



## RPG-HATPRO-G5 series

High-precision microwave radiometers for continuous atmospheric profiling

### Applications

**Tropospheric Profiling**  
of temperature, humidity,  
and liquid water

**Water Vapour Monitoring**  
e.g. at astronomical sites

**Nowcasting**

- Atmospheric stability
- Severe weather

**Atmospheric Attenuation**  
for satellite communication

**Boundary Layer Profiling**

- High-resolution temperature profiles (better than balloons)
- 24/7 monitoring of temperature inversions
- Fog detection
- Air pollution applications

**Data Assimilation**

Input for weather and climate models

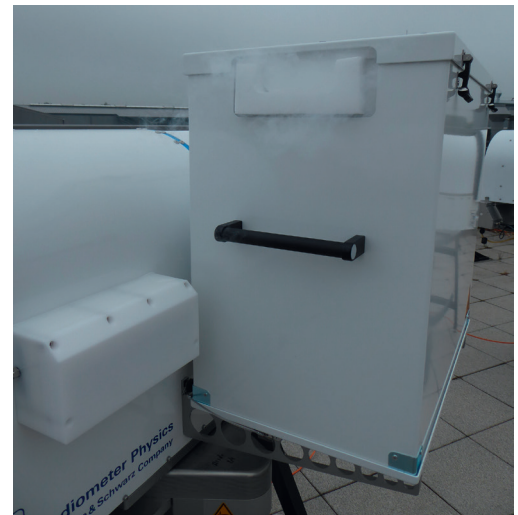
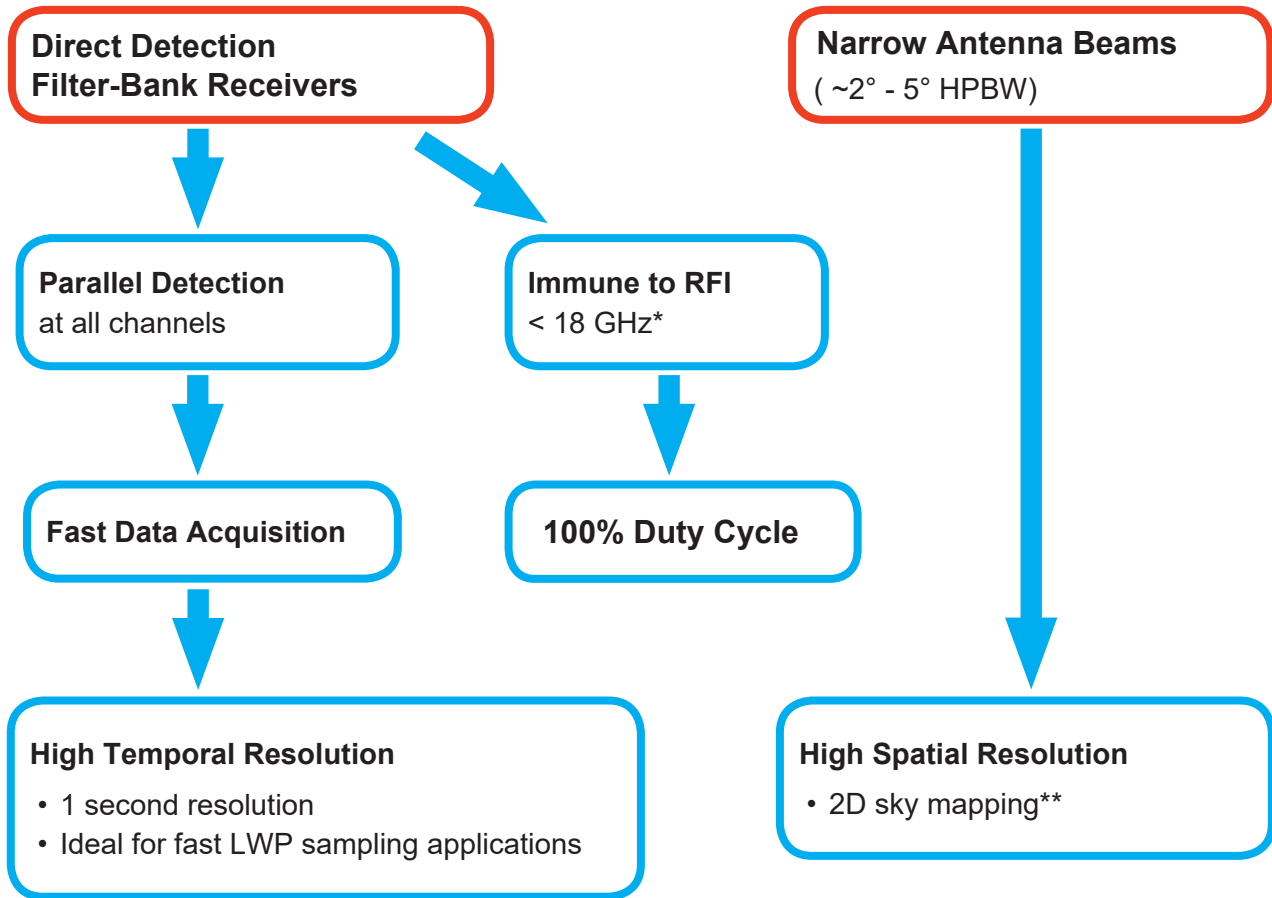
**Satellite Tracking**

Tropospheric delay and attenuation along line of sight

Absolute calibration of  
**Cloud Radar** receivers



## Design



RPG-HATPRO-G5 radiometer during the absolute calibration procedure.

\* e.g. radio transmitters or mobile phones, \*\* only with azimuth positioner



## Improvements with Generation 5

**High Precision Calibration Target**  
providing  $\pm 0.15$  K absolute accuracy



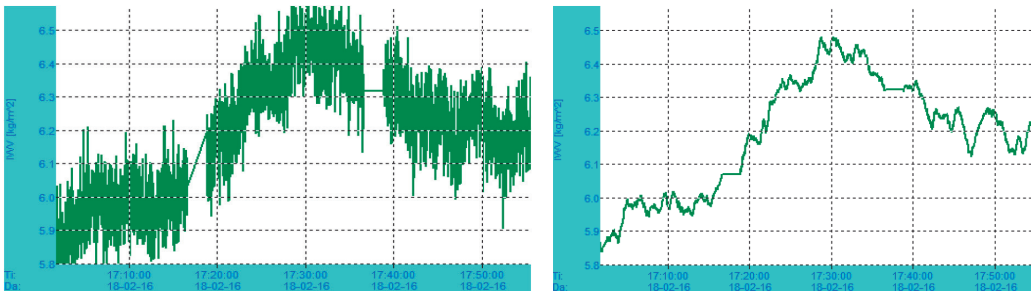
**Data Sampling Rate**  
increased by a factor 20

**Rapid Noise Switching**  
16x faster than with G4

**Complete removal of 1/f noise contributions**

**Integration to noise levels < 50 mK within 10 seconds**

**Improved Performance of Atmospheric Products - e.g. factor 3 for IWV (Integrated Water Vapour):**



Left: IWV time series with 1 second sampling, right: IWV time series with 30 seconds sampling.

