



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

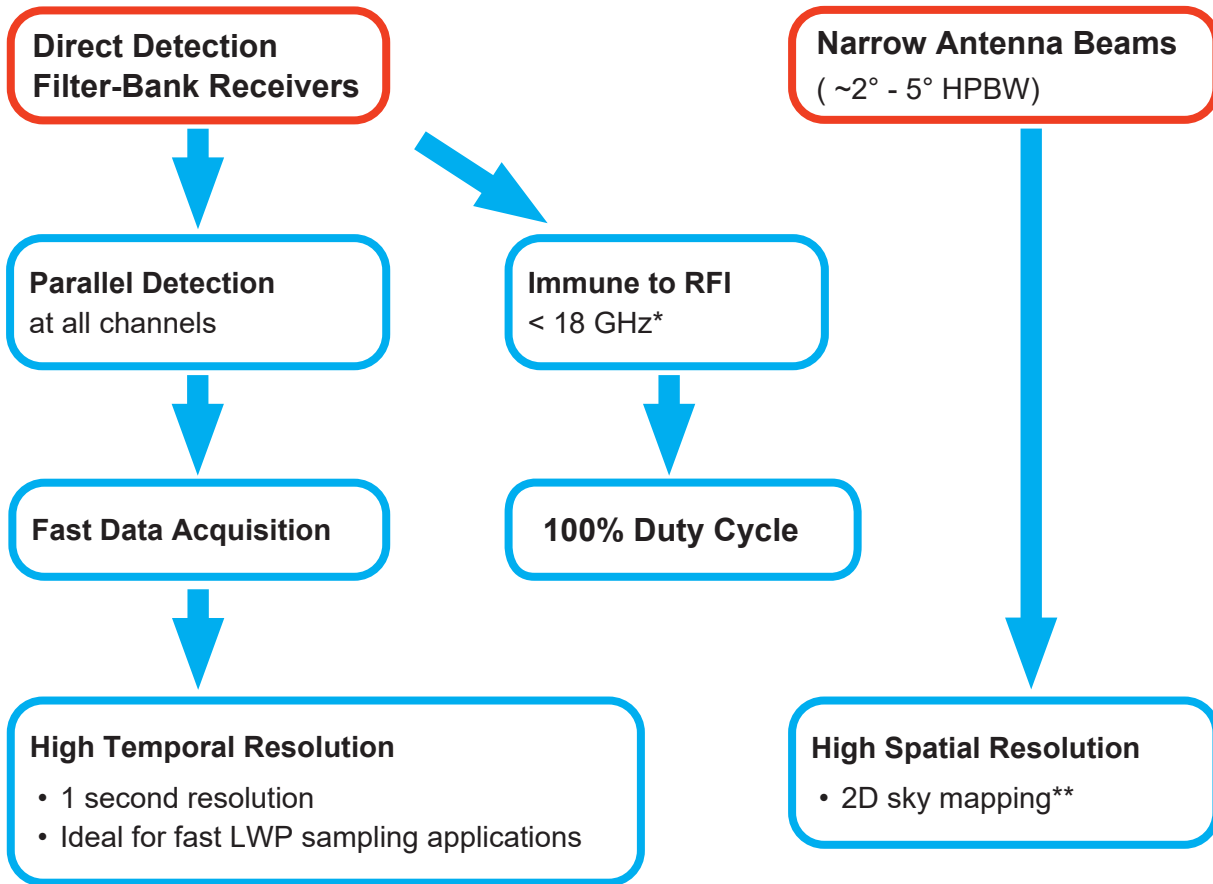
Satellite Tracking

Tropospheric delay and attenuation along line of sight

Absolute calibration of
Cloud Radar receivers



Design



RPG-HATPRO-G5 radiometer during the absolute calibration procedure with RPG's LN2-cooled target PT-V2.

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



Improvements with HATPRO Generation 5

High Precision Calibration Target
enabling ± 0.25 K absolute accuracy



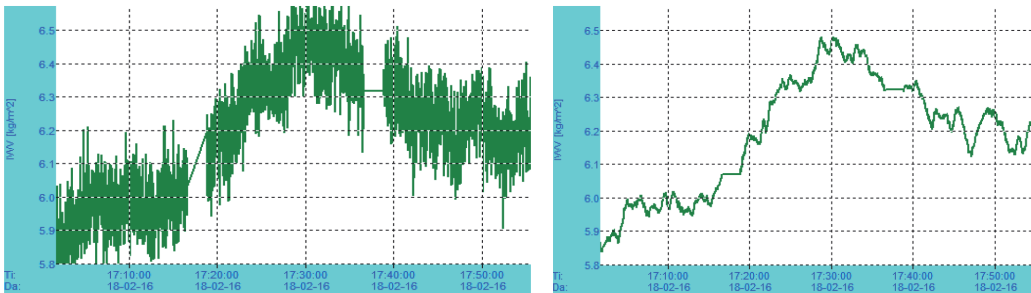
Data Sampling Rate
increased by a factor 20

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^2 become visible!

