NASA Technical Memorandum 82574

# Application of VISSR Atmospheric Sounder (VAS) Data

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## TABLE OF CONTENTS



## LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

# APPLICATION OF VISSR ATMOSPHERIC SOUNDER (VAS) DATA

## INTRODUCTION

A current limitation in short range (0 to 12 hr) weather forecasting techniques is a lack of understanding of the physical processes which take place at the mesoscale. This is primarily due to the relatively few data sets available which describe features at this scale. Direct measurements using hourly surface observations are a significant help in monitoring the ambient and changing conditions at the mesoscale near the ground, however, the current synoptic scale upper air observations at 1200 and 0000 GMT do not provide the temporal and spatial resolution which is necessary to capture the four-dimensional variability of the atmosphere. Much work has been done which utilizes satellite imagery to study clouds and cloud systems in order to better understand the environments in which they form. Unfortunately, these measurements only allow the scientist to infer the structure of the atmosphere. Recent work using imagery and sounding data from the VISSR Atmospheric Sounder (VAS) [1-4] has projected some hope of increased time and space resolution of basic and derived atmospheric quantities important in describing the structure of the mesoscale environment.

The VISSR Atmospheric Sounder (VAS) is currently operational onboard the GOES East and GOES West satellites with the capability to collect various types of imagery upon request (References 5, 6, and 7 give instrument descriptions and operating modes). Sounding data can be obtained from these measurements by inverting the radiative transfer equation. This procedure is by no means a simple task but can produce vertical profiles of temperature and moisture having 30 to 150 km horizontal resolution and temporal resolution from 1 to 3 hr. Usually these vertical profiles are treated as if they were rawinsonde observations (i.e., point measurements at various pressure levels). This assumption presents some problems to the meteorologist because these soundings are integrated volumetric averages; they also are irregularly spaced, may contain biases due to poor vertical resolution, and are subject to instrument errors and errors due to undetected clouds which contaminate clear fields of view. The purpose of this report is to discuss these problems, present a technique which produces a consistent four-dimensional VAS sounding data set, and to highlight some strengths and weaknesses of using VAS soundings to describe the mesoscale environment.

## DATA AND PROCEDURES

In the spring of 1982, Marshall Space Flight Center conducted a field experiment aimed at collecting rawinsonde measurements of similar resolution to those available from VAS radiance measurements. The observational network for the experiment consisted of 24 NWS upper air stations, 12 special network stations (operated by the staff of Texas A&M University), plus two additional sites operated by the Army and the Air Force (Fig. 1). Details of this AVE/VAS experiment can be found in References 8 and 9. VAS radiance data were collected at 1100, 1435, 1735, 2035, and at 2335 GMT on 6 March and at 0235 GMT on 7 March 1982 as one part of the satellite observation phase of the AVE/VAS experiment.

Vertical profiles of temperature and moisture were produced from these radiance observations by the NESS Developmental Laboratory at the University of Wisconsin. The algorithm used to invert the radiative transfer equation is an iterative scheme which employs output from the Limited Fine Mesh (LFM) model as first guess constraints. Details of this procedure can be found in Reference 1. Because VAS is an infrared sounder, radiation reaching the satellite in each band is influenced by clouds and accurate retrievals are possible only in predominantly cloud-free regions. This, however, can produce irregularly spaced retrievals where cloud systems are present.

