



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

Now-Casting

- 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

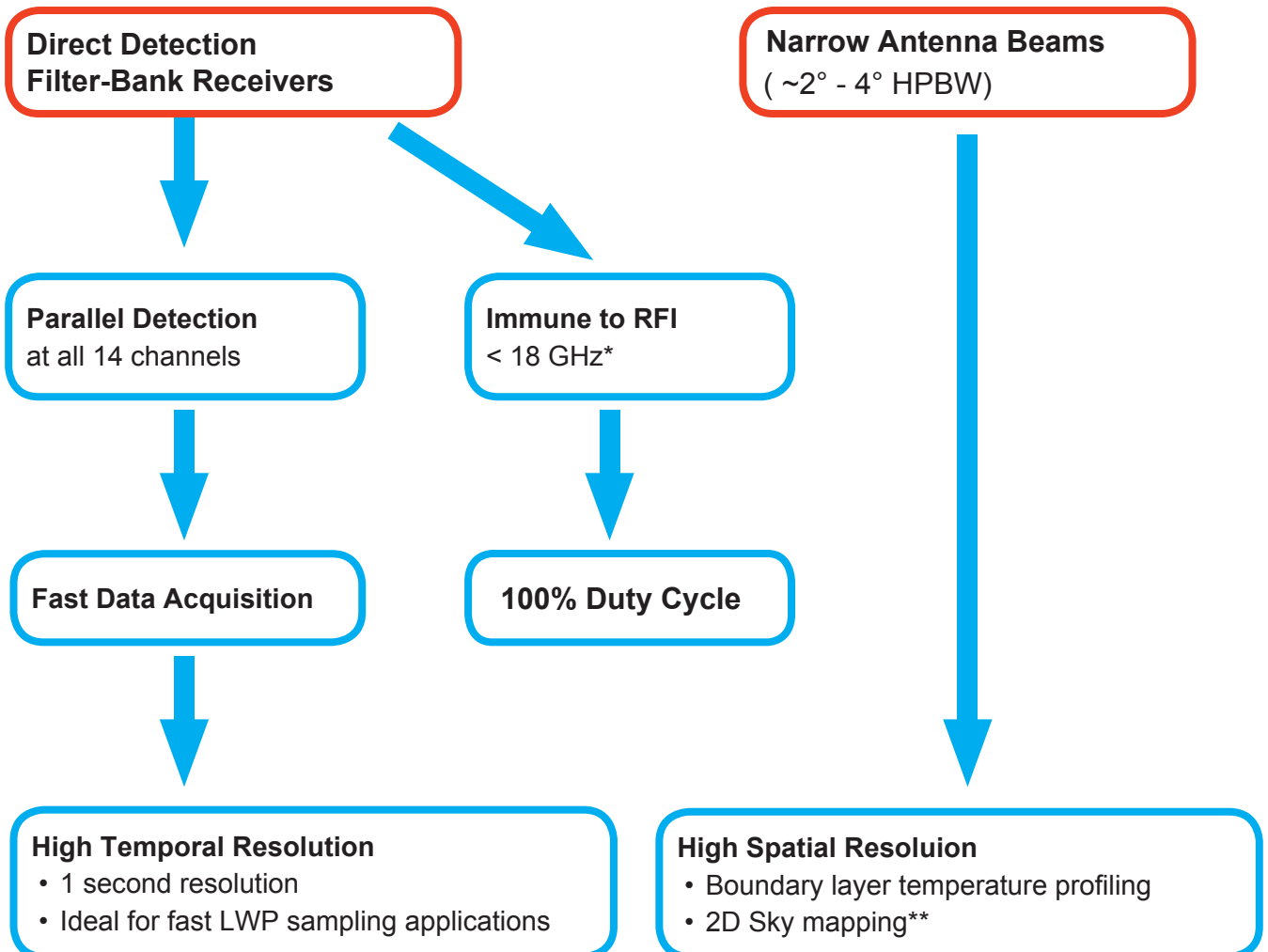
Tropospheric delay and attenuation along line of sight

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 ± 0.1 K absolute accuracy



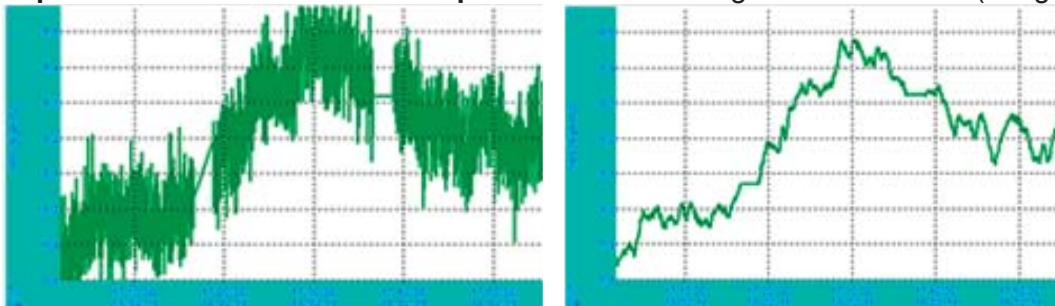
Data Sampling Rate
increased by a factor 20

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/m² become visible!

