Time Trends of VAS Satellite-derived Soundings

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ABSTRACT

Time tendencies of operationally prepared Visible-Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) retrievals and derived products are evaluated by comparing them against corresponding tendencies from radiosonde soundings. Temperature and dewpoint trends from the two sources are compared, as are trends of thickness and precipitable water. VAS retrieval tendencies also are compared with those of the first-guess limited-area fine-mesh model (LFM) input to determine relationships and/or improvements. Time intervals of 6 h receive the greatest attention; however, 3- and 9-h periods also are considered.

Agreements between VAS and radiosonde observation (RAOB) trends generally are found to be very poor, with correlations between two versions usually less than .5. VAS trends compare less favorably with the "ground truth" than do trends of LFM data, which served as first guess. VAS-RAOB trends of vertically integrated parameters, that is, thickness and precipitable water, agree somewhat better than those of temperature and dewpoint, but correlations still are very poor. In evaluating 3-, 6-, and 9-h intervals, statistical agreements between VAS and radiosonde trends are found to improve considerably with increasing time intervals. VAS trends are found to degrade the first-guess (LFM) trend about as often as they improve it.

1. Introduction

The Visible–Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) has been carried on Geostationary Operational Environmental Satellites (GOES) since 1980. Details about the VAS instrument can be found in Menzel et al. (1981), Smith et al. (1981), and Chesters et al. (1982). Vertical profiles of temperature and humidity (i.e., retrievals) can be obtained from VAS radiances by using statistical (e.g., Lee et al. 1983) or physical (e.g., Smith et al. 1985; Hayden 1988) algorithms.

VAS retrievals have the potential for filling the 12-h data gap between routine radiosonde releases since they are available as frequently as every 90 min. Investigators who have used VAS retrievals at intervals shorter than 12 h include Mostek et al. (1986), Zehr et al. (1988), Ellrod (1989), and Fuelberg et al. (1991). Most VAS retrievals used operationally are derived from the simultaneous physical algorithm (Smith et al. 1985; Hayden 1988), and forecasters at the National Severe Storms Forecast Center have employed them to better locate stability and humidity features and their evolutions (Wade et al. 1985; Mosher and Schoeni 1988).

Operational VAS retrievals have been evaluated to a limited extent (e.g., Velden et al. 1984; Wade et al. 1985; Hayden 1988; Franklin and Lord 1988; Kitzmiller and McGovern 1989; Franklin et al. 1990; Fuelberg and Olson 1991, hereafter called FO). These studies have noted that VAS retrievals suffer from limited vertical resolution, bias errors, a dependence on the temperature–dewpoint profiles that serve as first-guess input to the algorithm, and a frequent inability to improve upon synoptic-scale patterns and gradients of the first-guess data. These findings must be tempered against those of case studies (cited above) in which VAS has provided much useful information.

The current paper describes an evaluation of time tendencies of VAS operational retrievals and derived parameters. Periods shorter than 12 h are investigated to assess VAS's ability to supplement traditional ground-based data. The paper emphasizes 6-h intervals, but there is some discussion of both 3- and 9-h periods. There are evaluations of data at individual pressure levels, as well as evaluations of layer-integrated parameters. Finally, VAS-derived tendencies are compared with those of the first guess.

2. Methodology

The evaluation methodology was relatively simple in that time trends of VAS-derived temperature and dewpoint were compared with those from radiosonde observations (RAOBs). The Cooperative Huntsville Meteorological Experiment (COHMEX) (Dodge et al. 1986) provided "ground truth" RAOBs for validating the VAS retrievals. The COHMEX soundings were taken at 3-h intervals during the summer of 1986 at

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both National Weather Service and special sites (Fig. 1). The data consisted of temperature and dewpoint at the surface and at 25-mb increments from 1000 to 100 mb, as well as dewpoints at these levels through 300 mb.

The VAS retrievals were prepared operationally by the National Environmental Satellite, Data, and Information Service (NESDIS) in Madison, Wisconsin, using the simultaneous physical algorithm (Smith et al. 1985; Hayden 1988). First-guess soundings needed in the calculations were forecasts from the 0000 UTC run of the limited-area fine-mesh model (LFM). Observed hourly surface data were blended into the forecast profiles through 850 mb. Retrievals that NESDIS judged to be cloud contaminated or nonrepresentative were not evaluated, but all other retrievals were accepted without additional scrutiny. The VAS retrievals were available only in areas without extensive cloud cover; their average spacing in these regions was approximately 100 km. Temperatures were reported at the surface, 1000, 950, 920, 850, 780, 700, 670, 500, 400, 300, 250, 200, 150, and 100 mb, while dewpoints were reported at these levels through 300 mb. First-guess temperature–dewpoint data were provided at the same levels as the retrievals; they had been vertically interpolated from the LFM data levels. We examined data at eight levels common to both the retrievals and RAOBs: 850, 700, 500, 400, 300, 250, 200, and 100 mb. The 1000- and 950-mb surfaces were not considered since retrieval data so near the ground are heavily influenced by observed surface reports that are part of the first guess (FO). The VAS retrievals were available at 90-min intervals during daylight hours; however, they were unavailable when the satellite was performing rapid scanning.

The VAS and RAOB soundings comprising each data pair were not exactly collocated in either time or space, but several procedures minimized these differences. At each of the two times comprising a trend interval (either 3, 6, or 9 h), all VAS retrievals within a 1° latitude radius of each RAOB site were averaged to produce a single mean VAS sounding that was assigned to that site. Between one and nine retrievals formed each mean sounding, with the average being four. This procedure is similar to that used by McMillin et al. (1983) and Rabin et al. (1991).

The next step was to compute the VAS and RAOB time tendencies. The VAS data were at 3-h intervals, but the radiosonde releases frequently were not made at exactly the same times as the retrievals. In calculating the RAOB time tendencies, the soundings were required to be within 1 h of the respective VAS retrieval times. Discrepancies in the VAS–RAOB intervals (usually only a few minutes) were handled by normalizing the radiosonde trends to the appropriate value per 3, 6, or 9 h. These requirements for pairing, and the absence of retrievals during rapid scanning (a frequent occurrence during the afternoon), greatly limited