Elev. [DEG]	G4 IWV-Ret. Accuracy [kg/m^2]		G5 IWV-Ret. Accuracy [kg/m^2]	
		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*

IR Radiometer

for cloud base height detection**

IR Scanner

for synchronous IR and microwave observations**

Data Backup

on embedded Radiometer-PC

Ethernet Interface

for network capability

Interference mitigation

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

Fibre-Optical Data Cable

for lightning protection and secure data transmission

*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

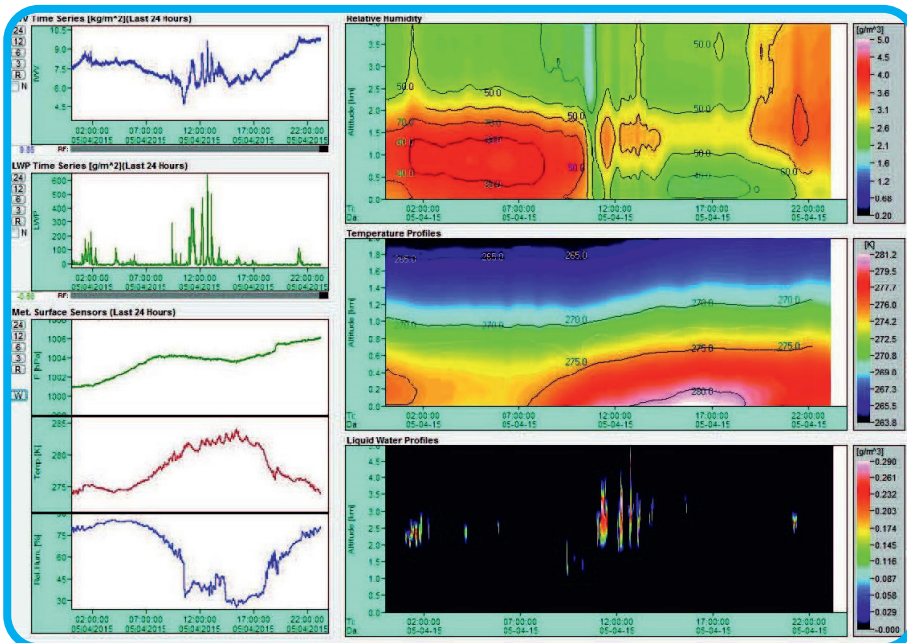
- Instrument status / control
- Data quality flags
- Data flagging

Thermodynamic Diagrams and Stability Indices

Satellite Tracking with navigation files

Automatic Recovery after power failures

Free Software Updates



Output Data

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

Calibration

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

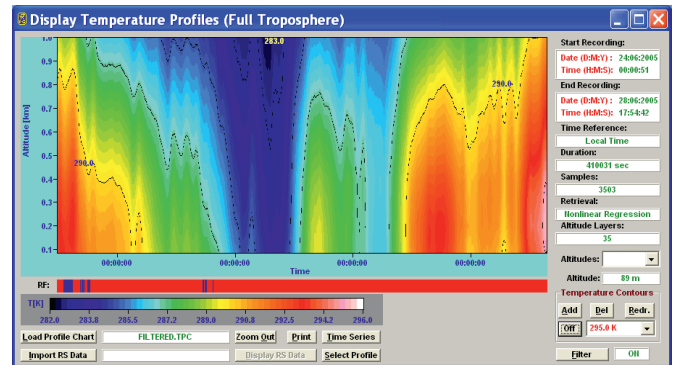
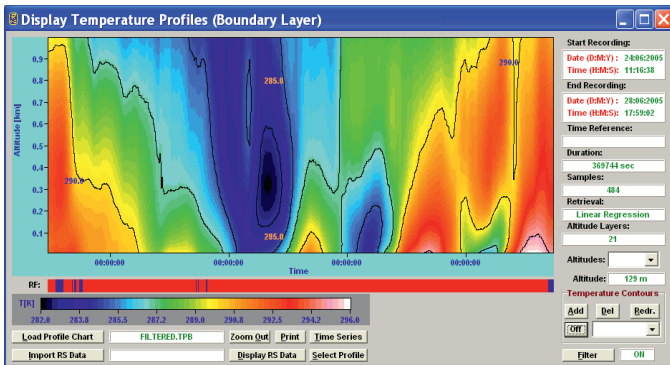
*only with azimuth positioner

