Radiometric profiling of tropospheric temperature, humidity and cloud liquid

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Abstract. We describe a radiometric profiler that provides accurate temperature, humidity and cloud liquid profiles during clear and cloudy conditions. The radiometer observes radiation intensity at 12 microwave frequencies, along with infrared and surface meteorological measurements. Historical radiosonde and neural network or regression methods are used for profile retrieval. We compare radiometric, radiosonde and forecast profiles and summarize results from other studies regarding retrieval methods and accuracy evaluations. Radiometric profiling, particularly when combined with wind profiling radar and advanced assimilation methods, provides continuous, accurate and reliable measurements needed for improved local high resolution modeling and forecasting. We describe the potential to extend local radiometric soundings and forecast improvements to regional scale using "slant" observations of integrated signal delay along individual GPS ray paths.

Introduction

A radiometric profiler has been developed that provides temperature and humidity soundings up to 10 km height and low resolution cloud liquid soundings (Figure 1). The radiometer observes radiation intensity at 12 frequencies in a region of the microwave spectrum that is dominated by atmospheric water vapor, cloud liquid water, and molecular oxygen emissions. Observation frequencies were chosen by eigenvalue analysis to optimize profile retrieval accuracy [Solheim et al., 1998]. A vertical infrared sensor and surface temperature, humidity and pressure sensors are included.

The water vapor absorption line at 22 GHz is pressure broadened with decreasing height. By observing radiated power at selected frequencies in this region the water vapor profile can be determined. The molecular oxygen absorption band centered at 60 GHz is relatively strong, limiting observed emission to several hundred meters above the radiometer. Moving away from band center, the absorption decreases and emission can be observed at increasing height. By observing radiated power at selected frequencies in the oxygen band, the temperature profile can be determined. Liquid water emission in the microwave spectrum increases approximately with the frequency squared. By observing radiated power in this region, low resolution cloud liquid profiles can be determined. Cloud base temperature is derived from the zenith infrared observation. Cloud base height can be determined using cloud base temperature and the temperature profile retrieval.

Figure 1. Radiometric profiler <http://radiometrics.com>.

Historical radiosondes at specific sites are used with regression or forward modeling and neural network methods to derive tropospheric profiles from the microwave, infrared, and surface meteorological observations. Neural network and regression methods are discussed by Solheim et al. [1998] and Güldner and Spänkuch [2001], respectively. We discuss radiometric profiler accuracy and reliability, and present example radiometric soundings and comparisons with radiosonde and forecast soundings. We also describe a mobile thermodynamic and wind profiling system with applications in high resolution mesoscale forecasting, advanced assimilation methods, and use of GPS slant delay observations to extend local forecast improvements to regional scale.

