High accuracy determination of temperature, water vapor and cloud parameters with a novel suite of microwave channels in an alpine environment

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Objectives

- In 2005/2006 the Environmental Research Station **Schneefernerhaus** (UFS), located at Germany's top (Zugspitze) at 2650m NN, has been equipped with a dual system of new state-of-the-art microwave radiometers.
- One, the commercially available **HATPRO** (Humidity and Temperature PROfiler), continuously observes **profiles of temperature and humidity.** Furthermore, elevation scans are possible practically down to 0° and are being exploited to derive the temperature profile of the lowest atmospheric levels with **high vertical resolution** (~100 m).
- The second instrument **DPR** (Dual Polarization Radiometer), a special development for the University of Munich, consists of two receivers at 90 and 150 GHz, the latter with the possibility of measuring the incoming radiation in both parallel and perpendicular polarization components. Features of this novel instrument are an improved determination of the **liquid water path (LWP),** sensitivity towards **ice hydrometeors** and the evaluation of atmospheric absorption models.
- In conjunction with routine meteorological observations at UFS and the Zugspitz-summit (2962m NN) and the air-chemistry observations within the **WMO Global Atmospheric Watch** program, the continuous vertical profiles will give detailed insights into the air mass origin and support process studies.

Microwave Spectrum

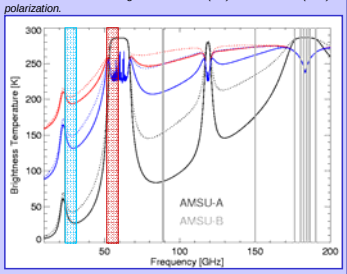
- HATPRO performs simultaneous brightness temperature (TB) measurements at 14 different channels located around the 22.235 water vapor line (22.235 to 31.4 GHz) and the 60 GHz oxygen absorption complex (51.26 – 58.8 GHz).
- DPR observes the atmospheric radiation at the two window frequencies 90 and 150 GHz, which are also used by the satellite instrument AMSU.
- **Liquid cloud emission** increases roughly proportional to the frequency squared resulting in stronger TB differences between clear and cloudy scenes.

TB enhancement due to LWP of 250 gm^{-2} at different frequencies with respect to a standard atmosphere

f [GHz]	31	36	90	150
ΔTB (zenith)	9	12	50	35

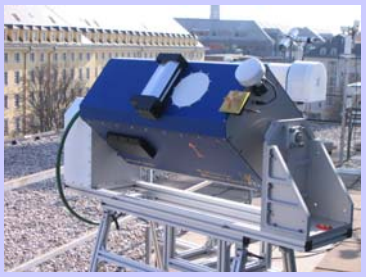
- While for the standard atmosphere the water vapor continuum already leads to a saturation effect, the dry air at the UFS still gives enhanced sensitivity at 150 GHz.

Radiative transfer simulation for standard atmospheric profile during clear sky (solid) and cloudy (LWP = 250 gm^{-2}; dashed) conditions. Satellite observations are given for vertical (red) and horizontal (blue) polarization.

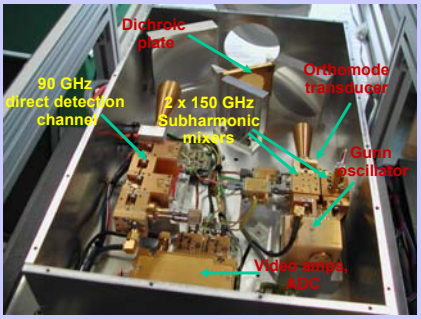


- Auxiliary measurements of environmental temperature, pressure and humidity are performed. Furthermore, the radiometers incorporate rain detection sensors and GPS clocks for time synchronization.

