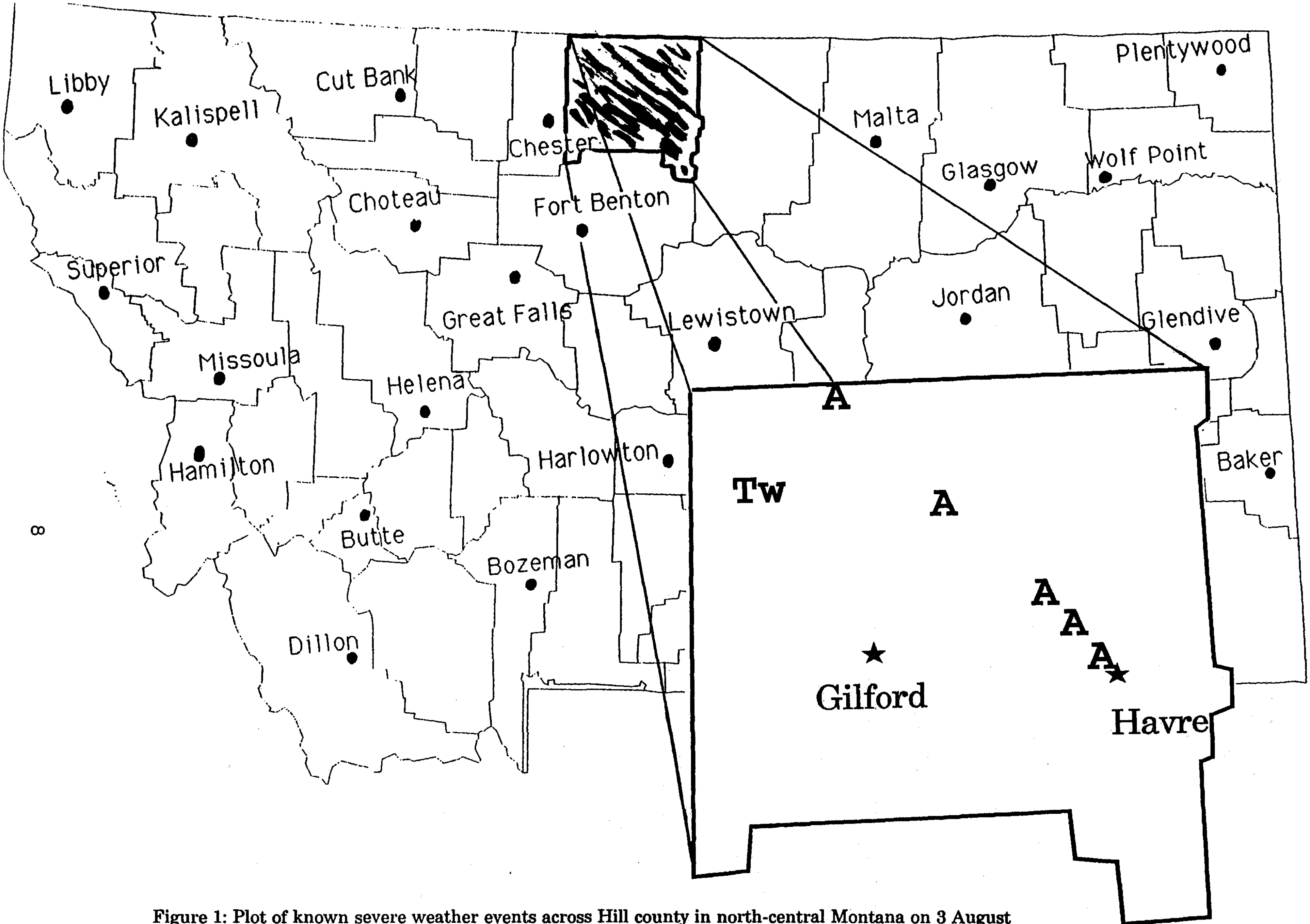


Figure 1: Plot of known severe weather events across Hill county in north-central Montana on 3 August 1992. (Reports from Storm Data and local storm reports.) T = tornado W = wind damage A = hail greater than 3/4 inch diameter.

