Applications

- Tropospheric profiling of temperature, humidity and liquid water
- High-resolution boundary layer temperature
- profiles, better resolution than balloons
- Input for weather and climate models (data assimilation)
- Satellite tracking (GPS, Galileo,…) wet/dry delay + humidity profiles along line of sight
- Now-casting atmospheric stability: severe weather
- Temperature inversion detection, fog, air pollution
- Absolute calibration of cloud radars
- Wet and dry delay corrections in VLBI applications
- Water vapour monitoring for astronomical sites

Features

- New in Generation 4:
  - Ethernet interface, improved thermal stabilization
  - Equipped with Vaisala® WXT 520 weather station to measure 2 m above surface: wind (speed & direction), rain rate (RR), pressure, temperature, rel. humidity
- Temperature, Humidity and Liquid Water Profiler (0-10 km)
- Fast data acquisition due to direct detection filter-bank receivers (100% duty cycle)
- All 14 microwave channels measured in parallel4
- High temporal resolution (1 second), high spatial resolution (~2°- 4° HPBW)
- IWV (integrated water vapour) and LWP (integrated cloud liquid) full sky maps (350 points) within 6 minutes (only with azimuth positioner option)
- Determination of cloud coverage, monitoring of fast changes in 3D humidity field
- Satellite tracking mode to determine the wet / dry delay and atmospheric attenuation in the line of sight for all visible satellites like GPS, Galileo, etc. (only with azimuth positioner option), humidity profile along line of sight available
- Immune to RF interference below 18 GHz (e.g. radio transmitters, mobile phones etc.), direct detection receiver layout
- Purely passive operation, no internal oscillators or other RF sources
- Extremely short calibration cycles (absolute calibration takes only 4 minutes)
- Automatic calibration with sky-tipping (software controlled)
- History of calibrations, post-processing possible
- Fully automatic internal calibrations including noise sources (noise switching, gain calibration, manual liquid nitrogen calibration required only every 6 month)
- Very high vertical resolution of temperature profiles (50 m) in the planetary boundary layer, important for the detection of low level temperature inversions
- Rain and fog mitigation system, strong blower and hydrophobic coating
- Efficient heater system (1.8 kW) preventing formation of dew (condensation of water and ice) on radome

- Data formats: Binary, netCDF, ASCII, BUFFR
- All levels of product data available:
  - Level-0 voltage raw data
  - Level-1 calibrated brightness temperature data
  - Level-2 retrieved products data (LWP, IWV)
- Instrument can be upgraded by another radiometer to increase its capabilities and accuracy (Master / Slave configuration), e.g. with a RPG-LWP-150-90 radiometer
- Fibre-optical data cable for lightning protection and secure data transmission
- Operating software for radiometer includes:
  - Remote Operation (web-server application)
  - Detailed instrument status and control
  - Automatic recovery after power failures
  - User defined schedules for measurements and calibration
  - Internal data file backup system
  - Satellite Tracking (GPS data from receiver and RINEX orbit parameter files)
  - User interface for complex scan pattern definition
  - Data manipulation and display, time series, analysis
  - Housekeeping data
  - Data quality checks / quality flags
  - Detection and removal of RF Interferences
  - Free software updates from FTP server
  - Customized retrievals for meteorological data, including stability indices
  - Thermodynamic diagrams (Skew-T, Stüve, Emagram, Tephigram)
- North-alignment by software feature (sun-tracking plus GPS)
- GPS clock and receiver

