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A PRELIMINARY ASSESSMENT OF THE ACCURACY OF SELECTED METEOROLOGICAL PARAMETERS DETERMINED FROM NIMBUS 6 SATELLITE PROFILE DATA

by

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1. INTRODUCTION

Satellites provide meteorologists with an overall view of the atmosphere and may observe several synoptic-scale weather systems at one time. The potential for the use of satellites is great since one instrument system may take atmospheric soundings over the entire earth at almost any spatial resolution. Another advantage is that satellites could provide soundings in data-sparse regions, such as over oceans.

Rawinsonde and satellite measurements are not totally equivalent. Rawinsonde data represent essentially point measurements, while satellite data represent mean values for an area around the sounding point. Satellites have contributed little quantitative data of value in atmospheric analysis in areas where rawinsonde data are adequate; but in areas where rawinsonde data are sparse, satellites have made a significant contribution. The accuracy and representativeness of satellite data remain poorly understood. A study of the capabilities of satellites as compared to rawinsonde capabilities should improve this understanding.

The objective of this research is to examine the capabilities of satellites relative to rawinsondes to measure various meteorological variables. The variables can be classified into "basic," such as temperature and moisture which are the quantities computed from radiance measurements, and "derived", which are computed from the basic quantities, such as geopotential height, gradients, advection, and others.

There have been many studies to determine the accuracy of rawinsonde data. Lenhard (1970) stated that Leviton and Johannessen reported an rms error for temperature of 1°C in 1953. Case (1962) adopted an rms error of 0.7°C based on laboratory results. Hodge and Harmantas (1965) found the rms error to be 0.5 C. More recently, Wheeler (1968) reported 0.36°C and Lenhard (1970) 0.30°C. The rms error for moisture measurements has been

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less varying with time and was estimated at 10% for relative humidity by Case (1962). Fuelberg (1974) used the same estimate for the Atmospheric Variability Experiment (AVE) data.

As the quality of satellite data improves, satellites are playing greater roles in providing data for atmospheric analysis. Initially, meteorological satellites were used only for cloud photography, but more recently weather satellites have advanced to the point of providing vertical profiles of temperature and moisture (Smith _et al._, 1972). Smith (1969) found that patterns of geopotential height determined from satellite data are similar to those determined from rawinsonde data. Temperature and humidity profiles have been shown to have essentially the same characteristics in the Nimbus III satellite data as in rawinsonde data (Rosenkranz _et al._, 1972). Other studies also indicate that satellite fields of temperature, geopotential height, and the lapse rate of temperature correspond quite closely to those determined from rawinsonde data (Scoggins _et al._, 1977). Moisture flux computed from satellite data also compares favorably (Negri _et al._, 1977) with that computed from rawinsonde data.

For most areas of the world, mesoscale systems are important in local forecasts. Numerous studies have led to the conclusion that mesoscale systems embedded within the general synoptic-scale weather patterns are often responsible for the development and maintenance of convective activity (Fankhauser, 1969; Lewis _et al._, 1974). Since both satellite and rawinsonde soundings are being utilized in synoptic analysis, a comparison is needed of capabilities of the two systems for determining various mesoscale features.

The Atmospheric Variability Experiments (AVE) have provided an excellent source of rawinsonde data. These experiments consist of soundings taken every three hours over the Eastern and Central United States. Several studies have been conducted which relate synoptic-scale conditions to convective activity. By use of the AVE II and AVE IV data, McCown and Scoggins (1977) examined gradients of temperature, wind speed, geopotential height, and mixing ratio. They found large variability in patterns of gradients over three hours compared to those computed over longer time intervals. They also found that the largest mixing ratio gradients occurred near convective activity. Wilson and Scoggins (1976) related conditions during AVE II to areas of convective activity and found that large changes in stability, vertical motion, and moisture were associated with convection. Read and Scoggins (1977) studied the vorticity budget of the AVE IV data, and found that the observed local tendency of vorticity was usually positive in convective areas with an order of magnitude of 10^{-10} sec^{-2}. They also found that the production of vorticity through divergence was highly correlated with convective activity.

The previously mentioned studies, along with many others, have shown relationships between synoptic-scale conditions and convective activity. Similar determinations for satellite data have been very limited. Hillger and Von der Haar (1977) used satellite-derived data to detect mesoscale features. Their results showed that present satellite capabilities permit partial resolution of moisture and temperature variations on this scale. They also found that significant synoptic features can be detected, such as cold troughs and large horizontal moisture gradients.

In a study using data over the Central United States, Moyer et al. (1978) have computed averages and standard deviations of the differences between satellite and rawinsonde data as a function of pressure for temperature, geopotential height, geostrophic wind speed, dew point, and lapse rate of temperature. Their study forms the foundation for the specification of satellite errors used in this research. The differences between rawinsonde and satellite sounding data calculated in their study are used to evaluate the rms errors of the "basic" variables for the Nimbus 6 satellite data. The other source is previously documented rms errors for rawinsonde data. The rms errors of "derived" parameters will be calculated through a propagation of error analysis. The result will be two sets of rms errors of meteorological variables: one set for satellite data and the other for rawinsonde data. Comparisons will be made between the rawinsonde and satellite rms errors of measured and derived quantities as well as between the rms errors and average and near-extreme values of the parameters determined from the AVE data.

2. INFORMATION USED IN ERROR PROPAGATION ANALYSIS

a. Rawinsonde

The rms errors of basic meteorological variables are important in determining errors in derived quantities. The rms errors in temperature, mixing ratio, geopotential height, and wind speed for rawinsonde data have been considered from several sources (Case, 1962; Lenhard, 1970; and Fuelberg, 1974). The assumed rms errors for these parameters are presented in Table 1. It should be noted that the computation of the rms errors in geopotential height was based on an rms error for temperature of 0.3 C. The rms errors in mixing ratio were calculated by taking 10% of the saturation mixing ratio at each specified pressure level for a standard atmosphere; the dryness present at 200 mb has no associated rms error for moisture. The rms errors in wind speed were taken from Fuelberg's study which utilized a more sophisticated filtering of the angle data than is normally used. The rms errors for rawinsonde data in Table 1 will be used in this study to determine the rms errors for derived variables.

Table 1. Assumed rms errors for rawinsonde data.

Pressure (mb)	Temperature (°C)	Geopotential Height (gpm)	Wind Speed (m sec^{-1})	Mixing Ratio (g kg^{-1})
850	0.3	2.0	1.0	0.69
700	0.3	6.0	1.7	0.40
500	0.3	10.0	3.0	0.15
200	0.3	30.0	5.7	----

b. Satellite

Errors in satellite data were taken from a study by Scoggins *et al.* (1977) who determined discrepancies between rawinsonde and satellite variables as a function of pressure. A more recent study by Moyer *et al.* (1978) presents slightly different values than used in this study. A major problem encountered in comparing the two types of data by Scoggins *et al.* and Moyer *et al.* was that rawinsonde stations and satellite sounding points do not coincide geographically or in time. The satellite soundings were taken at 1700 GMT, whereas the rawinsonde soundings were taken at 1200 and 0000 GMT. To facilitate comparison, the rawinsonde soundings were interpolated linearly in time to obtain approximate atmospheric conditions at 1700 GMT.

Fields of various parameters were prepared using a gridding procedure for both the satellite and interpolated rawinsonde for 1700 GMT. The fields were then compared on constant pressure surfaces by computing means and standard deviations of the differences using gridded data. This procedure was repeated at several pressure levels. This analysis technique was applied to several geographic areas to determine the effects of topography, air mass, and cloud cover on the differences between the two types of data.

The geographic locations examined were the Central United States, the Western United States, Canada, and the Caribbean. Their results show variations in the means and standard deviations of the differences, which can partially be explained by the differences in the atmospheric structure and radiative characteristics of the ground at these various geographic locations. For example, the tropopause height is lower in Canada than in the Caribbean, which causes a variation in altitude where the temperature differences associated with the tropopause were greatest.

The average and standard deviation of the differences between rawinsonde and satellite temperatures (SAT-RW) as a function of pressure for the Central United States are presented in Fig. 1. Discrepancies in both the mean and standard deviation are less than 2°C throughout the entire sounding. The smallest average discrepancies occur in the middle troposphere, and the largest near the tropopause. The standard deviation of the differences is between 1° and 2°C between 850 and 100 mb. Staelin et al. (1973) and Hillger and Von der Haar (1977) found similar differences in comparisons of temperature profiles of satellites to those of rawinsondes.

Scoggins et al. (1977) computed discrepancies similar to those in Fig. 1 for several variables. Table 2 contains the standard deviations of the discrepancies between satellite and rawinsonde data for several variables for the Central United States. The discrepancies found in the temperature are smaller than those of moisture (dewpoint). These discrepancies contain both rawinsonde and satellite rms errors. In order to obtain rms errors in satellite data, a propagation of error technique was applied. This procedure will be specified in Section 4.

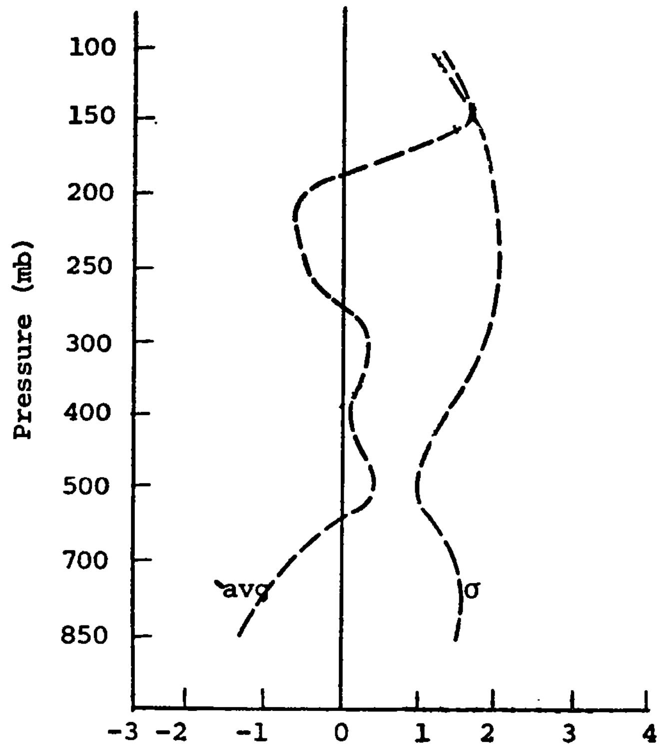


Fig. 1. Average and standard deviations of differences between temperature measured by rawinsonde (RW) and satellite (SAT) for the Central United States (from Scoggins *et al.*, 1977).

