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OBSERVING AND FORECASTING A MESOSCALE SNOW EVENT USING MAPS[1]

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1. Introduction

On December 22, 1991, a closed upper level low began to lift northeast into the Southern Plains. The Nested Grid (NGM) and Aviation (AVN) models forecast the 500 mb low to move from western New Mexico at 1200 UTC to southwest Kansas at 0000 UTC, 23 December (Figures 1a & 1b). Positive vorticity advection (PVA) was forecast to move across southeast Colorado during the day. At the surface, a low was forecast to intensify and move from southeast Colorado at 1200 UTC, 22 December to the northern Texas Panhandle at 0000 UTC, 23 December, with high pressure building into northeast Colorado from Wyoming (Figures 2a & 2b). This pattern is well known as a precipitation producer for eastern Colorado. Forecasts reflected high probabilities of precipitation for most of eastern Colorado during the day, but because of the southern location of the upper low and quick movement of the 500 mb PVA into Kansas, no heavy precipitation was forecast.

The 12-hour forecast from the NGM model verified well with both the track and intensification of the 500 mb low. However, the 700 mb low at 0000 UTC was a little deeper than forecast by the NGM, elongated further to the north, and there was a tighter 700 mb temperature gradient in northeast Colorado (Figures 3a & 3b). The grid spacing of the NGM likely hampered its ability to delineate this temperature gradient and the subsequent mesoscale snow event that occurred during the afternoon of 22 December. During a 7-hour period from 1800 UTC, 22 December to 0100 UTC, 23 December, 6 to 16 inches of snow fell in a narrow band to the east and south of Akron, Colorado (AKO) (Figure 4).

This heavy snow was not forecast by the WSFO Denver forecasters. A detailed post analysis revealed that the Mesoscale Analysis and Prediction System (MAPS) data provided many clues to the general location and duration of this mesoscale snow event.

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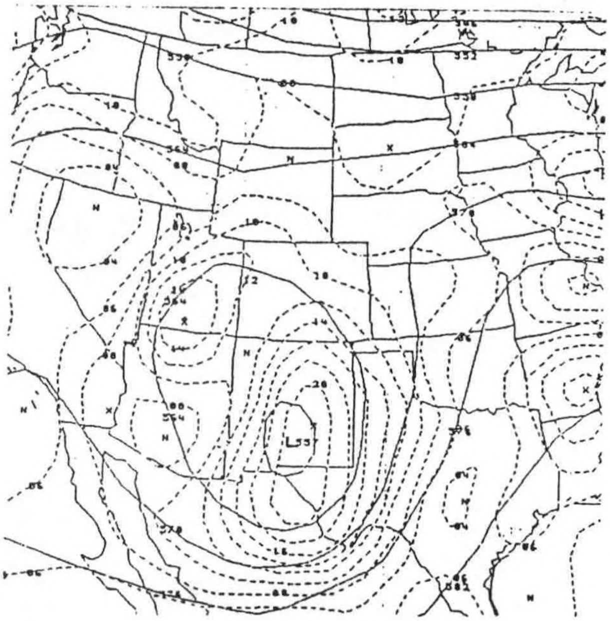
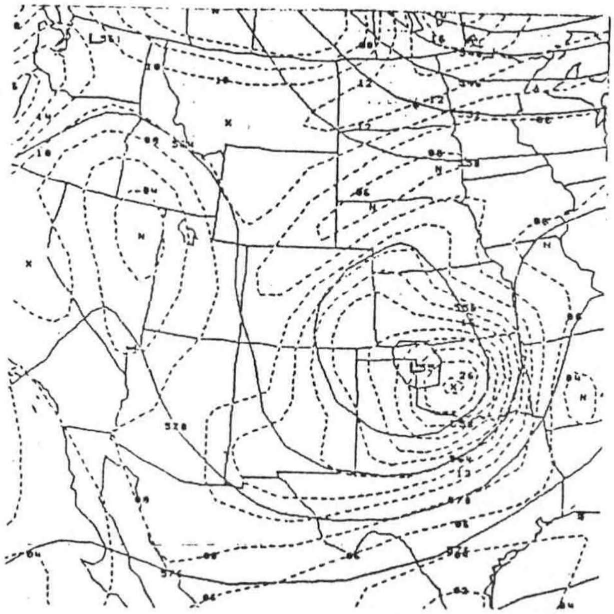
[1]Contained in *Postprints, NWS Winter Weather Workshop*, NOAA Technical Memorandum NWS WR-218, Portland, Oregon, December 1992.

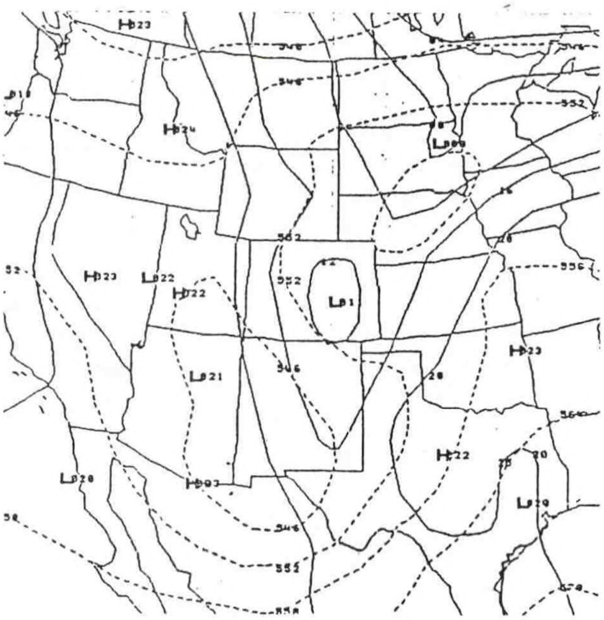


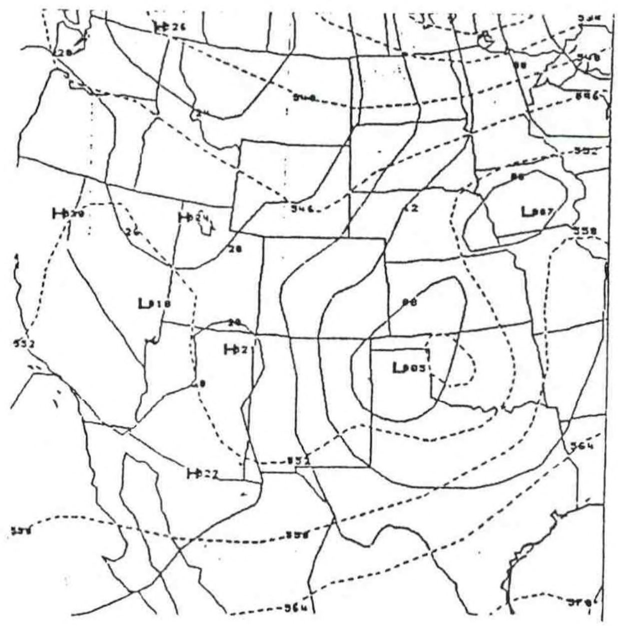


NGM 500 mb heights and vorticity

Figure 1a. Analysis 1200 UTC December 22, 1991.