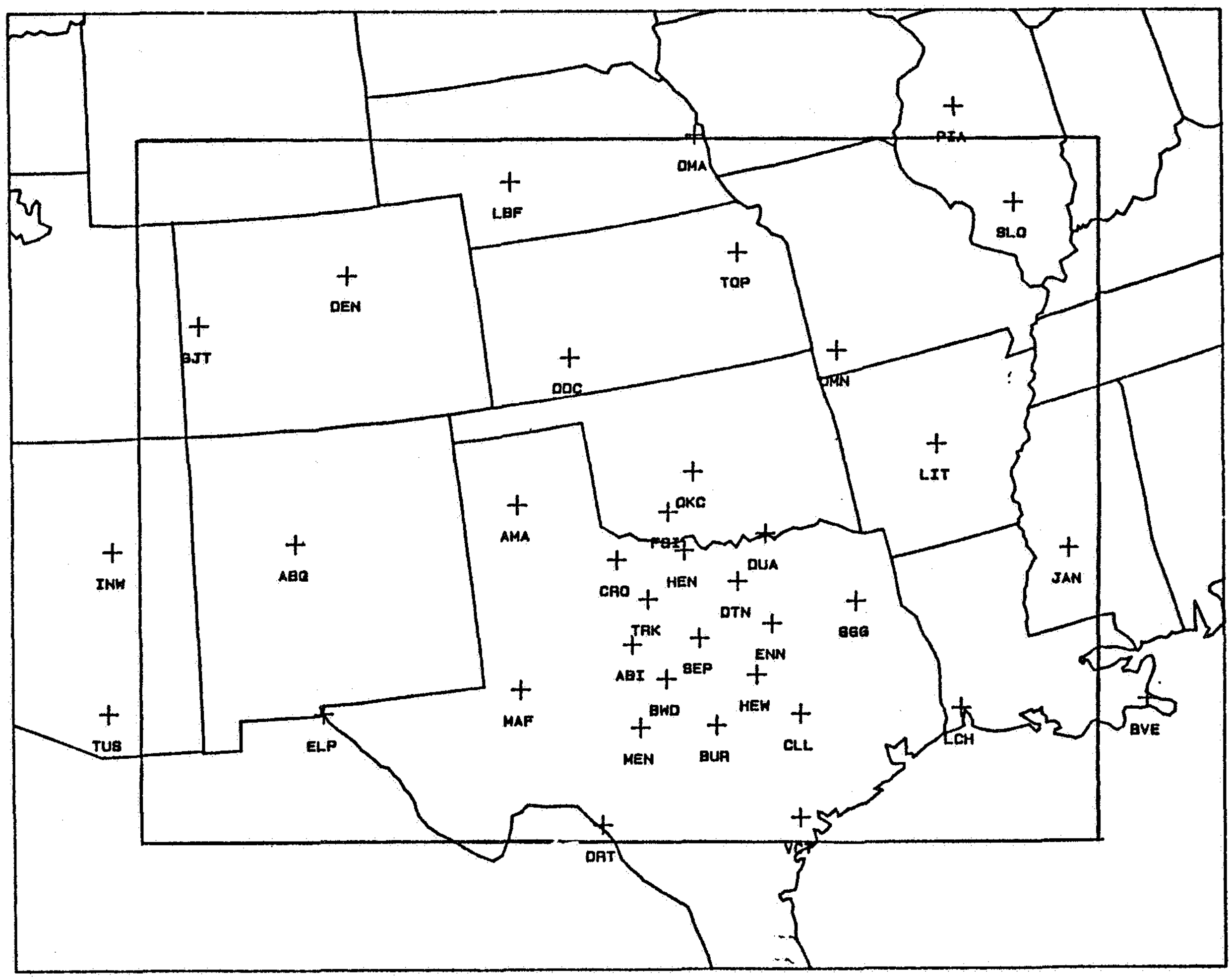


Figure 1. Stations participating in the AVE/VAS experiment on 6-7 March 1982. The inner box encloses the analysis region used for both the satellite and rawinsonde data.

The rawinsonde data used in this study consist of six consecutive 3 hr releases from each of the rawinsonde sites in Figure 1 beginning at 1200 GMT 6 March 1982 and running through 0300 GMT on 7 March 1982. The data were linearly interpolated to a common hour of release (10 min after each satellite scan time) using a scheme similar to Fuelberg and Jedlovec [10] and Frankhauser [11]. This procedure produces rawinsonde data which are valid at the same time at all pressure levels and at a time which is similar to that of the satellite sounding data. The rawinsonde data were objectively analyzed on to a 16 by 12 grid (Fig. 1) using a two-pass Barnes analysis scheme [12] to produce gridded fields which represent the sub-synoptic scale flow patterns (Fig. 2).

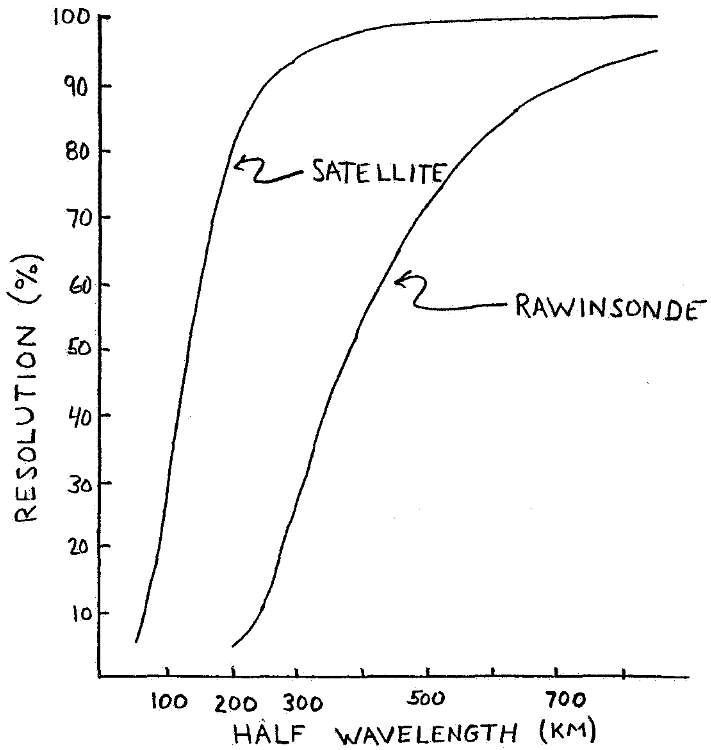


Figure 2. Resolution curves (as a function of half wavelength) for the rawinsonde and satellite gridded fields. The satellite curve is based on the conventional analysis technique and not the modification used in the study.