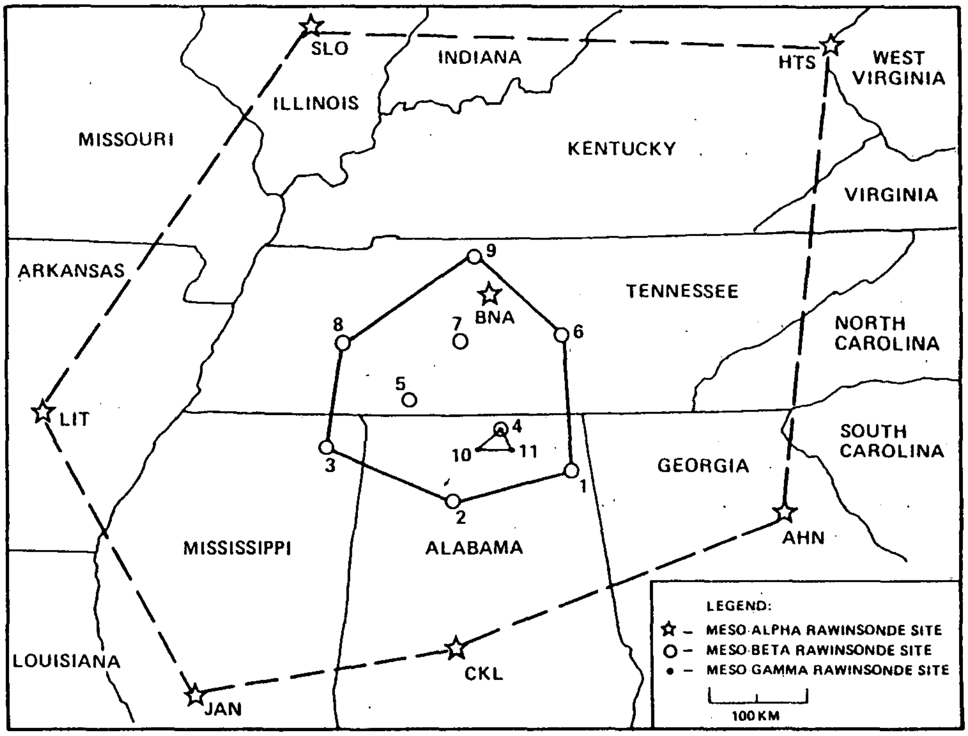

FIG. 1. The COHMEX radiosonde sounding network (after Williams et al. 1987).

the number of available VAS–RAOB pairs. Therefore, the trends were not categorized according to time of day; that is, 3-, 6-, or 9-h trends could have occurred during either the morning or afternoon.

The true error of VAS retrieval trends will be overestimated by discrepancies between the VAS and RAOB trends. In addition to true error, VAS–RAOB discrepancies are caused by noncollocation in space and time, placement of the retrievals within the averaging region, and errors in the sonde data. The time and space pairing procedures utilized will reduce collocation errors. Retrieval placement within the 1° latitude averaging domains can produce fictitious time tendencies. As an extreme example, consider the trend calculated from a single retrieval located at the eastern edge of the region at time one and at the western edge at time two. The computed trend in this case could be heavily influenced by a strong horizontal gradient. Although this type of placement has been avoided, it is not possible to totally eliminate the effects of less obvious situations. Root-mean-square errors of radiosonde temperatures have been estimated to range from 0.4° to 0.8°C (Hoehne 1980; Pratt 1985). The National Weather Service specifies that sonde hygristor errors be within 5% relative humidity at values above 30%, and within 7% at values below 30% (Nordahl 1982). However, Pratt (1985) found that errors could be considerably greater than these amounts under certain conditions. By lifting pairs of radiosondes on single balloons, Hoehne (1980) found that dewpoint differences were within about 2°C for 54% of the ascents.

3. Results

a. Level data

Solid lines in Fig. 2 describe differences between VAS and RAOB 6-h temperature tendencies. These results are based on approximately 45 VAS–RAOB sounding pairs. Mean differences ($T_{\mathrm{VAS}} - T_{\mathrm{RAOB}}$) are less than 0.5°C $(6\ \mathrm{h})^{-1}$ at all levels except 100 mb; values are positive in the lower troposphere and negative between 300 and 200 mb. Standard deviations of trend differ-

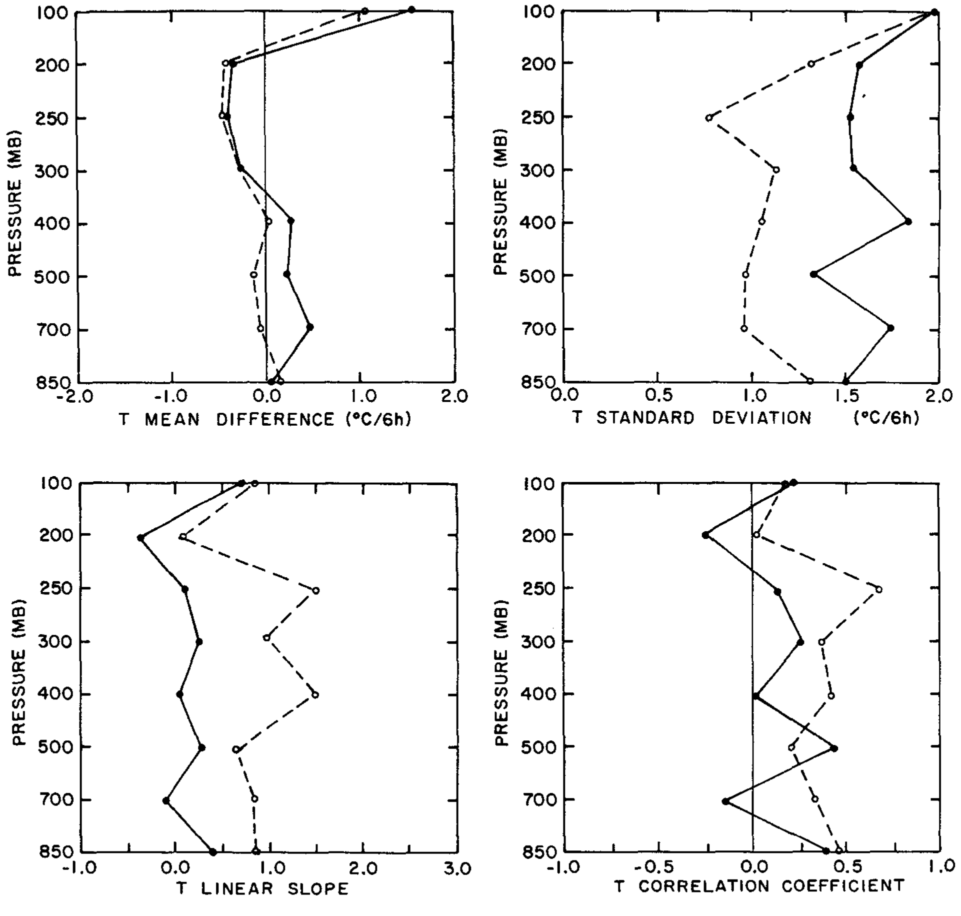

FIG. 2. Vertical profiles of statistics evaluating 6-h trends of VAS temperatures against corresponding values from radiosondes (solid). Statistics for first-guess–radiosonde evaluations are given by dashed lines. The panels describe mean differences among 6-h trends, standard deviations of differences between trends, linear best-fit slopes between trends, and linear correlation coefficients between values.

ences range from approximately 1.3°C $(6\ \mathrm{h})^{-1}$ at 500 mb to 2.0°C $(6\ \mathrm{h})^{-1}$ at 100 mb.

A least-squares procedure was used to calculate linear best-fit regression lines between the VAS and RAOB tendencies. A slope of 1.0 indicates that VAS trends always agree with the sonde-derived versions or that VAS trends are uniformly too large or too small over all values. Slopes not equal to 1.0 imply a differential bias. For example, a slope less than 1.0 indicates that VAS retrievals exaggerate the RAOB trend. Slopes for 6-h temperature tendencies (Fig. 2, solid lines) range from 0.4 to −0.4, except at 100 mb where it is 0.7. At 500 mb, for example, the slope of 0.29 indicates that VAS would depict a RAOB trend of 1°C $(6\ \mathrm{h})^{-1}$ as being 3°C $(6\ \mathrm{h})^{-1}$. Linear correlations between VAS and RAOB 6-h temperature tendencies (Fig. 2) range from .43 at 500 mb to −.25 at 200 mb.

