

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.



Technical Memorandum 86205

ASSESSMENT OF VAS SOUNDINGS IN THE ANALYSIS OF A PRE-CONVECTIVE ENVIRONMENT

Louis W. Uccellini, Ralph A. Petersen,
Dennis Chesters, and Anthony Mostek

(NASA-TM-86205) ASSESSMENT OF VAS SOUNDINGS
IN THE ANALYSIS OF A PRECONVECTIVE
ENVIRONMENT (NASA) 64 p HC A04/MF A01

N85-27427

CSCI 04A

Unclas
G3/46 21401

MARCH 1985

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

ASSESSMENT OF VAS SOUNDINGS IN THE ANALYSIS
OF A PRE-CONVECTIVE ENVIRONMENT

by

Louis W. Uccellini
Laboratory for Atmospheres
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

Ralph A. Peterson
Laboratory for Atmospheres
NASA/Goddard Space Flight Centers
Greenbelt, MD 20771

Dennis Chesters
Laboratory for Atmospheres
NASA/Goddard Space Flight Centers
Greenbelt, MD 20771

and

Anthony Mostek
General Software Corporation
Landover, MD 20785

Present Affiliation:
NOAA/NMC
Camp Springs, MD 20748

March 1985

CONTENTS

ABSTRACT	ii
INTRODUCTION	1
CONVECTION ON 13 AND 14 JULY 1981	5
Synoptic Overview	5
Surface Observations	10
Imagery Review	18
VAS RETRIEVALS USED IN ASSESSMENT STUDY	23
Retrieval Technique Review	23
Data Base Preparation for VAS Sounding Study	27
VAS RETRIEVAL ANALYSIS OF THE PRE-CONVECTION ENVIRONMENT	30
VAS Retrievals of 850 mb Temperature	30
VAS Retrievals of 850 mb Dewpoint Temperature	33
VAS Retrieval of Equivalent Potential Temperature	37
Retrievals of Layer-Integrated Properties	45
SUMMARY	51
ACKNOWLEDGEMENTS	55
REFERENCES	57
FIGURE CAPTIONS	61

ABSTRACT

Retrievals from the VISSR Atmospheric Sounder (VAS) are combined with conventional data to assess the impact of geosynchronous satellite soundings upon the analysis of a pre-convective environment over the central United States on 13 July 1981. VAS retrievals of temperature, dewpoint, equivalent potential temperature, precipitable water, and lifted index are derived with 60 km resolution at 3 hour intervals. When VAS fields are combined with analyses from conventional data sources, mesoscale regions with convective instability are more clearly delineated prior to the rapid development of the thunderstorms. The retrievals differentiate isolated areas in which moist air extends throughout the lower troposphere (and are therefore more conducive for the development of deep convective storms) from those regions where moisture is confined to a thin layer near the earth's surface (where convection is less likely to occur). The analyses of the VAS retrievals identify significant spatial gradients and temporal changes in the thermal and moisture fields, especially in the regions between radiosonde observations. The detailed analyses also point to limitations in using VAS data. Even with nearly optimal conditions for passive remote sounding (generally clear skies, minimal orographic effects, and a rapidly changing moisture field), the VAS retrievals were still degraded in some regions by small clouds which are unresolved in the infrared imagery. These analyses, however, demonstrate that the geosynchronous VAS can be used in a case study mode to produce high-resolution spatial and temporal measurements which are useful for the quantitative analysis of a cloud-free pre-convective environment.

1. Introduction

The development of severe local storms is generally preceded by multi-scale dynamic and thermodynamic processes which interact to produce an environment conducive to the growth of deep convection. Synoptic scale cyclones, mesoscale jet streak and frontal circulations, moisture and temperature advections, and sensible heating can all combine to prime a region for severe convection (Palmen and Newton, 1969). Unfortunately, the spatial and temporal resolution of the current operational radiosonde network is not always adequate to observe the evolution of wind, temperature, and moisture fields with sufficient detail needed to analyze and forecast the development of severe storms (Browning, 1980). In particular, Barnes and Lilly (1975) emphasize that the moisture distribution is particularly difficult to resolve, since two-thirds of the water vapor in a convective environment variance occurs on scales less than 200 km. Results from the SESAME experiment indicate that radiosonde observations with a frequency of 3 hours and spacing of a few hundred km were needed to properly resolve the important changes in the wind, temperature, and moisture which occurred prior to the onset of the Wichita Falls tornado outbreak on 10-11 April 1979 (Kocin et al., 1982; Moore, 1982; Wilson, 1982). The deficiencies in the spatial and temporal resolution of the operational observing network were important motivating factors for establishing the National STormscale Operational and Research Meteorology (STORM) field program planned for the late 1980's. Temperature and moisture soundings derived from radiance data measured by the Visible and Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS) are

being considered as a key part of the research data sets needed by the STORM experiment to study the scale-interactive processes that lead to mesoscale convective systems.⁴

The purpose of this study is to assess the ability of VAS-derived retrievals to supplement the operational surface and radiosonde networks in the analysis of temperature and moisture fields for a pre-convective environment. VAS, which is currently available as an integral part of the Geostationary Operational Environmental Satellite (GOES) system, was designed to provide the timely observations necessary to capture the rapid evolution of mesoscale temperature and moisture distributions (Suomi et al., 1971; Smith et al., 1981). Simulation experiments showed that statistically based retrievals using VAS radiances could detect convectively unstable conditions in clear air when local training matrices designed specifically for pre-convective environments are used to derive the retrievals (Chesters et al., 1982). However, even in the controlled simulation experiments, VAS soundings underestimated the magnitude of the convective instability due to the inability of the broad infrared spectral bands to properly resolve the vertical moisture and temperature distribution in the lower troposphere. These initial results revealed a need to incorporate the conventional surface data into the retrieval algorithm to improve VAS soundings. A subsequent study by Lee et al. (1983) showed that the addition of surface data improves the VAS moisture and temperature retrievals and provides more spatially coherent fields in the lower troposphere.

⁴STORM-Central Phase Preliminary Program Design (May 1984), prepared by the National Center for Atmospheric Research, Boulder, Colorado, 147 pp.

An investigation is now presented which assesses the ability of VAS observations on 13 July 1981 to provide quantitative temperature and moisture information in the analysis of the pre-convective environment. The additional information available from VAS should help fill the large temporal and spatial data gaps present in the operational radiosonde network. The 13 July 1981 data were previously used by Lee et al. (1983) for strictly statistical evaluations of VAS sounding accuracy and also by Chesters et al. (1983) and Petersen et al. (1984) for studies based solely on VAS moisture imagery. Chesters et al. (1983) show that the VAS "split window" can accurately depict the mesoscale evolution of water vapor fields. Petersen et al. (1984) combine the split window and the 6.7 μm upper-tropospheric water vapor images to delineate regions where dry air overlies moist air, a vertical moisture distribution which is conducive for convective instability.

The sounding analysis presented in this paper attempts to expand upon the results inferred from the image analyses emphasized in the previous studies by: 1) assessing the ability of VAS retrievals to measure quantitatively the structure and evolution of the thermal and moisture fields in an ideal pre-convective environment (few clouds, minimal orographic effects, rapid changes in the moisture fields) and 2) showing that VAS moisture, temperature, and stability fields combined with conventional data provide better analyses of this severe weather event produced by either set of data alone. A synoptic overview of the 13 July 1981 case is presented in Section 2 along with detailed surface data analyses and a brief review of the VAS imagery. The "VAS plus surface" sounding algorithm is outlined in Section 3. The application of VAS

soundings to the study of a rapidly developing convective system is presented in Section 4, with a summary of the results provided in Section 5.

2. Convection on 13 and 14 July 1981

In this section, a synoptic overview is presented, followed by a more detailed description of the surface parameters such as the temperature, dewpoint, equivalent potential temperature (θ_e), frontogenesis diagnostics and convergence. The VAS imagery is then shown to visually depict the rapidly changing moisture field for comparison to the satellite sounding fields in Section 4.

a. Synoptic overview

National Weather Service (NWS) surface and radar analyses for 13 and 14 July 1981 are shown in Figs. 1 and 2. At 1200 GMT (Fig. 1a), a weak surface low was drifting from eastern Colorado toward Nebraska along a slowly moving front that extended through Iowa and northern Illinois into southern Michigan. The southeastern United States was dominated by a broad high pressure system centered near the Mississippi and Alabama border. The anticyclonic circulation produced a southerly flow of humid air over a broad area west of the Mississippi River, where surface dewpoints exceeded 20°C over much of the region from the Gulf of Mexico to southern Minnesota. Corresponding radar observations at 1135 GMT (Fig. 2a) indicate that precipitation over the Midwest was confined to a region near the frontal zone with several areas of thunderstorms in South Dakota, Iowa, northern Illinois, and Ohio. An area of rainshowers and thunderstorms was also present in the Texas-Louisiana coastal area and in eastern Colorado.

During the day, the frontal zone across the northern Midwest remained ill-defined as the weak surface low moved into western Nebraska by 1800 GMT

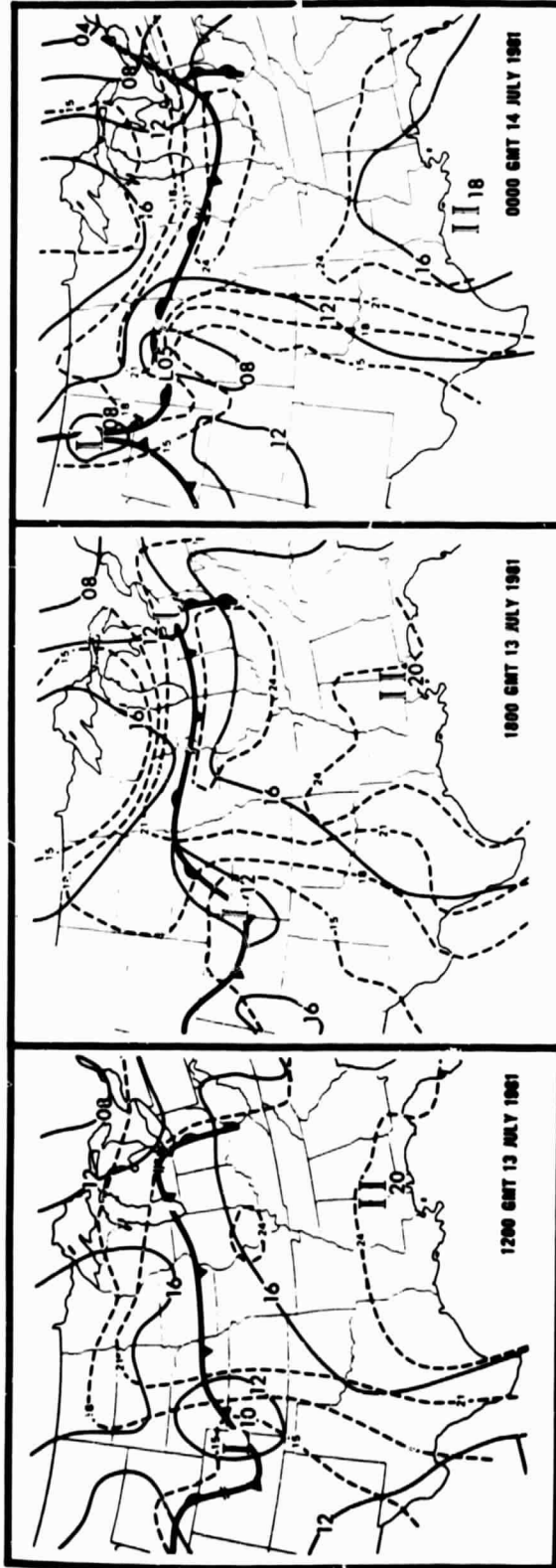


Figure 1. National Weather Service surface charts (dashed contours-surface dewpoint °C) for 13 July 1981 at (a) 1200 and (b) 1800 GMT and 14 July 1981 at (c) 0000 GMT.

ORIGINAL FILED IN
OF POOR QUALITY

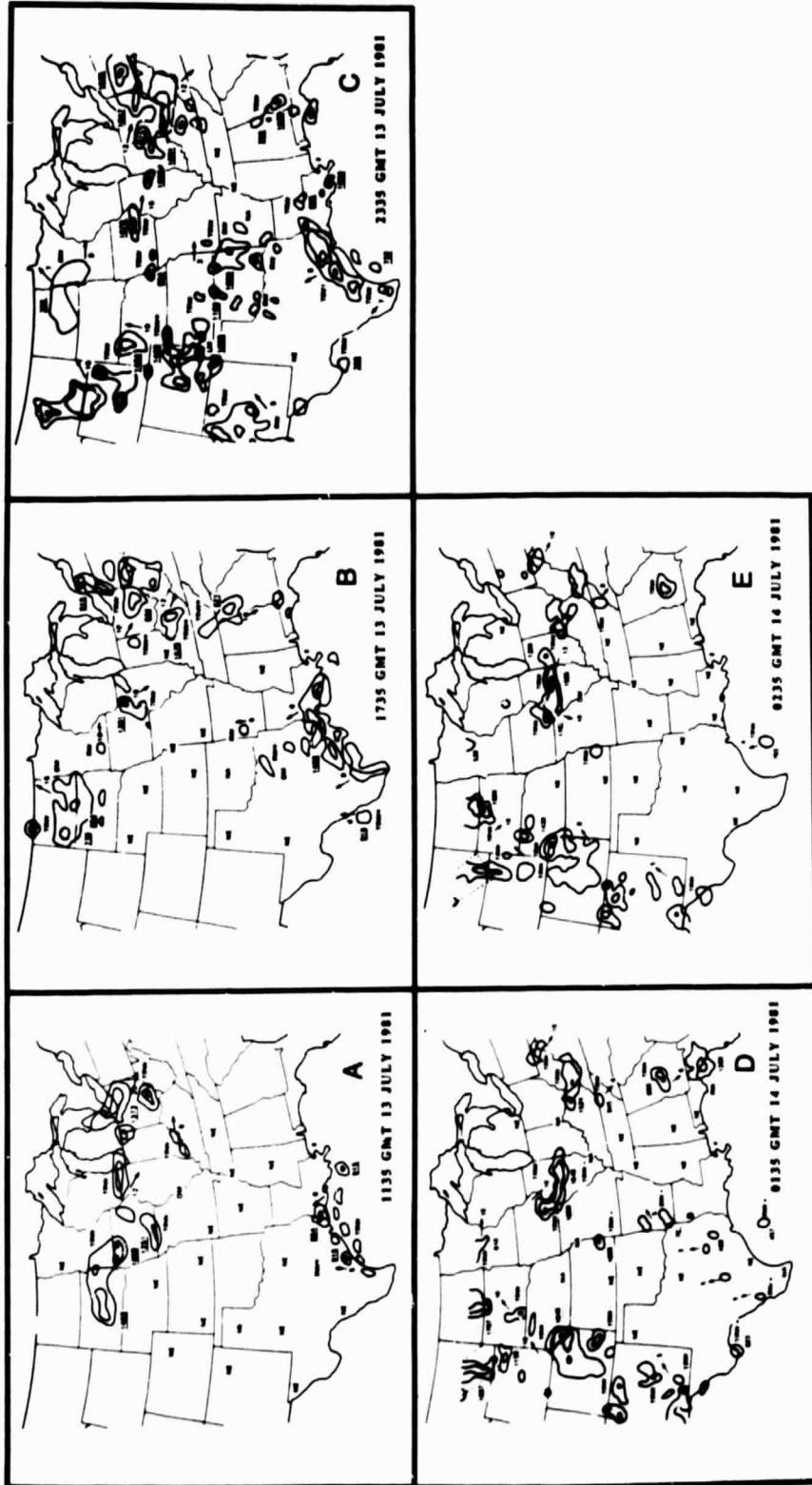


Figure 2. NWS radar depictions for 13 July 1981 at (a) 1135, (b) 1735, and (c) 2335 GMT and 14 July 1981 at (d) 0135 GMT and (e) 0235 GMT (cell heights, dam; cell motion, knots).

(Fig. 1b), and into South Dakota by 0000 GMT (Fig. 1c). The southerly air flow and the morning insolation over the central United States combined to produce surface temperatures above 35°C . By 1735 GMT (Fig. 2b), the area of thunderstorms originally over Iowa moved toward northern Illinois and weakened, while the precipitation in the Dakotas moved northward and diminished. Thunderstorms along the Gulf continued to strengthen, while scattered areas of rain began to develop over the Ohio Valley. By 2335 GMT (Fig. 2c), several bands of showers and scattered thunderstorms developed over Oklahoma while an area of thunderstorms developed in eastern Colorado. Subsequently, the Colorado storms decayed as they moved into Kansas and Nebraska, while the thunderstorms along the Texas-Gulf of Mexico coast died rapidly as they moved inland. Of particular interest to this study are the 16,780 m (55,000 ft) high storms which developed in less than 2 hours along the diffuse frontal zone in eastern Iowa. These storms continued expanding into a east-west oriented squall line that moved into central Illinois by 0135 and 0235 GMT (Figs. 2d and 2e).

