Improved VAS Regression Soundings of Mesoscale Temperature Structure Observed During the 1982 Atmospheric Variability Experiment

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1. Introduction

The VISSR Atmospheric Sounder (VAS) is an upgrade to the Visible-Infrared Spin-Scan Radiometer (VISSR) on the Geosynchronous Operational Environmental Satellites (GOES) launched since 1980. VAS has twelve infrared channels designed to provide frequent, high-resolution information about temperature and moisture fields over the United States. For example, VAS multispectral data have provided time-lapse images of overlapping moisture structures in the middle and lower troposphere (Chesters *et al.*, 1983; Petersen *et al.*, 1984), and VAS soundings have been useful in objective mesoscale analyses of preconvective environments (Mostek *et al.*, 1986; Petersen and Keyser, 1987). While VAS soundings add important mesoscale information for diagnostic analyses of severe storm environments, Mostek *et al.* (1986) found that the lack of midday radiosondes over the United States was an important limitation to a VAS sounding algorithm based on regression techniques. Furthermore, these VAS case studies suffer from a lack of conventional "ground truth" data which independently resolves upper air conditions.

Because the operational radiosonde network is too sparse and infrequent to properly resolve the mesoscale structure apparently observed by VAS, an Atmospheric Variability Experiment (AVE) was performed in 1982 in a joint effort by NASA, NOAA and Texas A&M University to verify VAS mesoscale sounding capabilities (Dodge *et al.*, 1985). AVE radiosondes were launched at 3 hour intervals from a regional network of National Weather Service (NWS) stations in the central United States while VAS simultaneously gathered radiometric data. At the same time, a mesoscale network consisting of 13 special AVE radiosonde sites was operated in north-central Texas, also launching balloons at 3 hour intervals. The AVE regional observations at non-synoptic intervals establish a larger setting for understanding the events observed at high-resolution by the AVE mesoscale network over north-central Texas.

On 6 March 1982, a late winter storm passed over the AVE regional and mesoscale networks. The strong temperature gradients in the cloud-free post-frontal environment provide optimal conditions for verifying VAS temperature soundings using the AVE "ground truth" observations.

Three different satellite retrieval algorithms were originally applied to the same VAS radiances from the 6 March 1982 case: two physical models developed by Smith *et al.* (1983) and a statistical model developed by Lee *et al.* (1983). The VAS soundings were evaluated with respect to the AVE profiles for accuracy by Jedlovec (1985) and for structure by Fuelberg and Meyer (1986). They found that VAS temperature soundings from all three algorithms were remarkably similar. Deviations with respect to the AVE mesoscale verification data averaged ±2°C, and VAS horizontal gradients and changes compared fairly well to the AVE data at many pressure levels.

However, the VAS soundings on 6 March 1982 failed to resolve temperature profile deviations from the average lapse rate. In particular, the VAS soundings scarcely detected a mid-level cold pool over north-central Texas. Although the vertical resolution of the VAS channels is limited by their broad weighting functions, such a cold pool should decrease the brightness of several infrared channels by several times their noise levels and hence should have been better resolved by the satellite soundings. There was a similar deficiency in the VAS soundings for the lowest layer of the troposphere, where a temperature inversion was not resolved.

It is important to establish how well VAS can resolve profile anomalies such as occurred on 6 March 1982 because temperature structures indicate local processes that are often unresolved by the operational synoptic network. VAS soundings must provide moderate vertical resolution of thermal structures to be useful for mesoscale analysis or numerical forecast models. This study aims to show that the poor vertical resolution in the initial VAS soundings for the 6 March 1982 case can be improved and that the insensitivity of the regression retrievals to the rather large temperature anomalies was due to limitations in the sounding algorithms and not in the VAS radiometer itself.

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Therefore, the VAS soundings for the 6 March 1982 case are recomputed using a enhanced version of the regression retrieval algorithm which was originally developed for VAS by Lee *et al.* (1983). Two simple improvements are introduced: (1) the regression matrix is calculated using the radiosonde observations from the AVE regional sites at 1700 and 2000 GMT on 6 March 1982; and (2) the statistical conditioning factor is changed from a conservative 10/1 signal/noise ratio to an optimistic 100/1 ratio for those VAS channels which are sensitive to tropospheric temperature. The aim is to tune the VAS regression retrieval algorithm for asynoptic conditions by using midday ground-based profiles collected by the relatively sparse AVE radiosondes launched from NWS sites, without introducing any horizontal structure into the first-guess field (as the physical algorithm does) and without drawing upon the special mesoscale AVE "ground truth" radiosondes used for independent verification over north-central Texas.

Section 2 briefly discusses synoptic conditions for 6 March 1982 based on operational data sources, and describes the VAS/AVE database. Section 3 discusses the differences between the original VAS regression algorithm (VAS1) and the enhanced algorithm (VAS2). Section 4 compares AVE, VAS1 and VAS2 temperature soundings, looking for improved resolution of the mid-level the cold pool. Section 5 compares AVE, VAS1 and VAS2 low-level moisture soundings to determine whether structure in the water vapor soundings is also improved by the algorithm enhancements. Section 6 summarizes the results and discusses the implications of this case study for eventual production of VAS soundings for mesoscale applications on a more routine or operational basis.

2. Operational and VAS/AVE Data

a. Synoptic discussion

This case is characterized by a late winter storm which passed over the south-central United States, producing snow in Colorado, Oklahoma and northern Texas and cold rain from central Texas to the Gulf Coast. Behind the storm system, cold dry air pushed rapidly southeastward into the region, so that a cloud-free post-frontal environment prevailed over north-central Texas after 1700 GMT. Fig. 1 presents a time-series of surface analyses and corresponding GOES visible imagery for the afternoon of 6 March. The GOES images in Fig. 1-b depict a rapid clearing across Oklahoma and north-central Texas behind the storm system, with melting snow cover across southern Colorado and the Texas-Oklahoma panhandle. The surface temperature fields in Fig. 1-a indicate that a strong temperature gradient is present beneath the cloud cover behind the front along the Gulf Coast, that cooler temperatures are maintained by snow cover in Colorado and the Texas-Oklahoma panhandle, and that mid-afternoon solar heating warms the dry air in the boundary layer over west-central Texas.

Fig. 2-a presents a synoptic analysis of upper air conditions based on the operational NWS radiosonde observations at 0000 GMT on 7 March 1982. The post-convective environment across Texas contains strong low- and mid-level temperature gradients associated with a subtropical jet streak at the base of a mid- and upper-level trough which extends from the upper-Mississippi valley southeastward into Texas. The clear zone depicted in Fig. 1-b over north-central Texas and Oklahoma extends across the AVE regional and mesoscale network mapped in Fig. 2-b, providing ideal conditions for calculating VAS temperature soundings which can be compared to the special AVE radiosondes operating that day. More complete synoptic analyses for this case are described by Jedlovec (1985) and Fuelberg and Meyer (1986).
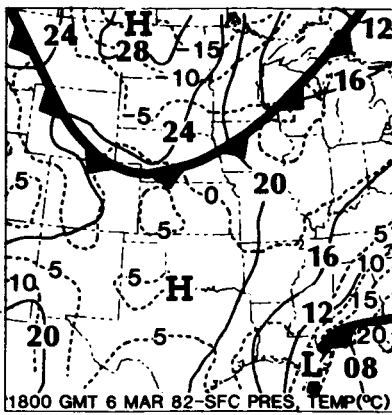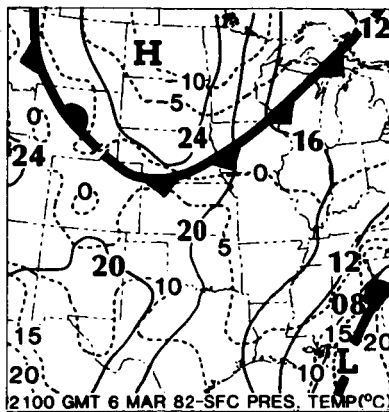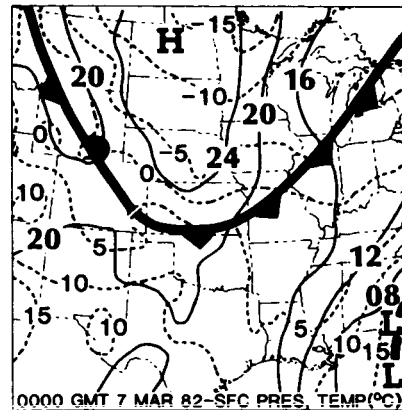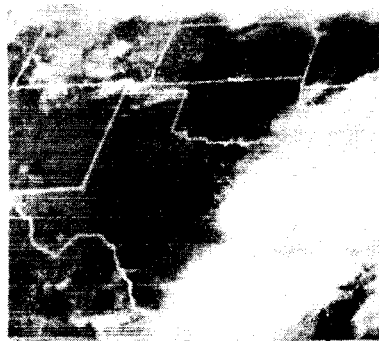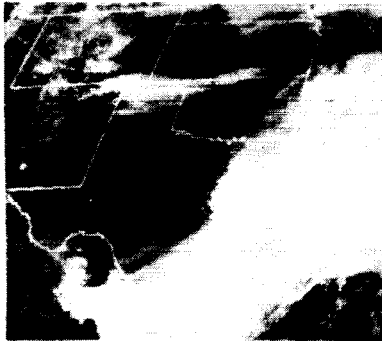
a) SFC analysis