In a diagnostic mesoscale study, the meteorologist is concerned with the evolution of features over a given region and how they influence the observed weather. In an operational mode, diagnostic analyses of past and current observations are also used in a similar manner. The use of VAS data for this procedure poses some difficulties. As cloud systems form, develop, decay and move through the region, VAS sounding locations vary and data void regions change with time. This causes problems in analyzing the fields, looking for time consistency of features, and in the actual gridding of the data [2]. Ideally one would like to use other types of measurements to supplement the soundings, particularly in cloudy or poorly sampled regions. The approach taken in this study draws upon recent experience gained in evaluating VAS sounding data and in the use of various analysis techniques in mesoscale studies.

Objective analysis schemes [12-14] are very effective in producing gridded fields of meteorological parameters where data spacing is uniformily spread over the entire analysis region. The amount of detail contained in these fields can be controlled to produce consisted mesoscale analyses. A scheme similar to Barnes [12] is employed in this study to produce gridded analyses of basic and derived parameters of satellite data over a 2000 x 1500 km region in the central part of the United States (Fig. 1). The resolution provided by the scheme for the satellite data is graphically displayed in Figure 2. In choosing the 4c and gamma values which determine the resolution, consideration was given to the spacing of the data and data uncertainties in order to produce fields which could adequately resolve features having wavelengths greater than 300 km. The general procedure in the scheme is to apply a correction pass to an initial gridded field where the correction at each grid point is based on the data values and their distance from each grid location. Mathematically this can be expressed as follows

$$G_{i,j} = I_{i,j} + \frac{\sum_{k=1}^{N} (X_k - XI_k) \cdot W_k'}{\sum_{k=1}^{N} W_k'} \tag{1}$$

where,

G = the final grid point value

I = the grid value from the initial pass

X = an observation

XI = an initial pass value interpolated to an observation

i = x coordinate increment

j = y coordinate increment

N = the total number of observations

W′ = the weight factor given by

$$W' = \exp \frac{-1 \cdot (D)^2}{\gamma \cdot 4c}$$

with D being the distance between the grid point and the observation. This scheme will produce very nice results on uniformily spaced observations with judicious values of gamma and 4c.

In data sparse regions the "goodness" of the interpolated values becomes questionable since both the influence of distant data and the sum of the weight factors can be small [Equation (1)]. This difficulty has been experienced by anyone getting "bullseyes" or "irregularities" in their gridded fields. Reducing the sum of the weights of the observations [denominator of Equation (1)] in data sparse regions, as in this study, increases the influence of the first pass on the final field and produces a somewhat smoother (depending on the information content of the first guess) but consistent analysis in these areas. Mathematically, this modification is accomplished with a slight modification to Equation (1) as follows

$$G_{i,j} = I_{i,j} + \frac{\sum_{k=1}^{N} (X_k - XI_k) \cdot W_k'}{\sum_{k=1}^{N} W_k' + ifl} \tag{2}$$

The value assigned to "ifl" is somewhat arbitrary and depends on the selected gamma, 4c value, and on the data density. A general guideline obtained from experience is to pick "ifl" such that in data rich areas "ifl" is much less than the sum of the weights and in data sparse regions "ifl" should be greater than or equal to the sum of the weights.

This procedure, however, is not without repercussions. First, resolution of features in the output fields can not be determined as precisely as before since the resolution of the first pass field has not been quantitatively determined. Second, the first pass field in data void regions may not be adequate. To avoid this possibility, the first pass gridded field usually produced by the Barnes scheme was substituted with the first guess field used in the actual retrieval of the satellite temperature and moisture profiles (in this case, an LFM forecast field). The positive effect of using this first guess is a consistant field in data void regions. Near the edge of data sparse regions, the analysis procedure produces a nice blend of the initial pass (first guess) and the satellite soundings which is consistent with the data trends. In regions of dense satellite soundings, the scheme does not significantly alter the sum of the weights normally assigned and produces a conventional product. Use of this first guess is also appropriate since the final retrieved VAS soundings are not totally independent from their first guess [1]. The results of applying this technique will be shown in the next section. Ground truth rawinsonde measurements will also be used in the discussion to evaluate the VAS data and these procedures.

## RESULTS

The intent of this report is not specifically to evaluate the VAS sounding data used in this study. This task has been taken up by this author and others in more appropriate places (see Satellite Conference proceedings). However, the accuracy of the VAS derived soundings does enter into this study since a judgment must be made in keeping mesoscale detail in the gridded fields and how well the described procedures produce reliable analyses. Figure 3a displays a subjective hand analysis of 700 mb satellite derived temperatures at 2035 GMT and the corresponding ground truth rawinsonde observations are in Figure 3b. Several major items should be apparent from looking at these figures. First, dense areas of satellite soundings are available over limited regions. A large data gap exists over east Texas, Arkansas, and Missouri where clouds prohibit accurate retrievals and thinly spaced observations are present over Colorado. Several pockets of cold temperatures exist over northern Kansas, west Texas and along the Big Bend region. A very small pocket of warmer air exists over eastern New Mexico. This latter feature is quite small and mainly due to one satellite sounding. The ground truth rawinsonde data indicate actual environment conditions over the region. The coldest air is centered over Nebraska and Kansas with a thermal trough extending down through west Texas. A ridge of warm air exists in Colorado and New Mexico.