**Even humidity fluctuations of 20g/m<sup>2</sup> become visible!**

Elev. [DEG]	G4 IWV-Ret. Accuracy [kg/m <sup>2</sup> ]		G5 IWV-Ret. Accuracy [kg/m <sup>2</sup> ]	
		RMS		RMS
90		0.347		0.125
75		0.356		0.129
60		0.377		0.147
51		0.400		0.167
42		0.447		0.204
36		0.560		0.244
30		0.640		0.309
24		0.759		0.418
19.2		0.861		0.521
10.2		2.359		1.233

IWV Accuracies at different elevation angles for generations G4 and G5 (1 second sampling).



### Hardware Features



#### Integrated Automatic Weather Station

Vaisala® WXT536 to measure surface wind, rain rate, pressure, temperature, and relative humidity

#### Mitigation System for Rain / Fog / Dew

- Powerful blower
- Radome with hydrophobic coating
- Efficient heater system

#### Azimuth Positioner

for full sky scanning \*

#### Data Backup

on embedded Radiometer-PC

#### IR Radiometer

for cloud base height detection\*\*

#### Ethernet Interface

for network capability

#### Optical Fibre Data Cable

for lightning protection and secure data transmission

#### Interference mitigation

High frequency RFI (G5 and G6 mobile network) mitigated by channel redundancy.

#### IR Scanner

for synchronous IR and microwave observations\*\*

\* only with azimuth positioner, \*\*optional



## Software Features

### State-of-the-art Retrievals

- Neural Network (NN)
- Customized

### Accurate North-Alignment

via sun-scanning\* and positioning with the integrated GPS receiver

### Atmospheric Data Products

- Profiles of temperature / humidity / liquid
- Integrated Water Vapour (IWV)
- Integrated cloud liquid
- Atmospheric attenuation
- Cloud base height\*
- Wet/dry atmospheric delay

### Detailed Housekeeping Data

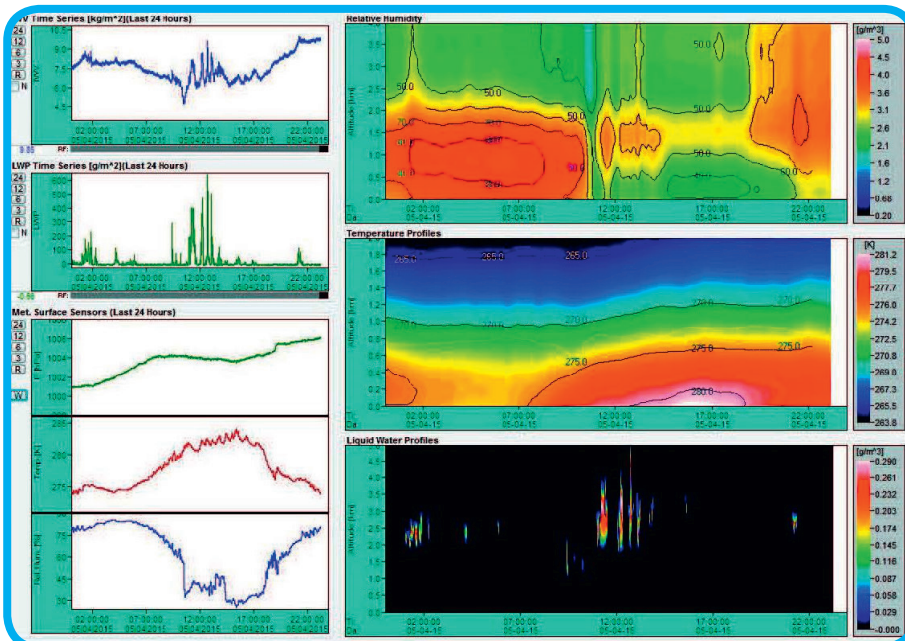
- Instrument status / control
- Data quality flags
- Data flagging

### Thermodynamic Diagrams and Stability Indices

### Free Software Updates

### Satellite Tracking with navigation files

### Automatic Recovery after power failures



### Output Data

- Level 1 (brightness temperatures)
- Level 2 (retrieved products)
- Automatic conversion to netCDF, ASCII, RAOB®

### Calibration

- Short calibration cycles
- Automatic skytipping
- Automatic internal calibrations including noise sources
- Manual liquid nitrogen calibration (every 6 months)

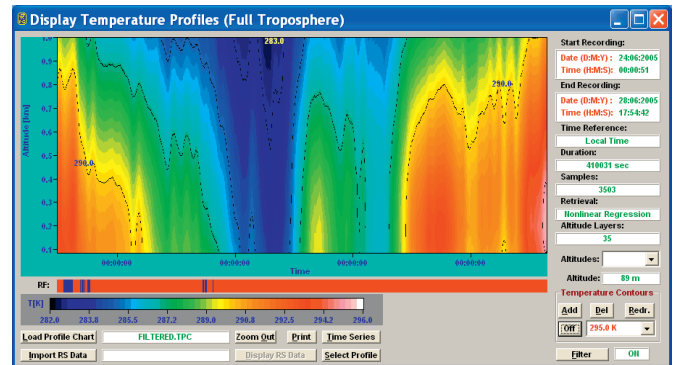
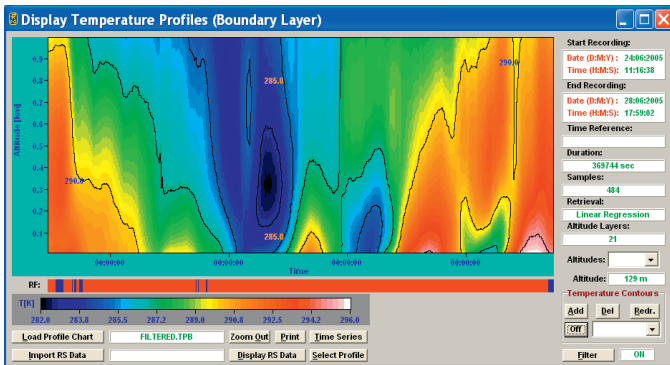
\* only with azimuth positioner