Elev. [DEG]	G4 IWV-Ret. Accuracy [kg/m ³] RMS	G5 IWV-Ret. Accuracy [kg/m ³] 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

- Strong blower
- Radome with hydrophobic coating
- Efficient heater system (1.8 kW)

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

IR Scanner

for synchronous IR and microwave observations*

*optional



Software Features

State-of-the-art Retrievals

- Neural Network (NN)
- Customized

Accurate North-Alignment

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

Atmospheric Data Products

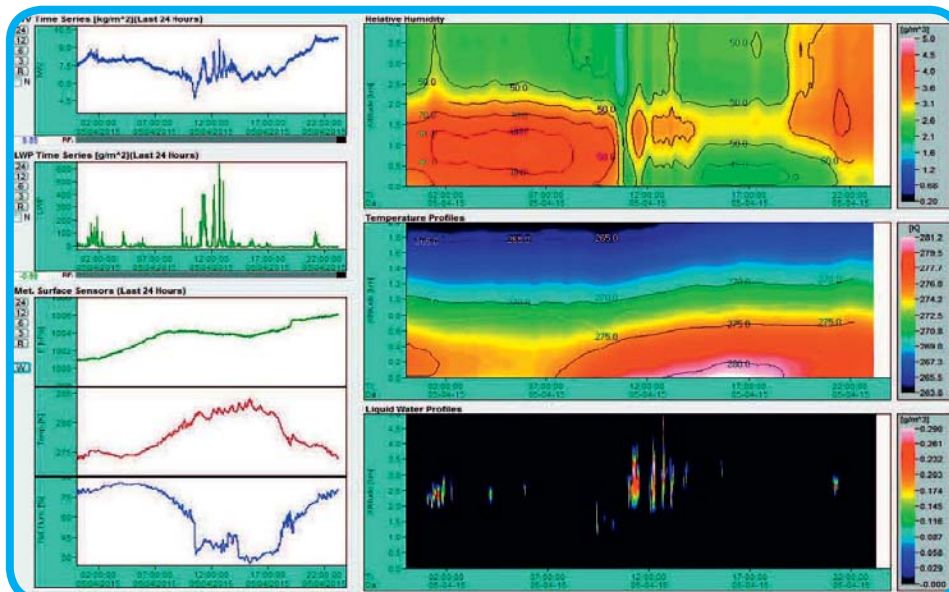
- Profiles of temperature / humidity / liquid
- Integrated Water Vapour (IWV)
- Integrated cloud liquid
- Atmospheric attenuation
- Cloud base height*

Detailed Housekeeping Data

- Instrument status / control
- Data quality checks / flags

Thermodynamic Diagrams

and stability indices



Free Software Updates

Automatic Recovery after power failures

Output Data

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

Calibration

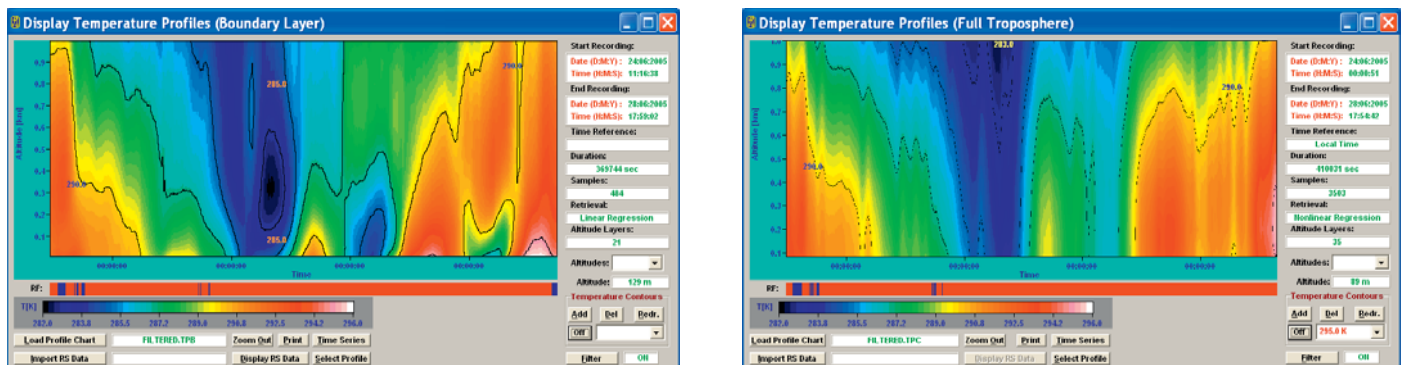
- Short calibration cycles
- Automatic sky-tipping
- Automatic internal calibrations including noise sources
- Manual liquid nitrogen calibration (every 6 months)