**only with optional IR Radiometer

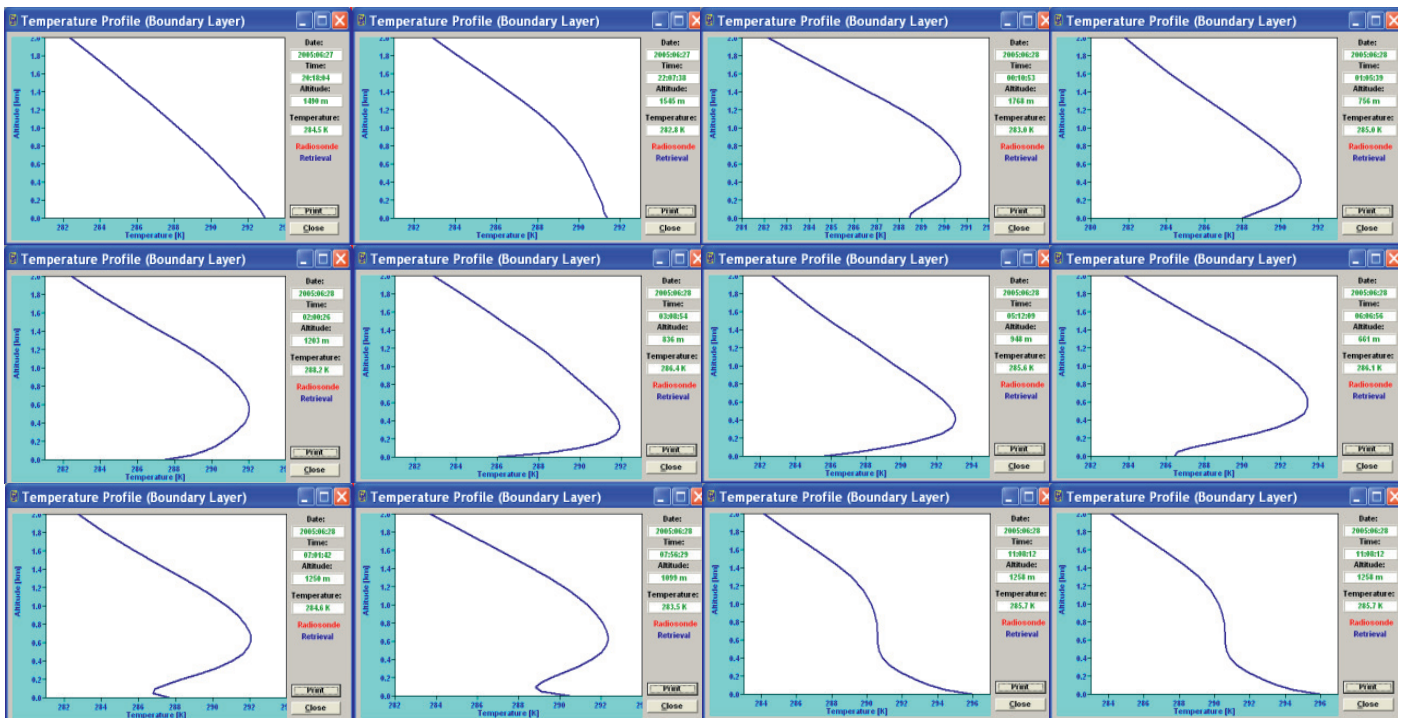


Boundary Layer Temperature Profiling

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):

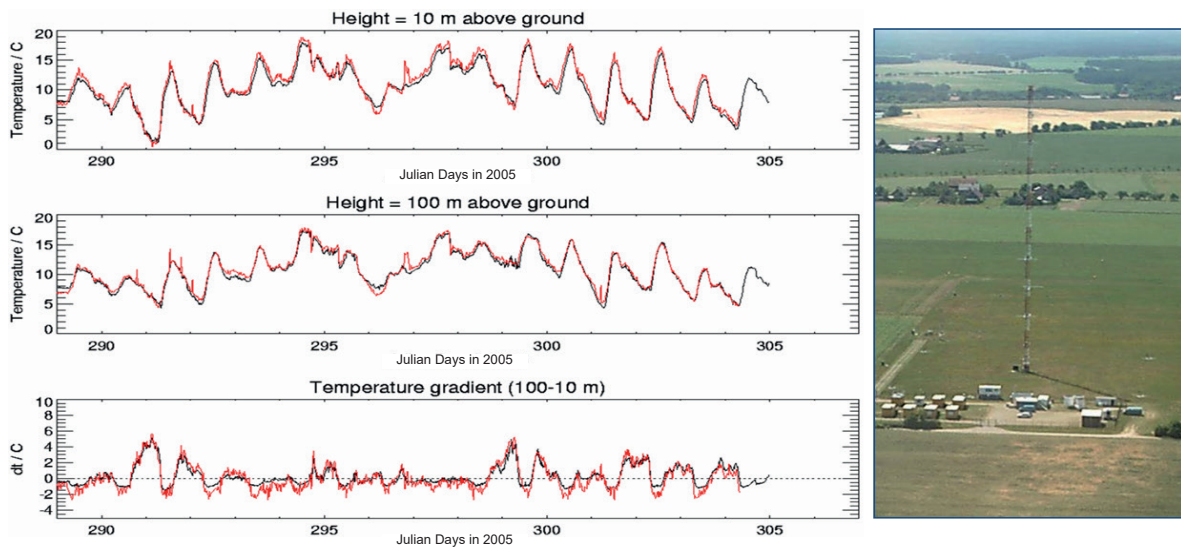


The boundary layer mode allows for monitoring the formation and decay of temperature inversions in time:



Inter-comparison with meteorological tower

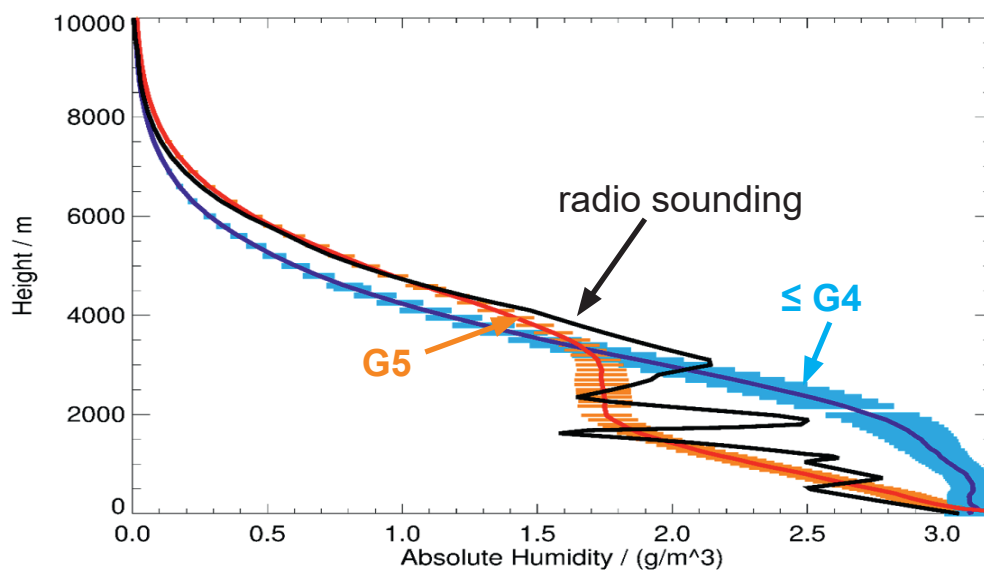
Boundary layer temperatures retrieved from RPG-HATPRO measurements were, for example, validated by an inter-comparison with a 100 m meteorological tower operated by the German weather service (DWD) in Lindenberg / Germany. The tower is equipped with in-situ temperature sensors every 10 height meters.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

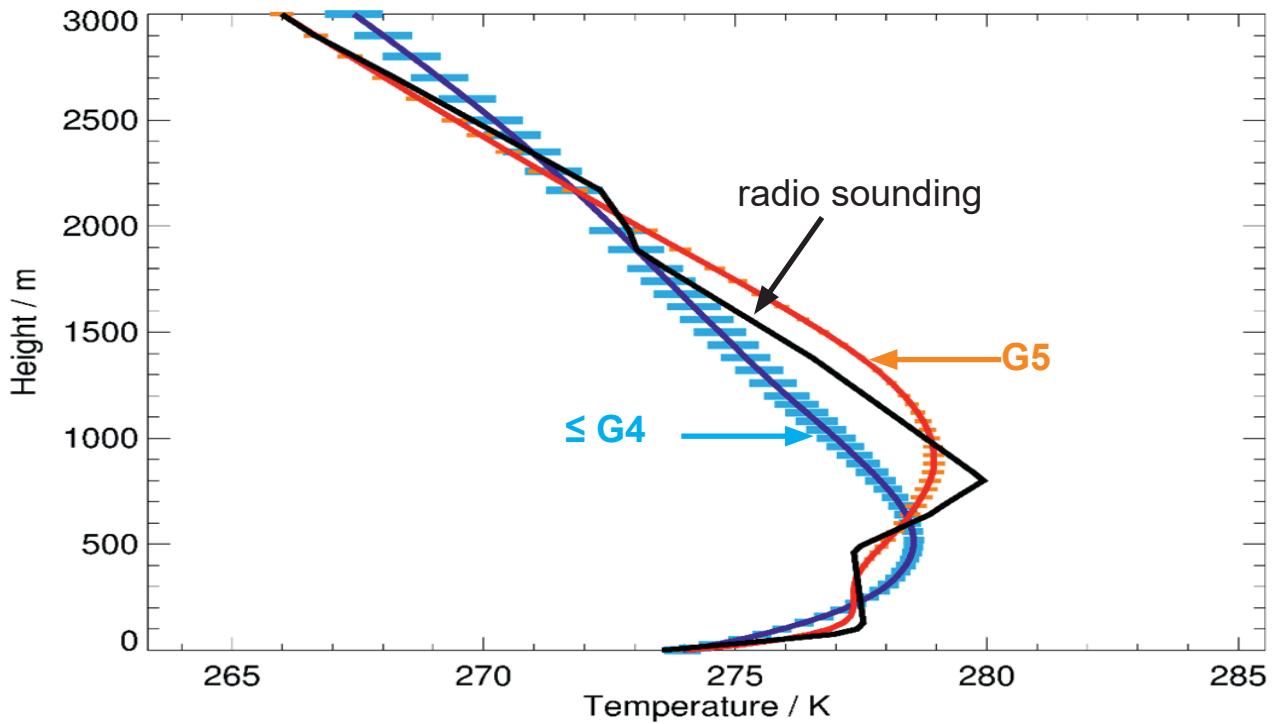
Humidity Profiling:



