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An Introduction to Ground-Based Radiometric Profiling during Dynamic Weather Conditions

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Introduction

The state of the atmosphere is traditionally probed twice daily by radiosondes at multiple locations to provide the greater part of information needed for weather prediction. However, local thermodynamic changes that occur between radiosonde soundings can have a profound effect on local weather. Continuous thermodynamic retrievals from ground-based radiometric profilers can be used to "fill the gaps" between radiosonde soundings. We present thermodynamic retrievals from a commercial radiometric profiler during dynamic weather conditions. Retrievals include temperature and humidity soundings up to 10 km height, and one-layer cloud liquid soundings. The temperature and humidity retrievals are similar in accuracy to radiosonde soundings when used for numerical weather prediction [Ware et al., 2003a]. We present case studies of radiometric retrievals and comparisons with radiosonde soundings during dynamic weather conditions at Boulder, Colorado. For these case studies the radiometer observation interval was 5 min, and neural network retrieval methods were applied. Case studies include fog, summer monsoon, snowfall, and boundary layer turbulence.

Supercooled Fog

Radiometric retrievals up to 2 km height during upslope conditions in Boulder on 16 Feb 01 are shown in Figure 1. The arrival of cold upslope air near 1100 UTC is seen in the radiometric temperature retrievals (upper contour) below 500 m height. High relative humidity (middle contour) and sudden onset of fog (lower contour) are also seen. A comparison of the Boulder retrieval and the Denver radiosonde sounding at Denver (50 km southeast of Boulder) at 1200 UTC is shown in Figure 2. Elevated temperature inversion at 1 km height, high relative humidity below 500 m height, and tropopause height below 10 km are seen in both the radiometric retrieval and radiosonde sounding. Fog with a maximum density of 0.14 g/m3 at 300 m height is seen in the retrieval. Fog was not predicted by traditional radiosonde-based forecasts. However, variational assimilation of Boulder radiometric retrievals led to accurate fog forecasts in the Boulder-Denver area [Vandenberghe and Ware, 2003]. Trends of continuous relative humidity retrievals can be used to predict the onset of fog. Increased skill is expected with direct assimilation of raw radiometric brightness temperature observations into numerical weather models [Nehrkorn et al., 2003].

Snowfall

Radiometric retrievals up to 3 km height during a snowfall event in Boulder on 23 Dec 02 are shown in Figure 3. "Equivalent" liquid density (bottom contour plot) variations with ~15 min period and 0.1 g/m3 magnitude are seen from 500 m to 1.2 km height from 2050 to 2210 UTC. The liquid density retrieval is "equivalent" because the physical retrieval model is based on liquid emission only and does not include emission and scattering from ice. If ice and scattering are included in the retrieval model, ice retrievals in addition to liquid retrievals can be obtained [Li et al., 1997]. The Denver radiosonde sounding and the Boulder radiometer retrieval at 0000 on UTC 24 Dec 02 are shown in Figure 4. Both plots show similar temperature lapse rates and tropopause height below 10 km. During the 11 hours prior to snowfall the relative humidity at 1 km height steadily increased from 50% to 100%. Since relative humidity saturation is required for cloud formation and precipitation, trends of continuous relative humidity retrievals can potentially improve local short term fog and precipitation forecasting.

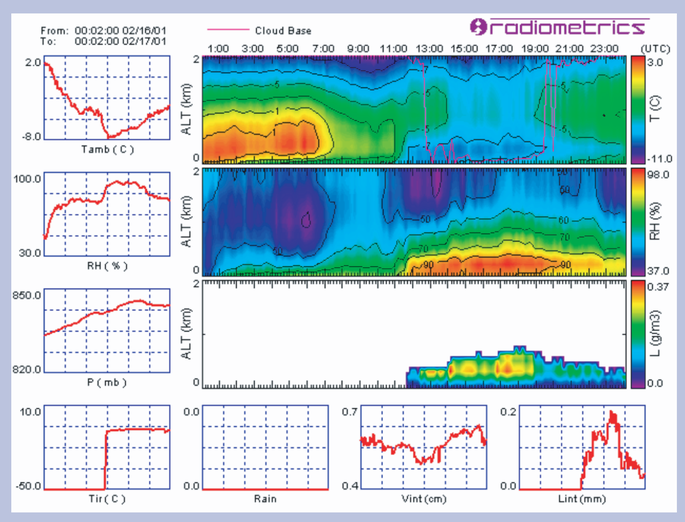

Figure 1. Radiometric retrievals to 2 km height showing supercooled fog associated with upslope weather conditions at Boulder on 16 Feb 01. Poor visibility and icing conditions during this upslope event led to major disruptions in surface and air transportation in the Denver area, including diversion of international flights from for 18 hours.