Figure 1b. 12-hour forecast valid 0000 UTC December 23, 1991.

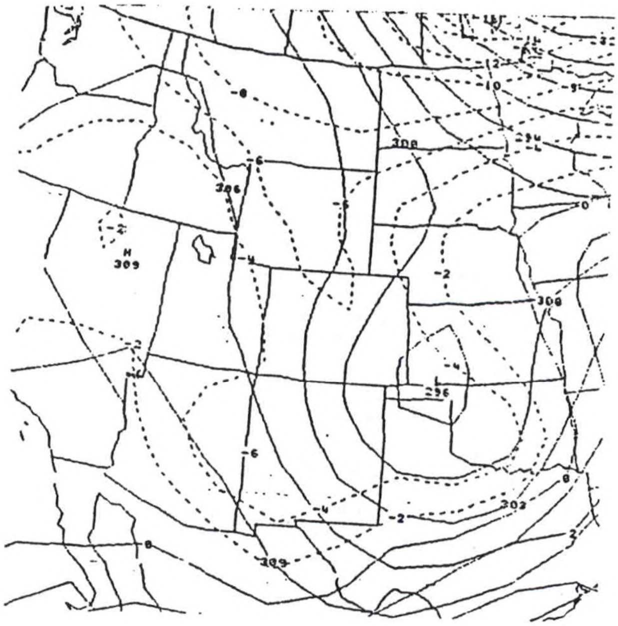


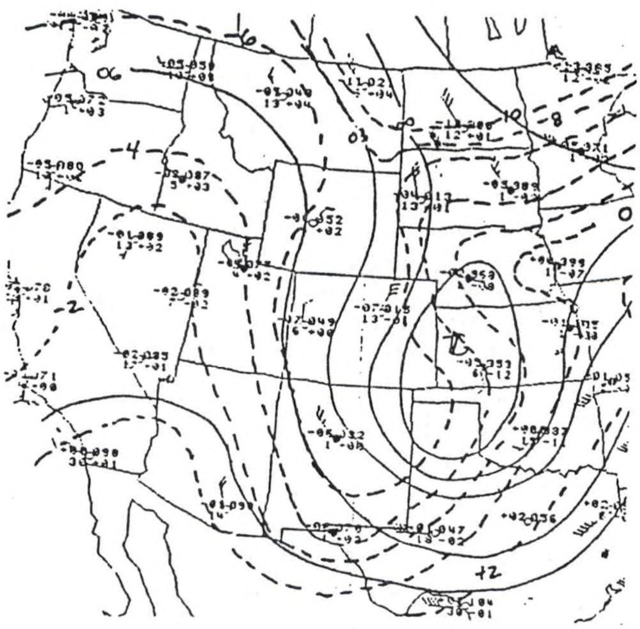


NGM surface pressure and surface to 500 mb thicknesses

Figure 2a. Analysis 1200 UTC December 22, 1991.

Figure 2b. 12-hour forecast valid 0000 UTC December 23, 1991.





Comparison

Figure 3a. NGM 12-hour forecast of 700 mb heights and temperatures, valid 0000 UTC December 23, 1991.

Figure 3b. A 0000 UTC analysis at the same time.

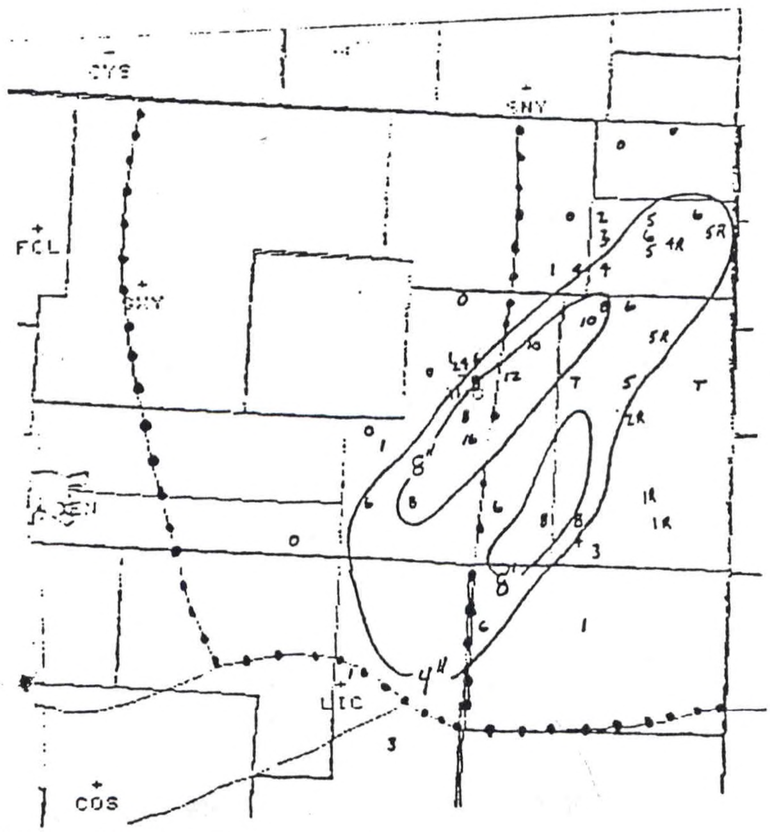


Figure 4. Snowfall map, 1800 UTC December 22, 1991 to 0100 December 23, 1991. Snowfall contoured at four inches and eight inches. Light solid lines indicate county and state borders, dotted lines are zone boundaries. R indicates rain mixed with snow.

