

Statistical Evaluation of Ground- and Space-Based Retrievals

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1. Introduction

Several studies have shown that combining ground- and space-based remote sensor measurements provides temperature soundings that are more accurate than either system provides alone. Westwater and Grody (1980) and Westwater et al. (1984,1985,1989) used a six-channel microwave radiometer for the ground-based component; Schroeder et al. (1991) used a 915 MHz Radio Acoustic Sounding System (RASS) for the ground-based component and Television and Infrared Observation Satellite (TIROS-N) Operational Vertical Sounder (TOVS) for the space-based component. In the last study an inverse covariance weighting and another simple blending technique were used to combine the RASS measurements and TOVS derived temperature profiles. The resulting temperature profile showed remarkable ability to detect sharp temperature inversions during extreme weather situations.

To satisfy operational needs for temperature and humidity profiles with vertical resolution comparable to that obtainable for winds from the Wind Profiler Demonstration Network (WPDN), Stankov et al. (1993) developed and have operated since June 1993 a Combined Remote Sensors Sounding Method (CRSSM). This method combines in near real-time hourly data from the ground-based RASS, a two-channel microwave radiometer, surface meteorological observations, lidar ceilometer, and commercial airliner data from the Aerodynamic Research Incorporated (ARINC) Communication, Addressing and Reporting System (ACARS) with the space-based data from TOVS.

This study reports on the results of an experiment sponsored by the Forecast Systems Laboratory (FSL) of the National Oceanic and Atmospheric Administration (NOAA) conducted in February and March 1994 at Platteville, Colorado, to test the performance of the CRSSM for possible use with the WPDN systems. The technique inserts the retrievals from ground-based sensors and ACARS directly into the International TOVS Processing Package (ITPP) by constructing first guess fields for temperature and humidity. Examples of individual profile retrievals for both clear and cloudy weather conditions, a 24-h time-height cross-section analysis of the retrieved temperature and relative humidity profiles, and the statistical performance of the retrieved temperature and dewpoint temperature profiles for the entire dataset which consists of 119 soundings, are shown. In situ measurements obtained from the radiosondes released at Platteville, Hudson (located 10 km west of Platteville), and Denver (located 50 km south of Platteville), Colorado, are used for verification.

2. Measurements

Measurements were taken between 26 January and 28 March 1994 at Platteville, Colorado, where the Environmental Technology Laboratory (ETL) has operated a suite of remote sensors for ten years and the FSL operates a 404 MHz wind profiler/RASS system, a component of the WPDN. These ground-based remote sensors were designed to operate continuously and unattended. The data were collected in the field and ingested into the FSL and ETL databases where they were available in near real-time for use in the temperature-and-humidity-profile retrievals. ACARS and TOVS data were also available in near real-time from the FSL database. ACARS data were available on an hourly basis, and the TOVS data were available three to four times a day as TIROS-10 and TIROS-11 passed over the area. For verification of the retrieved profiles the author used *in situ* data obtained by the ETL-released radiosondes. The number of radiosondes released by the ETL at Platteville was augmented by the radiosondes released at Hudson, Colorado, some 10 km west of Platteville, as part of the Winter Icing and Storms Project (WISP) (Rasmussen et al. 1992) and the National Weather Service radiosondes released at Denver, Colorado, some 50 km southwest. The WISP radiosonde measurements were collected during the Intensive Operational Periods (IOP) and therefore most of them were collected during winter storms with cloudy weather conditions. Most of the ETL radiosondes were released during clear weather conditions and the NWS radiosondes are released routinely twice a day.

Of the total 119 soundings, 54 were obtained during clear weather conditions, and 65 were obtained during cloudy weather conditions. Of the 119 soundings, 64 Denver radiosondes and 55 Platteville area (i.e. including Hudson) radiosondes were used for verification.

3. Instrumentation

a. Two-channel microwave radiometers

A ground-based, zenith-pointing microwave radiometer system observes downwelling radiation emitted by the atmosphere. It measures the brightness temperatures in the 20.6 GHz and 31.65 GHz frequency channels and reports the data as two-min averages. Those channels respond to the changes in the water vapor and liquid water, respectively. Measured brightness temperatures are converted to path-integrated water vapor and path-integrated liquid water using a simple statistical estimation algorithm (e.g., Hogg et al. 1983). Estimated absolute radiometric accuracy of brightness temperature measurements is 0.5 K for both channels. The radiometer-derived integrated water vapor agrees well with that measured by the radiosondes with an rms difference of 1.1 mm (Hogg et al. 1983, Martner et al. 1993, Han et al. 1994).

b. Wind profiler/RASS system

Wind profilers are Doppler radars that measure winds by measuring the Doppler shift of signal backscattered from refractive index perturbations at a scale of one-half of the radar wavelength. These perturbations drift with the mean wind, and measuring their translational velocity provides a direct measure of the mean wind (Balsey and Gage 1982). RASS adds appropriately matched acoustic sources to a wind profiler to obtain measurements of virtual temperature (Peters et al. 1983, May et al. 1990). The profilers measure the speed of refractive index perturbations induced by vertically propagating acoustic waves (approximately matched with the radar's half-wavelength) as they ascend at the local speed of sound, which is directly related to the virtual temperature at each height. The height range of RASS is a function of radar wavelength, acoustic and transmitter power, and the receiving antenna's area. In this study the author uses NOAA's WPDN 404-MHz Platteville RASS system with a vertical resolution of 150 m and a temporal resolution of 1 h. The accuracies of all RASS systems are comparable to those obtained by radiosonde (Martner et al. 1993).