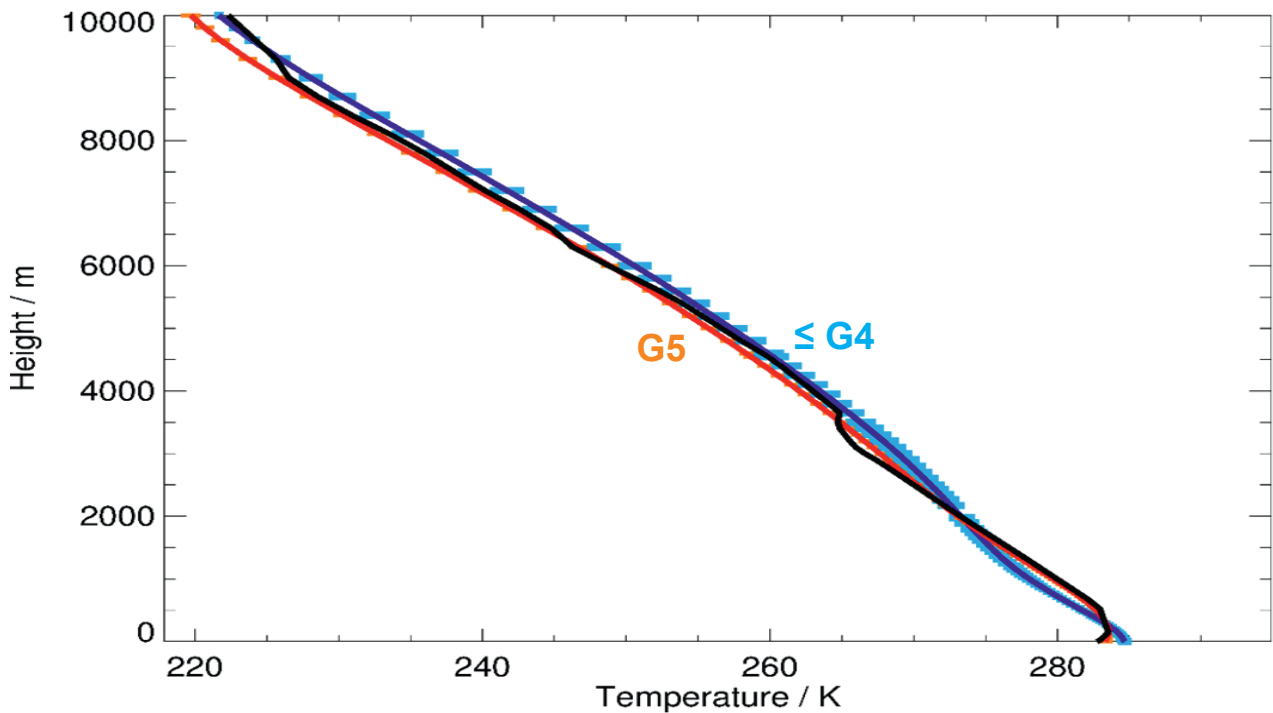
Improvement example of Generation 5 (G5) absolute humidity profile over previous radiometer generations (≤ G4). Black: radio sounding for comparison, light blue: G4 retrieval noise, orange: G5 retrieval noise.



Temperature Profiling:



Boundary layer temperature profiling inter-comparison example.

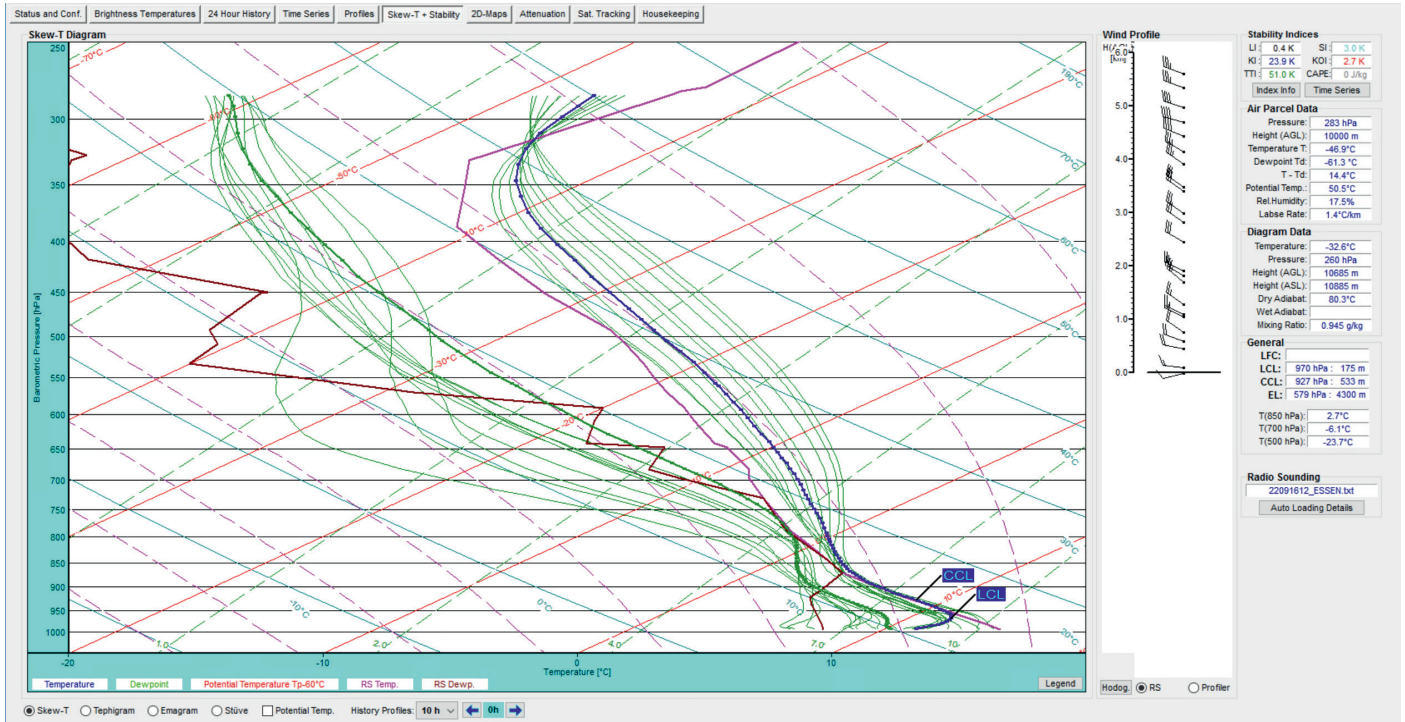


Full troposphere temperature profiling inter-comparison example.