Figure 3c indicates the type of product available over the region with the conventional application of the analysis scheme. In areas where data density is adequate, the satellite soundings are well analyzed, however, in data sparse regions the contours are bunched and/or disorganized. At the eastern edge of the large data void, a somewhat artificial and misleading cold trough is present. This is due to the scheme and also the trend of the data where cloud-contaminated retrievals produce a cold bias. Figure 3d shows the analyzed satellite data when the modified scheme is employed. The LFM first guess data grid which the scheme utilizes is shown in Figure 3e. This scheme produces a much more realistic analysis in data void regions while maintaining the integrity of the analysis in other regions. The small warm pocket over New Mexico has been modified and the artificial cold trough in the cloudy area has been removed. The cold trough extending back into west Texas is still present and is one of the dominant features in the satellite and rawinsonde analysis. The application of this scheme at all time periods has produced a consistent satellite data set with considerable mesoscale detail. Some of the important aspects of this data set will now be discussed.

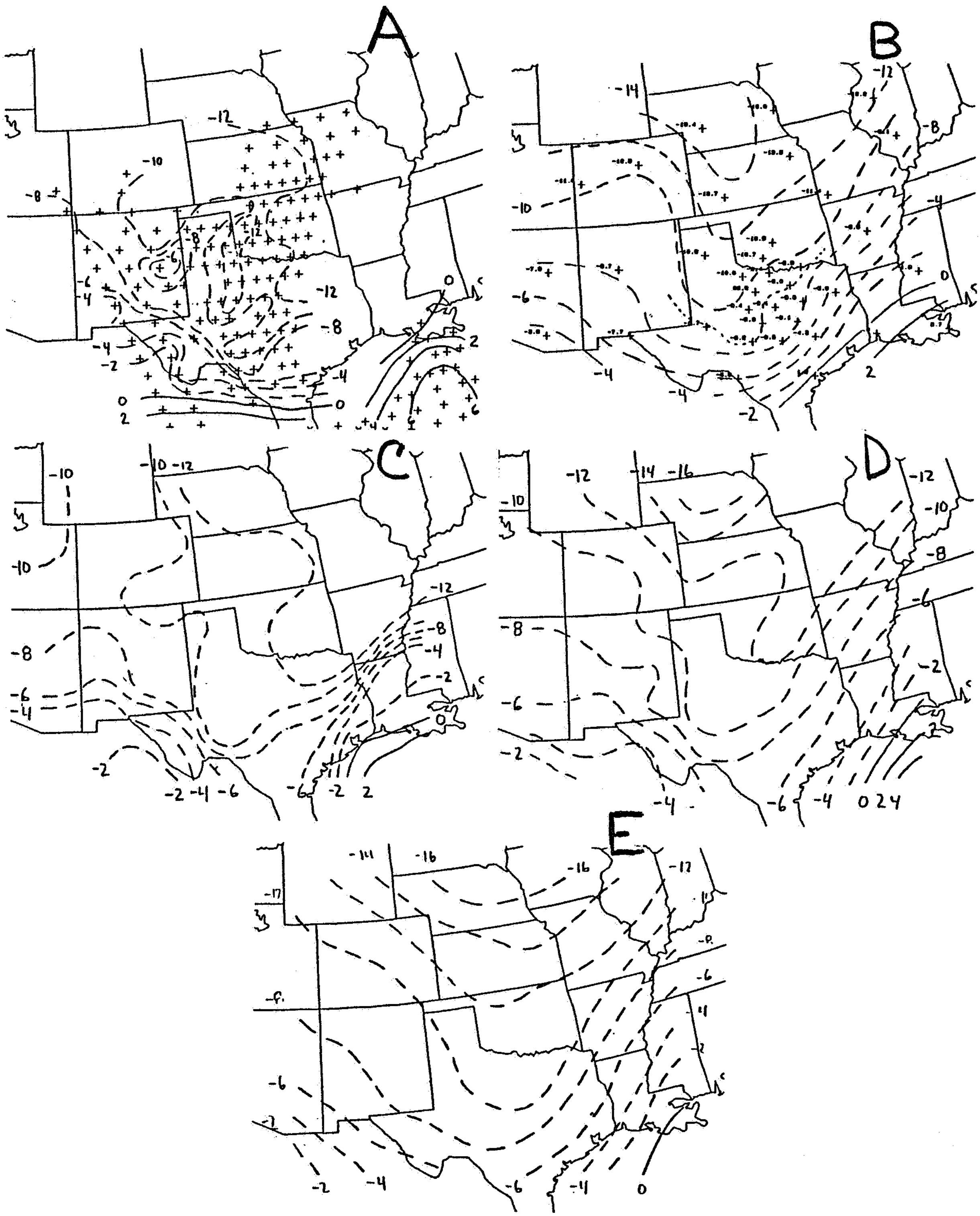


Figure 3. Subjective manual analysis of 700 mb temperature fields at 2035 GMT 6 March 1982 for the VAS (A) and rawinsonde (B) data sets. Conventional two-pass objective analysis of VAS data (C), and the modified two-pass gridded field (D) substituting a Limited Fine Mesh forecast field (E) for the first pass, for 700 mb temperatures.