*e.g. radio transmitters or mobile phones

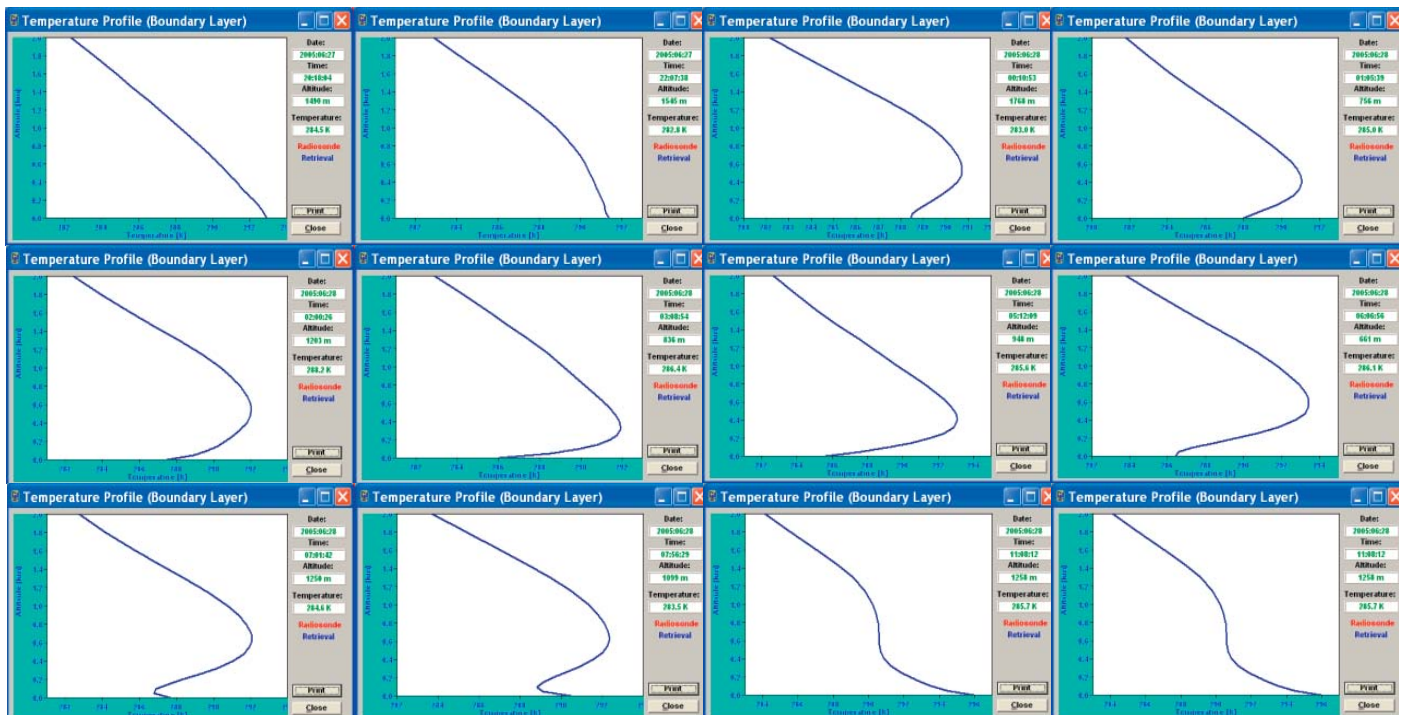
** only with azimuth positioner

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):

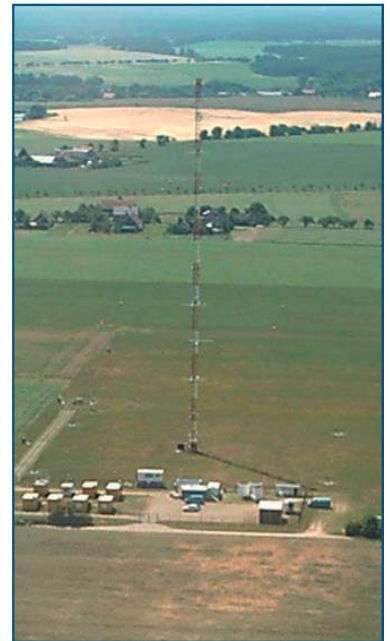
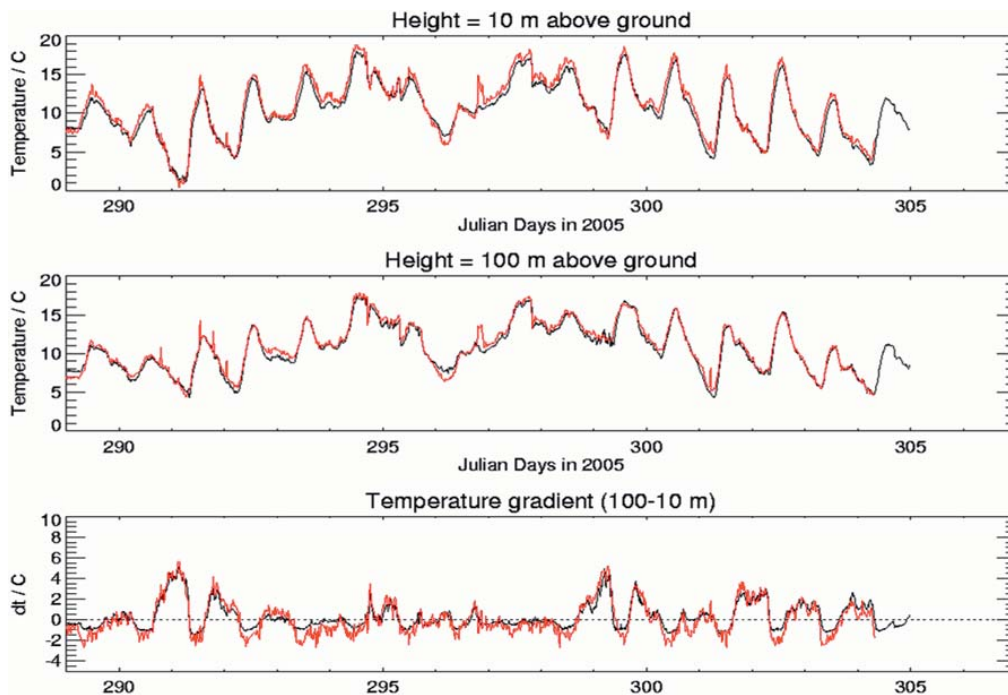


The boundary layer mode allows for monitoring the formation and decay of temperature inversions in time:



Inter-comparison with a meteorological tower

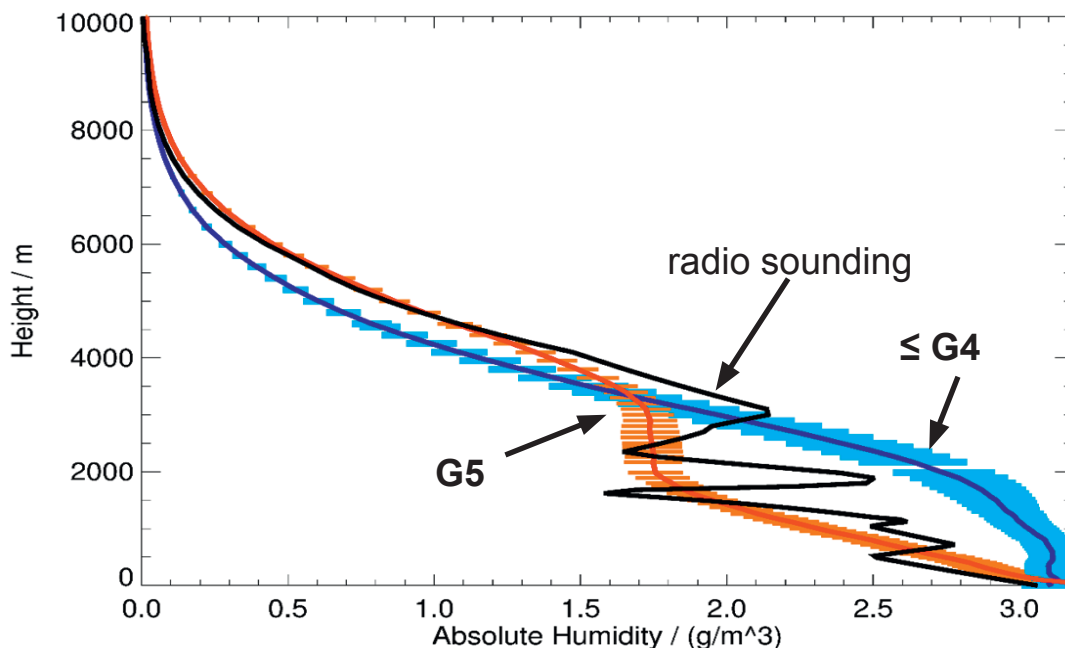
Boundary layer temperatures retrieved from RPG-HATPRO measurements were, for example, validated by an inter-comparison with a 100 m meteorological tower operated by the German Weather Service (DWD) in Lindenberg / Germany. The tower is equipped with in-situ temperature sensors every 10 height metres.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

