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Continuous Thermodynamic Profiling for Improved Short Term Weather Forecasting

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***Abstract*-The troposphere is subject to short term change resulting from radiation, convection, and advection. Weather forecasts based on radiosondes are insensitive to local changes that occur between radiosonde soundings. Continuous thermodynamic and wind soundings can "fill the gaps" between radiosonde soundings, providing improved local weather forecasting. By including slant observations from a GPS network, local forecast improvements can be extended to regional scales. Radiometric observations including supercooled fog, boundary layer turbulence, summer monsoon and snowfall conditions are presented. Applications include severe storm forecasting, airport weather, urban pollution, and atmospheric dispersion.**

Keywords - microwave radiometer, thermodynamic profiling, wind profiling, slant GPS, weather forecasting

I. Introduction

The state of the atmosphere is traditionally probed twice daily at multiple locations in developed countries to provide the greater part of information needed for weather prediction. However, local tropospheric changes that occur between radiosonde soundings can have a profound effect on local weather. These changes are often inadequately resolved by satellite measurements, particularly during cloudy conditions and in the terrestrial boundary layer. Ground-based radar and radiometry can provide continuous wind and thermodynamic soundings to improve local weather forecasting. Wind profiling radar is widely used operationally, whereas radiometric profiling is currently under evaluation for operational use. We show that radiometric profiling has equivalent accuracy to radiosondes when used for numerical weather modeling. We present case studies of radiometric soundings during fog, boundary layer turbulence, summer monsoon, and snowfall. We also discuss joint use of radiometric soundings with slant GPS observations, and identify applications for continuous wind and thermodynamic profiling.

II. Thermodynamic Profiling

Continuous thermodynamic soundings can be retrieved from passive ground-based multichannel microwave and infrared radiometer observations [1,2]. Retrievals include temperature and humidity soundings up to 10 km height, and one-layer cloud liquid soundings. The accuracy of these soundings is equivalent to radiosondes when used for numerical weather modeling (Fig. 1).

Continuous wind and thermodynamic soundings can be used to "fill the gaps" between twice daily radiosonde soundings traditionally used to constrain the state of the atmosphere for numerical weather modeling. By including slant observations from GPS networks [3], local constraints can be extended to regional scales. This approach provides the potential for significant improvements in forecasting major convective storms [4,5]. Applications include improved forecasting of short term weather; airport fog, icing, visibility, convection, urban pollution and atmospheric dispersion.

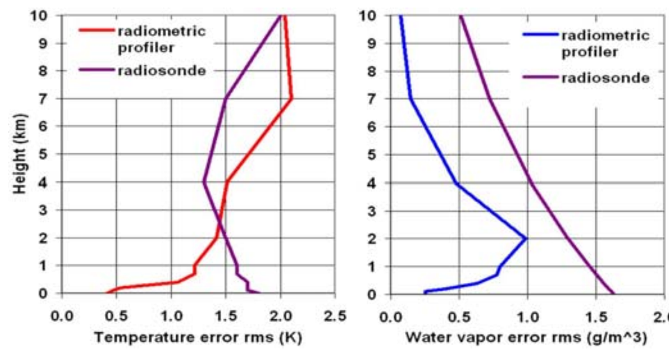

Figure 1. Radiometric retrieval accuracy determined by comparison with radiosondes [3,4]. Radiosonde errors are provided by the National Centers for Environmental Prediction <http://lnx21.wwb.noaa.gov/oberr/reanl-obs.html>.

III. Case Studies

In this section we present thermodynamic soundings retrieved from radiometric profiler observations at Boulder, Colorado, during fog, monsoon, boundary layer turbulence and snowfall conditions. Observations were obtained by Radiometrics TP/WVP-3000 multifrequency microwave and infrared radiometers [6,7].