c. Operational laser ceilometer

A laser ceilometer similar to the routinely operated NWS ceilometer at Stapleton International Airport was operated by the ETL at Platteville. It is a model CT 12 K, manufactured by Vaisala and operated at 904 nm. This instrument measures the height of cloud base every 30 sec and has a vertical resolution of about 15 m. The maximum height of the ceilometer measurements is 3.7 km AGL, but because the laser beam attains only shallow penetration into the cloud, it does not provide information about cloud thickness.

d. ACARS

The FSL is currently receiving in real-time flight level temperature and wind data from commercial carriers (Benjamin et al. 1991). Depending on the carrier, the soundings can have a vertical resolution of 2000 ft (700 m) and originate every 7.5 min, but they may have an irregular distribution in space and time because of flight patterns and schedules. However, over major airports such as Denver's Stapleton International Airport, the reports are dense. The temperature and wind data are available during the ascent/descent into Denver and every 2000 ft from 31,000 to 43,000 ft (9.45 to 13.11 km) during the constant level flights. These data are immediately forwarded to the ETL's databases to be used in combination with the remote sensing data. A horizontal area of about 250 km² is selected for averaging the constant level ACARS, but the ascent/descent ACARS are not averaged.

e. Radiosondes

Three different radiosonde sounding systems were used during the experiment. The ETL released 20 radiosondes manufactured by the Atmospheric Instrumentation Research Inc., (AIR) and measured only the thermodynamic variables (pressure, temperature, and humidity). Because of the lack of either TOVS or ground-based measurements at the time of the radiosonde releases, out of the 20 radiosonde soundings only eight were used in this study.

The Cross-Chain Loran Atmospheric Sounding System (CLASS) released by the National Center for Atmospheric Research (NCAR) uses a Vaisala radiosonde and provides *in situ* wind, temperature, and water vapor measurements. Winds are provided at 10-sec intervals and thermodynamic variables (temperature, pressure and humidity) are received every 3 sec (Smith et al. 1990). During the IOP,

CLASS radiosondes were launched every 3 h but they rarely reached levels above 200 mb. Out of 80 CLASS radiosondes released at Hudson during the experiment, only 47 were used in this study because of the lack of either TOVS or ground-based measurements at the time of radiosonde ascent.

The NWS radiosondes are routinely launched twice a day at 1100 and 2300 UTC. The accuracy of radiosonde soundings is described by Pratt (1985) and Wade (1994). A 5-y- long historical dataset of radiosondes for February, March, and April 1981–1985 was used for statistical information in the first guess formulation, and 64 NWS radiosonde soundings obtained during the experiment were used for comparison with retrieved profiles.

f. Surface meteorological instruments

A standard surface meteorological station measures surface pressure, temperature, and relative humidity providing 2-min averages as a part of the ETL suite of instruments at Platteville. The accuracy of the surface pressure measurement is 0.5 mb, surface temperature accuracy is 0.5°C, and surface relative humidity accuracy is 5%.

g. TOVS

TOVS is a three-instrument system consisting of the High-resolution Infrared Radiation Sounder (HIRS/2), the Microwave Sounding Unit (MSU), and the Stratospheric Sounding Unit (SSU). HIRS/2 is a 20-channel instrument taking atmospheric measurements in the IR region and providing temperature profiles from the surface to 50 mb, water vapor content in three atmospheric layers, and total ozone content (Rao et al. 1990). MSU is a four-channel microwave radiometer making measurements little influenced by clouds, and SSU is a three-channel instrument that measures radiation emitted by carbon dioxide at the top of the atmosphere. These raw data are forwarded from the FSL to the ETL database, where it is preprocessed and used in the retrieval algorithm. The TOVS observations closest in distance to Platteville were chosen for the retrieval. The distance varied between 10 and 150 km. The time difference between ground-based observations and the TOVS data was up to 7 h.

4. Technique description

a. Space-based retrieval of temperature and humidity profiles

Since 1988 the International TOVS Processing Package (ITPP) has used the physical retrieval technique, based on the radiative transfer theory, to obtain vertical profiles of the temperature and humidity from TOVS measurements of the upwelling infrared and microwave radiation (Rao et al. 1990, Susskind et al. 1984). Like other physical retrieval algorithms, the ITPP algorithm involves starting from a first guess of the atmospheric and surface conditions from either forecast, climatology, or a statistical regression. From the user-selected first guess profiles provided by the ITPP, upwelling brightness temperatures at the top of the atmosphere are computed and compared to the satellite-observed brightness temperature data. Based on the amount of disparity, the first guess profiles are adjusted iteratively in an attempt to match the measurements. When the brightness temperature residuals are below the instrumental noise, convergence is achieved. In the description of results the author will refer to the temperature and humidity profiles obtained from the ITPP, which used first guess profiles based on the ITPP-provided climatology as the "satellite" retrievals.

b. First Guess from the ground-based remote sensors

The basic advantage of the physical retrieval methods such as the one used by the ITPP is that they employ other *a priori* knowledge through the use of the first guess profiles. This allows formulation of the first guess profiles of temperature and humidity from the combined ground-based remote sensors measurements. The linear statistical inversion technique described by Strand and Westwater (1968) and applied to RASS measurements by Schroeder et al. (1991) is used to formulate the first guess of temperature and humidity profiles to be used in the ITPP. This technique is based on a large, independent, historical radiosonde dataset describing the site climatology to establish the statistical regression relationship between a measurement vector and the profile levels. The radiosonde dataset from Denver for February, March, and April 1981–1985 was used here. This historical dataset determines the regression coefficient vector which, when applied to the actual measurement vector, provides temperature and humidity at each chosen profile level. A physical model that relates the measurement vector to the radiosonde observed pressure, temperature, and dewpoint is used to simulate a measurement vector for each radiosonde sounding of the historical dataset. Here, in addition to