The statistics in Fig. 2 indicate poor agreement be-

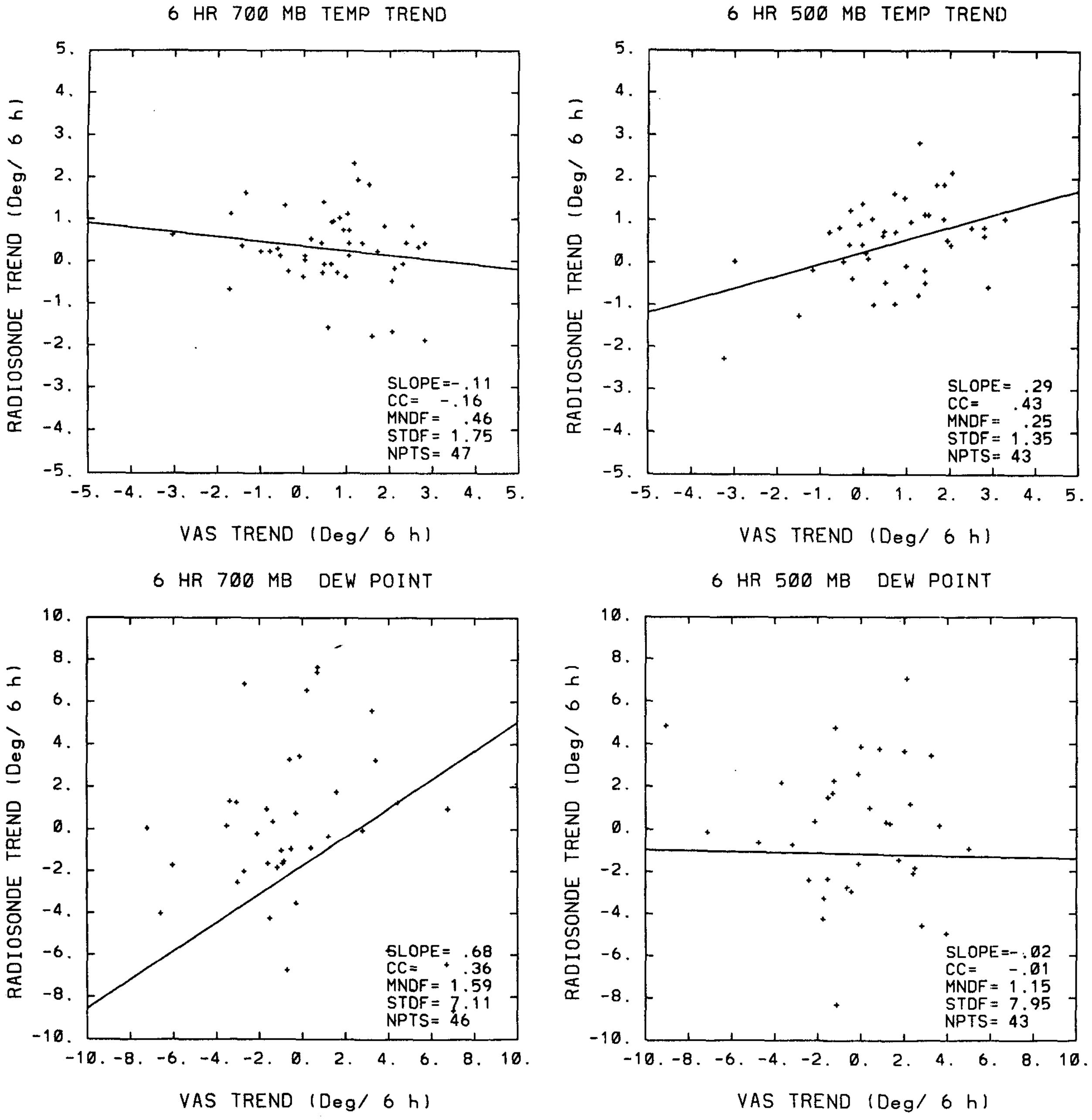

FIG. 3. Scatter diagrams of radiosonde versus VAS 6-h trends of (top) temperature at 700 and 500 mb, and (bottom) dewpoint temperature at 700 and 500 mb. Statistics in the lower-right corner of each panel are best-fit linear slope, linear correlation coefficient (CC), mean difference (MNDF), standard deviation of differences (STDF), and number of points.

tween VAS and RAOB 6-h temperature tendencies, and scatter diagrams of the two trends graphically illustrate these disappointing findings. Figure 3 (top) contains panels for levels of comparatively good (500-mb) and poor (700-mb) agreement where each dot represents a VAS–RAOB pairing. Both panels exhibit a great deal of scatter that corresponds to the small, even negative, correlation coefficients. Magnitudes of VAS tendencies generally are much greater than those from the sondes, as indicated by slopes much less than 1.0.

It is informative to evaluate time tendencies of the LFM-derived first-guess soundings and to compare findings with those of the resulting retrievals. Statistics comparing first-guess 6-h temperature trends to corresponding RAOB values are given as dashed lines in Fig. 2. Fuelberg and Olson (1991), Hayden (1988), and others have shown that VAS retrievals are very dependent on the first guess, and current results indicate that first-guess temperature trends actually agree better with RAOB trends than do the VAS-derived versions (solid lines). Specifically, correlations of first-guess trends are greater than those of the retrievals at most levels; slopes are uniformly closer to 1.0; and mean differences and standard deviations of differences are consistently smaller. Additional information about the first guess will be given in section 3d.

VAS–RAOB 6-h dewpoint tendencies (Figs. 3 and 4) compare even less favorably than the temperature trends (Figs. 2 and 3). The dewpoint trends are virtually uncorrelated, and most slopes are near zero, indicating that VAS trends tend to be greater than the RAOB versions. Mean differences and standard deviations of differences between VAS and RAOB dewpoint tendencies are much greater than those for temperature. As observed with temperature, the first-guess dewpoint trends (dashed lines in Fig. 4) generally agree better with the RAOB values than do the retrievals.

The poor VAS–RAOB trend agreements described above are not unexpected. VAS and radiosondes sample the atmosphere in fundamentally different ways. Sondes are direct sensors, providing measurements at specific points in three-dimensional space. Conversely, VAS is a remote sensor with only 12 infrared channels, each sampling a broad layer of the atmosphere. VAS is therefore unable to resolve finescale vertical features, such as inversions and shallow humidity layers, that are easily detected by RAOBs. As a result, VAS will not adequately depict temporal fluctuations of thin features. Vertically integrated parameters, such as precipitable water and thickness, are thought to be more appropriate VAS measurements than temperature and dewpoint (e.g., FO), and section 3b will evaluate tendencies of these parameters. Finally, VAS retrievals also represent a horizontal average, since radiances from a number of fields of view are averaged together to improve signal-to-noise ratios. Our methodology of evaluating the mean VAS retrieval within a 1° latitude radius of each radiosonde site leads to further spatial averaging.