Aloft, the central United States was dominated by a nearly stationary anticyclonic circulation around a ridge located over the Ohio Valley at the 250 mb level (Figs. 3a and 3b) and over the Gulf Coast at the 850 mb level (Figs. 3c and 3d). The broad anticyclonic flow produced weak, but persistent southerly flow west of the Mississippi River which transported warm, moist air toward the northern Midwest. Trough/jet streak systems were found only to the northeast of the Great Lakes and over the Rocky Mountains. The thunderstorms in the central and northern United States therefore developed in a region in which large-scale dynamic forcing is weak. Maddox and Doswell (1982) have noted that this type of situation

ORIGINAL PAGE IS
OF POOR QUALITY

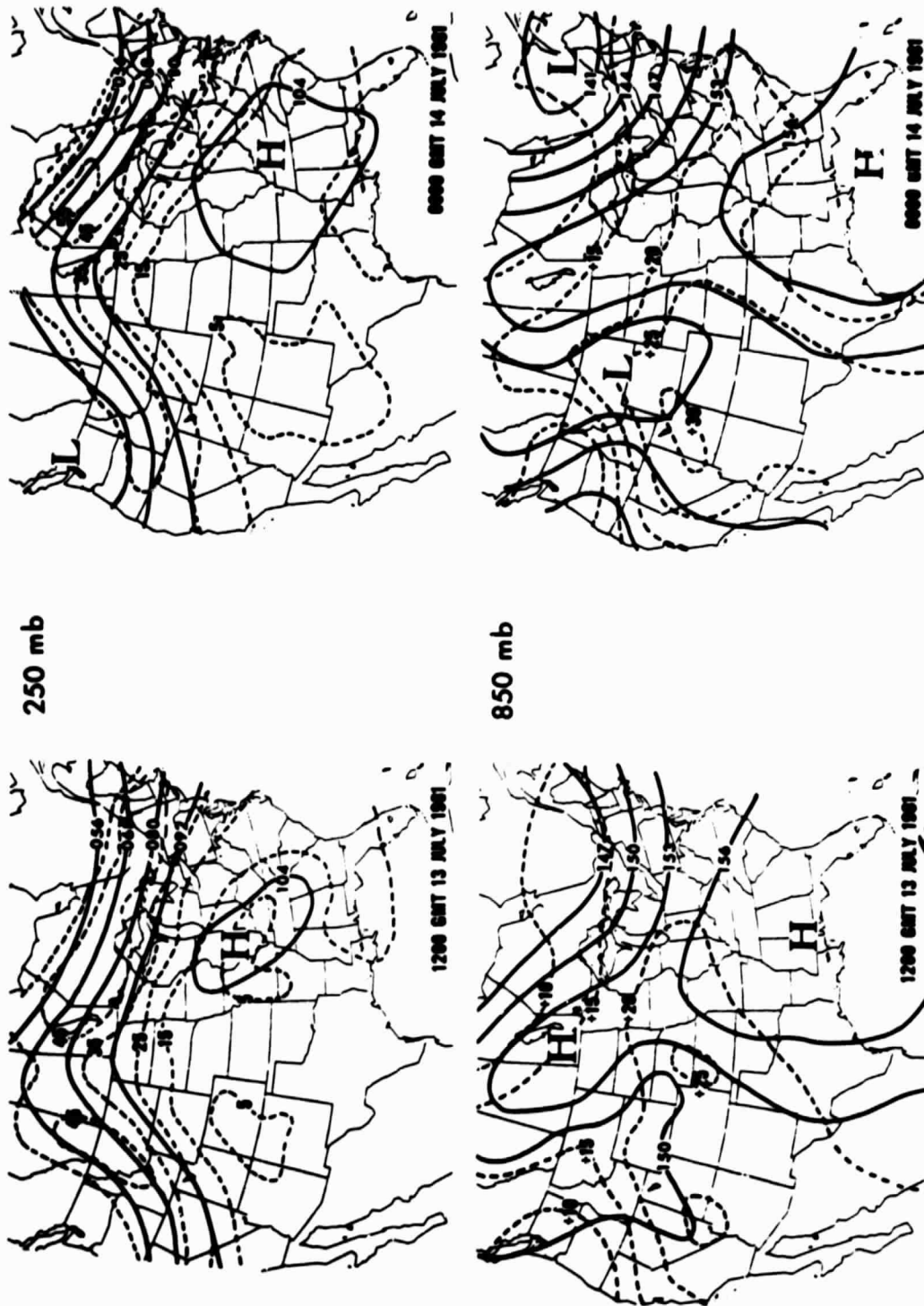


Figure 3. National Weather Service 250 mb (a) and (b) and 850 mb (c) and (d) charts for 13 July 1981 at 1200 GMT and 14 July 1981 at 0000 GMT (geopotential heights, solid, dam; 250 mb isotherms, dashed, $m s^{-1}$; 850 mb temperature, dashed, $^{\circ}C$).

poses forecast problems in contrast to situations where synoptic scale forcing is large and more readily resolved by the operational observing network and numerical models. As such, the 13 July 1981 case offers the opportunity to test the usefulness of VAS soundings in analyzing the thermodynamic structure of a pre-convective environment within a relatively benign synoptic scale setting.

b. Surface observations

The conventional surface temperatures and dewpoints over the Midwest for 1200, 1500, 1800, 2100 GMT 13 July, and 0000 GMT 14 July 1981 (Fig. 4) are especially useful in tracing the evolution of the pre-storm environment in the middle United States.⁵ At 1200 GMT (Fig. 4a), the surface front across the north-central United States is barely evident, as a diffuse temperature gradient extends across southern Wisconsin and Iowa. After 1500 GMT (Fig. 4b), the surface temperature gradient along the frontal zone became progressively stronger, especially in an area from South Dakota southeastward through Iowa into Illinois from 1800 to 0000 GMT (Figs. 4c, 4d, and 4e). Temperatures northeast of the front rose slowly and generally remained below 30°C, while observations to the south of the front increased rapidly, exceeding 36°C across Nebraska, Kansas, and southern South Dakota by 2100 GMT. Some local effects were also apparent. For example, the temperature at stations across central Wisconsin rose above 30°C, while along Lake Michigan Green Bay cooled from 32°C at 2100 GMT to 28°C at

⁵The temperature analyses in Fig. 4 were produced using the standard National Weather Service (NWS) and Federal Aviation Administration (FAA) surface network and GEMPAK-Barnes analysis scheme described by Koch et al. (1983).

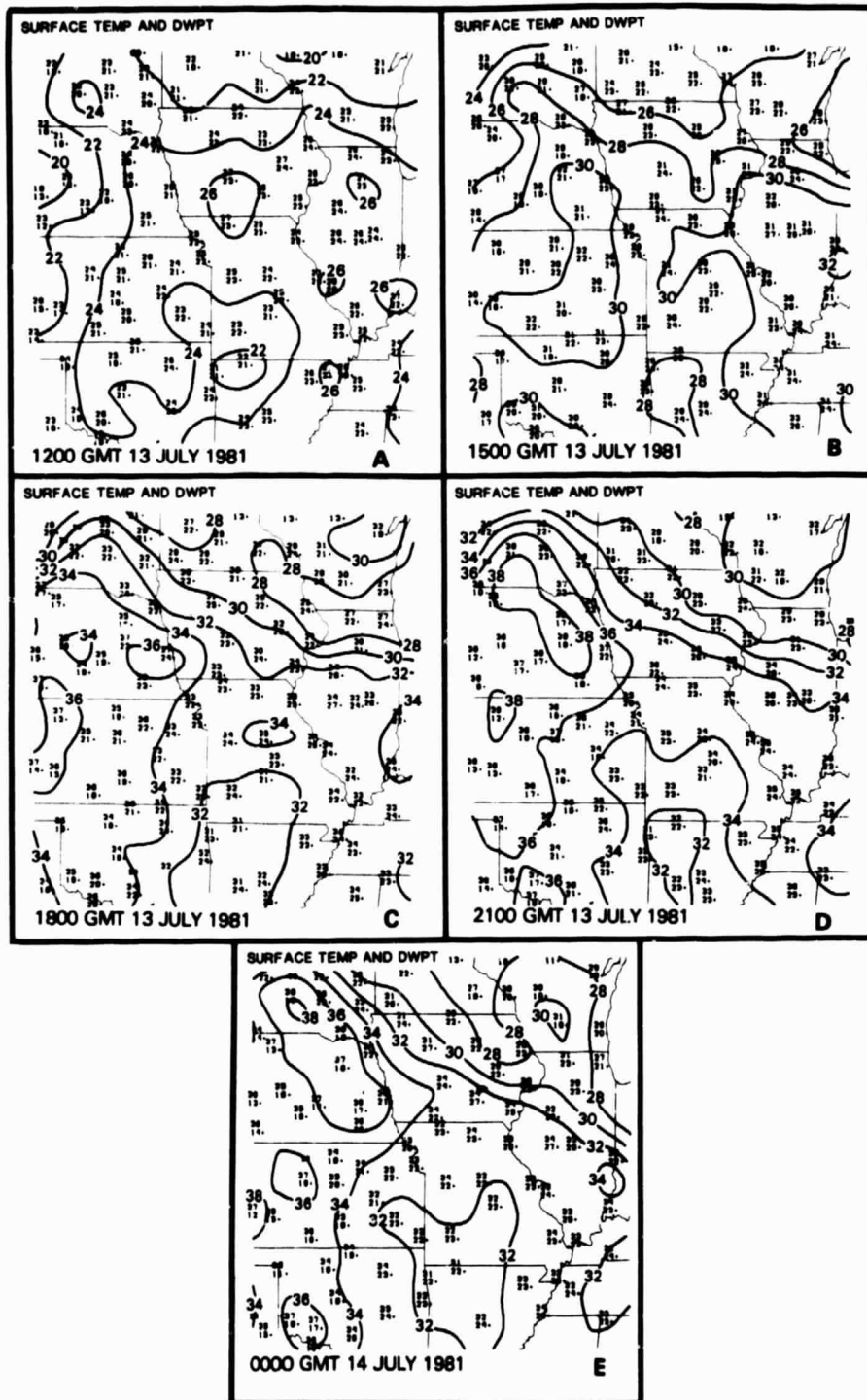


Figure 4. Surface temperature (top number plotted at each station) and dewpoint temperature (degrees C) reports from hourly NWS and FAA surface network for 13 July 1981 at (a) 1200 GMT, (b) 1500 GMT, (c) 1800 GMT, (d) 2100 GMT, and (e) 0000 GMT 14 July 1981. Contours of the temperature fields are shown at intervals of 2°C.

0000 GMT. These effects will be important in describing some of the discrepancies between the VAS and radiosonde analyses in Section 4.

The surface dewpoint temperatures just south of the surface front (in Fig. 4) reached extremely high values, with several readings exceeding 24°C in Iowa and central Illinois by 2100 GMT (Fig. 4d). Areas of Oklahoma, southeast Kansas, and Missouri also reported values between 22° and 24°C by 2100 GMT. These high surface dewpoint temperatures imply that there was some potential for the development of convective storms. The drop in dewpoint temperatures over eastern Nebraska from 23° to 20°C between 1800 and 0000 GMT suggests that drier air either moved across from the western plains or was transported downward toward the surface.

The thermodynamic potential for convection is clearly displayed by the surface equivalent potential temperature (θ_e) fields (Fig. 5). Surface θ_e values in the 2-hourly analyses along the frontal zone extending from South Dakota to Illinois were generally above 360 K at 1800 GMT (Fig. 5a). The area encompassed by the 365 K contour increased substantially by 2200 and 0000 GMT (Figs. 5c and 5d). The θ_e gradient along the edges of the localized maximum intensified in southern Minnesota, northeast Iowa, and southwest Wisconsin after 2000 GMT due, in part, to the frontogenetical processes occurring in that region (as discussed later in this section). The convection, which developed rapidly in eastern Iowa by 2335 GMT (Fig. 2c), was located on the southern edge of this gradient, near the region where maximum θ_e values exceeded 370 K (Fig. 5d). The convective bands in Oklahoma (Fig. 2c) also developed along the moist edge of the θ_e gradients, near the 365 K maxima in northeast Oklahoma at 2000 and 2200 GMT (Figs. 5b and 5c).

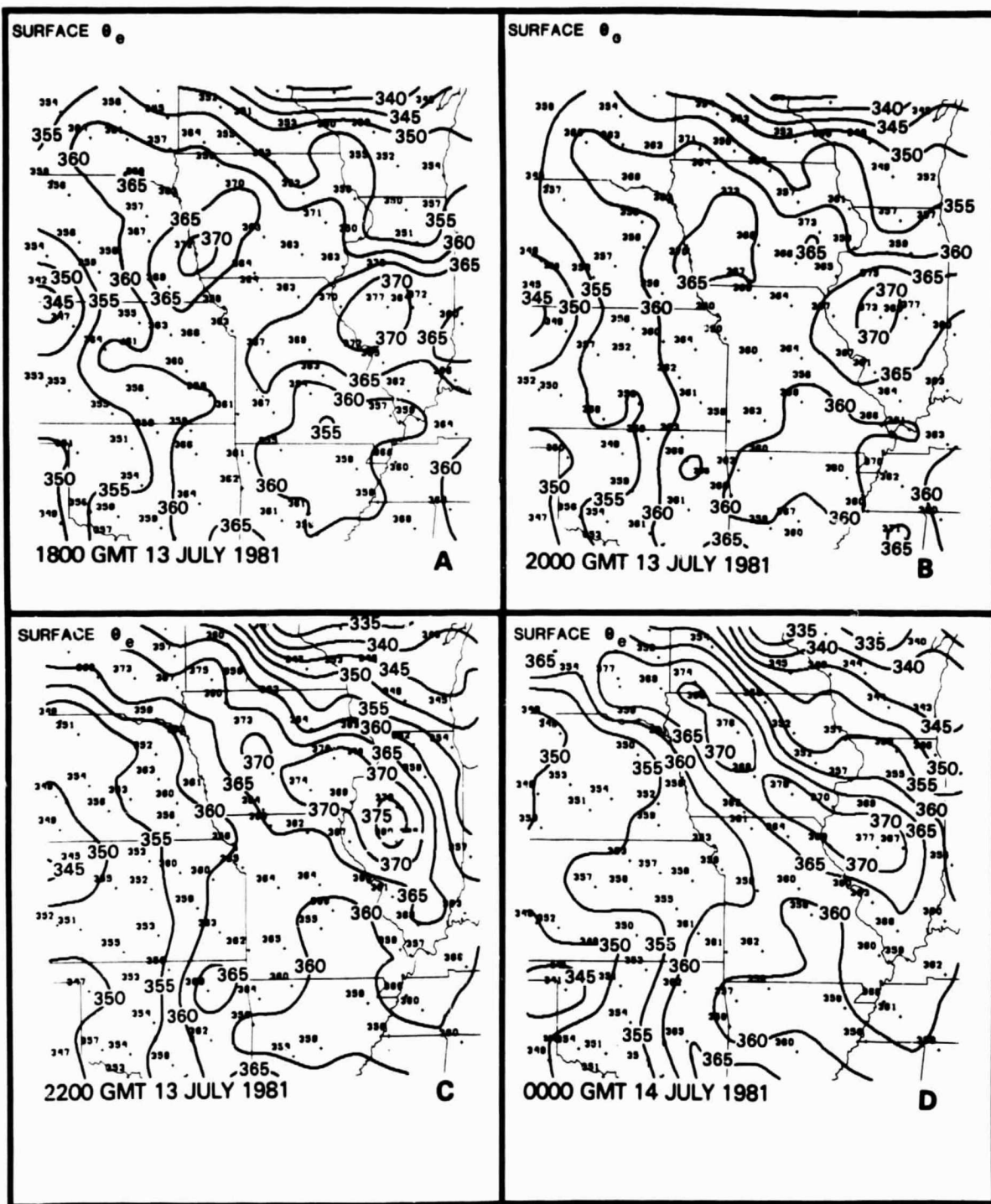


Figure 5. Surface equivalent potential temperature (θ_e degrees K) reports from hourly NWS and FAA surface network for 13 July 1981 at (a) 1800 GMT, (b) 2000 GMT, (c) 2200 GMT, and (d) 0000 GMT 14 July 1981. Contours are shown at intervals of 5 K.

Surface θ_e fields indicate a potential for convective storms in several areas of the Midwest, especially along the line from South Dakota to south-central Illinois and also over eastern Oklahoma (Figs. 5c and 5d). However, convection developed in only portions of those areas. This inconsistency reflects the problem that can arise by inferring potential convective instability from surface temperature and dewpoint data alone, without taking into consideration information regarding the vertical distribution of these fields. This issue will be addressed further in the discussion of the VAS low-level moisture analyses (Section 4b).