Table 2. Standard deviations of the differences between rawinsonde and satellite data over the Central United States (from Moyer, *et al.*, 1978).

Pressure level (mb)	Temperature (°C)	Dew-point (°C)	Mixing Ratio (g/kg)
850	1.51	4.45	5.9
700	1.57	4.91	2.7
500	0.93	6.87	0.9
200	1.94	--	--

Scoggins *et al.* (1977) also found a wide range of rms discrepancies between satellite and rawinsonde data for the four areas examined. They found the discrepancies to depend on geographic location and to vary with pressure (altitude). The discrepancies for the Central United States were used in this research in determining satellite rms errors in the basic meteorological variables. This geographic location was chosen because of its proximity to the AVE data to which many subsequent comparisons are made, and because the magnitudes of the discrepancies between satellite and rawinsonde data for this area are intermediate to the other areas and, therefore, may be considered representative.

c. Specification of means, standard deviations, and near extreme values of gradients of meteorological parameters

The magnitudes of rms errors in the measured (basic) or derived quantities relative to observed magnitudes of these quantities, determine the relative accuracy at which these quantities can be measured. Therefore, reasonable estimates of average and near-extreme values of variables or terms evaluated from rawinsonde data are needed for comparisons with corresponding satellite data. Results from AVE studies are used to establish these values for vorticity, advection, etc.

By using data from AVE II and AVE IV, McCown and Scoggins (1977) calculated gradients over a 315-km interval for several variables. They determined average and near-extreme gradients at four pressure levels for both experiments. The average gradients were determined from the entire gridded field at each pressure level, and the near-extreme gradients were the largest found over any 315-km interval at each pressure level. Data taken from this study are presented in Table 3. The magnitudes of the gradients in AVE II are larger than in AVE IV because of differences in the synoptic situations. The near-extreme values are approximately three standard deviations from the means, which suggest that the variables are normally distributed.

In another study of gradients near convective regions, Ninomiya (1971) found results similar to those listed in Table 3. Sanders and Paines (1975) found mean and near-extreme values of gradients similar to, but slightly larger than, those found in the AVE data when they examined a convective storm region. Miller (1967) found moisture gradients similar to those of McCown and Scoggins (1977). With other studies reporting atmospheric gradients similar to those of the AVE data, the values in Table 3 appear reasonable and were used in this research to represent typical atmospheric conditions.

Table 3. Averages, standard deviations, and near extremes of gradients in AVE II and AVE IV (from McCown and Scoggins, 1977).

Parameter	Pressure Level	AVE II			AVE IV		
		Mean	Max	Std Dev	Mean	Max	Std Dev
Height (m/315 km)	850 mb	41.2	119.4	21.8	28.1	70.7	16.9
	700 mb	54.2	137.3	26.8	37.5	89.3	15.5
	500 mb	77.3	225.8	42.2	56.5	130.7	17.1
	200 mb	104.6	315.9	54.1	95.9	212.3	29.0
Temperature (°C/315 km)	850 mb	3.4	10.5	1.9	3.3	11.9	1.9
	700 mb	3.4	9.6	2.0	2.7	7.0	1.2
	500 mb	3.4	12.6	2.6	2.2	5.2	1.1
	200 mb	3.8	16.6	2.3	2.0	6.5	1.2
Windspeed (m/s/315 km)	850 mb	6.6	21.5	3.7	6.3	21.7	3.8
	700 mb	6.9	18.9	3.6	6.7	19.8	3.8
	500 mb	9.6	29.7	5.2	6.8	21.2	3.8
	200 mb	12.7	65.7	7.6	8.4	31.5	5.2
Mixing ratio (gm/kg/315 km)	850 mb	3.1	10.8	2.2	2.6	9.4	1.6
	700 mb	2.3	7.8	1.4	2.0	6.0	1.1
	500 mb	1.0	3.8	0.7	0.8	2.7	0.6

3. PROPAGATION OF ERROR

The method of analysis used in this study is presented by Deming (1943) and is as follows. If Q is a function of x, the linear term in a Taylor's series can be used to express the effect on Q of a small error in x. If Δx is the error in x, the resulting error in Q is

$$\Delta Q = \frac{\partial Q}{\partial x} \Delta x \tag{1}$$

which shows that the error in Q is linearly proportional to the error in x. The relationship of the errors is not necessarily linear except when Q is a linear function of x, but the linear relationship is closely approximated when Δx is small, or when the higher derivatives of Q are small. The higher derivatives will be neglected in this study; Eq. 1 will be used to represent the relationship between ΔQ and Δx.

Meteorological parameters usually are a function of several variables. The error in a parameter that is a function of several variables can be expressed through a Taylor series. If Q is a function of x_i $(i=1,2,3\ldots n)$, and if x_i is in error by Δx_i, the error in Q can be expressed as

$$\Delta Q = \frac{\partial Q}{\partial x_1} \Delta x_1 + \frac{\partial Q}{\partial x_2} \Delta x_2 + \frac{\partial Q}{\partial x_3} \Delta x_3 + \ldots \frac{\partial Q}{\partial x_n} \Delta x_n . \tag{2}$$

Squaring and averaging Eq. 2 gives

$$\sigma_Q^{\ 2} = \left(\frac{\partial Q}{\partial x_1}\sigma_{x_1}\right)^2 + \left(\frac{\partial Q}{\partial x_2}\sigma_{x_2}\right)^2 + \left(\frac{\partial Q}{\partial x_3}\sigma_{x_3}\right)^2 + \ldots$$

$$+ 2\left(\frac{\partial Q}{\partial x_1}\frac{\partial Q}{\partial x_2}\sigma_{x_1}\sigma_{x_2} r_{x_1x_2} + \frac{\partial Q}{\partial x_1}\frac{\partial Q}{\partial x_3}\sigma_{x_1}\sigma_{x_3} r_{x_1x_3} \ldots\right) \tag{3}$$

where σ_Q is the standard deviation of the error in Q, σ_{x_i} is the standard deviation of the error in x_i, and $r_{x_ix_j}$ are the correlations between Δx_i and Δx_j. If the errors in x_1, x_2, $x_3 \ldots x_n$ are independent, the correlations become zero. If Δx_i are small compared to $\frac{\partial Q}{\partial x_i}$, and if the terms involving squares, higher powers, cross products of Δx_i, and higher derivatives are negligible, Eq. 3 becomes

$$\sigma_Q^{\ 2} = \left(\frac{\partial Q}{\partial x_1}\sigma_{x_1}\right)^2 + \left(\frac{\partial Q}{\partial x_2}\sigma_{x_2}\right)^2 + \ldots \left(\frac{\partial Q}{\partial x_n}\sigma_{x_n}\right)^2 \tag{4}$$

which expresses the standard deviation of the error in Q in terms of the standard deviation of the errors in x_i. This equation can be used to determine the standard deviation of the error in any meteorological quantity if the standard deviations of the errors in the independent variables are known. The magnitude of the derived errors relative to the mean and near-extreme values of the quantities themselves can be interpreted in terms of how accurate a given quantity can be computed on a probability basis when a normal or Gaussian distribution is assumed.

The propagation of error technique presented here will be used to derive rms errors for computed quantities using errors specified in basic parameters for both rawinsonde and satellite. These errors will be compared to determine how accurately the parameters can be determined from satellite data relative to rawinsonde data. Means and near-extreme values of some quantities are presented for comparison with the derived rms errors.

4. SPECIFICATION OF ERRORS IN SATELLITE PARAMETERS

Standard deviations of the differences between satellite and rawinsonde soundings have been considered, but errors per se in satellite data have not. The standard deviations contain both rawinsonde and satellite rms errors and, therefore, represent a measure of the difference between the two data-gathering systems, rather than the rms error for the satellite observations alone. Deming (1943) shows that the standard deviation of the sum or difference between variables A and B ($\sigma_{S \text{ or } D}$) that have rms errors of σ_A and σ_B, is given by:

$$\sigma^2_{S \text{ or } D} = \sigma_A{}^2 + \sigma_B{}^2. \quad (7)$$

This equation was used to compute satellite rms errors for the basic variables. The equation becomes

$$\sigma_{SAT} = [\sigma_{DIF}{}^2 - \sigma_{RW}{}^2]^{1/2} \quad (8)$$

where σ_{DIF} is the standard deviation of the differences between rawinsonde and satellite data, σ_{RW} is the rms error in rawinsonde data, and σ_{SAT} is the rms error in satellite data. Equation 8 was applied using the rawinsonde rms errors and the standard deviations of the differences between rawinsonde and satellite data presented previously.

With the rms errors in the basic meteorological variables for both rawinsonde and satellite, the propagation of error technique presented in Section 3 was used to determine the rms error for selected derived meteorological parameters computed from both rawinsonde and satellite measurements. Satellite rms errors were then compared to corresponding rawinsonde rms errors for both basic and derived meteorological variables, and to mean and near-extreme values of these variables determined from AVE data.