b) GOES visible

FIG. 1. Operational subsynoptic observations during the last three AVE observing periods over the central United States on the afternoon of 6 March 1982, following a late winter storm over the Texas-Oklahoma region: (a) analyses of surface pressure (solid, mb), temperature (dashed, °C) and surface fronts; and (b) GOES visible images. The bright areas in the GOES images of the Texas-Oklahoma panhandle are melting snow cover, not clouds, and the image at sunset is contrast enhanced in order to distinguish the faintly lit clouds from the surface.
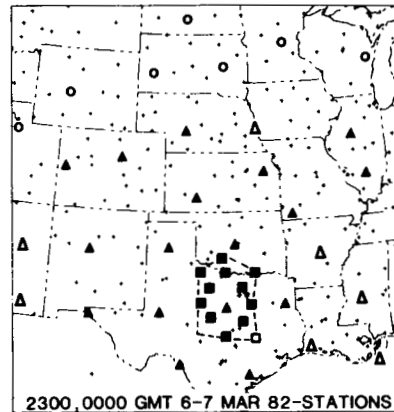
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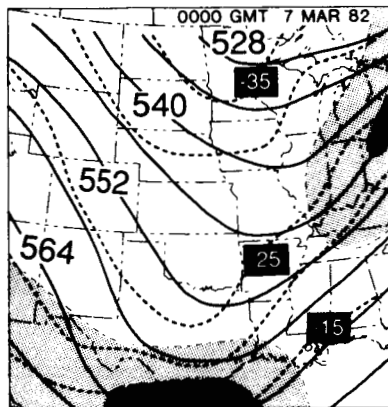
a) NWS analysis

b) NWS, FAA and AVE sites

FIG. 2. The central United States at 2300-0000 GMT on 6-7 March 1982: (a) a synoptic upper-air analysis of 500 mb geopotential height (solid, dam), of 500 mb temperature (dashed, °C), and of 300 mb wind speeds (lightly stippled for 45 to 55 m sec^{-1} and darkly stippled above 55 m sec^{-1}); and (b) a map showing the location of FAA surface reports (+), radiosonde profiles from the synoptic NWS operational network (O), from the asynoptic AVE regional network (Δ), and from the special AVE mesoscale (Π) network. Cloud-free radiosonde sites determined from Fig. 1-b are marked with filled symbols, and cloudy sites are marked with unfilled symbols.

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b. The database

Table 1 provides a summary of the datasets gathered during the VAS/AVE operations on 6 March. Five periods of contemporaneous data were obtained within ±1 hour at 3 hour intervals. For simplicity, they are called:

- "dawn" (1100 to 1300 GMT),
- "morning" (1400 to 1600 GMT),
- "noon" (1700 to 1900 GMT),
- "mid-afternoon" (2000 to 2200 GMT),
- "sunset" (2300 to 0100 GMT).

Only the last three periods (collectively called "afternoon") are analyzed in this study because clouds covered most of the Texas-Oklahoma region prior to 1700 GMT. Of the seven datasets listed in Table 1; the first four entries enumerate the ground based radiosonde and surface datasets pictured in Fig. 2-b, and the last three entries list the available satellite data swaths. The database consists of:

1) NWS synoptic radiosonde observations in North America, consisting of the conventional upper-air measurements obtained at 1200 and 0000 GMT.

2) AVE regional radiosonde observations in the central United States, launched asynoptically at 3 hour intervals from the NWS sites.

3) AVE mesoscale radiosonde observations in north-central Texas, also launched at 3 hour intervals from special mobile sites.

4) Federal Aviation Administration (FAA) surface stations in the central United States, whose reports are utilized as predictors in the VAS regression algorithm in order to improve sounding accuracy in the boundary layer (see Lee *et al.*, 1983). The surface reports of cloud cover are also used to decide whether or not a nearby VAS sounding should be attempted when the GOES visible data is ambiguous at that location.

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5) GOES infrared (IR) satellite data in 12 VAS channels over the central United States, acquired at 3 hour intervals within ±1 hour of the corresponding AVE observations. The VAS infrared data is available at approximately 15 km horizontal resolution.

6) GOES Visible-Infrared Spin-Scan Radiometer (VISSR) visible (vis) data at 1 km horizontal resolution. The VISSR data is obtained simultaneously with the VAS data, and indicates areas where visible cloud cover precludes infrared soundings.

7) TIROS Operational Vertical Sounder (TOVS) soundings from the operational NOAA polar-orbiting satellite over the AVE region at 1500 GMT, based upon its complement of microwave and infrared (μwave+IR) instruments. The independent TOVS data will be used in Section 4 to compare the resolution of operational soundings from a polar-orbiting satellite to the VAS/AVE soundings in the mesoscale cold pool over north-central Texas. Because the TOVS soundings are reported as layer averages, they are interpolated to pressure levels for comparison to the corresponding VAS and AVE soundings.

TABLE 1. Ground-based and satellite-based datasets for the VAS/AVE case on 6 March 1982. The datasets are grouped into five local-time periods that occur within ±1 hour at 3 hour intervals between operational synoptic observations. The noon, mid-afternoon and sunset periods capture significant temperature gradients and are sufficiently cloud-free to be suitable for verifying VAS temperature soundings using the AVE mesoscale observations. Fig. 2 maps the locations of ground-based observing sites during the final observing period at sunset.

Local time:	DAWN			MORNING			NOON			AFTERNOON			SUNSET		
GMT (hour):	11	12	13	14	15	16	17	18	19	20	21	22	23	00	TOTAL
GROUND-BASED															
NWS synoptic:		94											125		219
AVE regional:	24			23			24			24			24		119
AVE mesoscale:	11			13			12			12			12		60
FAA surface:		510			557			574			586		544		2753
SATELLITE															
VAS infrared:	IR			IR			IR			IR			IR		5
VISSR image:				vis			vis			vis			vis		4
NOAA/TOVS system:							µwave+IR								1

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3. The VAS Sounding Algorithm

a. VAS channels

The weighting functions for all twelve VAS infrared channels are shown in Fig. 3. VAS is sensitive mainly to tropospheric and cloudtop temperature, surface (skin) temperature, and water vapor. Some VAS channels have sensitivities which should be mitigated when the retrieval algorithm is being enhanced for maximum response to tropospheric temperature. In particular, channels 9 and 10 are indicators of mid-level water vapor, while channel 12 indicates surface (skin) temperature and is sensitive to cloud contamination and reflected sunlight. Consequently, channels 9, 10 and 12 are given no additional weight in the enhanced regression algorithm.

Radiometric noise always requires some attention in a satellite sounding algorithm. VAS single-sample noise characteristics range from less than ±0.1 K brightness temperature noise for the 11 μm window, channel 8, to more than ±3.0 K noise for the stratospheric 15 μm band, channel 1 (Chesters et al., 1985). In order to reduce random noise to approximately ±0.25 K for the mid- and lower-tropospheric channels, VAS observations are first "dwell averaged" by repeated observations of the same scanline and filter and then spatially averaged to create 60 km sounding fields-of-view. For comparison, the horizontal resolution of the AVE special mesoscale network is approximately 100 km between sites.

b. Statistically conditioned regression

VAS regression soundings are calculated by a statistically conditioned algorithm that utilizes a combination of VAS radiances and ancillary FAA surface data to predict atmospheric temperature, moisture and stability values over the United States (Lee et al., 1983). The ancillary surface data improves accuracy in the boundary layer. The statistical conditioning suppresses noisy channels and stabilizes a regression matrix calculated from a modest number of observations (Marquardt and Snee, 1975).
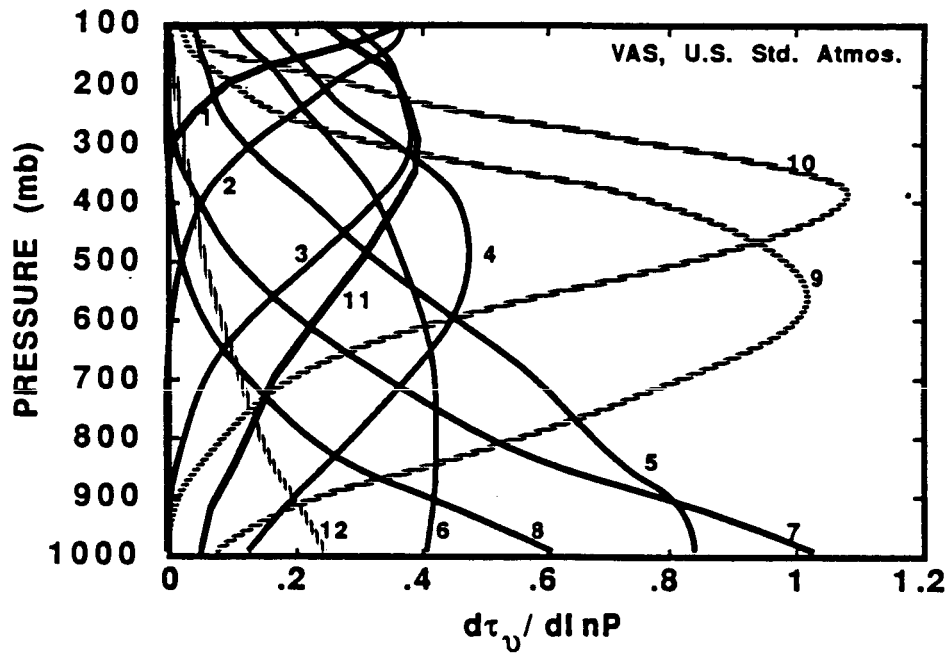
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FIG. 3. VAS weighting functions (dτ/dlnP) using the US Standard Atmosphere profile. Dashed lines indicate those channels which do not receive more optimistic signal/noise conditioning in the VAS2 soundings.