The scattered nature of the convection also points to the need to isolate those mechanisms which provide the lifting necessary to initiate the storms. To determine if any lifting mechanism might be diagnosed which could release the convective instability inferred from the surface analyses, surface streamline, convergence and surface frontogenesis (Koch, 1984) fields are shown in Figs. 6 and 7. The streamline and convergence analyses were derived from grids of u - and v -wind components of the surface winds, and the frontogenesis fields were generated in a manner described by Koch (1984). Along the front, surface convergence persisted from 1800 through 0000 GMT, with maximum convergence ($-4 \times 10^{-5} \text{ s}^{-1}$) located over eastern Iowa at 2200 GMT preceding the storm development in that region (Fig. 6c). By 0000 GMT (Fig. 6d), the convergence intensified to $-6 \times 10^{-5} \text{ s}^{-1}$ along the axis of dilatation and near the warm edge of the θ_e gradient in Iowa as the severe convective cells developed (Fig. 2c). The coincidence of maximum convergence with a col in the streamlines and with strong gradients in temperature and θ_e fields suggests that a frontogenetic process could be operating to initiate the convection in Iowa in a manner

ORIGINAL FILED
OF POOR QUALITY

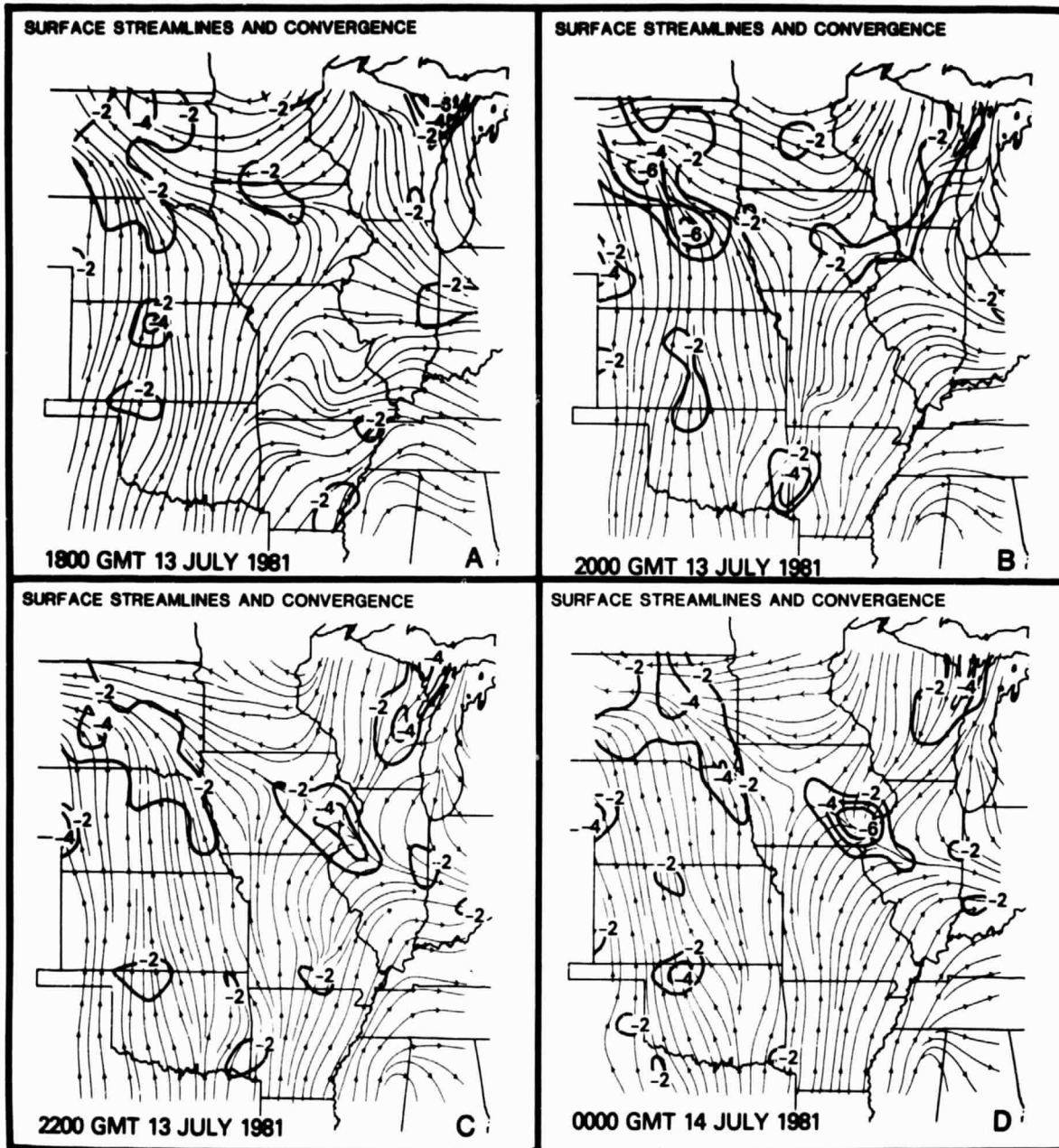


Figure 6. Surface streamline and convergence (10^{-5} sec^{-1}) fields derived from grids of surface wind u - and v -components from the NWS and FAA surface network for 13 July 1981 at (a) 1800 GMT, (b) 2000 GMT, (c) 2200 GMT, and (d) 0000 GMT 14 July 1981.

similar to that discussed by Berry and Bluestein (1982) and Koch (1984). Fig. 7 reveals that the surface frontogenetical function was large across eastern Iowa between 2000 and 0000 GMT, acting to increase the magnitude of the weak front through the entire period and likely contributes to upward vertical motion.

Surface convergence was also present in the other areas where convection developed. By 2000 GMT (Fig. 6b), bands of convergence had become established in central Kansas and across eastern portions of Oklahoma corresponding with weak convection observed by 2300 GMT (Fig. 2c). Persistent surface convergence was analyzed over South Dakota and eastern Nebraska, but only two minor storm cells developed near Omaha by 2335 GMT, to the south of the maximum convergence values. However, over north-central South Dakota, a rapidly developing storm grew to 17,000 m (56,000 ft) by 0135 GMT 14 July 1981 (Fig. 2d). An area of convergence was present over western Nebraska, along the edge of the domain where radar summaries depict rapid storm development over eastern Colorado by 2330 GMT (Fig. 2c). However, despite the surface convergence these storms decayed rapidly as they moved into the dry air over Nebraska (Figs. 2d and 2e), an area where dewpoints remained less than 15°C (Fig. 11e). The surface frontogenesis analyses again point to a potential initiation mechanism both in the Kansas-Oklahoma region and in South Dakota (Fig. 7). Only weak frontogenesis (less than $.5 \text{ K } 10^2 \text{ km}^{-1} \text{ } 3 \text{ hr}^{-1}$) is present across Kansas and central Oklahoma, while the persistently strong frontogenesis (greater than $2 \text{ K } 10^2 \text{ km}^{-1} \text{ } 3 \text{ hr}^{-1}$) across South Dakota provides a strong signal for the rapid convective development there.

SURFACE FRONTOGENESIS

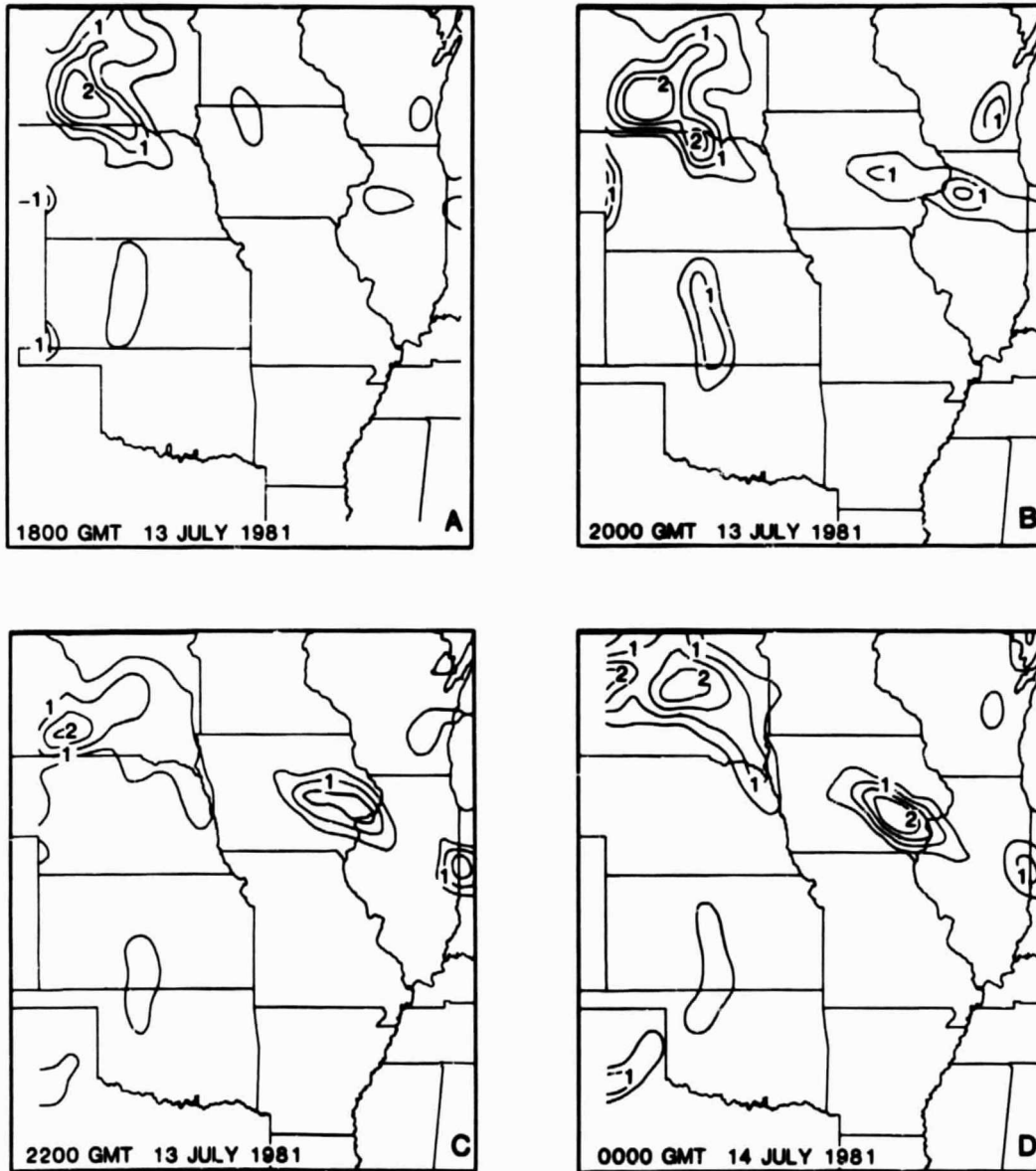


Figure 7. Surface frontogenesis ($10^{-2} \text{ km}^{-1} \text{ 3 hr}^{-1}$) fields derived from grids of potential temperature (K) and surface wind components from the NWS AND FAA surface network for 13 July 1981 at (a) 1800 GMT, (b) 2000 GMT, (c) 2200 GMT, and (d) 0000 GMT 14 July 1981.

In summary, the conventional surface temperature and dewpoint data provide evidence for a rather large area with a potential for convective storms. Diagnostic computations based on surface winds and temperature fields help to better define those areas in which the necessary processes are occurring that mechanically lift the airmass and act to initiate the storm system. The satellite analyses shown in Section 4 are not only designed to assess the utility of VAS soundings in further resolve the restricted areas in which convective instability exists prior to the onset of the convective storms, but also to determine if the dissipation of the storms can be anticipated as they move into areas which are not favorable for convection.

c. Imagery review

Visible images between 1200 GMT and 2300 GMT 13 July 1981 (Figs. 8a through 8e) and infrared (11 μ m) images between 0000 GMT and 0300 GMT 14 July 1981 (Figs. 8f through 8h) agree with the evolution of the precipitation shown on the corresponding radar summaries (Fig. 2). The scattered nature of the showers in Arkansas at 1800 and 2100 GMT (Figs. 8c and 8d), the banded structure of the moderate thunderstorms in Oklahoma (Figs. 8d and 8e) and the sudden development of the intense thunderstorms over eastern Iowa at 2300 GMT (Fig. 8e) are clearly illustrated. The infrared imagery at 0000, 0100 and 0300 GMT 14 July show that the storms continued to develop in central Illinois but did not expand into the southern part of the state, while the weaker convection in the south-central United States dissipated during the period (Figs. 8f, 8g and

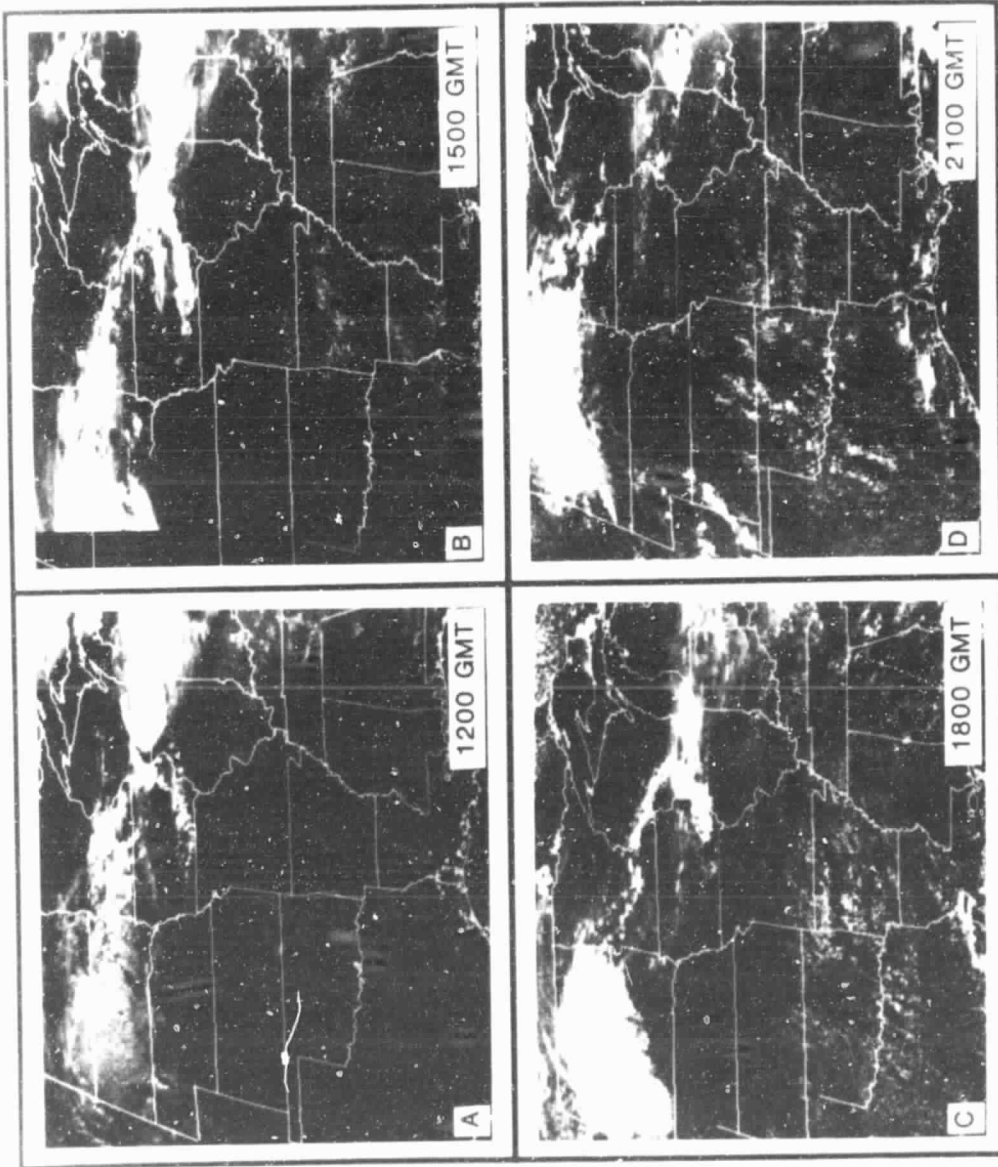


Figure 8. Visible and 11 μ m images over the assessment study area for 13 July 1981 visible at (a) 1200 GMT, (b) 1500 GMT, (c) 1800 GMT, (d) 2100 GMT, and (e) 2300 GMT, and 14 July 1981 infrared (11 μ m) at (f) 0000 GMT, (g) 0100 GMT, and (h) 0300 GMT. Note the development of the scattered cirrus clouds across Oklahoma, Kansas, and Arkansas at 1800 and 2100 GMT and the rapid growth of the convective cells over eastern Iowa and eastern Illinois through 0300 GMT.