5. RESULTS

a. RMS Errors in Basic Variables

A comparison of the rms errors in basic variables for rawinsondes with those of satellites is presented in Fig. 2. Satellite rms errors are larger than those for rawinsondes at all pressure levels for all variables. Both satellite and rawinsonde rms errors in geopotential height and wind speed increase with height. Satellite rms errors for temperature are between 1° and 2°C with a minimum near 500 mb, while the assumed rms error in rawinsonde temperature is constant with pressure. The rms errors for geopotential height for both systems are similar in magnitude and variation with height. RMS

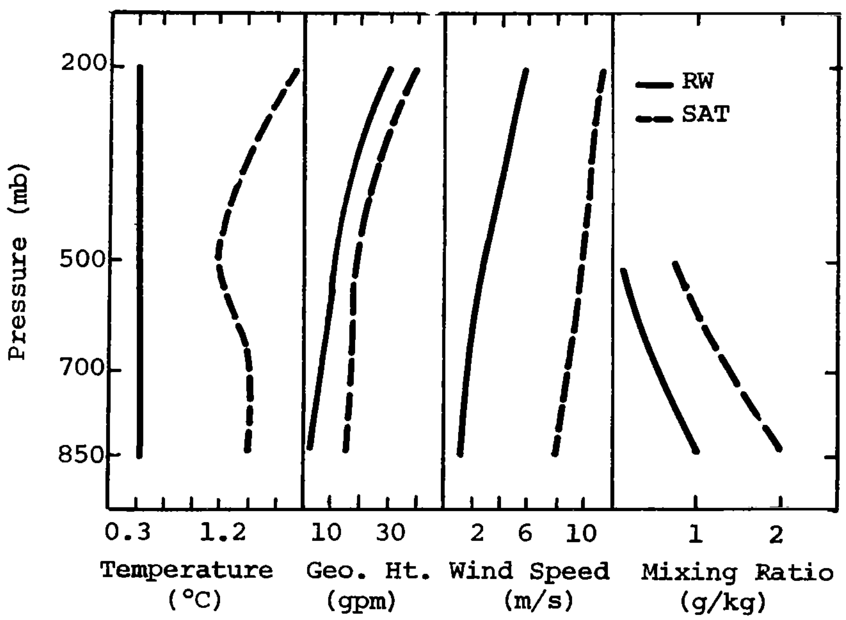


Fig. 2 RMS errors in rawinsonde (RW) and satellite (SAT) profile data.

errors in rawinsonde wind speed are much less than those for satellite data. The satellite errors range from 8 m/sec at 850 mb to 11 m/sec at 200 mb. These errors indicate that most winds encountered in the atmosphere would be subject to large relative errors with only high wind speeds like those near jet streams being detected relatively accurately by the satellite. The decrease in rms errors in mixing ratio with height are associated with the usual decrease in the mixing ratio with height. The large satellite rms errors in mixing ratio would lead to large rms errors in computed quantities. Yet, Negri et al. (1977) was able to determine reasonable values of moisture convergence, and also that satellite moisture distributions correlated well with the AVE data.

The fact that rms errors for rawinsonde data are smaller than those for satellite data does not necessarily indicate that satellite data are poor. In fact, in some cases the errors tend to be relatively small. For example, a 700-mb temperature of 0.0°C ± 2.0°C, and a 500-mb height of 5700 gpm ± 20 gpm are relatively accurate, while a 700-mb mixing ratio of 5 g/kg ± 1.75 g/kg is of fair accuracy, and an 850-mb wind speed of 10 m/sec ± 7 m/sec is not of acceptable accuracy. In many (perhaps most) cases, errors in satellite data are not too large to be useful especially in regions of near extreme values. The poorest satellite measurements are those of wind speed and mixing ratio.

b. RMS Errors in Derived Parameters and a Comparison with Mean and Near-Extreme Values

Many meteorological parameters can be derived from the basic variables discussed in the previous section. Several derived variables have been chosen for this study, and the rms errors in these variables determined for rawinsonde and satellite data. The rms errors for the derived variables were compared to average and near extreme magnitudes determined from AVE II and AVE IV data. Results of these comparisons are presented below.

1) Gradient of temperature. The rms errors calculated for the gradient of temperature are presented in Fig. 3. The rms error for rawinsondes is constant with height and has a value of 0.42C/315 km. Satellites have larger rms errors than rawinsondes at all pressure levels, with values ranging from 1.3C/315 km at 500 mb to 2.74C/315 km at 200 mb. As indicated in the figure, rms errors for rawinsondes are smaller than the mean AVE

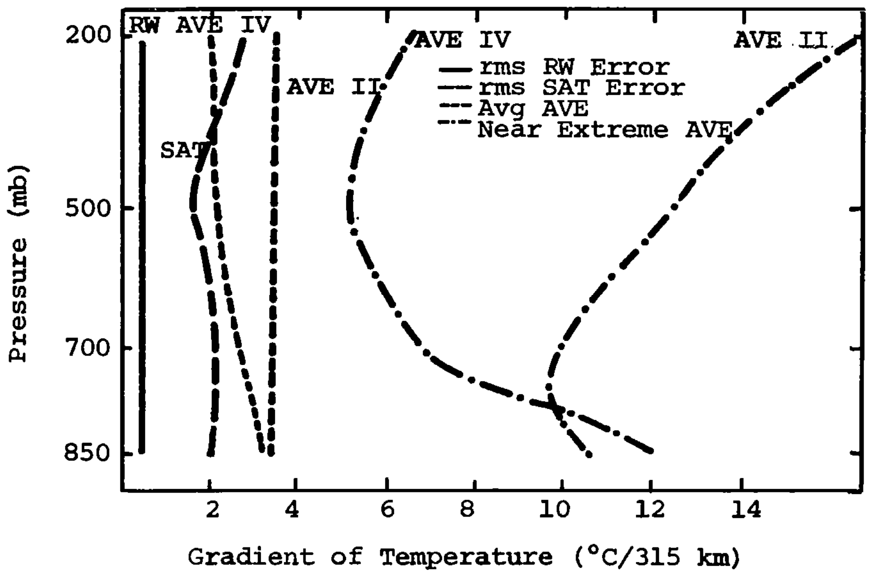


Fig. 3. RMS errors in the gradient of temperature determined from rawinsonde and satellite data compared to mean and near extreme temperature gradients determined from AVE II and AVE IV data as a function of pressure.

values. This means that typical values found in the AVE data are well within the measuring capability of the rawinsonde. The satellite rms errors are less than the mean gradient values of AVE II at all pressures, but above 500 mb the rms errors are larger than the mean AVE IV values. This indicates that above about 500 mb satellite rms errors are too large to permit an accurate determination of the AVE IV mean temperature gradient. Also present in this figure are the near-extreme temperature gradients found in the two AVE data sets. The calculated rms errors for both rawinsondes and satellites are small when compared to these near-extreme gradient values. Consequently, it appears that the near-extreme atmospheric temperature gradients can be determined with relatively good accuracy from both rawinsonde and satellite data. Analyzed fields (not shown) support this conclusion.

2) Gradient of geopotential height. The rms errors in the gradient of geopotential height for rawinsondes and satellites along with the mean and near-extreme geopotential height gradients calculated from the AVE II and AVE IV data are presented in Fig. 4. The rms errors for rawinsondes are smaller than those for satellites at all pressure levels. The rms errors for both rawinsondes and satellites reach a maximum at 200 mb. Both the satellite and rawinsonde rms errors are smaller than mean AVE gradients at all levels, while the magnitudes of near-extreme AVE gradients are much larger than the rms errors for either type of data. Therefore, both rawinsonde

and satellite data have rms errors small enough to distinguish gradients of geopotential height normally encountered in the atmosphere, but again rawinsondes have the greater accuracy. It should be noted that the larger gradients can be determined with a greater relative accuracy than the smaller gradients. This means that regions of strong wind can be determined with greater relative accuracy than regions with light wind.

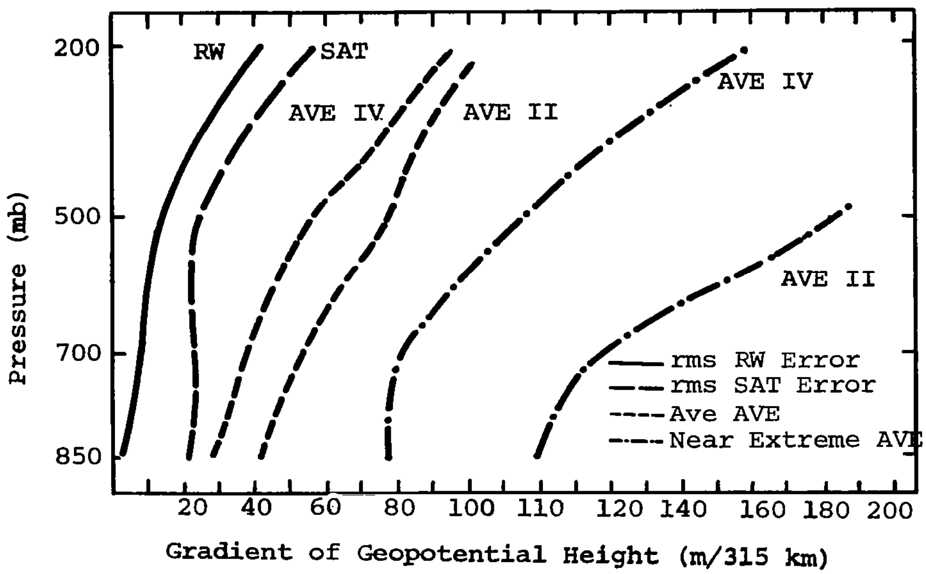


Fig. 4. RMS errors in the gradient of geopotential height determined from rawinsonde and satellite data compared to the mean and near-extreme geopotential height gradients determined from AVE II and AVE IV data as a function of pressure.