2. Overview of MAPS

The first isentropic version of MAPS became available to forecasters at WSFO Denver with the arrival of the second generation prototype AWIPS workstation (DARE-II) in December 1989. The version of MAPS in use in December 1991 consisted of a complete surface and upper air analysis available every three hours. Data from RAOBS, profilers, satellite, surface observations and automated aircraft reports are used by MAPS, with boundary conditions provided by the NGM. The data is analyzed on a 60 km horizontal resolution grid with 25 vertical levels (five terrain following sigma layers and 19 isentropic levels). Forecasts are made using a primitive equation model formulated in isentropic coordinates. Forecasts for three and six hours are available every three hours and at 0000 and 1200 UTC 3-, 6-, 9-, and 12-hour forecasts are produced.

MAPS data arrives in the workstation in gridded form on both isentropic and isobaric surfaces, as well as on the sigma layers. This information is then accessed in real-time using application programs which display the output in either plan view or cross section form. Forecast soundings can also be created. MAPS data can be fully integrated with the numerous other data sets available on the workstation. Further details on the inner workings of the MAPS model can be found in Benjamin (1989) and Benjamin et al. (1991a and b).

Utilizing the isobaric data from MAPS at the WSFO has been relatively straightforward. However, using the isentropic data has been a bit more complex. Isentropic analysis is only now beginning to make a comeback to the popularity enjoyed several decades ago. Few operational forecasters have had the opportunity to use this type of information in day-to-day forecasting so that training and experience are necessary to become adept at exploiting them.

Although there are some problems associated with isentropic analysis, the many advantages far outweigh any difficulties or problems that may be encountered. Several of the advantages of isentropic analyses have been cited by Moore (1987). These include better resolution of frontal zones, more coherent patterns of moisture transport, more direct indications of areas of ascent and descent, and with the use of cross sections, a quick indication of locations of fronts, and static stability.

3. Synoptic and Mesoscale Discussion

At 1200 UTC, 22 December 1992, the 700 and 500 mb lows were located near Albuquerque, New Mexico (ABQ). MAPS cross sections indicated a well defined stratospheric extrusion of high potential vorticity (PV) air to 500 mb over southeast Colorado (Figure 5). The PV bullseye on the 316K isentropic surface associated with this extrusion was forecast to advect into southwest Kansas during the afternoon (Figure 6).

It has been shown (Hoskins et al. 1985, Smith and Benjamin 1989) that on isentropic surfaces, PV is a good conservative tracer to follow the motion of upper troughs in the atmosphere. It maintains its continuity until altered by some diabatic process or friction. On a constant theta surface, the advection of PV from the base of a cold trough to the northeast would bring the PV lower into the troposphere, and from an area of relatively high static stability to relatively low stability. As the column of air is stretched in the area of lower static stability, the relative vorticity increases, and the trough intensifies (Holton 1972). On December 22, the high PV air over southeast Colorado was descending into air with very high 500-850 mb lapse rates, so further intensification was expected.

As the system lifted northeast and intensified, the lows at 700 and 500 mb became more elongated than indicated on either the NGM or MAPS forecasts. This was one element helpful to the development of the mesoscale snowstorm, as the circulation around the 700 and 500 mb lows was brought closer to northeast Colorado. Although MAPS height fields did not indicate this elongation, MAPS temperature, moisture, and wind fields on isentropic surfaces, and at 700 mb and 850 mb, provided strong indications of the developing snowstorm.

A well defined sloping frontal boundary was forecast by MAPS in northeast Colorado that afternoon. A forecast cross section valid at 1800 UTC, 22 December from near Cheyenne, Wyoming (CYS) to near Goodland, Kansas (GLD) showed the frontal boundary in the theta-E isentropes, with abundant moisture riding up over the boundary (Figure 7).

MAPS 700 mb forecasts valid at 2100 and 0000 UTC showed a tight temperature gradient between Denver and Akron (Figures 8a & 8b) Deformation vectors at 2100 UTC were parallel to the isotherms indicating maintenance of the temperature gradient. By 0000 UTC, the magnitude of the deformation vectors were smaller, while cross isotherm vectors to the west suggested a weakening of

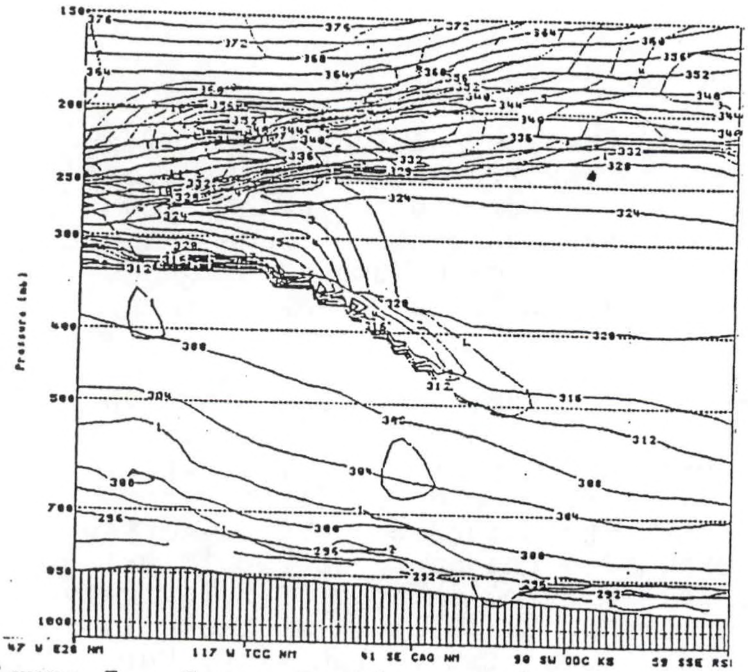


Figure 5. Cross-Section of MAPS theta and potential vorticity from northeast New Mexico to southwest Kansas, 1200 UTC December 22, 1991.