Figure 4 displays a time series of analyzed satellite and rawinsonde 700 mb temperatures. The satellite data (Fig. 4a, 4c, 4e, 4g, 4i, and 4k) exhibit much mesoscale variability which has good time continuity. A strong thermal gradient exists over the eastern portion of the region with a cold trough positioned over Kansas and Oklahoma and swings back southwestward into west Texas and New Mexico (Fig. 4a). A warm region exists over western Kansas and Colorado with another cold region in the

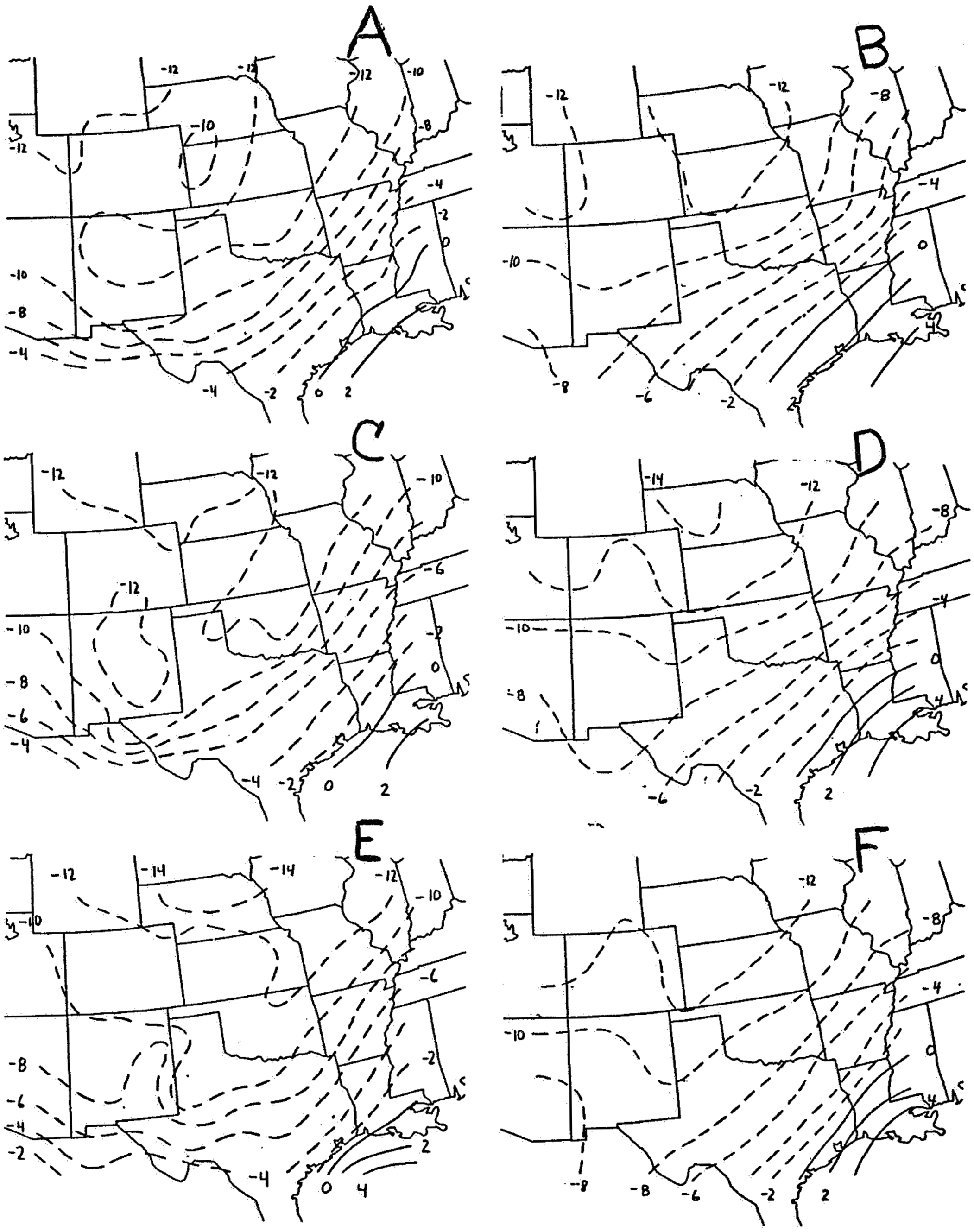


Figure 4. Satellite analyses of 700 mb temperature at 1100 GMT (A), 1435 GMT (C), 1735 GMT (E), 2035 GMT (G), 2335 GMT (I), and 0235 GMT (K) using the modified scheme. Corresponding rawinsonde analyses are shown in B, D, F, H, J, and L. Units are in degrees C.