ORIGINAL FILED AT
OF POOR QUALITY

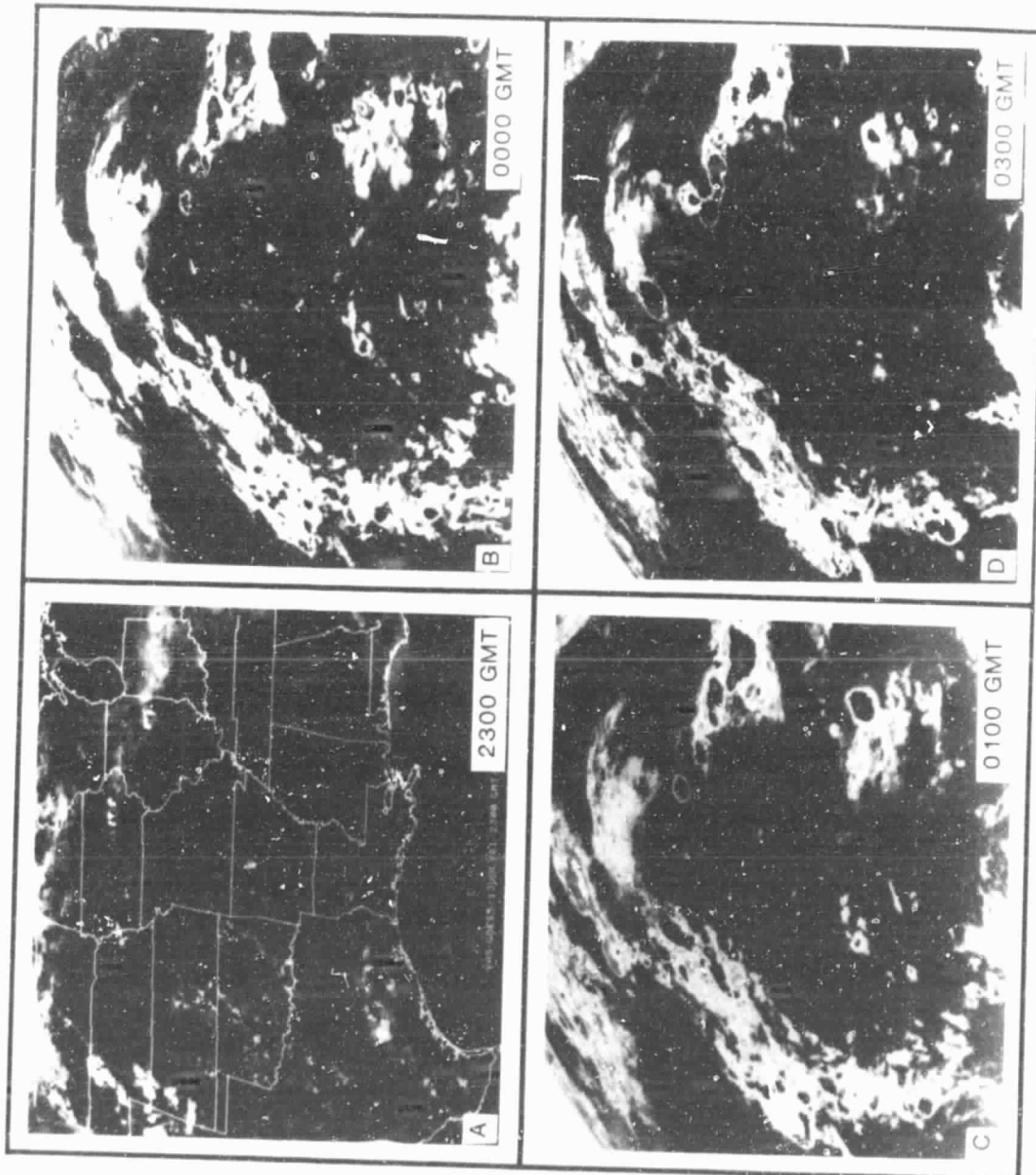


Figure 8. (Continued)

8h). Also, the storms in eastern Colorado decayed as they move into Nebraska, while those over northern South Dakota grow rapidly.

Additional information about the low- and middle-tropospheric moisture distribution can be obtained from the VAS 6.7 μm images and split window images (Fig. 9). [See Chesters et al. (1983) and Petersen et al. (1984) for detailed descriptions.] The split window images reveal the low-level moisture maximum (lighter shading) which becomes well defined over Iowa between 1500 and 2100 GMT (Figs. 9a through 9c) in the wake of morning thunderstorms. The high precipitable water values in Iowa, which coincide with the region of maximum surface θ_e (Fig. 5c), are observed more than two hours prior to the sudden development of convection in the eastern part of the state (Figs. 2c through 2e). Fig. 9 also reveals a narrow band of dry air (darker shading) extending eastward from Nebraska, through northern Missouri, and into the southern half of Illinois. Radiosonde data (not shown) confirm that this dry slot defines a region where low dewpoints are present throughout much of the lower troposphere even though the surface dewpoints remained very high. The image sequence from the 6.7 μm mid-tropospheric water vapor channel (Figs. 9e through 9h), shows broad regions of moist air (gray) punctuated by narrow bands of dryness (dark) moving anticyclonically over the eastern two-thirds of the United States. The convection in Iowa developed after a band of mid-level dryness (Figs. 9g and 9h) translated over the low-level moisture maximum in the vicinity of the surface front, thereby increasing the potential for convective instability immediately prior to the onset of the storm development.

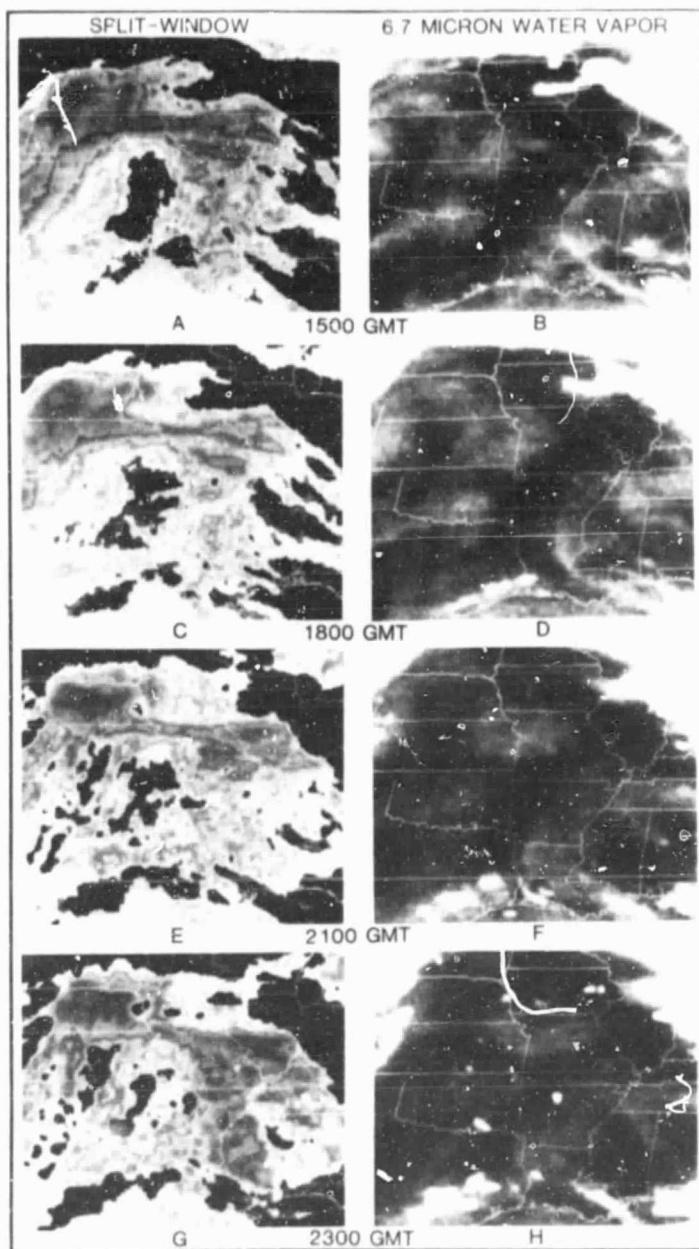


Figure 9. VAS split window images of low-level moisture (left column) derived from the 11.2 and 12.7 μm channels for 13 July 1981 at (a) 1500 GMT, (b) 1800 GMT, (c) 2100 GMT, and (d) 2300 GMT. Grey scale contrast is enhanced to highlight very moist areas. Solid black areas are either regions of obvious cloud cover or because boundary layer air temperature estimated for the central United States was too warm for areas farther north. Image sequences from the VAS 6.7 μm mid-tropospheric water vapor channel (right column) for 13 July 1981 at (e) 1500 GMT, (f) 1800 GMT, (g) 2100 GMT, and (h) 2300 GMT. Moist air appears as lighter grey with the dark areas and bands resulting from a drier and warmer signal upwelling from lower levels of the troposphere.

3. VAS Retrievals Used in Assessment Study

In the previous section, conventional surface temperature, dewpoint and wind information combined with the VAS moisture imagery were shown to effectively monitor the pre-storm environment in the central United States for this case. The detailed horizontal structure in the VAS water vapor imagery proved to be particularly helpful in delineating areas with a potential for convective instability. In the remainder of this paper, an attempt is made to quantify the information apparent in the VAS imagery. The method of retrieving temperature and moisture profiles using VAS radiance data in a regression-based retrieval technique is described in this section. Section 4 then assesses whether the VAS retrievals can indeed add useful quantitative information to the data bases already available for the analysis of the pre-storm environment.

a. Retrieval technique review

The regression algorithm used in this study combines surface temperature and dewpoint observations with radiance data from up to 12 VAS infrared channels (Lee et al., 1983). Linear regression provides direct retrievals of atmospheric parameters from radiance observations based on previously established parameter/radiance correlations without any a priori knowledge of instrumental bias or transmission functions (see, e.g., Smith et al., 1970; Fritz et al., 1972). The parameter/radiance correlations are obtained for a set of coincident satellite/radiosonde/surface observations, encompassing both the spatial and diurnal variation of the airmass over the particular area in question. The major factors which can affect the

regression coefficients and subsequent accuracy of the retrievals are:

- 1) the quality and statistical appropriateness of the radiosondes;
- 2) possible cloud contamination in the radiances; 3) the number of coincident observations (per time period and geographic distribution);
- 4) and precise collocation among the satellite, radiosonde and surface observations.

The paucity of clear-air radiosondes in the region of interest and the lack of midday synoptic observations needed to develop correlation statistics are major limitations in applying the regression technique to mesoscale studies over the United States. Over limited areas, the small number of coincident satellite, radiosonde, and surface data can produce retrieval matrices with large coefficients of opposing signs which can over-interpret the fluctuations normally encountered with real data. To stabilize the solutions, a "conditioning factor" is applied which takes into account the radiometric noise-to-signal ratio for the VAS channels. The application of this method, called "ridge regression" by Marquardt and Snee (1975), to VAS retrievals is described by Lee et al. (1983). Their results show that the best soundings are produced by including:

- 1) combined dawn (1200 GMT) and dusk (0000 GMT) collocated satellite/radiosonde measurements; 2) regional site selection to produce regression coefficients for the local environment; and 3) coincident observations from the same date as used for the study.

The VAS channels and their weighting functions for the US Standard Atmosphere are shown in Fig. 10 and the major characteristics are summarized in Table 1. The most important sounding characteristics of the VAS channels are that: 1) the radiation from the lower troposphere is

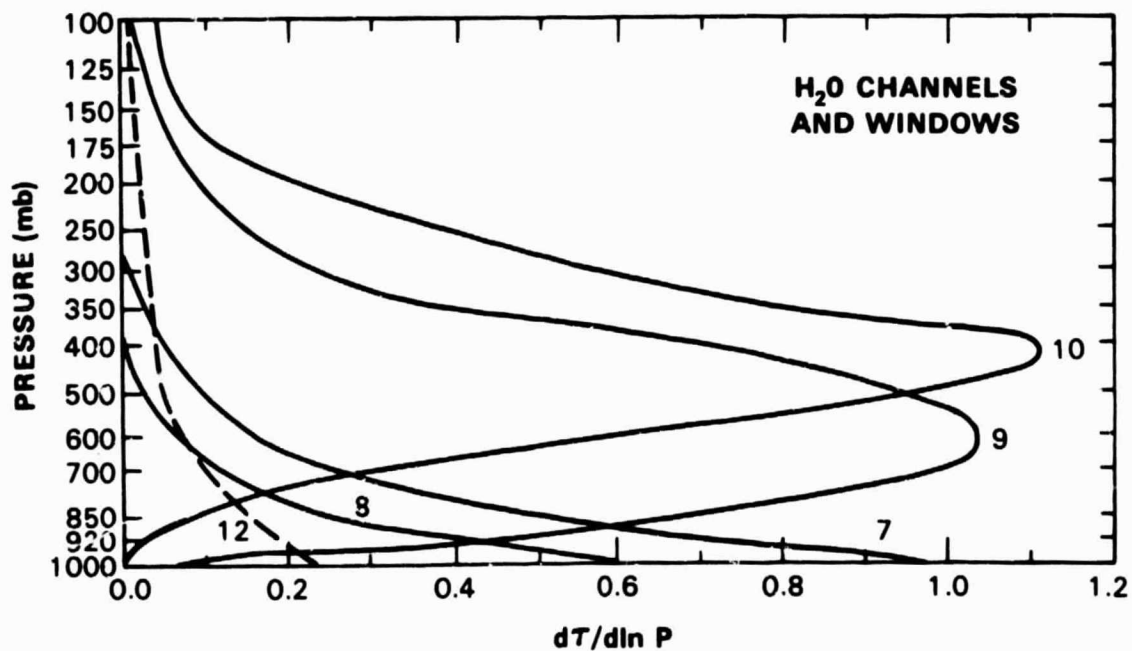
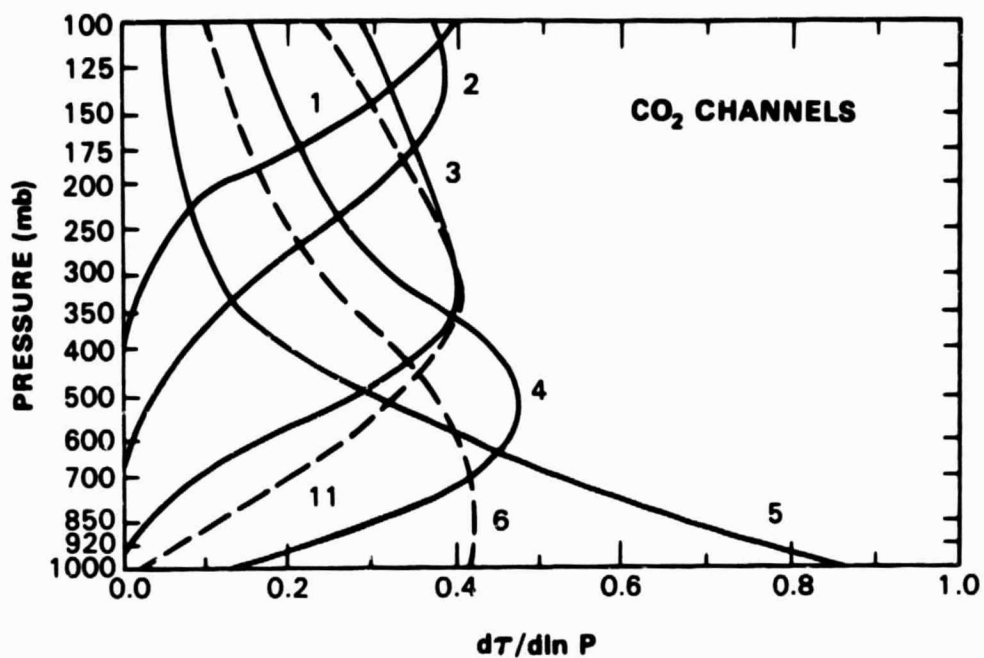


Figure 10. The VAS weighting functions, $dT/d \ln P$, for the U.S. Standard Atmosphere. The temperature sounding channels are shown in the top panel and the water vapor and window channels in the bottom panel. The shortwave channels are indicated with dashed lines.

Table 1: The general design features of the VAS channels. VAS channel 8 is the VISSR 11 μm window operated with the large detectors and its view of the surface is significantly affected by molecular absorption from atmospheric water vapor and carbon dioxide. Each of the VAS bandpasses was selected with temperature, water vapor, surface and cloud detection in mind, based upon experience with the infrared sounders in polar orbit.