3) Gradient of mixing ratio. The rms errors in the gradients of mixing ratio for rawinsondes and satellites are presented in Fig. 5. The rms error in rawinsonde gradients is from approximately 1.0 g/kg/315 km at 850 mb to 0.27 g/kg/315 km at 500 mb. Satellite rms errors range from 2.83 g/kg/315 km at 850 mb to 1.27 g/kg/315 km at 500 mb. Rawinsonde rms errors are smaller than satellite rms errors as well as the average values

found in AVE II and AVE IV, while the satellite rms errors are about equal to the average AVE values at all pressures. This means that the satellite measurements of mean moisture gradients would be subject to large relative errors. However, the near-extreme gradients determined from AVE II and AVE IV data are considerably larger than the rms errors for both satellite and rawinsonde, indicating that data from either system could be used to determine these gradients with relatively good accuracy. Data in Fig. 5 show that both mean and near extreme gradients of mixing ratio can be measured quite accurately by the rawinsonde system.

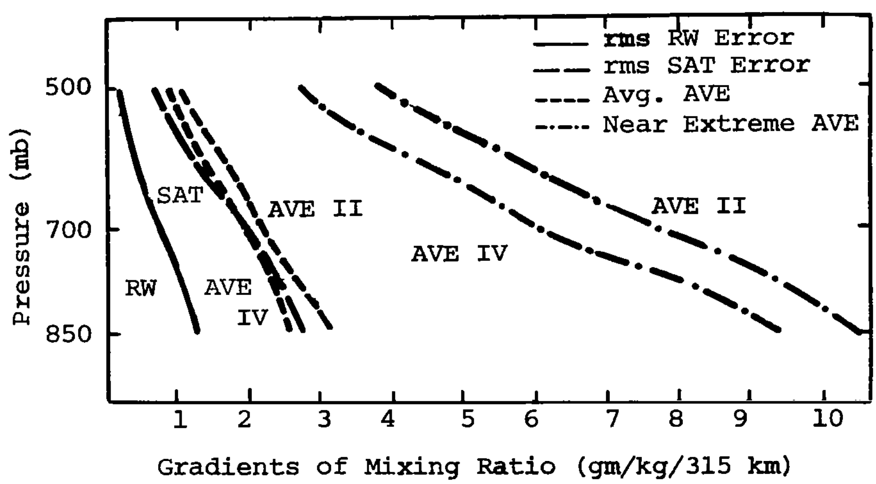


Fig. 5. RMS errors in the gradient of mixing ratio for rawinsonde (RW) and satellite (SAT) compared with average and near-extreme gradients determined from AVE II and AVE IV data.

4) Gradient of wind speed. The RMS errors calculated for the gradient of wind speed for both rawinsonde and satellite are presented in Fig. 6. The profile of errors in rawinsonde data shows a gradual increase in magnitude

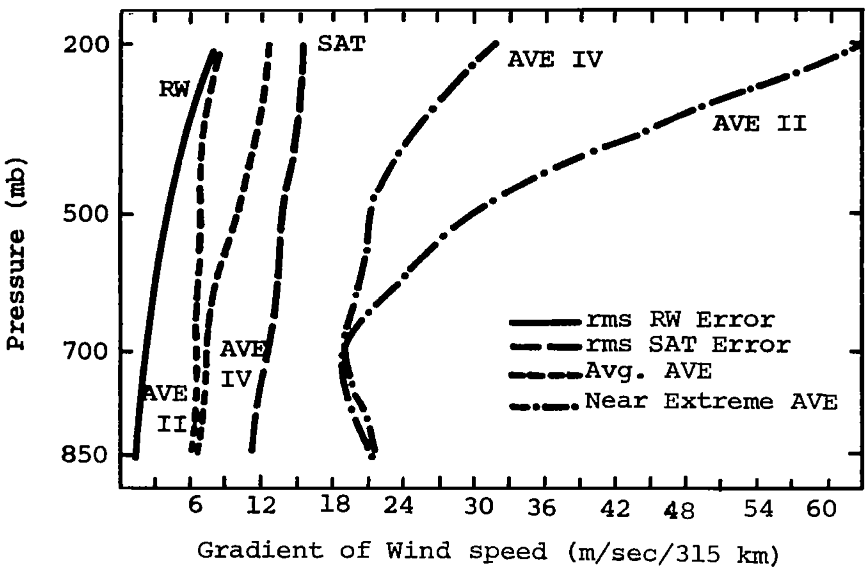


Fig. 6. RMS errors in the gradient of wind speed for rawinsonde (RW) and satellite (SAT) compared with average and near-extreme gradients determined from AVE II and AVE IV data.

with altitude from approximately 2 m/sec/315 km at 850 mb to 6 m/sec/315 km at 200 mb. The corresponding range for satellite errors is 11 to 14 m/sec/315 km. The rms errors for rawinsonde are less at all altitudes than the average gradients in both AVE II and AVE IV, while the satellite rms errors are larger than the average gradients in both AVE experiments at all altitudes. These results suggest that average gradients of wind speed (wind shear) can be determined from rawinsonde data but not from satellite data. The relative accuracy of gradients in wind speed determined from rawinsonde data decreases with altitude in both AVE II and AVE IV with the magnitude of the rms errors approaching the average AVE IV gradients at 200 mb. The relative accuracy in either case (rawinsonde or satellite) is a function of the magnitude of the average gradients existing at the time.

Profiles of the near extreme gradients in both AVE II and AVE IV shown in Fig. 6 are considerably greater than the rms errors in either the satellite or rawinsonde gradients. There is no question about the capability of rawinsondes to measure the near-extreme gradients in wind speed with reasonable accuracy, but because of the relatively large rms errors in gradients determined from satellite data relatively large errors would result in the extreme gradients determined from satellite data. The relative accuracy of the near-extreme gradients determined from either rawinsonde or satellite data is a function of the magnitude of the near-extreme gradients. In AVE II, a near-extreme gradient above 500 mb would be determined with reasonable accuracy in either case, but below 500 mb the relative accuracy in the gradients determined from satellite data would be rather poor for either AVE II or AVE IV.

5) Advection of temperature. RMS errors in the advection of temperature for rawinsonde and satellite compared with average and near-extreme values in AVE II and AVE IV are shown in Fig. 7. The results show that the rms errors in the advection of temperature due to errors in wind and temperature in rawinsonde data approach the average in the AVE data, and that rms errors in advection determined from satellite data exceed the average for both AVE II and AVE IV. These results show that even for the rawinsonde data, average

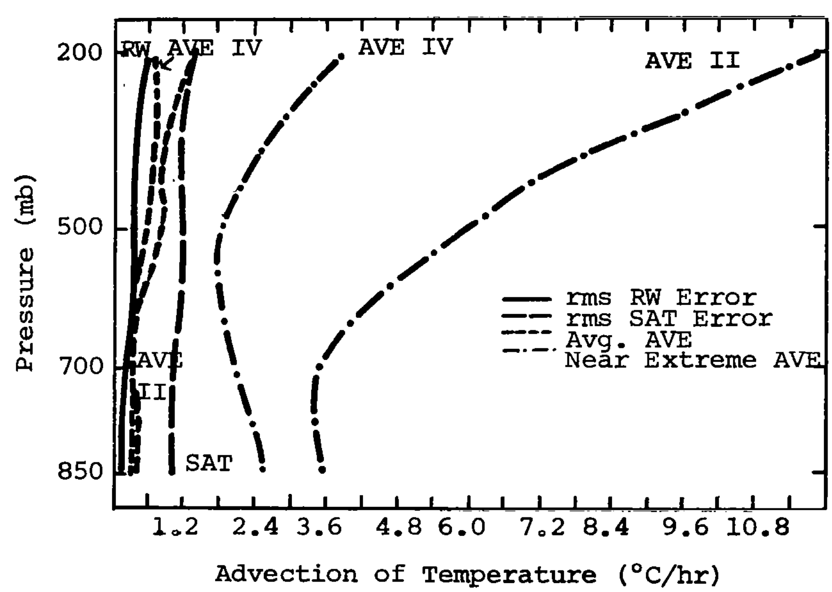


Fig. 7. RMS errors in the advection of temperature for rawinsonde (RW) and satellite (SAT) compared with average and near-extreme values determined from AVE II and AVE IV data.

values for the advection of temperature can not be determined with great accuracy. This result is due to the relatively small average values. However, for both rawinsonde and satellite data, the near-extreme values for temperature advection are larger than the rms errors, although AVE IV near-extreme values are not much larger than rms satellite errors in the mid troposphere. For rawinsonde data, the near-extreme values of temperature advection can be determined with relatively good accuracy for both AVE II and AVE IV, but in the case of satellite data relatively large errors would result in the determination of near extreme gradients in AVE IV. The near-extreme gradients could be determined with relatively good accuracy from satellite data for AVE II. These results are similar to the results discussed above for the gradient of wind speed, and again show that the relative errors in the determination of gradients is a function of the existing meteorological conditions.

