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AN EXAMPLE OF A WINTER SYNOPTIC AND MESOSCALE FORCING EVENT OVER IOWA AS SEEN THROUGH THE WSR-88D AND GRIDDED MODEL OUTPUT

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1. Introduction

During the morning and early afternoon hours of January 16, 1994, a weather system moved across central and eastern Iowa. This system was depicted well using the NMC[1] NGM (part of the Regional Analysis and Forecast System [RAFS]) gridded model output and WSR-88D data. Arctic high pressure was slowly retreating to the east while strong low- and mid-level warm advection was taking place across the plains. During the morning hours, extensive mid-level cloudiness developed in response to the intrusion of warm air at the 8,000-10,000 foot level that was portrayed well using the WSR-88D clear air mode (VCP 31). Meteorologists chose to use the long pulse mode (31) to utilize the slower antenna rotation to gather as much data as possible during this particular weather event. During this mode of operation, meteorologists increase the risk of ingesting poor velocity data (aliased velocities). However, during a 12-hour period the velocity algorithms handled the wind regime over Iowa quite well and very little, if any, velocity data were lost.

During the previous 24 hours, the gridded model output from RAFS forecasted 40-50 knot winds at the 850 mb level for the morning hours of the January 16 with advection of theta-e being positive. That is,

$$(-\vec{V}_h \cdot \vec{\nabla}_h \theta_e) > 0 \qquad (1)$$

(hereafter referred to as θ_e increasing over central Iowa; advection of $\theta_e > 0$). The actual values of θ_e were not that important; however, the overall trend during the past 6 to 12 hours was what forecasters had to focus on. The forecast problem for this particular time frame was to determine whether or not the low levels of the atmosphere would saturate sufficiently enough to allow precipitation to occur across the forecast area.

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[1] Presently, National Center for Environmental Prediction (NECP).

The purpose of this paper is to illustrate the flexibility the forecasters now have with the influx of gridded model output from NMC into the forecast process, and using this information together with the invaluable environmental data from the WSR-88D. Meteorologists can use this information to facilitate the forecast process and to assist in solving the forecast problem for their area of concern.

2. Synoptic and WSR-88D Overview

Arctic air was firmly established across the Upper Midwest as noted on the 1200 UTC 850 mb analysis (Figure 1) with -20°C to -25°C air over the Great Lakes. However, the 850 mb high pressure ridge was east of Iowa allowing southerly winds to transport warmer air northward into the Southern Plains. Also, note the dew points increasing across Oklahoma and eastern Texas. One problem the forecaster needed to solve would be whether the low-level jet, which extended from central Texas northward to southwest Iowa, would be able to transport the moisture far enough north in time to interact with an approaching short wave trough at 850 mb over the Dakotas, thus enhancing expected snowfall over Iowa. One important feature the reader should recognize is the split flow configuration at 850 mb, with a significant short wave trough shown in the southern branch over western Texas. It appears, based on the morning 850 mb analysis, that the Northern Plains short wave trough would be able to move eastward across Iowa later in the day, thus shearing the bulk of the low-level moisture into extreme eastern Iowa and cutting off the needed moisture for any significant snow. We will take a look and see if this indeed occurred.

The advection of θ_e has been used for analysis and short range forecasting of heavy precipitation, including case studies of heavy snow or snowbursts (Scofield 1990). Before there is any discussion of the gridded model output θ_e product used for this particular weather event, it would be prudent to summarize some of the important features that are associated with θ_e and forecasting precipitation, specifically snowfall. The temperature that a parcel would attain if were raised from a reference level (we will use the 850 mb for this discussion) until **all** of its moisture is condensed out, then lowered **dry adiabatically** to the 1000 mb level, is the θ_e. Rather than going through the derivation of θ_e (Wallace and Hobbs 1977), a brief discussion will follow on each of the terms in (2) below and describe the physical processes that are involved. The potential temperature in degrees Kelvin (K) is represented by θ, **L** is the latent heat of condensation in Joules per kilogram (Kg), **Ws** denotes the saturation mixing ratio in grams per Kg, **T** is the temperature in deg K, and **Cp** represents the specific heat capacity at constant pressure of dry air in Joules deg K^{-1} Kg^{-1}.