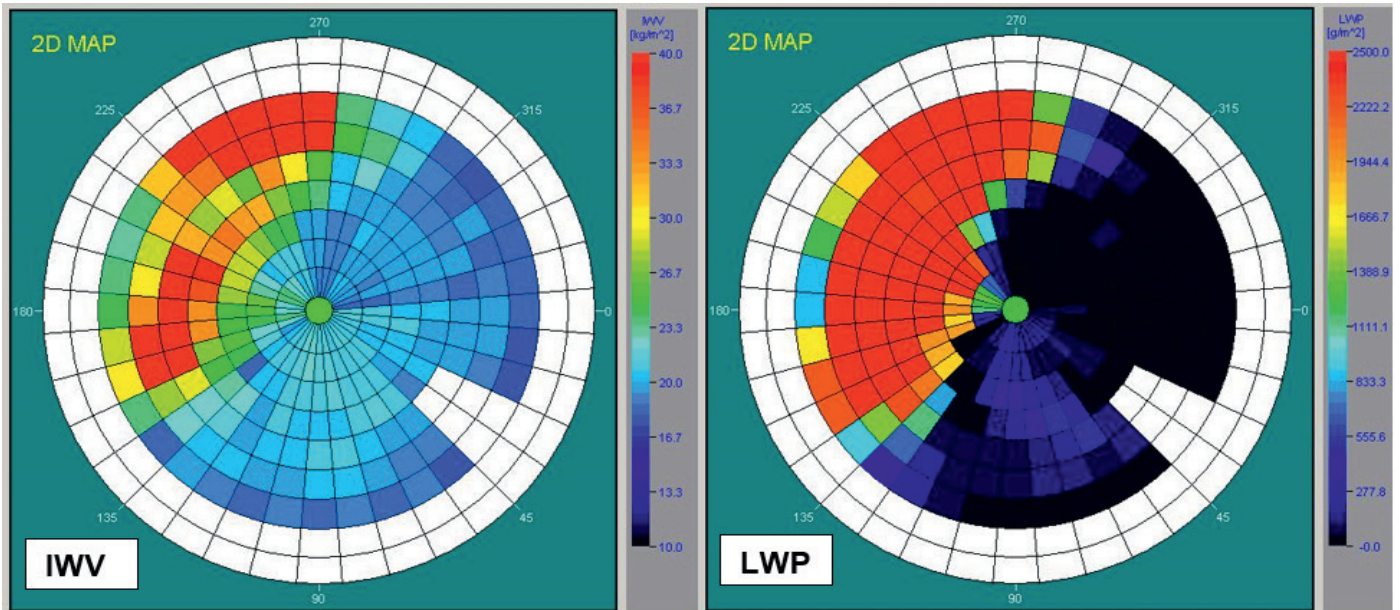


Thermodynamic Diagrams

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), Convective Available Potential Energy (CAPE) and characteristic levels (LFC, LCL, CCL, EL) are calculated.

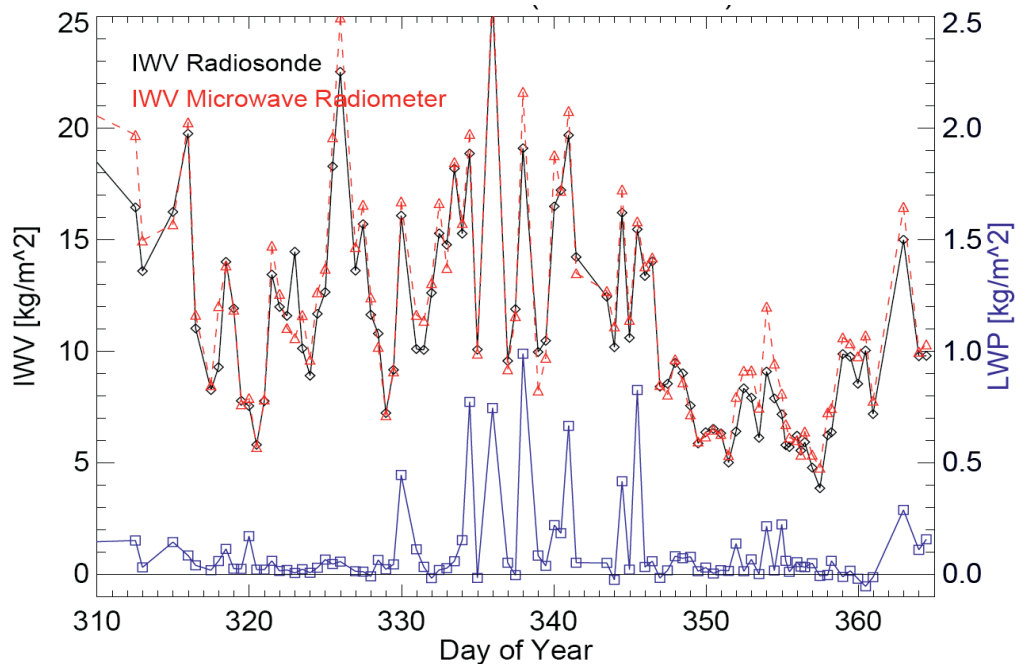


Integrated Water Wapour (IWV) and Liquid Water Path (LWP)



Full Sky IWV and LWP maps* show inhomogenous water vapour distribution and cloud coverage.