the RASS virtual temperature, the measurement vector includes data from the two-channel radiometer, surface measurements, ACARS, and ceilometer. Brightness temperatures at 20.6 and 31.65 GHz are computed from each radiosonde sounding of the historical dataset using the radiative transfer equation (Askne and Westwater, 1986). From each radiosonde temperature, pressure, and dewpoint profile of the historical dataset, the virtual temperature profile is computed and simply interpolated onto the height levels of the RASS observed profile, which also includes the surface measurements as the lowest data point. Similarly, each radiosonde temperature profile of the historical dataset is interpolated onto the heights of the ACARS temperature reports. Finally, the single cloud layer boundaries are included by interpolating dewpoint profiles of the historical dataset to the observed cloud-base height and estimated cloud-top height and forcing the data vector dewpoint to be saturated at and between those heights. A moist-adiabatic approximation (Stankov et al. 1995) was used to estimate the cloud-top height. The top of the liquid cloud is found by raising an air parcel in a thermodynamic moist-adiabatic process from cloud base until enough vapor condenses to equal the path integrated liquid water measurement of the radiometer. Random noise was added to all components of the data vector; the rms values of the noise vector correspond to experimentally determined accuracies. The regression coefficients obtained from the least square fit at a given altitude constitute the retrieval coefficient vector (Schroeder 1990). The 36 levels which coincide with the TOVS pressure levels (related to the weighting functions of the selected frequencies) that are located above ground at Platteville were chosen for the profile heights. The temperature and humidity profiles retrieved by the statistical inversion method from the historical radiosonde dataset and ground-based remote sensor measurement vector will be referred to as "climatological" retrievals in the description of results.

c. Mixed profiles

By using the statistical inversion retrievals described in Section 4b instead of the first guess profiles from the ITPP, the temperature and humidity profiles that are based on remote sensor data from both the ground and space are obtained. For humidity the profile retrieved in this way is the final result in this study. For the temperature, however, there is one more step employed. Because the TOVS pressure levels have poor resolution in the boundary layer (due to the limited number of channels) the retrieved temperature profiles are poorer near the ground than the original surface, and RASS temperature measurements. As the final step, then the retrieved temperature profiles are simply replaced with the raw measurements up to the height of the top RASS measurement. In discussing results these temperature and humidity profiles are referred to as the "mixed" retrievals.

5. Results

a. Individual temperature and dewpoint profiles

A comparison of two cases of retrieved temperature and dewpoint profiles during clear and cloudy weather conditions with the *in situ* temperature and dewpoint profiles observed by the NWS radiosonde released at Denver is shown in Figures 1 and 2. Figure 1 shows a skewT-logP diagram up to 50 mb of a clear weather case that occurred at 2300 UTC on 2 February 1994. Figure 1a shows Denver NWS radiosonde observations of temperature (right solid line) and dewpoint (left solid line) profiles, RASS (open circles), and ACARS (filled squares) temperature observations. Out of five ACARS temperature reports, three were obtained during ascent/descent flight pattern representing a single report each, and two were the averages of the several constant level flight reports. They all agreed with the Denver-released NWS radiosonde temperature observations. Platteville radiometer measurements at that time showed no path-integrated liquid and 0.155 cm of precipitable water vapor which compared to the path-integrated water vapor from Denver radiosonde of 0.251 cm. Surface temperature and dewpoint measurements from the radiometer site at Platteville differed from the surface observations at the radiosonde site in Denver by 3 and 7°C, respectively. Surface pressure difference between Denver and Platteville reflects the terrain height difference of 100 m between the two sites. RASS-observed virtual temperature measurements reached only to 600 mb level. Comparison of the radiosonde observed profiles (solid lines) and the profiles retrieved by the ITPP (dashed lines) when only the satellite observations and the ITPP provided first guess are shown on Figure 1b. The agreement up to the 200-mb level is rather poor, while above the 200-mb level the agreement improves dramatically. Thermodynamic profiles retrieved by using the above described technique, i.e. mixed profiles (dashed lines) show excellent agreement with the *in situ* observed profiles (Figure 1c).

A case of cloudy weather conditions at 23 UTC on 27 February 1994 is shown in Figure 2. The clear sky retrieval data vector consisting of surface, radiometer, RASS, and ACARS measurements

that is used for the first guess formulation is augmented by the additional cloud-base measurements from the lidar ceilometer and the moist adiabatic cloud-top height estimate. On this day RASS virtual temperature measurements reached up to 500-mb level and ACARS temperature measurements consisted of three single reports during ascent/descent, and two from the constant level flights representing an average of several reports. Surface temperatures from the Denver radiosonde and Platteville radiometer sites differed by only 0.14°C and the dewpoint difference was 2°C . The radiometer reported 0.030 mm of path integrated liquid water and 0.892 cm of precipitable water vapor compared to 0.849 cm from the Denver radiosonde Lidar ceilometer-measured cloud-base height was 4.29 km MSL, and moist adiabatic cloud-top height estimate was 4.55 km MSL. Satellite retrieved thermodynamic profiles in Figure 2b do not agree with the radiosonde-observed profiles until the 100-mb level. However, the mixed profiles are again in very good agreement with the radiosonde observed profiles (Figure 2c).