Statistical conditioning factors are estimated from signal/noise (S/N) ratios, where the "signal" (S) is the atmospheric variance (±°C, air temperature) and the "noise" (N) is observational error (±K, brightness temperature). Lee *et al.* (1983) studied the effect of different signal/noise ratios upon VAS regression soundings, and they found that S/N>100/1 produces erratic soundings, S/N<1/1 suppresses the effects of a predictor, and retrievals are otherwise insensitive to the exact value of S/N. For the VAS1 soundings, S/N=10/1 was used for all predictors, based upon relatively conservative signal and noise estimates, ±5°C and ±0.5 K, respectively. For the VAS2 soundings, S/N=100/1 is used for the VAS and surface predictors of atmospheric temperature, based upon optimistic signal and noise estimates appropriate to the lower troposphere, ±10°C and ±0.1 K, respectively. In both sets of regression retrievals, S/N=1/10 is applied to suppress channel 12, and S/N=10/1 is applied to the water vapor channels 9 and 10.

c. VAS1 and VAS2 regression matrices

Regression requires a dependent radiosonde dataset to calculate the retrieval matrix. The VAS1 matrix was calculated from a total of 50 cloud-free synoptic scale observations for three observing periods:

1) 18 reports from the 1200 GMT operational NWS radiosonde network;

2) 15 "synthetic" profiles at NWS sites which are time-interpolated to 1800 GMT using the 1200 and 0000 GMT operational radiosondes and are also adjusted in the boundary layer to match nearby FAA surface observations of temperature and dewpoint; and

3) 17 reports from a combination of the AVE regional and the NWS operational radiosonde networks at 2300 and 0000 GMT, respectively.

The "synthetic" profiles were introduced at 1800 GMT in order to compensate for a deficiency in regression matrices determined from synoptic observations. The 1200 and 0000 GMT operational soundings do not include any of the high surface temperatures that normally develop in the United States between 1500 and 2100 GMT. Space-time interpolation is the simplest way to establish a

set of dependent profiles containing midday conditions when using nothing but the operational synoptic database.

The VAS2 dependent dataset is drawn from the same spatial region as the VAS1, but contains more accurately observed midday conditions to help the algorithm distinguish between the radiometric effects of surface and atmospheric temperature. The VAS2 dataset also does not contain 1200 GMT observations at local dawn, which are not very useful for determining the VAS1 regression coefficients for low-level parameters because of the poor radiometric contrast between the surface and the lower atmosphere at this time of day. The VAS2 regression matrix was calculated from a total of 49 cloud-free regional scale observations from three afternoon observing periods:

       1) 15 reports from the AVE regional radiosonde network at 1700 GMT and

       2) 17 reports from the AVE regional radiosonde network at 2000 GMT, in addition to

       3) 17 reports also used to determine the VAS1 matrix, from a combination of AVE regional and NWS operational radiosonde networks at 2300 and 0000 GMT, respectively.

Table 2 compares the statistical design of the VAS1 and VAS2 methods. In both methods, the satellite retrievals are verified against the same independent set of 32 mesoscale radiosonde observations during the last three observing periods by the AVE special network over north-central Texas. The confidence level for the RMS difference between 32 VAS-AVE profiles should be approximately $\pm 0.5°C$. During each of the three afternoon observing periods, there are approximately 130 VAS retrievals and 27 AVE combined regional and mesoscale radiosonde observations available for objective analyses over the Texas-Oklahoma region.

TABLE 2. Comparison of the experimental designs for the VAS1 and VAS2 soundings. The VAS2 regression matrix is trained using asynoptic AVE regional radiosondes and more optimistic signal/noise conditioning than VAS1. All VAS profiles are verified with the same independent AVE mesoscale observations. Objective analyses of the VAS soundings are compared to corresponding analyses of combined AVE regional and mesoscale data in the region for each of the three cloud-free observing periods during the afternoon of 6 March.

VAS1	VAS2
REGRESSION MATRIX TRAINING	
50 sites, total	49 sites, total
NWS synoptic 1200 GMT	AVE regional 1700 GMT
NWS synoptic "1800" GMT	AVE regional 2000 GMT
AVE regional 2300 GMT	AVE regional 2300 GMT
NWS synoptic 0000 GMT	NWS synoptic 0000 GMT
SIGNAL/NOISE CONDITIONING	
	100/1 for chan. 1 to 8 and 11
10/1 for chan. 1 to 11	10/1 for chan. 9 and 10
10/1 for SFC temp. and dewpt.	100/1 for SFC temp. and dewpt.
1/10 for channel 12	1/10 for channel 12
PROFILE VERIFICATION	
32 mesoscale sites, total	32 mesoscale sites, total
noon, mid-afternoon and evening	noon, mid-afternoon and evening
REGIONAL ANALYSES	
≈130 VAS retrievals, each	≈130 VAS retrievals, each
≈27 AVE radiosondes, each	≈27 AVE radiosondes, each
noon, mid-afternoon and evening	noon, mid-afternoon and evening

4. VAS/AVE Temperature Soundings

a. The 500 mb cold pool

The poor vertical resolution of the original VAS1 soundings is illustrated in Fig. 4, which compares a retrieved temperature profile with a corresponding radiosonde profile at local noon from Henrietta, Texas (HEN), located under the cold pool near the north edge of the AVE special mesoscale network. The VAS1 profile scarcely resolves three separate temperature deviations from the average lapse rate: from 200 to 300 mb (the tropopause), from 400 to 600 mb (the cold pool), and below 850 mb (an inversion in the boundary layer). Low-level inversions are well known for being difficult to resolve using VAS (Robinson *et al.*, 1986), while tropopause determination suffers from large noise levels in the VAS upper-level channels. However, mid-level temperature variations should be detected by several of the VAS channels whose weighting functions are significant near 500 mb, as illustrated in Fig. 3.

Because the cold pool is approximately 4°C colder through a layer that is approximately one-quarter the thickness of a VAS weighting function, the cold pool should decrease the brightness temperature by approximately 1 K for those VAS channels which are sensitive to mid-level temperature. Of course, this "signal" must compete with radiometric noise (at least ±0.25 K) and with the effects of other temperature variations above and below the cold pool. Attempts were made to detect the cold pool using multispectral imaging techniques with linear combinations of VAS channels 3, 4, 5 and 6, but the cold pool's net effect is apparently too faint to detect so easily.

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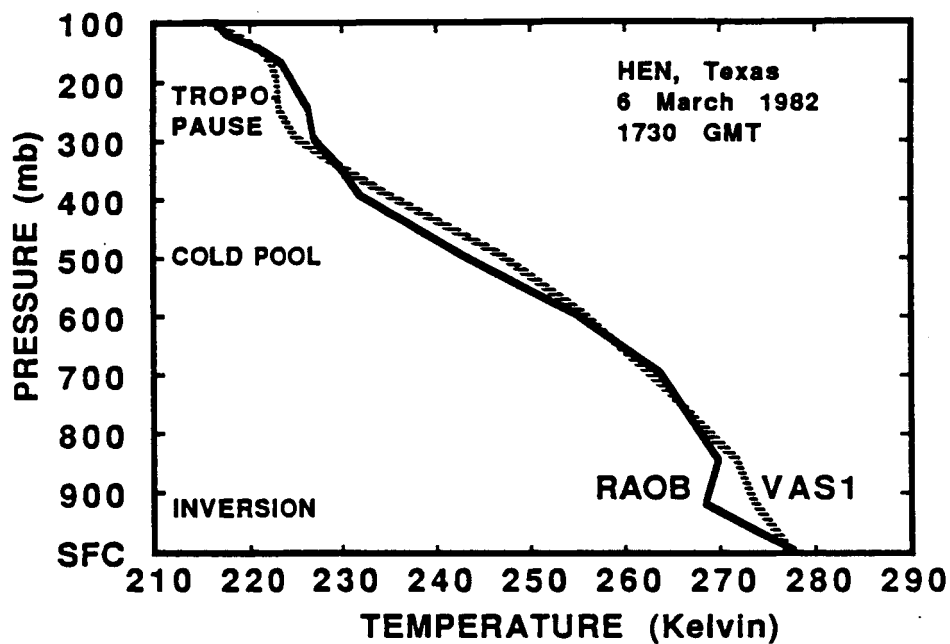
FIG. 4. The AVE radiosonde temperature (solid, °C) profile from Henrietta, Texas (HEN) at 1700 GMT located on the northern edge of the special mesoscale network compared to the corresponding VAS1 satellite retrieval at 1730 GMT (dashed). Temperature deviations from the average lapse rate occur in an inversion just above the surface, for a cold pool near 500 mb, and at the tropopause.

The horizontal extent of the cold pool at 500 mb over Texas-Oklahoma is presented in Fig. 5 for the midday AVE, VAS1 and TOVS soundings. The combined AVE radiosonde analysis in Fig 5-a indicates that the cold pool entered the mesoscale network from the Texas panhandle region behind a strong mid-tropospheric thermal gradient across the cloudy area over eastern Texas. The analysis in Fig. 5-b based on VAS1 soundings places a relatively weak cold feature over central Oklahoma, in the data-void region of the AVE observations. The VAS1 temperature gradient over the southern mesoscale network also differs from the corresponding AVE analysis in that it is weaker and oriented in a more north-south direction. Much of this difference in gradients is due to the lack of VAS soundings in the cloudy region over southeastern Texas.