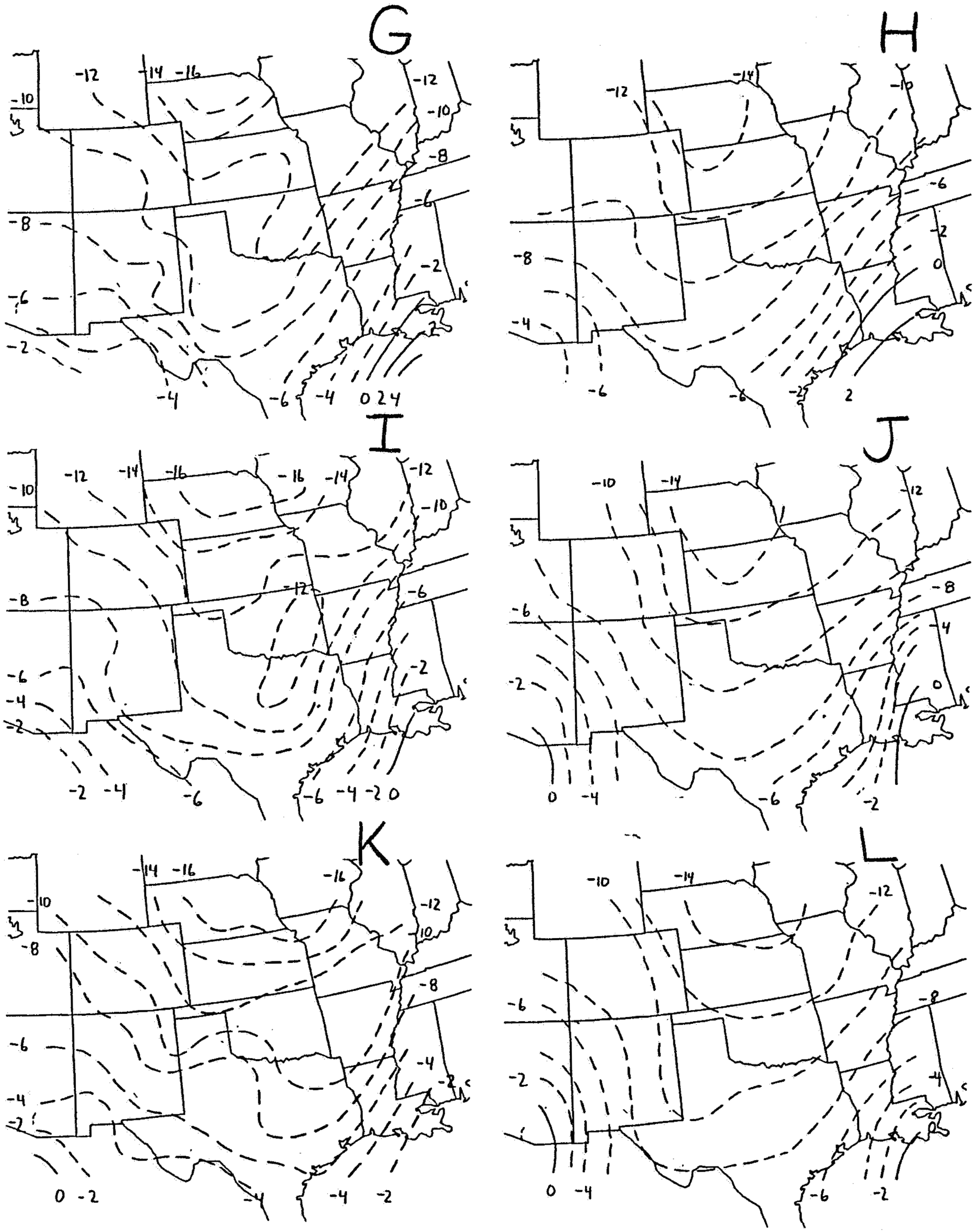


Figure 4. (Concluded).

extreme northwest corner. These features move southeastward with time (Fig. 4e to 4k) as cold air moves down into central Texas. The cold trough extending into New Mexico is replaced by warm air as a strong thermal ridge begins to form over this region between 1735 and 0235 GMT. The mesoscale trough-ridge pattern in the satellite data is apparent in the rawinsonde analyses (Fig. 4b, 4d, 4f, 4h, 4j, and 4l). By 2335 GMT, both the satellite and rawinsonde data indicate that this pattern gives way to the larger region of cold air which has moved in from the north.

Two features exist in the satellite data analysis which have a poor correlation to the ground truth rawinsonde measurements. First, the leading edge of the cold trough over central Texas and Oklahoma (Fig. 4a) breaks off and becomes an isolated cold pocket by 1735 GMT (Fig. 4c) and persists for several time periods. This is not observed in the rawinsonde data and is probably a result of a cold bias in the soundings due to cloud contamination. Second, a small scale warm ridge develops at 0235 GMT over southcentral Texas (Fig. 4k) which is not apparent in the rawinsonde analysis (Fig. 4l). There is no apparent explanation for this feature.