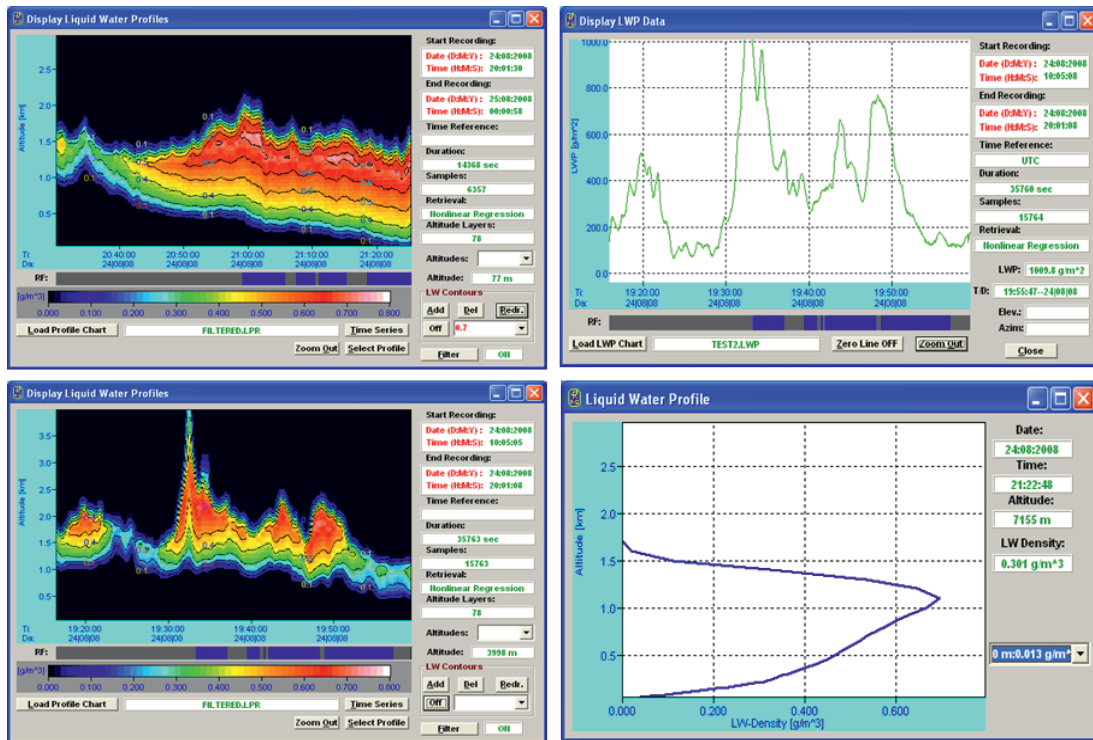
IWV measurements remain accurate even with an LWP of 1000 g/m²



Accurate measurements of IWV and LWP are recorded simultaneously. IWV accuracy is maintained even in case of thick clouds and light rain. Retrieved IWV is plotted against IWV calculated from 2 months of radiosonde profiles.