The corresponding analysis from the TOVS operational satellite soundings is shown in Fig. 5-c. TOVS had unfortunately stopped taking data for calibration while it was passing over the Texas-Oklahoma panhandle. Thus, the TOVS soundings completely fail to detect the cold pool. Over the cloud-free part of the special mesoscale network, TOVS soundings indicates a mild north-south temperature gradient similar to VAS1. Ideally, TOVS soundings could be better than VAS because TOVS has microwave channels, more infrared channels, and lower noise levels. However, Hillger and Vonder Haar (1979) found that TOVS operational soundings do not fully resolve mesoscale structure, leading Hillger and Vonder Haar (1981) to develop an algorithm which better utilizes the channels and resolution of the TOVS instruments.
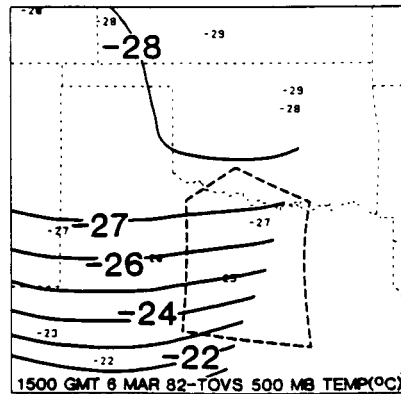
NOON
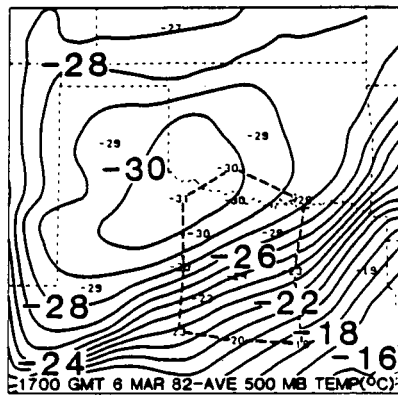
a) AVE combined
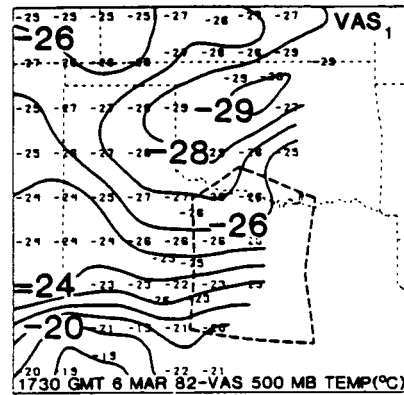
b) VAS1

c) TOVS

FIG. 5. Temperature (°C) analyses at 500 mb for local noon over Oklahoma and north-central Texas from: (a) 1700 GMT AVE regional and mesoscale radiosonde data combined; (b) 1730 GMT satellite soundings using the original VAS1 regression algorithm; and (c) 1500 GMT operational satellite soundings from the TOVS system on the NOAA polar orbiter. The dashed outline encompasses the area of the AVE special mesoscale network.

b. VAS1 and VAS2 soundings

Temporal consistency for the improved VAS2 satellite soundings is demonstrated in Fig. 6, which presents a comparison between time-series of 500 mb temperature analyses for AVE, VAS1 and VAS2 soundings during the three afternoon periods on 6 March. The AVE analysis (Fig. 6-a) clearly captures the cold pool moving southeastward across north-central Texas and the frontal gradient moving across the Gulf Coast. The original VAS1 temperature soundings (Fig. 6-b) capture some of the pool and temperature gradient at noon, but fail to properly resolve the horizontal structure during the late-afternoon soundings. The new VAS2 temperature soundings (Fig. 6-c) are much more temporally consistent than the VAS1 analyses, capturing the cold pool as a distinct structure at all three times. The VAS2 soundings still underestimate the intensity of the cold pool, but are consistent in centering this feature over the AVE data-void region of eastern Oklahoma. The VAS2 temperature gradient across the southern portion of the mesoscale network is stronger than the corresponding VAS1 gradient, but still weaker than the AVE gradient. The VAS2 gradient is also more properly aligned with the northwest-southest direction presented in the AVE analyses.
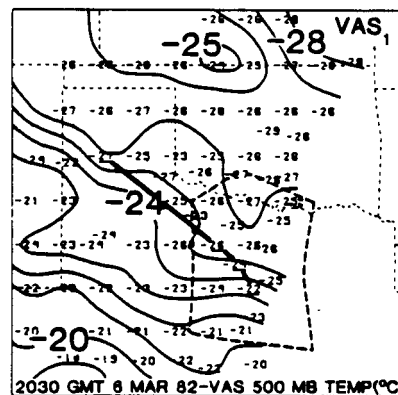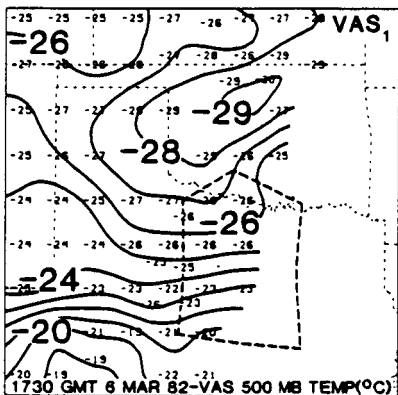
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NOON | **MID-AFTERNOON** | **SUNSET**
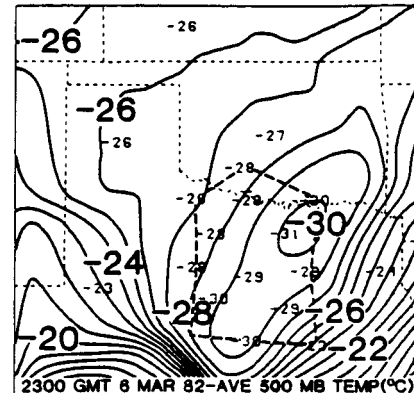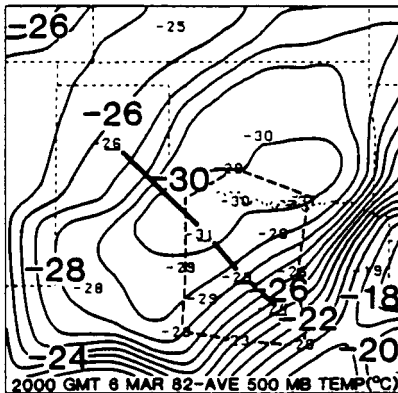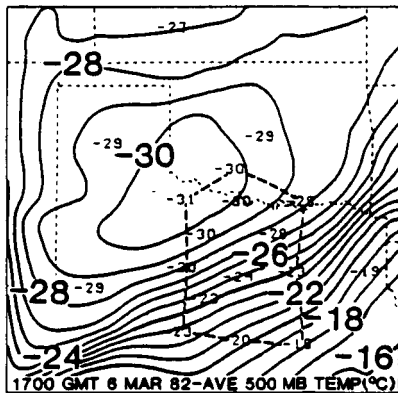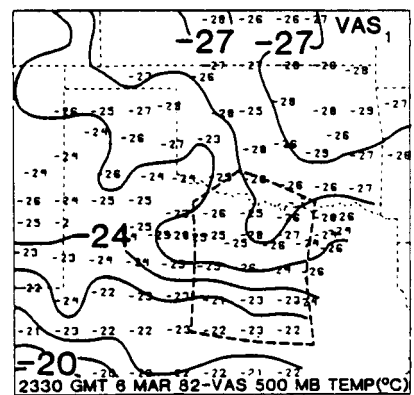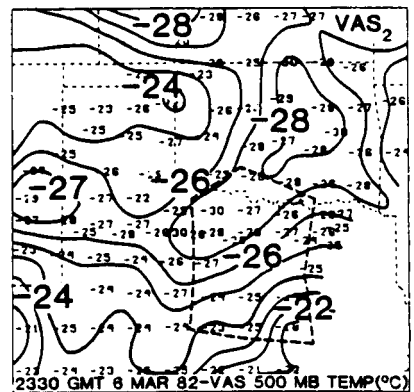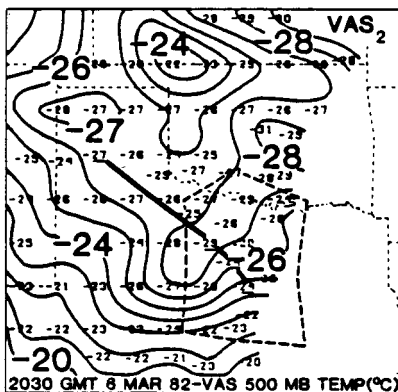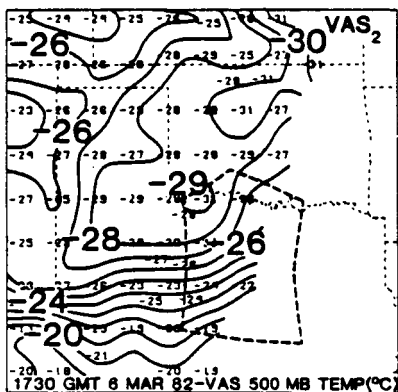

a) AVE combined

b) VAS1

c) VAS2

FIG. 6. A time-series of temperature (°C) analyses at 500 mb over north-central Texas and Oklahoma during the three cloud-free observing periods on 6 March 1982 for: (a) AVE regional and mesoscale radiosondes combined; (b) original VAS1 soundings; and (c) enhanced VAS2 soundings. Vertical cross sections of potential temperature are presented in Fig. 8 along the paths indicated by the thick solid lines drawn diagonally across the mid-afternoon fields.