VAS Ch. No.	Spectral Center μm	Spectral Center cm^{-1}	Peak weight (mb)	10%-90% radiance layer (mb)	Purpose for Sounding	Main Abs. Gas	Other Signif. Effects
1	14.73	678.7	70	4-120	temp	CO_2	O_3
2	14.48	690.6	125	4-225	temp	CO_2	O_3
3*	14.25	701.6	200	15-475	temp	CO_2	O_3
4*	14.01	713.6	500	40-900	temp	CO_2	O_3
5*	13.33	750.	920	420-surface	temp	$\text{CO}_2, \text{H}_2\text{O}$	O_3
6	4.525	2210.	850	520-surface	temp + cloud	N_2O	Sun
7*	12.66	790.	1000	720-surface	moisture	H_2O	CO_2 + dust
8*	11.17	895.	surface	920-surface	surface	H_2O	CO_2 + dust
9*	7.261	1377.2	600	110-820	moisture	H_2O	CO_2
10*	6.725	1487.	400	240-620	moisture	H_2O	---
11	4.444	2250.	300	7-1000	temp + cloud	$\text{N}_2\text{O}, \text{CO}_2$	Sun
12	3.945	2535.	surface	surface-surface	surface	H_2O	Sun + dust

*Available at 6.9 km as well as 13.8 km geometrical fields-of-view.

mixed with both surface and mid-tropospheric contributions in all the key VAS channels (5, 6, 7, 8, and 12), 2) the shortwave infrared window (channel 12 at 3.9 μm) can be affected by reflected sunlight, and 3) no VAS water vapor channel has a distinct peak response in the lower troposphere. These last two observational limitations led Lee et al. (1983) to include conventional surface temperature and dewpoint data as predictors in the regression technique. This surface information proved critical in improving the accuracy and spatial coherence of the VAS soundings in the lower troposphere.

b. Data base preparation for VAS sounding study

Temperature and dewpoint temperature data from selected radiosondes across the central and eastern United States at 1200 GMT on 13 July and 0000 GMT on 14 July 1981 provide the basis for the ridge regression used in this assessment study. At each site, temperature and dewpoint values were extracted at the 15 pressure levels from 100 to 1000 mb indicated on Fig. 9. At sites with no 920 or 1000 mb report, surface temperature and dewpoint temperature values were inserted at the missing level(s). The necessary VAS radiances were acquired at NASA's Goddard Space Flight Center at 1200, 1500, 1800, 2100, and 2300 GMT. Each radiance dataset was obtained using the VAS dwell sounding mode (Chesters et al., 1982). This process required approximately 50 minutes to survey North America between 20° and 50° N latitude. The radiances were then averaged by combining sets of five adjacent, partially overlapping samples on each scan line to generate a high resolution sounding-field-of-view of approximately 20 km square (nadir view) for each of the 12 VAS channels.

Nearly contemporaneous surface station observations of temperature, dewpoint temperature, altimeter setting, sea-level pressure, and cloud cover were acquired for 1200, 1500, 1800, 2100, and 0000 GMT.

The visible imagery indicates that the Midwest was generally clear for this case, especially at 1200 and 1500 GMT (Figs. 8a and 8b). The clear conditions early in the day satisfy an important requisite of a pre-convective VAS sounding study, that clear column radiances be available both for training the regression matrix and for selecting sounding points (Lee et al., 1983). Nevertheless, the visible imagery also reveals that numerous small cumulus clouds appeared over the south-central United States and across central Iowa along and just to the north of the surface front at 1800 and 2100 GMT (Figs. 8c and 8d). The partly cloudy conditions after 1500 GMT require a "person-in-the-loop" technique (Smith et al., 1978), that uses visible imagery to detect clouds which are significantly smaller than the 15 km resolution of the VAS infrared channels and thus helps to eliminate cloud contaminated retrievals.

To avoid the inclusion of cloud contaminated radiances at the radiosonde sites used to determine the regression matrix coefficients, their locations were plotted on images of the VAS window channels (11 and 3.9 μm). Where radiosonde sites were located at the edges of clouds or in partly cloudy areas, cloud-free radiances from within 50 km of the radiosonde site were used. Surface data were then included using the observation nearest the radiosonde site. In this manner, 26 dawn (1200 GMT) sites and 25 dusk (0000 GMT) sites (where sets of matched VAS 12 channel radiances, radiosonde observations at 15 levels, and surface temperature and dewpoint are distributed uniformly about the Midwest) were

selected to generate the regression matrix⁶. The regression matrices were used to retrieve directly the temperature and dewpoint information at 15 pressure levels, and various diagnostic parameters (retrieved directly), including: θ_e and mixing ratio at the six levels from 500 to 1000 mb, three stability indices (Showalter, lifted and total totals), two-layer thicknesses (500 to 920 mb and 700 to 920 mb), and accumulated precipitable water between 100 and 1000 mb. The careful cloud screening also increased the number of mesoscale retrieval sites to between 132 at 1200 GMT to 160 at 1800 GMT from the 90 retrievals per time period available in the Lee et al. (1983) study.

⁶For this case, statistical experiments were done to establish the optimum predictor/predictand configuration. The selective exclusion of either noisy channels (14 to 15 μm) or skin-sensitive window channels (11 and 3.9 μm) degrades the retrieved parameters, except at the lowest levels where the surface predictors always dominate the retrievals. The removal of the shortwave window channel (3.9 μm) causes only a marginal overall bias (warming) in the retrieved temperature fields. Lee et al. (1983) also evaluated the regression coefficients themselves for this case, and found them to be consistent with radiation transfer and atmospheric physics. Because no harmful effects could be attributed to any of the available predictors, all 12 VAS channels and the two surface parameters were incorporated into the regression retrieval scheme.

4. VAS Retrieval Analysis of the Pre-Convective Environment

In this section, VAS soundings derived at 1200, 1500, 1800, 2100 and 2300 GMT 13 July 1981 are used to analyze the pre-storm environment, especially in the vicinity of the rapidly growing thunderstorms over Iowa. The temperature, dewpoint and θ_e fields retrieved at specific pressure levels are presented first, followed by a discussion on the use of retrieved layer parameters (precipitable water and lifted index) for delineating the convective potential. The individual VAS retrievals are plotted with the analyses in order to indicate the spatial distribution and point-to-point variations among the retrievals and the accuracy of the analysis algorithm. Comparisons of the 2300 GMT 13 July 1981 VAS soundings with the 0000 GMT 14 July 1981 radiosonde analyses⁷ are shown to help evaluate the validity of mesoscale information added by VAS retrievals between the radiosonde sites.

a. VAS retrievals of 850 mb temperature

The time-series of retrieved 850 mb temperature fields from 1200 to 2300 GMT in Fig. 11 displays several important mesoscale features, including 1) the development of a warm tongue over Missouri ahead of the diffuse frontal zone located in Iowa, 2) the persistence of relatively cooler air pockets over Arkansas and northern Iowa, and 3) the rapid heating over western Kansas and Nebraska. The strong heating over the

⁷ A Barnes objective analysis (Koch et al., 1983) is used on the irregularly-spaced satellite data to generate a grid at half degree latitude/longitude intervals. Due to the great data spacing, the radiosonde analyses used to compare with the satellite fields are obtained on a 1.5 degree grid.

ORIGINAL PAGE IS
OF POOR QUALITY

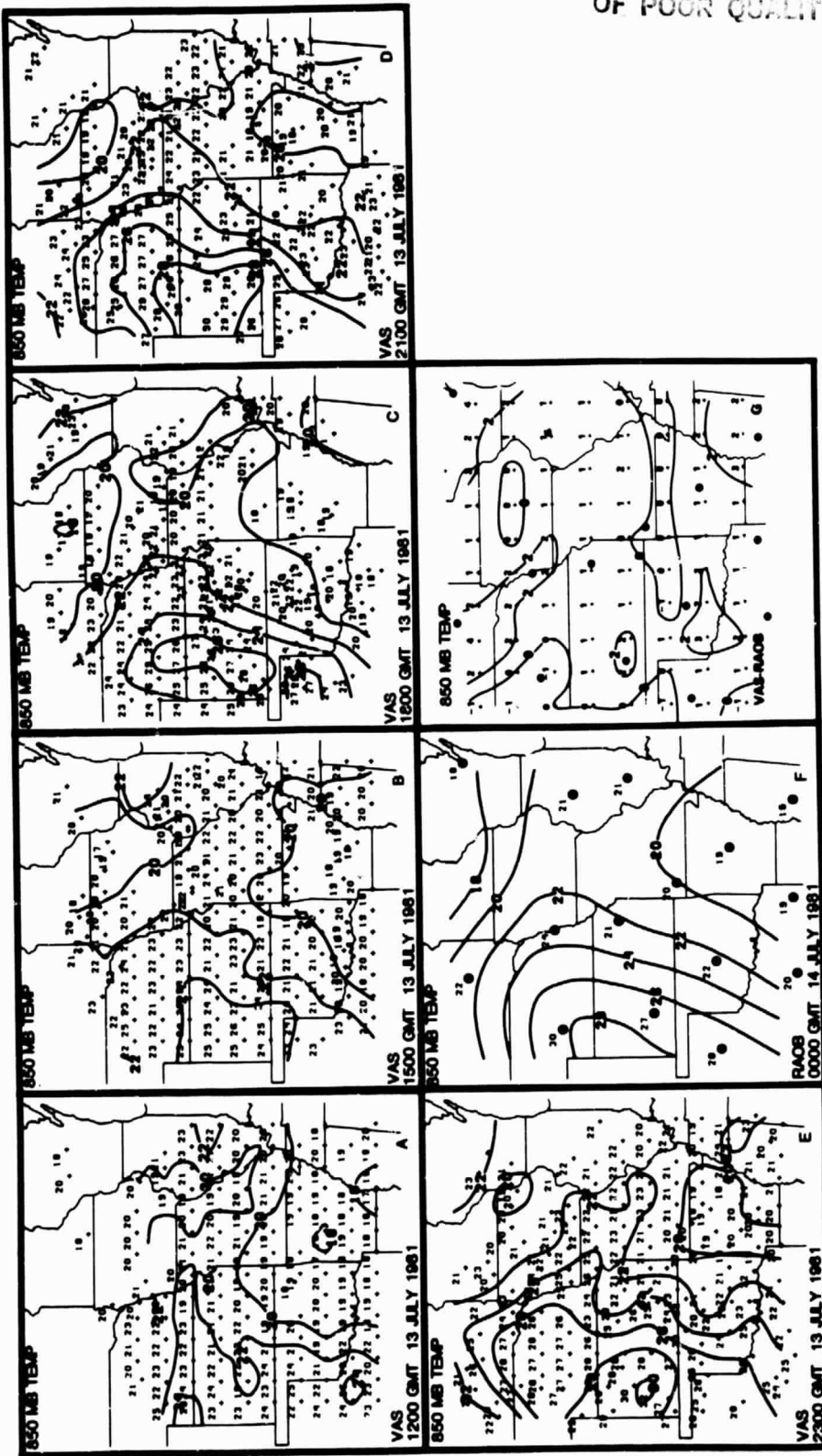


Figure 11. Time series of retrieved VAS 850 mb temperature fields ($^{\circ}\text{C}$) at (a) 1200 GMT, (b) 1500 GMT, (c) 1800 GMT, (d) 2100 GMT, (e) 2300 GMT 13 July 1981, (f) the radiosonde (RAOB) analysis for 0000 GMT 14 July 1981, and (g) the VAS (2300 GMT) minus radiosonde (0000 GMT) difference field. Increased clustering of the VAS retrieval sites occurs at 1800 GMT due to the scattered cirrus over the area. The fields are contoured at 2°C intervals. Warmer VAS retrievals over South Dakota and eastern Nebraska which result in the large positive numbers in (g). A θ symbol indicates the location of the RAOB sites on the difference charts.

plains results from strong insolation at the surface and subsequent thermal mixing through the boundary layer [the retrieved temperatures at 850 mb are consistent with an adiabatic lapse rate which drops approximately 10°C from the surface (near 940 mb) to 850 mb]. An analysis of the VAS 11 and $3.9\text{ }\mu\text{m}$ window channel predictors reveals that the large diurnal variation in the skin temperature observed by these channels had little effect on the low-level temperature retrievals.

The VAS analysis at 2300 GMT (Fig. 11e) generally agrees with the corresponding radiosonde analysis (Fig. 11f). However, several areas where the VAS analysis was significantly warmer than the radiosonde analysis are apparent in the difference field (Fig. 11g). The 2°C discrepancies near Dodge City, Kansas are the result of two anomalously warm retrievals (greater than 30°C). The consistently warm VAS retrievals over central and western Wisconsin between 1800 and 2300 GMT (Figs. 11c, 11d, and 11e; there is only one VAS retrieval in southwestern Wisconsin at 2300 GMT due to an increasing cloud cover) conflict with the radiosonde analysis (Fig. 11f) which is heavily influenced by the single report at Green Bay which appears to be anomalously cold. The result is a large positive difference over that area (2 to 4°C between the VAS and radiosonde analyses in Fig. 11g). As noted in Section 2b, surface streamline analyses and temperature reports suggest that Green Bay was locally influenced by flow off Lake Michigan after 2000 GMT (Fig. 6 and Fig. 4d). The VAS soundings are otherwise consistent with the surface reports in central Wisconsin (Figs. 4c, 4d, and 4e). This example points to an aliasing problem when using coarse resolution radiosonde data to adequately resolve the low-level temperature structure near the Great Lakes for this case.

Despite these discrepancies, the high-resolution satellite and the low-resolution radiosonde data show generally good agreement at the radiosonde sites, as expected using dependent regression retrieval coefficients. Differences which occur in the analyses between the radiosonde sites show that the more spatially continuous VAS soundings are inserting information into data-void areas in a coherent and physically consistent manner in both space and time. For example, the relatively warmer 850 mb temperature field retrieved over eastern Nebraska, southern South Dakota, southern Oklahoma, and Missouri (Fig. 11g) occurs in an area where the collected VAS/radiosonde data are almost identical. These warm temperatures combined with the relatively cooler air over north-central Iowa yield a systematic increase in the satellite-derived temperature gradient in an area where surface frontogenesis was occurring (Fig. 7).

b. VAS retrievals of 850 mb dewpoint temperature

The 850 mb dewpoint temperature fields derived from VAS (Fig. 12) also reveal distinct mesoscale structures, such as: 1) the appearance of a moisture maximum with dewpoints exceeding 16°C over southern Iowa and western Illinois between 1800 GMT and 2300 GMT (this feature may have been present earlier, but was screened by cloud cover in the area); 2) a dry tongue across Missouri which reaches into southern Illinois by 2300 GMT; and 3) the progression of very dry air (dewpoints less than 11°C) across the western edge of the domain into central Nebraska by 2300 GMT, which acts to increase the moisture gradient in the eastern part of the state. The moisture maximum in Iowa and north-central Illinois is an important factor in the development of the storms in eastern Iowa (as will

ORIGINAL WORK
OF POOR QUALITY

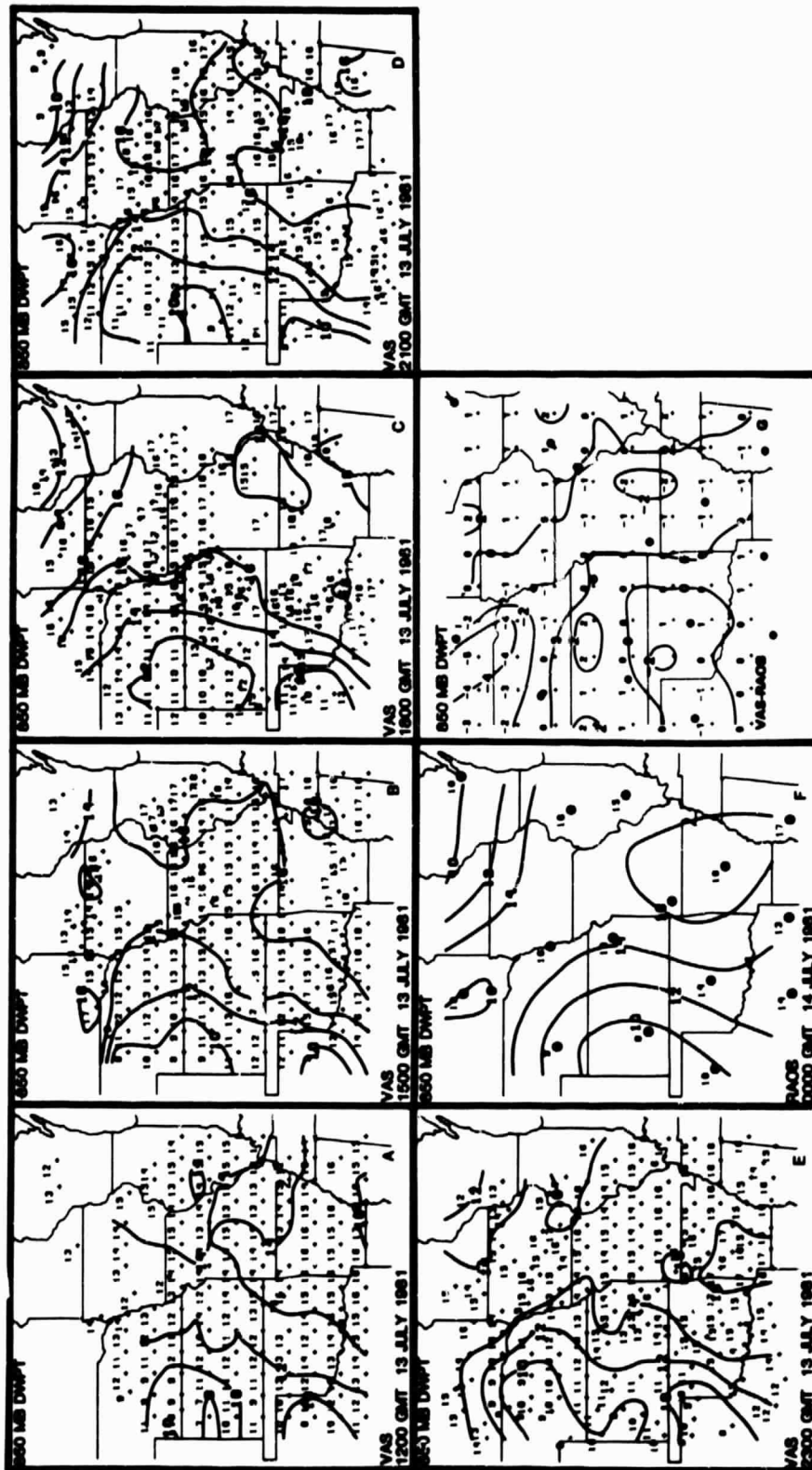


Figure 12. Same format as Fig. 11 for retrieved VAS 850 mb dewpoint temperature fields. The wetter RAOB analysis over South Dakota and southern Missouri results in large negative numbers in (g).

be discussed later) while the dry slots appear to be important in inhibiting convection in Nebraska, Missouri and southern Illinois.

