Boundary layer temperature profile observations using ground-based microwave radiometers

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Abstract

The use of ground-based microwave profilers is an accurate and relatively inexpensive and way to continuously observe the temperature profile of the boundary layer with a high temporal resolution. Here we present observations of a 14-channel microwave radiometer (HATPRO) which has been used under various climatic conditions. To obtain the temperature profile with a high vertical resolution (down to 50 m close to the surface), observations are taken at seven frequencies (51 to 59 GHz) and under several elevation angles from 90 to 5 degrees. The error for the retrieved temperature profiles for the lowest 1000 m is less than 0.5 K.

1 Introduction

Microwave profilers which measure several frequencies along the 60 GHz oxygen absorption complex are a well established technique for observing the atmospheric temperature profile from the ground as well as from space. From the ground observations are typically taken in zenith direction at about 5 to 10 frequency channels from 50 to 60 GHz (Westwater et al., 2005). The vertical resolution decreases from about is about 500 m in 300 m height and rapidly decreases to 1 km in 5000 m height (Güldner und Spänkuch, 2001). The performance in the boundary layer can be improved significantly by scanning the atmosphere under different elevation angles. This paper presents a new instrument optimized for this purpose as well as some measurement examples.

2 Instrumentation

The HATPRO (Humidity And Temperature PROfiler) microwave radiometer (Rose et al., 2005) continuously measures thermal emission by atmospheric components (water vapor, oxygen, cloud water) at 14 channels located in 2 frequency bands. Seven frequencies are located along the high-frequency wing of the water vapor absorption line at 22.235 GHz, and 7 channels are located along the low-frequency wing of the oxygen absorption complex around 60 GHz.

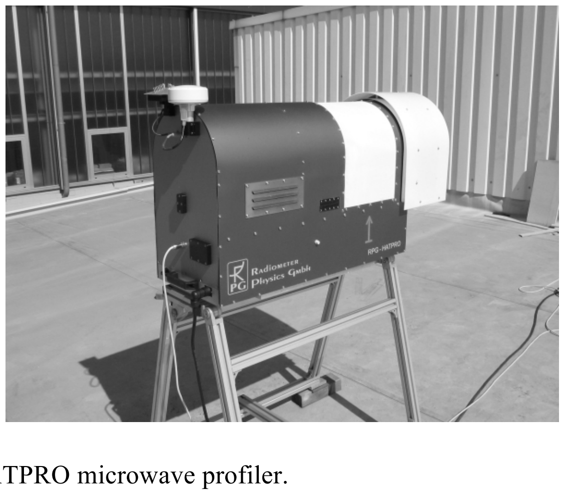

Figure 1. Photograph of a HATPRO microwave profiler.

For boundary layer retrievals observations are taken at 6 elevation angles from 90 to 5 degrees. For the highest frequency (59 GHz) which is nearly opaque this results in a variation of about 1-2 K. This makes clear that a high receiver stability and low noise level of HATPRO is absolutely necessary for a successful observation. Profiles of water vapor and temperature are derived from the observed brightness temperatures via multi-variate regression algorithms based on a large (at least 10 years) of atmospheric profiles from radiosoundings. Retrieval algorithms were developed for the traditional zenith pointing geometry as well as a so called boundary layer retrieval which involves the angular information of the highest four frequencies. The theoretical accuracy of the latter algorithm outperforms the zenith algorithm strongly within the boundary layer (Fig. 2): For the lowest 1500 m of the troposphere the accuracy is below <0.5 K). It should be noted that in this approach a horizontally homogenous atmosphere is assumed.

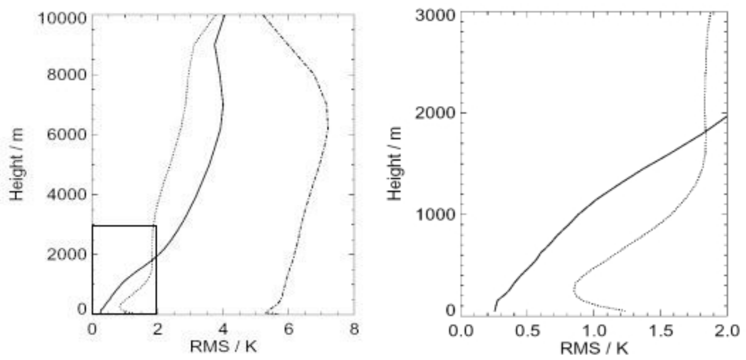

Figure 2. Theoretical RMS for zenith temperature profile retrievals (dotted) and improved profiles below 1500 by performing elevation scans. The standard deviation of the data set is shown by the dashed line.