$$\theta_e = \theta_{exp}\left(\frac{LW}{TC_p}\right) \qquad (2)$$

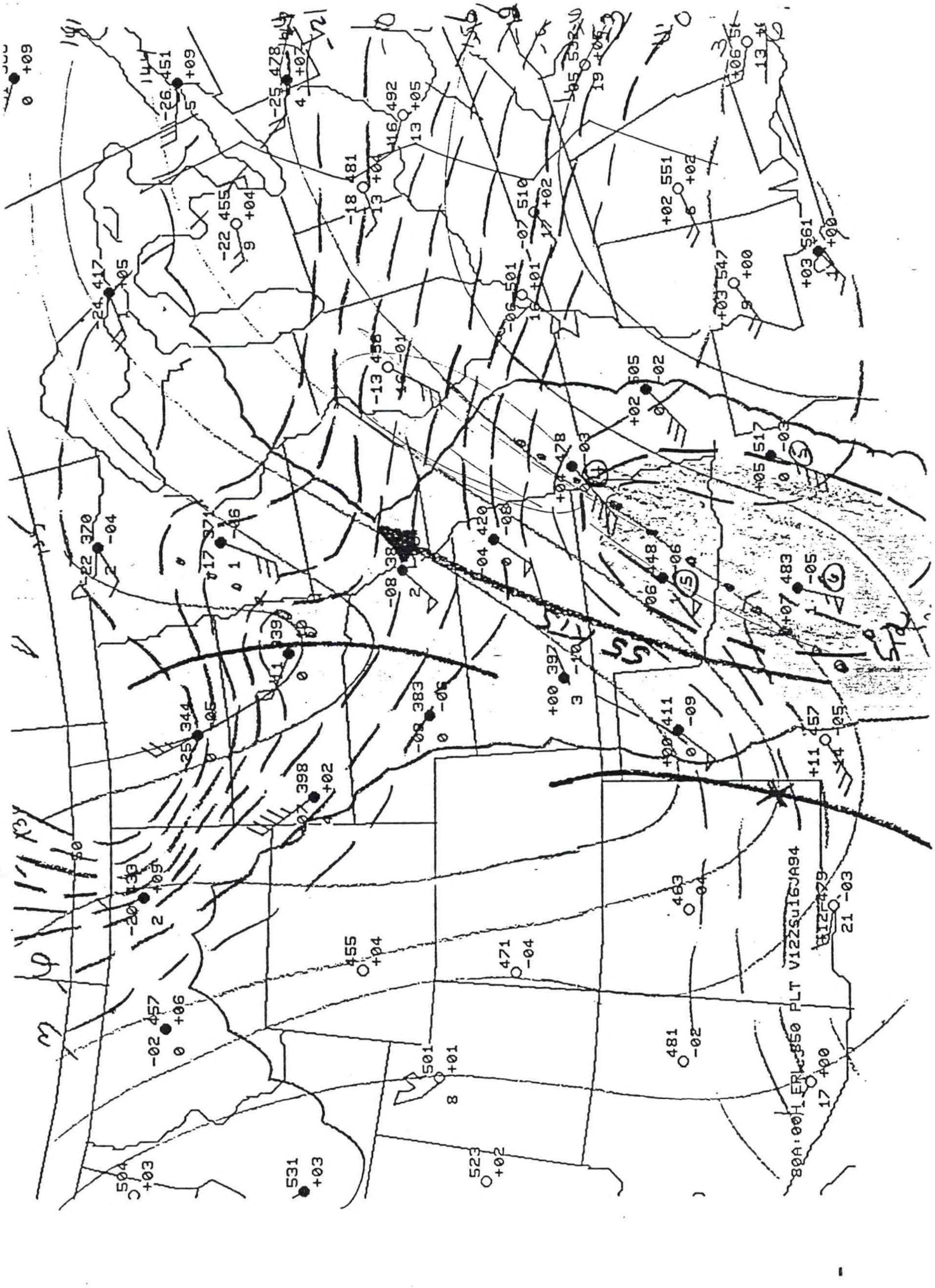


Figure 1. 850 mb analysis for 1200 UTC January 16, 1994 with heights analyzed every 30 meters and temperature analyzed every 3°C. Note higher dew points moving northeast out of Oklahoma into southwest Missouri.