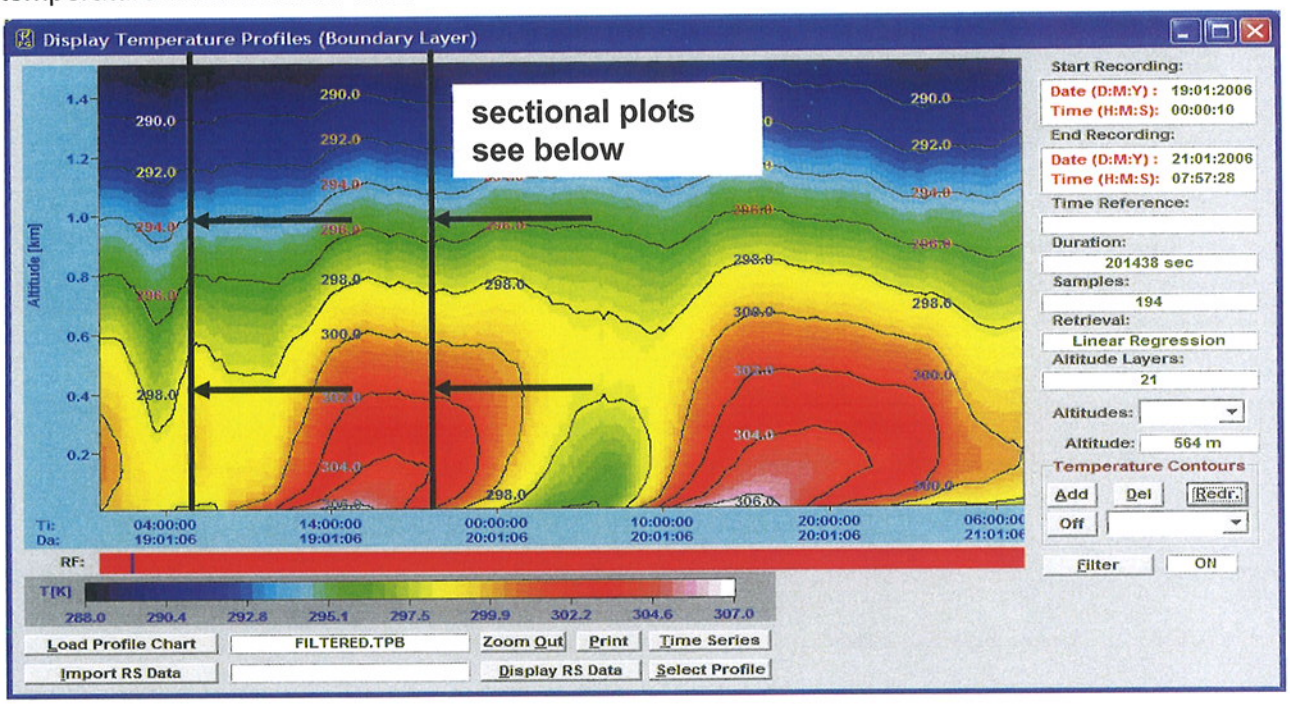
Introduction

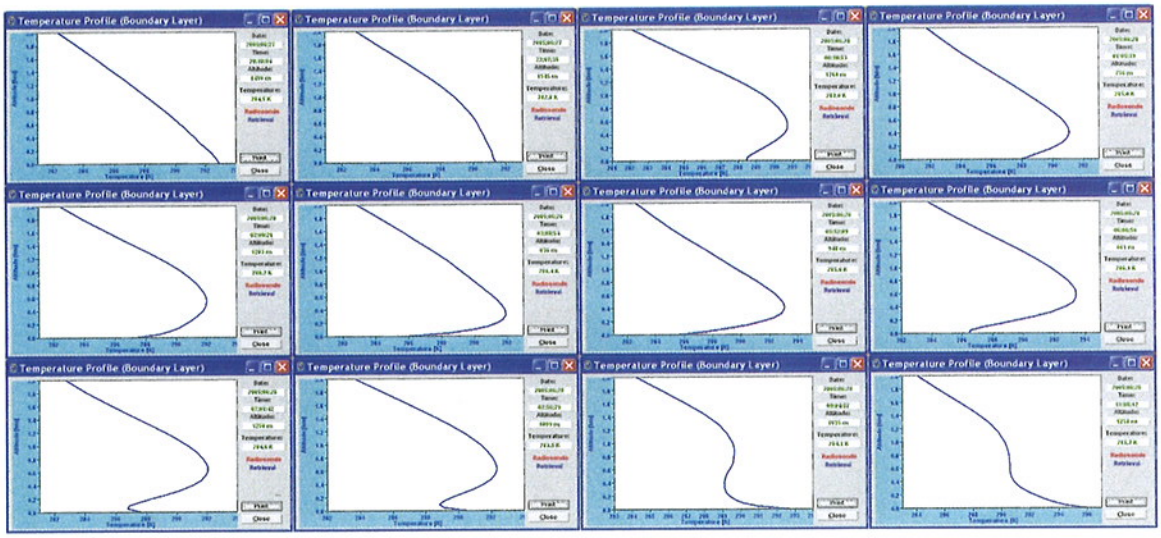
The RPG-HATPRO humidity and temperature profiling passive microwave radiometers measure a variety of atmospheric quantities with high temporal and spatial resolution. Due to their two 7 channel filter-bank receivers it offers a high speed parallel detection of all 14 channels. In contrast to other systems that utilize a sequential channel scanning e.g. with a synthesizer (the classical spectrum analyzer concept) the RPG-HATPRO is capable of performing fast LWP (Liquid Water Path) sampling with 1 second time resolution and outstanding noise performance of < 2 g/m^2 RMS while simultaneously measuring full troposphere (up to 10 km altitude) profiles of temperature and humidity. In addition the instrument supports two different scanning modes to achieve a maximum accuracy and vertical resolution for temperature profiling in the full troposphere (< 10000 m, vertical resolution 150 – 250 m) and boundary layer (< 1000 m, vertical resolution 50 m).
These two modes are referred to as zenith mode (observation only in zenith direction for full troposphere temperature and humidity profiling, LWP, IWV) and boundary layer mode (observation in 6 different elevation angles for boundary layer temperature profiling). In boundary layer mode the system scans the sky in elevation to increase the amount of acquired information by sampling all channels in different directions (down to 5° elevation angle).
It has been shown that this method increases the vertical resolution and accuracy of temperature profiles in the atmospheric boundary layer while the zenith mode is best for profiling the whole troposphere with lower vertical resolution. A high vertical resolution in the boundary layer is essential in order to resolve temperature inversions which mainly occur in that layer.