In order to assess the effect of algorithm enhancement on the accuracy of VAS temperature soundings at other pressure levels, the root mean square (RMS) differences between the VAS1 and VAS2 profiles and the independent AVE mesoscale verification radiosondes are presented in Fig. 7. The error maxima for the VAS1 soundings correspond to the problem levels indicated in Fig. 4: the tropopause, the cold pool and the boundary layer inversion. The VAS2-AVE errors in the temperature soundings decrease by approximately $\pm 1.0°C$ in these three layers, demonstrating the effectiveness of the VAS2 algorithm enhancement. The greatest residual errors occur at 500 mb, and are reflected in the differences between the VAS and AVE analyses in Fig. 6. Approximately half of the "signal" from the cold pool is recovered using the enhanced VAS2 algorithm. The remainder of the "signal" is not retrieved, due either to the limitations of a regression approach, to confusion with radiometric noise, or to blurring with other pressure levels by the VAS weighting functions. Unfortunately, no more algorithm enhancements are available. If the regression matrix were determined from the AVE mesoscale radiosondes, the residual errors presented in Fig. 7 might decrease, but they would no longer provide independent verification. More elaborate statistical conditioning has been tried, but it does not significantly reduce the VAS2 errors near 500 mb.
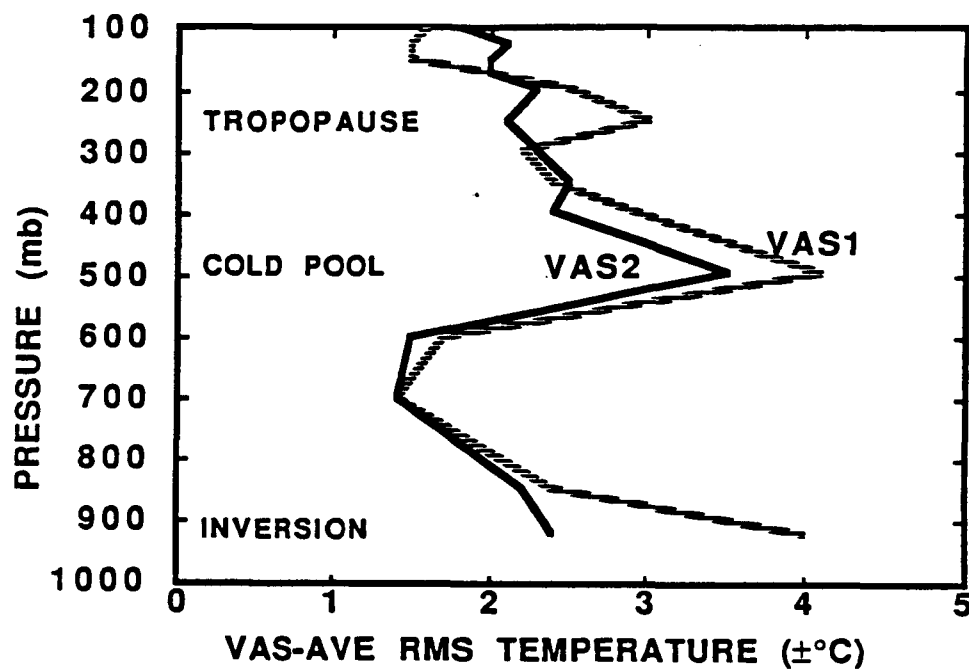
FIG. 7. RMS errors in the retrieved temperature (°C) profiles, comparing the original VAS1 and enhanced VAS2 retrievals to co-located profiles from the independent AVE mesoscale network during the last three observing periods on 6 March 1982.

c. VAS resolution

Because satellite soundings can mis-assign a 500 mb temperature variation to adjacent levels, simple vertical blurring in VAS soundings should result in thickness observations that are still approximately correct for layer averages. To test this hypothesis, vertical cross sections of potential temperature $\theta(p)$ were calculated and are presented in Fig. 8 for the AVE, VAS1 and VAS2 soundings during the mid-afternoon episode, when the cold pool was entering the mesoscale network from the northwest. The cross sections extend from the Texas panhandle into the special mesoscale network along the diagonal lines drawn on the corresponding mid-afternoon panels in Fig. 6. Each cross section is based upon an objective analysis of potential temperature drawn from four individual soundings indicated with vertical lines in Fig 8. The VAS cross sections in Figs. 8-b and 8-c do not extend quite as far to the southeast as the AVE cross section due to lingering cloud cover above the southeastern edge of the special radiosonde network at this time. The AVE cross section in Fig. 8-a clearly delineates the tropopause, cold pool, and low-level inversion, while the VAS1 cross section scarcely resolves any of these structures. By contrast, the VAS2 cross section determines these structures nicely, and the 500 mb cold pool is especially well defined. Therefore, the new VAS2 algorithm is successful in delineating the bulk thermodynamic effect of the cold pool over a deep layer.
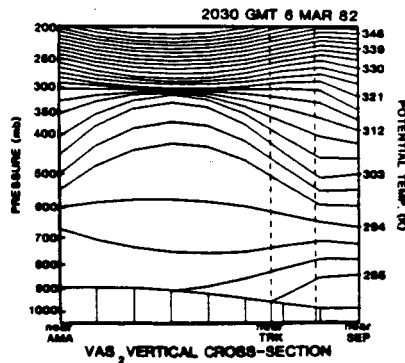
a) AVE θ(P)

b) VAS1 θ(P)
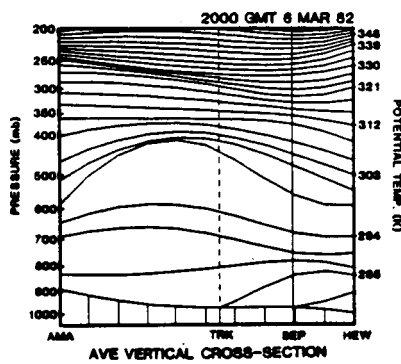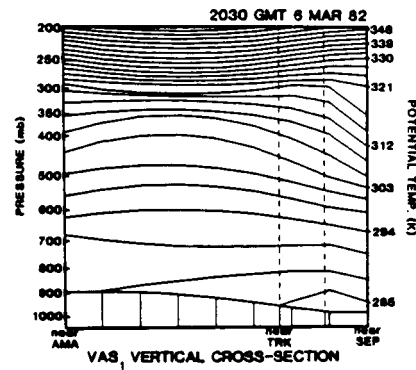
c) VAS2 θ(P)

FIG. 8. Vertical cross-sections of potential temperature (θ(p), Kelvin) across north-central Texas at mid-afternoon on 6 March 1982 based upon temperature profiles from: (a) the AVE regional and mesoscale networks, (b) the original VAS1 soundings and (c) the enhanced VAS2 soundings. The cross sectional path is indicated on the corresponding mid-afternoon analyses in Fig. 6.

While vertical resolution is limited, VAS soundings can provide very good horizontal resolution over large regions. For instance, the AVE mesoscale network provides 100 km resolution only in a limited area over north-central Texas, while the VAS soundings provide 60 km resolution over the entire cloud-free region. Fig. 9 compares the effects of different resolution and coverage on 500 mb temperature analyses at local sunset, using (a) the AVE regional network alone, (b) the AVE regional and mesoscale networks combined and (c) the VAS2 soundings. The AVE regional observations in Fig. 9-a contain a single report of -29°C at Stephensville, Texas (SEP) in the center of the special network, but the 500 mb cold pool is not resolved until mutually supporting radiosonde data is supplied by the AVE mesoscale network in Fig. 9-b. However, the AVE combined analysis in Fig. 9-b provides little resolution across the northern Texas panhandle and Oklahoma, where the VAS2 soundings in Fig. 9-c apparently resolve several additional features:

      1) another cold pool over the Texas-New Mexico border,

      2) a warm pool over the Texas-Oklahoma panhandle, and

   3) an extension to the original cold pool over central Oklahoma.

Although these thermal features are too far west and north to be verified by using the AVE mesoscale radiosondes, the additional structures are just as creditable as the thermal gradient and cold pool resolved by the VAS2 soundings over the "ground truth" network in north-central Texas.