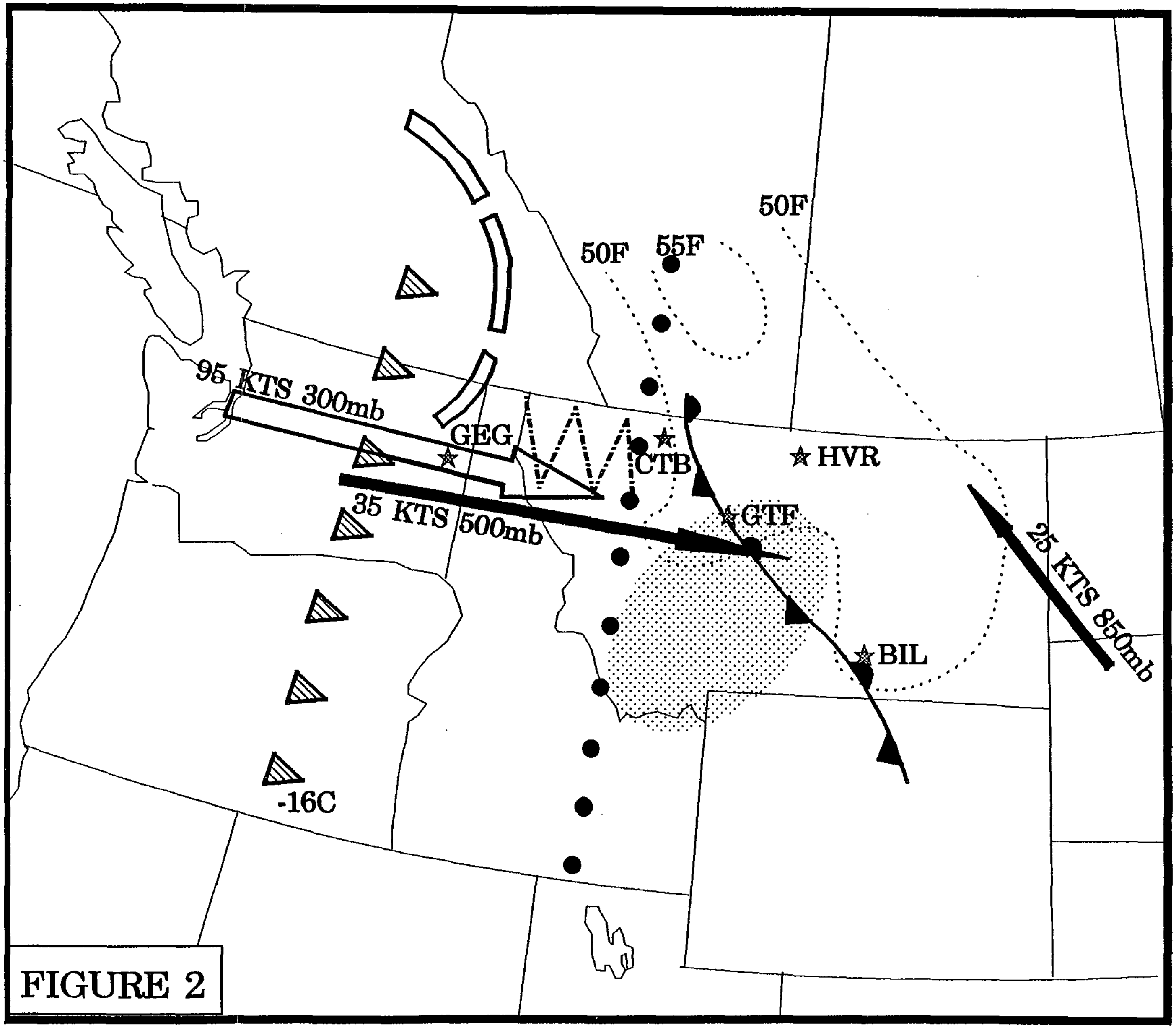


Figure 2: Composite analysis at 1200 UTC on 3 August 1992. Arrow represent jet maxima at various levels. Dotted line represents the 850 mb thermal ridge. Large dashed line denotes 700 mb short wave trough. Triangular line indicates thermal trough at 500 mb. Jagged dot-dashed line represents diffluence at the 500 mb level. Thin dashed lines represent surface isodrosotherms analyzed every 5°F (>50°F). Stippled area denotes Lifted Indices less than or equal to zero.

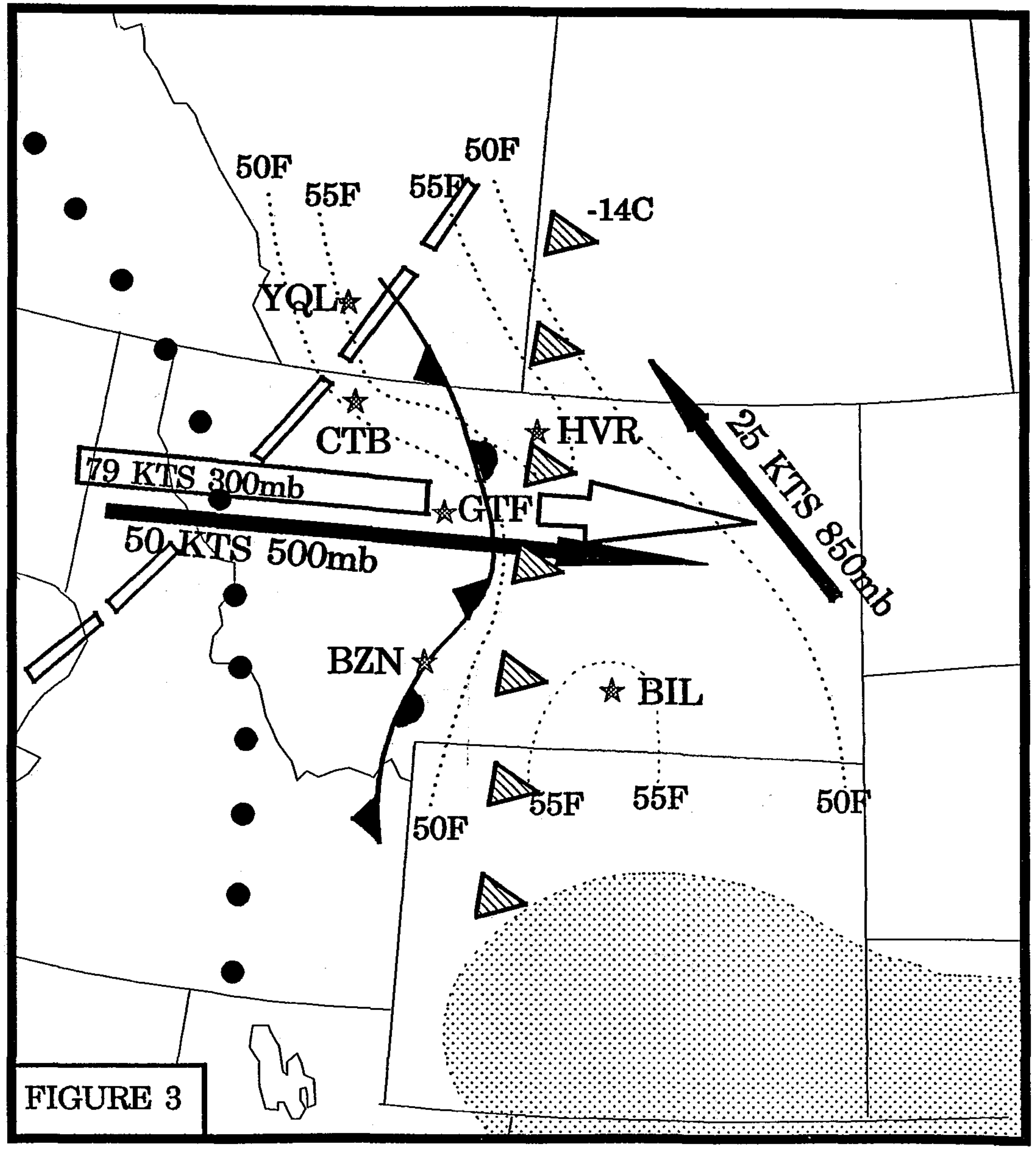


Figure 3: Same as Figure 2 except at 0000 UTC on 4 August 1992.