A. Upslope Induced Supercooled Fog

Upslope weather conditions occurred in the Denver area east of the Colorado Front Range during 16-21 February 2001, as shown in Fig. 2. The arrival of cold upslope air, clearly seen in the radiometric temperature retrievals around 1100 UTC, caused saturation of relative humidity and condensation of supercooled fog below 500 m height. Poor visibility and icing conditions during this upslope event led to major disruptions in

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surface and air transportation in the Denver area, including diversion of flights from Denver International Airport for 18 hours. Fog conditions were not predicted by traditional radiosonde-based forecasts. However, assimilation of radiometric soundings from Boulder (50 km NW of Denver) led to accurate fog forecasts in the Denver area [8].

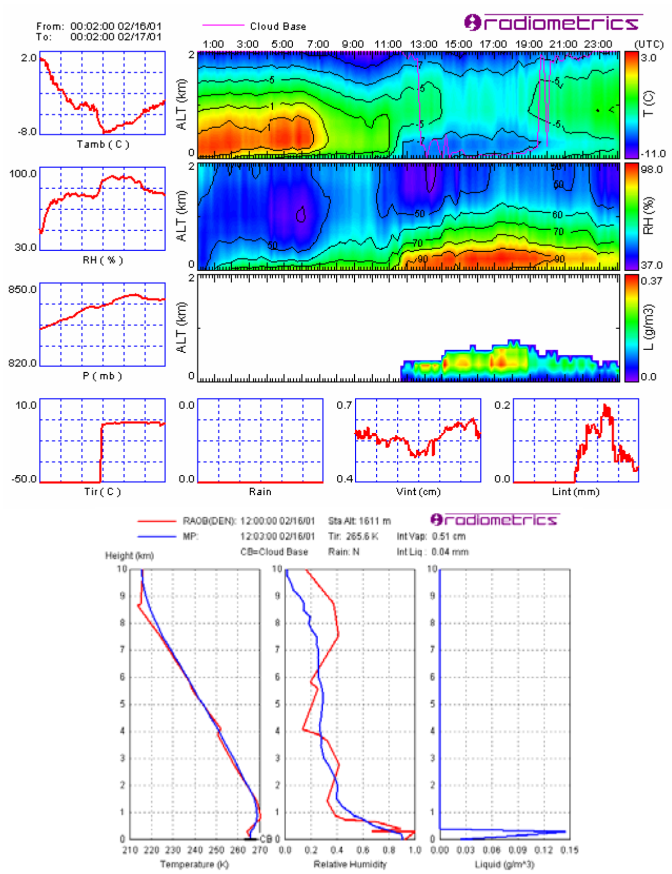

Figure 2. Radiometric retrievals at Boulder, Colorado, showing supercooled fog associated with upslope conditions. Radiometric retrieval (blue) and Denver radiosonde sounding (red) are shown below. A temperature inversion near 1 km height with RH saturation and supercooled fog below 500 m are seen in the radiometric and radiosonde soundings.

During the 12 hours prior to the onset of fog conditions, RH steadily increased from 45% to near saturation below 500 m height. This illustrates the potential use of RH profile trends to predict the onset of saturation associated with fog, clouds, and precipitation. Although predictive capability is expected to be site dependent, familiarity with site specific RH trends should allow improved prediction.

B. Boundary Layer Turbulence

Boundary layer temperature fluctuations as large as 4 K are seen in radiometric retrievals at Boulder from 1244 to 1644 UTC on 20 December 2002 (Fig. 3). Strong winds and turbulence were reported in the foothills above Boulder during this period. Fluctuations in boundary layer relative humidity and surface pressure that are out of phase with the temperature maxima were also observed. These boundary layer fluctuations are probably associated with wind-generated gravity waves. Similar fluctuations were seen in retrievals from two additional radiometric profilers at the same location. The retrievals also showed stable temperatures below 100 m height associated with a surface temperature inversion that was also observed in the 20 December 1200 UTC Denver radiosonde sounding.