6) Vorticity. Profiles of satellite and rawinsonde rms errors in relative vorticity are presented in Fig. 8. The profiles show an increase in

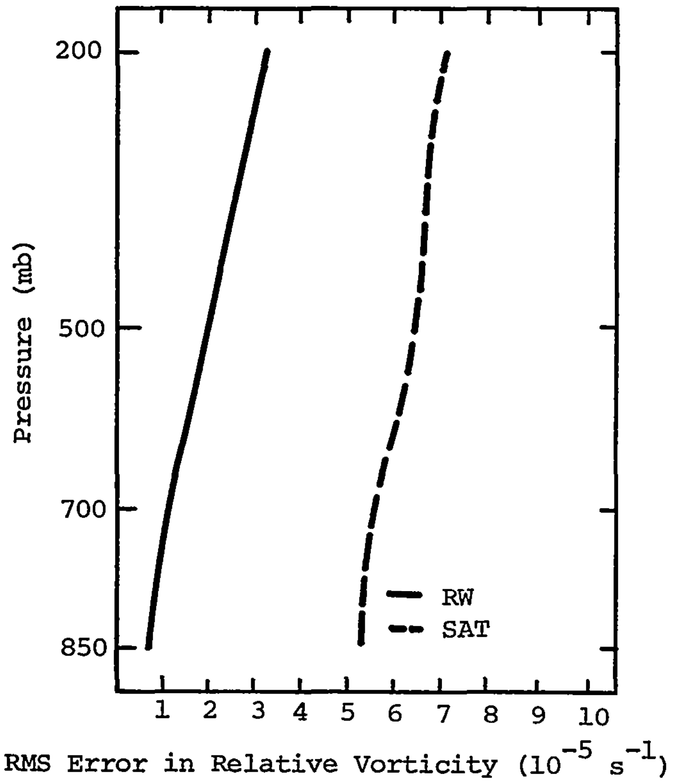


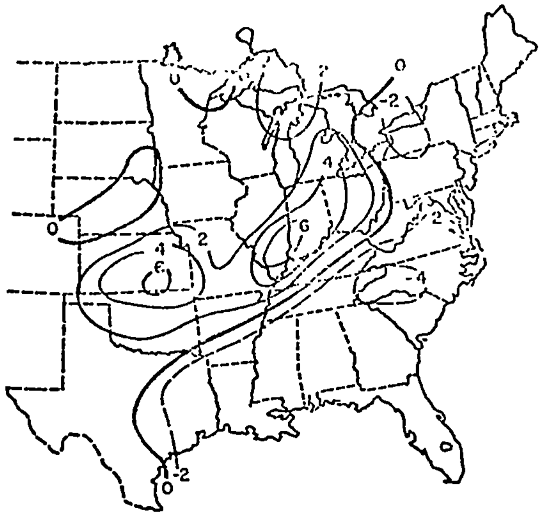
Fig. 8. RMS errors in relative vorticity determined from rms errors in rawinsonde (RW) and satellite (SAT) data.

magnitude with altitude with the satellite errors being considerably greater than rawinsonde errors at all altitudes. The rms errors in relative vorticity determined from rawinsonde data vary from approximately 6 x $10^{-6}sec^{-1}$ at 850 mb to 3.2 x $10^{-5}sec^{-1}$ at 200 mb, while the corresponding values determined from satellite values are 5.3 x $10^{-5}sec^{-1}$ and 6.5 x $10^{-5}sec^{-1}$, respectively. It is clear from Fig. 8 that the rms error in relative vorticity determined from rawinsonde data is considerably smaller than that determined from satellite data, and that rms errors in satellite data would, in most cases, be larger than the expected average magnitude of vorticity and even greater than some maximum and minimum values. The results presented in Fig. 8 indicate that, in most cases, rawinsonde data may be used to determine relative vorticity with acceptable accuracy, while satellite data can be used to determine relative vorticity with acceptable accuracy only when values are quite large.

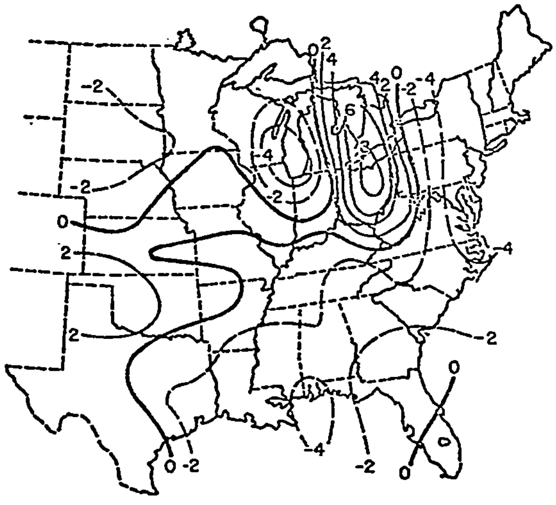
Near-extreme values of relative vorticity are not available for comparison with the rms values presented in Fig. 8. To gain an appreciation of the relative accuracy of rawinsonde and satellite values of vorticity in a typical situation, vorticity fields determined from AVE IV data at 850, 700, and 500 mb are presented in Fig. 9. Over large portions of these charts, and especially in the centers of both positive and negative values, rawinsonde errors are considerably smaller than the magnitudes of the vorticity. This indicates that rawinsonde data are adequate for determining patterns of vorticity relatively accurately. In contrast, even the maximum and minimum values of vorticity from the charts are barely larger than the satellite rms errors. This suggests that errors from vorticity computed from satellite wind are unacceptably large even in centers of modestly high values.

7) Divergence. The equation for the rms error in divergence is identical to that for vorticity. Therefore, the profiles for vorticity in Fig. 8 represent errors in divergence as well. Since the magnitude of divergence is about equal to that of vorticity in synoptic systems, the above discussion on vorticity also applies to divergence.

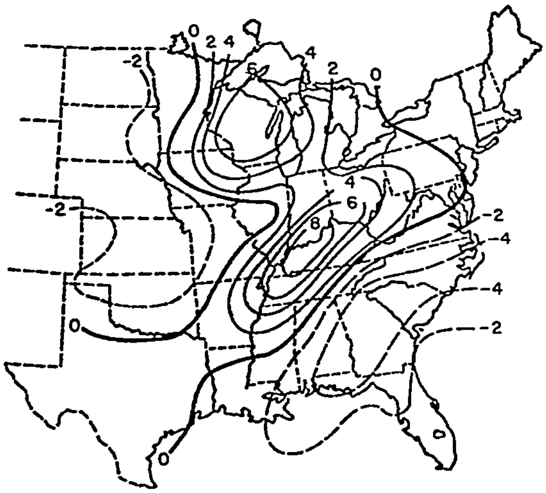
8) Lapse rate of temperature. Profiles of rms errors in the lapse rate of temperature for rawinsonde and satellite data are presented in Fig. 10. RMS errors determined for rawinsonde data are less than 1°C km^{-1} between 850 and 200 mb, while values for satellite are about 2°C km^{-1} below 500 mb and approach 3°C km^{-1} at 200 mb. Computations were performed over 100-mb layers and plotted at the mid-point of the layer. Typical lapse rates in the



(a) 850 mb, 1200 GMT 24 April 1975.



(b) 700 mb, 0000 GMT 24 April 1979.



(c) 500 mb, 1200 GMT 25 April 1975.

Fig. 9. AVE IV fields of relative vorticity ($10^{-5} sec^{-1}$).

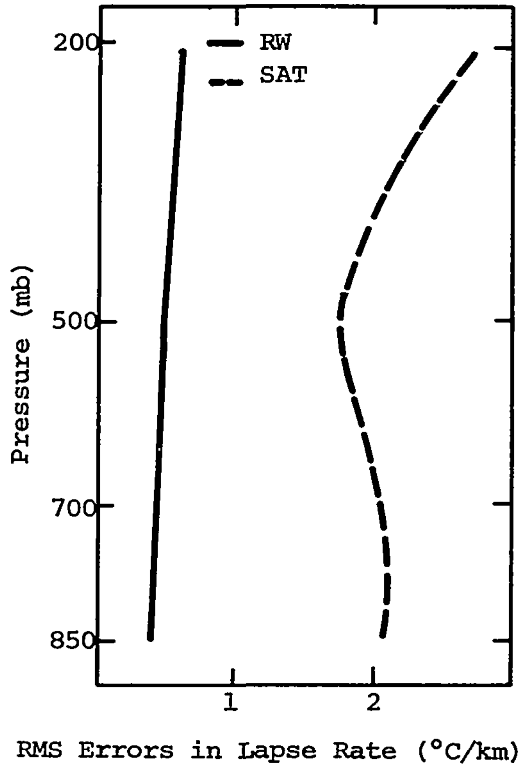


Fig. 10. RMS errors in lapse rate of temperature determined from rms errors in rawinsonde (RW) and satellite (SAT) data.

troposphere are 6-7°C km^{-1} which are considerably larger than the rms errors in Fig. 10 for either rawinsonde or satellite. It should be remembered that satellite temperatures represent volume averages while rawinsonde temperatures represent essentially point values. Thus, only a rather gross estimate of the lapse rate of temperature can be obtained from satellite data and only within a rather deep layer.

6. SYNOPTIC CHARTS PREPARED FROM SATELLITE DATA

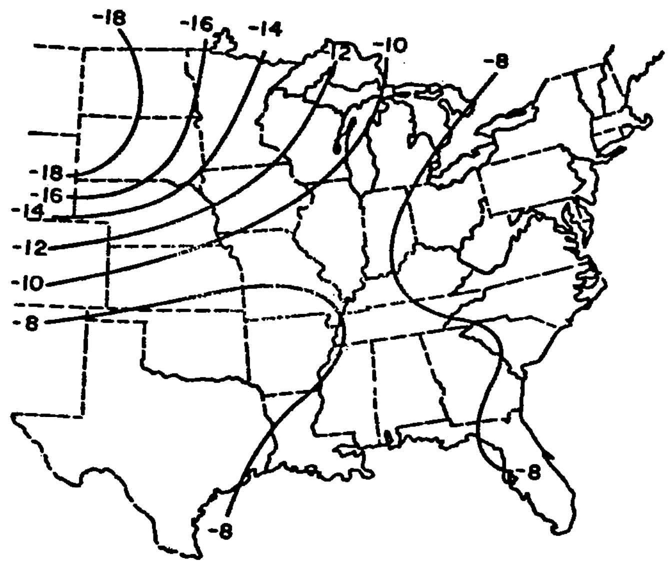
a. Temperature and dew-point temperature

Synoptic charts of temperature and dew-point temperature prepared from rawinsonde and Nimbus 6 satellite data are presented for the purpose of gaining some appreciation for the results presented in Section 5. As shown in Section 5, the rms error for satellite temperature is about 1.5°C, while that for dew-point temperature is about 5°C. Therefore, fields of temperature prepared from satellite and rawinsonde data should show a greater degree of resemblence than those of dew-point temperature. As noted in Section 5, the relative accuracy of a given measurement depends upon the magnitude of the variable being measured. This means that even with relatively large rms errors in a given variable the major characteristics of the field can be detected in the data.