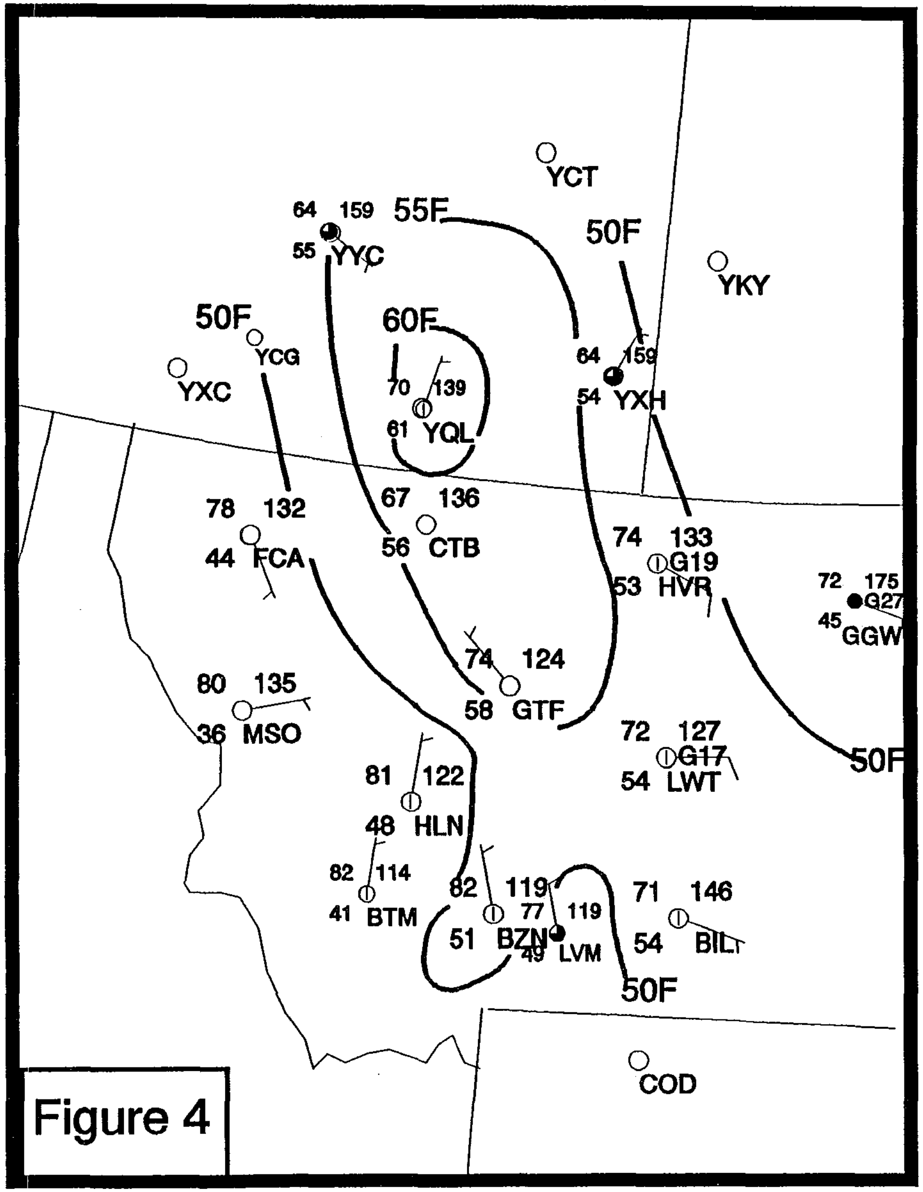


Figure 4: 1800 UTC surface analysis on 3 August 1992. Solid lines represent isodrosotherms analyzed every 5°F.

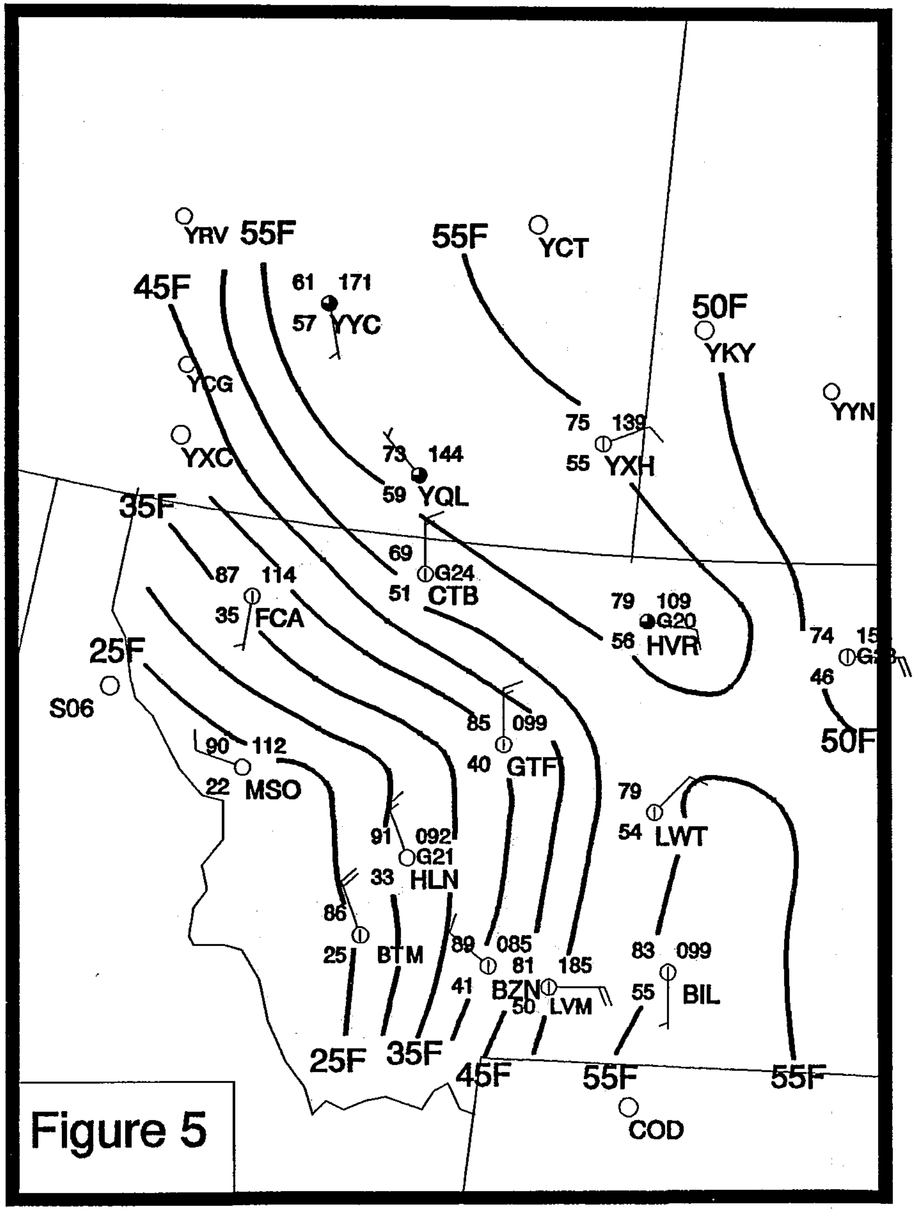


Figure 5: 0000 UTC surface analysis on 4 August 1992. Solid lines represent isodrosotherms analyzed every 5°F.