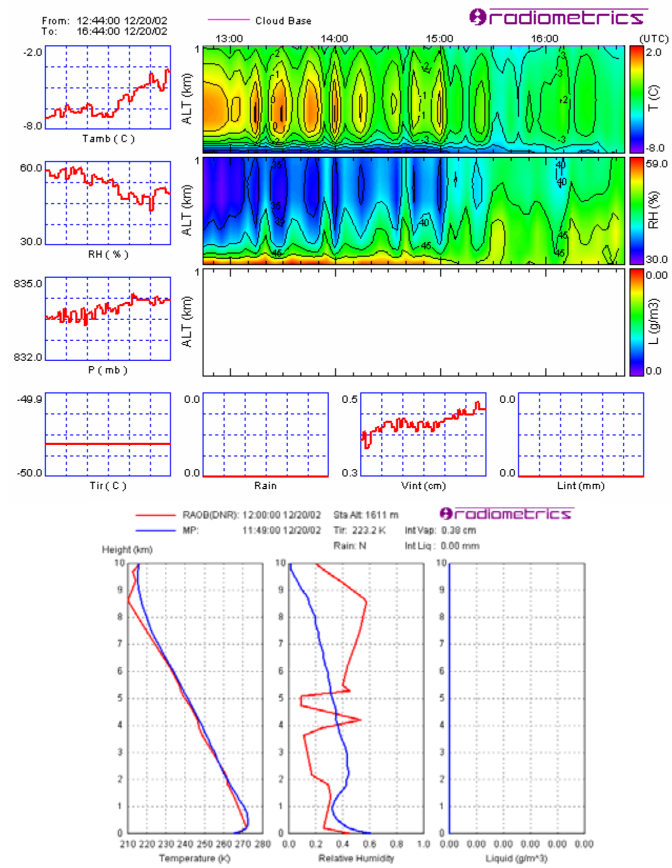

Figure 3. Radiometric retrievals at Boulder, Colorado, showing 15-min periodic variations in boundary layer temperature with amplitude as large as 4 K at 500 m height. Radiometric retrieval (blue) and Denver radiosonde sounding (red) are shown below.

C. Summer Monsoon

Relative humidity increases to saturation near 5 km height during summer monsoon conditions in the Denver area. Radiometric retrievals at Boulder on 19-20 August 2002 (Fig. 4) show typical monsoon conditions including occurrence of cloud at 4-6 km height during the afternoon (3-5 pm local time, or the final two hours of the day UTC). Integrated water vapor increased from 1.68 cm at 2242 UTC to a maximum of 2.50 cm at 0109 UTC, integrated liquid and liquid density reached maxima of 0.20 mm and 0.17 g/m^3 at 2308 UTC, and a brief rain shower occurred at 2355 UTC.

D. Snowfall

Light snowfall occurred on 23 December 2002 in Boulder, Colorado. Radiometric retrievals during this snowfall event are shown in Figure . Liquid density peaks as large as 0.31 g/m^3 were retrieved from 2050-2210 UTC at 20 min intervals near 800 m height. The radiometric retrieval model is based on emission only and therefore “equivalent” integrated liquid and liquid profiles are provided. If scattering is included in the model, actual liquid retrievals can be obtained [9]. In this case, RH at 1 km height steadily increased from 50% to saturation during 11 hours prior to snowfall. Since saturation is required for cloud formation and precipitation, RH trends at specific heights can be used for short term cloud and precipitation forecasting.