It can be seen from (2) that θ_e is the potential temperature θ of a parcel of air when its saturation mixing ratio **Ws** is zero. Therefore, θ_e can be found as follows: The air is expanded pseudoadiabatically until all the vapor has condensed, precipitated, and released its latent heat. The parcel is then compressed dry adiabatically to the standard pressure of 1000 mb, where it will attain the temperature θ_e. If the parcel of air is initially **unsaturated**, **Ws** and **T** are the saturation mixing ratio and temperature at the level where the parcel first becomes saturated **after** being lifted **dry adiabatically**. "The word **equivalent** implies the sum of **latent and sensible heat** contained in an air parcel, while the word **potential** refers to the air parcel temperature resulting from dry adiabatic reduction to a standard pressure at 1000 mb. Thus the **equivalent temperature** represents the sum of the actual temperature plus the temperature increment that is related to the heat latent in water vapor" (Saucier 1955).

Important in the above discussion is that θ_e is conservative with respect to dry and moist processes for a closed system; that is, it can be followed in the 12 hour sounding data. If an air parcel is subjected to only **adiabatic** transformations as it moves through the atmosphere, θ and θ_e will remain constant. Parameters which remain constant during certain transformations are said to be conserved. A conservative quantity for dry adiabatic transformations is the θ, while θ_e is conserved for **both saturated and non-saturated adiabatic processes**, which makes θ_e a very useful parameter in atmospheric thermodynamics, since atmospheric processes are often close to adiabatic. Therefore, θ_e, its advection are useful "diagnostic" tracers of air. In essence, the warmer and/or more moist the air at a reference level (850 mb), the higher the 850 mb θ_e. Thus, we have combined the temperature and dew point and have expressed the result as one value.

How was that "value" described above used in this particular weather event? Figure 2 illustrates the gridded model output forecast advection of θ_e starting with the 1200 UTC forecast on January 15 and ending with the expected conditions 24 hours later at 1200 UTC on the January 16. Note from this illustration that the advection of θ_e was **increasing**. Thus, the air parcels would likely track southeastward due to being lifted, in the presence of this northwest mid and upper tropospheric flow regime. In addition, the low level wind flow was forecast to increase with time as the weather system consolidated over the Ohio River Valley late in the period. The forecaster, based on the available information, could infer strong isentropic ascent would occur over Iowa and Missouri. The main problem would be when and where the lower levels of the atmosphere would "saturate" to allow precipitation to occur.

The 1200 UTC upper air diagnostics (not shown), indicated that the low levels were becoming increasingly saturated across the eastern half of Missouri into southeast Iowa. Mid-level warm air advection maximized over eastern Iowa into southwest Wisconsin and northwest Illinois. It appeared the greatest