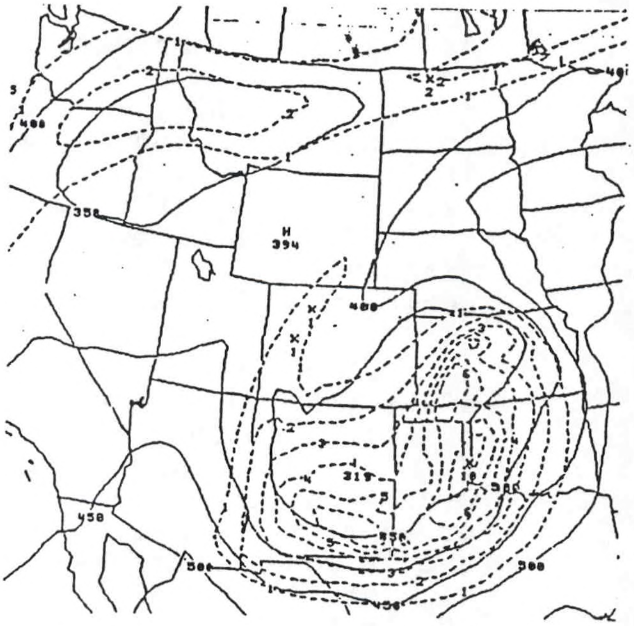


Figure 6. MAPS 12-hour forecast of 316K pressure and potential vorticity valid 0000 UTC December 23, 1991.

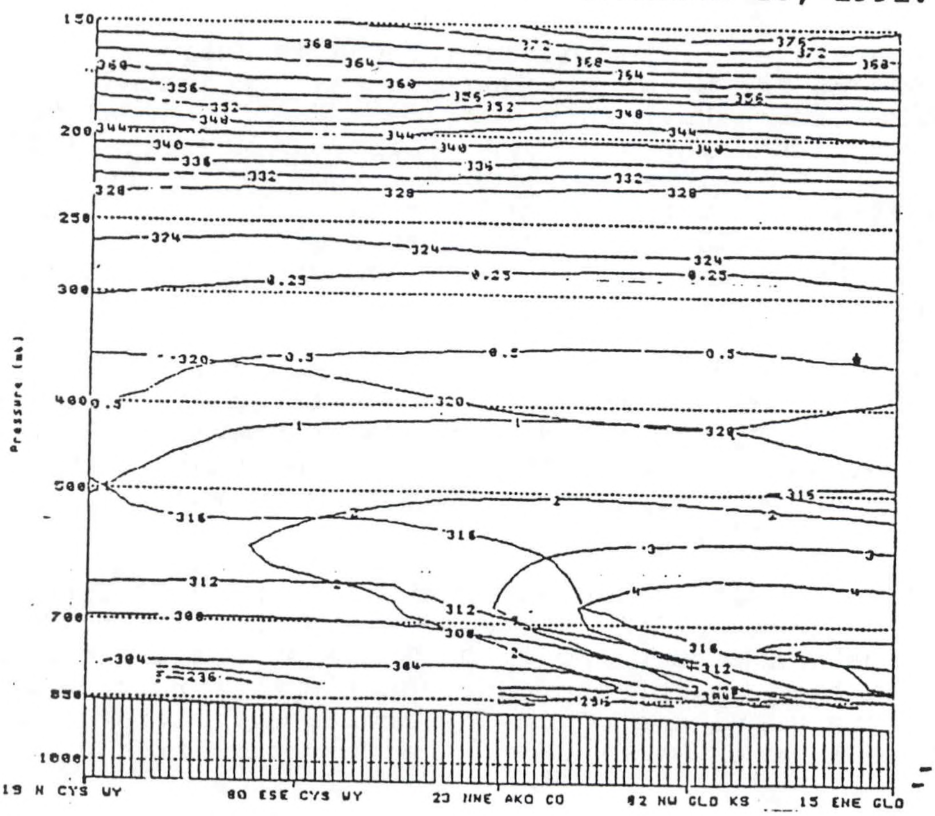


Figure 7. MAPS forecast Cross-Section from southeast Wyoming to northwest Kansas of theta-E and mixing ratio, valid 1800 UTC December 22, 1991.

the temperature gradient. This was an early clue to the duration of the event.

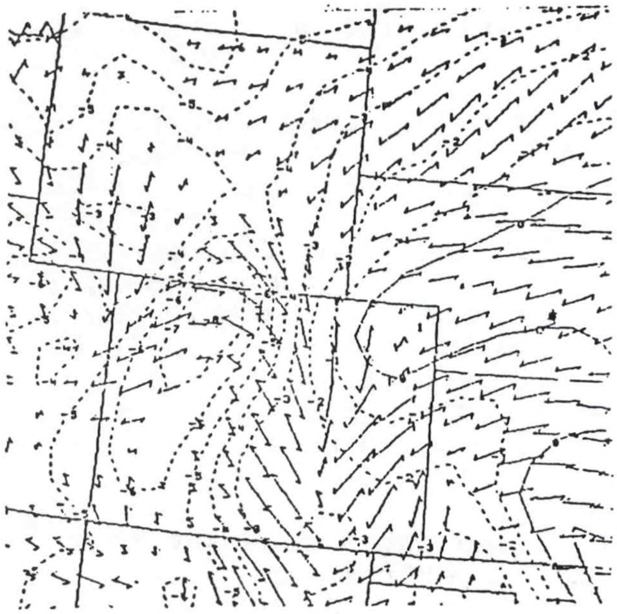
MAPS forecasts at 700 mb valid at 1800 UTC showed an axis of confluence to the east of the temperature gradient. This axis extended from southwest Nebraska into Colorado near Limon. A moisture gradient was indicated, with a large area of condensation pressure deficits (the amount of lifting in millibars necessary to reach saturation) less than 20 mb to the southeast of the confluent axis (Figure 9). Divergence charts at 700 mb (not shown) and 850 mb (Figure 10) indicated convergence oriented along the axis. A cross section of divergence from near Cheyenne, Wyoming to near Goodland, Kansas, displayed this area of low level convergence, with mid level divergence of equal magnitude centered at 500 mb (Figure 11).

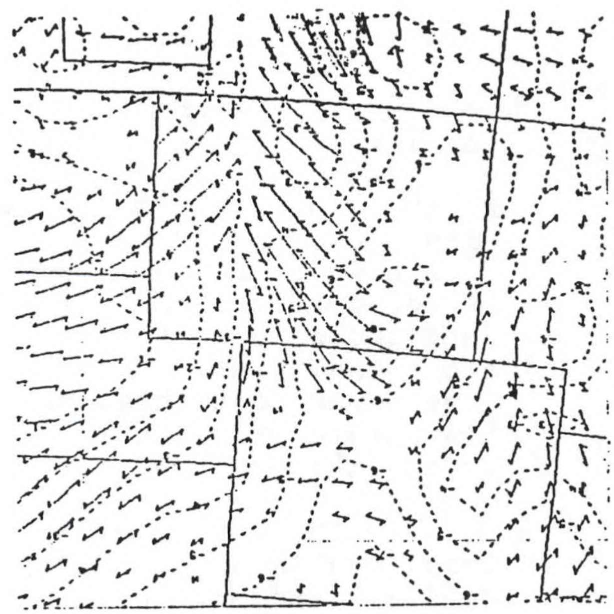
In the warmer moist air, 850-700 lapse rates forecast the least stable air (6°C/km) to be located in extreme southwest Nebraska and northwest Kansas (Figure 12). By 2100 UTC, the least stable air from 700 to 500 mb, with a lapse rate of 7°C/km was located along and just west of the 700 mb confluent axis (Figure 13).