Highlights

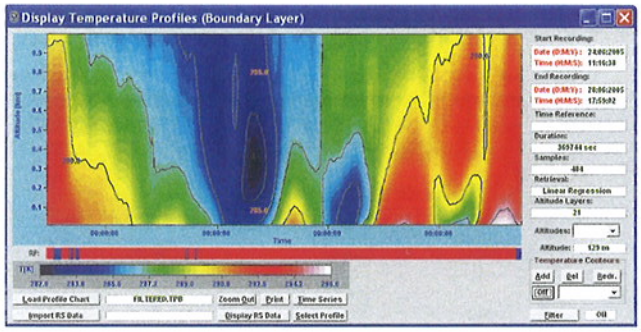
Temperature Profiling

Fast and accurate boundary layer profiling allows for the monitoring of the formation and decay of temperature inversions vs. time:

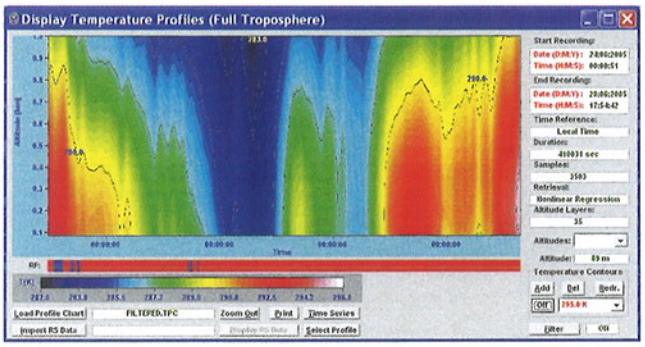




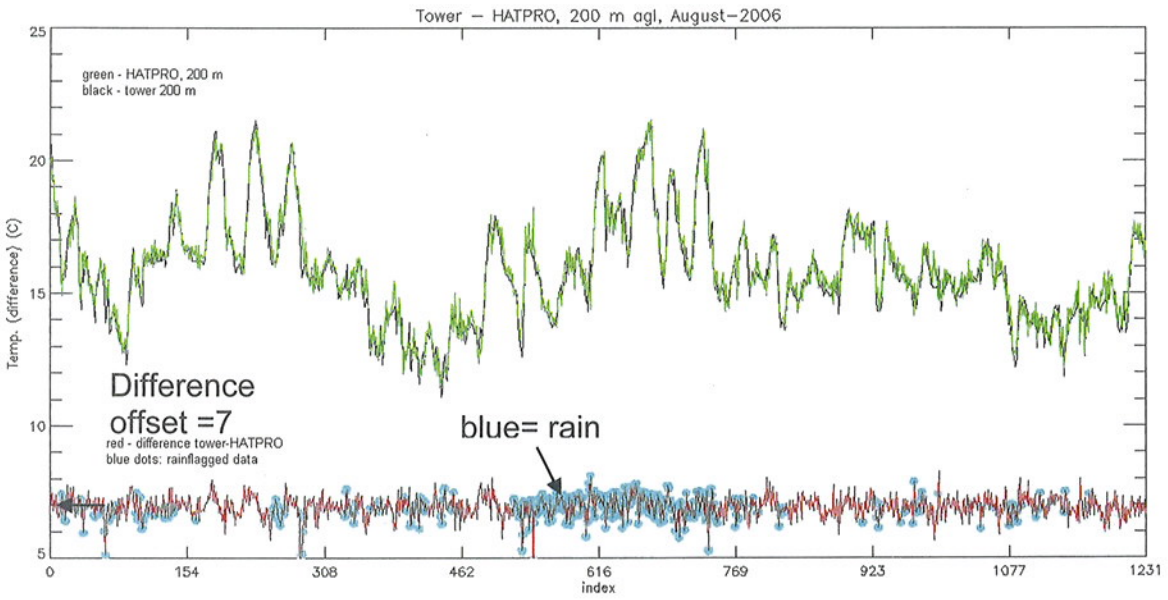
Vertical scanning for high resolution boundary layer scans:
The Boundary Layer observation mode with vertical scanning shows: The vertical structure (inversions) is resolved much better.



The Simple Zenith Observation Mode shows comparing poorer resolving of the vertical structures in the lower 500 m layer.