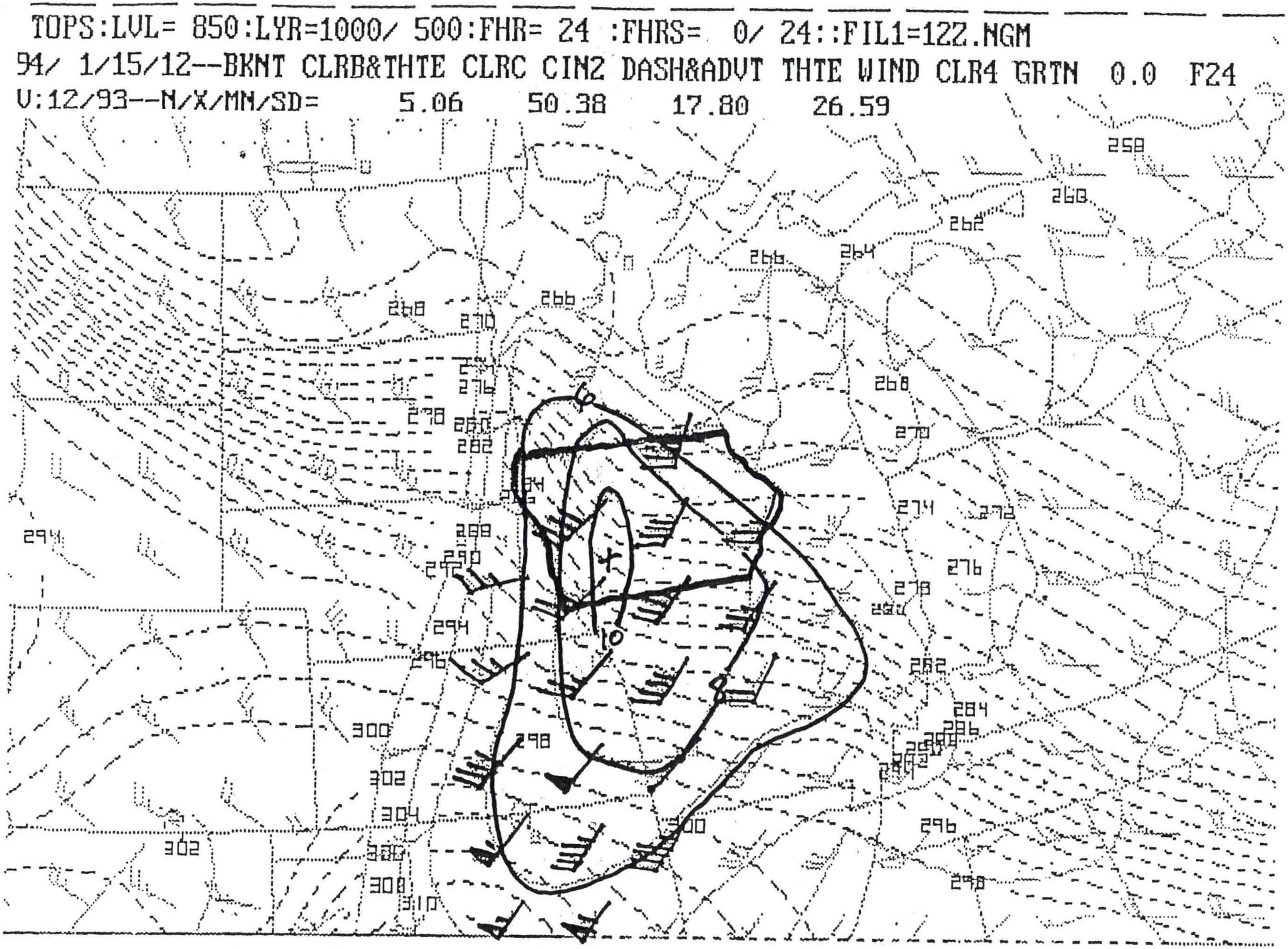


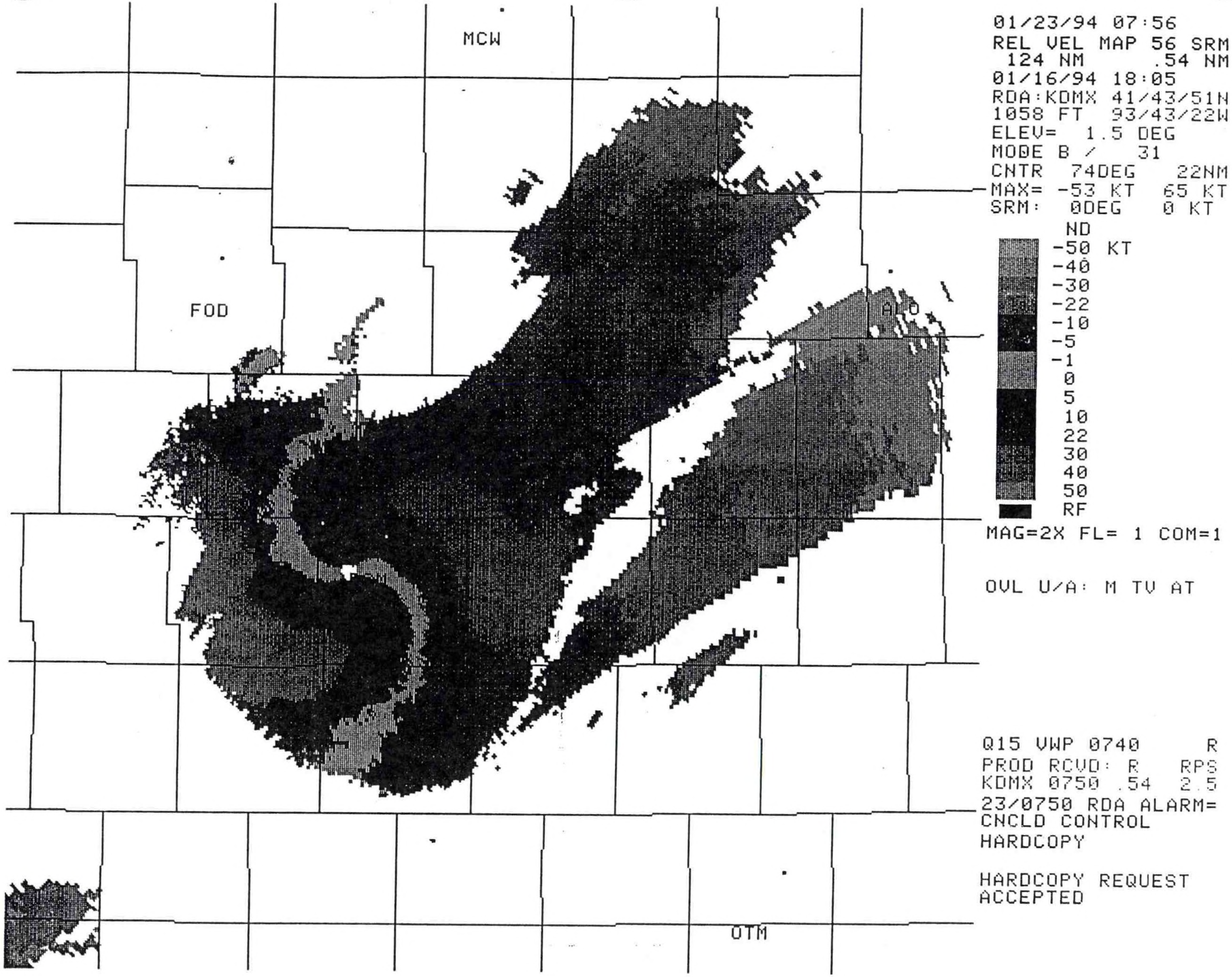
Figure 2. Theta-e and advection of theta-e forecast positions from the RAFS gridded model output for 24 hours (1200 UTC January 15, 1994 model run). Dashed lines are theta-e analyzed every 2°K. Maximum advection of theta-e analyzed every 2°K 12 hrs ^{1} indicated by "+".