Lack of height coverage of RASS data or a lack of ACARS data availability influences how well both temperature and dewpoint profiles are retrieved. Martner et al. (1993) described the height coverage of the 404-MHz RASS system at Platteville to be 500 mb (~ 5.6 km MSL) 40% of the time and 600 mb (~ 4.2 km MSL) 90% of the time. Figures 3 and 4 show how mixed retrieved profiles deteriorate as the RASS data become confined to the boundary layer and with no availability of ACARS reports for clear and cloudy conditions. They start with the profiles containing the complete data vector available for a given hour, then gradually eliminating all the RASS virtual temperature measurements above a given pressure level, and finishing with all ACARS constant level reports removed, but all the RASS measurements present. Figure 3a-f shows the results for a clear weather case at 1100 UTC 15 February 1994, and Figure 4a-f for cloudy weather case at 2300 UTC 21 February 1994. Both cases show that reducing the height coverage of RASS measurements gradually deteriorates temperature and dewpoint profiles but the dewpoint profiles deteriorate much faster than the temperature profiles. In the clear case (Fig. 3a-f), with a strong ground-based inversion, the temperature profile is in good agreement with the radiosonde temperature profile as long as the RASS height coverage reaches above the ground-based inversion top at 700-mb, and the ACARS reports provide the temperature measurements near the tropopause level. Dew point profiles in this case depend more strongly on the availability of the RASS measurements above the 700 mb level (~ 3 km MSL). In the cloudy case (Fig. 4a-f) the retrieved temperature profile deteriorates as the height coverage of the RASS drops, especially if the RASS does not provide data at the significant levels in the profile such as the tropopause height. Retrieved dewpoint profiles deteriorate much faster with the lack of RASS height coverage. This comparison illustrates the importance of temperature observations near the significant levels such as temperature inversions, whether they are located near the ground, tropopause, or in the midlayers associated with clouds. Thus, extending the RASS height coverage with ACARS reports of temperature is extremely important.

b. Statistical analysis for temperature profiles

From 26 January 1994 to 28 March 1994 there were 119 radiosonde soundings collected at Denver, Hudson, and Platteville, for comparison with the retrieved profiles based on the ground-based remote sensor measurements at Platteville and TOVS data. Performance statistics for the entire temperature dataset are shown in Figure 5. Scattergrams of the radiosonde temperature observations versus remotely sensed or retrieved temperatures are shown in the top row. The bottom row has five panels that represent the height dependence of the mean differences (remote-retrieved) at each height (solid line), standard deviation of the differences at each height (thin horizontal lines), and the number of profiles used for computation of mean and standard deviation at each height (dashed line). The temperature difference scale is on the bottom x-axis, and the scale for the number of profiles is on the top x-axis of the lower row's plots. Radiosonde profiles, remotely sensed data, and the retrieved profiles were interpolated to the same height grid with vertical resolution of 150 m, before making comparisons. The five columns of plots in Figure 5 compare RASS, RASS plus ACARS, climatological, satellite, and mixed, temperature profiles with the radiosonde temperature profiles, respectively. The correlation coefficient (R), for the total number of points is marked on the scattergram, and the mean (M) and the standard deviation (SD) of the total number of points are marked on the bottom row plots.

Comparing the RASS-observed profiles with the radiosonde observations in the first column of Figure 5 reveals that several RASS profiles reached 5 km AGL, but 50% of the profiles reached 2.5 km AGL. This agrees well with Martner et al.'s (1993) results. The correlation coefficient is 0.98;

the mean of the differences is 0.61°C ; and the standard deviation of the differences $\text{SD}=1.98^{\circ}\text{C}$. The overall agreement of RASS and radiosonde data during our experiment is very good and agrees well with earlier results (May et al. 1990, Martner et al. 1993).

The second column of Figure 5 compares the RASS plus ACARS (simply interpolated onto the vertical height grid) with the radiosonde data. Adding the ACARS temperature reports to the RASS measurements increases the height coverage to 11 km AGL, which is around the tropopause height. The overall correlation coefficient is 0.99, but the mean of the differences and the standard deviation increase compared to RASS data in the first column of Figure 5. Not unexpectedly, the main contribution to the differences comes from the layers of the atmosphere between the top gate of the RASS profile and the first height of the ACARS report.

Using statistical inversion, the ITPP, or the mixed retrieval technique gives the full column information on the temperature field. The best performance is achieved by the climatological profiles (column 3), but the mixed profiles (column 5) come in a close second. Extending the temperature profiles to the 35 km AGL using statistical inversion results in the same overall correlation coefficient ($R=0.99$), but decreases mean ($M=0.54^{\circ}\text{C}$), and standard deviation ($\text{SD}=2.68^{\circ}\text{C}$) when compared to the results in column 2 of Figure 5. Satellite temperature profiles have the smallest overall correlation coefficient ($R=0.905$), the largest mean differences ($M=-1.83^{\circ}\text{C}$), and standard deviation ($\text{SD}=9.57^{\circ}\text{C}$). These results are most likely due to the fact that TOVS data get updated in the Front Range area three to four times a day, so that the data used for comparison are up to seven hours late. The overall performance of the mixed temperature profiles is slightly worse than that of the climatological profiles with $R=0.985$, $M=0.41$, and $\text{SD}=3.59$, but examining the height dependence of their performance reveals that above the top of the ACARS reports the temperature profiles are heavily influenced by the satellite retrieval.

The total dataset of 119 soundings was divided into a subset of only Denver radiosonde soundings, Platteville radiosonde soundings, clear weather cases, and cloudy weather cases and the results were summarized in Table 1. For the mixed-temperature profiles the best statistics are obtained for the case when only the Platteville radiosondes were used for comparison. This is expected, however, since all the ground-based remote sensors were located at Platteville and thus they sampled the same volume of air as the radiosondes. In this case the correlation coefficient is 0.99, the mean of the differences is 0.30°C , and the standard deviation is 2.59°C . However, the highest levels these radiosondes ever reached was 150 mb (~ 12 km AGL) and only 50% of the 55 Platteville radiosondes reached levels above 280 mb (~ 8 km AGL). The statistics for the comparison of the Denver radiosondes and remote sensor/retrieved temperature profiles which do cover the entire troposphere are a little worse than the Platteville statistics. Here the radiosondes sample a volume of air 50 km away. The overall dataset comparison is still very good, however, with $R=0.99$, $M=0.41^{\circ}\text{C}$, and $\text{SD}=3.59^{\circ}\text{C}$. Performances under clear and cloudy weather conditions are comparable to each other and to the statistics for the total dataset.

