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

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

**Atmospheric Attenuation**
for satellite communication

**Data Assimilation**
Input for weather and climate models

**Satellite Tracking**
Tropospheric delay and attenuation along line of sight

**Absolute calibration of Cloud Radar** receivers

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RPG Radiometer Physics GmbH
Werner-von-Siemens-Str. 4
53340 Meckenheim, Germany
Design

Direct Detection Filter-Bank Receivers

Parallel Detection at all 14 channels

Imune to RFI < 18 GHz*

Fast Data Acquisition

100% Duty Cycle

High Temporal Resolution
• 1 second resolution
• Ideal for fast LWP sampling applications

High Spatial Resolution
• Boundary layer temperature profiling
• 2D Sky mapping**

Narrow Antenna Beams (~2° - 4° HPBW)

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 20 g/m² become visible!

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

Even humidity fluctuations of 20 g/m² become visible!

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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>30</td>
<td>0.347</td>
<td>0.125</td>
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<td>75</td>
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<td>60</td>
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<td>0.147</td>
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<td>51</td>
<td>0.400</td>
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<td>42</td>
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<td>36</td>
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<td>0.244</td>
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<td>30</td>
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<td>0.418</td>
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<td>19.2</td>
<td>0.861</td>
<td>0.521</td>
</tr>
<tr>
<td>10.2</td>
<td>2.359</td>
<td>1.233</td>
</tr>
</tbody>
</table>
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)

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* 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 inhomogeneous water vapour distributions and cloud coverage:

*only with azimuth positioner
IWV measurements remain accurate even with an LWP of 1000g/m²:

**Liquid Water Profiling:**

![Liquid Water Profiling Diagram]
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
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</table>
| 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/m³ maximum bias typical (absolute humidity)  
0.1 g/m³ 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/m³ RMS  
Threshold: 50 g/m² LWP  
Only single layer clouds are modelled |
<p>| IR radiometer option | 9.6-11.5 μm band, accuracy 1 K, noise: 0.2 K RMS |
| LWP | Accuracy: ± 10 g/m², sensitivity: 2 g/m² RMS |
| IWV | Accuracy: ± 0.12 kg/m² RMS, sensitivity: 0.04 kg/m² RMS |
| Full sky IWV and LWP maps (only with azimuth positioner) | 300 points in 8 minutes rapid scanning |</p>
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| Satellite tracking mode (only with azimuth positioner) | • 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                              | • 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:  
• temperature, pressure, relative humidity  
• wind speed, wind direction, and rain rate |
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<tbody>
<tr>
<td>Data interface / rate</td>
<td>Ethernet (TCP/IP)</td>
</tr>
<tr>
<td>Instrument control (external PC)</td>
<td>Windows™ System with Ethernet interface</td>
</tr>
<tr>
<td>Instrument control (internal)</td>
<td>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.</td>
</tr>
<tr>
<td>Housekeeping data</td>
<td>Detailed instrument status information, including health checks, quality flags, calibration history, and log files</td>
</tr>
<tr>
<td>Retrieval algorithms</td>
<td>Neural Network algorithms</td>
</tr>
<tr>
<td>Optical resolution</td>
<td>HPBW (frequency dependent): 3.0° - 4.2° for water vapour, 1.8° - 2.2° for temperature profiler</td>
</tr>
<tr>
<td>Side-lobe level</td>
<td>&lt; -30 dBC</td>
</tr>
<tr>
<td>Pointing range / resolution</td>
<td>Elevation: 0° to 180° (0.1° steps), full s/w control Azimuth (optional): 0° to 360° (0.1° steps), full s/w control</td>
</tr>
<tr>
<td>Pointing speed</td>
<td>45°/sec (elevation), 40°/sec (azimuth, optional)</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-40°C to +45°C</td>
</tr>
<tr>
<td>Power consumption</td>
<td>&lt; 120 Watts average, 350 Watts peak for warming-up (without dew blower heater), blower: 130 Watts maximum</td>
</tr>
<tr>
<td>Lightning protection</td>
<td>Power line: circuit breakers Data line: optical fibre cable (max. length: 1400 m)</td>
</tr>
<tr>
<td>Input voltage</td>
<td>90-230 V AC, 50 to 60 Hz</td>
</tr>
<tr>
<td>Weight</td>
<td>60 kg (without dew blower)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>63 × 36 × 90 cm³</td>
</tr>
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