Filterbank Radiometers for Atmospheric Profiling

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Motivation

CLIWA-NET Study Work Package (2000-2003):

"Design of a Low Cost LWP/Profiling Radiometer for Operational Networks"

- **Accurate LWP (liquid water path) and IWV (integrated water vapour) with high temporal resolution**
- **Tropospheric temperature profiles (0-10000 m)**
- **High resolution boundary layer temperature profiles (0-1000 m)**
- **Tropospheric humidity profiles**

Existing instruments too expensive!

General Instrument Concept

Optimization for Operational Networks:

Requirements:

- Wide operating temp. range (-30 to +40 C)
- Precipitation detection and protection
- Portability
- Low maintenance level for instrument support
- Data interface connection to INTERNET or other network
- Automatic built-in retrieval of atmospheric parameters

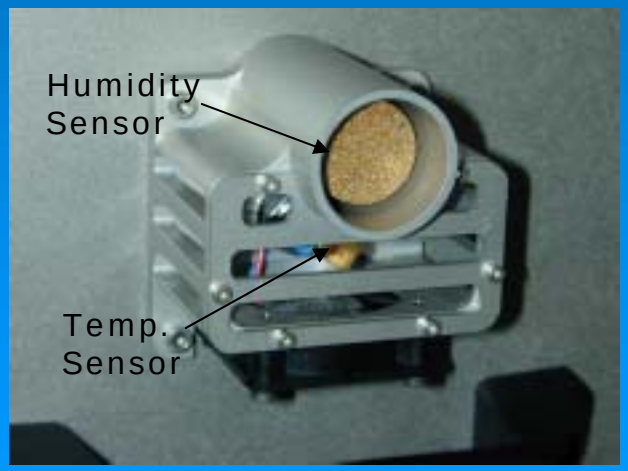
General Instrument Concept

4. Expandable Functionality:

- Master/Slave Configuration
- Automatic Detection
- Retrieval Support

General Instrument Concept

Weather Station and Time Reference:



Rain Sensor: Provides rain flag for measurement documentation, control of shutter system

GPS-Clock: Provides time reference standard for synchronization to satellite data

Humidity Sensor: Provides input data for retrievals, Dew Blower heating

Temperature Sensor: Provides input data for retrievals

Pressure Sensor: Provides input data for retrievals, LN-target calibration

Optional IR-Radiometer: Cloud base height detection

General Instrument Concept

3. Rain, Hail, Snow and Dew Protection System:

Optional Automatic Shutter System:

Controlled by Rain Sensor

Dew Blower:

- Removable
- Heater controlled by H.-Sensor

Utilized Microwave Frequencies

Frequencies:

Humidity Profiling (Trop):
22-31.4 GHz Band (7 chan.)

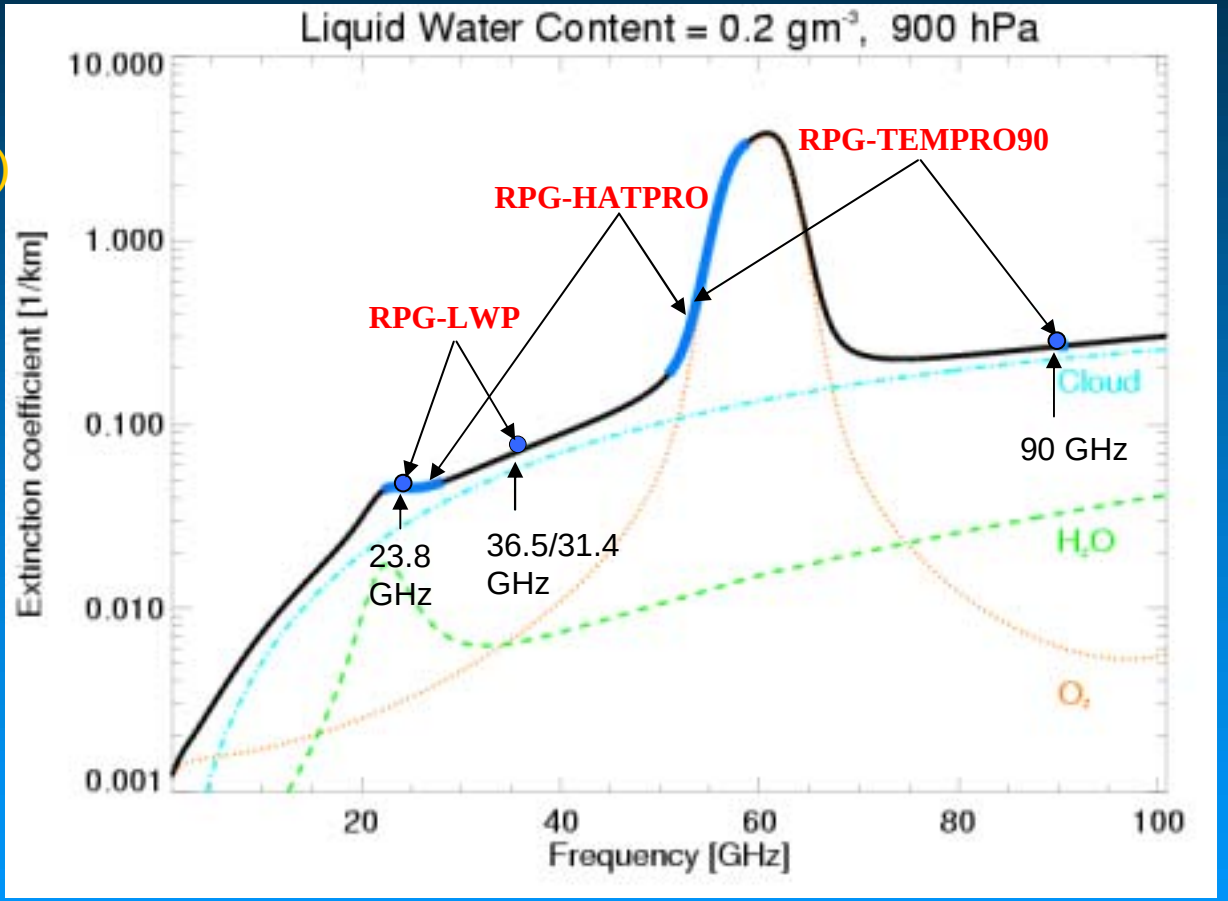
LWP/IWV, Wet/Dry Del.:
23.8/36.5 (31.4) GHz