c. Statistical analysis for dewpoint

The retrieved and the radiosonde dewpoint profiles were interpolated to the same 150 m vertical resolution grid and compared in Figures 6. Performance statistics described by these figures parallel the statistics of Figures 5 but they are for the dewpoint. Dew point profiles have a correlation coefficient lower than the one for the temperature, and the overall standard deviation for the dewpoint profiles ($R=0.94$, $\text{SD}=6.84^{\circ}\text{C}$) is twice as large as that for temperature. The mean difference is -0.25°C , and it is small and negative compared to the temperature means. However, the mixed dewpoint profiles provide superior dewpoint profiles to the satellite-only retrieved ones. Table 2 summarizes the statistics when the total dataset is divided into only Denver, Platteville, clear, or cloudy subset. The best mixed dew point profile statistics are obtained for the dataset containing only the profiles obtained during clear weather conditions. The statistics for all the different groups of data are rather similar, except for the satellite-only obtained profiles which show significantly poor performance in each group of data.

6. Summary and conclusions

A statistical analysis from the experiment conducted to test operational integrated sounding system for combining ground- and space-based remote sensors data was presented. The retrieved thermodynamic profiles are comparable to those obtained by the radiosondes with the temperature

profiles showing far better performance than the humidity profiles. In addition, the statistical analysis shows that in comparison with statistically obtained profiles based on RASS, ACARS, two-channel radiometer, and the cloud lidar, there is no improvement of the profile retrievals when the satellite data are included in the retrieval system. This is mostly due to the RASS measurements having high accuracy and vertical and temporal resolution and TOVS instrument having poor vertical resolution in the boundary layer with the temporal resolution of only three or four passes a day. In the Front Range area of Colorado the surface pressure is at about 840 mb and the ITPP-chosen pressure-levels in the boundary layer are at 1000, 950, 920, 850, 780, and 700 mb. Therefore, the first four TOVS levels are not included in the profile retrieval and there are only five points up to the 500 mb level. Because of that the TOVS retrieved soundings are dramatically improved by the use of ground-based remote sensor data through the first guess formulation. The future space-based platforms will carry a High-Resolution Interferometer Sounder (HIS) instrument with a much larger number of temperature and water-vapor-sensitive channels (Smith et al. 1990), which will provide temperature and humidity profiles with more accuracy than TOVS instrument.

The techniques developed in this study provide a valuable way to combine many new and different remote-sensor observations as they are being developed. For example, Gossard et al. (1982) pointed out that it may be possible to retrieve humidity gradients using radar- and RASS-derived wind and temperature profiles and structure parameters for the radio refractive index and vertical velocity component from clear air backscatter power and Doppler spectral width, respectively. This information on the vertical humidity gradients and their location in vertical can be used as an additional constraint in the humidity profile retrieval. Stankov et al. (1995) simulated the humidity gradients from the radiosonde measurements for one case with known successful refractive index measurements. However, to obtain some insight on what accuracy of humidity gradient measurements is required, and obtain statistical estimate of the retrieved humidity profile performance the dataset acquired for this study will be used.

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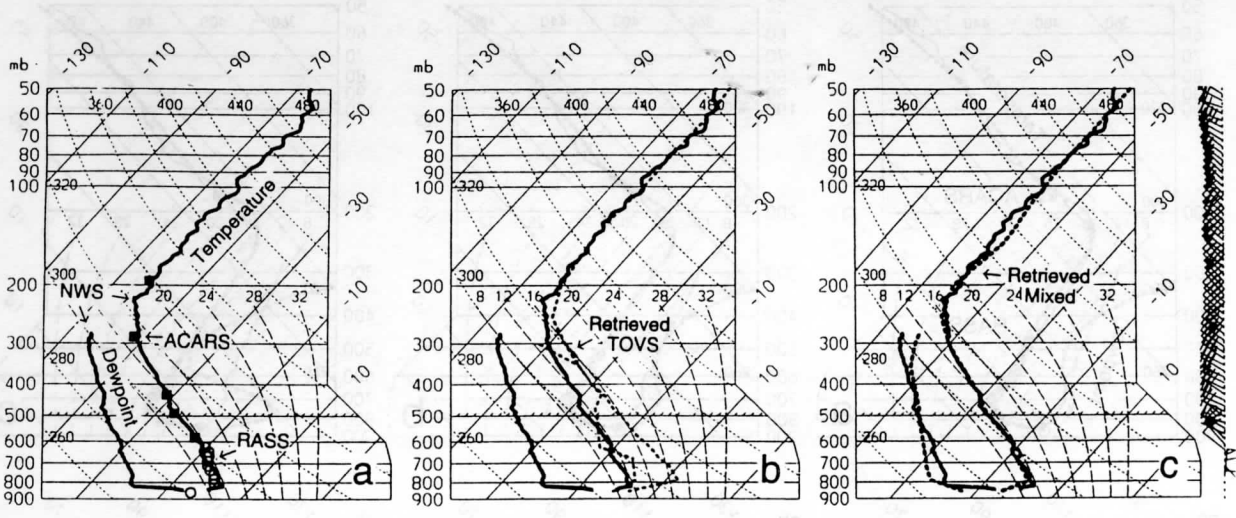


Figure 1. SkewT-logP diagram of temperature and dewpoint profiles at 23 UTC on 2 February 1994. a.) Radiosonde profiles (thick solid lines), (o) RASS virtual temperature measurements, (■) ACARS temperature reports; b.) radiosonde profiles (thick solid lines) and satellite only retrieved profiles (thick dashed lines); c.) radiosonde profiles (thick solid lines) and mixed retrieval profiles (thick dashed lines).