3 Results

During the last year, HATPRO microwave radiometers have been operated under very different climatological conditions. The data set includes observations from the high mountain station Schneefernerhaus in the German Alps in winter, results from the LAUNCH campaign in summer 2005 at Lindenberg (Germany) which show mid-latitude summer conditions. Furthermore, tropical measurements in Darwin as part of the Tropical Warm Pool International Cloud Experiment (TWP-ICE) as well as in Djougou, Benin as part of the African Monsoon Multidisciplinary Analysis (AMMA) have been performed.

During the two month campaign at Lindenberg HATPRO observations could be compared to radiosoundings by the German Weather Service. The comparisons (Fig.3) revealed a good agreement in different meteorological conditions with an RMS below 0.6 K below 1 km. Taking into account the differences caused by the observation of different air volumes, e.g. the radiosonde drifts away, this excellent comparion confirms the theoretical results.

The capability of the radiometer to detect shallow night-time inversions very well was investigates by comparing the observation with the ones by a 100 m mast located directly next to HATPRO. The statistical comparison over the whole period showed an RMS of ~0.5 K for 40 and 100 m height which is better than the one between the radiosonde and the mast. Looking at the temperature gradient (Fig. 4) the possibility of detecting inversions (up to 6 K/100m) with a good accuracy of 0.7 K. Largest discrepancies occur when the temperature gradient is positive, e.g. the surface is heating and spatial differences occur which do not allow the assumption of horizontal homogeneity.

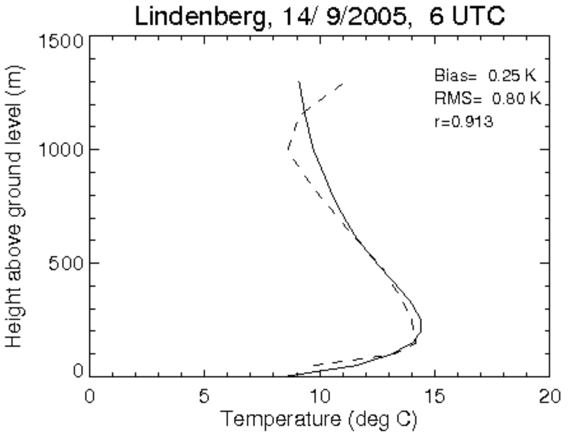

Figure 3. Two examples of boundary layer temperature profiles from Lindenberg, Germany. Dashed lines are radiosonde measurements, solid lines represent retrieved temperature profile from HATPRO boundary layer scans. Left: Shallow morning inversion. Right: Well-mixed daytime profile.

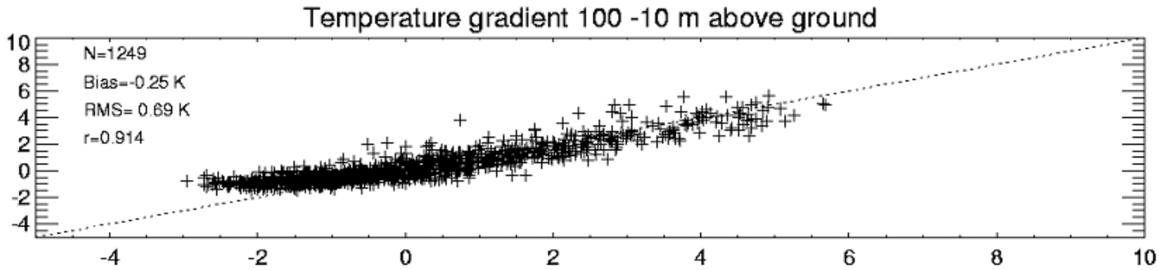

Figure 4. Comparison of HATPRO temperature gradient (x-axis, Kelvin) with corresponding values by a 100 m mast (y-axis) in Lindenberg.

4 Discussion, Conclusions, and Outlook

The possibilities for continuous observations of boundary layer temperature profiles by a highly stable ground-based microwave radiometer have been shown. The use of several observation angles compared to zenith observations improves the accuracy of temperature profiles for the lowest parts of the troposphere significantly by about a factor of 2 down to 0.5 K. Further work with these data include climatological studies on the diurnal cycle of the boundary layer temperature profiles in different climate zones as well as their use for the evaluation of numerical weather prediction models.

Literature

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