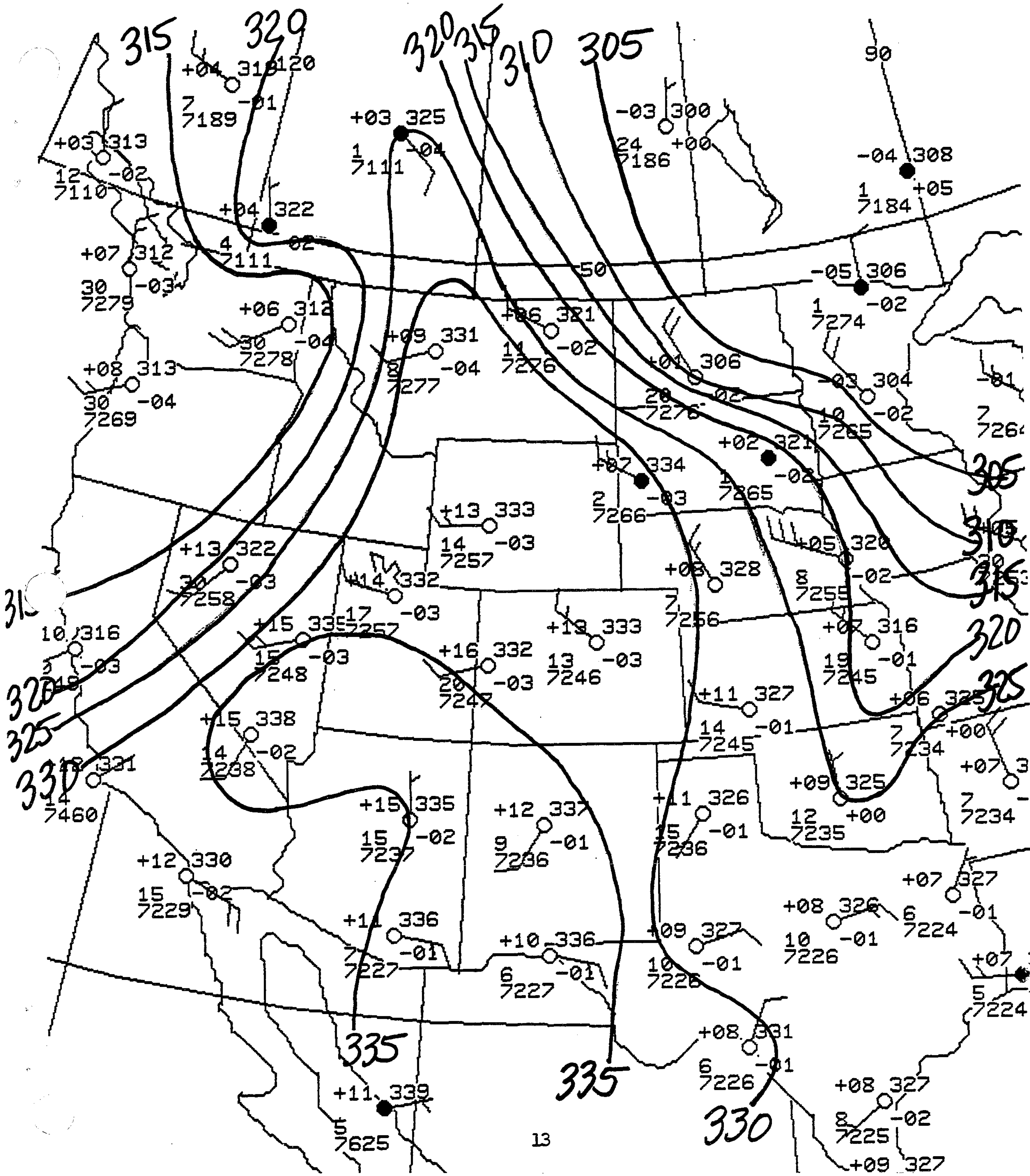


Figure 6: 1200 UTC 700 mb equivalent potential temperature analysis on 3 August 1992. Solid lines represent equivalent isentropes analyzed every 5K.

Figure 7: 0000 UTC 700 mb equivalent potential temperature analysis on 4 August 1992. Solid lines represent equivalent isentropes analyzed every 5K.