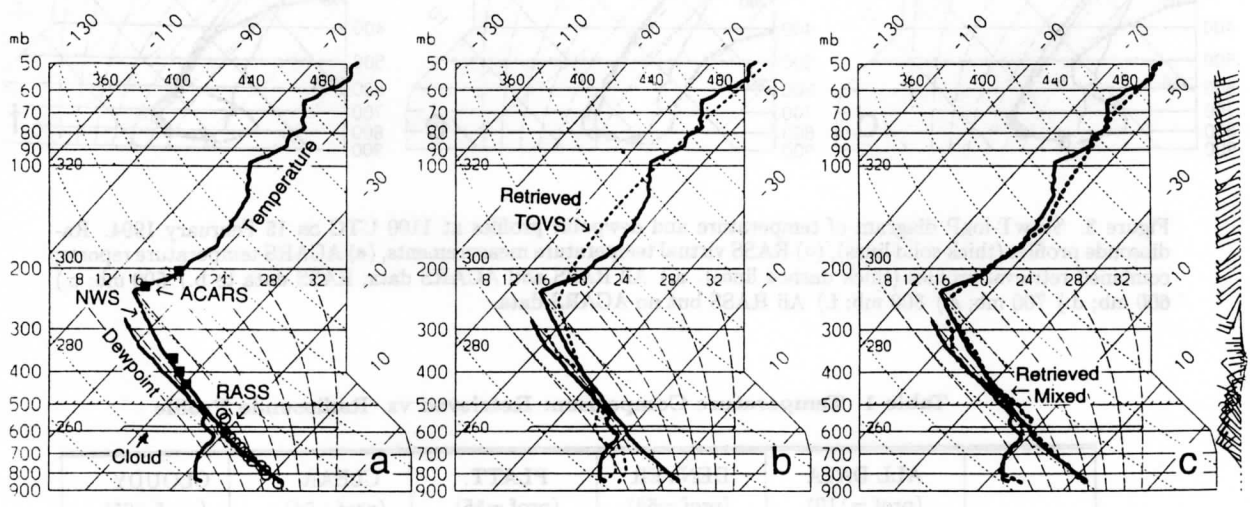


Figure 2. Same as Figure 1 but for 2300 UTC on 27 February 1994.

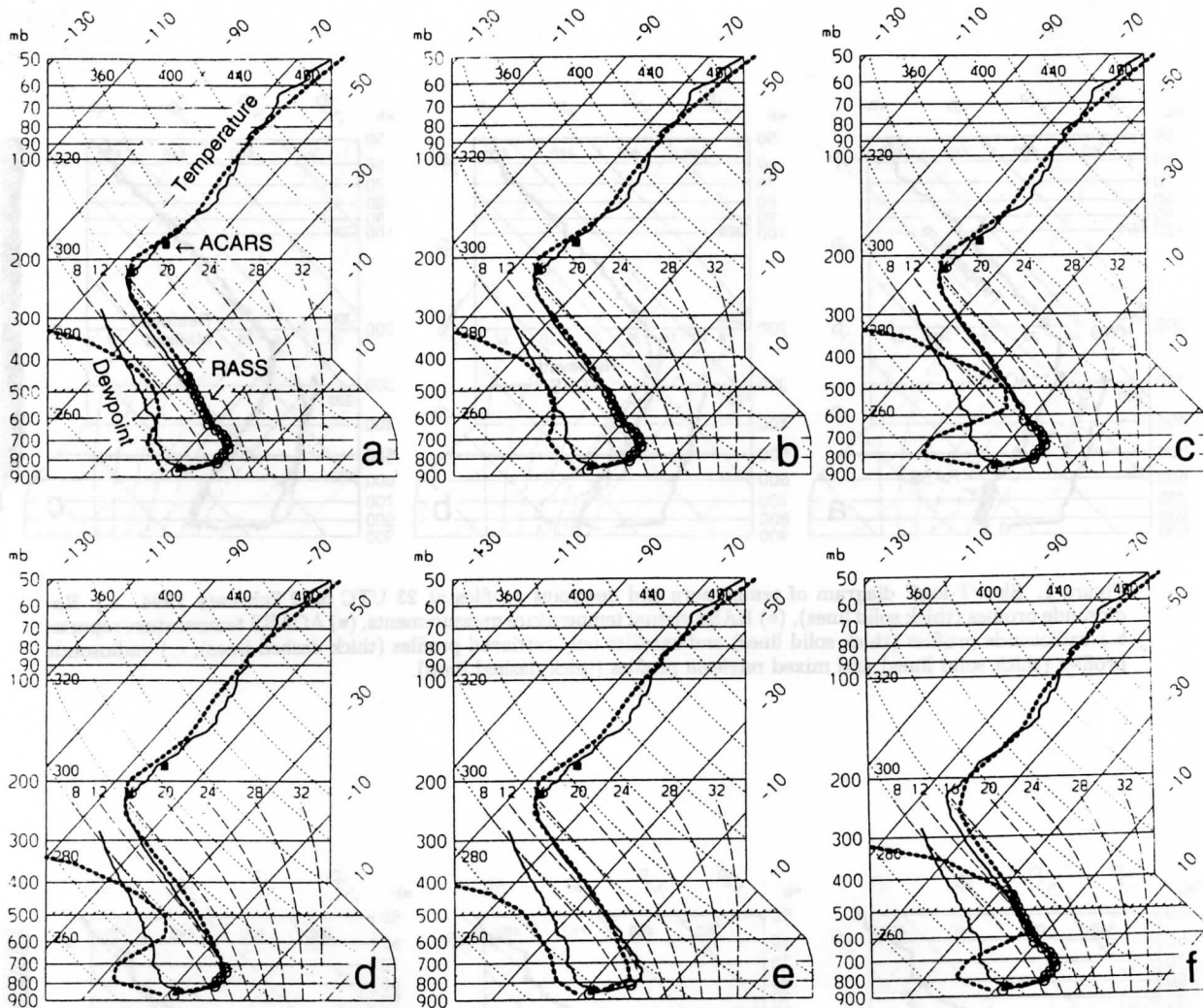


Figure 3. SkewT-logP diagram of temperature and dewpoint profiles at 1100 UTC on 15 February 1994. Radiosonde profiles (thick solid lines), (o) RASS virtual temperature measurements, (■) ACARS temperature reports; combined retrieval profiles (thick dashed lines). a.) All RASS and ACARS data; RASS data to b.) 500 mb; c.) 600 mb; d.) 700 mb; e.) 800 mb; f.) All RASS but no ACARS data.