A comparison between Figs. 9-a and 9-c indicates how bridging the gap between a ground-based regional profiler network and high resolution satellite radiances can provide mesoscale resolution of upper-air thermal features. This case study indicates that significant structural information could be retrieved operationally if regional profilers were routinely operated at asynoptic periods and used to determine a VAS regression retrieval matrix for the remainder of the field.
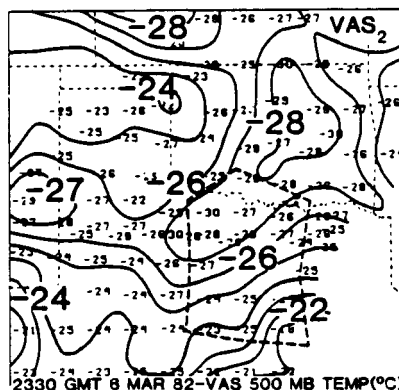
SUNSET
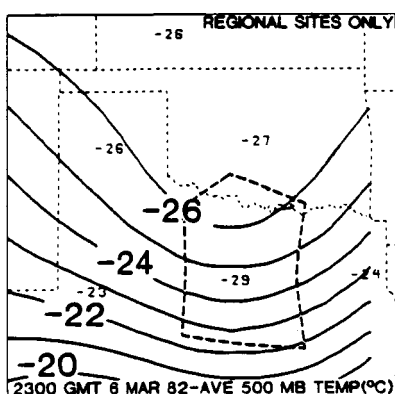
a) AVE regional
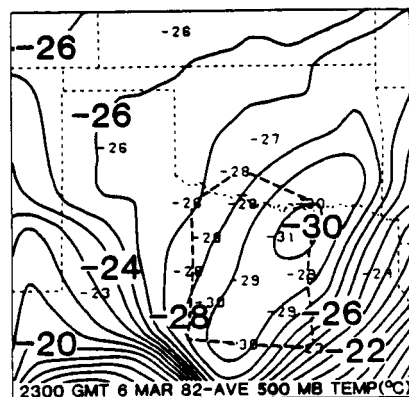
b) AVE combined

c) VAS2

FIG. 9. Sample temperature (°C) anlayses at 500 mb during the 6 March sunset period which indicate the effect of increasing horizontal resolution in the observations over the Texas-Oklahoma region for: (a) the AVE regional profile network alone; (b) the AVE regional and mesoscale networks combined; and (c) the VAS2 regression soundings based upon asynoptic regional profile observations.

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5. VAS/AVE moisture soundings

Fig. 10 presents the AVE, VAS1 and VAS2 time-series of 850 mb dewpoint analyses during the afternoon of 6 March. The AVE "ground truth" dewpoint analyses in Fig. 10-a are quite chaotic, with large variations in space and time among the mesoscale radiosonde observations within each period and between periods. The objective analysis scheme can not draw reliable dewpoint contours using the AVE mesoscale radiosonde data because there are few mutually supporting observations. By contrast, the VAS1 850 mb dewpoint soundings in Fig. 10-b are temporally and spatially self-consistent and retrieve a persistently dry feature over the western edge of the AVE mesoscale network. The corresponding VAS2 850 mb dewpoint soundings in Fig. 10-c are temporally less consistent than VAS1, but retain some of the VAS1 structural features such as the dry pocket over western Texas.

Dewpoint sounding accuracy at other pressure levels is presented in Fig. 11 in the form of RMS differences between the VAS1 and VAS2 soundings and the verification profiles from the AVE mesoscale radiosondes. The lowest levels agree fairly well, but VAS dewpoint soundings from 600 to 800 mb have large errors because VAS lacks a water vapor sounding channel for the mid-troposphere. VAS-AVE differences are not available above 500 mb because the AVE radiosondes do not provide reliable moisture observations of the upper troposphere.
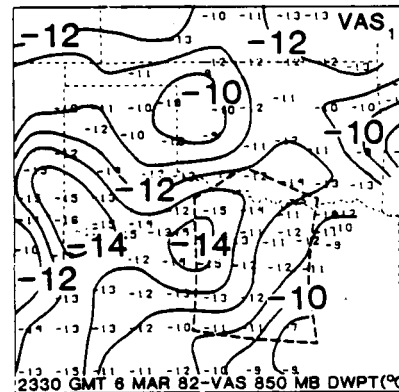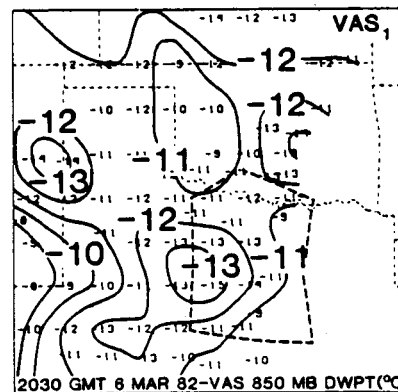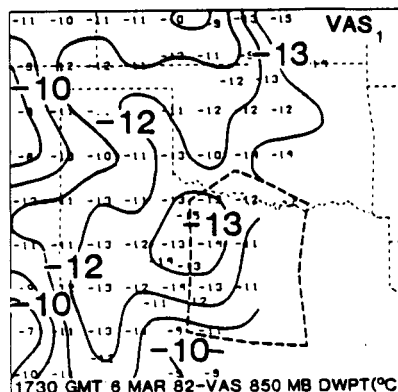
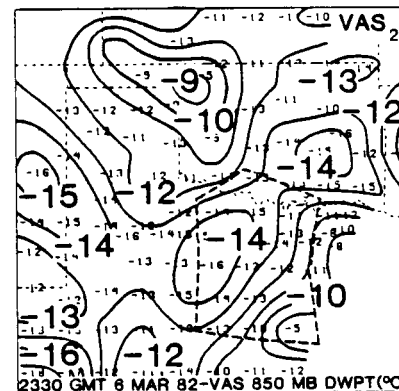**NOON**   **MID-AFTERNOON**   **SUNSET**
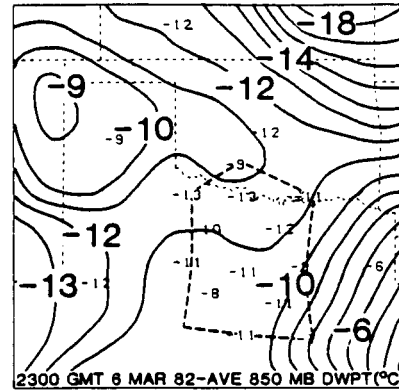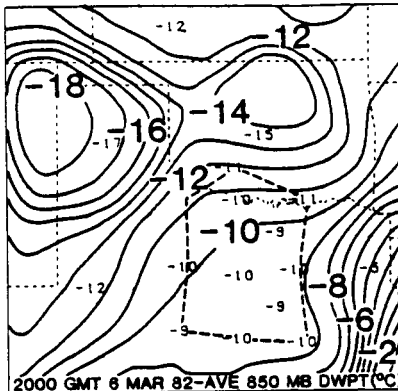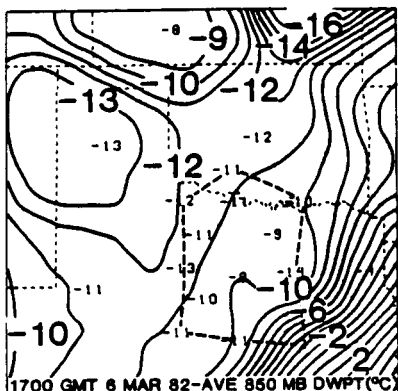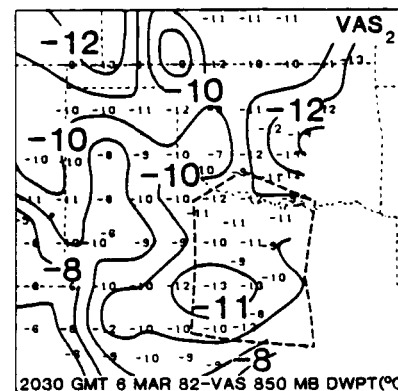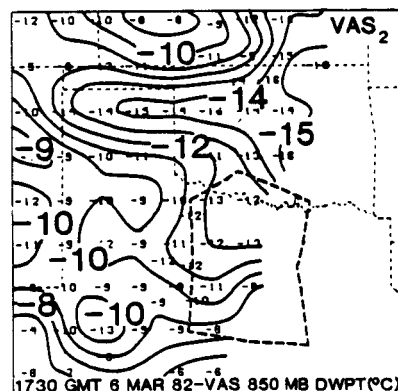

a) AVE combined

b) VAS1

c) VAS2

FIG. 10. A time-series of dewpoint temperature (°C) analyses at 850 mb over north-central Texas and Oklahoma during the three cloud-free observing periods on 6 March 1982 for: (a) AVE regional and mesoscale radiosondes combined; (b) original VAS1 soundings; and (c) enhanced VAS2 soundings.

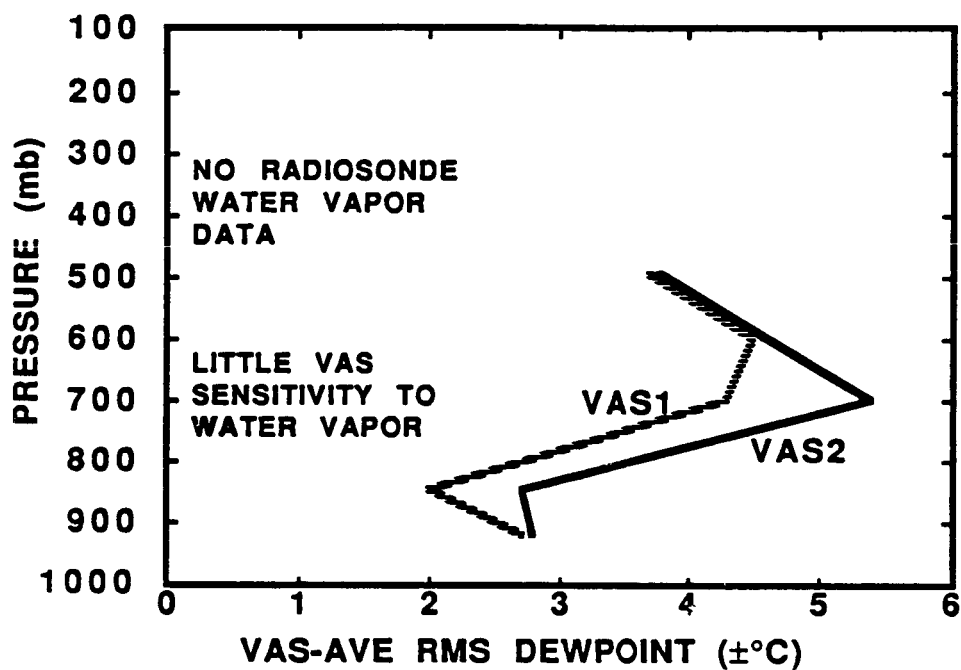FIG. 11. RMS differences in the retrieved dewpoint temperature (°C) profiles, comparing the original VAS1 and enhanced VAS2 retrievals to co-located profiles from the independent AVE mesoscale network during the last three observing periods on 6 March 1982.

