Combined Ground- and Satellite-Based Profiling of Temperature and Water Vapor

B. B. Stankov, E. R. Westwater, J. B. Snider, and J. H. Churnside
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Environmental Technology[(a)] Laboratory
Boulder, CO 80303

Fundamental studies on clouds and radiative transfer require representative measurements of temperature and water vapor profiles. To supplement radiosonde balloon launches, information on vertical profiles of temperature and water vapor at Cloud and Radiation Testbed (CART) sites will be provided by remote sensors.

Instruments planned for deployment include wind profilers and Radio Acoustic Sounding Systems (RASS) at 915- and 50-MHz, dual-channel microwave radiometers, and cloud lidars providing cloud base height (Wesely 1992). Future CART instruments may include millimeter wavelength radars and Raman lidars. In addition to DOE operated instruments, data from nearby National Weather Service (NWS) wind profilers/RASS at 404-MHz and synoptic radiosonde launches will also be available. Finally, image and radiance data from thermal sounding channels from geostationary and polar-orbiting satellites will be available.

The fusion or integration of these data into a representative picture of temperature, water vapor, and clouds over a CART domain will be a challenging task for four-dimensional data assimilation models (Dabberdt et al. 1992). In the work reported here, we have summarized work supported by DOE's algorithm development program, for which computer codes will be supplied to DOE/ARM.

Combined RASS and TIROS[(b)] Operational Vertical Sounder (TOVS) Temperature Sensing

Neither thermal soundings from polar-orbiting satellites (e.g., from TOVS) nor from RASS are completely adequate for operational needs. TOVS soundings typically lack the vertical resolution needed for many applications, while RASS is lacking in coverage above about 500 mb. We are developing techniques to combine TOVS and RASS data to take advantage of each system's separate strengths.

Wind profilers are Doppler radars that measure winds by measuring signals backscattered from refractive index perturbations at the scale of one-half the radar wavelength. These perturbations drift with the mean wind, and measuring their translational velocity provides a direct measure of the mean wind. The RASS combines acoustic sources with wind profilers to obtain measurements of the profile of virtual temperature (May et al. 1988). The profilers measure the speed of refractive index perturbations induced by 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.

Currently, wind profiler and RASS combinations operate at three electromagnetic frequencies: 915, 404, and 50 MHz. If corrections for vertical winds are introduced, all RASS systems measure virtual temperature with an RMS accuracy of about 0.5 K. The height range of RASS is a function of acoustic and electromagnetic transmitter power, as well as the areas of the receiving antenna. Atmospheric limitations include acoustic attenuation, which is a strong function of frequency, and horizontal wind, which advects the acoustic pulse out of the electromagnetic pulse. For representative RASS systems, height ranges reached 50% of the time are 0.7, 3.2, and 5.5 km for the 915-, 404- and 50-MHz systems (Martner et al. 1993). Temporal resolutions of 20-60 minutes are commonly available. To provide complete profiles, both the upper and lower altitude range gates require supplementary information.

Another source of information is from flight-level temperature and wind data from commercial carriers, available

(a) Formerly the Wave Propagation Laboratory
(b) Television and infrared observation satellite.

from Aircraft Communication and Recording System (ACARS) data (Benjamin et al. 1991). Depending on the carrier, the soundings could have a vertical resolution of 2000 ft (about 700 m), could originate every 7.5 min, and could have an irregular distribution in space and time because of flight patterns and schedules. For flight-level data, temperature and winds are available as much as every 2000 ft from 31,000 to 43,000 ft.

Data from RASS and ACARS may be combined with radiance observations from NOAA polar orbiting satellites made by the TOVS and are available approximately four times each day. To illustrate the potential for combining data from these instruments, Figure 1 shows soundings without (a) and with (b) TOVS data. The physical retrieval algorithm used for the results in Figure 1 is based on statistically extrapolating RASS and ACARS data to levels extending to 0.1 mb and inserting this first guess profile into the International TOVS Processing Package (ITPP). These algorithms are among those that will be supplied to DOE for implementation at the Oklahoma CART site.

Water Vapor Profiles from Dual-Channel Radiometers

Until advanced moisture sensing instruments such as Raman lidar are implemented at ÇART sites, only twice-daily radiosonde soundings are available for <u>direct</u> measurement of moisture profiles. We are investigating several techniques for deriving water vapor profiles between radiosonde launches, some of which depend on the direct assimilation of precipitable water vapor (PWV) into a four-dimensional data assimilation model (Dabberdt et al. 1992).

