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A TECHNIQUE FOR FORECASTING UPSLOPE CLOUDINESS OVER THE HIGH PLAINS

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1. Introduction

Cloudiness associated with boundary-layer upslope flow is a major source of MVFR (marginal visual flight rules) and IFR (instrument flight rules) ceilings across the central High Plains of the United States. Upslope cloudiness forms when an easterly component of the boundary layer wind is directed along the east-west elevation gradient located east of the Rocky Mountains.

While the basic synoptic conditions favorable for upslope cloudiness are well known (Siebers et al. 1983), little information has been documented on the forecasting of the MVFR and IFR ceilings that can result. This paper will introduce a method for forecasting MVFR and IFR ceilings due to terrain induced boundary layer upward vertical motion utilizing PCGRIDDS (Petersen 1992).

2. The Data Set

Data for this study was collected over two months, mid-January to mid-March 1994. The area studied was the region of the central High Plains (i.e. eastern Colorado, western Kansas, western Nebraska, and the Texas and Oklahoma Panhandles) where terrain induced upward vertical motion is common. The study verified 6-, 12-, 18- and 24-hour Eta and NGM boundary layer forecasts for events characterized by -0.5 μbs^{-1} or greater rising motion (produced by orographic lifting) covering an area of at least 20,000 square miles (roughly equivalent to the western one third of Kansas).

A prediction was judged successful when greater than three-quarters of the forecast area was covered by MVFR or IFR ceilings within plus or minus one hour of the valid time. A weather depiction and cloud chart was used to determine the coverage of MVFR and IFR ceilings. Fifty-eight forecast upslope events were collected and verified for this study.

3. The Forecast Technique

A. Vertical motion calculations

Interpretation of model gridded output (using PCGRIDDS) enables the forecaster to calculate an approximation to upward vertical motion forced by orographic lifting. At the surface, vertical motion can be expressed as (Equation 1-62 in Haltiner and Williams 1980):

$$\omega_s = \vec{V}_s \cdot \vec{\nabla} p_s + \frac{\partial p_s}{\partial t} \qquad (1)$$

where the subscript **s** refers to a terrain following surface (x, y), $\vec{V}_s$ is the horizontal wind vector, $\vec{\nabla} p_s$' is the pressure gradient along the terrain following surface, and $\partial p_s / \partial t$ is the local change in pressure. Performing a scale analysis, typical values of the terms in (1) on the synoptic scale would be: $\vec{V}_s \sim 10\ ms^{-1}$, $\vec{\nabla} p_s \approx 2x10^{-4}\ mbs^{-1}$ over the High Plains, and $\partial p_s / \partial t \approx 2x10^{-4}\ mbs^{-1}$. From this it can be shown that $\vec{V}_s \cdot \vec{\nabla} p_s \approx 2x10^{-3}\ mbs^{-1}$ and $\partial p_s / \partial t \sim 2x10^{-4}\ mbs^{-1}$. Thus, the advection pressure term can be as much as an order of magnitude larger than the local change in pressure term. Therefore, (1) can be approximated as:

$$\omega_s \approx \vec{V}_s \cdot \vec{\nabla} p_s \qquad (2)$$

Equation (2) can be represented by the PCGRIDDS command:

dotp wind grad pres

where negative values indicate upward vertical motion. The Eta or NGM's base pressure field (Eta depicted in Figure 1), which closely follows the model terrain field, is used for the pressure while the boundary layer velocity forecast is used for the wind.