Table 1. Temperature Comparison: Retrieved vs. Radiosonde Profile

	ALL DATA (prof.=119)			DENVER (prof.=64)			PLATT. (prof.=55)			CLEAR (prof.=54)			CLOUDY (prof.=65)		
	R	M	SD	R	M	SD	R	M	SD	R	M	SD	R	M	SD
RASS	0.98	0.61	1.98	0.97	0.66	2.23	0.98	0.56	1.65	0.98	0.32	1.99	0.98	0.83	1.94
+ACARS	0.99	1.27	2.93	0.99	1.54	3.18	0.99	0.82	2.43	0.99	0.95	2.86	0.99	1.56	2.97
CLIMAT.	0.99	0.54	2.68	0.99	0.60	2.77	0.99	0.34	2.33	0.99	0.25	2.63	0.99	0.85	2.71
SATELL.	0.91	-1.83	9.57	0.88	-1.72	10.19	0.95	-2.02	7.10	0.89	-1.59	10.59	0.92	-2.09	8.33
MIXED	0.99	0.41	3.59	0.98	0.43	3.86	0.99	0.30	2.59	0.98	0.29	3.92	0.99	0.54	3.18

R=Correlation Coefficient

M=Mean of the differences (remote-sonde)

SD=Standard Deviation of the differences (remote-sonde)

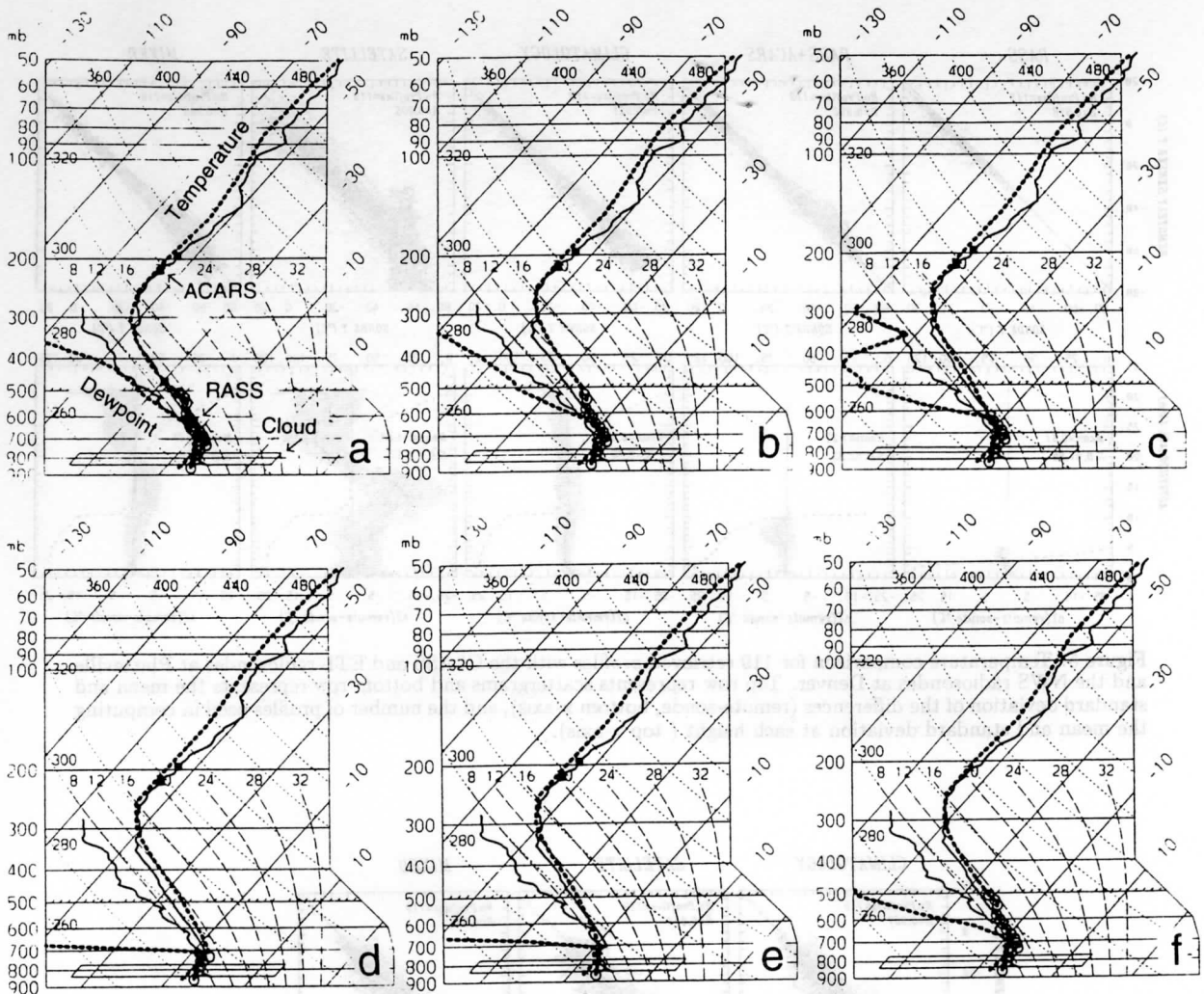


Figure 4. Same as Figure 3 but for 2300 UTC on 21 February 1994.