A comparison between the large-scale VAS (2300 GMT 13 July) and radiosonde (0000 GMT 14 July 1981) 850 mb dewpoint fields (Figs. 12e and 12f) indicates a generally good agreement. The radiosonde and VAS data both resolve the moisture maximum extending from Arkansas toward South Dakota and the dry air in western Kansas and Nebraska. However, due to the lack of radiosonde data in northern Missouri and Iowa, the precise extent of the moist and dry areas cannot be determined. Differences between the VAS and radiosonde analyses (Fig. 12g) depict areas in which VAS retrievals appear to insert mesoscale detail into the 850 mb dewpoint analyses, by adding coherent structure between the radiosonde sites. For example, the retrievals detect larger 850 mb dewpoint temperatures both over northern Kansas and, more importantly, in an area from northern Illinois across eastern Iowa to southeastern Minnesota. No radiosonde sites are located in this region so that the moisture which supported the isolated convective storms over Iowa could not have been properly resolved using conventional sounding data alone. On the other hand, VAS retrievals indicate lower dewpoints (negative differences) from southeast South Dakota to southern Missouri. These relatively dry retrievals are consistent with the development of low-level dryness in eastern Nebraska, as observed in the split-window imagery (Fig. 9) and surface reports (Fig. 4). The continual decrease of the 850 mb dewpoints in Nebraska may be responsible for the weakening of the Colorado thunderstorms as they moved into that region after 0000 GMT 14 July (Figs. 2d and 2e). Since the moisture gradient in the VAS analysis (Fig. 12e) is concentrated in eastern Nebraska (in

contrast to the broad moisture gradient which is spread across Nebraska into South Dakota), large differences occur between the VAS and radiosonde dewpoint analyses (such as that observed in South Dakota with dewpoint differences exceeding 4°C in Fig. 12g). The effects of local cloud cover on the Huron radiosonde report probably produced the nearly saturated dewpoint reading which was then extrapolated through that portion of the analysis domain. As such, VAS data may be more representative of the larger cloud-free area across southeastern South Dakota (Fig. 8e) than the isolated radiosonde report.⁸

The moisture maximum in the VAS retrievals over Iowa and the minimum across Nebraska are quantitative confirmation of the moist regimes detected in the split-window imagery (Fig. 9) and generally agree with the surface dewpoint reports (Fig. 4) which are input data to the retrieval process. However, the VAS retrievals do more than merely mimic the surface analyses. For instance, in northern Missouri and southern Illinois (where no convection developed), the surface dewpoints remain nearly constant (23 to 24°C ; Figs. 4c through 4e), while VAS soundings resolve a gradual drying process (from 17 to 14°C in Figs. 12c through 12e) across Missouri and southern Illinois in agreement with the split window imagery. These retrievals show that VAS soundings can differentiate between those areas in which the moisture distribution in the lower troposphere is deep (and more capable of supporting convective development) from those areas in which the

⁸Since no training is done in a cloudy saturated environment, the regression coefficients are biased towards drier air. Thus, VAS soundings will not reproduce the wet observations measured by a radiosonde passing through a cloud. Once again, detailed comparisons between coarse resolution radiosondes and finer resolution VAS data sets are made difficult by the aliasing produced by non-representative radiosonde data over a large area.

moisture is confined to a shallow layer (and less capable of supporting convection).

c. VAS retrieval of equivalent potential temperature

The previous discussion on the 850 mb temperature and dewpoint retrievals illustrates the additional spatial and temporal resolution offered by VAS soundings over the operational radiosonde network. The retrievals add quantitative mesoscale detail to the moisture and temperature fields which are consistent with previous qualitative VAS imagery studies. Horizontal analyses and vertical cross sections of θ_e retrievals are now presented to evaluate the quantitative capability of VAS retrievals for resolving the convective instability in this case.

The 850 mb θ_e data (Fig. 13) provide ample evidence for convective development across Iowa, where an isolated θ_e maximum is already apparent by 1800 GMT (Fig. 13b). Although the VAS 850 mb θ_e retrievals are influenced by the surface θ_e values, the VAS radiances provide important additional information, which narrows and shifts the retrieved θ_e maximum. For example, while the surface θ_e analysis has a broader maximum extending toward the southern half of Illinois at 2200 GMT (Fig. 5c), the VAS 2100 GMT soundings (Fig. 13c) confine the area of large θ_e values to eastern Iowa and northern Illinois. This localization is consistent with drying in the lower troposphere over Missouri and southern Illinois, as observed in the 850 mb VAS dewpoint (Figs. 12c and 12d), in the split window images (Figs. 9c and 9d) and by the Salem, Illinois radiosonde (Chesters et al., 1983).

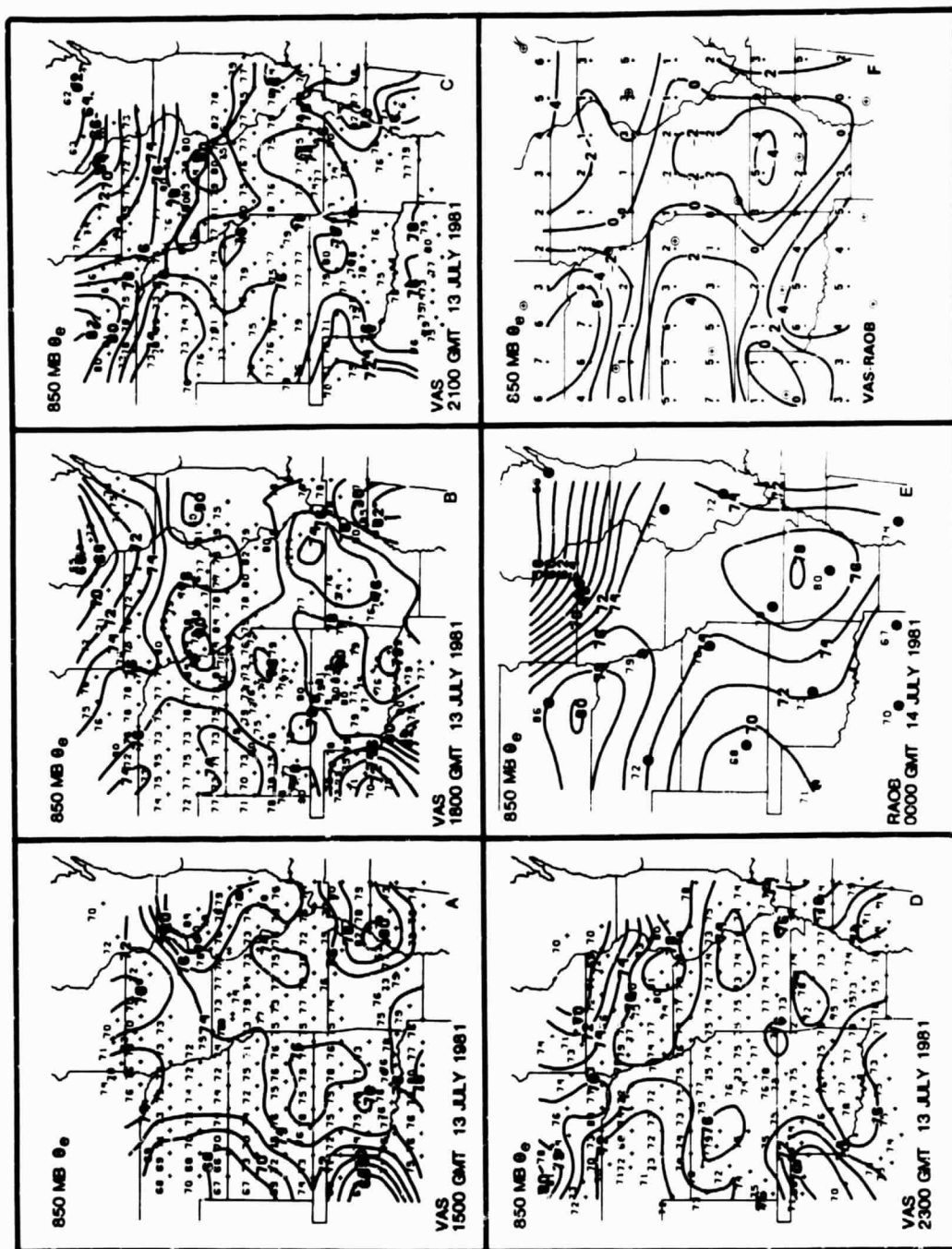


Figure 13. Time-series of retrieved VAS 850 mb θ_e fields (degrees C-Celsius is used instead of Kelvin to avoid cluttering the fields with three digit numbers). The 1200 GMT field is not shown, so that (a) 1800 GMT, (b) 2100 GMT, (c) 2300 GMT 13 July 1981, (d) the RAOB analysis at 0000 GMT 14 July 1981, and (e) the VAS minus RAOB difference field. Large RAOB θ_e values occur over northern Nebraska and Arkansas which result in the large negative values (less than -4°C) in (f).

The VAS-RAOB difference field for 850 mb θ_e (Fig. 13f) shows that the VAS θ_e retrievals (Fig. 13d) underestimate the radiosonde θ_e maxima over Arkansas, South Dakota, and eastern Nebraska (Fig. 13e). The large negative differences in South Dakota and Nebraska (over 4°C) are again probably the result of the cloud contaminated radiosonde report at Huron, South Dakota. The radiosonde analysis extrapolates these high moisture readings into data void areas across northeastern Nebraska. In other areas, the higher density VAS retrievals appear to provide additional information. The lower θ_e values in the VAS analysis in southern Missouri and northern Arkansas reflect the cooler airmass isolated in that region by the VAS soundings (Figs. 11d and 11e). The VAS analysis displays larger θ_e values across southern Oklahoma, central Kansas, eastern Iowa, and the northern half of Illinois, where the split window image reveals relative maxima of water vapor in the lower troposphere. The VAS maximum over Kansas is the result of high θ_e retrievals (greater than 70°C) over much of the state, which are consistent with the slightly higher surface θ_e values at this time (Fig. 5d). Again, the drying across the state of Nebraska yields increasing θ_e gradients in northeastern Nebraska and southeastern South Dakota (Figs. 13c and 13d) which are noticeably weakened and misplaced in the radiosonde analysis (Fig. 13e).

The afternoon series of 500 mb θ_e retrievals (Fig. 14) displays a complex mesoscale pattern with a variation of about 10°C across the field. The θ_e pattern contrasts with the retrieved 500 mb temperature field (not shown), which is nearly homogeneous (with only a three degree variation across the domain) and with the retrieved 500 mb dewpoint field (not shown), which is very chaotic and shows little consistency in space and

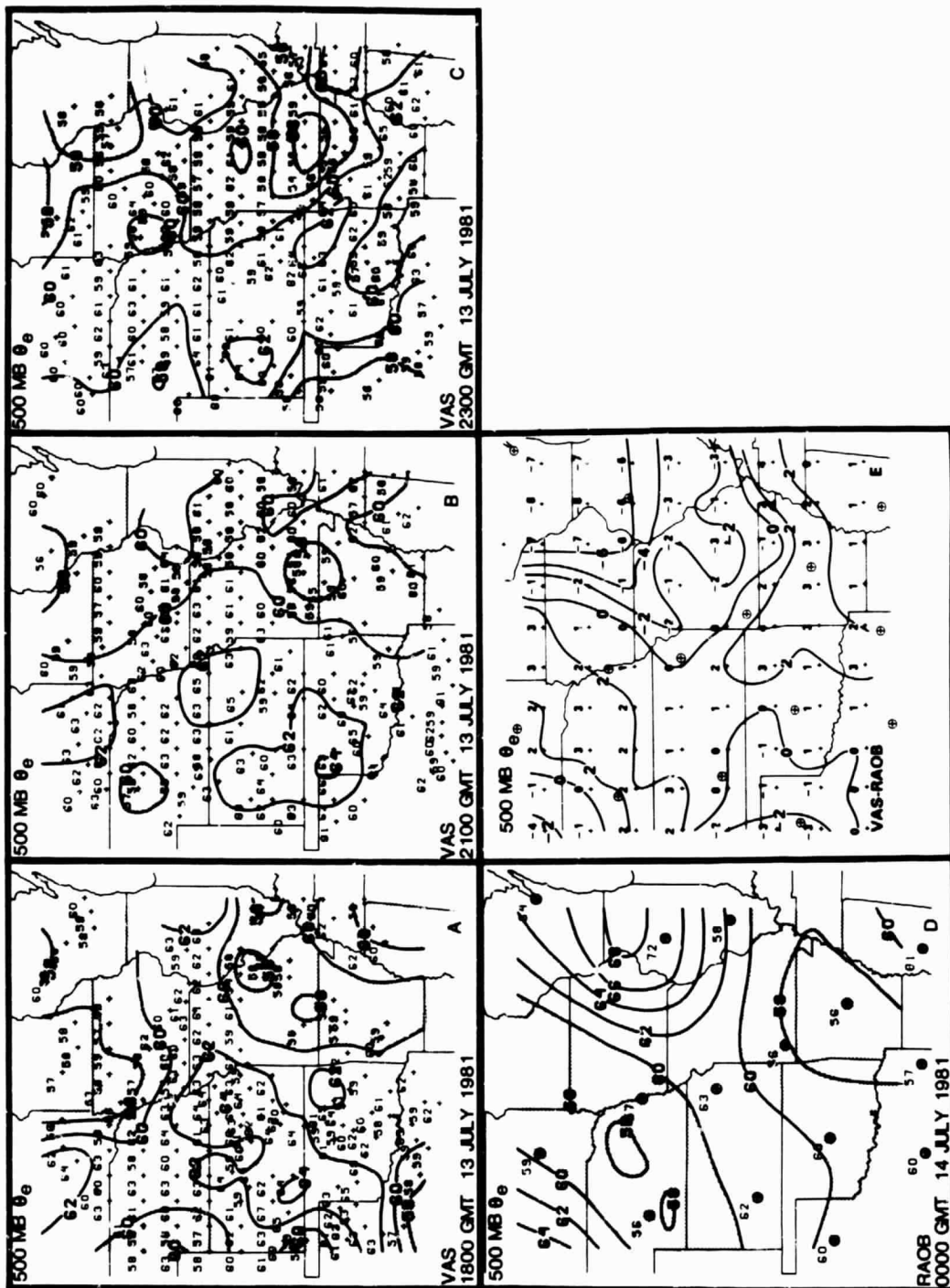


Figure 14. Time series of retrieved VAS 500 mb θ_e fields ($^{\circ}\text{C}$) similar to Fig. 13. Shading indicates θ_e values less than 59°C . The extremely high radiosonde θ_e value of 72°C at Peoria, Ill. is the result of cloud contamination and results in the large negative differences between radiosonde and VAS analyses (e) over eastern Iowa and Illinois.

time. Higher θ_e values (61° to 64°C) are retrieved over northern Illinois at 2100 and 2300 GMT (Figs. 14b and 14c), but these values are less than the Peoria radiosonde report at 0000 GMT (Fig. 14d) (which is affected by a narrow layer of clouds between 578 and 470 mb). Except for the large differences over Wisconsin and northern Illinois, the VAS and radiosonde θ_e values seldom differ by more than 2°C (Fig. 14e). More important, the structure apparent in the banded VAS minimum θ_e (shaded areas less than 60°C across parts of Iowa, Illinois, southern Missouri and Arkansas; Fig. 14) generally correspond with the dry regions observed with the $6.7\ \mu\text{m}$ channel (Fig. 9). For example, the minimum in θ_e in western Iowa at 1800 GMT (Fig. 14a) shifts to the east in conjunction with the dry slot in the $6.7\ \mu\text{m}$ imagery (Fig. 9c). By 2300 GMT, the 500 mb θ_e minimum (Fig. 14c) moves over the 850 mb θ_e maximum (Fig. 13d) in south-central Iowa. This progression indicates that the space-time resolution provided by VAS is capable of detecting differential moisture advection processes which destabilized this region during the 3 hour period preceding convection.