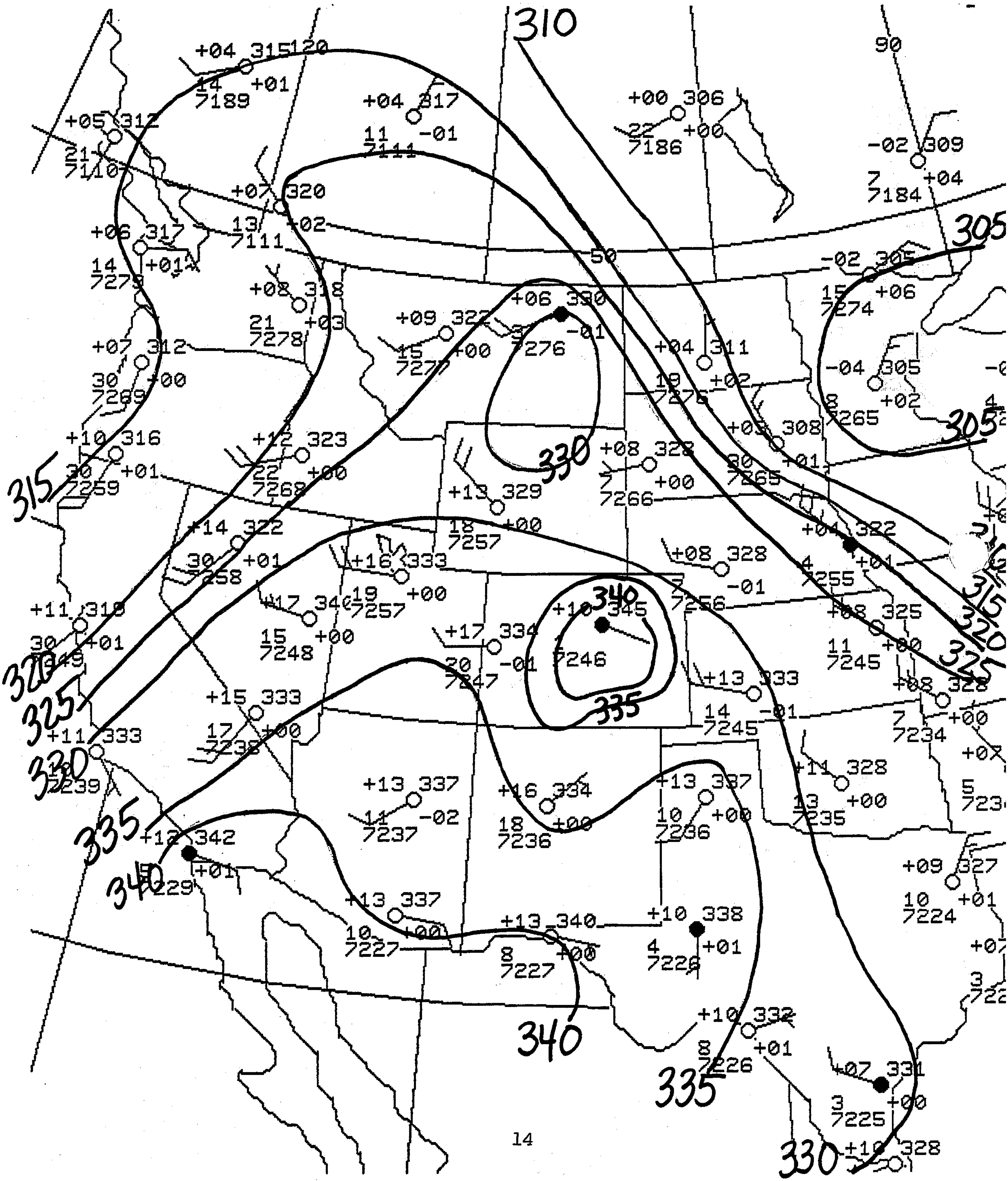
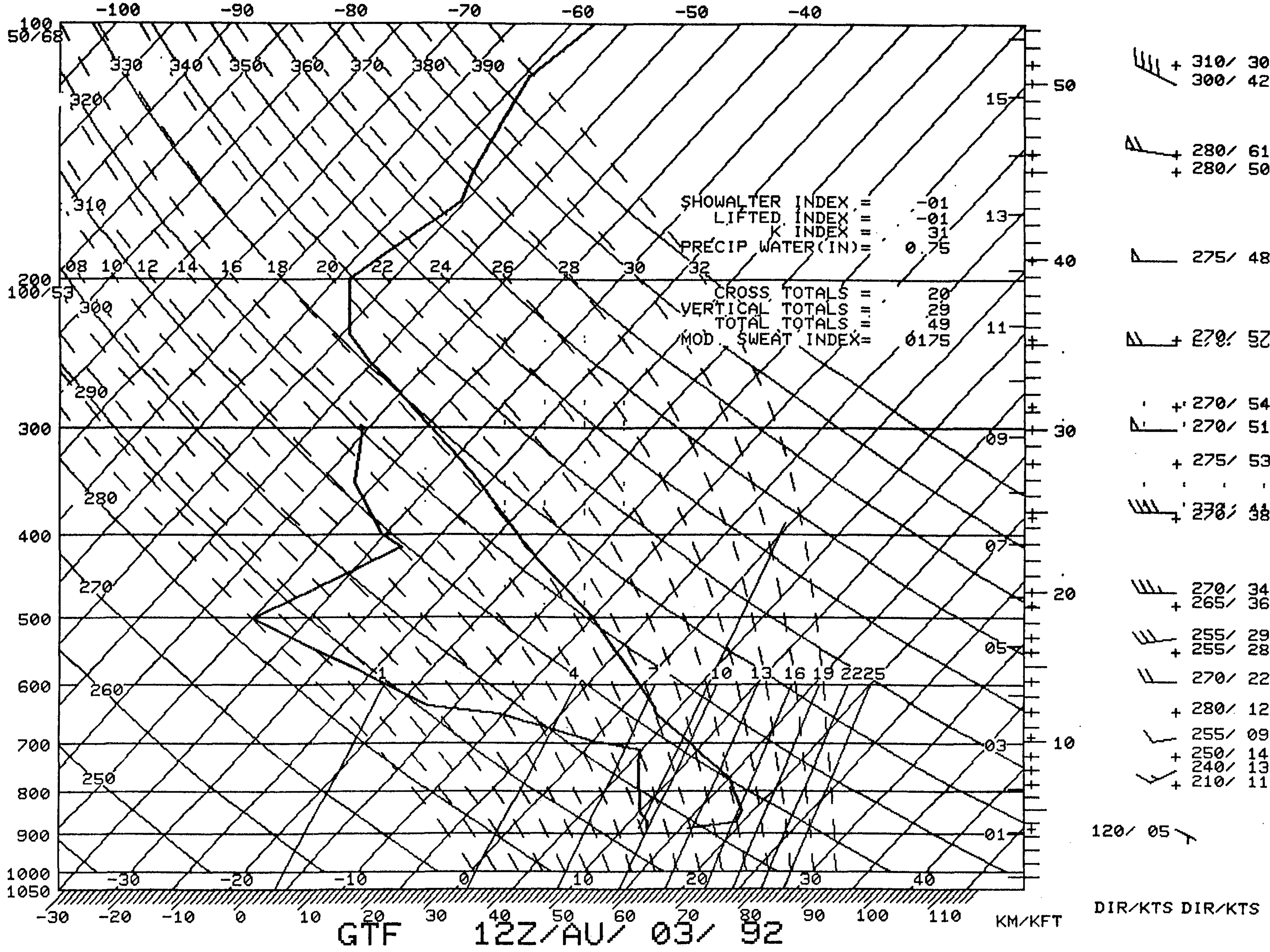


Figure 8: 1200 UTC Great Falls, Montana [illegible]F) SkewT-logP sounding on 3 August 1992.



GTF 12Z 3 AUG 92

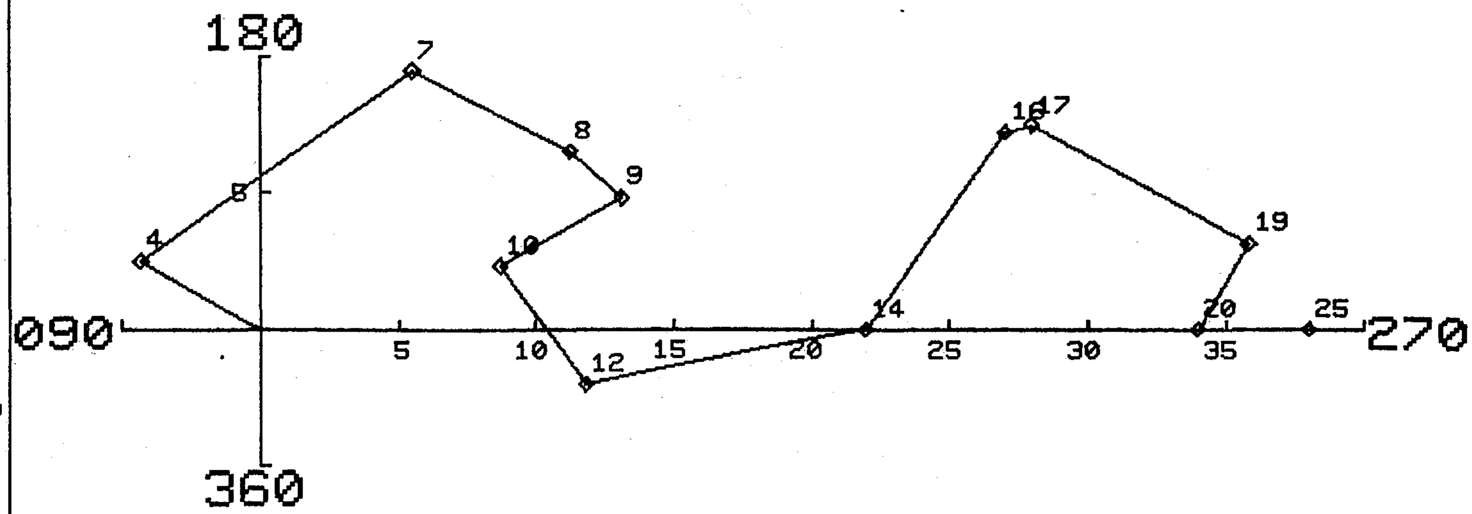
UNITS : KNOTS, LVLS : THSD FT (MSL)

```
B R N =    28
B+    =   161 (M/SEC)**2 X 10
B-    =     0 (M/SEC)**2 X 10
SHR   =    58 (M/SEC)**2
WMAX  =    57  M/SEC
EL    =   197 MB,    402  HND FT
MPL   =   489 HND FT
VS5   =     7 (M/SEC)**2
SS15  =    68 10-4 SEC-1
```

```
PARCEL FROM PMAX
ENTRAINMENT = 60 PERCENT
P0    =   888 MB
PMAX  =   771 MB
LCL   =   679 MB
LFC   =   511 MB

EI    =    -2 J/KG X 10
EI+   =     6 (+ PART)
EI-   =    -7 (- PART)

ENERGY CHANGE IN LAYERS
P1      P2
 771     511       -7 J/KG X 10
 511     236       15
 236     100     -472
```




```
LI    =     0
KI    =    31
SWI   =    -1

CCL   =        MB
```