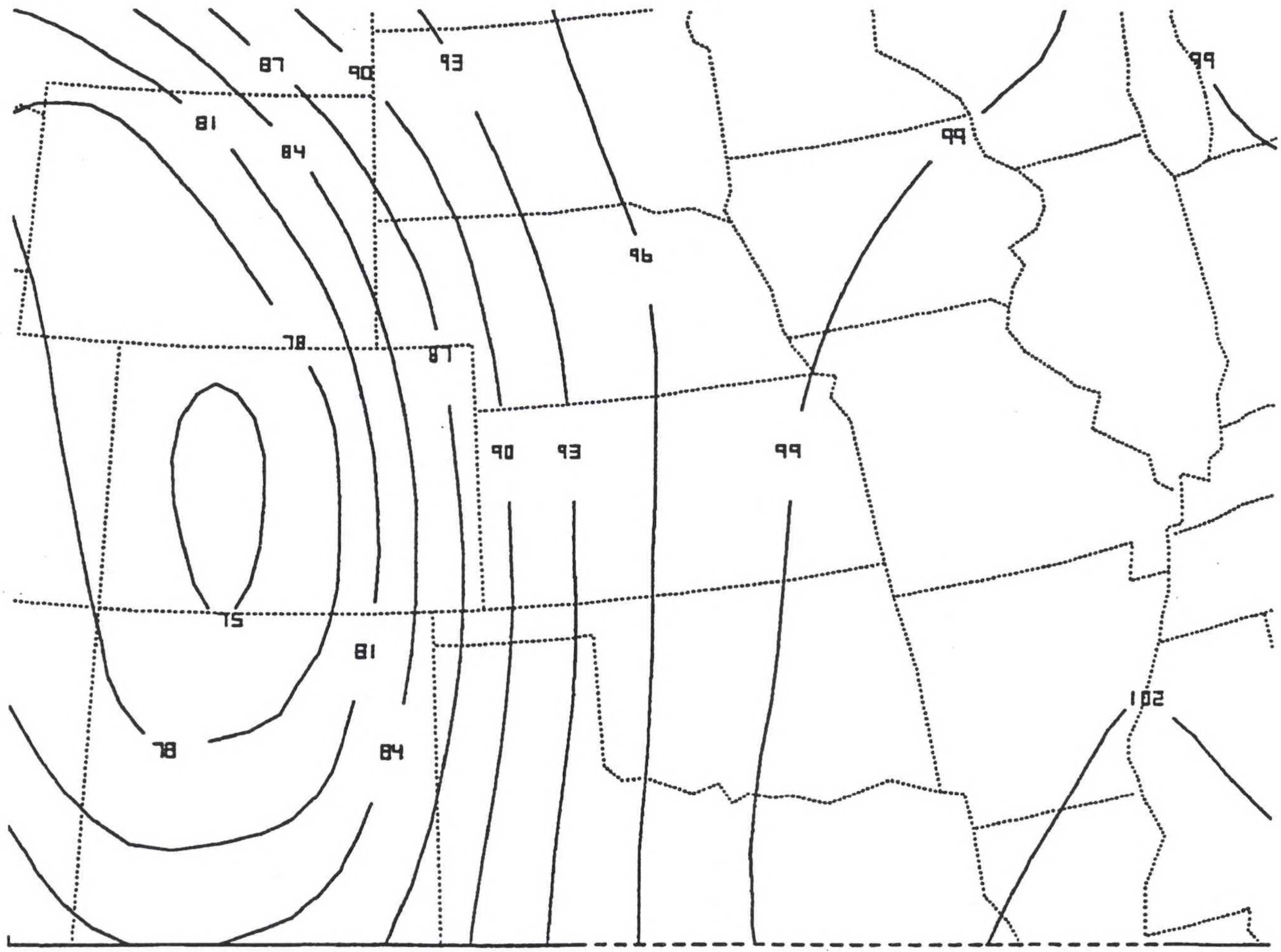

Figure 1. Eta model base pressure field (in tens of mb).

B. The forecast scheme

An initial forecast scheme based only on the presence of boundary layer upslope flow was tested. MVFR or IFR ceilings were predicted to occur in areas of -0.5 μbs^{-1} or greater terrain induced upward vertical motion. Initial review of the data suggested the presence of boundary layer upslope alone was insufficient for the accurate forecasting of MVFR and IFR ceilings as only 35 of the 58 cases tested (60%) resulted in MVFR or IFR ceilings.

A second forecast scheme, using upslope flow combined with boundary layer relative humidity (RH), was then tested. The addition of low-level RH provided a check to ensure sufficient moisture would be available for cloud formation.