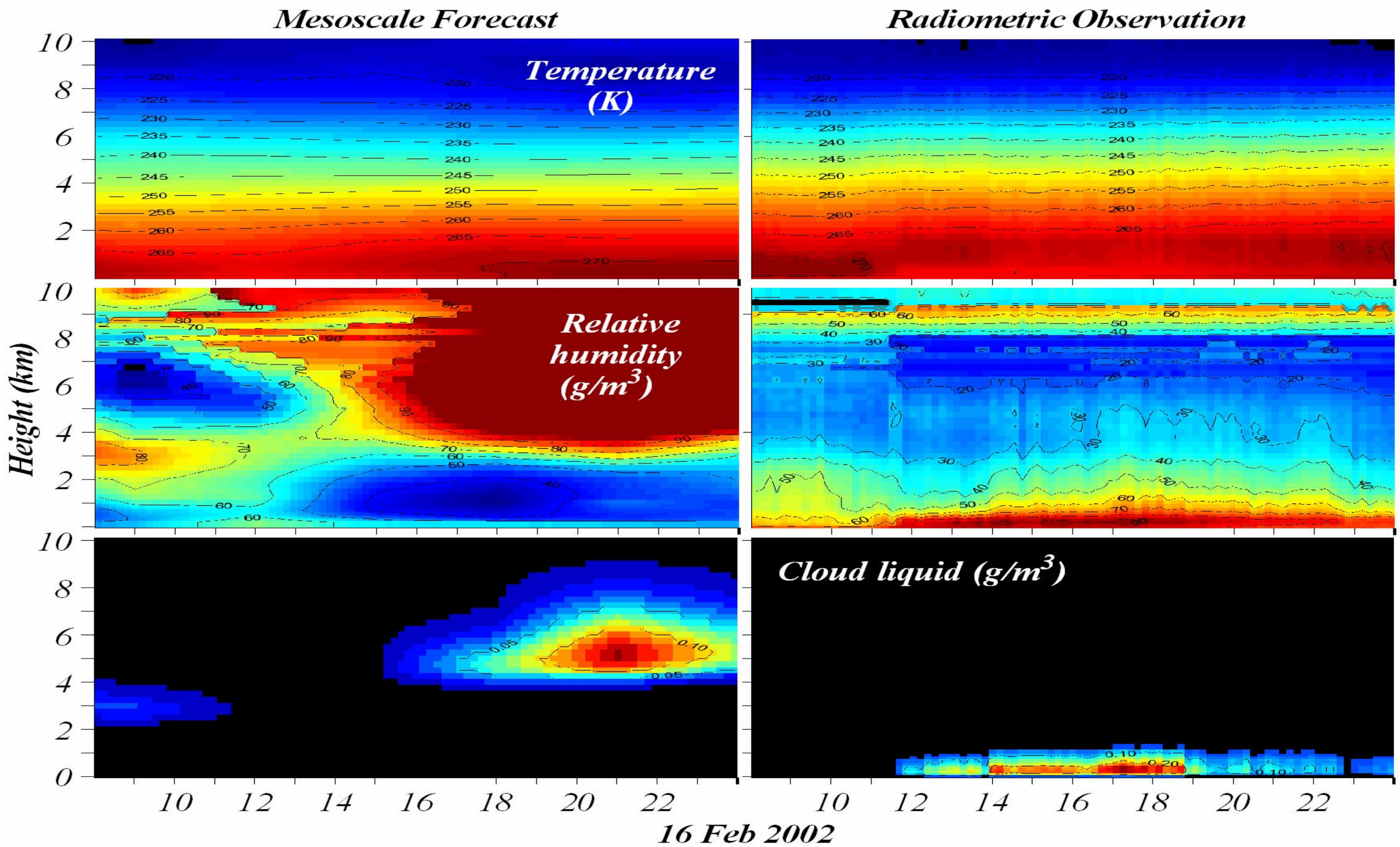

Figure 2. Forecast and radiometric observations (neural network retrieval) at Boulder, Colorado, USA, on 16 Feb 2001.

Example Observations

Radiometric soundings at Boulder, Colorado, are compared with the Mesoscale Meteorology model version 5 (MM5) <http://www.mmm.ucar.edu/mm5> forecasts in Figure 2. The 3-hr 10-km MM5 forecasts are based on the 16 Feb 2000 UTC analysis. The observed and forecast temperature, relative humidity, and liquid profiles are significantly different. The observed temperature profile is warmer by up to 5 K. The relative humidity forecast shows saturation after 1600 UTC above 4 km height, in contrast with the observation which shows saturation below 0.5 km. Similarly, cloud liquid with 0.15 g/m^3 maximum density is forecast at 5 km height at 2100 UTC compared to radiometric observations of 0.3 g/m^3 at 200 m height just after 1700 UTC. The observations were taken during the onset of upslope and fog conditions that occurred along the Colorado front range over a period of four days. As a result of these conditions Denver International Airport diverted several hundred flights during an 18 hour period. Efforts are currently underway by one of the authors (Vandenberghe) to assimilate radiometric soundings into local models to improve local forecasting including fog.