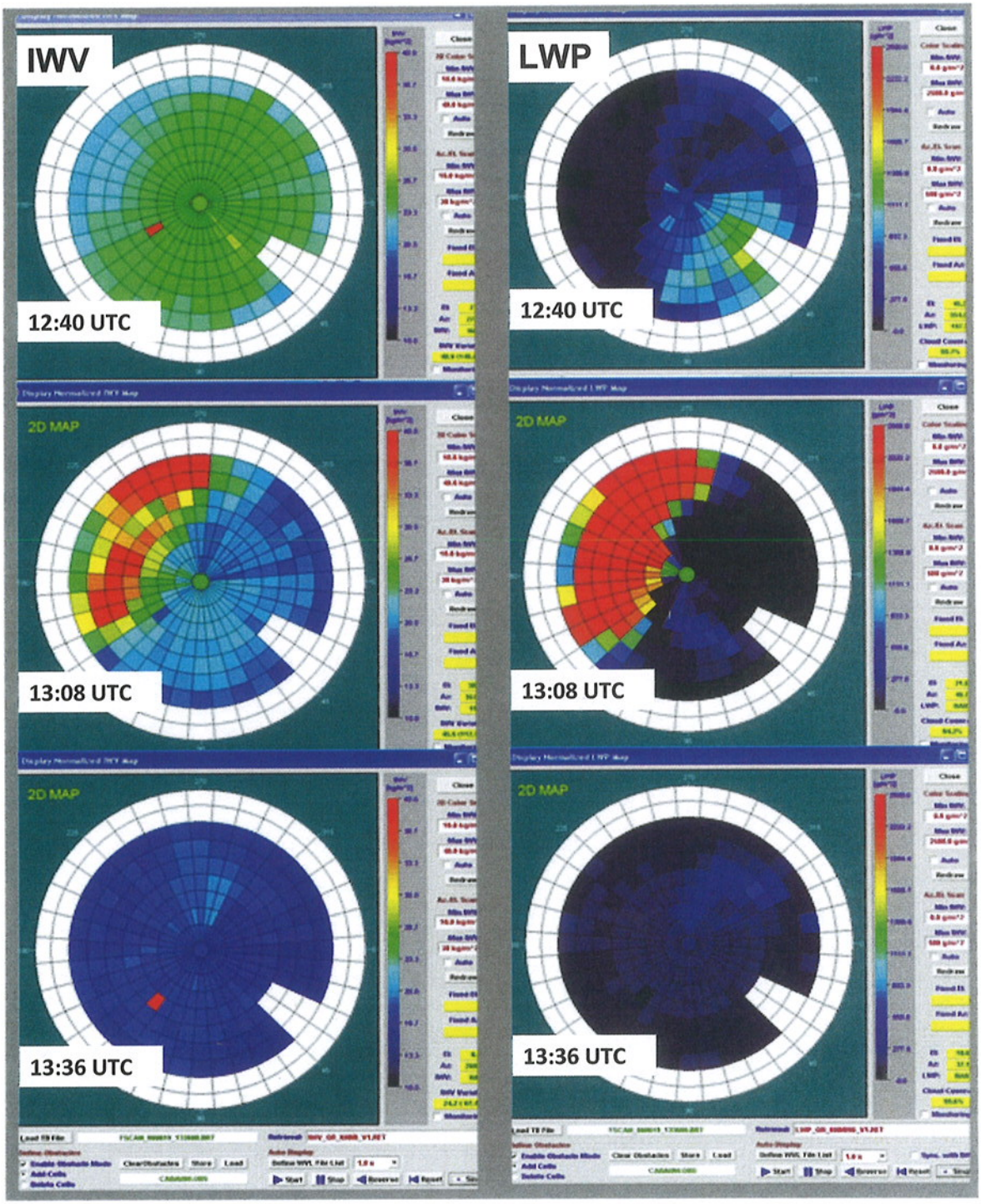


Direct comparison HATPRO versus meteorological tower measurements:
Comparison of HATPRO 200 m temperature measurements (in BL mode) with meteorological tower temperature sensor readings in the same altitude (courtesy of Henk Klein-Baltink, KNMI, Netherlands). The red line shows constant match even during rain events.



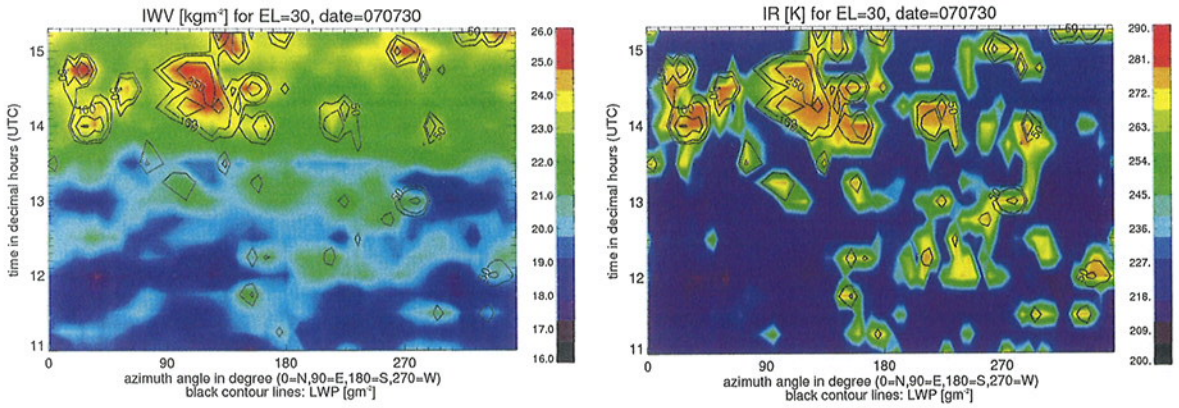
Integrated Water Vapor (IWV) and Liquid Water Path (LWP)

Full sky IWV and LWP maps below show inhomogeneous water vapour distributions and cloud coverage.

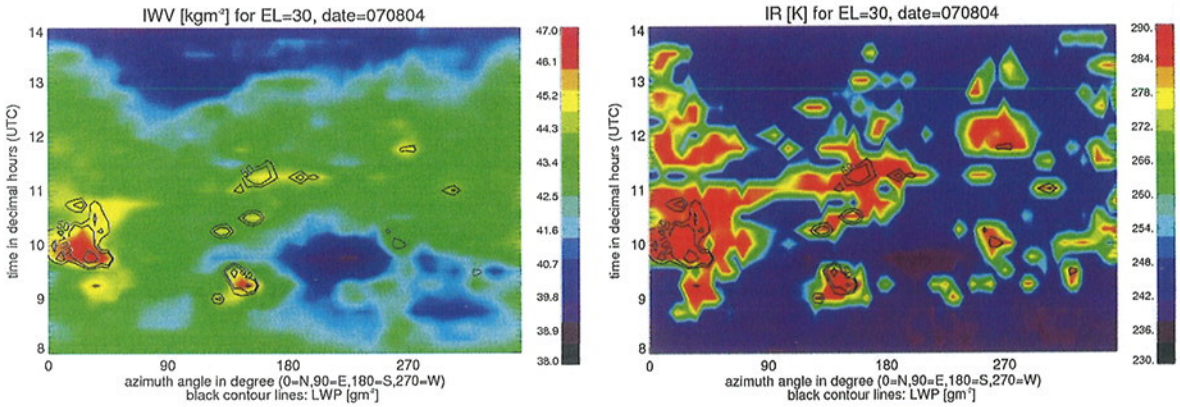


IWV/Sky-Temperature and LWP:

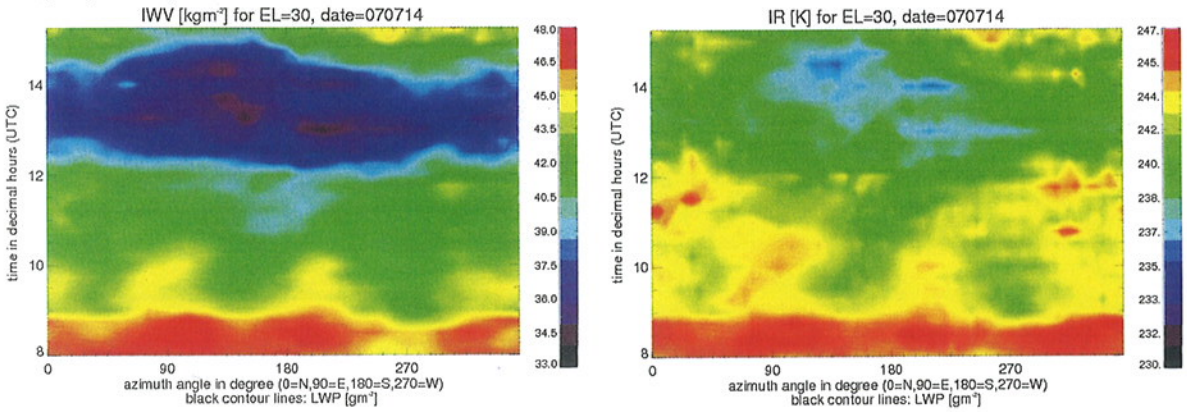
The spatial and temporal evolution of integrated water vapour content (IWV), sky-temperature (IR) and liquid water path (LWP) are visualized by Time-Azimuth-(Hovmöller) Diagrams (courtesy of Stefan Kneifel, University of Cologne).



30 July 2007: Development of Cu-convection after frontal passage; Observed IWV varies up to 20% even in regions with low LWP (<50 g/m²); max. LWP~500 g/m²

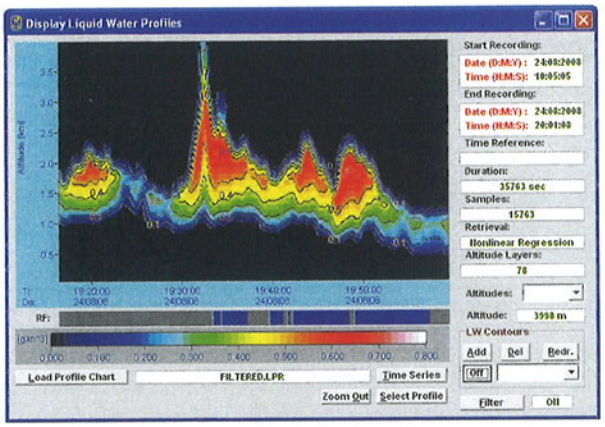


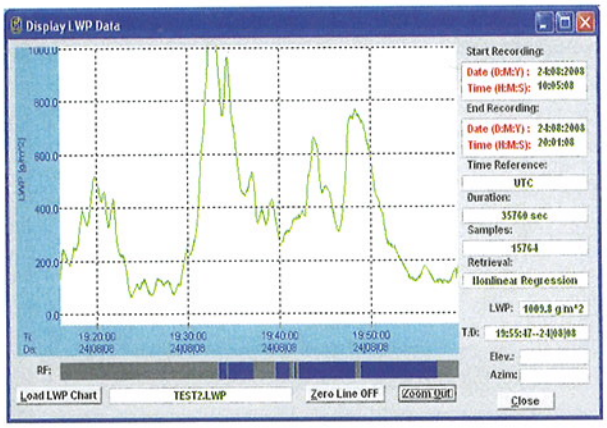
05 August 2007: Cloud development suppressed by strong subsidence; weak winds in the lower troposphere; IWV-differences of ~14% in the NE/SW from 6 to 15 UTC

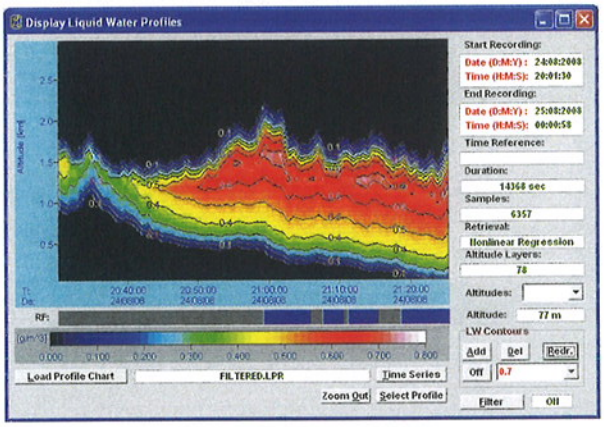


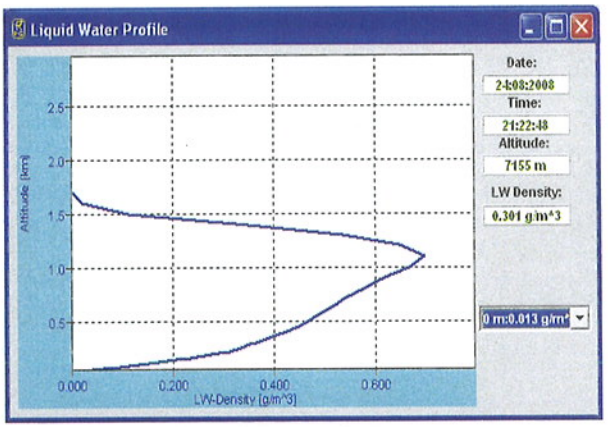
14 July 2007 (IOP 8a): Clear sky conditions (strong subsidence); Spatial and temporal structures appear in the measurements of IWV and IR-temperature.