Review of the cases suggested an RH value of greater than or equal to 80 percent to be a good cloud/no cloud threshold when combined with sufficient boundary layer upslope. Therefore, the forecast using PCGRIDDS commands (the complete PCGRIDDS macros are in Appendix A) would be:

dotp wind grad pres
relh

where IFR or MVFR ceilings are expected in areas of -0.5 μbs^{-1} or greater upward vertical motion due to upslope flow and where the boundary layer RH is greater than or equal to 80 percent. This restriction, due to low-level RH, decreased the number of forecast cases to 42. The RH restrictions imposed resulted in increased accuracy with 80 percent of the cases verifying. Utilizing this technique, a probability of detection (POD) of 0.94 along with a false alarm ratio (FAR) of 0.23 and a critical success index (CSI) of 0.74 was obtained.

4. Case Studies

A. 1200 UTC 15 January 1994

The 12-hour forecast from the 0000 UTC 15 January Eta model run (valid 1200 UTC 15 January) indicated terrain induced boundary upward vertical motion across western Kansas and western Oklahoma. Vertical velocities forced by the upslope flow in this area were from -0.5 to -1.0 μbs^{-1}. Boundary layer RH forecasts (using the b015 level[1]) indicated an area of greater than 80 percent RH across extreme northern Nebraska and northern Iowa. Combining these two parameters (Figure 2) suggested MVFR or IFR ceilings associated with upslope would not occur. The verifying weather depiction chart (Figure 3) valid at 1200 UTC 15 January indicated no MVFR or IFR ceilings across the central High Plains.

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[1] The Eta b015 surface is a terrain following surface which is located 15 mb above the model terrain.