Fuelberg and Meyer (1986) argue that the irregularities in the AVE radiosonde dewpoint soundings are due to analyzing a horizontal slice through a genuinely complex, rapidly changing moisture field. VAS dewpoint retrievals at any level are also questionable considering the poor vertical resolution of the VAS weighting functions. Moisture soundings over a thick layer should provide a more reliable test of VAS accuracy. Consequently, Fig. 12 compares AVE, VAS1 and VAS2 total precipitable water (PW) fields to determine whether the bulk moisture soundings are more coherent than level-specific dewpoint soundings. The AVE precipitable water fields presented in Fig. 12-a are indeed more uniform than the corresponding AVE 850 mb dewpoint fields in Fig 10-a, and are dominated by a strong northwest-southeast gradient within the cloudy region over eastern Texas. This PW gradient extends across the AVE special network, although it is considerably weaker there. Another PW feature in the AVE fields is a persistently dry region over northwest Texas which develops into a dry tongue over Oklahoma, both of which are inferred over regions with sparse AVE observations, unfortunately. In general, the PW amounts and patterns determined from the VAS1 and VAS2 soundings in Figs. 12-b and 12-c are roughly consistent with each other and with the AVE analyses over the cloud-free region in Fig. 12-a. As hoped, the VAS2 PW amounts are larger and the gradient across the AVE mesoscale network is stronger than in the corresponding VAS1 soundings, in better agreement with the AVE analyses. Outside of the region resolved by AVE mesoscale verification network, the VAS2 soundings display more PW structure than the corresponding VAS1 soundings, as witnessed by a persistently moist region over the melting snow in the Texas-Oklahoma panhandle. Unfortunately, the most significant moisture features in the VAS regression soundings appear to occur outside of the high resolution radiosonde network, and thus are not subject to independent verification.

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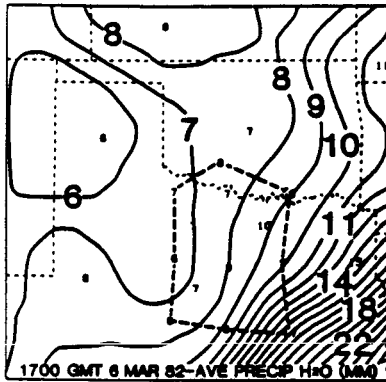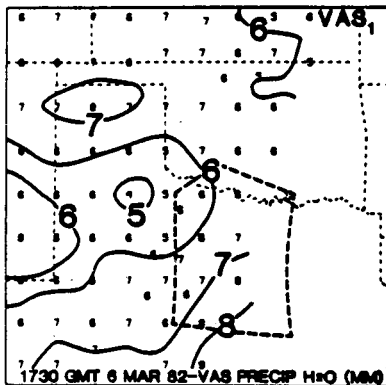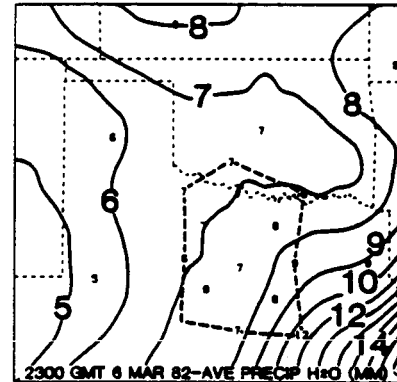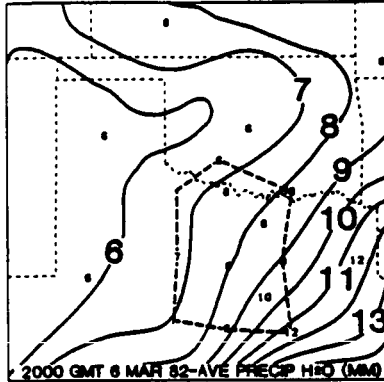
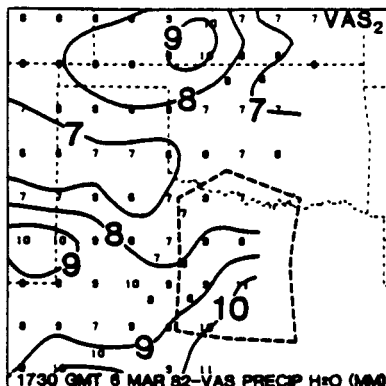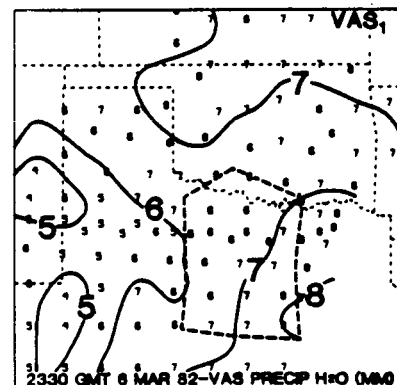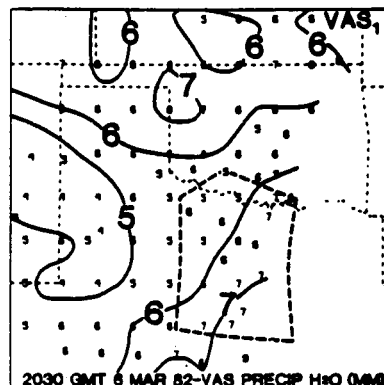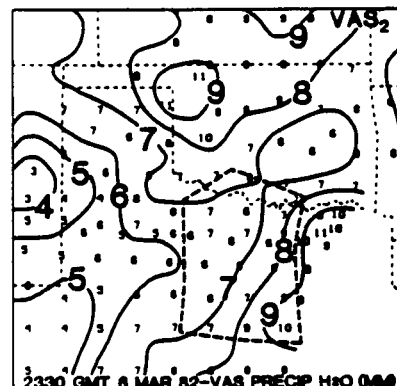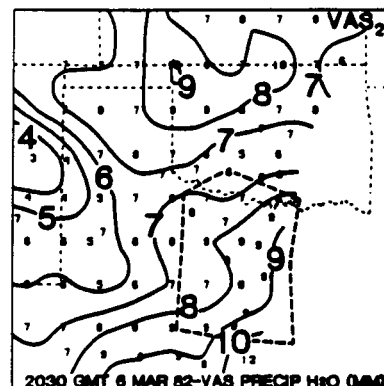FIG. 12. A time-series of total precipitable water (mm) analyses at 500 mb over north-central Texas and Oklahoma during the three cloud-free observing periods on 6 March 1982 for: (a) AVE regional and mesoscale radiosondes combined; (b) original VAS1 soundings; and (c) enhanced VAS2 soundings.

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In theory, the accuracy of VAS water vapor retrievals are fundamentally limited in a dry environment such as occurred over the AVE special network on the afternoon of 6 March 1982 (precipitable water less than 8 mm). The VAS channels were designed to measure infrared absorption by relatively large amounts of water vapor (precipitable water from 20 to 50 mm) for the detection of relatively moist pre-convective conditions (see Chesters *et al.*, 1982, 1983 and 1987; Robinson *et al.*, 1986). Birkenheuer and Snook (1986) independently report that VAS precipitable water soundings often are unreliable for amounts less than 18 mm . Therefore, the moisture observations in the dry post-convective environment on 6 March 1982 do not seem suitable for verification of VAS low-level water vapor soundings.

6. Summary, Conclusions and Discussion

An Atmospheric Variability Experiment was operated in 1982 to provide radiosonde observations of complex mesoscale environments suitable for verifying satellite soundings derived from VAS. On 6 March 1982, the AVE mesoscale network over north-central Texas captured significant temperature structures in cloud-free air behind a late winter storm. The corresponding set of original VAS soundings captured regional gradients and temporal changes for this event but did a poor job of resolving temperature deviations from the mean lapse rate. Previous studies of this case found equally poor vertical resolution in VAS soundings derived using either a physical or a statistical approach. Consequently, the 6 March case is re-processed using enhancements to the statistical algorithm in an attempt to determine whether the VAS retrievals were fundamentally limited by the radiances or merely underestimated by the original procedures.

The statistical algorithm is improved by calculating the regression matrix from asynoptic radiosondes launched at NWS sites in the AVE region and by applying more optimistic signal/noise conditioning factors to the regression matrix. VAS temperature soundings from the enhanced statistical algorithm display significantly smaller errors with respect to the independent mesoscale radiosonde observations over north-central Texas at those levels where the temperature profile departs significantly from the average lapse rate. As hoped, the enhanced VAS soundings resolve a mid-level cold pool fairly well, and improve accuracy in the tropopause and boundary layer. Some residual VAS-AVE discrepancies remain for the mid-level cold pool. Attempts to further enhance the statistical algorithm were unable to improve accuracy without introducing horizontal structure into the first-guess field or utilizing the independent mesoscale radiosonde observations.