Figure 9: 1200 UTC Great Falls, Montana (GTF) hodograph on 3 August 1992 in ms^{-1}. Points along the hodograph indicate thousands of feet (MSL).

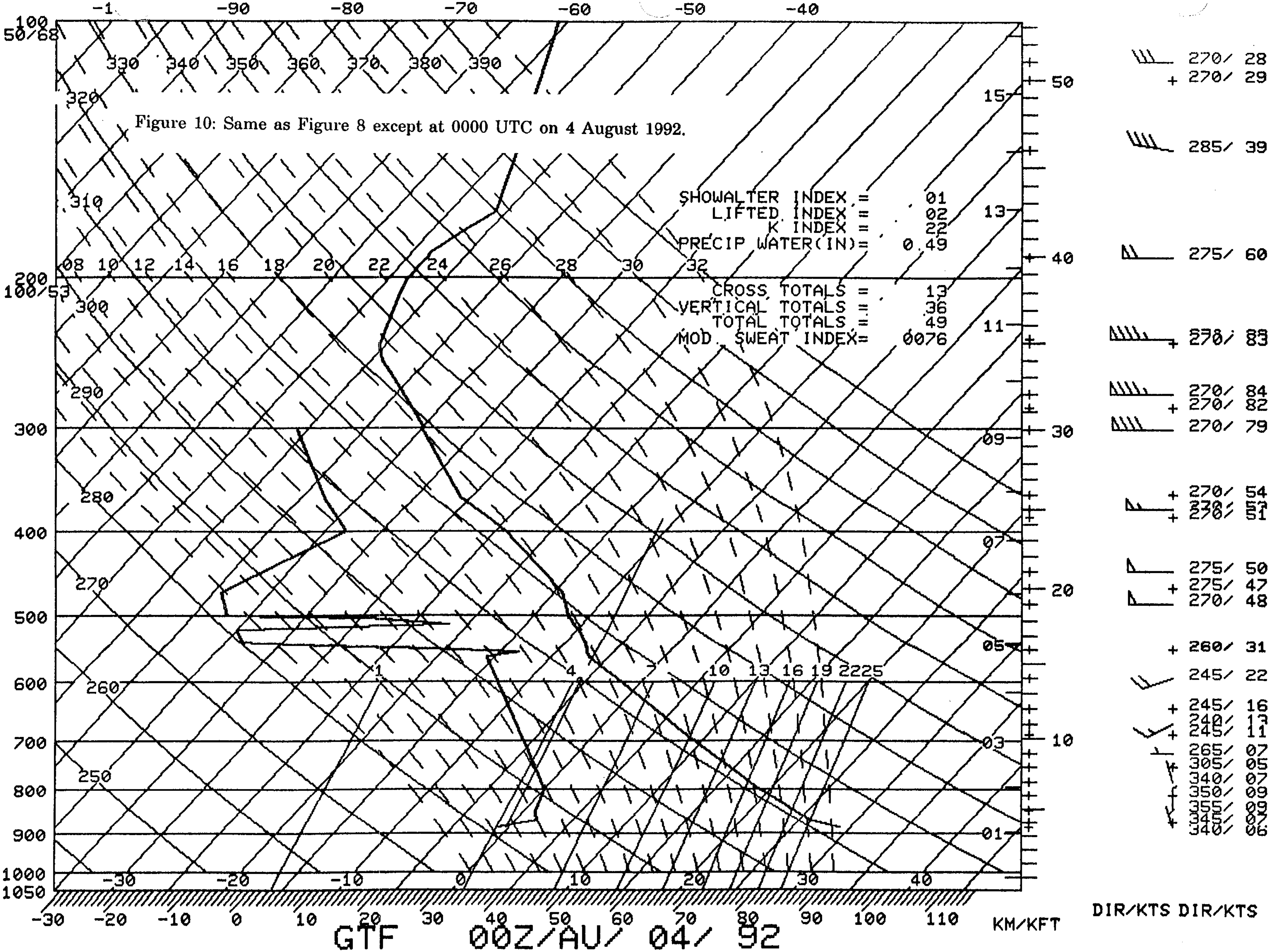


Figure 10: Same as Figure 8 except at 0000 UTC on 4 August 1992.

GTF 00Z 4 AUG 92

UNITS : KNOTS, LVLS : THSD FT (MSL)

```
B R N =      2
B+    =     12 (M/SEC)**2 X 10
B-    =      0 (M/SEC)**2 X 10
SHR   =     67 (M/SEC)**2
WMAX  =     16  M/SEC
EL    =    304 MB,    308  HND FT
MPL   =    365 HND FT
VS5   =      0 (M/SEC)**2
SS15  =     72 10-4 SEC-1
```

```
PARCEL FROM PMAX
ENTRAINMENT = 60 PERCENT
P0    =    886 MB
PMAX  =    869 MB
LCL   =    595 MB
LFC   =   -999 MB

EI    =    -30 J/KG X 10
EI+   =      0 (+ PART)
EI-   =    -30 (- PART)

ENERGY CHANGE IN LAYERS
P1       P2
 869      100     -679 J/KG X 10
```

```
LI    =      1
KI    =     22
SWI   =      1

CCL   =    579 MB
C TMP =     30 C,      86 F
WAVG  =  [illegible] G/KG X 10-1
```