Until such models are fully operational, we have provided DOE/ARM with a statistical method of deriving profiles from dual-channel microwave radiometric measurements of PWV and surface meteorological measurements. We have found that the accuracy of the derived profiles can be improved if the information on presence or absence of clouds is known. For example, this information can be derived from lidar ceilometer measurements or a precision radiation thermometer (PRT) infrared radiometer. An example of a dual-channel retrieval using both clear and cloudy coefficients is shown in Figure 2.

Another very important factor in determining the accuracy of profile retrievals is the accuracy and representativeness

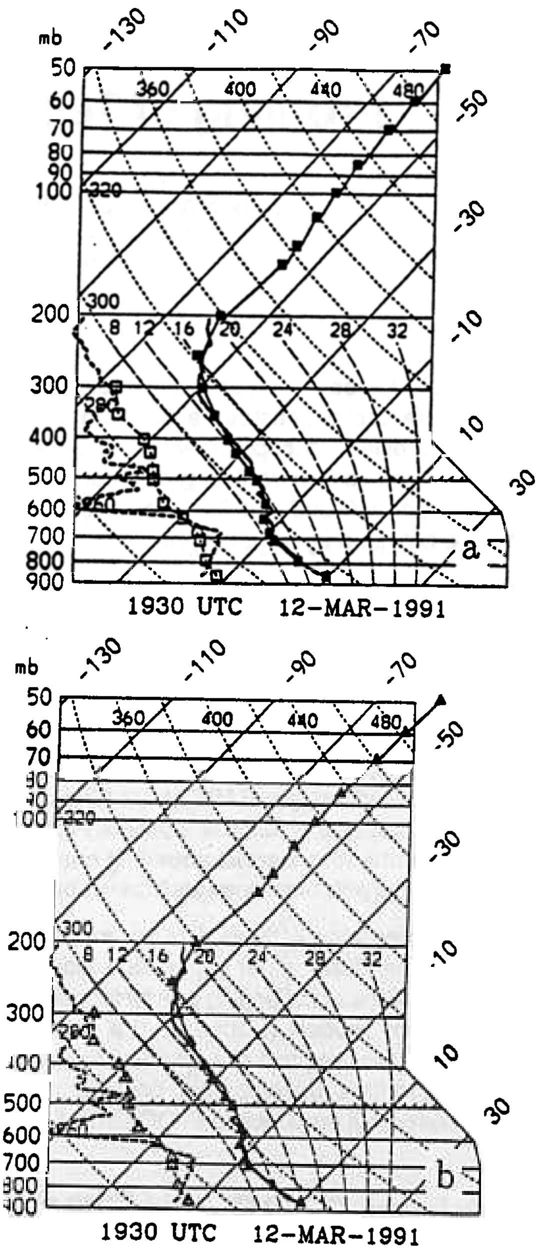

Figure 1. Skew T-log P diagrams of temperature and humidity profiles during clear conditions obtained at Platteville, Colorado, on 12 March 1991, 1930 UTC for (a) regression-derived first-guess temperature (solid squares) and dewpoint temperature (open squares); and (b) ITPP-retrieved profiles using regression-derived, first-guess temperature (solid triangles) and dewpoint temperature (open triangles).

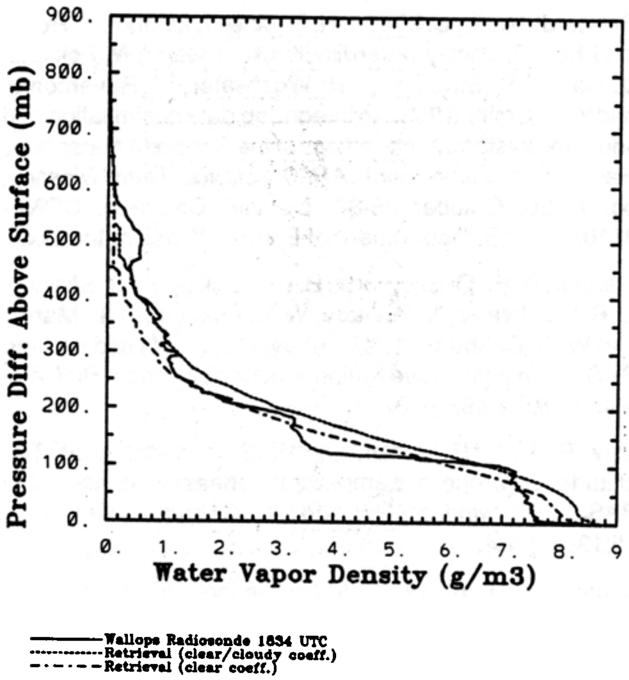

Figure 2. Dual-channel microwave radiometric retrieval of water vapor profile at Coffeyville, Kansas, 18 November 1991, 1834 UTC.