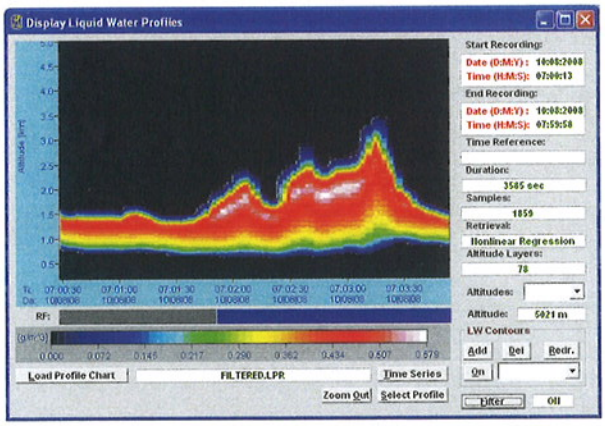
Liquid water profiling of clouds:

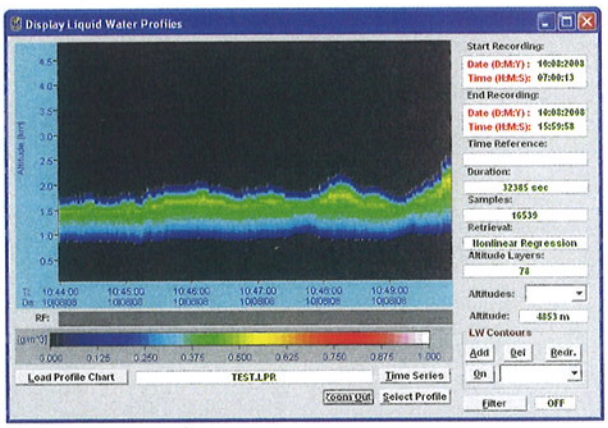


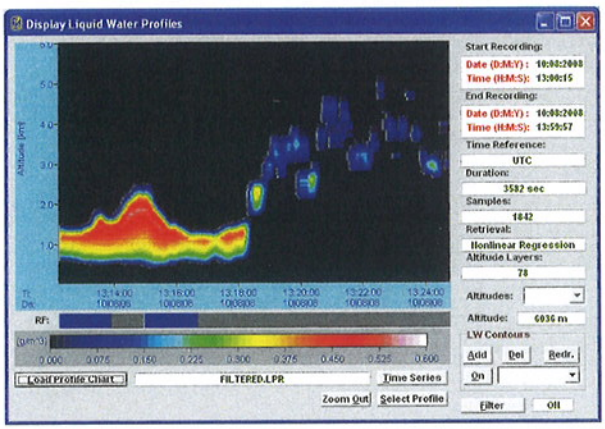


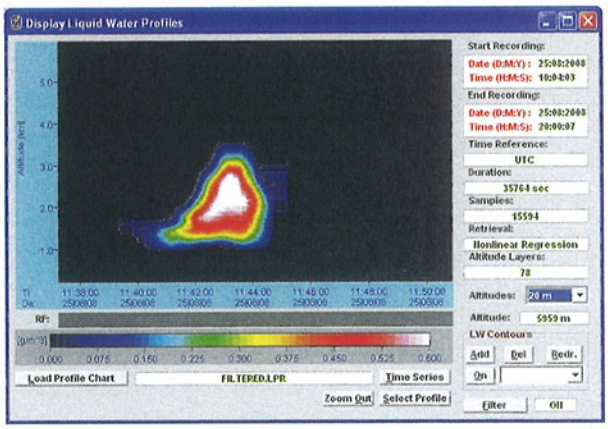




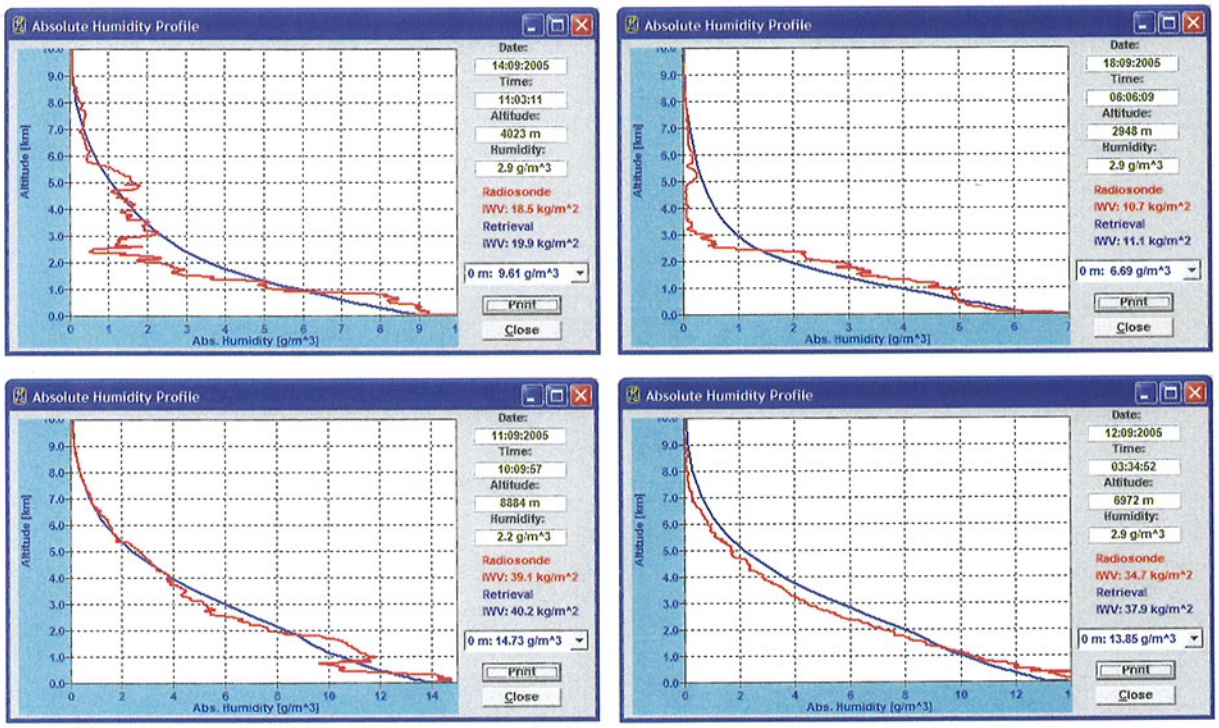




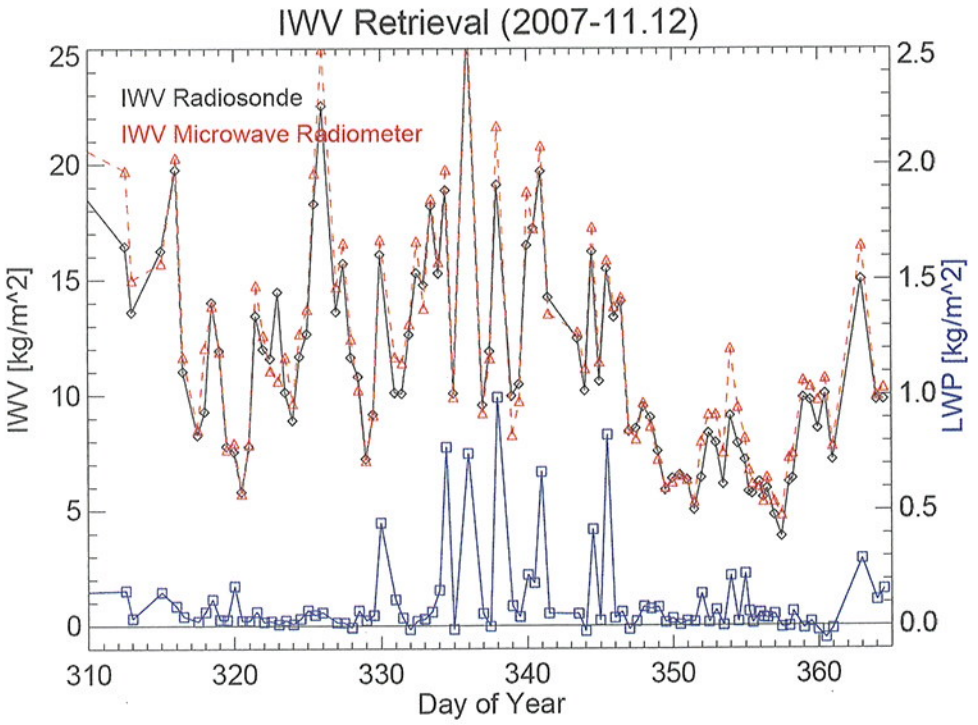