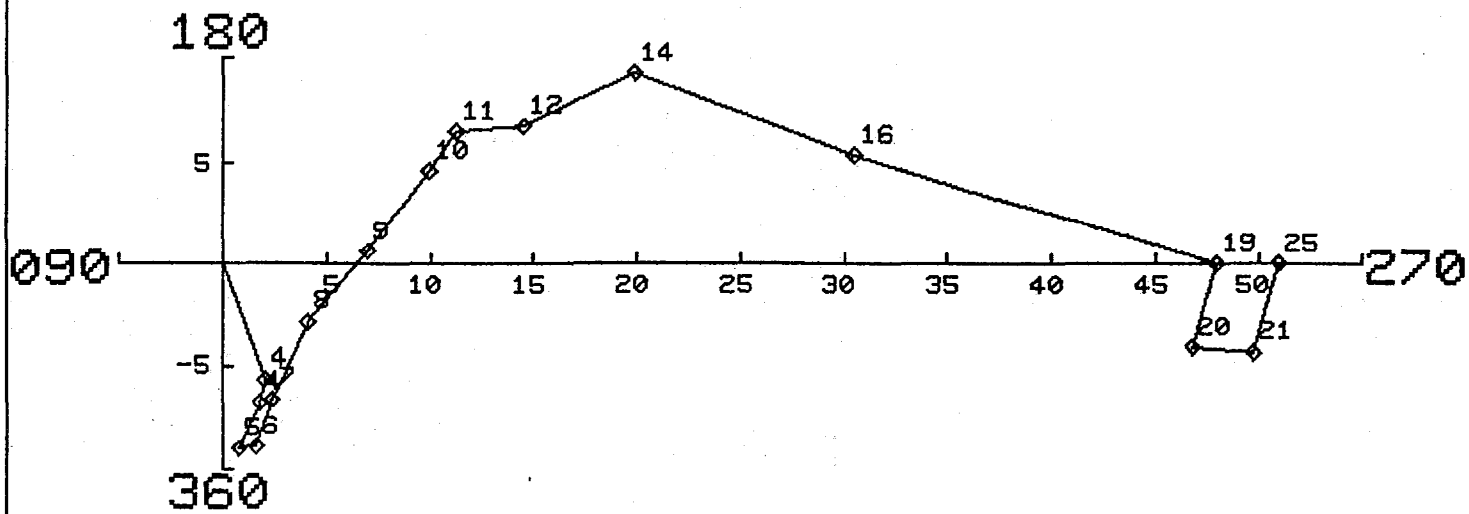


Figure 11: Same as Figure 9 except at 0000 UTC on 4 August 1992.

SFC ELV (FT) = 3655 = 16

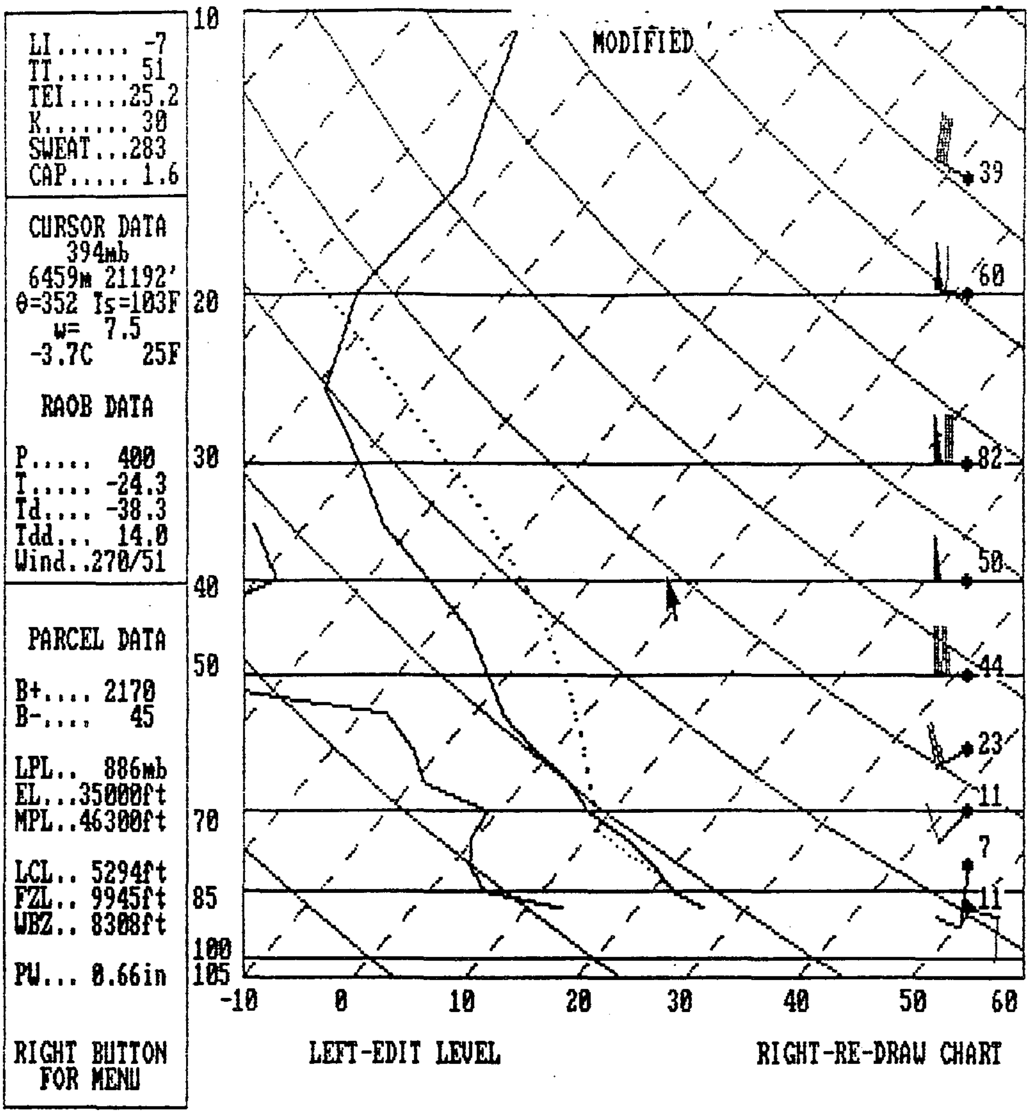


Figure 12: 0000 UTC 4 August 1992 modified SkewT-logP sounding for Havre, Montana (HVR) via the SHARP Workstation.