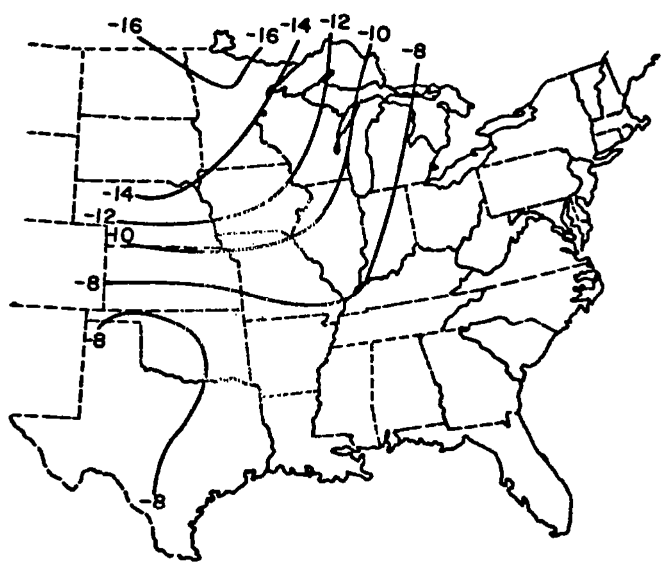
Synoptic charts of temperature prepared from Nimbus 6 satellite and rawinsonde data are presented in Fig. 11. It is evident that the major features shown in the rawinsonde data also appear in the satellite data. The fields differ in areas where the rms error in the gradient of temperature is small compared with the rms error in the gradient (see Fig. 3). Where the gradient is large the fields have a close resemblence. Also, as would be inferred from the rms errors in temperatures for both rawinsonde and satellite (see Fig. 2), the magnitude and position of the contours show close agreement.

Synoptic charts of dew-point temperature prepared from rawinsonde and satellite data are shown in Fig. 12. Because of the larger rms errors in dew-point temperature compared with those in temperature, charts prepared from satellite and rawinsonde data would not be expected to show the same degree of closeness as for temperature. This is evident in Fig. 12 which shows that only the major features of the dew-point temperature field are reflected in the satellite data. Patterns in the satellite fields are poorly defined because of the large rms error in gradients which result from the large rms errors in dew point. Also, the large rms errors in dew point cause variations in the position of contours as is clear from Fig. 12.

While only fields of two variables are shown as examples, the characteristics of these fields in relation to the rms errors in the variables and their gradients illustrate the relationships between the rms errors and the

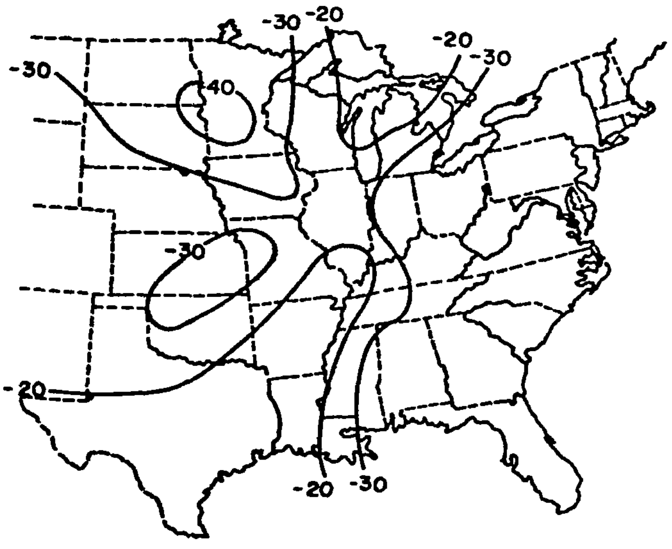


(a) Rawinsonde



(b) Satellite

Fig. 11. Rawinsonde and satellite 500-mb fields of temperature for 1700 GMT 25 August 1975.



(a) Rawinsonde

(b) Satellite

Fig. 12. Rawinsonde and satellite 500-mb fields of dew-point temperature for 1700 GMT 25 August 1975.

representation of the variables on synoptic charts. Satellite data may be used quite effectively in synoptic analysis, but only in some regions of the charts, and when rms errors are known and properly taken into account. The analysis presented in this report should be helpful in this regard.

b. Winds from cloud motions

Cloud motions, determined from SMS satellite data, were calculated by personnel at the Universtiy of Wisconsin for February 6, 1975 at 1800 GMT (fifth time period of AVE III). The ability of these cloud motion vectors to determine the ambient vector wind distribution was evaluated by comparing these data with the rawinsonde-measured winds in AVE III. Cloud motion vectors were calculated at nine levels from 900 mb to 100 mb with a given value representing a mean vector wind 50 mb above and below the assigned level. Approximately 70% of the 190 cloud motion vectors calculated over the AVE III network were located at 500 and 300 mb due to the cloud cover distribution. This limited the effective data comparison to these two levels.

Two methods of comparison were used in evaluating the accuracy of the cloud motion vectors. First, both rawinsonde and satellite-derived winds were plotted on constant pressure charts (500 and 300 mb only) and isotach analyses performed to determine the ability of the satellite winds to measure the spatial distribution of the wind vectors as seen by the AVE III rawinsonde network (Figs. 13-16). Next, relative frequency distributions of wind speed differences (absolute value) between the rawinsonde and satellite-derived winds were calculated as a function of horizontal distance between individual data points at 500 and 300 mb (Figs. 17 and 18). Individual data point comparisons were determined for three distance ranges (51-100 km, 101-150 km, and 151-200 km) on the constant pressure charts for both levels.

The vector wind and isotach analyses at both levels, derived from satellite data, reveal the dominate flow patterns as measured by the AVE III rawinsonde data. The polar jet stream is clearly seen in both the Gulf Coast States and turning northeastward along the Atlantic Coast States. However, exact locations and magnitudes of individual wind velocity centers compare poorly, especially at 300 mb. This difference is at least partly erroneous since the variable density of the satellite data and the spatial resolution of the rawinsonde data makes the determination of the exact

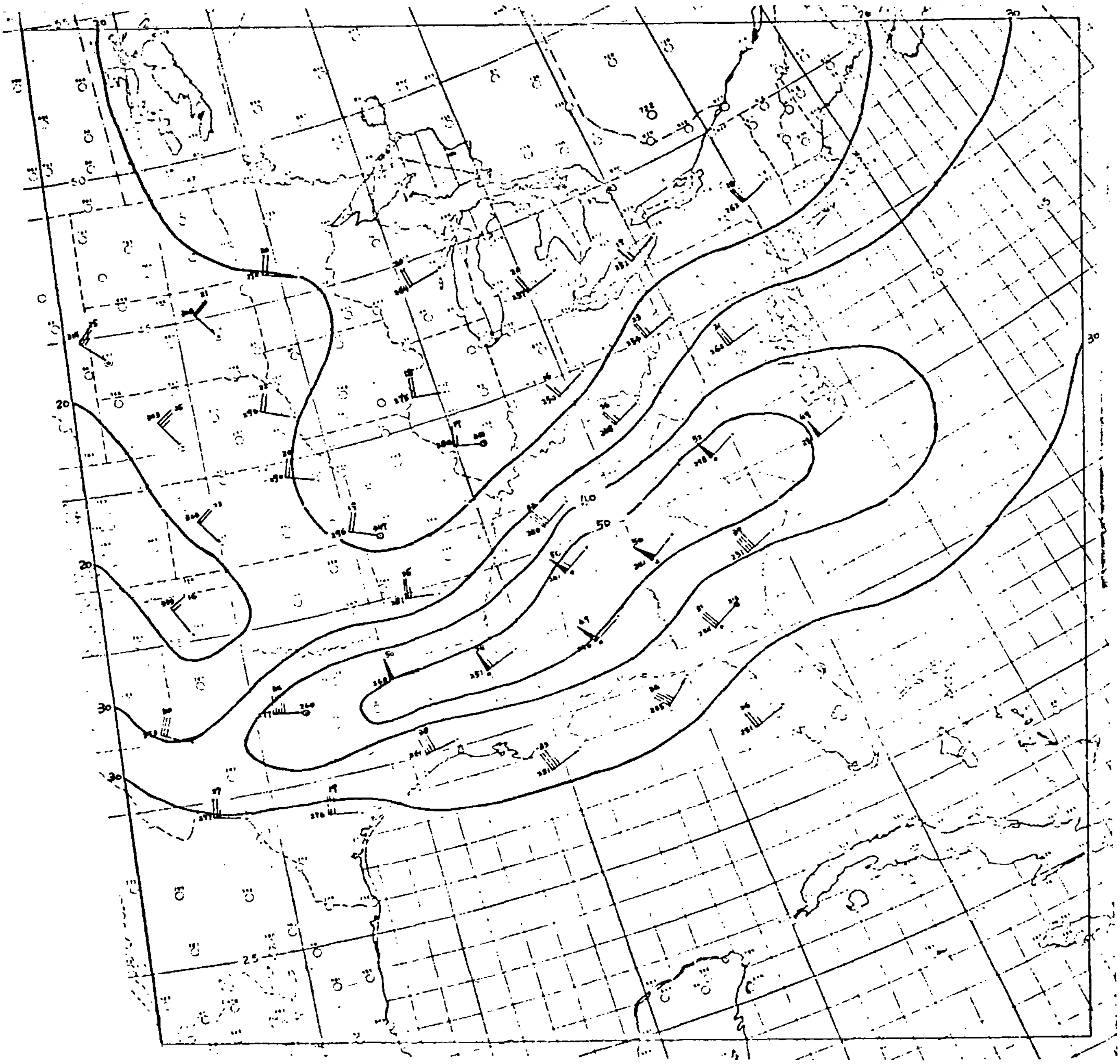


Fig. 13. Rawinsonde Wind and Isotach Analysis (kts.) at 500 mb on February 6, 1975 at 1800 GMT in AVE III.