Figure 5 shows the time continuity of the 500 mb height analysis for the satellite and rawinsonde data. These analyses are quite similar and show good time consistency. The satellite analyses (Fig. 5a, 5c, 5e, 5g, 5i, and 5k) appear to contain more detail which better describe the sharpness of the trough as it moves through the region. This is true except at 1735 GMT (Fig. 5e) where the height fluctuations seem disorganized and inconsistent with time. The satellite analysis does indicate the presence of a short wave upstream at 2335 GMT and 0235 GMT which is just barely evident in the rawinsonde analyses (Fig. 5j and 5l). It is also worth noting that the gradient observed in the rawinsonde data is maintained in the satellite analysis and provides more information than would be readily available to the operational meteorologist.

## CONCLUSIONS

A technique has been presented which successfully analyzes irregularly spaced satellite data incorporating Limited Fine Mesh model output in data sparse and cloudy regions. The scheme provides a proper blend of these two data sources such that a consistent and usable product is supplied in data void regions while the integrity of the mesoscale satellite soundings is preserved. Examples have been presented which indicate the success of the procedure in properly representing the mesoscale environment over a rather large analysis region. The application of this technique has produced a four-dimensional data set which exhibits significant mesoscale structure, much of which is verifiable with special asynoptic rawinsonde measurements. Although not presented, the calculation of time and space derivatives which are ofetn useful in real-time analysis as well as diagnostic studies, would produce a fairly consistent and reliable set of products ordinarily not available with satellite measurements.

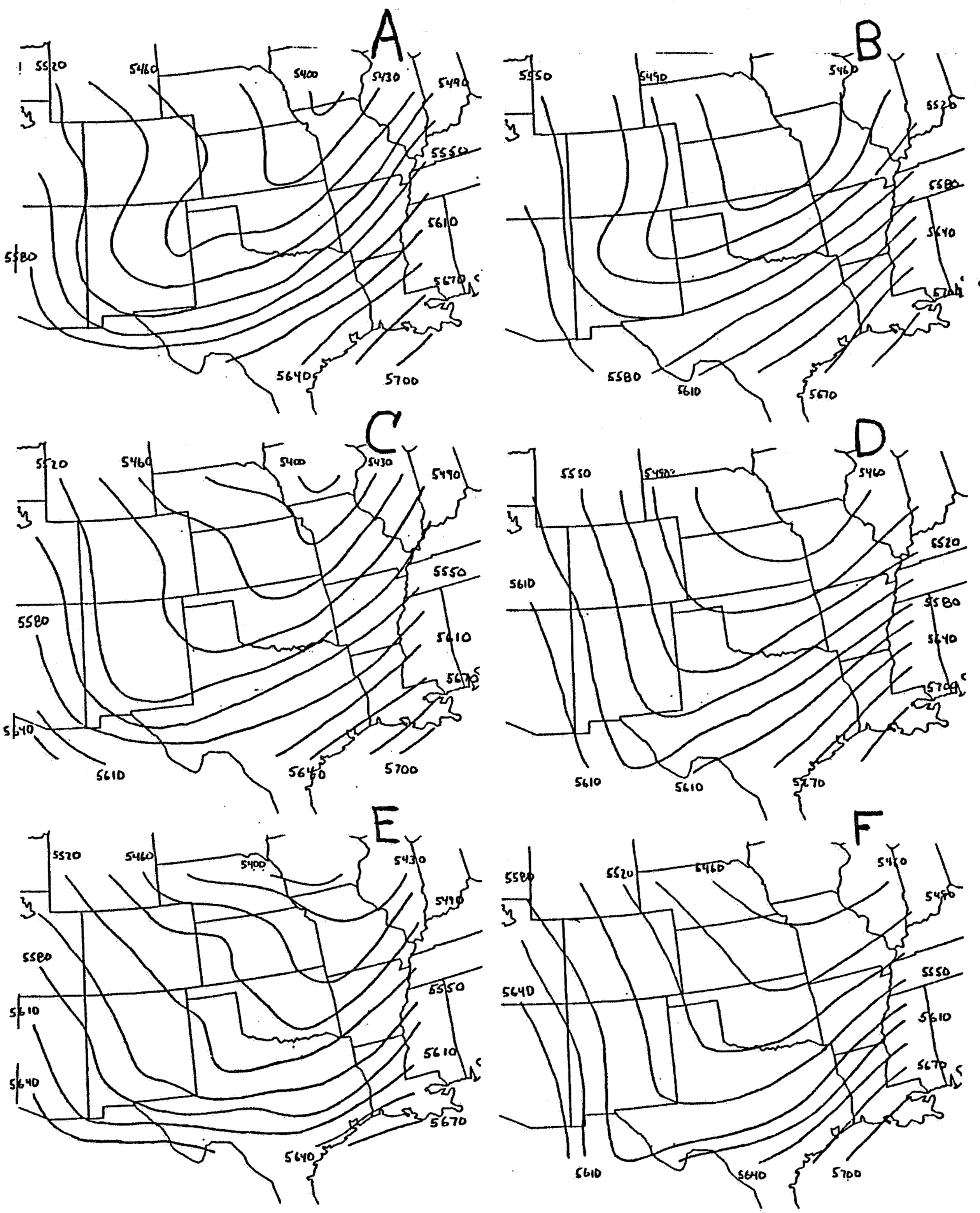


Figure 5. Same as in Figure 4 except for 500 mb geopotential height.
Units are in meters.