For the 6 March case, the VAS total precipitable water soundings indicate low-level moisture features which the AVE network could not properly resolve. The post-convective environment on 6 March is quite dry, making it difficult to determine low-level water vapor accurately from VAS

observations. Moreover, the AVE "ground truth" radiosondes do not appear to resolve the mesoscale structure of the dewpoint fields. Thus, the 6 March observations are not suitable for verifying the accuracy of VAS moisture soundings.

In conclusion, an enhanced VAS regression retrieval algorithm can detect significant temperature variations from a mean lapse rate and delineate three dimensional mesoscale temperature fields with useful accuracy. The enhanced VAS soundings better resolve faint atmospheric temperature structures which were poorly retrieved by the original VAS soundings reviewed by Jedlovec (1985) and Fuelberg and Meyer (1986). However, the improvement in the VAS retrievals in this case required the use of asynoptic radiosonde observations collected in addition to the operational network.

Thus far, several other case studies using VAS soundings have demonstrated only mixed success in providing an impact upon analysis of storm environments (Kitzmiller, 1986; Shoeni and Mosher, 1986; Mostek *et al.*, 1986) or numerical forecast models (Mostek and Olsen, 1986; Aune *et al.*, 1987). Like the original VAS soundings for the 6 March case, the VAS soundings in these other cases may not have fully utilized the information available in the VAS radiances. The results of this 6 March case study indicate that the success of atmospheric soundings from VAS radiances may depend upon the existence of upper-air observations at asynoptic times in order to resolve the mesoscale thermal fields during the period between 1200 and 0000 GMT over the United States.

To improve future geosynchronous sounding systems, an asynoptic network of ground-based temperature and moisture "profilers" could be combined with geosynchronous satellite observations to yield accurate soundings of mesoscale features (Westwater *et al.*, 1984). A combined satellite- and ground-based sounding system has the potential for exploiting the strengths of each observing system to provide high resolution datasets for analysis and prediction. In such a scheme, ground-based profilers provide asynoptic temperature and moisture information with very good vertical resolution at a select number of points in a region, while the satellite sounder

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provides radiance information with very good horizontal resolution to fill in mesoscale structure between profiler sites during each observing period, as previously discussed in connection with Fig. 9.

The best VAS sounding algorithm to implement for such a combined system is yet to be determined. VAS physical and regression algorithms could each benefit from asynoptic profiler data. The physical algorithm developed for VAS by Smith *et al.* (1983) requires a good first-guess temperature and moisture field, usually drawn from a numerical forecast model, but an asynoptic profiler network could provide this first-guess field instead. The regression algorithm originally developed for VAS by Lee *et al.* (1983) and enhanced in this study draws upon the asynoptic NWS regional network to improve the regression matrix. An asynoptic profiler network could be utilized in the same way to provide operational regression soundings. Chesters *et al.* (1986) have shown that the regression algorithm is fast enough to meet realtime imaging and analysis requirements for processing VAS soundings at mesoscale resolution. Of course, combined VAS/profiler soundings will require further testing and algorithm development before being implemented operationally. It appears that the operational distribution of some VAS data products could occur by the early 1990's (Boezi and Schmidt, 1985).

References

Aune, R.M., L.W. Uccellini, R.A. Petersen and J.T. Tuccillo, 1987: A VAS numerical model impact study using the Gal-Chen variational approach. *Mon. Wea. Rev.,* **115,** accepted for the April issue.

Birkenheuer, D. and J.S. Snook, 1986: Results of the PROFS real-time VAS product assessment. *Preprint, 2nd Conf. on Satellite/Remote Sensing and Applications,* Williamsburg, Amer. Meteor. Soc., 359-364.

Boezi, L.J. and H.L. Schmidt, 1985: Advanced weather interactive processing system for the 1990's: AWIPS-90. *Int'l. Conf. on Interactive Info. and Proc.Systems for Meteor., Oceanography and Hydrology,* Los Angeles, Amer. Meteor. Soc., 24-31.

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.

Chesters, D., L.W. Uccellini and W.D. Robinson, 1983: Low-level water vapor fields from the VISSR Atmospheric Sounder (VAS) "split window" channels. *J. Climate Appl. Meteor.,* **22,** 725-743.

Chesters, D., W.P. Menzel, H.E. Montgomery and W.D. Robinson, 1985: VAS instrument performance appraisal. *VAS demonstration: (VISSR Atmospheric Sounder) description and final report.* H.E. Montgomery and L.W. Uccellini, Eds. NASA RP-1151 [NTIS 86N13867], 17-33.

Chesters, D., A. Mostek and D.A. Keyser, 1986: VAS sounding images of atmospheric stability parameters. *Weather and Forecasting,* **1,** 5-22.

Chesters, D., W.D. Robinson and L.W. Uccellini, 1987: More accurate precipitable water fields retrieved from the VAS "split window". Accepted by *J. Climate Appl. Meteor..*

Dodge, J., J.R. Greaves and H.E. Montgomery, 1985: AVE/VAS ground truth experiment. *VAS demonstration: (VISSR Atmospheric Sounder) description and final report.* H.E. Montgomery and L.W. Uccellini, Eds. NASA RP-1151 [NTIS 86N13867], 50-54.

Fuelberg, H.E. and P.J. Meyer, 1986: An analysis of mesoscale VAS retrievals using statistical structure functions. *J. Climate Appl. Meteor.,* **25,** 60-76.

Hillger, D.E. and T.H. Vonder Haar, 1979: An analysis of satellite infrared soundings at the mesoscale using statistical structure and correlation functions. *J. Atmos. Sci.,* **36,** 287-305.

Hillger, D.E. and T.H. Vonder Haar, 1981: Retrieval and use of high-resolution moisture and stability fields from NIMBUS-6 HIRS radiances in pre-convective situations. *Mon. Wea. Rev.,* **109,** 1788-1806.

Jedlovec, G.J., 1985: An evaluation and comparison of vertical profile data from the VISSR Atmospheric Sounder (VAS). *J. of Atmos. and Oceanic Technology,* **2,** 559-581.

Lee, T.H., D. Chesters and A. Mostek, 1983: The impact of conventional surface data upon VAS regression retrievals in the lower troposphere. *J. Climate Appl. Meteor.,* **22,** 1853-1874.

Marquardt, D.W., and R.D. Snee, 1975: Ridge regression in practice. *Amer. Stat.,* **29,** 3-20.

Mostek, A. and D.A. Olsen, 1986: Eastern Pacific model impact study (EPAC) at the National Meteorological Center. *Preprint, 2nd Conf. on Satellite/Remote Sensing and Applications,* Williamsburg, Amer. Meteor. Soc., 164-167.

Mostek, A., L.W. Uccellini, R.A. Petersen and D. Chesters, 1986: Assessment of VAS soundings in the analysis of a preconvective environment. *Mon. Wea. Rev.,* **114,** 62-87.

Petersen, R.A., L.W. Uccellini, A. Mostek and D.A. Keyser, 1984: Delineating mid- and low-level water vapor patterns in preconvective environments using VAS moisture channels. *Mon. Wea. Rev.,* **112,** 2178-2198.

Petersen, R.A. and D.A. Keyser, 1987: An evaluation of various forms of VAS retrievals in the analysis of a preconvective environment. Accepted by *Meteor. and Atmos. Physics.*

Robinson, W.D., D. Chesters and L.W. Uccellini, 1986: Optimized retrievals of precipitable water fields from combinations of VAS satellite and conventional surface observations. *J. Geophys. Res.*, **91**, 5305-5318.

Shoeni, T.R. and F.R. Mosher, 1986: Real-time use of VAS data at the National Severe Storms Forecast Center. *Preprint, 11th Conf. on Weather Forecasting and Analysis*, Kansas City, Amer. Meteor. Soc., 411-415.

Smith, W.L., 1983: The retrieval of atmospheric profiles from VAS geostationary radiance observations. *J. Atmos. Sci.*, **40**, 2025-2035.

Westwater, E.R., W.B. Swezy, L.M. McMillin and C. Dean, 1984: Determination of atmosphereic temperature profiles from a statistical combination of ground-based profiler and operational NOAA 6/7 satellite retrievals. *J. Climate Appl. Meteor.*, **23**, 689-703.

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15. Supplementary Notes

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16. Abstract

   An Atmospheric Variability Experiment (AVE) was conducted over the central United States in the spring of 1982, collecting radiosonde data to verify mesoscale soundings from the VISSR Atmospheric Sounder (VAS) on the GOES satellite. Previously published VAS/AVE comparisons for the 6 March 1982 case found that the satellite retrievals scarcely detected a low-level temperature inversion or a mid-tropospheric cold pool over a special mesoscale radiosonde verification network in north-central Texas. Because the cold pool should present VAS with a radiance signal that is significantly larger than the noise, the previously published regression and physical retrieval algorithms did not fully utilize VAS' sensitivity to important subsynoptic thermal features.
   Therefore, the 6 March 1982 case is re-processed adding two enhancements to the VAS regression retrieval algorithm: (1) the regression matrix is determined using AVE profile data obtained in the region at *asynoptic* times, and (2) more optimistic signal-to-noise statistical conditioning factors are applied to the VAS temperature sounding channels. The new VAS soundings resolve more of the low level temperature inversion and mid-level cold pool. Most of the improvement stems from the utilization of asynoptic radiosonde observations at NWS sites. This case suggests that VAS regression soundings may require a ground-based asynoptic profiler network to bridge the gap between the synoptic radiosonde network and the high resolution geosynchronous satellite observations during the day.

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