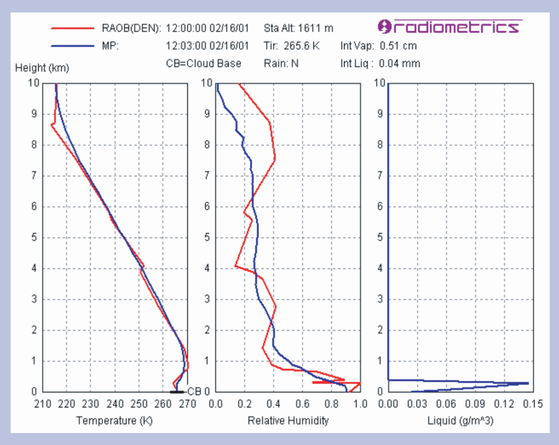

Figure 2. Boulder retrieval (blue) and Denver radiosonde sounding (red) showing supercooled fog, an elevated inversion at 1 km height and relative humidity saturation up to 300 m height at 1200 UTC on 16 Feb 01.

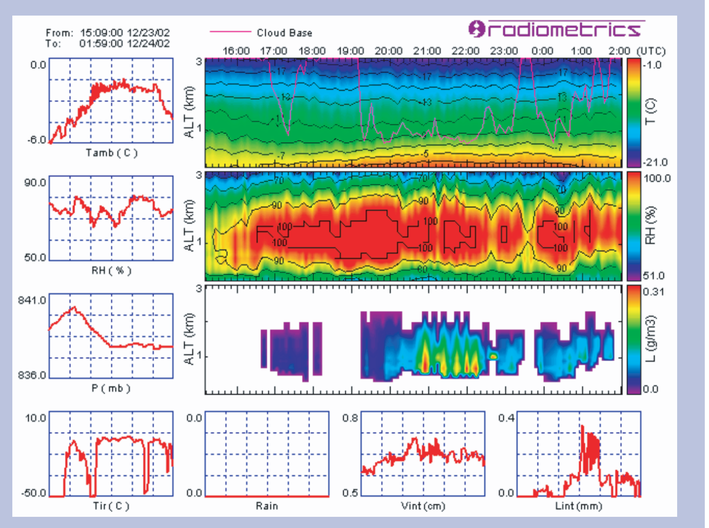

Figure 3. Radiometric retrievals to 3 km height during snowfall showing relative humidity saturation near 1 km height and waves of equivalent liquid at 15 min intervals at Boulder on 23 Dec 02

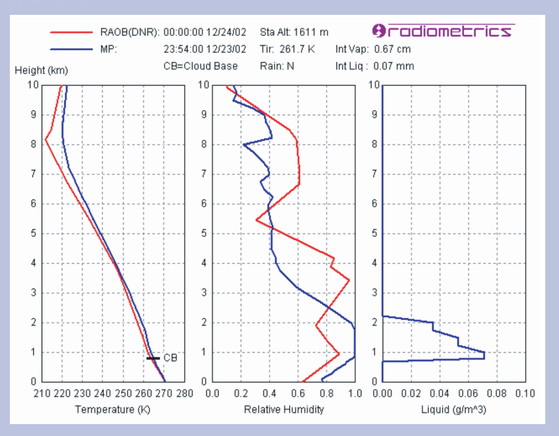

Figure 4. Boulder retrieval (blue) and Denver radiosonde sounding (red) showing a 7 K boundary layer temperature inversion and tropopause height below 10 km at 0000 UTC on 20 Dec 2003.

Summer Monsoon

Radiometric retrievals up to 6 km height associated with summer monsoon conditions at Boulder on 19-20 Aug 02 are shown in Figure 5. High levels of relative humidity (middle contour) and intermittent cloudiness at 3 to 5 km height (bottom contour) are seen. The Denver radiosonde sounding and the Boulder radiometer retrieval at 0000 UTC 20 Aug are shown in Figure 6. Continuous relative humidity and cloud liquid soundings can potentially be used to improve short term precipitation forecasts.

Boundary Layer Turbulence

Radiometric retrievals to 1 km height during strong gusty winds in Boulder on 20 Dec 02 are shown in Figure 7. Boundary layer temperature fluctuations as large as 3 C (upper contour plot) are seen from 1130 to 1530 UTC. The average period of the variations is 13 minutes. The boundary layer thermodynamic variations may be associated with boundary layer gravity waves.

Discussion

Radiometric profiling provides temperature and humidity soundings with equivalent accuracy to radiosondes when used for numerical weather modeling, as well as single layer cloud liquid soundings. The presented case studies provide new insights into short term thermodynamics of the atmosphere. Radiometric retrievals can be assimilated into numerical weather models providing continuous thermodynamic constraints. A more powerful method is to assimilate radiometric brightness temperatures directly. Radiometric methods for continuous thermodynamic profiling have significant potential for a variety of applications in meteorological research and weather forecasting.