As a result of these differences in sampling, as well as other factors, previous evaluations of VAS retrievals

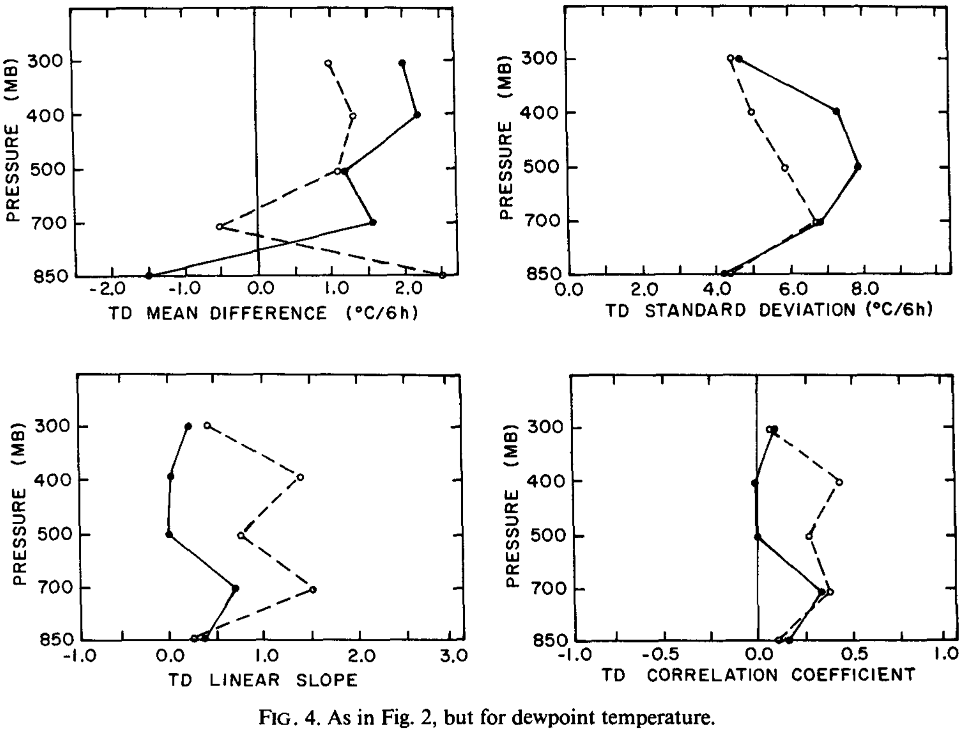

FIG. 4. As in Fig. 2, but for dewpoint temperature.

(not their time tendencies) have indicated considerable discrepancies with radiosonde data. Utilizing several months of data, FO found that standard deviations of VAS–RAOB temperature differences were approximately 2.0°C at all altitudes, while standard deviations of dewpoint discrepancies ranged from 2.5°C near the surface to a maximum of 7°C at 700 mb. Other investigators (e.g., Hayden 1988) have noted similar values. These limitations in the retrievals lead to the substantial discrepancies between VAS and RAOB sounding tendencies that are being described here.

Some of the RAOB trends being utilized in our study are small, reflecting summertime conditions over the southeast. The question arose whether VAS can represent large trends more accurately than small ones. Since visual inspection of the scatter diagrams (e.g., Fig. 3) was inconclusive in this regard, a quantitative approach was undertaken. Our methodology was to divide the data into two equal groups. Each contained those VAS–RAOB pairs in which the magnitude of the radiosonde-derived trend was less (greater) than the median value. Tables 1 and 2 contain statistics for these small- and large-trend groups along with those of the combined dataset. Median temperature trends (in brackets) are approximately 0.7°C (6 h)$^{-1}$, while those of dewpoint are about 2.4°C (6 h)$^{-1}$. The "large" trends exceeding these values generally will be meteorologically important because they correspond to considerable atmospheric change, especially if the trends continue for several 6-h periods. Furthermore, evaluations of large trends are less likely to be greatly influenced by uncertainties in the RAOB data that are serving as "ground truth."

Tables 1 and 2 show that mean and standard deviations of both temperature- and dewpoint-trend differences usually are greatest for the large-magnitude group. However, the remaining statistics indicate that VAS tends to capture the larger tendencies better. Correlation coefficients for the large-trend group generally are greater than those of the small-trend category and the combined dataset (Tables 1 and 2). Nevertheless, correlations for large magnitudes of temperature trends never exceed .70, while corresponding values for dewpoint never exceed .45. Since comparisons of correlations between groups having different numbers of points should be undertaken with caution, the *t* test (e.g., Press et al. 1989) was used to establish the level to which a given correlation is significant. Small values of SGNF (Tables 1 and 2) indicate a significant correlation for the given number of pairings; for example, the SGNF value of 0.015 for large temperature trends at 850 mb (Table 1) indicates that the correlation of .49 has only a 1.5% chance of occurring randomly. Results show that the greater correlations, which usually are associated with the large-trend group, are least likely to have occurred randomly. Conversely, the small correlations, usually associated with the small-trend group, are most likely to have occurred randomly. Fi-

TABLE 1. Statistics for RAOB versus VAS 6-h temperature trends at selected levels. The "all" category includes all trends regardless of magnitude, while the "small" ("large") categories contain statistics for trends less than (greater than) the median radiosonde-derived trend given in brackets at each pressure level. MNDF denotes the mean difference between VAS and RAOB trends; STDF is the standard deviation of differences; SLOPE is the linear best-fit slope between VAS and RAOB trends; CC is the linear correlation between values; SGNF is the level of significance of the correlation coefficient; and NPTS is the number of points in the sample.

Trend	MNDF [°C (6 h)$^{-1}$]	STDF [°C (6 h)$^{-1}$]	SLOPE	CC	SGNF	NPTS
300-mb temperature [0.8°C (6 h)$^{-1}$]						
All	0.27	1.52	0.24	.26	0.100	42
Small	−0.18	1.25	−0.03	−.10	0.641	21
Large	0.72	1.65	0.54	.42	0.057	21
500-mb temperature [0.8°C (6 h)$^{-1}$]						
All	−0.25	1.34	0.30	.43	0.004	43
Small	−0.50	1.49	−0.02	−.07	0.760	22
Large	0.72	1.07	0.63	.70	0.001	21
700-mb temperature [0.4°C (6 h)$^{-1}$]						
All	−0.44	1.71	−0.11	−.16	0.280	47
Small	−0.66	1.20	−0.03	−.11	0.601	24
Large	−0.21	2.12	−0.21	−.24	0.277	23
850-mb temperature [0.9°C (6 h)$^{-1}$]						
All	−0.08	1.57	0.37	.38	0.008	49
Small	−0.20	1.37	0.01	.03	0.887	25
Large	0.05	1.76	0.60	.49	0.015	24

nally, one should note that linear slopes for the large-trend group are somewhat greater at most levels, indicating a smaller exaggeration of the trend.

To summarize, VAS describes large temperature and dewpoint trends more accurately than small ones; however, the VAS–RAOB agreements still are very poor. It should be noted that large trends tend to be associated with more highly baroclinic situations where cloudiness might limit VAS's usefulness.