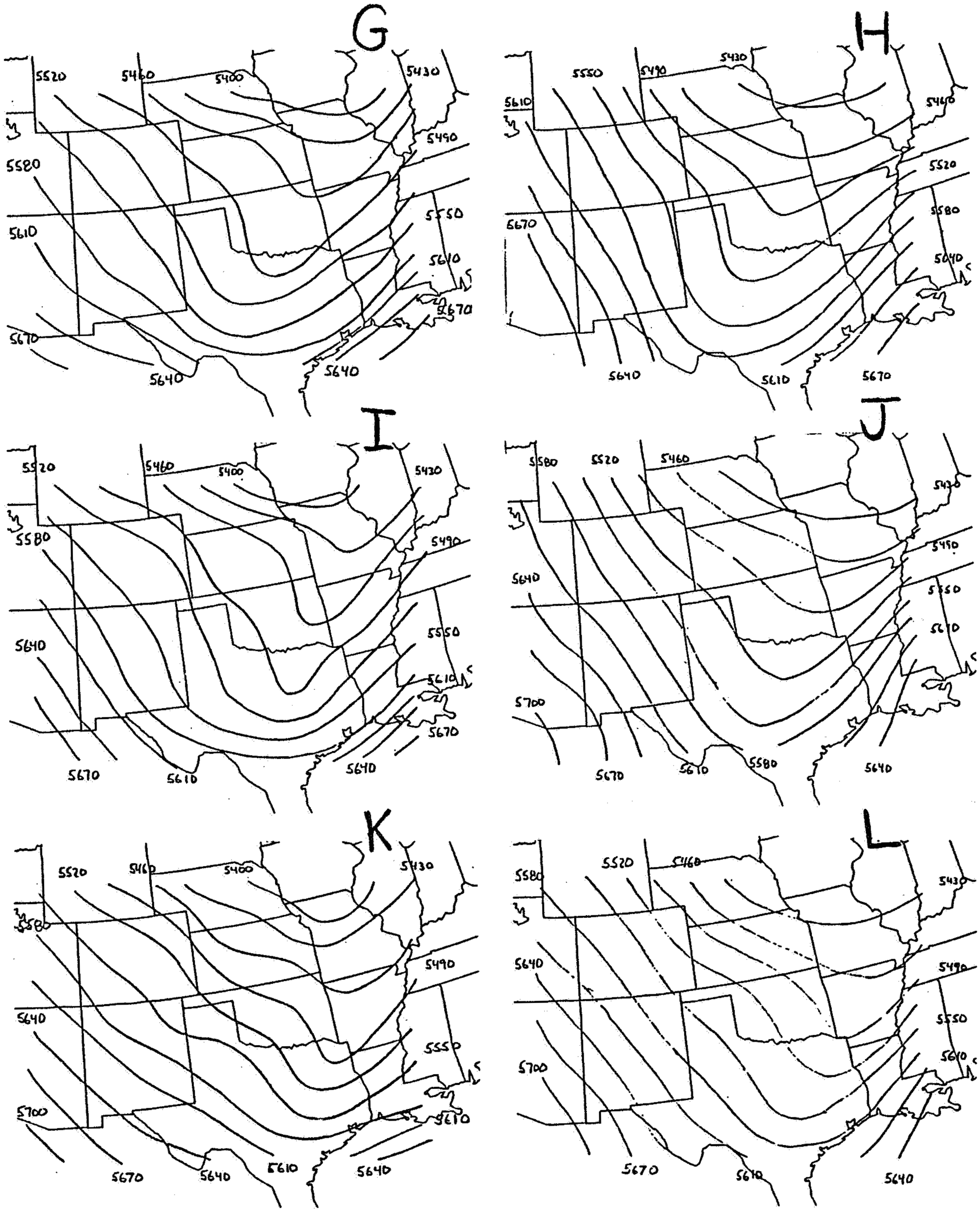


Figure 5. (Concluded).

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16. ABSTRACT

Recent studies using sounding data derived from VAS radiance measurements have projected a hope for increased time and space resolution of the mesoscale environment. Working with this new data, however, presents some problems normally not encountered when using conventional measurements because of the irregular spacing of the data, biases in the data, as well as errors due to cloud contaminated measurements. This report addresses these problems and presents an objective analysis technique which utilizes LFM guess fields to produce a consistent four-dimensional data set which adequately describes the mesoscale environment over a large area. Parameters derived from this data set can be useful in a diagnostic mode by both the operational and research communities.



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