References

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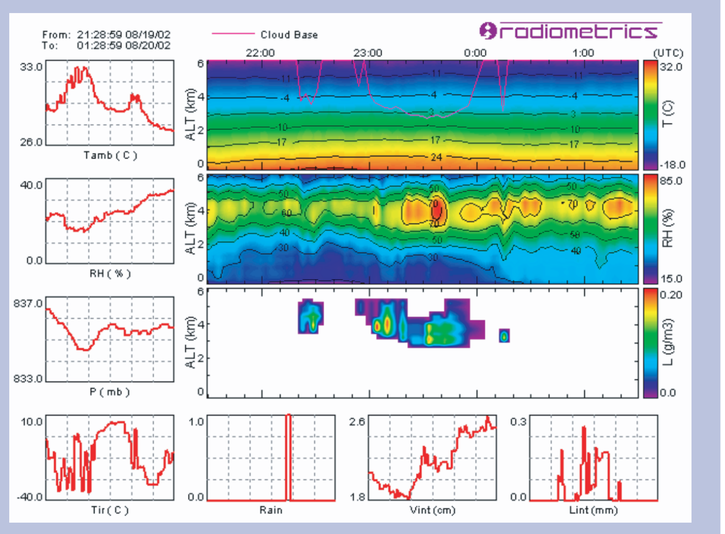

Figure 5. Radiometric retrievals to 6 km height during summer monsoon conditions showing elevated relative humidity levels and cloud liquid near 4 km height at Boulder on 19-20 Aug 02.

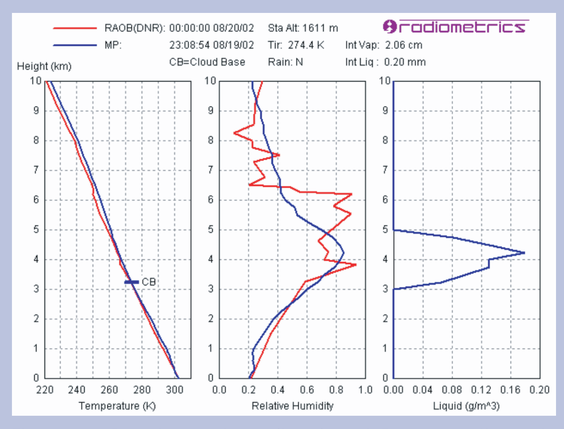

Figure 6. Boulder retrieval (blue) and Denver radiosonde sounding (red) during summer monsoon conditions showing elevated humidity near 4 km height at 0000 UTC on 20 Dec 02. The retrieval shows cloud liquid with 0.18 g/m3 maximum density near 4 km height.

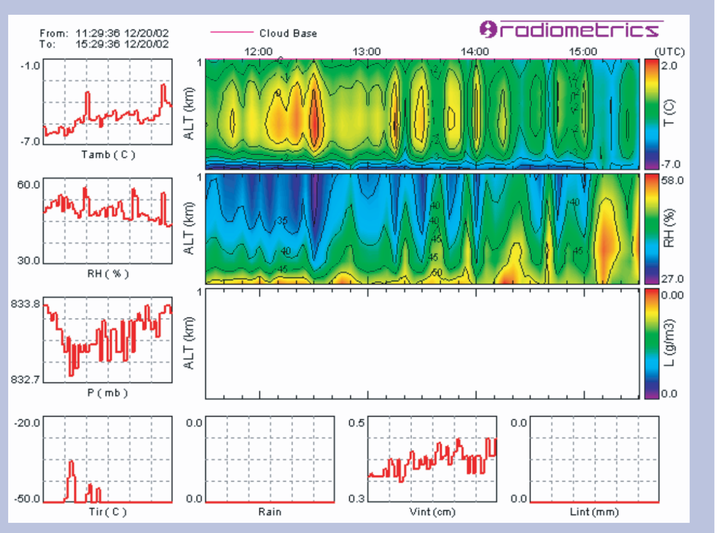

Figure 7. Radiometric retrievals to 1 km height showing 13-min periodic temperature variations associated with gusty winds and boundary layer turbulence at Boulder on 23 Dec 02.

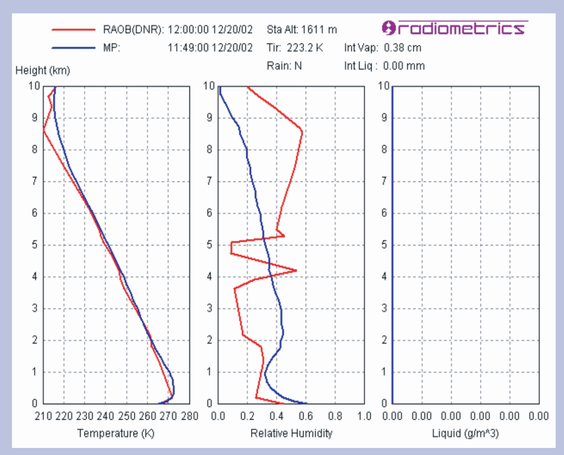

Figure 8. Boulder retrieval (blue) and Denver radiosonde sounding (red) showing 7 C temperature inversions and tropopause height below 10 km at Boulder on 20 Dec 03.