Isentropic forecasts at several levels valid at 1800 UTC provided a three dimensional look at the flow above the frontal zone, showing the advection and condensation of moisture over the boundary. Figure 14 shows the limited moisture available at the 296 K level (about 800 mb), but strong southeast winds in Kansas would be advecting moisture into northeast Colorado during the afternoon. Figure 15 shows a larger area of nearly saturated air to the southeast of the confluent boundary at the 300K isentropic surface. Condensation pressure deficits were 10 mb at Goodland, and 150 mb at Akron, which was located in the very dry low level air to the west of the boundary. This chart indicates that the southeast winds in Kansas were lifting the moist air to saturation over the sloping frontal boundary.

At the 308K and 312K isentropic surfaces (about 550 mb and 450 mb), respectively, the confluent axis was located further west, consistent with a sloping frontal boundary. Moderate east to southeast winds were blowing across northeast Colorado. Saturation of the air mass was evident, with condensation pressure deficits of 10 mb or less over a larger area, and much further west than at lower isentropic levels (Figures 16 & 17).

Note that the winds were northeast at 300K backing to east southeast at 308K. Wind forecasts valid three hours later, at





MAPS forecasts of 700 mb temperature and deformation valid

Figure 8a. 2100 UTC December 22, 1991   Figure 8b. 0000 UTC December 22, 1991

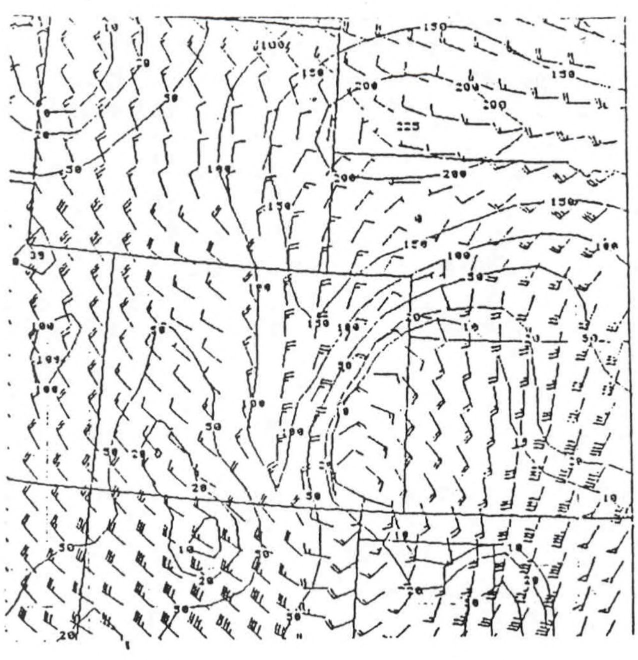


Figure 9. MAPS forecast of 700 mb wind and condensation pressure deficit, valid 1800 UTC December 22, 1991.

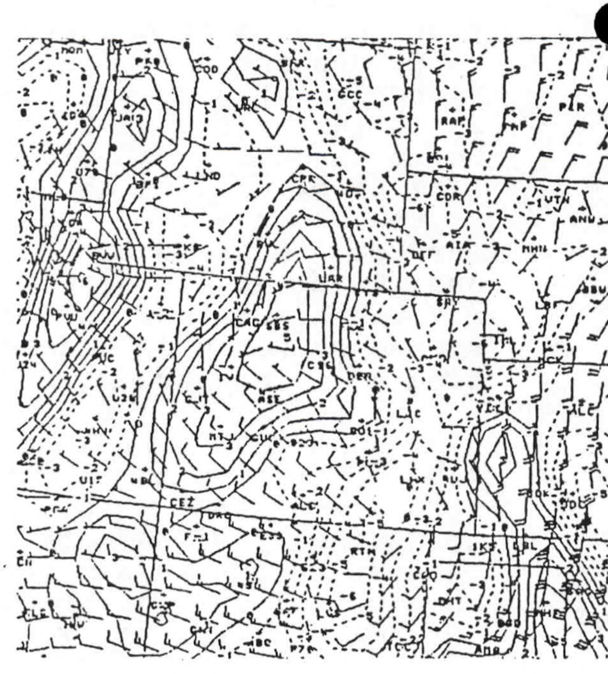


Figure 10. MAPS forecast of 850 mb divergence and wind, valid 1800 UTC December 22, 1991.