threat for any significant snow would be from eastern Iowa into Wisconsin and northern Illinois where the best low and mid-level "forcing" was present. Now with the available data at hand, including the gridded model output forecasts, meteorologists could concentrate on the "area of concern" when analyzing the potential for significant snow over Iowa.

How well did the forecasts from the θ_e gridded model output perform during this time period? Illustrations from the WSR-88D reflectivity and velocity (SRM) products (Figures 3 and 4) should help the reader understand just what evolved during this weather event. During the majority of winter weather events in Des Moines this year, the radar was "forced" to stay in "Mode B" or the clear air scan, that is, the Nominal Clutter Area in the Precipitation Detection Algorithm increased to the maximum allowable value, 80,000 km^2. For this time period, the WSR-88D operated in the long pulse, clear air mode VCP 31. Since the clutter area was set to the maximum level, precipitative areas and dBZ levels were not sufficient enough to allow the radar to change over to the precipitation mode (Mode A) throughout this particular weather scenario. The 1805 UTC 1.5 degree, .54 nm resolution SRM product (Figure 3) illustrated the typical "S" shaped warm advection signature as low-level southeast winds were accompanied by increasing veering winds with height, with 35-45 knot winds indicated in the layer from 4,000-5,000 feet (Above Radar Level - ARL).

The 0.5 degree, .54 nm resolution reflectivity product (Figure 4) for 1805 UTC indicated the highest power returns or dBZ levels, inferring the greatest isentropic ascent in this case, may have been located from Mason City (MCW) to Waterloo, Iowa (ALO). Power returns of 45 dBZs were noted and this area of northeast Iowa. Visibilities in this particular region through the regular reporting sights (SAOs in addition to AWOS), were reported as low as ½ to ¾ of a mile for a brief period of time. Low level moisture became entrained across north central through northeast Iowa as the best upward vertical motion field was at its maximum over this area, resulting in a swath of light to moderate snowfall during this time. This correlated well with the morning UA analysis as well as the gridded model output forecasts which indicated moisture and dynamics would "come together" in this area during the late morning hours. Note from the previous photo (Figure 3) how the low- and mid-level "inflow" was directed into this region. To the south and west of the higher dBZ values on (Figure 4), the lower dBZ values represented mid-level clouds (7500-10,000 feet ARL). The synoptic scale forcing was just as strong over eastern Iowa, but the low levels had not yet been saturated enough to precipitate. In other words, the air did not become sufficiently moist (to precipitate) through upward vertical motions until the parcels reached north central through northeast Iowa.