of surface meteorological measurements. We have found that if measurements of surface parameters depart substantially from those measured by a radiosonde, the resultant retrievals are poor. Accurate surface measurements can also be used for quality control of radiometrically derived PWV. Finally, when simultaneous and collocated measurements of cloud-base height, RASS, and microwave radiance are available, additional improvements to retrieval accuracy can be obtained (Stankov et al. 1993).

Neutral Network Radiometric Temperature Retrievals

Another approach that could have promise for obtaining profiles from combinations of sensors is artificial intelligence, in particular artificial neural networks. In an artificial neural network, we start with an input data vector that consists of radiometric data, RASS data, satellite data, and any other available data. The input data are used to generate a profile of temperature and/or humidity through a one- or two-step process. In the one-step version, each temperature value is a nonlinear weighted sum of all input data. In the two-step version, intermediate values are calculated as nonlinear weighted sums of all input data, and each of the output values is a nonlinear weighted sum of all of these intermediate values. The nonlinear weights are obtained by training the network with an historical data set. This process is similar to a statistical inversion in its dependence on an historical data set.

We have conducted a preliminary investigation into the utility of artificial neural networks (Churnside et al. 1994). Calculated temperature profiles using 6-channel microwave radiometer data from Stapleton Airport in Denver as the input data were compared with profiles obtained using a statistical inversion based on the same data (Schroeder 1990). We conclude that the overall performance of the neural network was comparable to that of the statistical inversion. This conclusion is based on an overall RMS error over the test data set of 4.3° for the neural network compared with 4.0° for the statistical inversion.

Qualitatively, the neural network method is better than the statistical inversion at reproducing strong inversions near the ground. This can be seen in Figure 3, where we have plotted the true profile, the statistical inversion, and the neural network retrieval for an extreme temperature inversion. The neural network comes closer to reproducing the inversion, although the retrieval is worse than the statistical inversion at high altitudes. This promising technique can also be applied to RASS and TOVS temperature retrievals, as well as to multi-sensor retrievals of water vapor.

Plans

Future work on retrieval algorithm development will focus on three main aspects: 1) incorporating ceilometer and RASS measurements into real-time moisture retrievals; 2) using the twice-a-day radiosonde releases as further constraints on moisture (and temperature) retrievals; and 3) comparing neural network, a priori statistical and non-statistical methods for moisture profile retrieval.

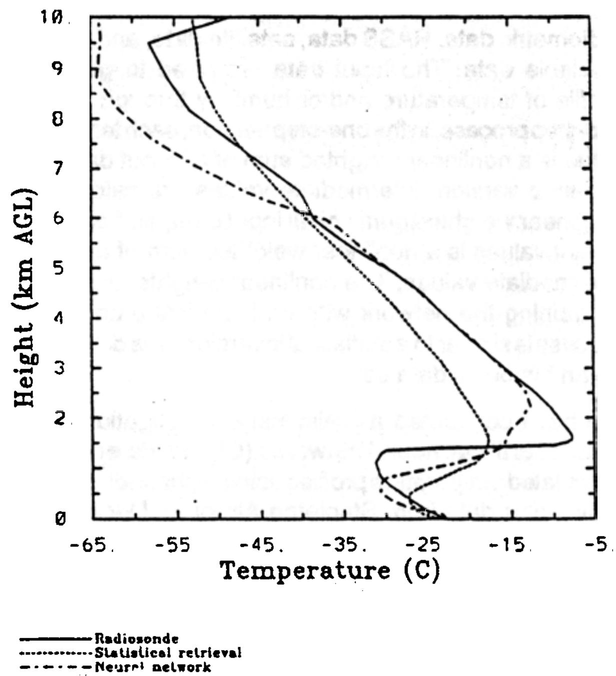

Figure 3. Temperature as a function of height for an extreme case from the radiosonde (solid line), the statistical retrieval (dotted line), and the neural network with 20 hidden-layer neurons (dashed line).

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