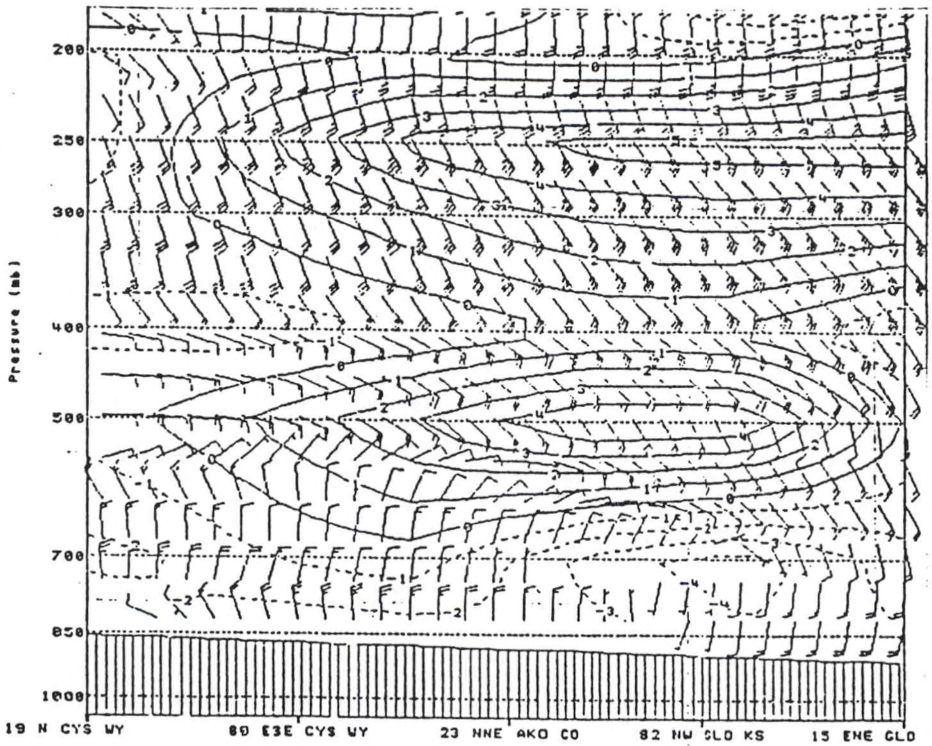


Figure 11. MAPS forecast Cross-Section from southeast Wyoming to northwest Kansas of wind and divergence, valid 1800 UTC December 22, 1991.

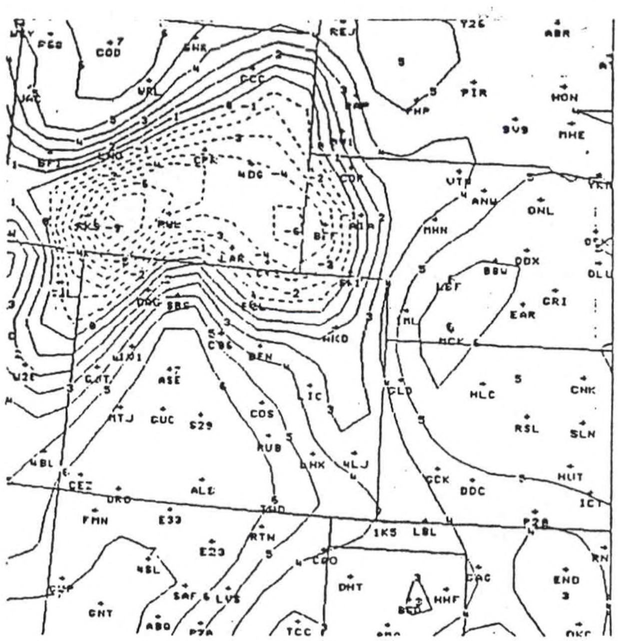


Figure 12. MAPS forecast 850 mb lapse rate valid 1800 UTC December 22, 1991.

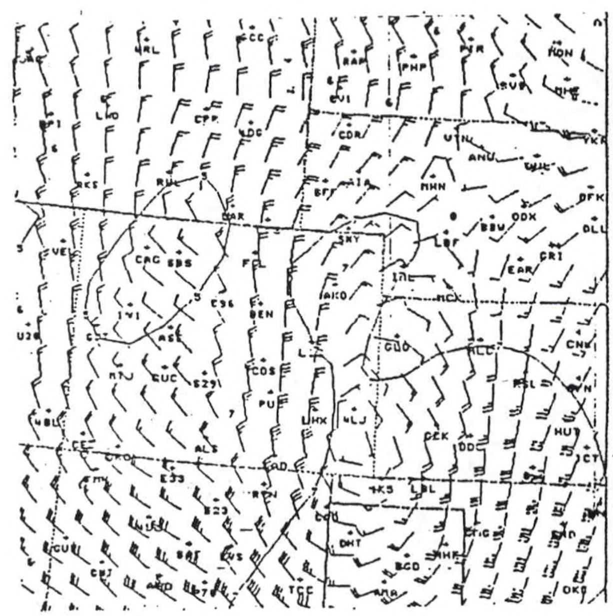


Figure 13. MAPS forecast of 700 mb wind and lapse rate, valid 2100 UTC December 22, 1991.

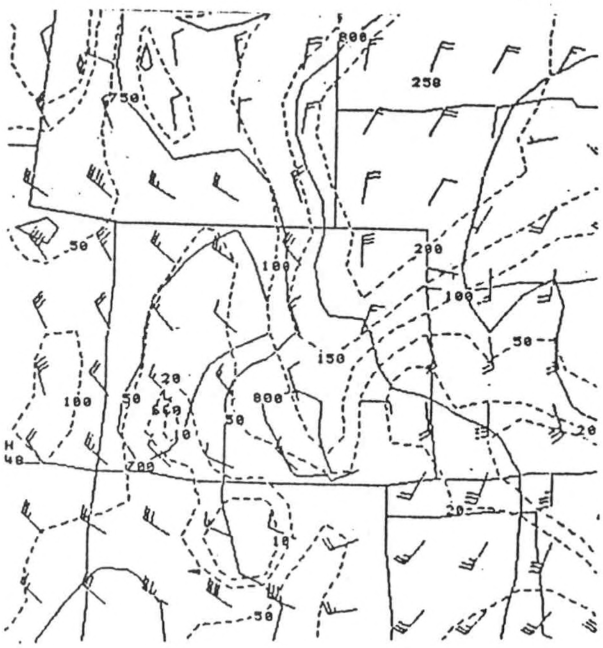


Figure 14. MAPS forecast, 296K isentropic surface of pressure, wind and condensation pressure deficit, valid 1800 UTC December 22, 1991.

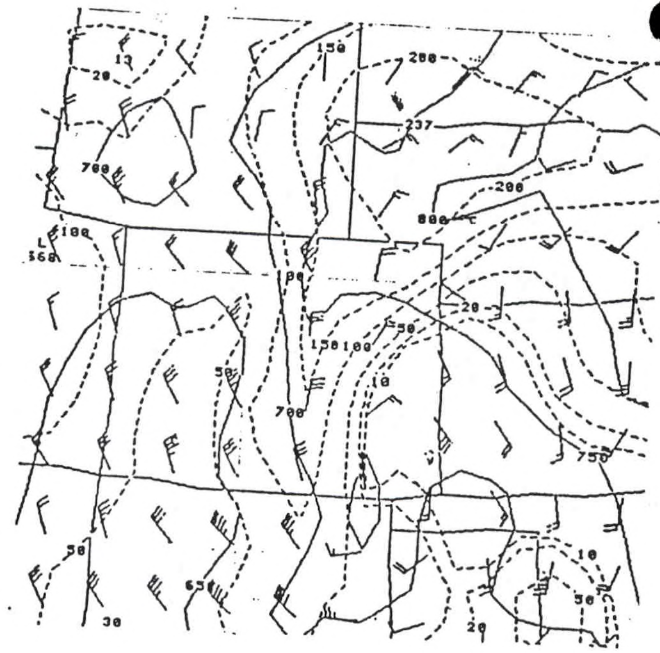


Figure 15. MAPS forecast, 300K isentropic surface of pressure, wind, and condensation pressure deficit, valid 1800 UTC December 22, 1991.