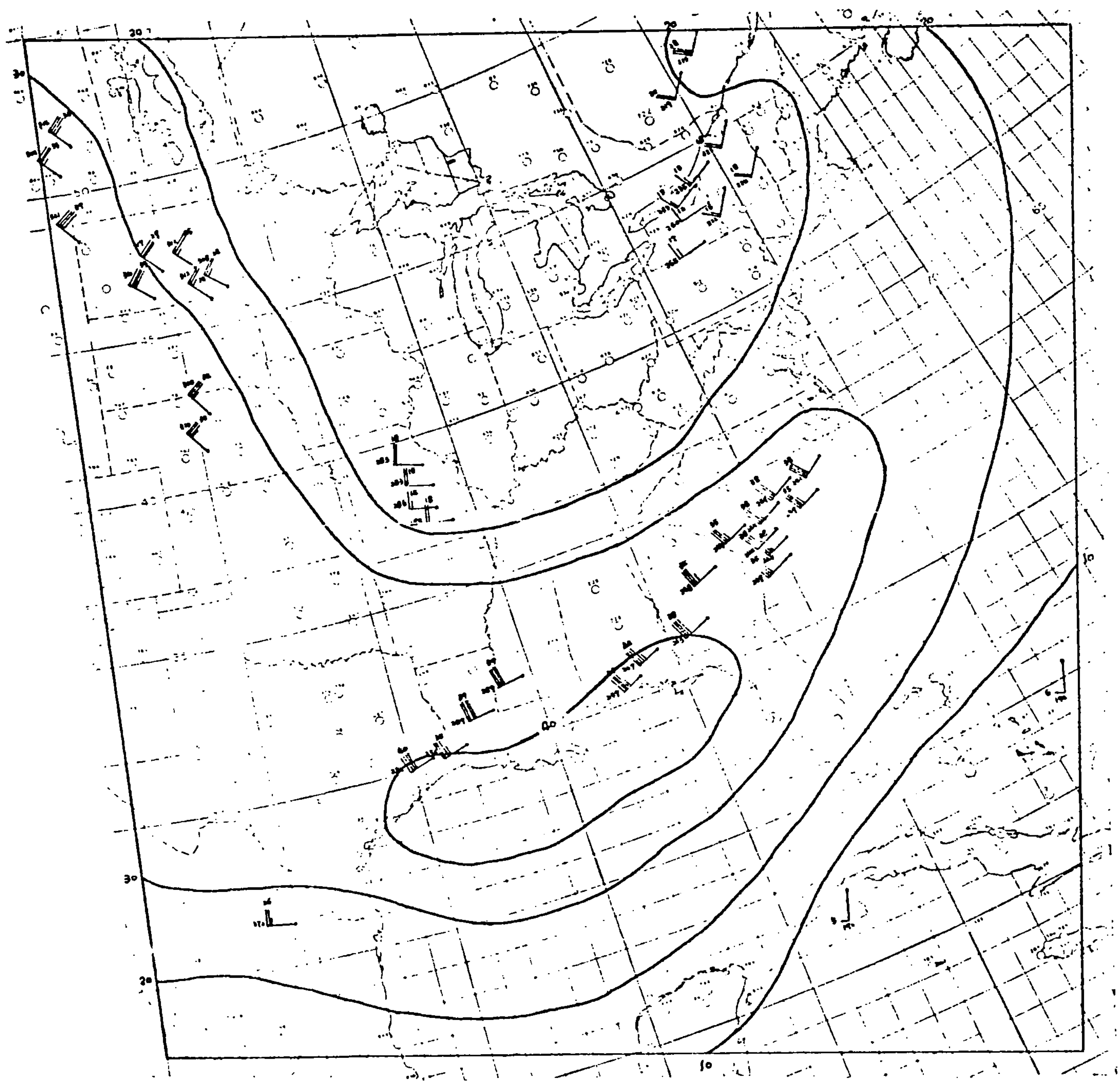


Fig. 14. Satellite Derived Wind and Isotach Analysis (kts.) at 500 mb on February 6, 1975 at 1800 GMT in AVE III.

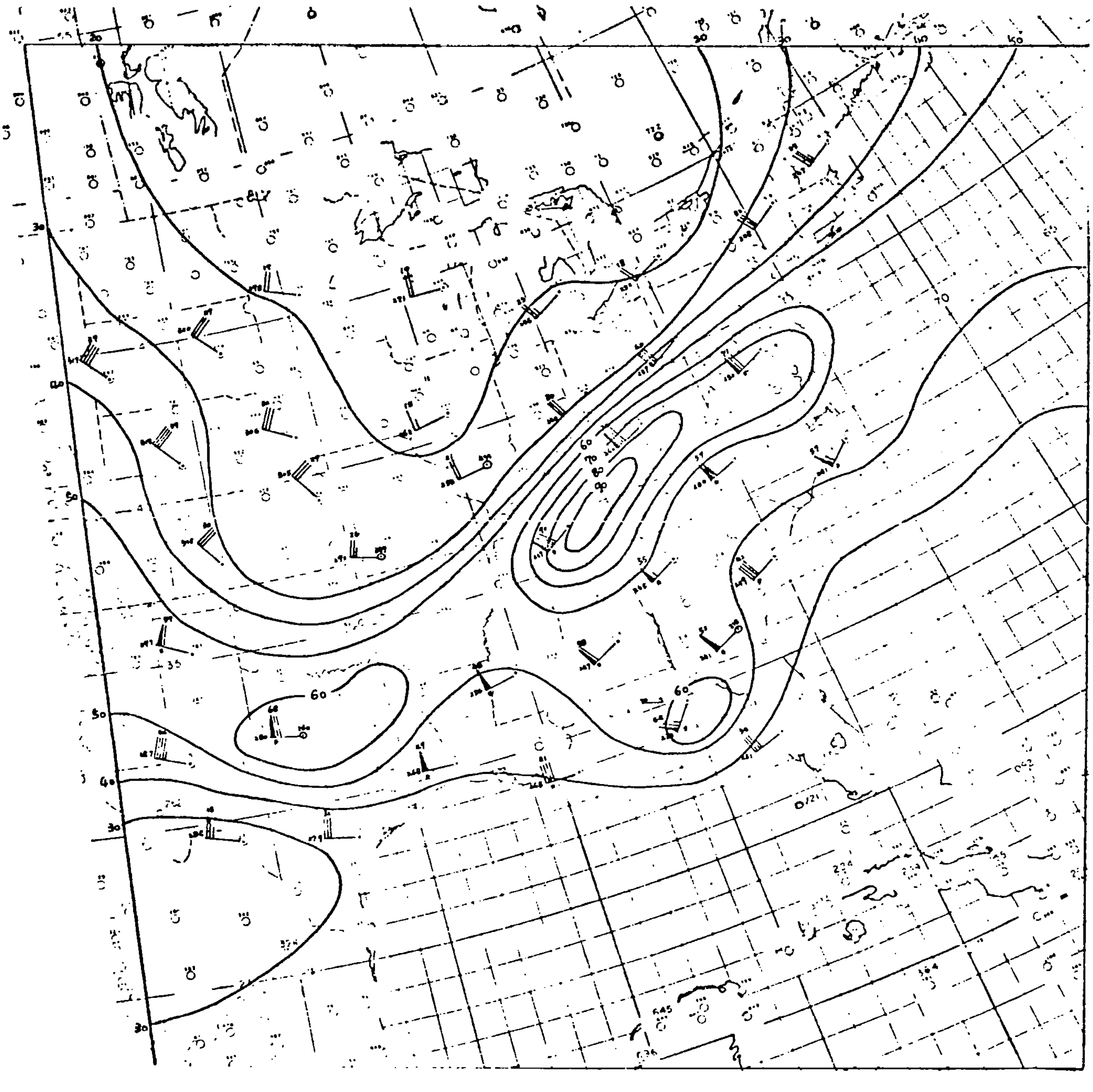


Fig. 15. Rawinsonde Wind and Isotach Analysis (kts.) at 300 mb on February 6, 1975 at 1800 GMT in AVE III.