The wind profile depicted on the SRM product (Figure 3), indicated inbound and outbound velocities of 45 to 55 knots across central into eastern Iowa. The winds were becoming more westerly at the 5,000-7,000 foot level ARL, indicating the approach of the northern stream short wave trough discussed earlier.



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01/23/94 07:56
REL VEL MAP 56 SRM
 124 NM      .54 NM
01/16/94 18:05
RDA:KDMX 41/43/51N
1058 FT   93/43/22W
ELEV=  1.5 DEG
MODE B /    31
CNTR  74DEG    22NM
MAX= -53 KT   65 KT
SRM:  0DEG     0 KT
      ND
     -50 KT
     -40
     -30
     -22
     -10
     -5
     -1
      0
      5
      10
      22
      30
      40
      50
      RF
MAG=2X FL= 1 COM=1

OVL U/A: M TV AT

Q15 VWP 0740      R
PROD RCVD: R    RPS
KDMX 0750 .54   2.5
23/0750 RDA ALARM=
CNCLD CONTROL
HARDCOPY

HARDCOPY REQUEST
ACCEPTED
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Figure 3. Storm Relative Velocity Map (SRM) with .54 nautical mile resolution and 1.5 degree elevation angle from KDMX (Des Moines), for 1805 UTC January 16, 1994. Velocities are in knots.