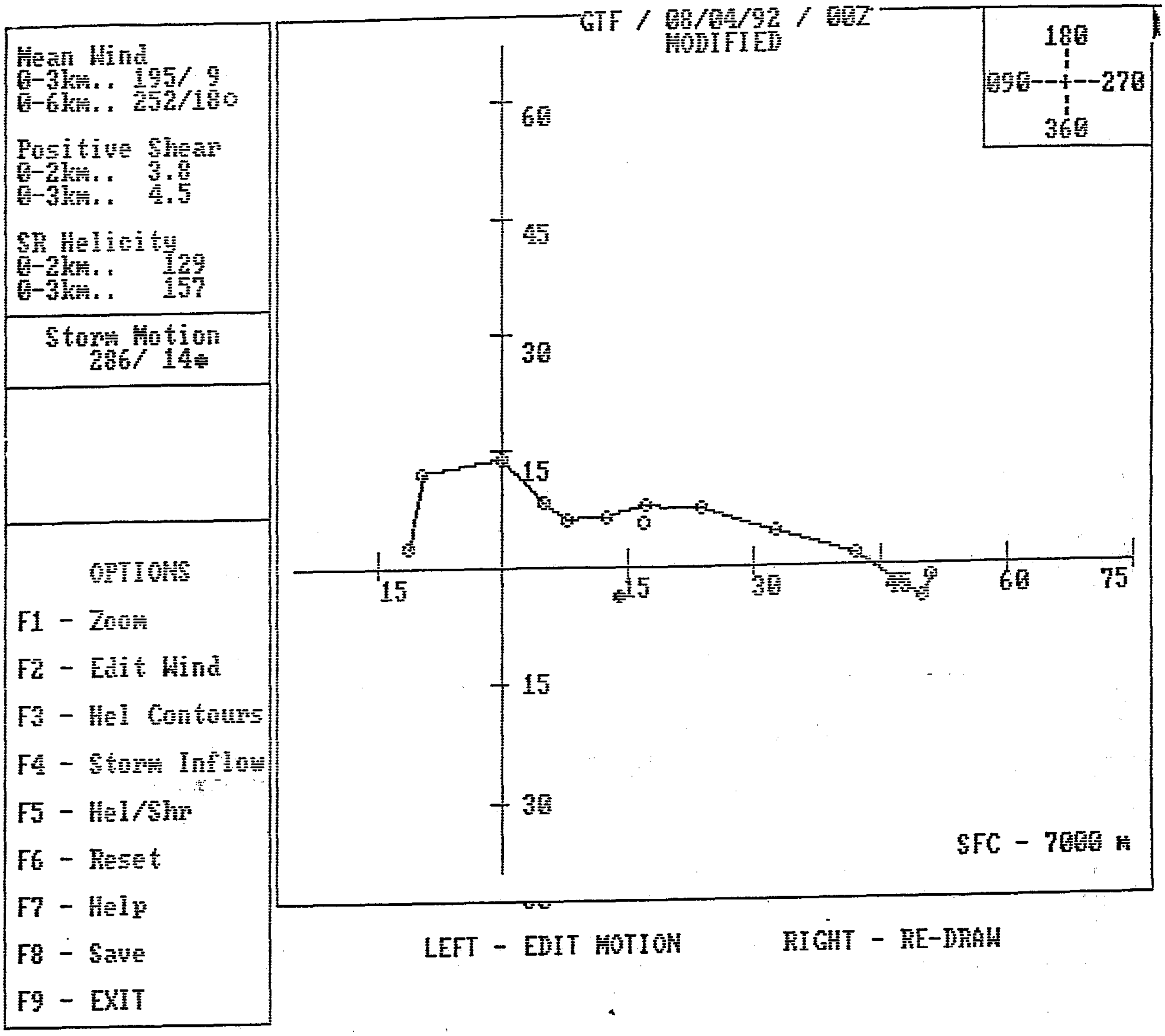


Figure 13: 0000 UTC 4 August 1992 modified hodograph for Havre, Montana (HVR) via the SHARP Workstation using the default storm motion (70% of the magnitude and 30° to the right of the 0-6 km mean wind).

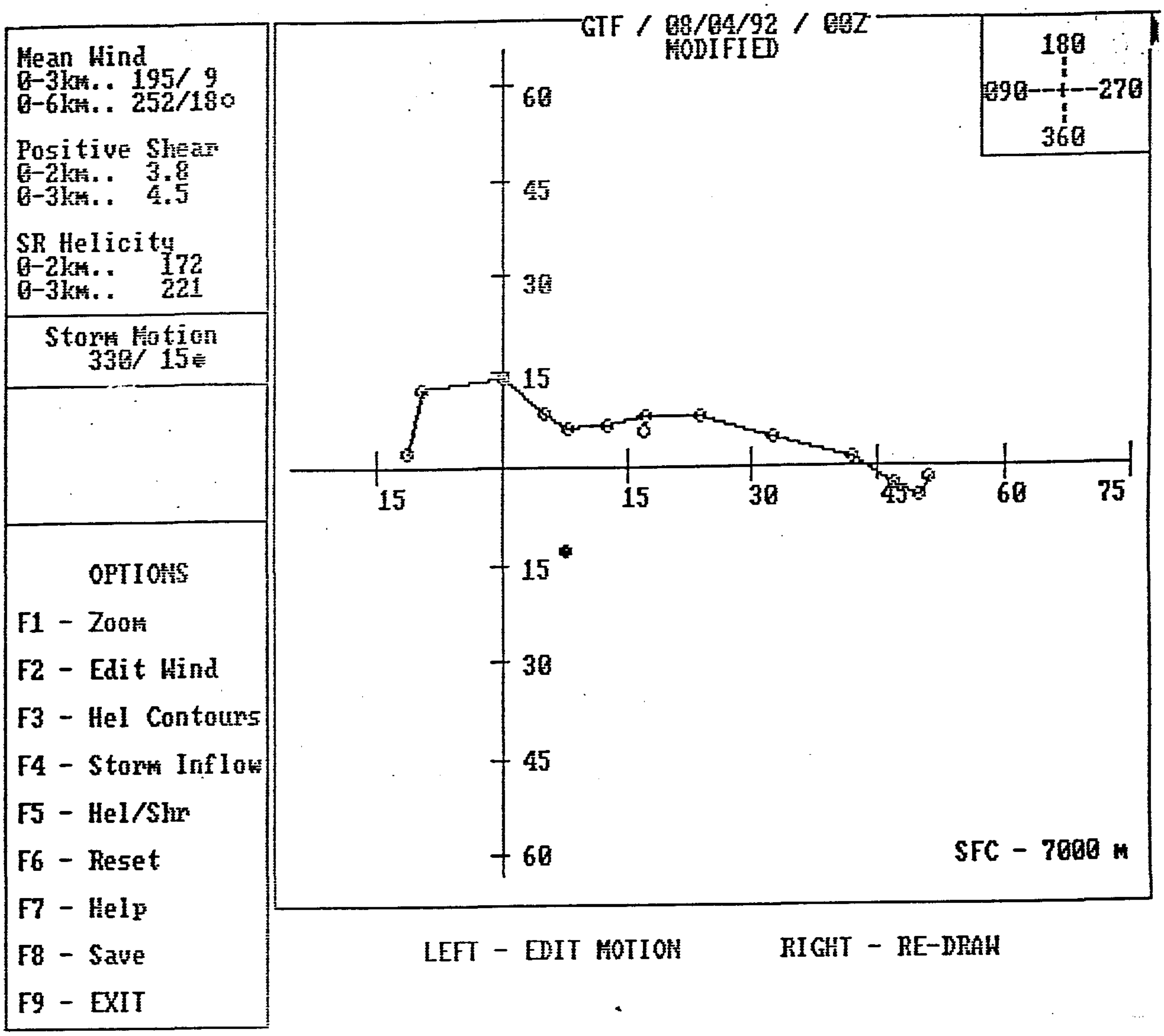


Figure 14: 0000 UTC 4 August 1992 modified Havre, Montana (HVR) hodograph using the observed storm motion from radar data.

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