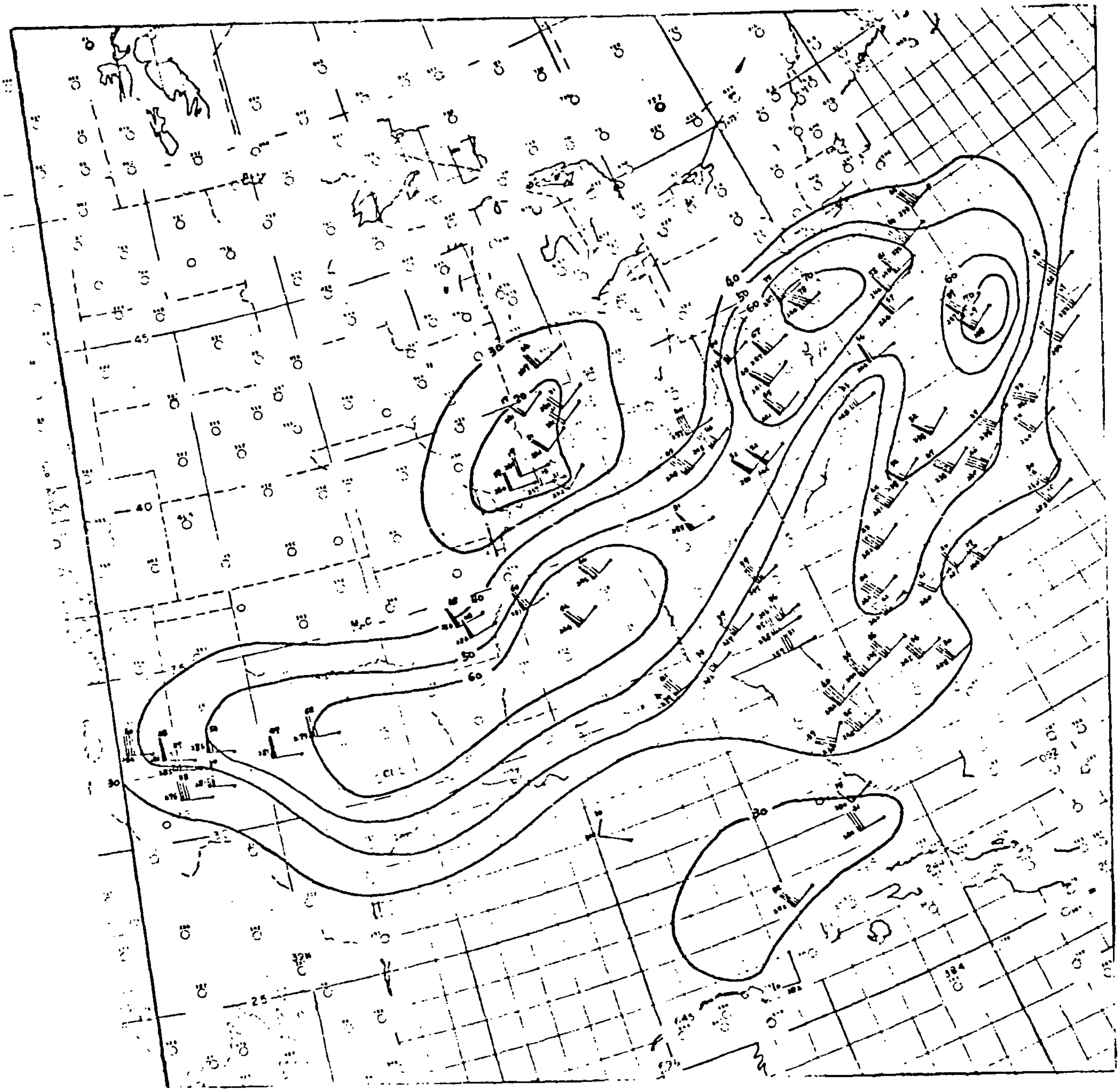


Fig. 16. Satellite Derived Wind and Isotach Analysis (kts.) at 300 mb on February 6, 1975 at 1800 GMT.

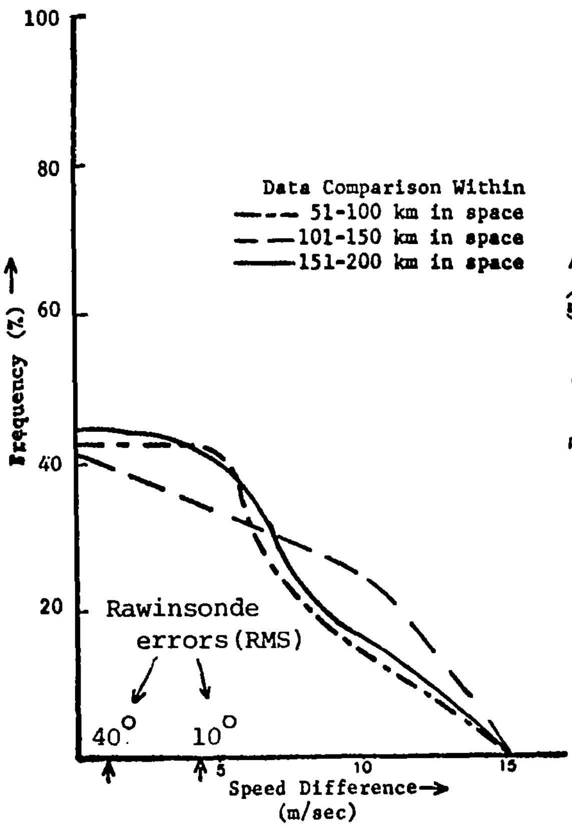


Fig. 17. 500 mb Relative Frequency Distribution of Wind Speed Difference (absolute value in m s^{-1}) between Rawinsonde and Satellite Derived Winds as a Function of Horizontal Distance on Constant Pressure Surfaces.

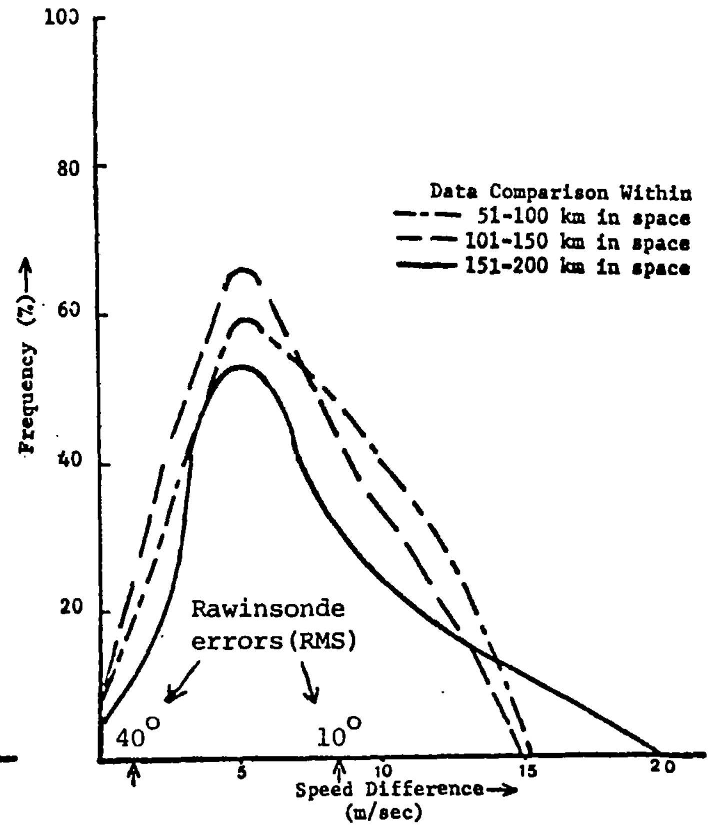


Fig. 18. 300 mb Relative Frequency Distribution of Wind Speed Difference (absolute value in m s^{-1}) between Rawinsonde and Satellite Derived Winds as a Function of Horizontal Distance on Constant Pressure Surfaces.

vector wind distribution over the entire network impossible.

The relative frequency distributions of the wind speed differences (absolute value) for various distance ranges show that individual speed differences range from 0 to 15 m sec^{-1}, and 0 to 20 m sec^{-1} at the 500 mb and 300 mb levels, respectively. However, most differences fall between 0 and 10 m sec^{-1} at both levels, independent of the distance range used in the comparison. The two arrows along the speed difference axis in both figures denotes the range in RMS errors in the AVE III wind data for elevations of 10° and 40° as shown. The relative frequency distributions at both levels show that more than 50% of the speed differences were within this range, indicating that satellite-derived winds usually represent the wind speed at a given point with about the same accuracy as the rawinsonde system.

7. SUMMARY

Root-mean-square errors in satellite data were determined from published values of discrepancies between satellite and rawinsonde data and RMS errors in rawinsonde data. A propagation of error method was used to solve for RMS errors in the satellite data for temperature, dewpoint temperature, mixing ratio, and wind speed as a function of pressure. RMS errors in the satellite data for each of these variables were larger than the corresponding rawinsonde values.

Gradients of each of the above variables were compared with average and near extreme gradients computed from the AVE II and AVE IV experiments. In all instances, it was found that the RMS errors in satellite gradients were approximately the same magnitude as the average measured gradients, but much smaller than the near-extreme gradients. Therefore, it was concluded that satellite data may be used to determine with relatively good accuracy the near extreme gradients. However, when the magnitude of the gradients was smaller than the mean value they could not be determined with acceptable accuracy. RMS errors in relative vorticity and the lapse rate of temperature also were larger for satellite than for rawinsonde. Average and near-extreme values were not available for comparison with these parameters, but it appears that the RMS errors in the parameters computed from satellite data are unacceptably large.

Synoptic charts were prepared to show the extent that patterns of temperature and dewpoint temperature could be represented with satellite data. The charts show that large-scale features of the temperature field can be represented with reasonable accuracy, while only gross features of the dewpoint field can be represented.

Cloud motion vectors provided by the University of Wisconsin and assumed to represent horizontal wind speed were plotted on charts and analyzed. Large gaps in the fields existed and a comparison between measured winds and cloud motion vectors at different levels indicated RMS errors in the satellite winds considerably in excess of those for rawinsonde winds. Inadequate wind and cloud motion data were available to permit definitive conclusions to be drawn.

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16. ABSTRACT

Published rms errors in rawinsonde data and discrepancies between satellite and rawinsonde profile data were used to determine rms errors in satellite profile data for temperature, dewpoint temperature, mixing ratio, and wind speed. Satellite rms errors were found to be 2 to 3 times as large as those for rawinsonde data. Gradients of the preceding parameters were computed for both rawinsonde and satellite data and compared with means and near-extreme values computed from the AVE II and AVE IV experiments. In all cases, it was found that satellite data can be used to determine with relatively good accuracy the near-extreme gradients but not those whose value does not exceed the average. Synoptic charts were prepared to show that patterns of temperature could be determined with relatively good accuracy, while those of dew point were not as good as those for temperature. Winds represented by cloud motion vectors (satellite winds) were compared with rawinsonde winds, and it was found that large gaps exist in satellite values for a given pressure level and that errors in the satellite-determined winds were larger than those for the rawinsonde winds. An important conclusion reached in the study is that satellite profile data are very useful in synoptic analysis, particularly in data-sparse regions as well as regions where near-extreme gradients exist in the measured parameters.

17. KEY WORDS

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Mesoscale Features

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