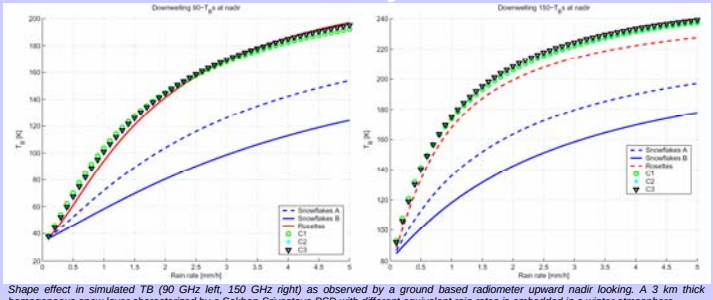
DPR Specifications



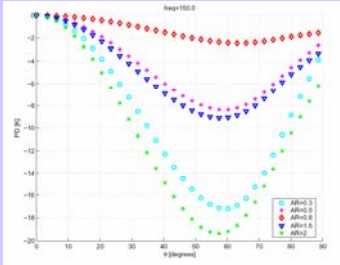
- **External elevation scanning** preserves the two orthogonal 150 GHz polarisations
- **Calibrations:** High brightness temperature accuracy is achieved by a combination of *absolute* and *relative* calibrations involving liquid nitrogen, noise diode standards and sky tipping.
- **Channel sensitivities:**
  - 90 GHz: 410 K, 2 GHz bandwidth
  - 150 GHz (V): 1480 K, 2.5 GHz bandwidth
  - 150 GHz (H): 1450 K, 2.5 GHz bandwidth
- **Frequency splitting** preserves polarisation information due to use of dichroic plate
- **Receiver Technology:**
  - 90 GHz: Direct detection
  - 150 GHz: Heterodyne system (DSB), will be upgraded to direct detection in second half of 2006
- **Optical Performance:** All channels 2.0° HPBW



DPR Potential – Snow Sensitivity Simulation



Shape effect in simulated TB (90 GHz left, 150 GHz right) as observed by a ground based radiometer upward nadir looking. A 3 km thick homogeneous snow layer characterized by a Sekhon-Srivastava PSD with different equivalent rain rates is embedded in a winter atmosphere.



Polarization difference at 150 GHz as a function of the viewing angle for a ground-based observation of a 2 km thick snow layer with RR = 1 mm/h and containing horizontally oriented spheroids. The different curves correspond to different axial ratio AR. AR is larger than 1 for oblate spheroids and smaller than 1 for prolate spheroids.

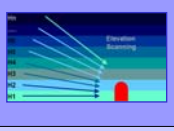
- Significant **TB enhancements** are simulated due to scattering of radiation emitted/reflected by the surface→ function of equivalent rain rate
- TB enhancement also clearly depends on crystal type (habit)
- TB enhancement more pronounced at 150 GHz
- **Polarization differences** occur for preferred particle orientations and off-nadir elevation angles
- Polarization differences as high as 20K possible, oblate particles cause stronger signals than prolate ones

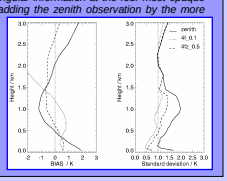
HATPRO Prospects

Boundary Layer Temperature

- At prescribed intervals (for example 20 min) boundary layer scans observe the atmosphere under several angles
- Assuming horizontal homogeneity the temperature profile can be determined with high vertical resolution

Comparison of HATPRO retrievals with 80 corresponding radio soundings in terms of BIAS and RMS difference. Retrievals were performed using zenith observations only (solid), using the angular information at the four most opaque frequencies (4f_0.1) and by further adding the zenith observation by the more transparent channels (4fz_0.5).





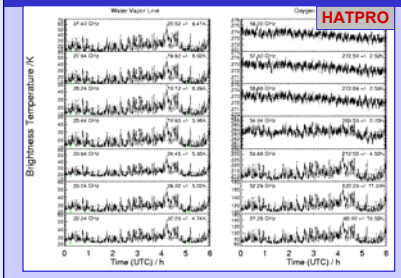
- Theoretical studies indicate that for DPR, together with distinct HATPRO channels, the accuracy for retrieving liquid water path may be on the order of 5 gm^{-2}.
- This is highly relevant for the detection of the often observed thin persisting supercooled cloud layers with liquid water contents lower than ~30 gm^{-2}, however with high radiative impact.

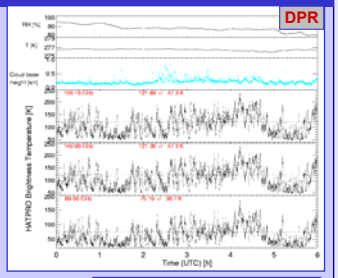
Improved LWP

LWP RMS errors for ~3000 m NN derived from empirical regression techniques based on radiosonde profiles

	all [gm^{-2}]	cloudy [gm^{-2}]	cloudy < 30 gm^{-2}
2 ch (22 + 31 GHz)	10.6	14.1	5.8
2 ch + 90 GHz	3.8	5.7	3.1
2ch + 90 + 150 GHz	3.8	5.3	3.3
Mean LWP	7.4	153.4	18.0

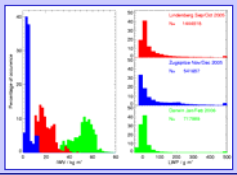
First Observations





Brightness temperature observation during the presence of a low level water cloud (base around 200 m, LWP ~ 0 - 400 gm^{-2}) with HATPRO (left) and DPR (right). The higher the frequency the stronger the TB variations caused by cloud water.

- HATPRO has been operated continuously for more than 2 months at UFS. Comparisons with climatologies from Darwin, Australia and Lindenberg, Germany reveal an unexpected high number of **medium LWP clouds**.
- Integrated Water Vapor (IWV) is mostly < 5 kgm^{-2} and thus does not provide a strong signal at 150 GHz.



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