Temp. Profiling (Trop&BL):

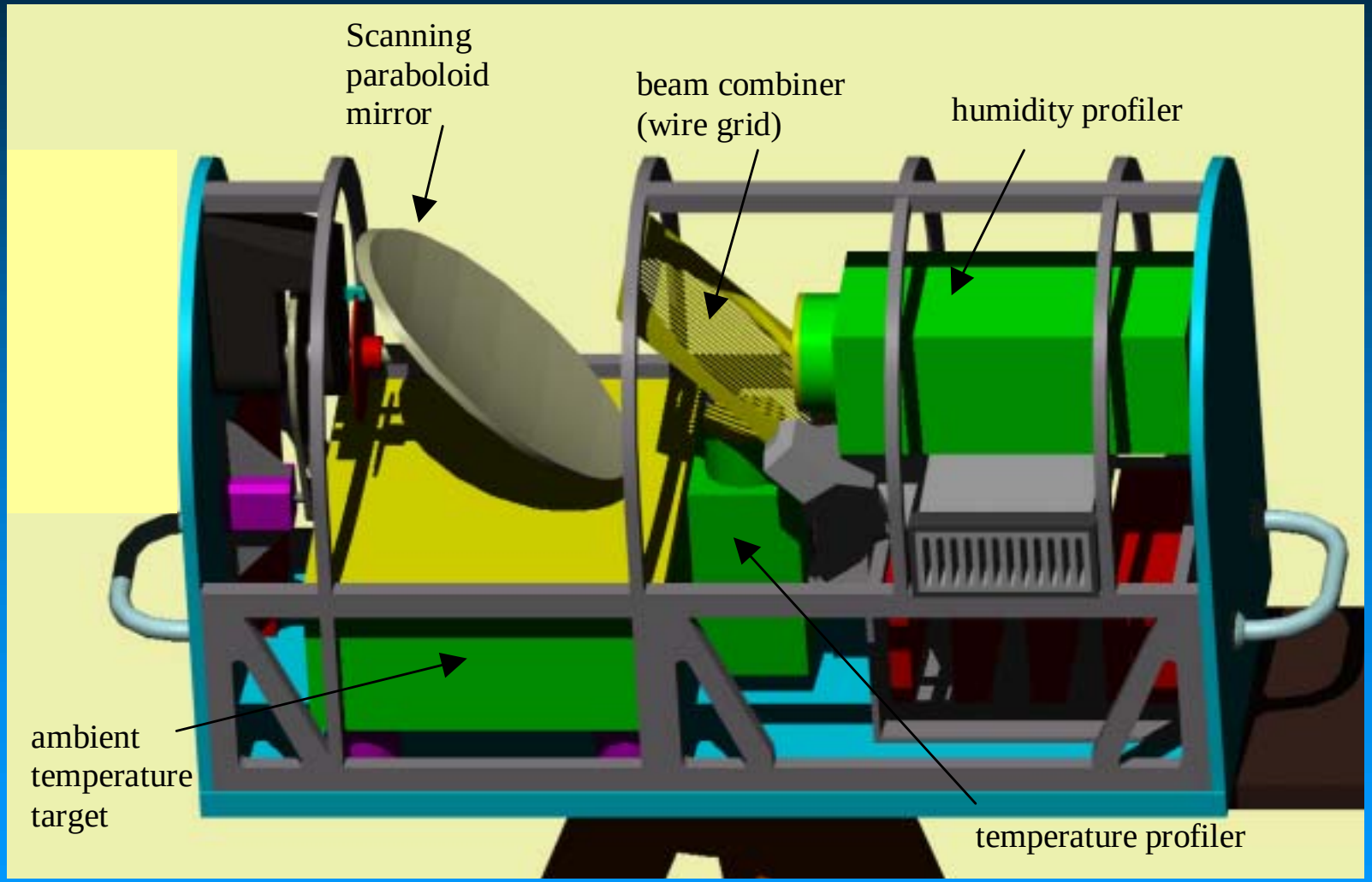
50-59 GHz Band (7 chan.)