\*\* only with optional IR Radiometer

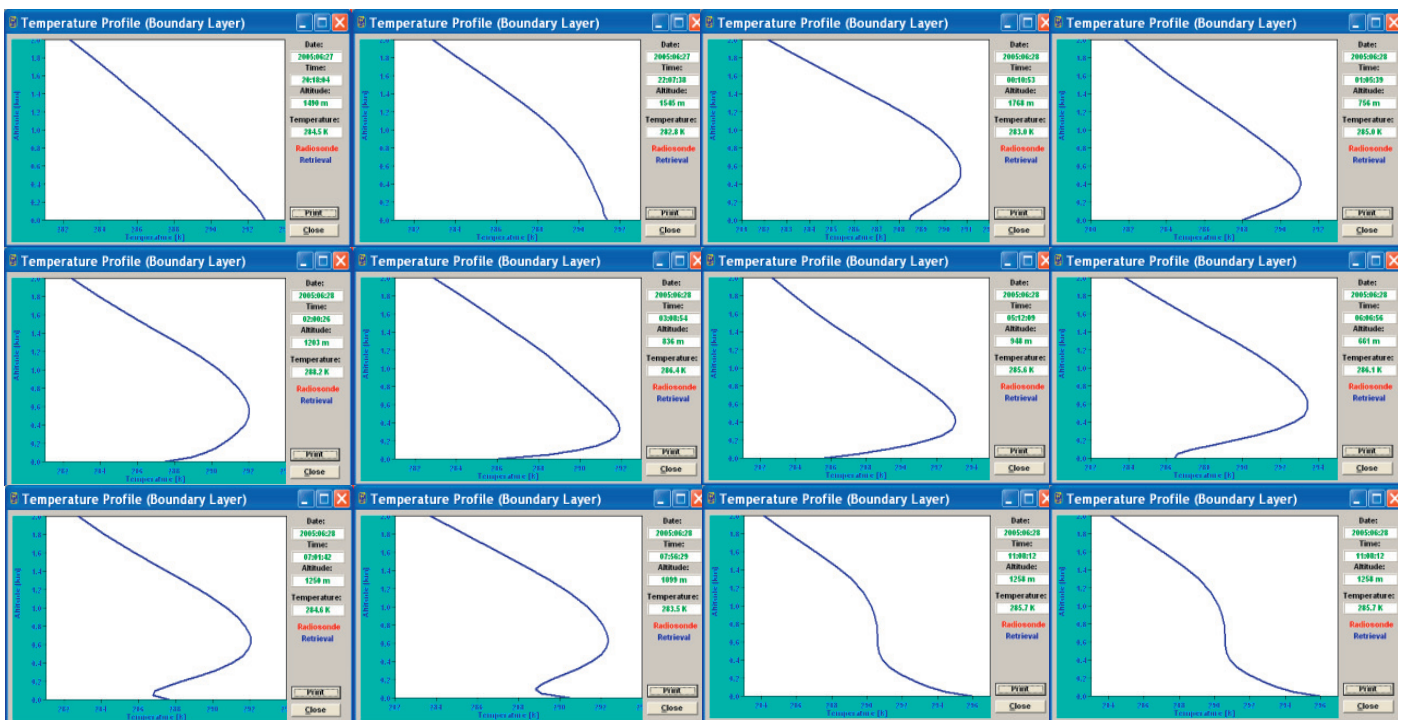


## Boundary Layer Temperature Profiling

Temperature profiles are continuously retrieved from zenith measurements for the entire troposphere (0-10 km). In addition, the boundary layer observation mode, based on frequent elevation scans, provides an enhanced vertical resolution below 2 km. Temperature inversions are much better resolved by the boundary layer scanning mode (left). The vertical resolution improves by a factor of 10 compared to the zenith observation mode (right):

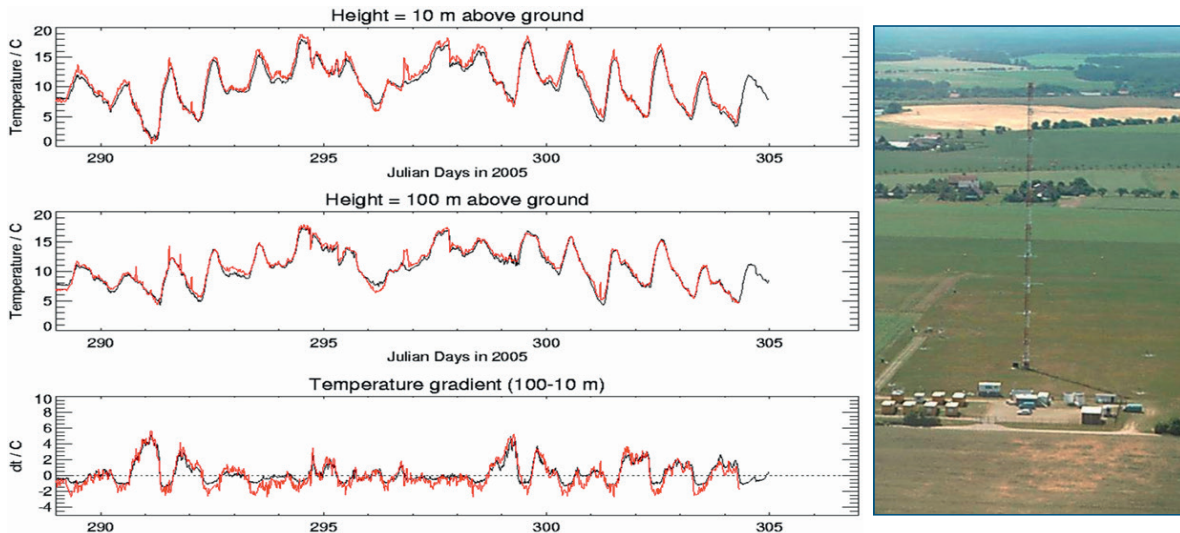


The boundary layer mode allows for monitoring the formation and decay of temperature inversions in time:



## Inter-comparison with meteorological tower

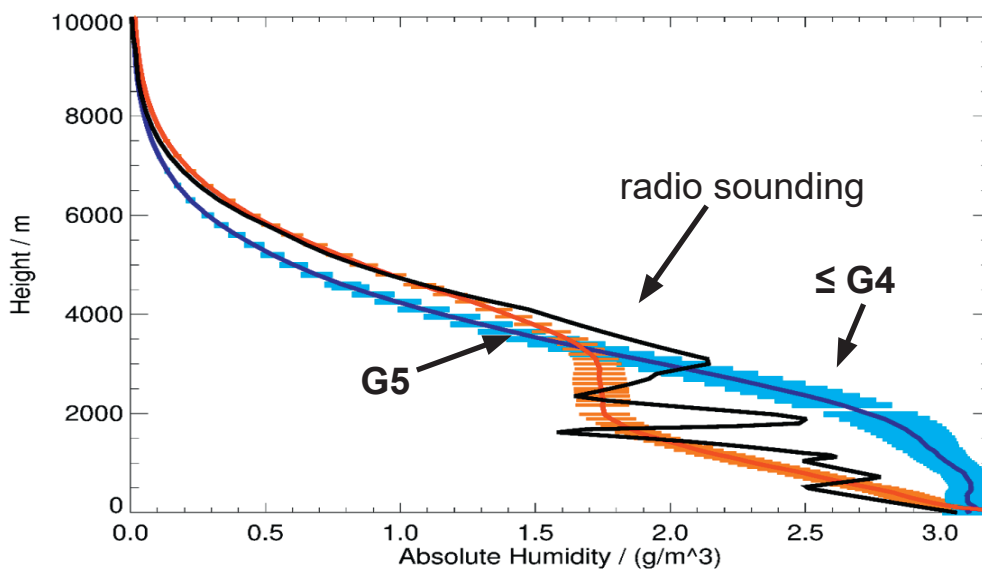
Boundary layer temperatures retrieved from RPG-HATPRO measurements were, for example, validated by an inter-comparison with a 100 m meteorological tower operated by the German Weather Service (DWD) in Lindenberg / Germany. The tower is equipped with in-situ temperature sensors every 10 height meters. The HATPRO radiometer was located right next to the tower.



A 2-week time series of temperature measurements. Black: Meteorological tower temperature sensor readings. Red: Radiometer readings in boundary layer scanning mode. Top: Temperature in 10 m altitude. Center: Temperature in 100 m altitude, Bottom: Temperature gradient resolving inversions. The radiometer data are in excellent agreement with the in-situ measurements (Courtesy of S. Crewell, University of Cologne).

## Tropospheric Profiling

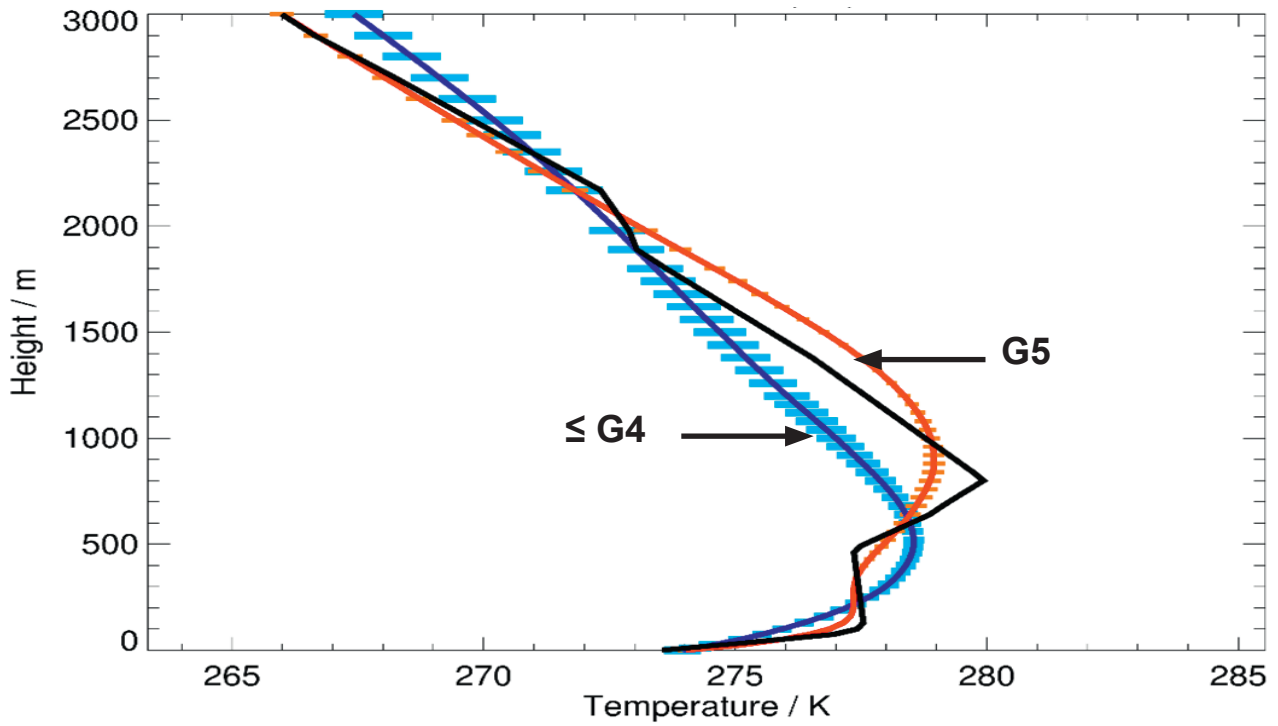
### Humidity Profiling:



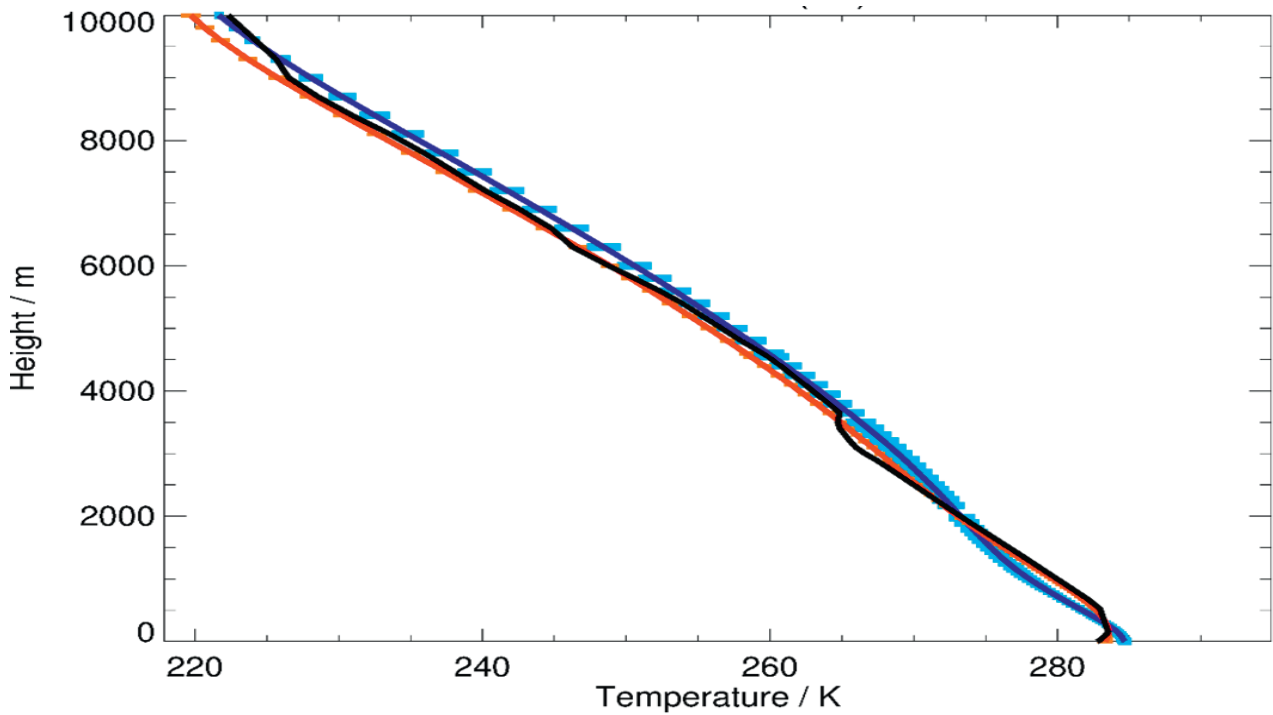
Improvement example of G5 absolute humidity profile over previous radiometer generations. Black: radio sounding for comparison, light blue: G4 retrieval noise, orange: G5 retrieval noise.



Temperature Profiling:



Boundary layer temperature profiling inter-comparison example.



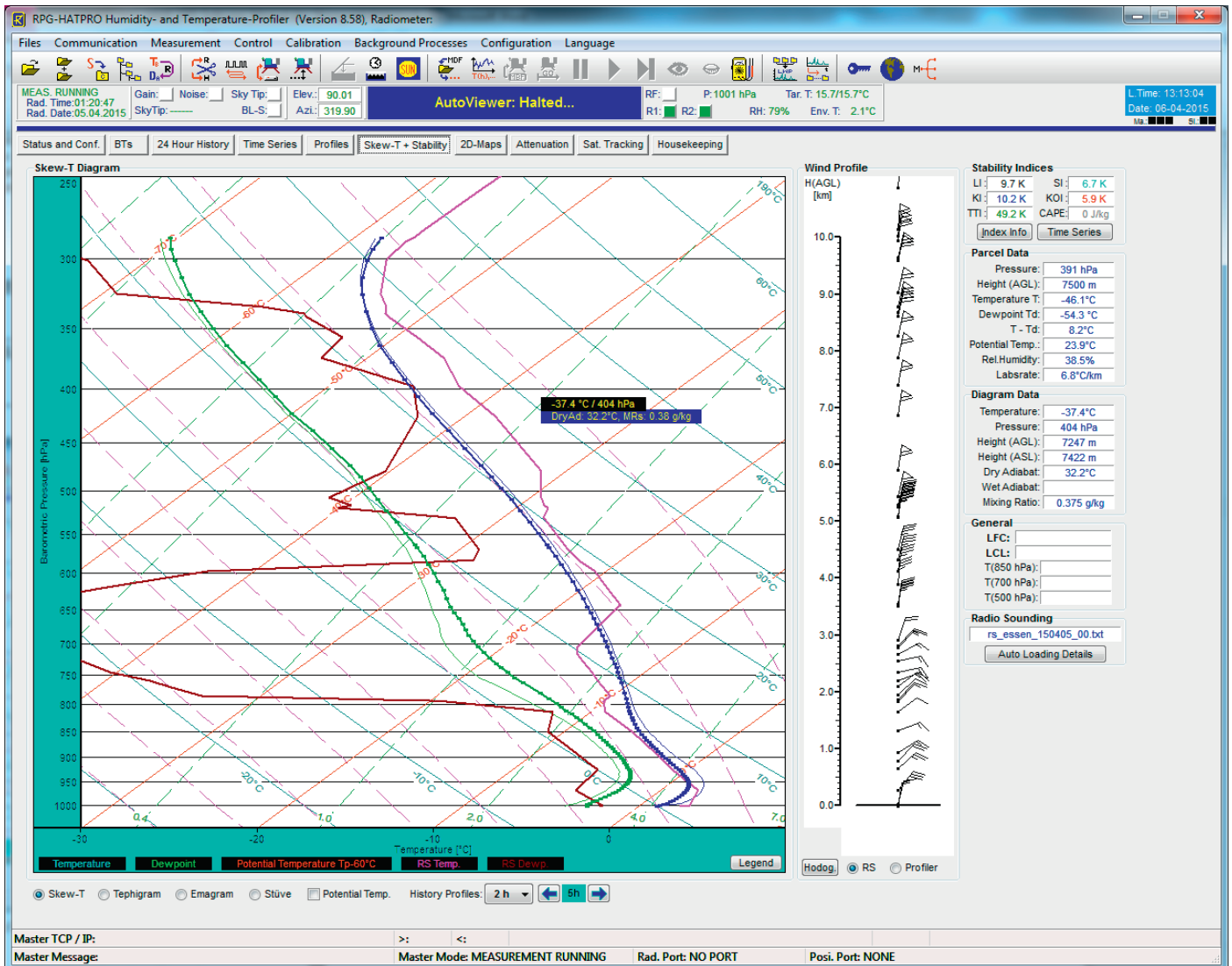
Full troposphere temperature profiling inter-comparison example.