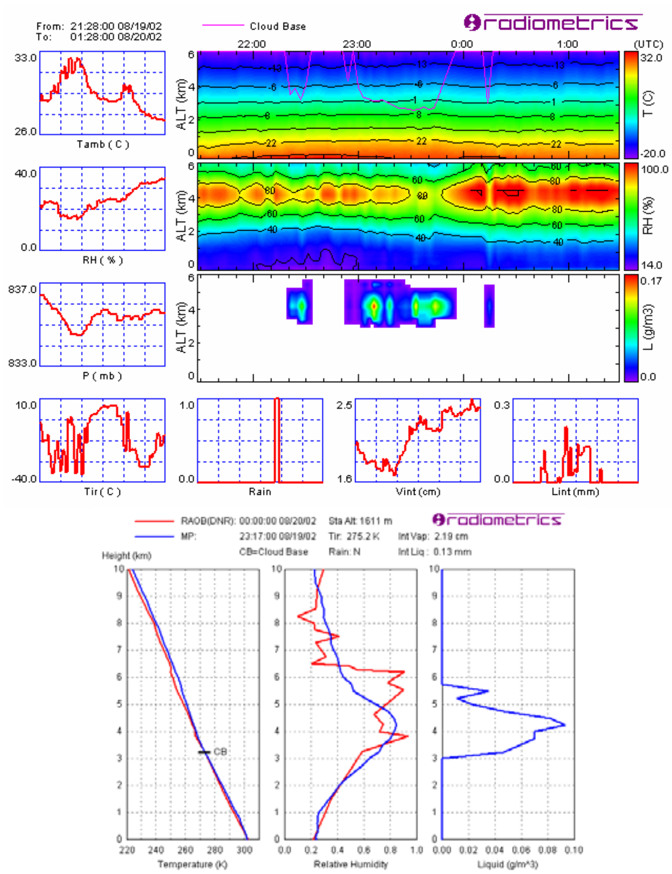

Figure 4. Radiometric retrievals at Boulder, Colorado, show elevated humidity near 5 km height associated with summer monsoon. Radiometric retrieval (blue) and Denver radiosonde (red) soundings are shown below.

Relatively low tropopause height, near or below 10 km, is detected in the radiometric and radiosonde soundings in Fig.'s 2, 3, and 5, but not in Fig. 4. Low tropopause is typically associated with low pressure, precipitation, and bad weather.

IV. Conclusions

Radiometric profiling provides temperature and humidity soundings with equivalent accuracy to radiosondes when used for numerical weather modeling. It also provides single layer cloud liquid soundings. Case studies of radiometric retrievals during fog, summer monsoon, boundary layer turbulence, and snowfall were presented. The case studies demonstrate that radiometric profiling provides new insights into short term thermodynamics of the atmosphere. Applications for radiometric profiling include improved local monitoring and prediction of clouds, fog and precipitation. The method can also be combined with slant measurements from GPS networks to extend local thermodynamic measurements to regional scales, providing significant improvements in short term weather forecasting.

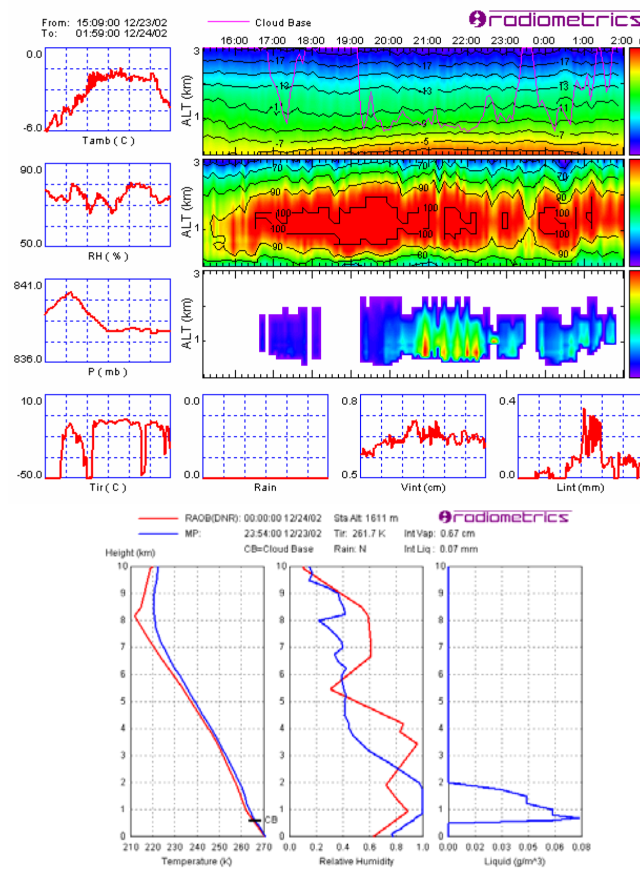

Figure 5. Radiometric retrievals at Boulder, Colorado, show relative humidity saturation near 1 km height associated with a snowstorm. Radiometric retrieval (blue) and Denver radiosonde sounding (red) are shown below.

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