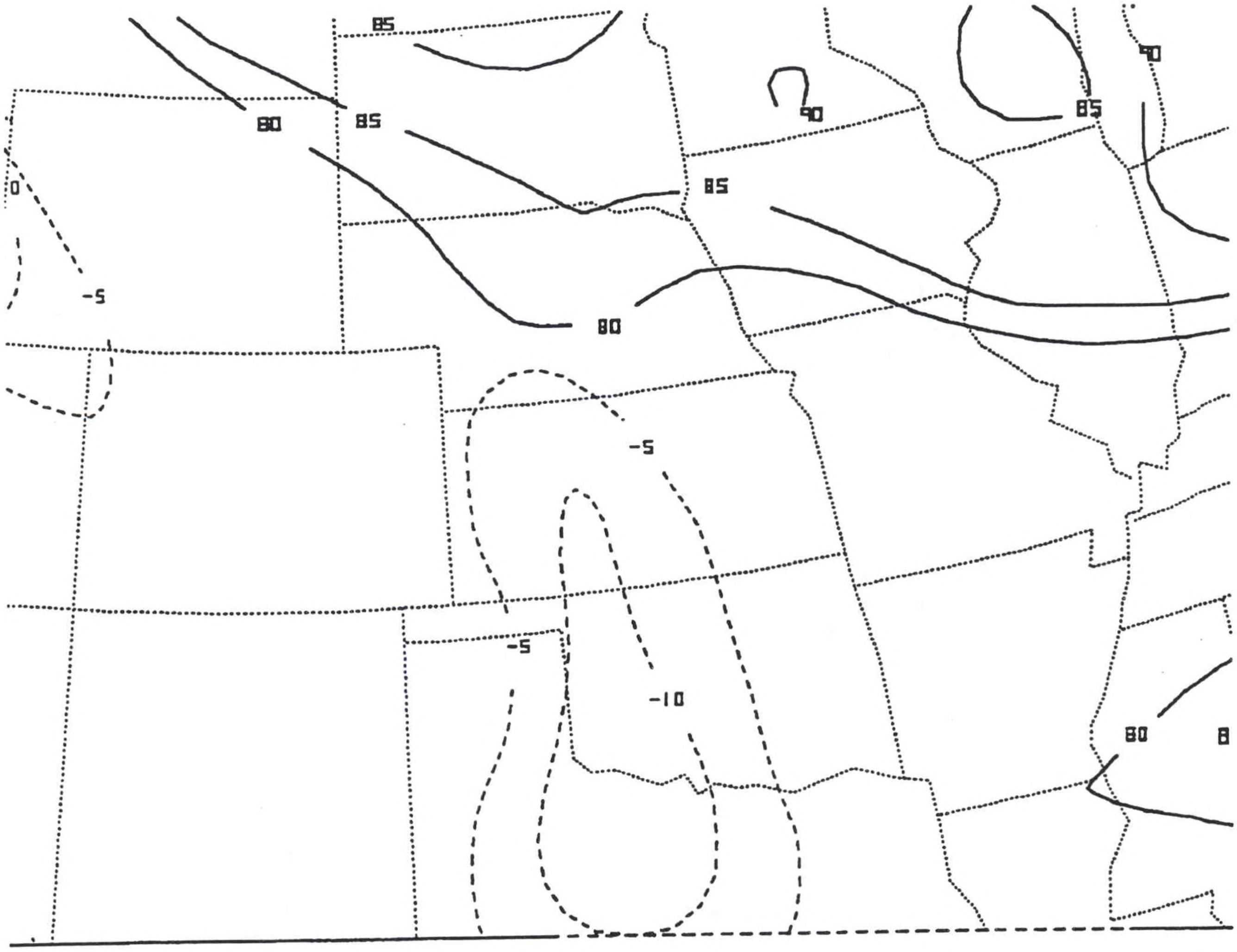

Figure 2. Eta model 12-hour forecast boundary layer vertical motion due to orographic forcing (μbs^{-1} with only $\geq$ 0.5 μbs^{-1} upward motion shown) and RH (in % with only RH values $\geq$ 80% shown) valid 1200 UTC 15 January 1994.