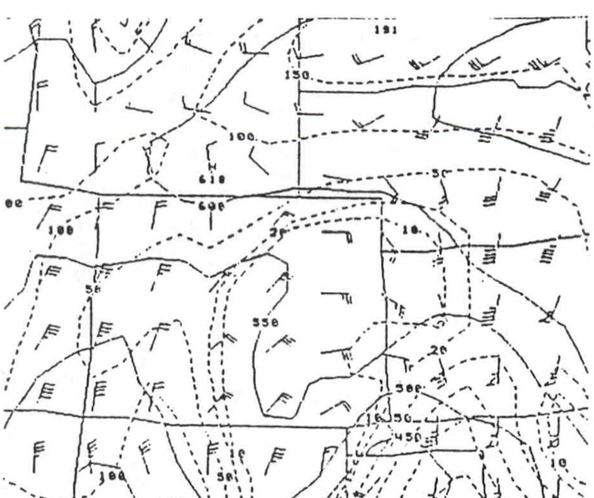


Figure 16. MAPS forecast, 308K isentropic surface of pressure, wind, and condensation pressure deficit, valid 1800 UTC December 22, 1991.

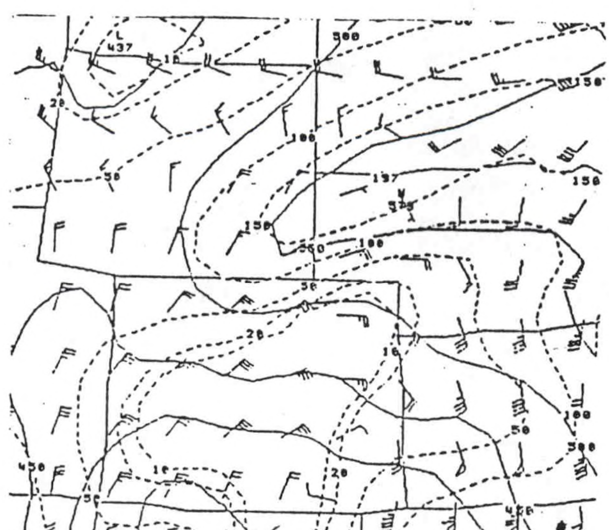


Figure 17. MAPS forecast, 312K isentropic surface of pressure, wind, and condensation pressure deficit, valid 1800 UTC December 22, 1991.

2100 UTC, showed winds becoming northerly below 700 mb, with deepening east to northeast winds above 700 mb.

The development of convection requires moisture, instability and some lifting mechanism. The MAPS forecast charts indicated that each of these elements was available over northeast Colorado during the afternoon of December 22. The next section suggests how a forecaster might have monitored the development of the heavy snow.

4. Real-Time Evaluation of the Event

Profiler data through the day was very informative in evaluating the developing system. The Granada profiler (GDA, located in southeast Colorado) depicted the passage of a closed circulation between 500 and 600 mb at 2200 to 2300 UTC (Figure 18). Prior to the passage of the low, strong southeast winds were noted at 700 mb. The Platteville (PLT) profiler, located 30 miles north northeast of Denver, showed strong east component winds between 500 and 250 mb at 1700 UTC. These winds backed to more northeast during the day, finally turning northerly at 0200 UTC (Figure 19). Although not available to the forecaster during the afternoon, the McCook profiler in southwest Nebraska depicted the passage of a circulation about 600 mb during the early evening.

Infrared and visible satellite imagery indicated a band of convection which began in extreme northwest Kansas at 1800 UTC. As discussed earlier, this was the area over which MAPS forecasted the strongest 850 convergence, and lowest 850-700 lapse rates at 1800 UTC. Along the strong southeast steering winds, the band of convection rotated northwest and moved over the sloping frontal boundary. The boundary provided a focus for the continuation of the convective process in a relatively narrow band. Conditional instability was also required to produce the locally heavy snow. Convection continued only in the areas of sustained condensation of moisture by lifting over the frontal boundary.

While this event was not easily detected in surface pressure patterns, the sequence of surface weather observations at AKO is consistent with this postulation (Table 1). Until 1900 UTC, Akron was post frontal, with northwest winds and low dew points. The sloping frontal boundary extended aloft over Akron, and the first indication of the event at Akron was the northeast winds beginning at 1946 UTC. Snow began at 2004 UTC, and continued heavy at times until 2343 UTC, dropping two inches of snow at the airport. As indicated in the MAPS 0000 UTC analysis of 700 mb

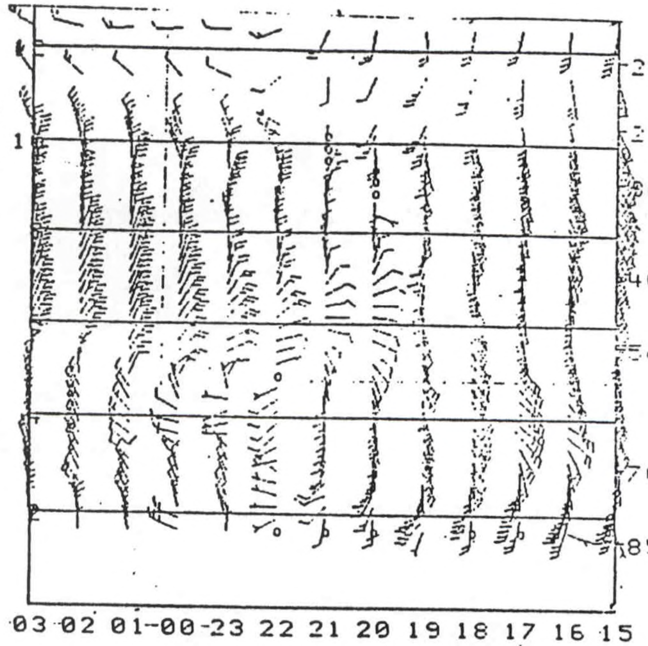


Figure 18. Time-Series, Granada Wind Profiler, 1500 UTC December 22 to 0300 UTC December 23, 1991.