Since magnitudes of VAS-sounding tendencies apparently are often unreliable, the question arose as to how frequently the signs of VAS temperature and dewpoint tendencies matched those of the RAOBs—even knowing only the correct signs of tendencies would be helpful. To investigate, the number of times that VAS tendencies had the same sign as the RAOBs was calculated and divided by the total number of cases. Similar calculations were performed on the large- and small-trend categories and on the first-guess data.

When all magnitudes of 6-h temperature tendencies are considered (the "all" category in Table 3), VAS is more likely than not to give the correct sign; however, the scores are far from encouraging. Percent correct scores for temperature are greater than 50% at all levels except 300 mb, but the best score is only 68% at 500 mb, and the vertical average is only 58%. Results for the "all" dewpoint category are even worse, with only the 500- and 700-mb levels achieving values greater than 50%.

Considering magnitudes of tendencies (Table 3), scores for the large-trend categories of both temperature and dewpoint are approximately 20% greater than those of the small-trend category. Although scores for large trends reach 60%–79% at some levels, it still is disconcerting to know that VAS will incorrectly identify the signs of many relatively large RAOB trends. Finally, scores for VAS temperature tendencies are worse than those of the first guess (numbers in parentheses) at virtually every level in the all, small, and large categories. On the other hand, scores for VAS dewpoints are better than those of the first guess in some categories below 400 mb, reaching 17% improvement in the large category at 850 mb.

b. *Layer-integrated parameters*

VAS cannot properly resolve the thin stable regions and moist or dry layers that appear in RAOBs because of its broad weighting functions. However, VAS retrievals might be able to represent the vertically integrated effects of these features. Fuelberg and Olson (1991) showed that VAS and RAOB versions of precipitable water and thickness exhibited better agreement than corresponding values of temperatures and dewpoints. We wanted to determine whether trends of these integrated parameters also exhibited better agreements. Therefore, trends of VAS and RAOB thickness and precipitable water were calculated for various layers

TABLE 2. Statistics for RAOB versus VAS 6-h dewpoint trends at selected levels. The "all" category includes all trends regardless of magnitude, while the "small" ("large") categories contain statistics for trends less than (greater than) the median radiosonde-derived trend given in brackets at each pressure level. MNDF denotes the mean difference between VAS and RAOB trends; STDF is the standard deviation of differences; SLOPE is the linear best-fit slope between VAS and RAOB trends; CC is the linear correlation between values; SGNF is the level of significance of the correlation coefficient; and NPTS is the number of points in the sample.

Trend	MNDF [°C (6 h)$^{-1}$]	STDF [°C (6 h)$^{-1}$]	SLOPE	CC	SGNF	NPTS
			300-mb dewpoint [2.7°C (6 h)$^{-1}$]			
All	1.99	4.69	0.25	.12	0.454	42
Small	2.79	1.82	0.35	.47	0.033	21
Large	1.20	6.36	0.24	.09	0.695	21
			500-mb dewpoint [2.6°C (6 h)$^{-1}$]			
All	−1.07	7.91	−0.07	−.02	0.938	43
Small	0.90	4.53	−0.14	−.32	0.139	22
Large	−3.14	10.06	0.10	.07	0.770	21
			700-mb dewpoint [2.4°C (6 h)$^{-1}$]			
All	−1.58	6.93	0.69	.36	0.015	46
Small	0.21	3.42	0.15	.45	0.031	23
Large	−3.37	8.94	1.17	.45	0.031	23
			850-mb dewpoint [1.8°C (6 h)$^{-1}$]			
All	−1.63	4.21	0.42	.19	0.203	48
Small	0.73	2.43	−0.12	−.25	0.229	24
Large	2.53	5.34	1.19	.35	0.086	24

TABLE 3. Percentage of cases when signs of VAS 6-h temperature and dewpoint trends agree with those of RAOBs. The "all" category includes all trends regardless of magnitude, while the "small" and "large" categories contain statistics for trends less than or greater than the median radiosonde-derived trend given at each pressure level. Percentages for first-guess trends are given in parentheses. Avg is the average of the five preceding entries.

Level (mb)	Median [°C (6 h)$^{-1}$]	All (%)	Small (%)	Large (%)
		Temperature		
300	0.8	43 (52)	39 (44)	48 (58)
400	0.7	65 (70)	53 (71)	78 (70)
500	0.8	68 (70)	57 (57)	79 (84)
700	0.4	52 (67)	44 (50)	61 (86)
850	0.9	63 (74)	59 (64)	67 (83)
Avg	0.7	58 (67)	50 (57)	67 (76)
		Dewpoint		
300	2.7	39 (39)	30 (30)	48 (52)
400	2.6	42 (54)	35 (40)	48 (71)
500	2.6	57 (50)	50 (43)	65 (62)
700	2.4	65 (61)	57 (52)	74 (74)
850	1.8	47 (34)	26 (22)	67 (50)
Avg	2.4	50 (48)	40 (37)	60 (62)

using data from all available levels, that is, the RAOB information at 25-mb increments, not just the levels common to both VAS and RAOBs.

Table 4 (top) contains correlation coefficients and slopes between 6-h tendencies of VAS–RAOB thicknesses. The five layers represent thick and thin regions, as well as layers in the middle and lower troposphere. Numbers of pairings are similar to those in Table 1. VAS–RAOB agreements remain very poor, with correlations for the various layers only near .30 and slopes near 0.20. Contrary to what may be expected, results for the thicker layers (e.g., 850–300 mb) generally are not superior to those for thinner layers (e.g., 700–500 mb). Each layer in Table 4 also contains temperature statistics (in brackets) that are averages for those pressure levels of the layer that are common to both the VAS and RAOB soundings, that is, averages of the data from Fig. 2. With average thickness [temperature] tendency correlations of .31 [.15], thickness provides some improvement over temperatures at individual levels. On the other hand, first-guess (LFM) thickness tendencies continue to be superior to those of the retrievals. Correlations for the guess thickness trends range from .58 to .33, while slopes for the guess data range from near 1.0 for the deeper layers to 0.60 for the thin layers.

Results for 6-h tendencies of precipitable water are given at the bottom of Table 4. In general, the findings are similar to those of thickness. VAS tendencies of precipitable water are better than those of dewpoint within the layers (in brackets), although they still are quite inaccurate. First-guess precipitable water trends are superior to those from VAS, especially in terms of linear slope.

Table 5 contains percentages when VAS depicts the correct signs of thickness and precipitable water trends. The methodology used here was identical to that em-

TABLE 4. Linear correlation coefficients and slopes for RAOB versus VAS 6-h trends of thickness and precipitable water for selected layers. Corresponding statistics also are given for RAOB versus first-guess trends. For comparison, the average correlation coefficients and slopes of temperature and dewpoint trends at the individual levels used in the thickness and precipitable-water calculations are given in brackets. Avg is the average of the five preceding entries.