Statistical analyses of the 850 and 500 mb θ_e (Table 2) were performed to demonstrate the relative spatial and temporal continuity of these retrieved fields. The mean values and standard deviations are consistent for both 850 and 500 mb θ_e for the three observation periods between 1800 and 2300 GMT. An RMS length scale, which is designed to measure the average gradients and/or distance between extrema within the field (Lee et al., 1983), varies between 95 and 107 km for 850 mb θ_e and between 76 and 92 km for 500 mb θ_e . The length scales provide a quantitative measure of the mesoscale structure of the θ_e fields at 850 and 500 mb. The smaller

Table 2. Statistics demonstrating the relative spatial and temporal continuity of the retrieved 850 and 500 mb θ_e and lifted index (LI) fields.

Time (GMT)	Field	Spatial Smoothness				Temporal Continuity		
		Average (°C)	St. Dev. (°C)	St. Dev. Gradient (\pm °C km ⁻¹)	RMS Scale Length (km)	Field	Covar (°C ²)	Corr (%)
1800	850 mb θ_e	71.7	2.32	0.022	105.5	850 θ_e 500 θ_e	4.4	68
	500 mb θ_e	60.2	1.78	0.019	92.5		1.7	66
2100	850 mb θ_e	71.7	2.78	0.026	107.3	850 θ_e 500 θ_e	4.7	81
	500 mb θ_e	60.6	1.44	0.017	86.8		1.1	51
2300	850 mb θ_e (°C)	70.6	2.08	0.022	95.2	850 θ_e 500 θ_e	4.7	81
	500 mb θ_e (°C)	59.6	1.54	0.020	76.4		1.1	51
				(\pm LI km ⁻¹)	(km)		(LI ²)	%
1800	LI	-3.5	1.37	0.012	117.1	LI	2.1	86
2100	LI	-2.4	1.81	0.014	131.1		2.8	86
2300	LI	-1.7	1.78	0.011	156.7			

RMS scale at 500 mb indicates a greater spatial variability in the middle tropospheric θ_e VAS retrievals, apparently due to the moisture patterns revealed by the 6.7 μm VAS channel (Fig. 9). A measure of the temporal continuity of individual features in the VAS θ_e analysis is given by the covariance and correlation between successive VAS observation frames. The 850 mb θ_e fields show a high covariance (4.5°C^2) and correlation (68% to 81%) compared to the 500 mb θ_e fields (1.1°C^2 to 1.7°C^2 and 51% to 66%) indicating that the lower tropospheric fields have a greater temporal continuity for this case. These results are quantitative evidence that the 850 and 500 mb θ_e fields possess mesoscale structure which can be tracked from one observation period to another (over 3 h) and should thus be useful for delineating convectively unstable airmasses.

To illustrate the magnitude of the convective instability as derived by the VAS retrievals, a vertical cross-section of θ_e (Fig. 15) was constructed from Nebraska, across southern Iowa and into central Illinois at 2100 GMT (as shown by the line in Fig. 13c). The cross-section demonstrates that the horizontal and vertical resolution of the VAS θ_e fields are sufficient to isolate the areas of convective instability preceding the rapid storm development in eastern Iowa. Because of the broad vertical weighting functions of VAS, the magnitude of $d\theta_e/dz$ is less than generally observed with radiosonde data. Nevertheless, the large negative values for $d\theta_e/dz$ in the cross-section clearly indicate that this region was convectively unstable. For example, a θ_e maximum in the lower troposphere extends across southern Iowa into northwestern Illinois. Above this maximum, the θ_e values decrease rapidly with height to a minimum near the 600 mb level. These features agree with the moist and dry regions seen

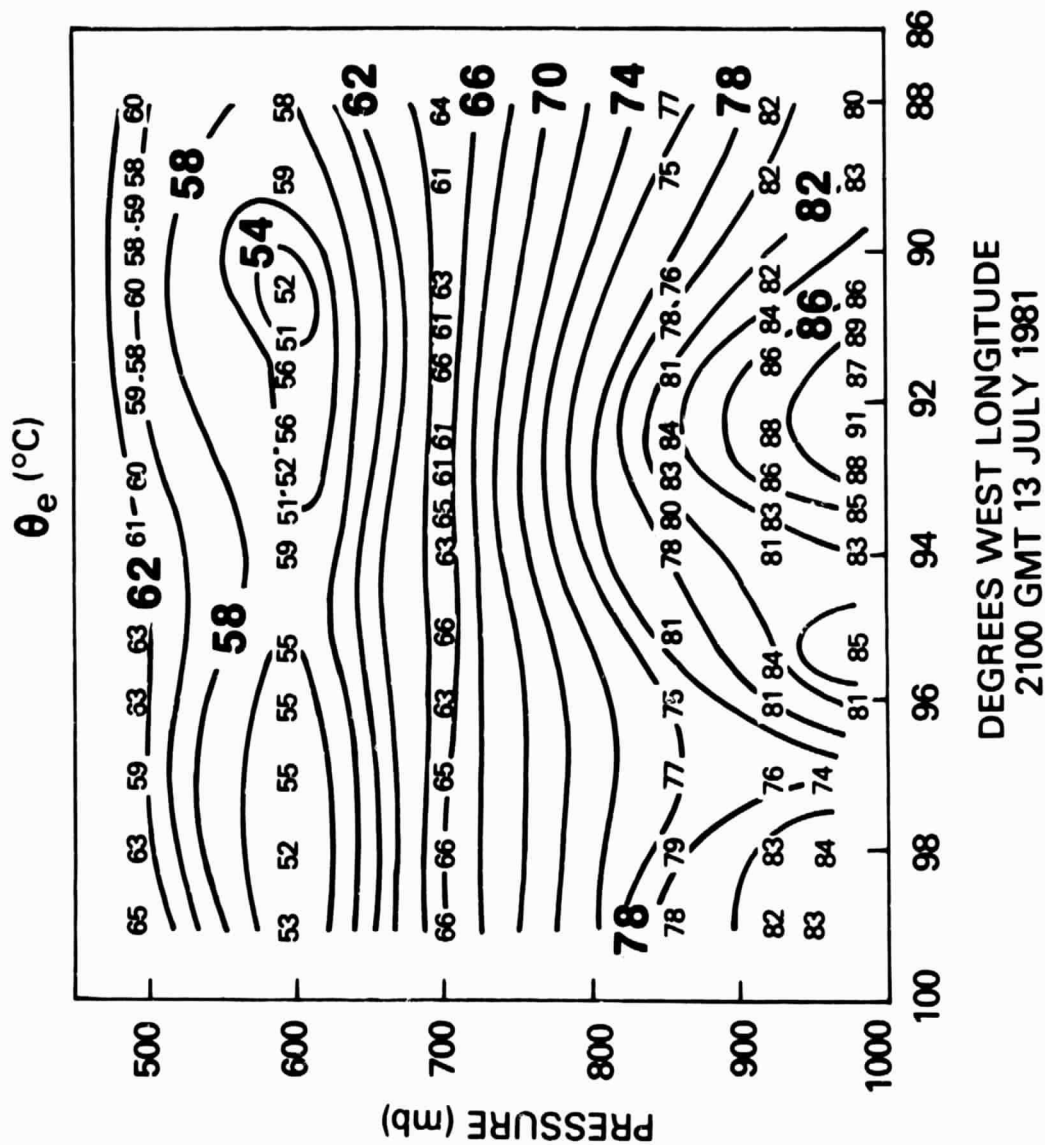


Figure 15. Vertical cross-section of θ_e between 500 and 1000 mb across southern Iowa and Illinois at 2100 GMT 13 July 1981 (see line drawn in Fig. 13c). VAS retrievals were done at 500, 600, 700, 850, 920, and 1000 mb and interpolated onto a .5 degree grid in both latitude and longitude. The rapid decrease in θ_e with height (negative $d\theta_e/dz$) between 94° and 88° longitude (eastern Iowa and western Illinois) indicates potential instability. Convective cells developed rapidly over this area during the following three hours.

in the split window (Fig. 7) and $6.7\ \mu\text{m}$ channel (Fig. 9). Thus, the vertical θ_e cross-section combined with the 850 mb and surface θ_e fields provided accurate and adequate information about the time evolution of the convective instability which preceded the rapid thunderstorm development over eastern Iowa and east-central Illinois.

d. Retrievals of layer-integrated properties

The 850 and 500 mb VAS retrievals are derived from noisy radiances. Since the VAS channels were designed with broad weighting functions, each observation actually represents the state of a relatively large layer of the atmosphere. Hence, large errors can be introduced into the level-specific retrievals. This situation is especially true for moisture retrievals above 850 mb. For example, excessively large point-to-point fluctuations are often observed in the 500 mb dewpoints (not shown), since the VAS channels can provide only a marginal indication of the sudden vertical or horizontal variations in the thin moisture layers often present above the boundary layer. Imprecise altitude assignment can result in apparently large errors when measurements are required at a specific set of spatially thin levels. The lack of independent VAS water vapor channels capable of resolving moisture structures between 500 and 1000 mb (Fig. 10) also appears to limit the mid-tropospheric dewpoint retrieval accuracy. Nevertheless, the retrieved 500 mb θ_e fields shown for this case appear more stable, both because of the homogeneous temperature pattern at 500 mb and because the $6.7\ \mu\text{m}$ channel data, which have been shown to be good indicators of relative humidity in the 300 to 600 mb layer for midlatitude summer conditions (Poc and Roulleau, 1983), contain clearly defined

moisture features. These problems are limiting factors in the "level" retrievals and point to the need to consider parameter retrievals based upon "layer" measurements.

Atmospheric parameters which represent vertically integrated quantities are particularly well retrieved by VAS given the broad weighting functions of the infrared sounding channels (Fig. 9). The Lee et al. (1983) statistical study showed that the combination of VAS and surface data provides measurements of precipitable water and thickness with mesoscale resolution and useful absolute accuracy. For this case, the retrieved fields of vertically integrated precipitable water (PW) present coherent patterns in both space and time (Figs. 16a through 16c). Two wet areas (greater than 45 mm) occur consistently over Arkansas/eastern Oklahoma and over northern Illinois/eastern Iowa separated by a narrow dry swath between. These areas correspond to the smoother pattern derived using radiosonde data alone (Fig. 16d), although the VAS gradients in Nebraska and Oklahoma are significantly larger. The VAS-derived maximum extending across Iowa is based on nearly 10 sounding points, while the radiosonde maximum in Iowa is the consequence of extrapolation into a data void region. The persistence of the large retrieved PW values over Iowa and Arkansas throughout the day may be the result of surface evaporation. By contrast, a gradual drying is observed both across central Missouri (values below 40 mm) and more noticeable across southern Illinois, where PW values decrease from as much as 45 mm at 1500 GMT to near 37 mm by 2300 GMT. This change is supported by the Salem, Illinois radiosonde report, which decreases from 43 mm at 1200 GMT to 34 mm at 0000 GMT. Most of the drying across southern Illinois appears to occur in the 3 hour

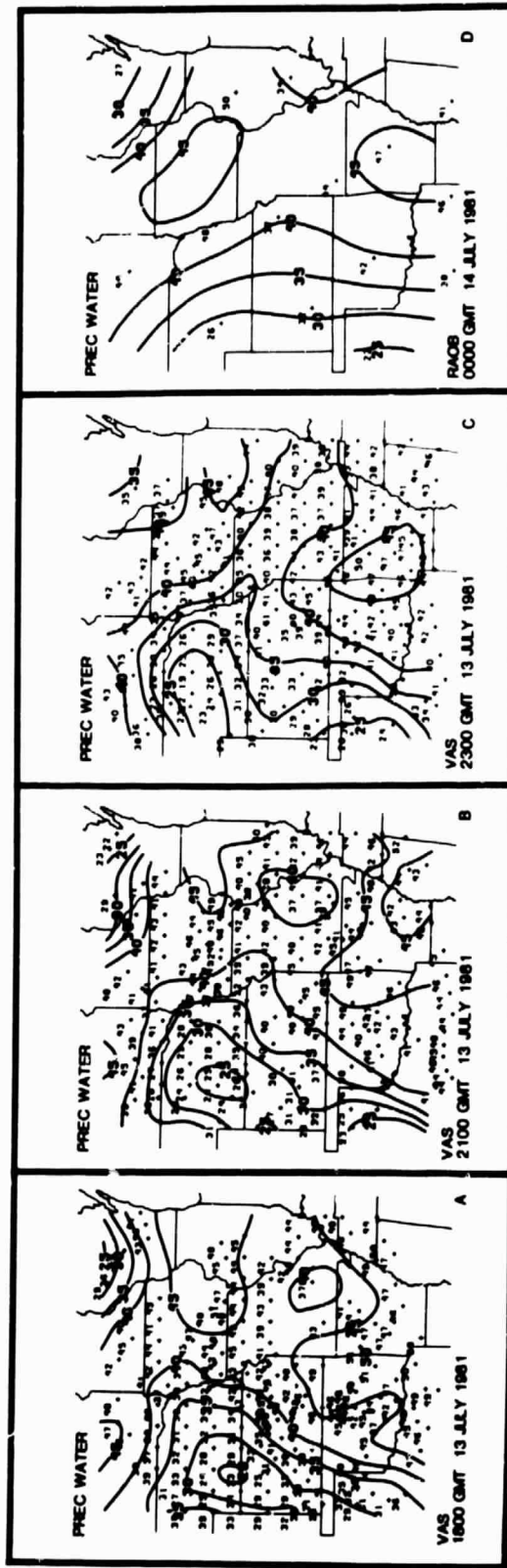


Figure 16. Time series of VAS retrieved precipitable water between 100 and 1000 mb (in mm of water) at: (a) 1800 GMT, (b) 2100 GMT, and (c) 2300 GMT 13 July 1981. Two wet areas (greater than 45 mm) occur over Arkansas/eastern Oklahoma and over northern Illinois/eastern Iowa with a dry swath between. Significant rapid drying occurs over Nebraska.

period between 1800 and 2100 GMT. The more dramatic decrease in PW over Nebraska enhances the moisture gradient across the eastern part of the state at 2100 and 2300 GMT and is consistent with the VAS 850 mb dewpoint field (Fig. 12), the surface dewpoint reports (Fig. 4), and the split window imagery (Fig. 9). These results show that timely VAS observations can quantitatively resolve changes in the horizontal distribution in the bulk moisture fields at a short enough time scale to be useful in severe weather prediction.

The lifted index (LI), which measures the thermodynamic contrast between the 500 mb level and a well-mixed boundary layer, was also retrieved directly using the regression procedure (Fig. 17). The magnitudes of LI produced in this diagnostic study (Figs. 17a through 17c) appear reasonable, especially in contrast to the extreme values that have been encountered when retrieving LI from VAS observations in real-time using operational techniques (Anthony and Wade, 1983). Compared with the 850 and 500 mb θ_e fields, LI field statistics (Table 2) show spatial and temporal continuity. Between 1800 and 2300 GMT the LI mean varies from -3.5° to -1.7°C and the standard deviation from 1.37° to 1.81°C , while the RMS scale length ranges from 117.1 to 156.7 km. These values indicate a more gradual spatial variation across the LI fields than found in the θ_e analysis (Table 1). The 2.1° to 2.8°C^2 covariance and 86% correlation statistics for lifted index (Table 2) indicate very good temporal continuity between 1800 and 2300 GMT.