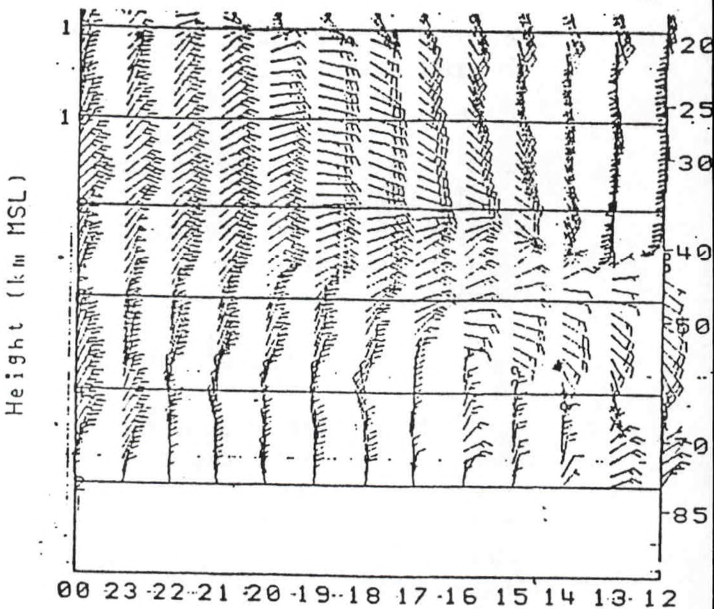


Figure 19. Time-Series, Platteville Wind Profiler, 1200 UTC December 22 to 0000 UTC December 23, 1991.

TABLE 1

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AKO SA 0148 E35 BKN 80 OVC 20 168/32/22/3107/995
AKO SP 0128 E35 BKN 80 OVC 15 2910/994
AKO SA 0047 E25 BKN 60 OVC 15 157/30/26/2911/992
AKO SP 0030 E25 BKN 50 OVC 10 2911/991
AKO RS 2353 E10 OVC 3F 111/30/24/3610/989/SE43/ 31515 90402
AKO SP 2328 W4 X 1S-F 0215/989
AKO SA 2250 W2 X 1/4S+F 139/28/28/0414/986
AKO SA 2146 W4 X 1/2SF 117/32/27/0214/981
AKO SP 2105 W4 X 1/2SF 0414/981
AKO SA 2048 E9 OVC 1S-F 114/34/17/0510/981/SB04/ 500
AKO SP 2032 E9 OVC 1S-F 0314/981/SB04
AKO SP 2017 E15 OVC 2S-F 0412/980/SB04
AKO SP 2004 E25 OVC 10S- 0310/980/ SB04
AKO SA 1946 E50 BKN 100 OVC 20 101/36/17/0206/980
AKO SA 1849 E60 BKN 100 OVC 30 099/34/17/3507/979
AKO SA 1748 E80 BKN 120 OVC 30 105/35/18/3309/981/ 805 28
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Surface Observations at Akron, Colorado (AKO) 1748 UTC December 22, 1991 through 0148 December 23, 1991.

temperature, the baroclinic boundary aloft pulled eastward rapidly and weakened (Figure 20). The winds at Akron turned northwest once again, and the dew point dropped.

The network radar at Limon, Colorado indicated light precipitation (VIP 1) in the area of heavy snow for the duration of the event. Although Doppler data from the Mile High radar was not available during the afternoon, but based on previous experience, it would have detected the band of heavy snow.

5. Concluding Remarks

The MAPS model will in time become available to forecasters at WFO's across the country. We at WSFO Denver have incorporated it into our daily analyses and forecasts and this is but one example of its utility in producing a better mesoscale forecast. Our experience has shown that the ability to incorporate new forecast tools takes time, and depends on an individual's initiative and interest. Also, for the short term forecast, a weather watch must be ongoing. In this case, MAPS indicated the potential for significant precipitation. However, it was the formation of convection outside the area of concern that advected into northeast Colorado that caused the heavy snow. There may be as many cases in which the potential for locally heavy snow is indicated, but not realized. We are convinced that a forecaster dedicated to mesoscale analysis would have identified this event. Even with the missing Doppler radar data, MAPS forecasts would have heightened awareness, and through close contact with spotters, a better mesoscale forecast would have been produced.

There is a large volume of data available on MAPS, and an additional challenge to forecasters will be to learn to focus on the most useful data fields. Of course, this will vary with the season and with the event. Identifying those forecast fields useful to mesoscale forcing is a major goal of an ongoing mesoscale risk reduction at WSFO Denver (Maddox, 1992).

6. References

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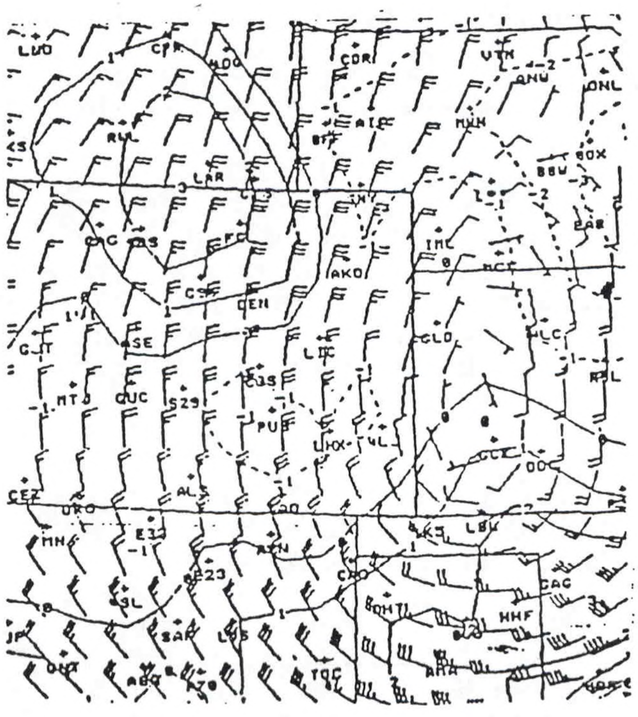

Figure 20. MAPS analysis of 700 mb divergence and wind, 0000 UTC December 23, 1991.