Table 2. Dewpoint Comparison: Retrieved vs. Radiosonde Profile

	ALL DATA (prof.=119)			DENVER (prof.=64)			PLATT. (prof.=55)			CLEAR (prof.=54)			CLOUDY (prof.=65)		
	R	M	SD	R	M	SD	R	M	SD	R	M	SD	R	M	SD
CLIMAT.	0.94	0.99	7.09	0.94	0.54	6.90	0.93	-0.82	7.42	0.94	-0.28	6.61	0.94	0.24	7.45
SATELL.	0.91	-1.78	8.54	0.91	-1.09	9.11	0.92	-2.20	7.88	0.91	-0.19	9.22	0.93	-3.02	7.74
MIXED	0.94	-0.25	6.84	0.94	0.12	6.63	0.94	-0.92	7.22	0.95	-0.41	6.23	0.94	-0.13	7.28

R=Correlation Coefficient

M=Mean of the differences (remote-sonde)

SD=Standard Deviation of the differences (remote-sonde)

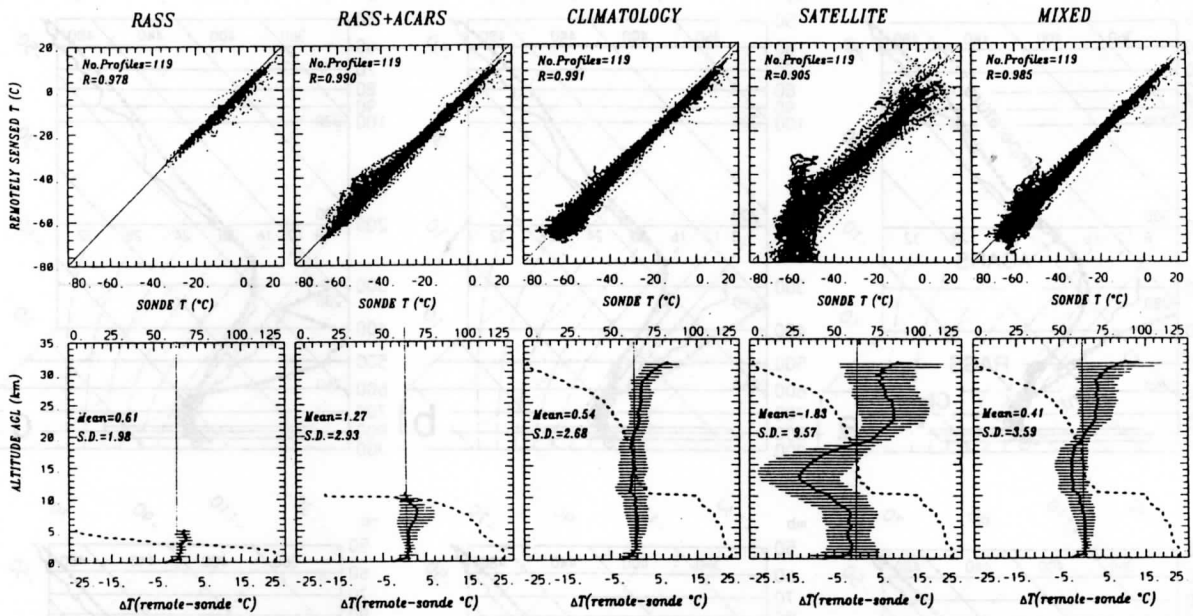


Figure 5. Temperature comparison for 119 retrieved profiles with the CLASS and ETL radiosondes at Platteville and the NWS radiosondes at Denver. Top row represents scattergrams and bottom row represents the mean and standard deviation of the differences (remote-sonde, bottom x-axis), and the number of profiles used in computing the mean and standard deviation at each height (top x-axis).

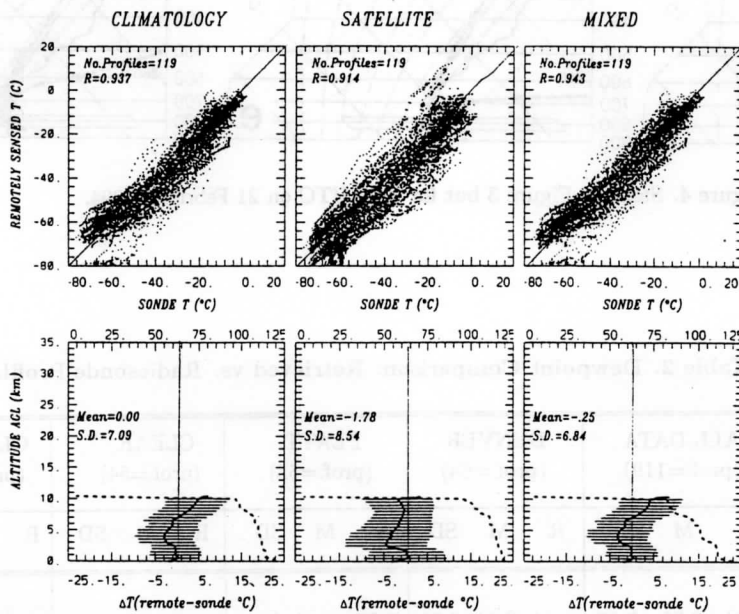


Figure 6. Dew point comparison for 119 retrieved profiles with the CLASS and ETL radiosondes at Platteville and the NWS radiosondes at Denver. Top row represents scattergrams and bottom row represents the mean and standard deviation of the differences (remote-sonde, bottom x-axis), and the number of profiles used in computing the mean and standard deviation at each height (top x-axis).

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