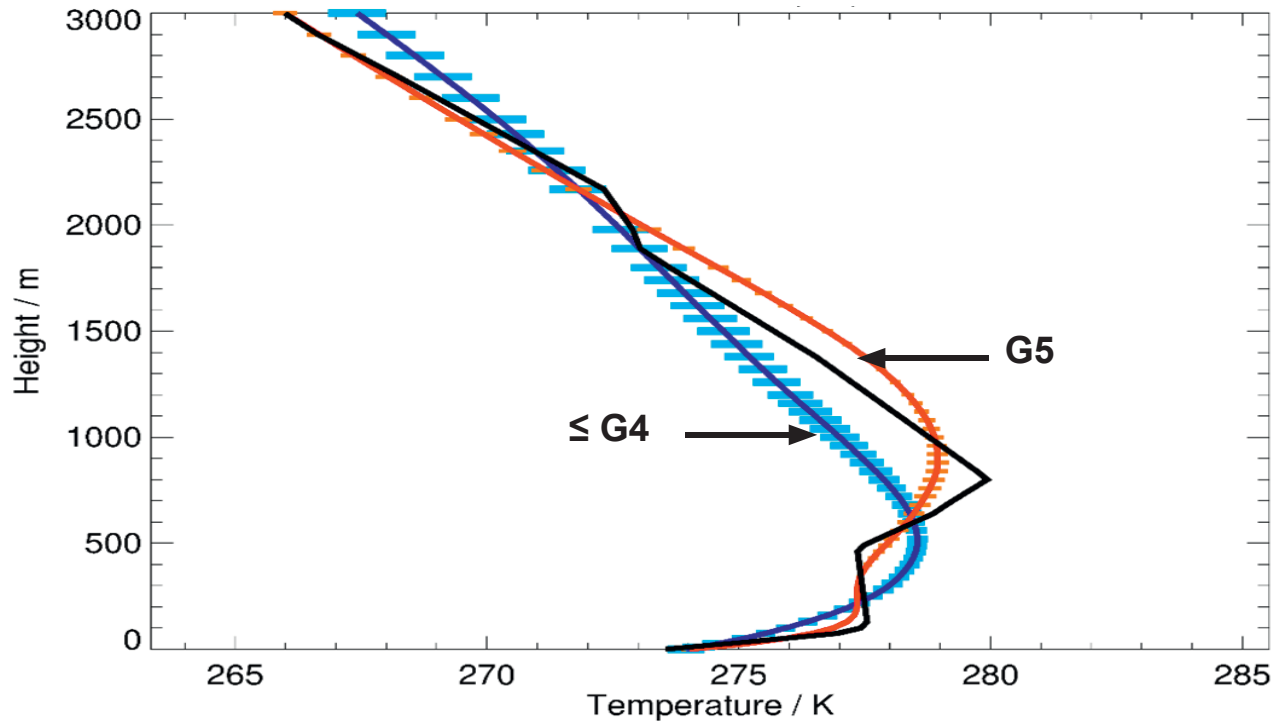
Tropospheric Profiling

Humidity Profiling:

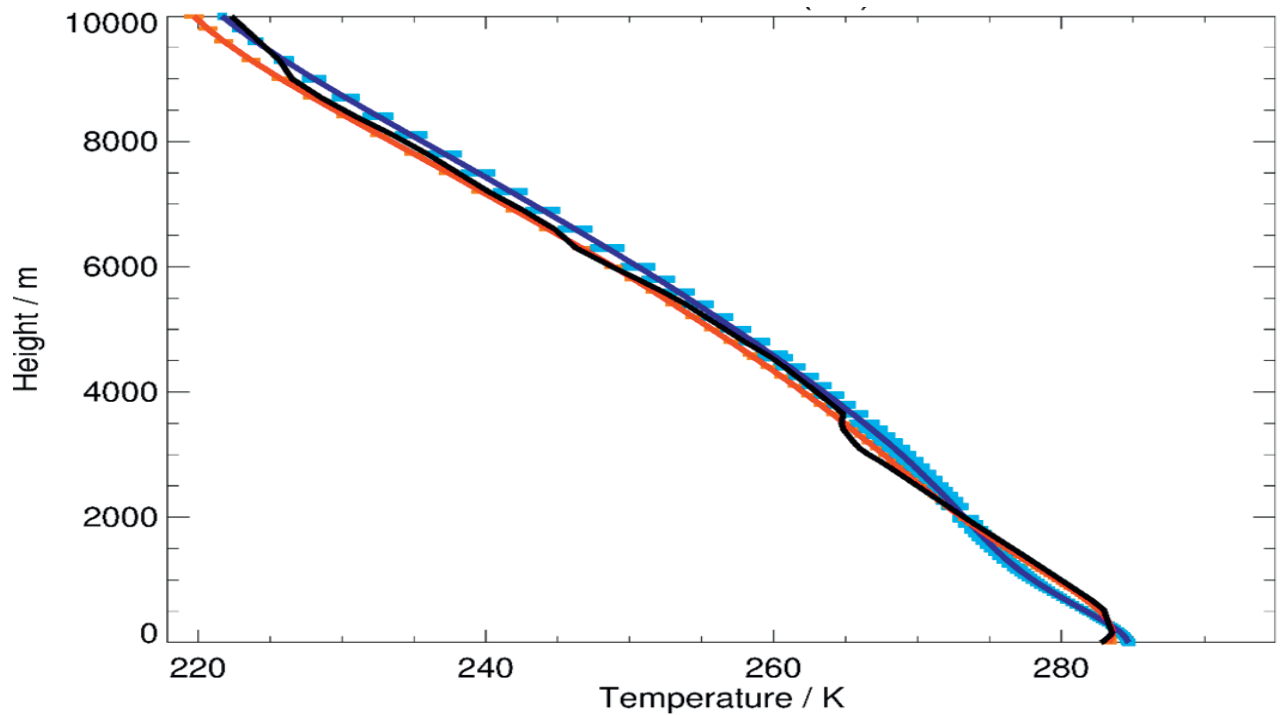


Improvement example of G5 absolute humidity profile over previous radiometer generations. Black: radio sounding for comparison, light blue: G4 retrieval noise, orange: G5 retrieval noise.

Temperature Profiling:



Boundary layer temperature profiling inter-comparison example.

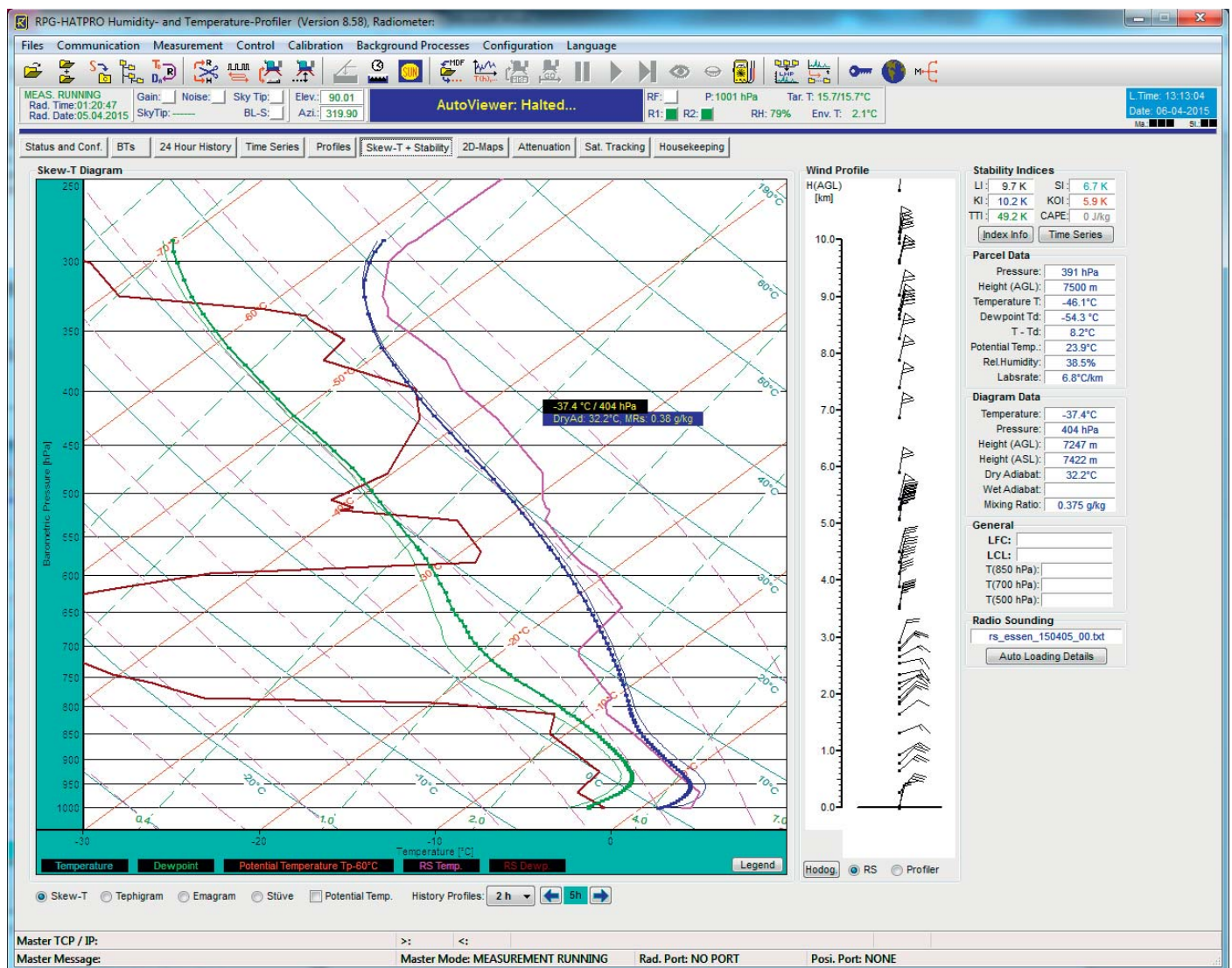


Full troposphere temperature profiling inter-comparison example.