The 1800 GMT lifted index analysis (Fig. 17a) reveals an area of potential instability (values less than -5°C) extending from southern Illinois through Iowa, with another area of potential instability over

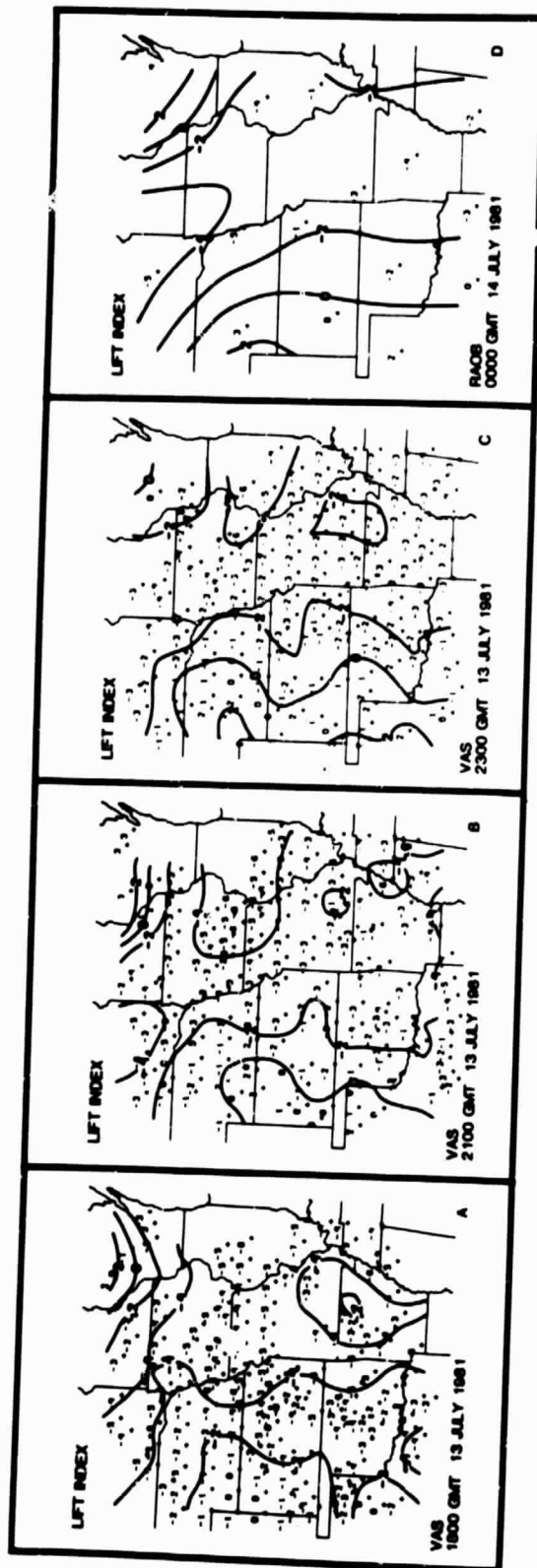


Figure 17. Time series of VAS retrieved lifted index (LI) in °C as in Fig. 16. The most unstable values occur over Iowa and northern Illinois (LI less than -4°C).

eastern Oklahoma and Kansas. These areas correspond with the regions where 850 mb moisture and θ_e values were maximized and where 500 mb temperatures were nearly uniform. By 2100 GMT (Fig. 17a), LI values across southeastern Iowa remained near -5 and -6°C , indicating continued convective instability. LI values in southern Illinois increased between 1800 and 2300 GMT as a result of the drying in the lower troposphere noted earlier. This stabilizing trend across southern Illinois resulted in a noticeable LI gradient across central Illinois and northeast Missouri (Fig. 17c). The decreased stability in Iowa and northern Illinois is confirmed by the convective development in that area after 0000 GMT (Figs. 2e and 2f), while the higher stability in southern Illinois is consistent with the lack of convection in that area. The stable LI values (greater than 0°C) across western Kansas and Nebraska also agree with the radiosonde analysis (Fig. 17d) and the radar charts (Fig. 2), which show the decay of the convection moving from Colorado into Nebraska.

5. Summary

This VAS assessment study combines conventional NWS surface station reports and VAS satellite soundings to quantitatively assess the mesoscale temperature and moisture structures presented in previous studies based solely on VAS imagery (Chesters et al., 1983; Petersen et al., 1984). Analyses of conventional surface temperature and moisture reports, as well as θ_e , streamlines, divergence, and surface frontogenesis, are shown to be useful tools in isolating areas with convective potential. However, the limited information contained in these data about the temporal evolution of the moisture distribution above the earth's surface limits the ability to resolve the important changes in the stability of the overlying atmosphere. The low- and mid-tropospheric analyses derived using a combination of VAS retrievals with 30 to 60 km resolution reveal a wealth of high-resolution quantitative information about the horizontal and vertical temperature and moisture distribution which cannot be resolved by the surface or radiosonde networks alone. The 3 h interval between sounding sets is also important in revealing significant changes in the moisture, θ_e and stability fields that preceded storm development in Iowa and Illinois in this case. The results of the case study confirm that the best analysis of the pre-storm environment occurs when the conventional and VAS data are combined to isolate mesoscale regions of convective instability and also lifting mechanisms which act to initiate the storm systems.

The temperature, dewpoint, θ_e , precipitable water and lifted index fields derived using VAS retrievals are consistent in time and space, agree well with the available radiosondes and with the VAS imagery results, and

are physically consistent with the eventual development of convection in Iowa and northern Illinois. Specifically, findings from this assessment study include: 1) VAS moisture retrievals and precipitable water estimates can differentiate those areas where water vapor extends over a deep portion of the lower troposphere and thereby are more able to support convection (i.e., southern Iowa and north-central Illinois) from those areas where the water vapor significantly decreases immediately above the earth's surface (i.e., southern Illinois and eastern Missouri). 2) VAS retrievals can provide measurements of low-level stability indicators (temperature, dewpoint, θ_e , $d\theta_e/dz$, precipitable water, and lifted index) with the mesoscale resolution, temporal consistency and useful absolute accuracy needed to resolve the evolution of convectively unstable airmasses. The VAS retrievals isolated a region where the convective stability was decreasing with time in Iowa and north-central Illinois (as inferred from negative $\partial\theta_e/\partial z$ and negative lifted index) prior to the onset of storm growth in those areas. 3) The VAS precipitable water and lifted index fields can also reveal areas where moisture decreases and stability increases (i.e., Nebraska, southern Illinois and eastern Missouri). Thunderstorms either weakened as they moved into these areas (Nebraska) or failed to develop (southern Illinois) during the observing period. 4) While VAS imagery and soundings can detect regions which are becoming less stable during the afternoon, the surface streamlines, convergence and frontogenesis computations are also important in specifying the location where convective activity is most likely to develop.

The results for this study are a promising indication that VAS is capable of filling in the data gaps in the conventional radiosonde and

surface networks and thus provides a more complete description of the temporal evolution of the three-dimensional structure of the pre-convective environment. This optimistic finding, however, should not be interpreted as an advocacy for the substitution of VAS for conventional data sources. The soundings produced in our analysis are heavily dependent on the contemporary conventional radiosonde and surface data sets. Thus, the VAS regression retrieval approach used in our analysis should be viewed as a means for interpolating between radiosondes and above the surface data both in space and time, using a statistical relationship between the VAS radiances and these convective data sets. As such, the soundings produced using the regression relationship with radiosondes at the beginning and end of the analysis period can only be used effectively in a case study mode. Thus, these soundings are not appropriate for extremely short range forecasting purposes, as is presently being done at the National Severe Storms Forecasting Center (Anthony and Leftwich, 1984) using a physical retrieval algorithm developed by Smith (1983).

The Lee et al. (1983) statistical validation and our assessment of the VAS soundings produced in this case study indicate that the retrievals contain the accuracy required for the analysis of preconvective environments. However, several problems were encountered with the VAS retrievals which could impact the successful application of VAS in other cases: 1) Small clouds can act to contaminate the 15 km sounding-field-of-view and introduce errors into the retrievals. This finding indicates that VAS data may be more accurate for those cases in which the pre-convective environment is generally clear. Cloud avoidance can be aided by using 1 km resolution visible data and cloud cover reports from the surface network in

conjunction with the 15 km resolution VAS infrared radiances; 2) The paucity of clear-air radiosonde sites in the region of interest and the lack of midday radiosonde observations are the two major limitations in applying or verifying a regression technique to mesoscale studies over the United States. The lack of midday radiosonde data can also have significant impact upon the regression matrix, which is trained at times when heating at the earth's surface is low over the central United States (1200 and 0000 GMT); 3) While a deep layer of moisture can be resolved through a vertically integrated parameter such as precipitable water, the precise vertical location of the moisture concentration within that layer may not be well determined (Petersen et al., 1984); 4) The absolute magnitude of many temperature and moisture features is not captured well on a level-by-level basis. However, the time rate of change (tendencies) of the parameters and the positioning of maxima and minima are generally correct; and 5) Variable cloud cover results in unavoidable data clustering which makes objective analyses and subsequent interpretation difficult since the continuity in the movement of important features in the analyzed fields can be interrupted.

Some of the constraints encountered in this study may be overcome through the development of: 1) objective cloud screening techniques which include the use of visible imagery; 2) expanded training sets or perhaps a library of training sets to include a larger area, more sites, and different types of environments; 3) a set of the most appropriate layer parameters which exploit the unique strengths of the VAS measurements; 4) a technique which automatically filters, averages, and retrieves at all the available clear sounding-fields-of-view, thereby producing thousands of

quality assured retrievals instead of one to two hundred for a given time frame; and 5) a physically based sounding technique which utilizes the potentially more accurate results from an inversion of the radiation transfer equation in order to avoid the labor-intensive and imprecise training of the regression matrices which depend upon radiosonde observations. Continued examination of these techniques may provide additional insight into the use of VAS for the analysis and prediction of severe local storms and other severe weather events. Regardless of these shortcomings, the results from this study indicate that the careful combination of VAS data with the conventional surface and radiosonde analysis can already help to resolve those processes which lead to the development and maintenance of convective storm systems.

Acknowledgements:

This work was funded through the VAS Demonstration Project of NASA's Operational Satellite Improvement Program and Severe Storms Research Program. The VAS Demonstration was managed by Dr. Harry Montgomery and Mr. James Greaves of NASA/GSFC. Drs. W. L. Smith and C. M. Hayden at the University of Wisconsin provided many useful discussions and suggestions concerning the development of VAS soundings and their application. Dr. W. P. Menzel with NOAA/NESDIS supplied visible data from the VAS archive database. Dennis A. Keyser and Wayne D. Robinson (General Software Corporation), Dr. T. H. Lee (Bell Laboratories), and H. Michael Goodman (Research and Data Systems, Inc.) all provided assistance with various phases of the analyses. Kelly Wilson typed the manuscript and Lafayette Long (General Software Corporation) assisted with the figure

preparations. Partial funding for the VAS Assessment was provided through the NASA Mesoscale Atmospheric Processes Research Program under the direction of Dr. James Dodge.

REFERENCES

- Anthony, R. W., and G. S. Wade, 1983: VAS operational assessment findings for spring 1982/83. Thirteenth Conf. on Severe Local Storms, Tulsa, Amer. Meteor. Soc., J23-J28.
- _____, and P. W. Leftwich, Jr., 1984: Operational VAS applications in identifying regions with potential for severe thunderstorm development. Tenth Conf. on Weather Forecasting and Analysis, Clearwater Beach, Amer. Meteor. Soc., 328-364.
- Barnes, S. L. and D. K. Lilly, 1975: Covariance analysis of severe storm environments. Ninth Conf. on Severe Local Storms, Amer. Meteor. Soc., Boston, 301-306.
- Berry, E. and H. B. Bluestein, 1982: The formation of severe thunderstorms at the intersection of a dryline and a front: The role of frontogenesis. Twelfth Conf. on Severe Local Storms, San Antonio, Amer. Meteor. Soc., 597-602.
- Browning, K. A., 1980: Review of local weather forecasting. Proc. Royal Soc., London, A371, 197-211.
- Chesters, D., L. W. Uccellini, and A. Mostek, 1982: VISSR Atmospheric Sounder (VAS) simulation experiment for a severe storm environment. Mon. Wea. Rev., 110, 198-216.
- _____, L. W. Uccellini, and W. Robinson, 1983: Low-level water vapor fields from the VISSR Atmospheric Sounder (VAS) "split-window" channels. J. Climate Appl. Meteor., 22, 725-743.

- Fritz, S., D. Q. Wark, H. E. Flemming, W. L. Smith, H. Jacobowitz,
D. T. Hilleary, and J. C. Alishouse, 1972: Temperature sounding from
satellites. NOAA TR NESS-59, 53 pp., [NTIS-72n 30352].
- Koch, S., 1984: The role of an apparent mesoscale frontogenetic
circulation in squall line initiation. Mon. Wea. Rev. (October
issue).
- _____, M. desJardins, and P. J. Kocin, 1983: An interactive Barnes
objective map analysis scheme for use with satellite and conventional
data. J. Clim. Appl. Meteor., 22, 1487-1503.
- Kocin, P. J., L. W. Uccellini, and R. A. Petersen, 1982: The role of jet
streak "coupling" in the development of the 10-11 April 1979 Wichita
Falls tornado outbreak. Twelfth Conf. on Severe Local Storms, San
Antonio, Amer. Meteor. Soc., 560-563.
- Lee, T.-H., D. Chesters, and A. Mostek, 1983: The impact of conventional
surface data upon VAS regression retrievals in the lower troposphere.
J. Clim. Appl. Meteor., 22, 1853-1874.
- Maddox, R. A. and C. A. Doswell III, 1982: An examination of jet stream
configurations, 500 mb vorticity advection and low-level thermal
advection pattern during periods of intense convection. Mon. Wea.
Rev., 110, 184-197.
- Marquardt, D. W. and R. D. Snee, 1975: Ridge regression in practice.
Amer. Stat., 29, 3-20.
- Moore, J. T., 1982: The forcing and evolution of the three dimensional
moisture convergence during the 10-11 April 1979 severe weather
outbreak. Twelfth Conf. on Severe Local Storms, San Antonio, Amer.
Meteor. Soc., 209-212.

- Palmer, E. and C. W. Newton, 1969: Atmospheric Circulation Systems. Academic Press, New York, 603 pages.
- Petersen, R. A., L. W. Uccellini, A. Mostek, and D. A. Keyser, 1984: The use of VAS moisture channels in delineating regions with potential for convective instability. Accepted for publication in Mon. Wea. Rev.
- Poc, M. M., and M. Roulleau, 1983: Water vapor fields deduced from METEOSAT-1 water vapor channel data. J. Clim. Appl. Meteor., 22, 1628-1636.
- Smith, W. L., H. M. Woolf, and W. J. Jacob, 1970: A regression method for obtaining real-time temperature and geopotential height profiles from satellite spectrometer measurements and its application to NIMBUS 3 "SIRS" observation. Mon. Wea. Rev., 98, 582-603.
- _____, C. M. Hayden, H. M. Woolf, H. B. Hornwell, and F. W. Nagel, 1978: Interactive processing of TIROS-N sounding data. Conf. on Weather Forecasting, Analysis, and Aviation Meteor., Silver Spring, Amer. Meteor. Soc., 390-395.
- _____, V. E. Suomi, W. P. Menzel, H. M. Woolf, L. A. Sromovsky, H. E. Revercomb, C. M. Hayden, D. N. Dickson, and E. R. Mosher, 1981: First sounding results from VAS-D. Bull. Amer. Meteor. Soc., 62, 232-236.
- _____, 1983: The retrieval of atmospheric profiles from VAS geostationary radiance observations. J. Atmos. Sci., 40, 2025-2035.
- Suomi, V. E., T. Vonder Haar, R. Kans, and A. Stamm, 1971: Possibilities for sounding the atmosphere from a geosynchronous spacecraft. Space Res., 11, 609-617.

Wilson, G. S., 1982: The structure and dynamics of mesoscale systems influencing severe thunderstorm development during AVE/SESAME 1. Twelfth Conf. on Severe Local Storms, San Antonio, Amer. Meteor. Soc., 192-196.

BIBLIOGRAPHIC DATA SHEET

1. Report No. TM 86205	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Assessment of VAS Soundings in the Analysis of a Pre-Convective Environment		5. Report Date March 1985	
		6. Performing Organization Code 610	
7. Author(s) Anthony Mostek, Louis W. Uccellini, Ralph A. Petersen, and Dennis Chesters		8. Performing Organization Report No. 85B0292	
9. Performing Organization Name and Address		10. Work Unit No.	
		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address Laboratory for Atmospheres NASA Goddard Space Flight Center Greenbelt, MD 20771		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract Retrievals from the <u>VISSR Atmospheric Sounder (VAS)</u> are combined with conventional data to assess the impact of geosynchronous satellite soundings upon the analysis of a pre-convective environment over the central United States on 13 July 1981. VAS retrievals of temperature, dewpoint, equivalent potential temperature, precipitable water, and lifted index are derived with 60 km resolution at 3 hour intervals. When VAS fields are combined with analyses from conventional data sources, mesoscale regions with convective instability are more clearly delineated prior to the rapid development of the thunderstorms. The retrievals differentiate isolated areas in which moist air extends throughout the lower troposphere (and are therefore more conducive for the development of deep convective storms) from those regions where moisture is confined to a thin layer near the earth's surface (where convection is less likely to occur). The analyses of the VAS retrievals identify significant spatial gradients and temporal changes in the thermal and moisture fields, especially in the regions between radiosonde observations. Even with nearly optimal conditions for passive remote sounding (generally clear skies, minimal orographic effects, and a rapidly changing moisture field), the VAS retrievals were still degraded in some regions by small clouds which are unresolved in the infrared imagery.			
17. Key Words (Selected by Author(s)) VAS, satellite soundings mesoscal retrievals, pre-convective environment		18. Distribution Statement Unclassified Category 15	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 60	22. Price*