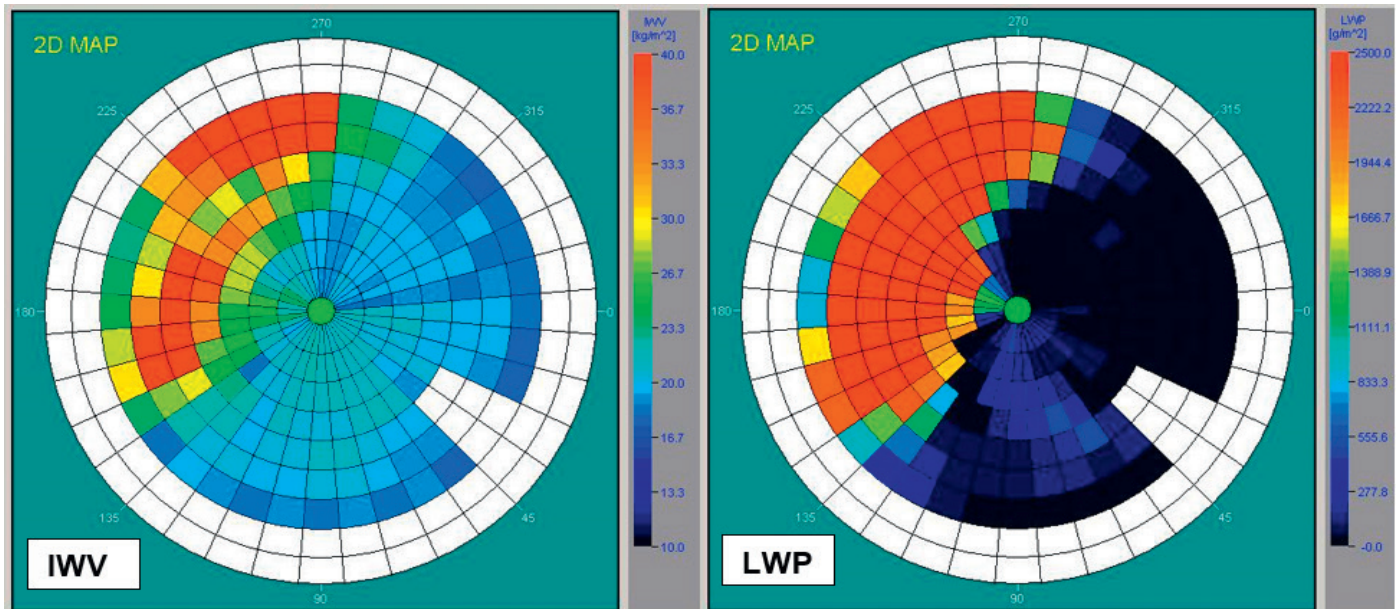
## Thermodynamic Diagrams

RPG's operating software offers a number of common thermodynamic diagrams. Apart from the most recent profiles of temperature and dew point (retrieved from humidity and temperature profiles), the history of mean hourly temperature profiles is displayed. Additionally, vertical profiles from radiosondes and wind profilers in ASCII format (e.g. RAOB®) can be uploaded and displayed. Common stability indices (Lifted Index (LI), Showalter Index (SI), K Index (KI), Total Totals Index (TTI), Convective Index (KOI), CAPE) and characteristic levels (LFC, LCL) are calculated.



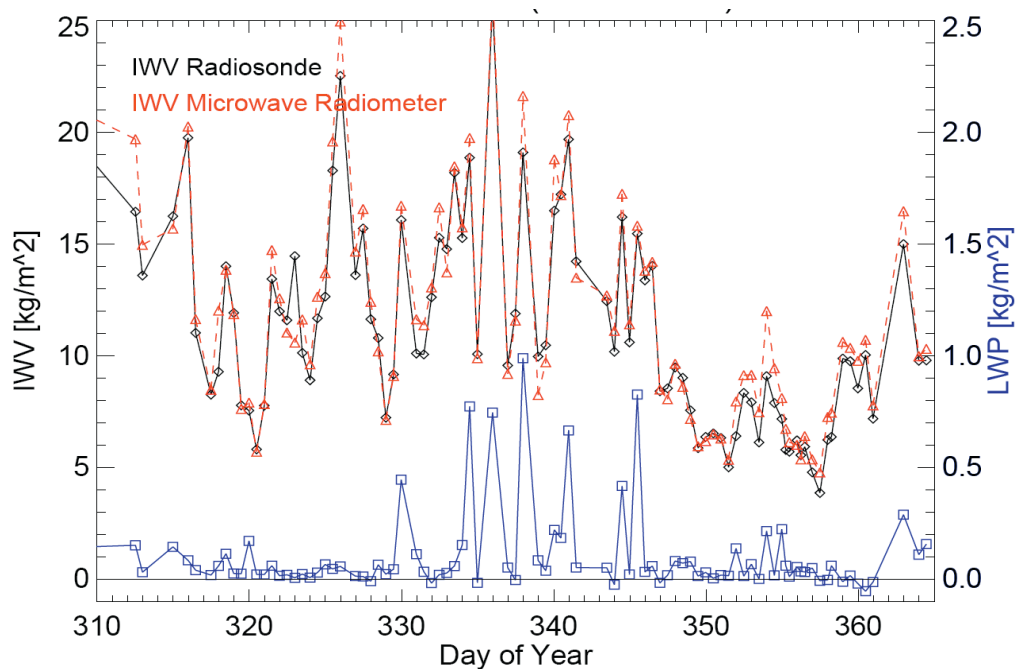
## Integrated Water Wavpour (IWV) and Liquid Water Path (LWP)

Full Sky IWV and LWP maps\* below show inhomogenous water vapour distributions and cloud coverage:



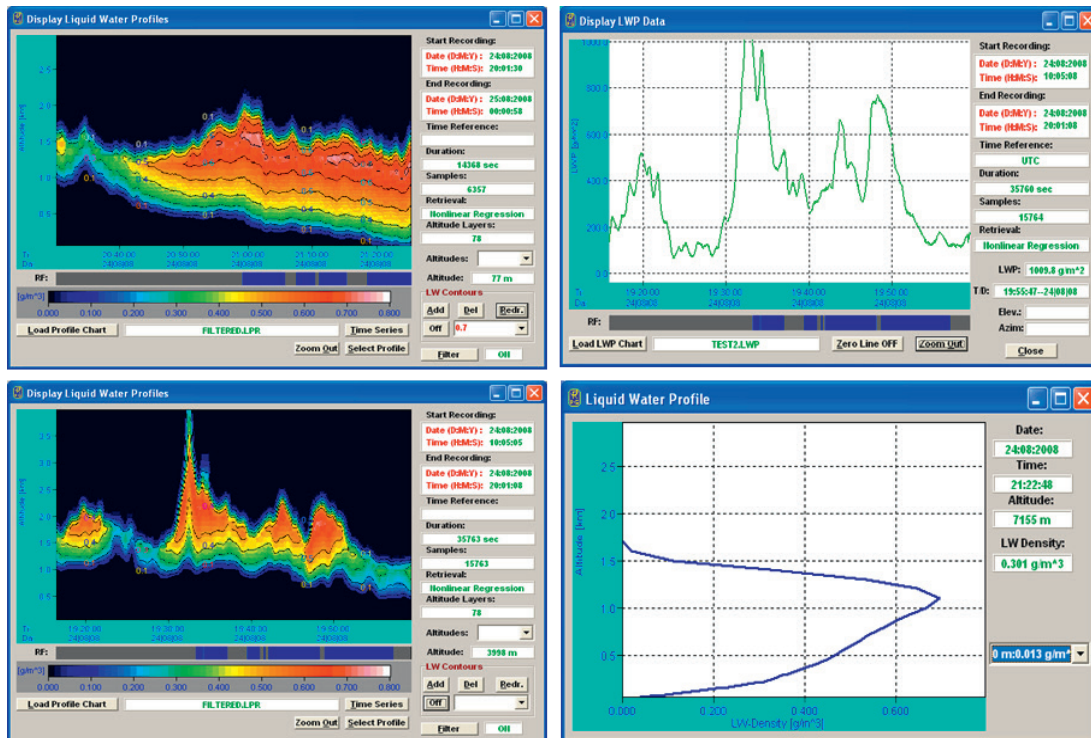
### IWV measurements remain accurate even with an LWP of 1000g/m²:

The figure below shows that accurate measurements of IWV and LWP are recorded simultaneously. IWV accuracy is maintained even in case of thick cloud and light rain. Retrieved IWV is plotted against IWV calculated from 2 months of radiosonde profiles.



\* only with azimuth positioner

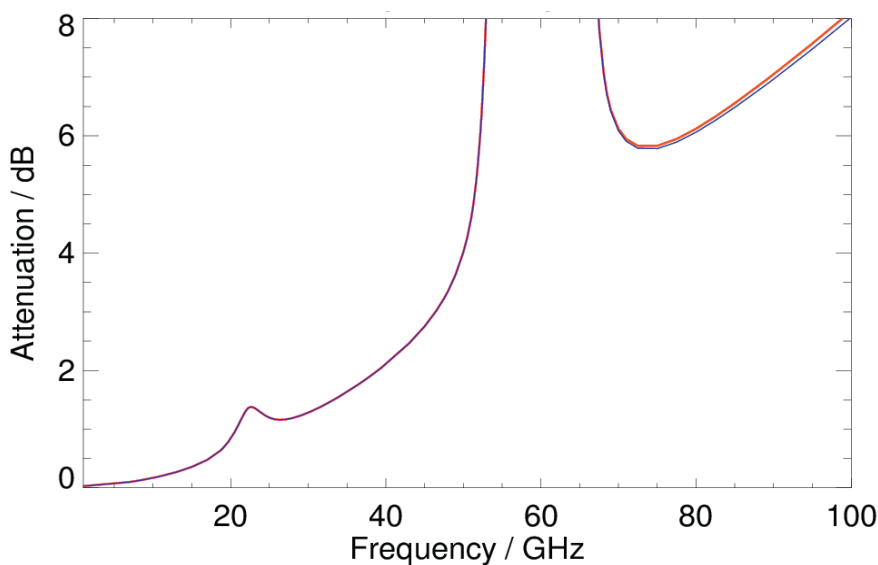
## Liquid Water Profiling



## Attenuation Measurements

HATPRO measurements at 14 radiometer channels allow for an accurate retrieval of **total atmospheric attenuation** spectra between 1 and 100 GHz.

Accuracy examples: 0.0025 dB RMS @13 GHz, 0.0050 dB RMS @27 GHz.



Attenuation spectrum between 1 and 100 GHz retrieved from HATPRO observations (blue) compared to „true“ values (red).





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## Profiling Radiometer Models

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- **RPG-HATPRO**
  - Humidity And Temperature PROfiler (standard profiling radiometer)
  - 7 channels: 22.24 GHz to 31.40 GHz
  - 7 channels: 51.26 GHz to 58.00 GHz
  - over-sampling for redundancy
  - customized direct detection channels for precise boundary layer mode
  - temperature profiles in elevation scanning mode
  
- **RPG-LHATPRO**
  - Low-Humidity And Temperature PROfiler
  - 7 channels: 51.26 GHz to 58.00 GHz
  - 6 channels:  $183.31 \pm 0.6$  GHz to  $\pm 7.5$  GHz
  - Designed for arctic conditions and/or high altitudes
  - Water vapour sounding at 183 GHz
  - 6 DSB channels with individual bandwidth
  
- **RPG-HUMPRO**
  - HUMidity PROfiler
  - 7 channels: 22.24 GHz to 31.40 GHz
  - over-sampling for redundancy
  
- **RPG-TEMPRO**
  - TEMperature PROfiler
  - 7 channels: 51.26 GHz to 58.00 GHz
  - over-sampling for redundancy
  - customized direct detection channels for precise boundary layer mode
  - temperature profiles in elevation scanning mode



Parameter	Specification
Height grid of atmospheric profiles (temperature / humidity / liquid water)	Number of layers: 93
	Vertical Resolution:
	25 m (range 0-100 m)
	30 m (range 100-500 m)
	40 m (range 500-1200 m)
	60 m (range 1200-1800 m)
	90 m (range 1800-2500 m)
	120 m (range 2500-3500 m)
Temperature profile performance	Accuracy:
	0.25 K RMS typical (range 0-500 m)
	0.50 K RMS typical (range 500-1200 m)
	0.75 K RMS typical (range 1200-4000 m)
Humidity profile performance	Accuracy:
	0.3 g/m <sup>3</sup> maximum bias typical (absolute humidity)
	0.1 g/m <sup>3</sup> RMS typical (absolute humidity)
	5% RMS typical (relative humidity)
Liquid water profile performance (only with IR radiometer)	Cloud base height accuracy:
	50 m (range 0-300 m)
	100 m (range 300 - 1.000 m)
	200 m (range 1.000 - 3.000 m)
	400 m (range 3.000 - 5.000 m)
	600 m (range 5.000 - 10.000 m)
	Density: 0.03 g/m <sup>3</sup> RMS
Threshold: 50 g/m <sup>2</sup> LWP	
Only single layer clouds are modelled	
IR radiometer option	9.6-11.5 µm band, accuracy 1 K, noise: 0.2 K RMS
LWP	Accuracy: ± 10 g/m <sup>2</sup> , sensitivity: 2 g/m <sup>2</sup> RMS
IWV	Accuracy: ± 0.12 kg/m <sup>2</sup> RMS, sensitivity: 0.04 kg/m <sup>2</sup> RMS
Full sky IWV and LWP maps (only with azimuth positioner)	More than 200 points in 8 minutes rapid scanning