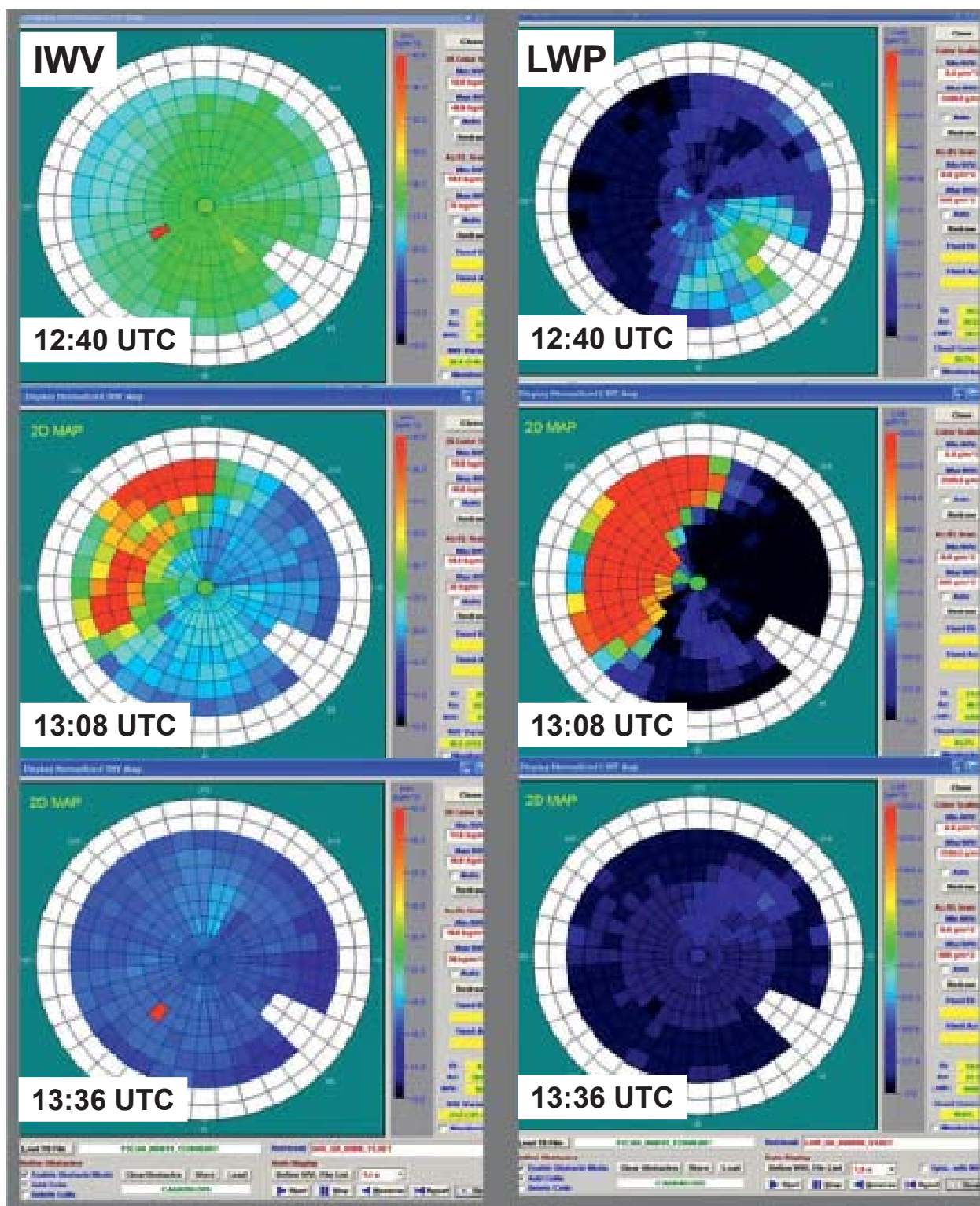
Thermodynamic Diagrams

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 Vapour (IWV) and Liquid Water Path (LWP)

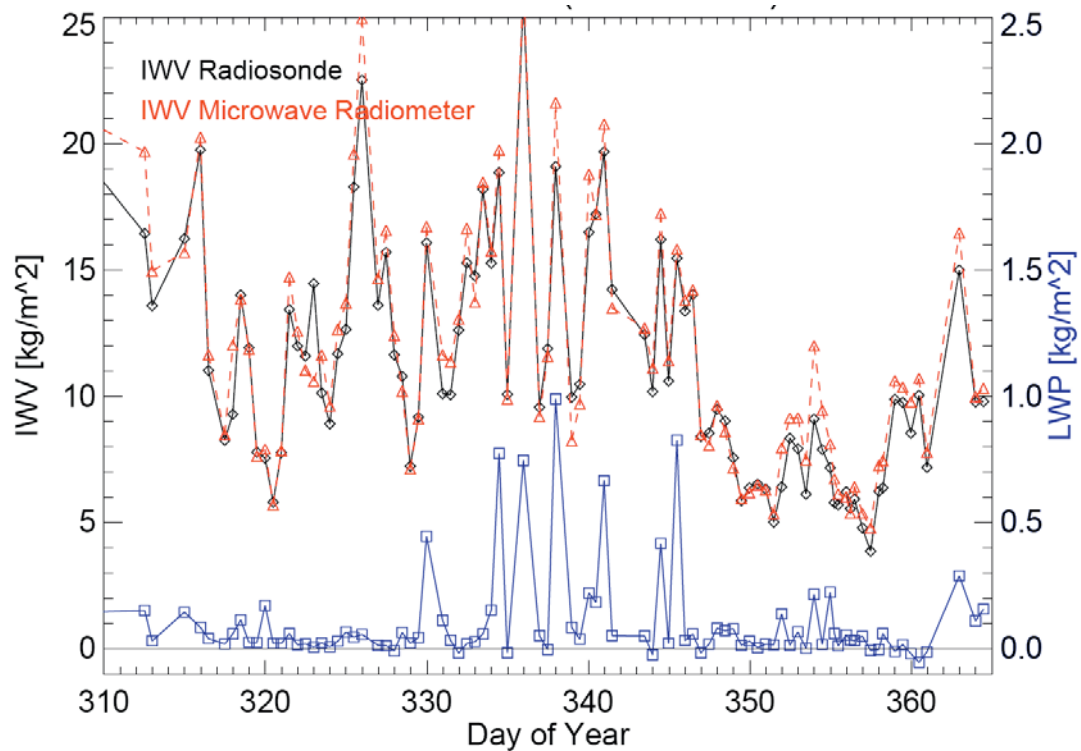
Full Sky IWV and LWP maps* below show inhomogenous water vapour distributions and cloud coverage:



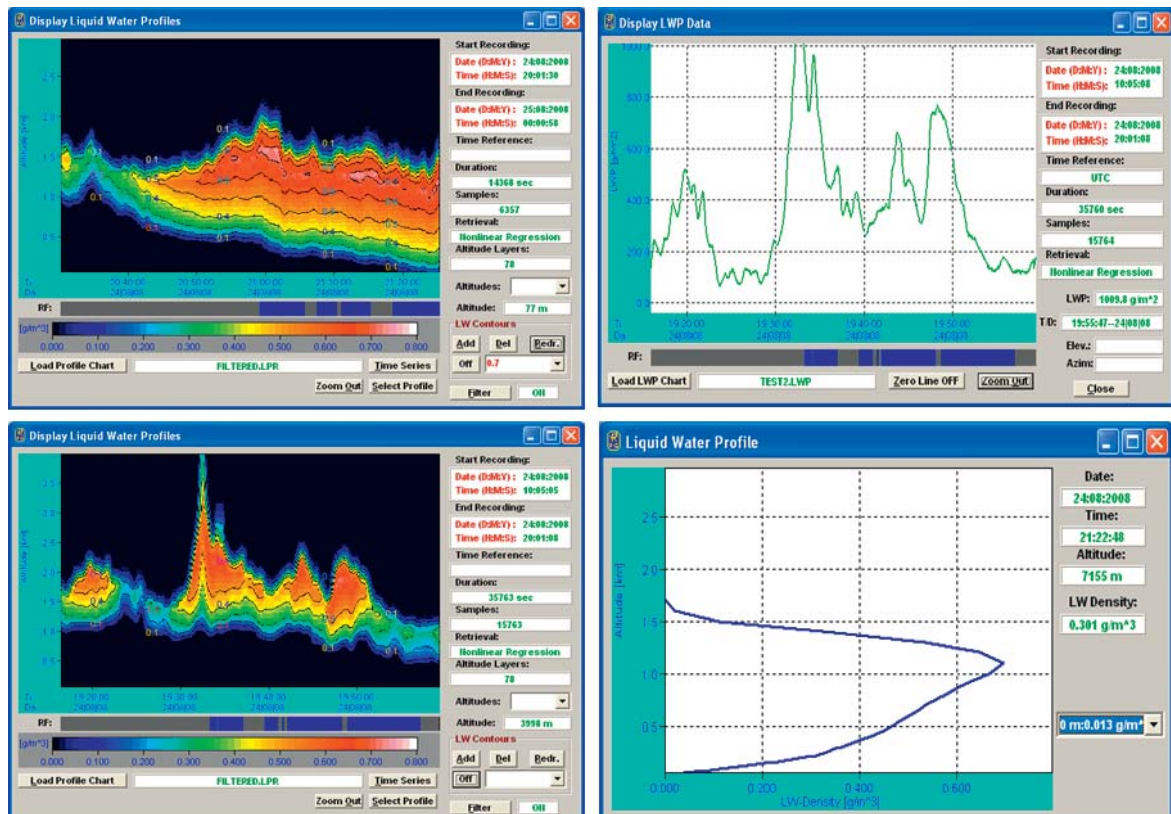
*only with azimuth positioner



IWV measurements remain accurate even with an LWP of 1000g/m^2 :



Liquid Water Profiling:

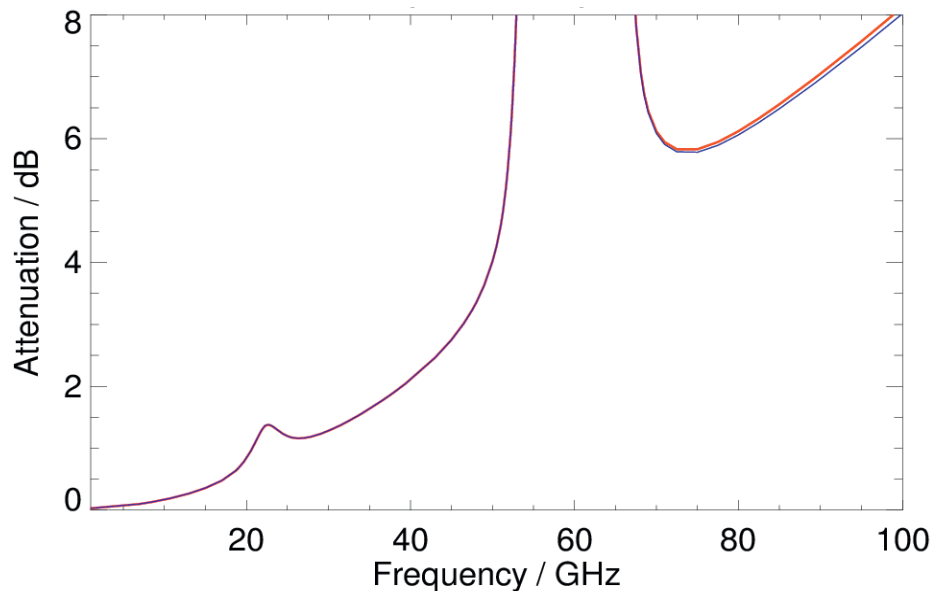




Attenuation Measurements

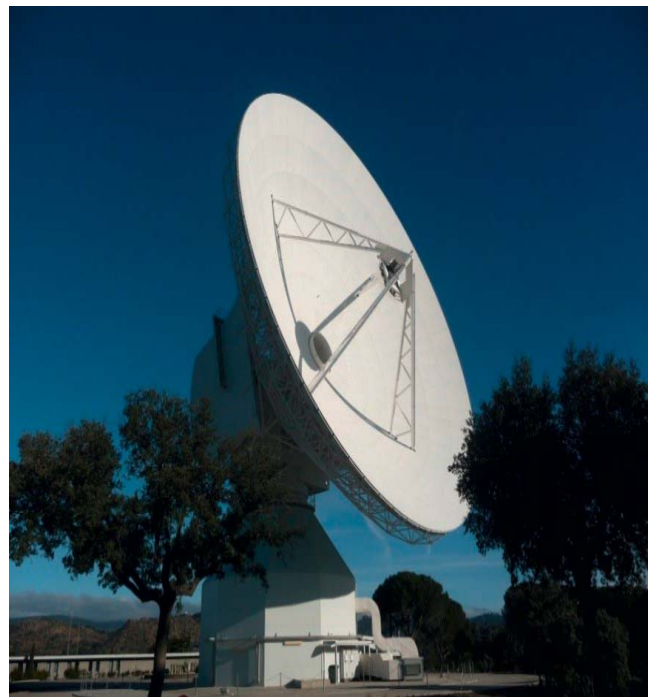
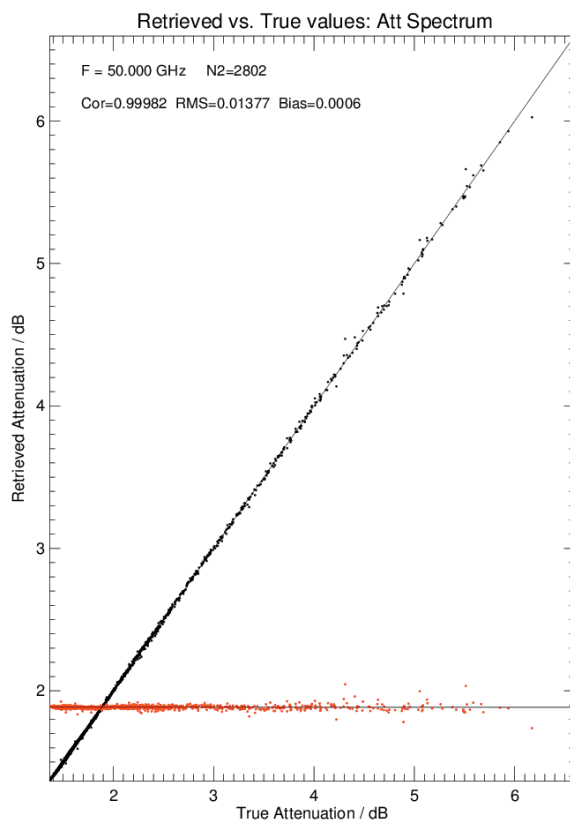
HATPRO measurements at 14 radiometer channels allow for an accurate retrieval of **total atmospheric attenuation** spectra between 1 and 100 GHz.

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



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

Bottom:
Scatter plot for "Retrieved Attenuation" vs. "True Attenuation" (black), de-trended in red.





Profiling Radiometer Models

- **RPG-HUMPRO**
 - HUMidity PROfiler
 - 7 channels: 22.24 GHz to 31.4 GHz
 - over-sampling for redundancy

- **RPG-TEMPRO**
 - TEMperature PROfiler
 - 7 channels 51 GHz to 58 GHz
 - over-sampling for redundancy
 - customized direct detection channels for precise boundary layer mode
 - temperature profiles in elevation scanning mode

- **RPG-HATPRO**
 - Humidity And Temperature PROfiler (standard profiling radiometer)
 - 7 channels: 22.24 GHz to 31.4 GHz
 - 7 channels 51 GHz to 58 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
 - Designed for arctic conditions and/or high altitudes
 - Water vapour sounding at 183 GHz
 - 6 DSB channels with individual bandwidth



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) 160 m (range 3500-4500 m) 200 m (range 4500-6000 m) 300 m (range 6000-10000 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) 1.00 K RMS typical (range 4000-10000 m)
Humidity profile performance	Accuracy: 0.3 g/m ³ maximum bias typical (absolute humidity) 0.1 g/m ³ 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 ³ RMS Threshold: 50 g/m ² LWP Only single layer clouds are modelled
IR radiometer option	9.6-11.5 μ m band, accuracy 1 K, noise: 0.2 K RMS
LWP	Accuracy: ± 10 g/m ² , sensitivity: 2 g/m ² RMS
IWV	Accuracy: ± 0.12 kg/m ² RMS, sensitivity: 0.04 kg/m ² RMS
Full sky IWV and LWP maps (only with azimuth positioner)	300 points in 8 minutes rapid scanning



Parameter	Specification
Satellite tracking mode (only with azimuth positioner)	<ul style="list-style-type: none"> Determines tropospheric wet delay and attenuation along line of sight for all visible GPS / Galileo satellites in a single scan (2 minutes). Tracking via RINEX 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, 31.4 GHz V-Band: 51.26 GHz, 52.28 GHz, 53.86 GHz, 54.94 GHz, 56.66 GHz, 57.3 GHz, 58.0 GHz
Channel bandwidth	2000 MHz @ 58.0 GHz, 1000 MHz @ 57.3 GHz, 600 MHz @ 56.66 GHz, 230 MHz @ all other
System noise temperatures	< 400 K typical for 22.24 – 31.4 GHz profiler < 600 K typical for 51.26 – 58.0 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
Radiometric range	0-800 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 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, 1.8 kW heter module to avoid the formation of dew in case of fog.
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, quality flags, calibration history, and log files
Retrieval algorithms	Neural Network algorithms
Optical resolution	HPBW (frequency dependent): 3.0° - 4.2° 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), 40°/sec (azimuth, optional)
Operating temperature range	-40°C to +45°C
Power consumption	< 120 Watts average, 350 Watts peak for warming-up (without dew blower heater), blower: 130 Watts maximum
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 ³