Layer (mb)	Correlation coefficients		Slopes	
	Guess	VAS	Guess	VAS
		Thickness		
850–300	.58	.28 [.19]	1.09	0.18 [0.16]
700–300	.48	.31 [.14]	1.02	0.18 [0.11]
850–400	.57	.33 [.17]	0.96	0.17 [0.14]
700–500	.33	.38 [.14]	0.60	0.20 [0.09]
950–700	.44	.26 [.11]	0.60	0.23 [0.13]
Avg	.48	.31 [.15]	0.85	0.19 [0.13]
		Precipitable water		
850–300	.36	.35 [.12]	0.99	0.59 [0.25]
700–300	.33	.19 [.21]	1.13	0.30 [0.22]
850–400	.36	.36 [.13]	0.98	0.62 [0.26]
700–500	.28	.25 [.17]	1.04	0.45 [0.33]
950–700	.27	.35 [.28]	0.54	0.60 [0.55]
Avg	.32	.30 [.18]	0.94	0.51 [0.32]

TABLE 5. Percentage of cases when signs of VAS 6-h thickness (top) and precipitable water (bottom) trends for selected layers agree with those of RAOBs. The "all" category includes all trends regardless of magnitude, while the "small" and "large" categories contain statistics for trends less than or greater than the median radiosonde-derived trend given at each pressure layer. Percentages for first-guess trends are given in parentheses. Median values of thickness are in geopotential meters per 6 h, while those of precipitable water are in millimeters per 6 h. Avg is the average of the five preceding entries.

Layer (mb)	Median	All	Small	Large
		Thickness		
850–300	17.9	58 (82)	55 (63)	61 (90)
700–300	14.4	63 (77)	55 (65)	70 (90)
850–400	12.7	60 (80)	50 (65)	70 (95)
700–500	6.0	73 (70)	68 (55)	76 (80)
950–700	9.4	70 (85)	70 (95)	70 (75)
Avg		65 (79)	60 (69)	69 (86)
		Precipitable water		
850–300	2.2	69 (69)	58 (79)	79 (63)
700–300	1.3	65 (71)	54 (67)	79 (75)
850–400	2.1	75 (69)	61 (71)	88 (67)
700–500	1.3	75 (67)	75 (67)	75 (67)
950–700	2.8	60 (55)	54 (52)	67 (58)
Avg		69 (66)	60 (67)	78 (66)

ployed earlier for temperature and dewpoint (Table 3). Numbers of VAS–RAOB pairings are similar to those in Tables 1 and 2. VAS correctly indicates the signs of large 6-h trends more often than those of small trends; the average score for the large (small) category of thickness is 69% (60%) and is 78% (60%) for precipitable water. These averages compare to 67% (50%) for temperatures and 60% (40%) for dewpoints at individual levels (Table 3). Thus, scores for vertically integrated VAS parameters are a considerable improvement over those for level data, with signs of large trends being correctly identified in approximately three-fourths of the cases. Scores for the all, small, and large magnitude thickness categories continue to be less than those of the first guess (numbers in parentheses). However, VAS does provide improved precipitable-water scores, especially in the "large"-magnitude category.

Current results are consistent with those of Rabin et al. (1991), who presented time series of VAS- and RAOB-derived precipitable water at several sites. Their plots indicated that VAS captured larger RAOB trends better than smaller ones. Present findings also agree with those of FO, who found that VAS thickness, and especially precipitable water, were superior to temperature and dewpoint.

TABLE 6. Average linear correlation coefficients and slopes for RAOB versus VAS 3-, 6-, and 9-h trends of temperature, dewpoint, thickness, and precipitable water. Statistics for all individual levels or layers of all VAS–RAOB pairs (numbers given below) have been combined to form average values for each parameter.

	3 h	6 h	9 h
	Temperature		
Correlation	.03	.19	.46
Slope	0.06	0.17	0.43
Number of pairings	1360	352	112
	Dewpoint		
Correlation	.12	.13	.27
Slope	0.21	0.26	0.80
Number of pairings	825	220	70
	Thickness		
Correlation	.09	.31	.38
Slope	0.07	0.19	0.25
Number of pairings	660	210	85
	Precipitable water		
Correlation	.14	.30	.59
Slope	0.21	0.51	0.71
Number of pairings	870	240	105

c. The 3- and 9-h tendencies

Trends of temperature, dewpoint, thickness, and precipitable water also were calculated over 3- and 9-h periods. To simplify the presentation, since results did not vary greatly with height, the temperature and dewpoint statistics shown in Table 6 are averages of those at the individual levels utilized earlier (Figs. 2 and 4). Similarly, statistics for thickness and precipitable water are averages for those layers shown in Tables 4 and 5. The number of pairings comprising each average varies greatly, ranging from 1360 for 3-h temperature tendencies to only 70 for 9-h dewpoint trends. Because of these large sample differences, only general statements about statistical comparisons will be made.

Agreements between VAS–RAOB tendencies (Table 6) improve with increasing time interval. Slopes and correlations for 3-h tendencies are very small, even smaller than those at 6 h, while values for 9 h are considerably better than those at 6 h. Precipitable water produces the best 9-h tendencies (correlation of .59, slope of 0.71), while the parameter having the worst 9-h correlation is dewpoint (.27). The improvement observed for longer periods is analogous to that seen for large trends at 6-h intervals (Tables 1, 2, 3, and 5). These results indicate that VAS best detects large and persistent sounding changes that occur over relatively deep layers. The evaluation of larger, often longer trends also is affected less by uncertainties in the radiosonde data. Although 12-h VAS tendencies (not investigated) probably would exhibit even better agreement than those shown here for 9 h, one of VAS's primary missions is to provide data at mesoscale time intervals, for example, intervals shorter than 12 h. In this regard, current results are disappointing. Nonetheless, accurate 12-h satellite data are useful for those regions of the earth where radiosonde sites are coarsely spaced, for example, over oceanic regions and less-developed countries.

d. Influence of the first guess

Previous sections have indicated that VAS tendencies are inferior to those of the LFM-derived first guess; this section explores the guess in more detail. The first point is that the VAS retrieval process adds variance to trends of the first guess. Although apparent at most levels, it is most evident at 400 mb (Fig. 5). The first-guess temperature and dewpoint trends (left panels) exhibit relatively small variation; however, when the guess soundings and VAS radiances are input to the retrieval algorithm, time trends of the resulting retrievals exhibit a much larger range of values (right panels), even larger than those of the RAOBs. The added variance does not appear to be meteorologically significant, as indicated visually by the greater amount of scatter and statistically by correlation coefficients that have plummeted to near zero.