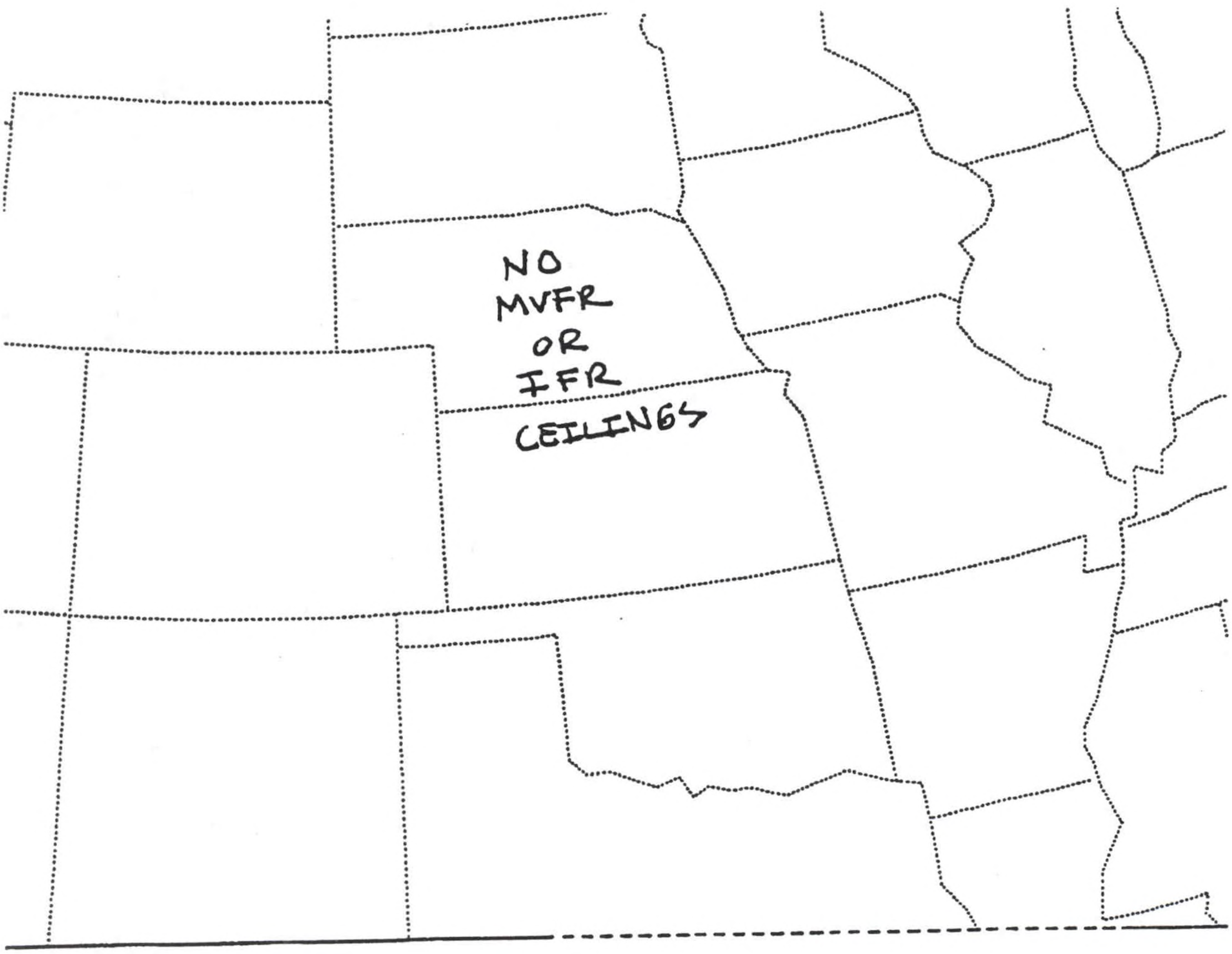

Figure 3. Weather depiction cloud chart valid 1200 UTC 15 January 1994. Area of MVFR and IFR ceilings is hatched.

B. 1800 UTC 30 January 1994

The six-hour forecast from the 1200 UTC 30 January Eta model run (valid 1800 UTC 30 January) indicated boundary layer upslope flow across extreme southeastern Colorado, southwestern Kansas, and most of the Texas and Oklahoma Panhandles. Vertical velocities in this area were predicted to be from -0.5 to -1.0 μbs^{-1}. Boundary layer predictions indicated a large area of greater than 80 percent RH across Kansas, Colorado, and the Texas and Oklahoma

Panhandles. Combining these two parameters (Figure 4) suggested MVFR or IFR ceilings associated with the upslope would occur over extreme southeastern Colorado, southwestern Kansas, and the Texas and Oklahoma Panhandles. The verifying weather depiction chart (Figure 5) valid at 1800 UTC 30 January showed MVFR or IFR ceilings over eastern Colorado, western Kansas, and the Texas and Oklahoma Panhandles.