Accuracy and Reliability

The radiometer K-band channels (22-30 GHz) are calibrated by tipping [Han and Westwater, 2000]. The V-band (51-59 GHz) calibration uses a patented cryogenic blackbody target. Tipping and cryogenic calibrations are automatically transferred to a temperature stabilized noise source. An internal mirror points to any elevation angle and an azimuth drive enables pointing to any sky direction. Radiated power observations are used directly in profile retrieval based on regression and radiosonde observations. For retrievals based on neural networks, the radiated power observations are converted to brightness temperatures using the Rayleigh-Jeans approximation of Planck's law [Solheim, 1993]. Instrument accuracy in brightness temperature determination is 0.5 K rms. The radiometer design has proven its reliability in locations including the arctic, mid-latitudes, and the tropics. Radiometric profile accuracy has been determined by statistical comparison with radiosondes [Güldner and Spänkuch, 2001]. Additional information on radiometer design and performance is available via <http://radiometrics.com>.

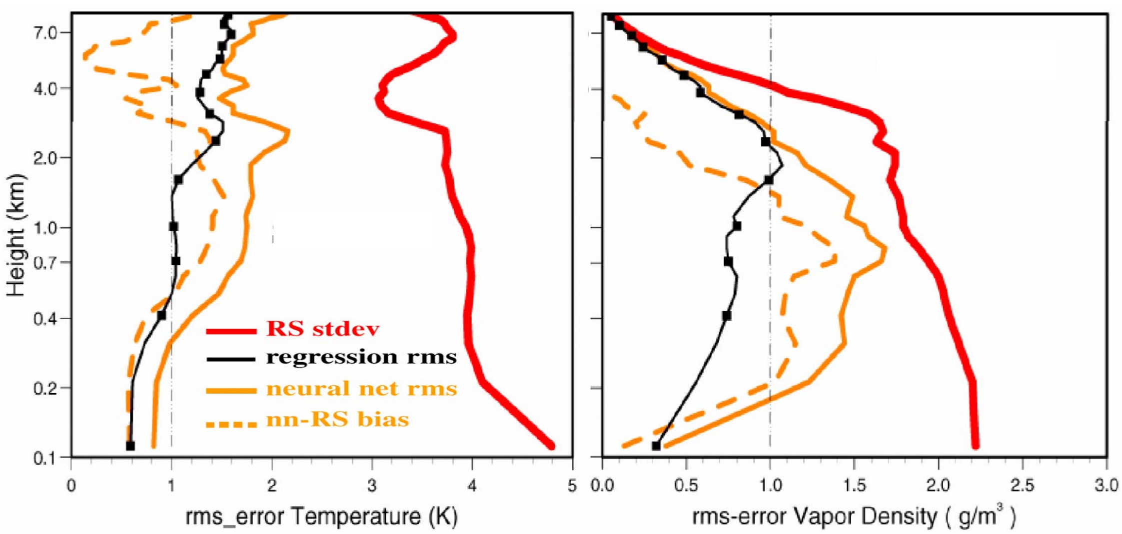

Figure 3. Radiometric profile retrieval accuracy based on statistical comparison with radiosondes (Güldner and Spänkuch, 2001). Radiosonde (RS) standard deviation (stdev), neural network (nn) and regression root mean square (rms) differences are shown.

The German Weather Service is evaluating the use of radiometric and wind profilers for use in operational forecasting. Comparisons between several hundred radiosondes launched at six hour intervals at Lindenberg and the radiometric profiler are shown for the summer months are shown in Figure 4.

For the regression analysis, the error in the temperature retrieval is roughly less than 1 K below 1.5 km height and less than 2 K below 7 km height. For the vapor density the error is less than 0.8 g/m^3 below 1 km, and less than 1.1 g/m^3 below 7 km. Güldner and Spänkuch [2001] provide details on the comparison of radiosonde and radiometer soundings. Neural network retrieval errors include radiometer calibration and errors in line shape assumptions used in forward modeling. Radiosonde sounding errors up to 10 km height are estimated at 1.3 to 2 K (temperature) and 2 g/m^3 (vapor) by the U.S. National Center for Environmental Prediction <http://lnx21.ncep.noaa.gov/oberr/reanl-obs.html>. In general, radiometric sounding error determined from comparison with radiosonde soundings is roughly comparable to radiosonde measurement error.