Relations between trends of the first guess and retrievals were examined further by calculating the amount of improvement or degradation of the guess trends by the retrieval process. Our procedure is similar

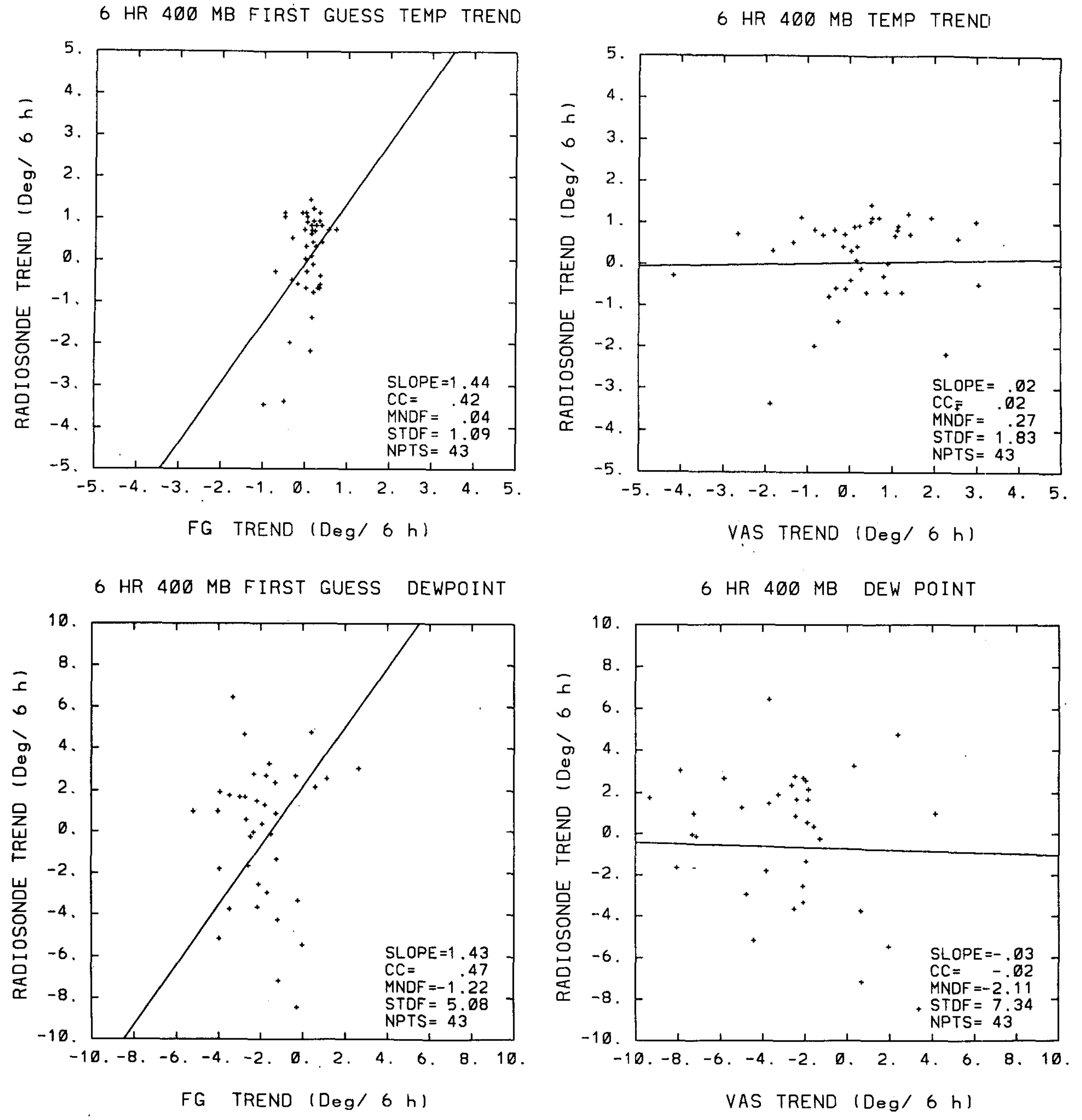

FIG. 5. Scatter diagrams of 400-mb 6-h trends for (upper left) first-guess versus RAOB temperatures, (upper right) VAS retrievals versus RAOB temperatures, (lower left) first-guess versus RAOB dewpoints, and (lower right) VAS retrievals versus RAOB dewpoints. Statistics in the lower right of each panel are as in Fig. 3.

to that of FO. As an example, if the first-guess temperature trend is 7.0°C $(6\ \mathrm{h})^{-1}$, with a VAS retrieval trend of 4.0°C $(6\ \mathrm{h})^{-1}$ and a corresponding RAOB trend of 5.0°C $(6\ \mathrm{h})^{-1}$, the difference between the VAS and guess trends is 3.0°C $(6\ \mathrm{h})^{-1}$; however, VAS provides only a 1.0°C $(6\ \mathrm{h})^{-1}$ improvement over the guess. Thus, positive improvement is defined as the VAS trend becoming closer than the guess trend to the observed RAOB tendency. Conversely, negative improvement signifies that a VAS trend compares less favorably with the RAOB version than does the first-guess trend.

Histograms of improvement and degradation for 6-h temperature and dewpoint trends at 700 and 500 mb are given in Fig. 6. These diagrams are similar to those at other levels (not shown) and are based on all trends regardless of magnitude. The histograms show distributions that are rather evenly oriented about zero,

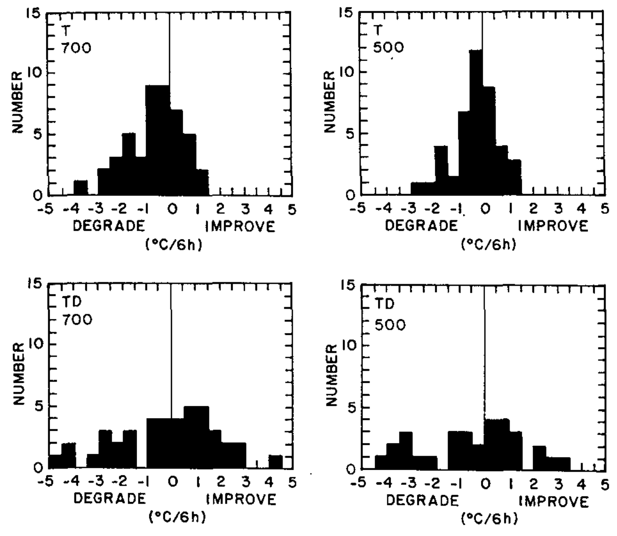

FIG. 6. Histograms of improvement and degradation of first-guess 6-h trends by VAS retrievals. Panels are for temperature and dewpoint at 500 and 700 mb.

with two of them having peaks in the negative region. Although one hopes that VAS retrievals will exhibit trends that are superior to those of the first guess, the histograms indicate that this often is not the case. This lack of consistent improvement agrees with findings of FO, who evaluated retrievals but not their tendencies.

The role of the first guess in producing VAS–RAOB trend discrepancies was investigated further by comparing errors in VAS retrieval trends with errors in first-guess trends. Scatter diagrams of these discrepancies are presented in Fig. 7 for 700-mb temperature and dewpoint, while Table 7 gives statistics at other levels. The relatively large correlations, especially for dewpoint, indicate that poor first-guess trends are associated with poor retrieval trends and vice versa. The slopes much less than 1.0, especially for temperature, signify that retrieval discrepancies are greater than those of the first guess; that is, trend errors in the guesses are magnified during the retrieval process. Although first-guess–retrieval differences for dewpoint are more highly correlated than those of temperature (averaging .86 versus .54), the greater slopes for dewpoint (averaging 0.76 versus 0.37) indicate less magnification of the first-guess trend error. The present correlations for errors in temperature trends (averaging .54) are similar to those reported by FO for temperature alone (averaging .51); however, current correlations for errors in dewpoint trends (averaging .86) are much greater than FO presented for dewpoint errors alone (averaging .31). Thus, VAS dewpoint trends are considerably more sensitive to errors in the guess trends than dewpoints are sensitive to guess errors at a specific time. Fuelberg and Olson (1991) and Hayden (1988) have noted that good first-guess data are vital to accurate retrievals, and that certainly seems to be the case with VAS time tendencies as well. VAS–RAOB trend discrepancies not attributable to the first guess may be due to several factors, including RAOB error, noncollocation of VAS–RAOB soundings, and limitations of the retrieval algorithm.