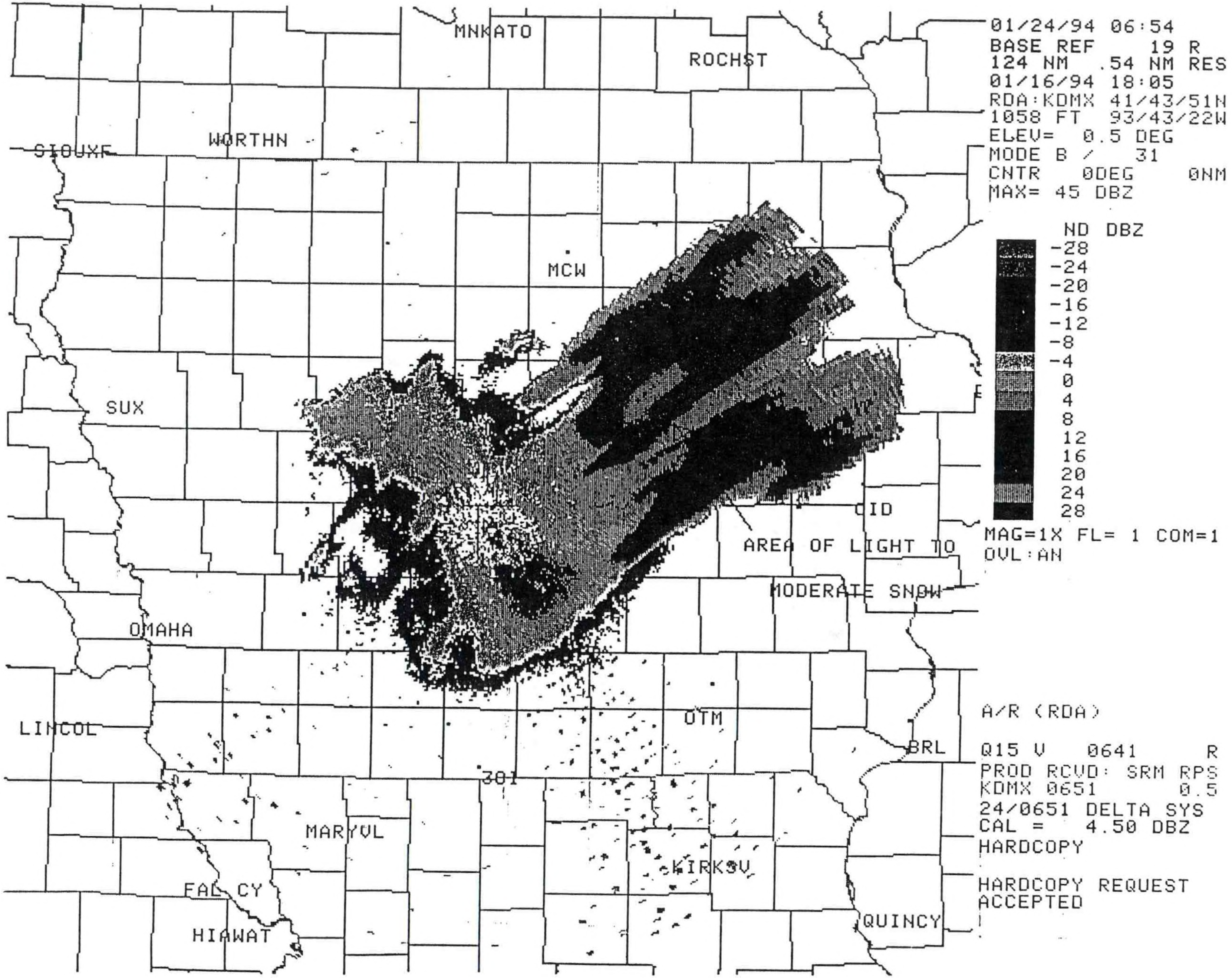

Figure 4. Base reflectivity with .54 nm resolution and 0.5 degree elevation angle from KDMX for 1805 UTC January 16, 1994.

Advection of θ_e from the gridded model output suggested an increase in warm air advection and moisture as the system progressed east with time. It has been noted that positive θ_e advection areas increasing with time and becoming better organized are often associated with heavier precipitation (Scofield 1990). Positive θ_e advection was present for a time during the early morning hours of January 16, but precipitation **was not** present with the advection area. This occurrence has been noted before with a warm air advection axis ahead of an approaching trough (Scofield 1990). Due to the lack of moisture and sufficient upward vertical motion early in the event, not much if any precipitation occurred. As the low- and mid-level moisture increased, the areal coverage and intensity of power returns from the WSR-88D reflectivity products were increasing with time, especially over eastern Iowa. The low-level jet materialized as forecasted by the RAFS gridded model output θ_e fields, and as a result the moisture streaked northeast into the eastern quarter of the state in time to interact with the mid-level "forcing" that was approaching from the west resulting in a light to moderate snow event.

4. Summary

Higher resolution WSR-88D and gridded model output (RAFS and ETA) can provide the forecaster detailed information for generating timely short and long term forecasts. One great advantage shared by both the gridded model output and WSR-88D data is the capability to use this information for review of weather events or local case studies. As is the case with the NMC gridded model output, once the model data is obtained, one can easily analyze the model forecasts and perform advanced diagnosis of the various fields available to them. Software such as **PCGRIDDS** gives the forecaster the ability to objectively view a number of elements (i.e., low-level wind fields advecting in higher values of θ_e and θ_e time and height cross sections, just to name a couple) that would otherwise be difficult to analyze subjectively in the present forecast process time constraints.

In addition to the gridded model output that has now become a daily forecast "routine", the WSR-88D data has become a most valuable tool in the short-range forecast process as was illustrated during the late morning and early afternoon hours of January 16, 1994. The gridded model output forecasts for 18-24 hours in advance allowed the forecaster to focus their attention in one particular area for that forecast time frame (assuming the model runs had initialized well; remember that you are looking only at model atmospheres, not the real atmosphere.) The WSR-88D gives the forecaster more flexibility during a winter weather event such as this, as the radar is kept in "clear air" mode throughout the particular occurrence to get a more detailed picture of what atmospheric changes where occurring during this time frame.

There have been numerous studies on how well the WSR-88D performed during significant convective outbreaks, but not much documentation on winter weather scenarios like that illustrated in this study. The integrated use of gridded model output and the WSR-88D is proving to be a powerful and important tool in the daily forecast process.

5. References

Saucier, W.J., 1955: *Principles of Meteorological Analysis.* University of Chicago Press, 438pp.

Scofield, R.A., 1990: Instability Bursts Associated with Extratropical Cyclone Systems (ECSs) and a Forecast Index of 3 to 12 Hour Heavy Precipitation. NOAA Technical Memorandum NESDIS-30, July, 77pp.

Wallace, J.M. and P.V. Hobbs, 1977: *Atmospheric Science, An Introductory Survey.* University of Washington, Academic Press, 417pp.