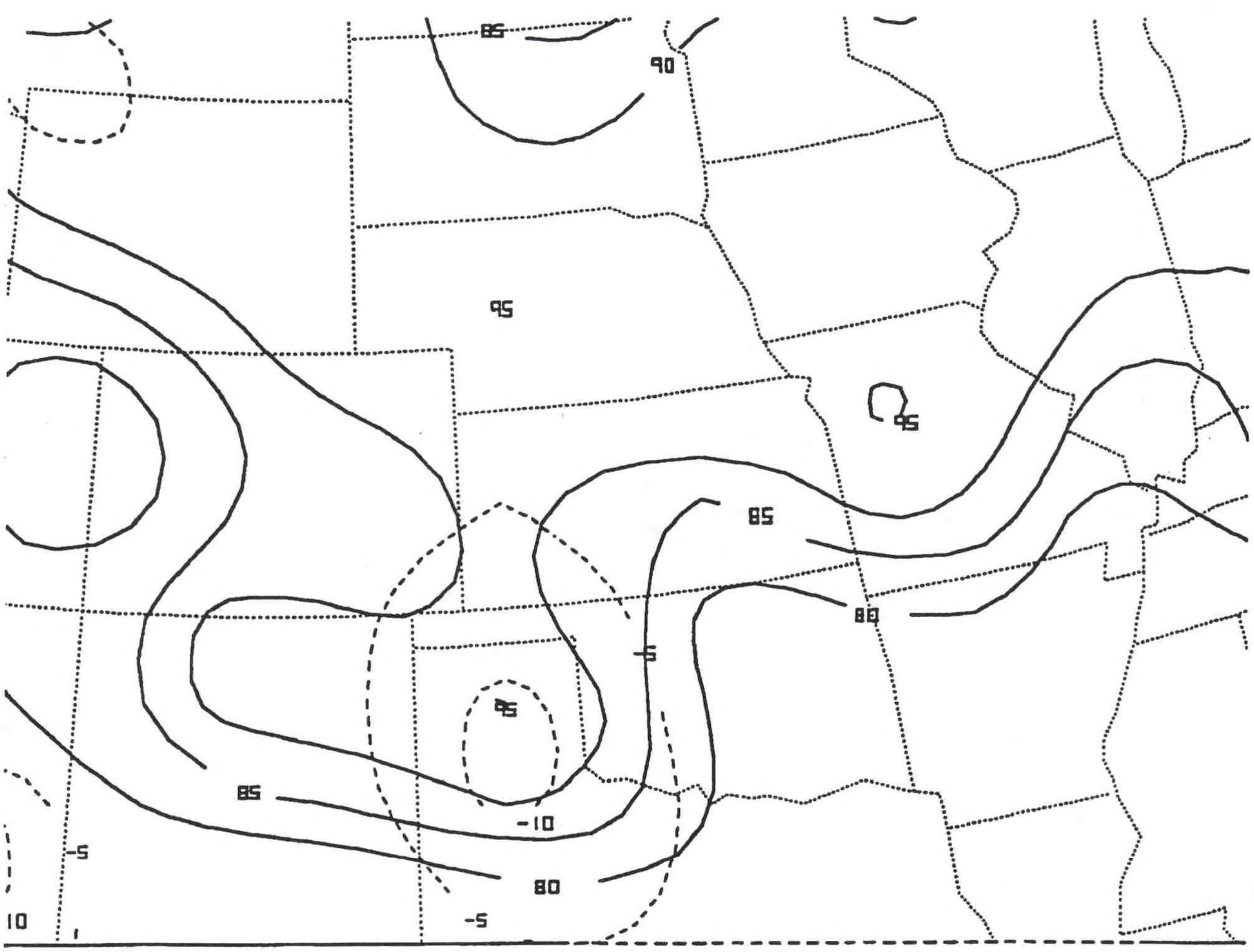

Figure 4. As in Figure 2 except six-hour forecast valid 1800 UTC 30 January 1994.