4. Summary and conclusions

This study has evaluated time tendencies of operationally derived VAS retrievals by comparing them

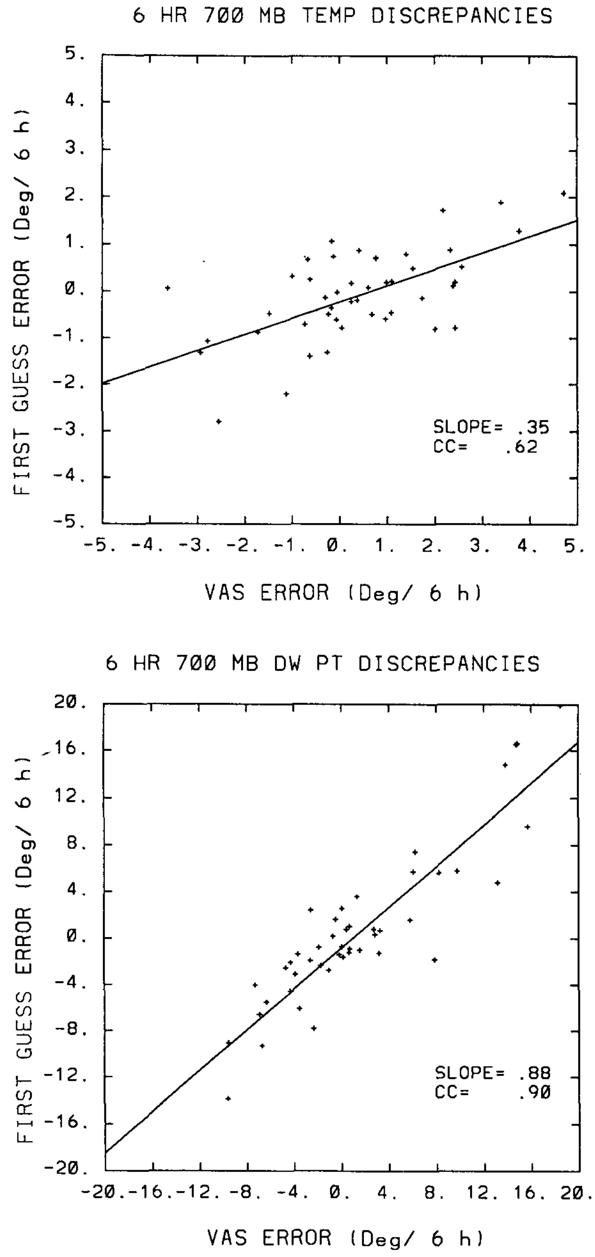

FIG. 7. Scatter diagrams of first-guess–RAOB discrepancy versus VAS retrieval–RAOB discrepancy. Panels are for 6-h trends of temperature and dewpoint at 700 mb.

TABLE 7. Linear correlation coefficients and slopes between first-guess–RAOB 6-h trend discrepancies and VAS–RAOB 6-h trend discrepancies. Avg is the average of the five preceding entries.

Level (mb)	Temperature		Dewpoint	
	Correlation	Slope	Correlation	Slope
300	.54	0.53	.89	0.84
400	.59	0.35	.78	0.54
500	.31	0.23	.82	0.61
700	.62	0.35	.90	0.88
850	.65	0.41	.90	0.91
Avg	.54	0.37	.86	0.76

against those of radiosonde soundings. The results generally were very disappointing. Six-hour time tendencies of VAS temperatures exhibited poor agreement with radiosonde-derived values, with correlations only varying between .4 to −.4 depending on altitude. Tendencies of VAS dewpoints showed even worse agreements. Trends of LFM first-guess data agreed better with the RAOBs than did trends of the resulting retrievals. Although VAS depicted large RAOB tendencies more accurately than small ones, even these results were quite poor. Signs of 6-h VAS tendencies agreed with those from RAOBs in only 58% of the temperature cases and 50% of the dewpoint cases. These statistics increased to 67% and 60%, respectively, for tendencies greater than the median value.

Time trends of vertically integrated parameters were superior to those of level-specific parameters. However, correlations between both VAS–RAOB 6-h thickness and precipitable water tendencies still were only approximately .3. On the other hand, VAS correctly indicated the signs of large thickness and precipitable water tendencies in about 75% of cases. These scores were considerably better than those of temperature and dewpoint at individual levels.

Agreements between VAS and RAOB tendencies also were calculated for 3- and 9-h intervals. Results were considerably better at the longer time intervals. The correlation between all magnitudes of 9-h precipitable-water tendencies was greater than that of the other parameters examined; however, even this value only reached .59.

We examined the role of the first guess in producing VAS time tendencies. Results indicated that tendencies of the LFM first-guess data had a relatively small variance. Conversely, the resulting VAS tendencies had a much greater variance that did not correspond with the radiosonde-derived values. This added variance is not thought to be meteorologically significant. VAS retrieval tendencies were not a consistent improvement over those of the guess values. Finally, errors in retrieval trends were found to be correlated with those of the first guess (.86 for dewpoint trends and .54 for temperature trends).

Our finding of poor VAS time tendencies is consistent with previous evaluations of the retrievals themselves (Velden et al. 1984; Wade et al. 1985; Hayden 1988; Franklin and Lord 1988; Kitzmiller and McGovern 1989; Franklin et al. 1990; FO). However, the extent of the tendency problem is surprising. Each of the earlier studies found that retrievals contain systematic and random errors, are unable to resolve thin vertical features, and are very dependent on the first-guess input. Time derivatives of VAS retrievals amplify the effects of these inadequacies. Current findings also support those of Kitzmiller and McGovern (1989), who found very low correlations between severe storm occurrences and 3- or 6-h time tendencies of VAS-derived stability and moisture.

Our pairing methodology might be considered a rather harsh evaluation because it does not consider horizontal patterns of VAS-derived tendencies. Since operational retrievals typically are made at spacings of approximately 100 km in clear regions, they have the potential for providing mesoscale resolution of tendency features. In fact, several case studies have employed VAS data advantageously to detect areas of rapid atmospheric changes. Mostek et al. (1986) and Fuelberg et al. (1991) utilized specially prepared retrievals, not the operational versions evaluated here, while Zehr et al. (1988) and Ellrod (1989) employed the standard operational retrievals. Our results indicate that VAS will detect large sounding changes most accurately, especially if they occur over a deep layer. VAS-derived precipitable-water trends appear to be the most accurate of the trends investigated.

Based on the work of Hillger and Purdom (1990), Hillger and Vonder Haar (1988), and Hoepner and Fuelberg (1992), it appears that the VAS spin budget and operational simultaneous physical algorithm could be modified to produce improved results, subject to operational time constraints. The GOES-Next series of satellites also may yield improved retrievals. Whatever their limitations, satellite remote sensing offers the only foreseeable means for obtaining the global information about the atmosphere that is needed in environmental and meteorological studies.

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