A high resolution mesoscale model with 3 x 3 km (horizontal) x 100 m (vertical) grid dimensions has 1 km^3 cell volumes. Taking volumetric and temporal sampling effects into account, radiometric profiling provides continuous, volumetric, thermodynamic information needed for improved high resolution mesoscale modeling. We expect significant improvements in high-resolution modeling and forecasting with proper assimilation of local radiometric soundings.

Mobile Profiling

Skill levels of 1-12 hour weather forecasting are notoriously poor. Reasonably accurate forecasts can be obtained during the first hour by assuming no change in weather. However, forecast skill rapidly degrades until initialization with new radiosonde observations. This situation can be improved using thermodynamic profiling. Mobile thermodynamic and wind profiling systems are shown in Figure 4. Soundings from mobile profiling systems can improve high resolution modeling and forecasting [Nehrkorn et al., 2001]. Further improvements are expected if radiometric brightness temperature and wind radar moments are directly assimilated into models. Direct assimilation avoids errors associated with profile retrievals. In addition, the wind radar moments contain moisture gradient information that can improve thermodynamic information from the radiometer [Stankov et al., 1996]. In addition, local thermodynamic and wind profiling observations can be extended to regional scale using “slant” observations of integrated signal delay along individual GPS ray paths [MacDonald et al., 2002]. Slant GPS observations at low elevation angles provide accurate constraints [Pany, 2002] on water vapor fields over distances of 100 km or more [Ware et al., 1997]. Slant GPS methods and their accuracy are discussed by Braun et al. [2002].

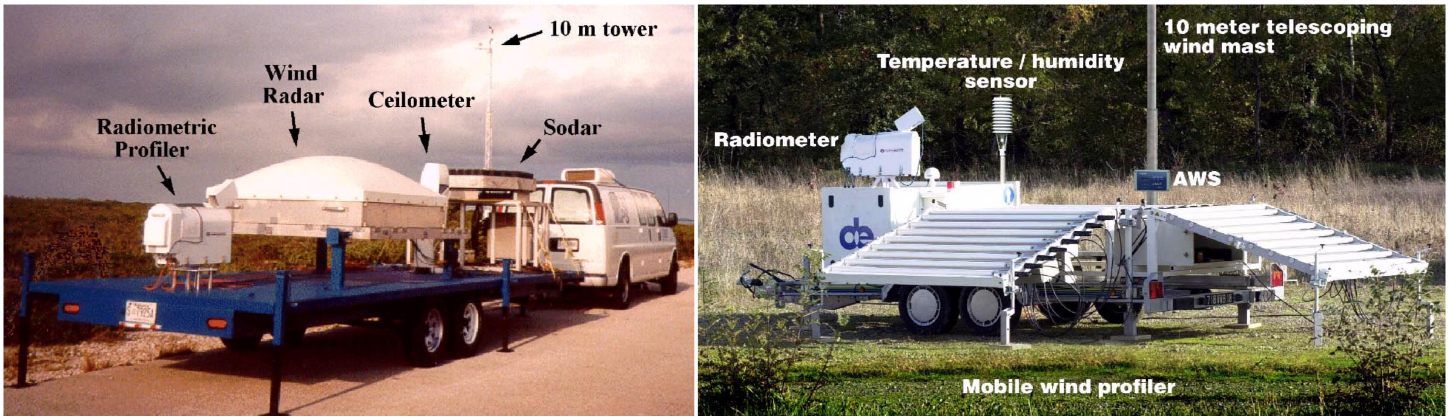

Figure 4. Mobile thermodynamic and wind profiling systems designed for research (left) <http://vortex.nsstc.uah.edu/mips> and commercial applications (right) <http://www.meteo.degreane.fr>

Conclusions

Radiometric profiling provides accurate and reliable temperature and humidity soundings up to 10 km height in clear and cloudy conditions, and low resolution cloud liquid soundings. These soundings can be used for local high-resolution forecasting. Results can be improved by including wind profiling, and advanced assimilation methods. If slant GPS observations are available, local forecast improvements can be extended to regional scale. Applications include airport operations, weather modification, improved dispersion and short-term precipitation forecasting, and climate studies.

References

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