Humidity Profiling



Integrated Water Vapour measurements remain accurate even with LWP of 1000 g/m2.

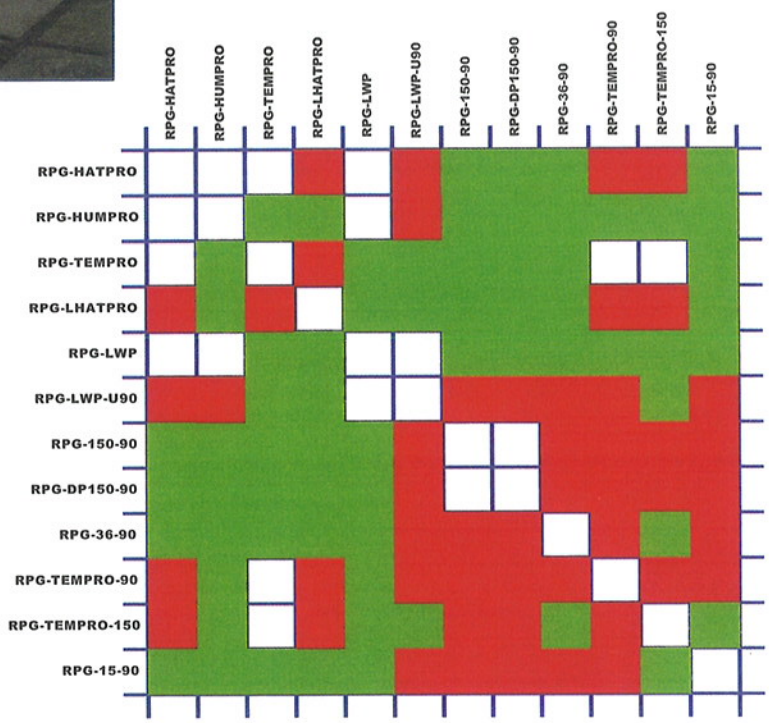


RPG Radiometer Combination

The RPG-HATPRO can be easily combined and synchronized with other RPG radiometers to a virtually single instrument.