*only with azimuth positioner

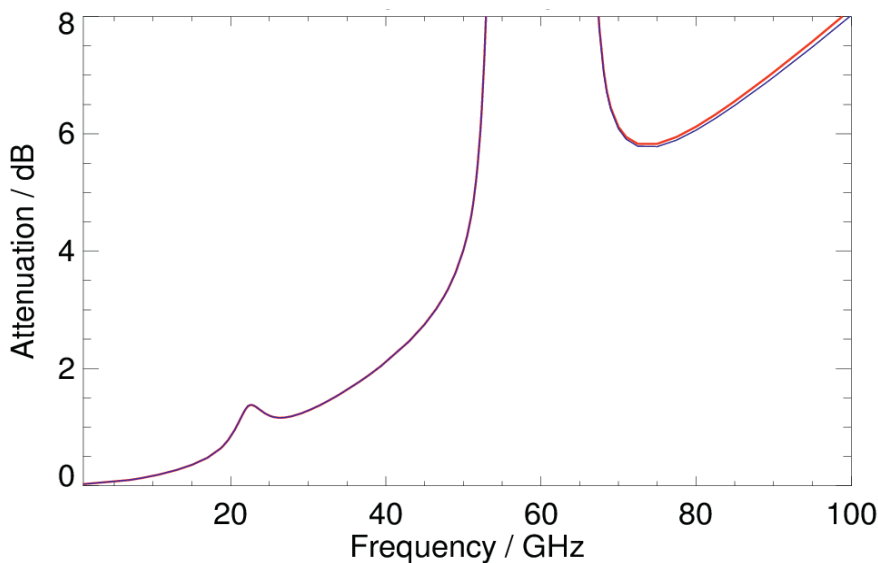
Liquid Water Profiling



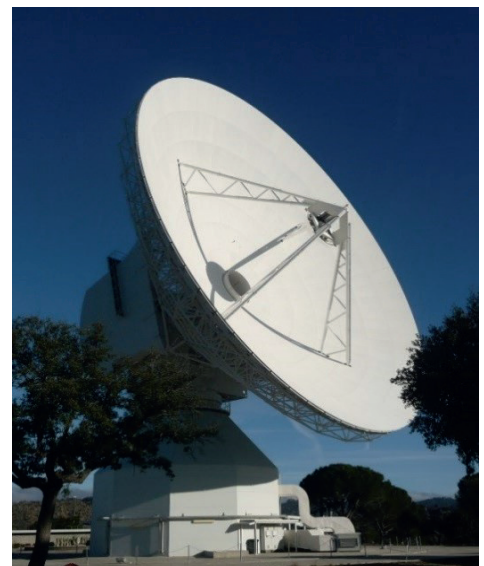
Attenuation Measurements

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).





Profiling Radiometer Models

- **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 ± 0.6 GHz to ± 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: 94
	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 (typical):
	0.25 K RMS (range 0-500 m)
	0.50 K RMS (range 500-1000 m)
	0.75 K RMS (range 1000-2000 m)
	1.00 K RMS (range 2000-3000 m)
Humidity profile performance	2.00 K RMS (range 3000-8000 m)
	Accuracy (typical):
	0.5 g/m ³ RMS (absolute humidity)
Liquid water profile performance (only with IR radiometer)	10 % RMS typical (relative humidity)
	Cloud base height accuracy:
	50 m (range 0-300 m)
	100 m (range 300 - 1000 m)
	200 m (range 1000 - 3000 m)
	400 m (range 3000 - 5000 m)
	600 m (range 5000 - 10000 m)
	LWC: 0.1 g/m ³ RMS (typical)
Threshold to produce a profile: 50 g/m ² LWP	
IR radiometer option	Only single layer clouds are modelled
	9.6-11.5 µm band, accuracy 1 K, noise: 0.2 K RMS
LWP	Accuracy: ± 20 g/m ² RMS (typical), 2 g/m ² sensitivity (typical)
IWV	Accuracy: ± 0.2 kg/m ² RMS (typical), 0.05 kg/m ² sensitivity (typical)
Full sky IWV and LWP maps (only with azimuth positioner)	More than 200 points in 9 minutes rapid scanning



Parameter	Specification
Satellite tracking modes (only with azimuth positioner)	<ul style="list-style-type: none"> • Tropospheric wet & dry delay and attenuation along line of sight • Tracking via satellite navigation files or direct GPS vector readings from integrated GPS receiver
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 < 700 K typical for 51.26 – 58.00 GHz profiler
Radiometric resolution	K-Band: < 0.10 K RMS (@ 1 s integration time) V-Band: 0.10 – 0.25 K RMS (@ 1 s integration time)
Absolute brightness temperature accuracy	±0.25 K
Absolute calibration	With internal ambient & external cold load
Internal calibration	<ul style="list-style-type: none"> • gain: with internal noise standard • gain + system noise: ambient temperature target + noise standard • abs. cal. of humidity profiler: sky tipping calibration
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	1-60 s (user-selectable)
Sampling rate for profiles	1-600 s (user-selectable)
Rain / fog mitigation system	Highly efficient blower system (130 W), 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"> • temperature, pressure, relative humidity • wind speed, wind direction, and rain rate



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	Artificial Neural Network (ANN) algorithms
Optical resolution	HPBW (frequency dependent): < 5.0° 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~)	< 200 W average, 650 W peak for warming-up (without dew blower), blower: 130 W maximum
Power consumption AC 2 (100 - 230 V~)	Heater module: 2 kW @ 230 V/AC
Lightning protection	Power line: circuit breakers Data line: fibre-optical cable (max. length: 1400 m)
Input voltage	90-230 V AC, 50 to 60 Hz
Weight	65 kg (without dew blower and heater module)
Dimensions	63 cm × 36 cm × 90 cm

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

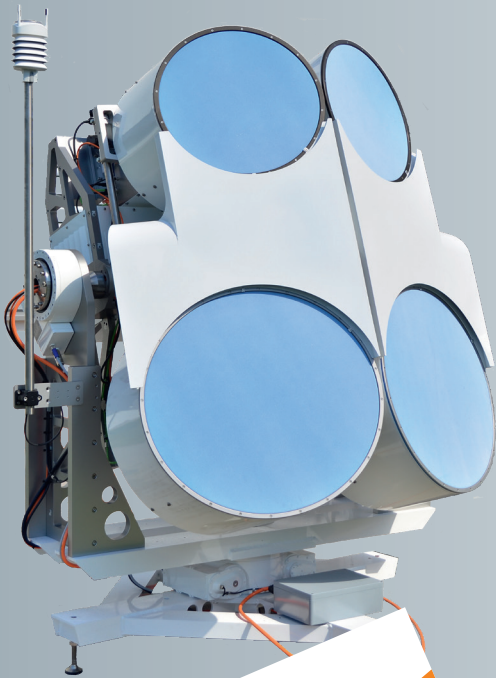
The RPG-HATPRO (Humidity And Temperature PROfiler) is becoming the radiometer of choice for meteorological networks and forecasting systems all around the world.

- 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 in 9 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**