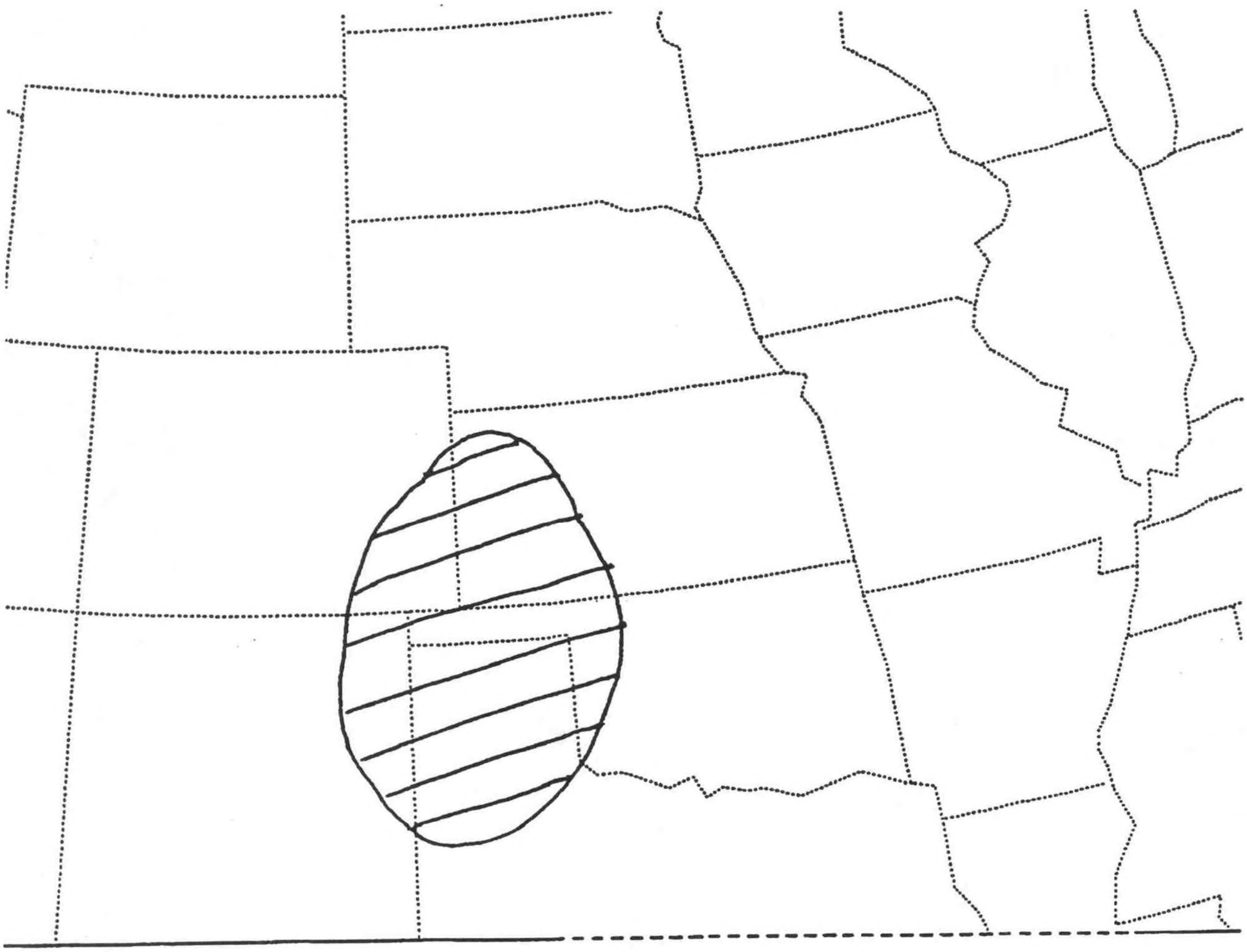

Figure 5. As in Figure 3 except weather depiction chart valid at 1800 UTC 30 January 1994.

5. Conclusion

While the general synoptic regimes that lead to terrain induced boundary layer upward vertical motions are well known, little information is available on the forecasting of the cloudiness that can result. A prediction scheme utilizing gridded model output was developed to forecast this cloudiness.

The presence of upslope flow alone proved to be insufficient to accurately forecast MVFR and IFR ceilings. A forecast technique combining low-level relative humidity and sufficient orographically forced vertical motion proved to be over 80 percent accurate in forecasting MVFR and IFR ceilings associated with upslope flow. By accounting for sufficient low-level moisture, a much higher level of accuracy could be obtained than by solely using the presence of upslope.

This technique should aid in the prediction of MVFR and IFR ceilings due to upslope flow, allowing forecasters across the High Plains to make more accurate aviation and public forecasts. Potential future work on this project includes testing this technique on an independent dataset.

6. Acknowledgements

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7. References

Haltiner, G. J., and R. T. Williams. 1980: *Numerical Weather Prediction and Dynamical Meteorology,* Wiley, New York, 477p.

Petersen, R. A., 1992: A PC based system for the display of gridded WAFS data, *Proceedings of the WMO Technical Conf on Tropical Aeronautical Meteor.* (TECTAN-92), Geneva, Switzerland, 1-6.

Siebers, A. L., and R. J. Williams, 1983: Forecasting Upslope Stratus and Fog in the Central Plains. *Preprints, Ninth Conf. Aerospace and Aeronautical Meteorology.* Omaha, NE, AMS (Boston), 112-117.

APPENDIX A

ETA UPSLOPE MACRO

```
loop
pres 0000 ci50 clr1
bknt b015 clr2/
dotp wind b015 grad pres 0000 c5-4 lt00 dash clr3/
txts - Upslope Vertical Motion (µbs-1) and Boundary Layer Winds (knots)
endl
loop
dotp wind b015 grad pres 0000 c5-4 lt00 dash clr1
relh b015 gt79 cin5 clr2/
txts - Upslope Vertical Motion (µbs-1) and Boundary Layer Relative Humidity
endl
```

NGM UPSLOPE MACRO

```
loop
pres 0000 ci50 clr1
bknt s982 clr2/
dotp wind s982 grad pres 0000 c5-4 lt00 dash clr3/
txts - Upslope Vertical Motion (µbs-1) and Boundary Layer Winds (knots)
endl
loop
dotp wind s982 grad pres 0000 c5-4 lt00 dash clr1
relh s982 gt79 cin5 clr2/
txts - Upslope Vertical Motion (µbs-1) and Boundary Layer Relative Humidity
endl
```