Master/Slave Combination Matrix:

Possible Master/Slave Combinations for current RPG models.
Green: Ideal combination (no channel overlaps).
Red: Channel overlaps



Profiling Radiometer Models

- RPG-HUMPRO
  - Humidity profiling radiometer
  - 7 channels: 22.24 GHz to 31.4 GHz
  - over-sampling for redundancy

- RPG-TEMPRO
  - Temperature profiling radiometer
  - 7 channels 51 GHz to 58 GHz
  - over-sampling for redundancy
  - customized direct detection channels for precise BL-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 BL-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

Options (all Models)

- Azimuth positioner
  - Fully supported by operating software
  - 0° to 360° rotation

- IR-radiometer suite
  - Single-Channel: Cloud base information
  - Dual-Channel: Sensitive to small LWP / effective radius of cloud particles
  - Steerable version available (fully synchronous steering with microwave obs)

- Warranty extensions
  - May be ordered at initial deployment
  - Continuation on a year-by-year basis

Detailed Instrument Specifications

Parameter	Specification
Humidity profile performance (zenith and along track)	Vertical resolution: 200 m (range 0-2000 m) 400 m (range 2000-5000 m) 800 m (range 5000-10000 m) Accuracy: 0.4 g/m^3 RMS (absolute hum.) 5% RMS (rel. humidity)
Temperature profile performance (zenith and along track)	Vertical resolution: BL-Mode: 50 m (range 0-1200 m) Z-Mode: 200 m (range 1200-5000 m) 400 m (range 5000-10000 m) Accuracy: 0.25 K RMS (range 0-500 m) 0.50 K RMS (range 500-1200 m) 0.75 K RMS (range 1200-4000 m) 1.00 K RMS (range 4000-10000 m)

Parameter	Specification
Liquid water profile performance (only with IR radiometer option)	Vertical resolution: 250 m (range 0-2000 m) 300 m (range 2000-5000 m) 500 m (range 5000-10000 m) Accuracy: cloud base height: 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 (range5000-10000 m) density: 0.03 g/m^3 RMS Threshold: 50 g/m^2 LWP Only single layer clouds are modelled
IR radiometer option	9.2-10.6 µm band, accuracy 1 K, noise: 0.2 K RMS
LWP	Accuracy: ± 20 g/m^2, Noise: 2 g/m^2 RMS
IWV	Accuracy: ± 0.2 kg/m^2 RMS, Noise: 0.05 kg/m^2 RMS
Full sky IWV and LWP maps (only with azimuth positioner)	350 points in 6 minutes rapid scanning
Satellite tracking mode (only with azimuth positioner option)	Determines wet/dry delay, atmospheric attenuation and humidity profiles along line of sight for all visible GPS / Galileo satellites in a single scan (2 minutes) scanning with RINEX navigation file or direct GPS vector reading from GPS clock
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 22.2 – 31.4 GHz profiler <500 K typical for 51.4 – 58.0 GHz profiler
Radiometric resolution	K-Band: 0.10 K RMS, V-Band: 0.15 K RMS (at 1 sec int. time)
Absolute brightness temperature	0.5 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 nonlinearity error correction	Automatic, four point method

Parameter	Specification
Brightness calculation	based on exact Planck radiation law
Integration time	≥ 0.4 seconds for each channel, user selectable
Sampling rate for profiles	≥ 1 sec, user selectable
Rain / fog mitigation system	Highly efficient blower system (130 Watts), hydrophobic coated microwave transparent window, 1.8 kW heater module preventing formation of dew under fog conditions
Environmental Sensors	On a 1-meter mast attached to the radiometer: - Temperature, pressure, relative humidity - Wind speed, wind direction
Data interface / rate	Ethernet (TCP/IP), 10 kByte/sec.
Instrument control (external PC)	Windows™ System with Ethernet interface
Instrument control (internal)	Embedded PC, controls all internal calibrations, data acquisition, data file backup on 1 GB flash memory, control of azimuth positioner, communication with host, can run measurements independently from host PC
Housekeeping	all system parameters, calibration history documentation
Retrieval algorithms	neural network, linear /nonlinear regression algorithms
Optical resolution	HPBW (frequency dependent): 3.0° - 4.2° for water vapour, 1.8° - 2.2° for temperature profiler
Side-lobe level	<-30dBc
Pointing range / resolution	Elevation: 0° to 180° (0.15° 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 max.
Lightning protection	Power line: circuit breakers Data line: Fibre optics cable (max. length: 1400 m)
Input voltage	90-230 V AC, 50 to 60 Hz
Weight	60 kg (without dew blower)
Dimensions	63 × 36 × 90cm^3