Parameter	Specification
Satellite tracking mode (only with azimuth positioner)	<ul style="list-style-type: none"> <li>• Determines tropospheric wet delay and attenuation along line of sight for all visible GPS / Galileo satellites in a single scan (2 minutes)</li> <li>• Tracking via satellite navigation files (e.g. RINEX) or direct GPS vector readings from integrated GPS receiver</li> </ul>
Channel centre frequencies	K-Band: 22.24 GHz, 23.04 GHz, 23.84 GHz, 25.44 GHz, 26.24 GHz, 27.84 GHz, 31.40 GHz V-Band: 51.26 GHz, 52.28 GHz, 53.86 GHz, 54.94 GHz, 56.66 GHz, 57.30 GHz, 58.00 GHz
Channel bandwidths	2000 MHz @ 58.0 GHz, 1000 MHz @ 57.30 GHz, 600 MHz @ 56.66 GHz, 230 MHz @ all other
System noise temperatures	< 400 K typical for 22.24 – 31.40 GHz profiler < 600 K typical for 51.26 – 58.00 GHz profiler
Radiometric resolution	K-Band: 0.07 K RMS, V-Band: 0.07 – 0.15 K RMS (@ 1 second integration time)
Absolute brightness temperature accuracy	±0.15 K
Absolute calibration	With internal ambient & external cold load
Internal calibration	<ul style="list-style-type: none"> <li>• gain: with internal noise standard</li> <li>• gain + system noise: ambient temperature target + noise standard</li> <li>• abs. cal. of humidity profiler: sky tipping calibration</li> </ul>
Receiver and antenna thermal stabilization	Stability better than 0.03 K over full operating temperature range
Gain non-linearity error correction	Automatic, 4-point method
Brightness calculation	Based on exact Planck's radiation law
Integration time	≥ 0.4 seconds for each channel (user-selectable)
Sampling rate for profiles	≥ 1 second (user-selectable)
Rain / fog mitigation system	Highly efficient blower system (130 Watts), hydrophobic coated microwave transparent window, 2 kW heater module to avoid the formation of dew.
Integrated weather station	Vaisala® WXT536 on 1-m mast mounted to radiometer: <ul style="list-style-type: none"> <li>• temperature, pressure, relative humidity</li> <li>• wind speed, wind direction, and rain rate</li> </ul>



Parameter	Specification
Data interface / rate	Ethernet (TCP/IP)
Instrument control (external PC)	Windows™ System with Ethernet interface
Instrument control (internal)	Embedded PC controls internal calibrations, data acquisition, azimuth positioner, and communication with Host-PC. Can run measurements independently from Host-PC - with possible data file backup on 10 GB flash memory.
Housekeeping data	Detailed instrument status information, including health checks, data flagging, calibration history, and log files
Retrieval algorithms	Neural Network algorithms
Optical resolution	HPBW (frequency dependent): 3.9° - 4.6° for water vapour, 1.8° - 2.2° for temperature profiler
Side-lobe level	< -30 dBc
Pointing range / resolution	Elevation: 0° to 180° (0.1° steps), full s/w control Azimuth (optional): 0° to 360° (0.1° steps), full s/w control
Pointing speed	45°/sec (elevation), 20°/sec (azimuth, optional)
Operating temperature range	-30°C to +45°C
Power consumption AC 1 (100 - 230 V~)	< 120 Watts average, 650 Watts peak for warming-up (without dew blower), blower: 130 Watts maximum
Power consumption AC 2 (100 - 230 V~)	Heater Module: 2 kW @ 230 V/AC
Lightning protection	Power line: circuit breakers Data line: optical fibre cable (max. length: 1400 m)
Input voltage	90-230 V AC, 50 to 60 Hz
Weight	60 kg (without dew blower)
Dimensions	63 × 36 × 90 cm <sup>3</sup>

## FMCW Cloud Radars

Radiometer Physics GmbH (RPG) has developed a line of polarimetric solid-state radars operating at 35 and 94 GHz for continuous cloud and precipitation observations.

- Accurate absolute calibration, hardware monitoring
- High spatial, temporal, and Doppler resolution
- Built-in passive radiometric channel for LWP estimation
- Rain mitigation system for keeping the radomes dry
- Data products: full spectra, moments, spectral polarimetry
- Optional scanner for volumetric processing
- Optional dual frequency configuration (35 + 94 GHz)
- Automated data exchange with RPG radiometers
- Turbulence, wind shear, fog, and cloud observations
- Particle size distribution, rain intensity, ice microphysics

## Profiling Radiometers

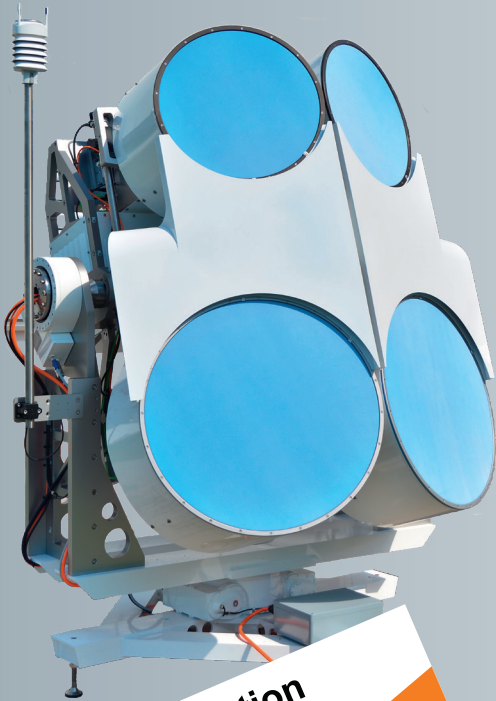
The RPG-HATPRO (Humidity And Temperature PROfiler) is becoming the radiometer of choice for meteorological networks and forecasting systems all around the world.

- 14 channels (22 to 31 GHz, 51 to 58 GHz, 183 GHz optional)
- Superior direct detection technology: EMI / EMC, parallel
- Network suitable, control + data flow via Ethernet
- Data products: IWV, LWP, T + RH profiles, stability indices
- Better boundary layer T-profiling than radio-soundings
- Full-sky scanning (more than 200 directions 8 minutes)
- Ground-based: complementing the satellite view!
- All-weather proof, reliable, robust... proven!
- IR radiometer extension for cloud base height detection

## Scintillometers

RPG is the only commercial supplier for scintillometers observing in the microwave spectral region.

- Microwave scintillometer RPG-MWSC operates at 160 GHz
- Synchronous observation of sensible and latent heat fluxes (combined with optical Large Aperture Scintillometer)
- Network suitable, control + data flow via Ethernet



Dual polarisation  
Dual frequency  
Scanning

New