LWP-Improvement:
90 GHz Channel

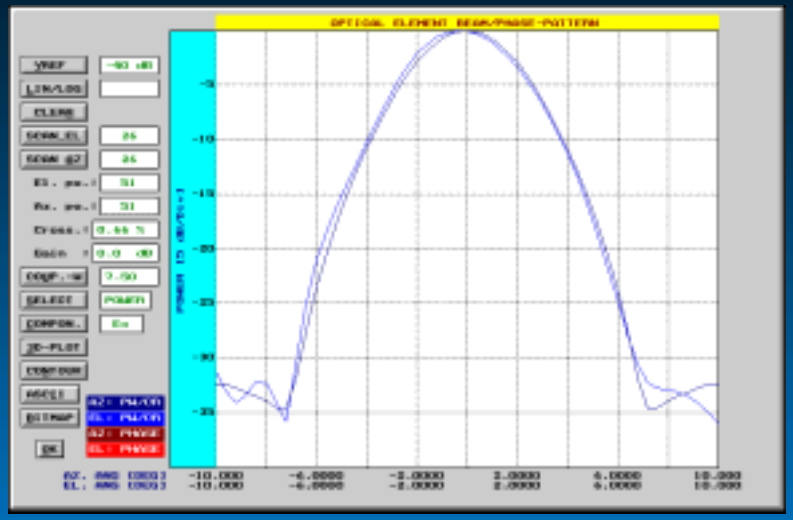
Humidity Profiling (BL):
183 GHz Channel

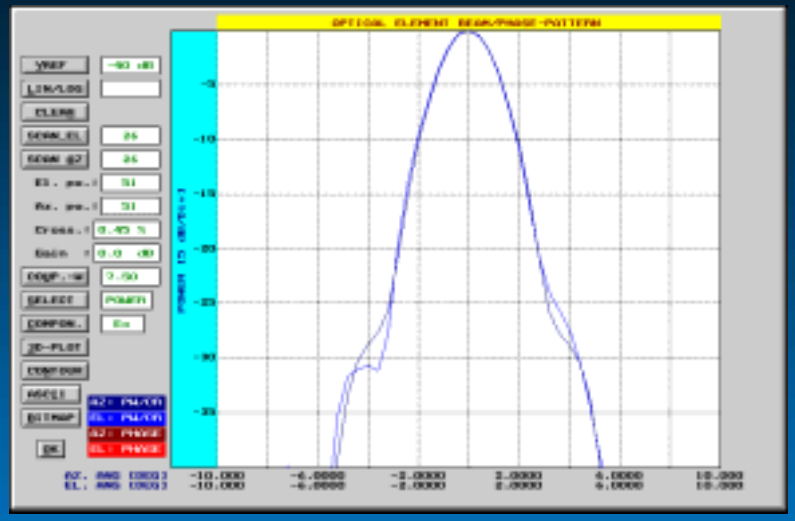


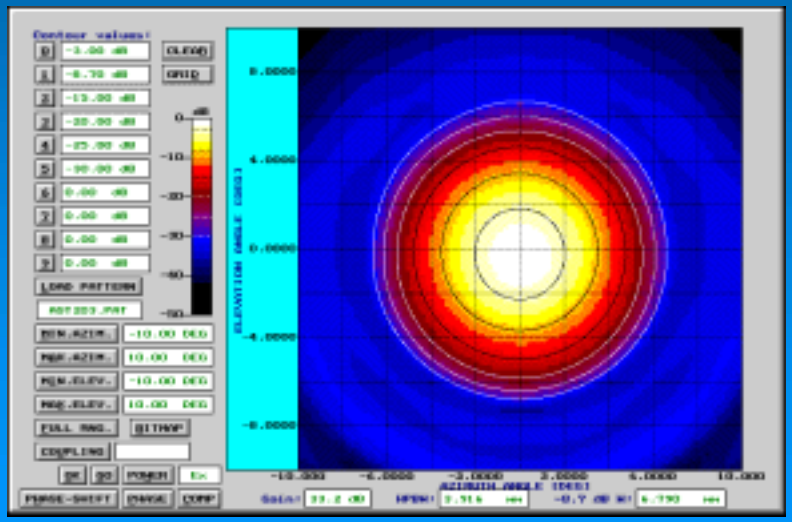
Principle System Layout

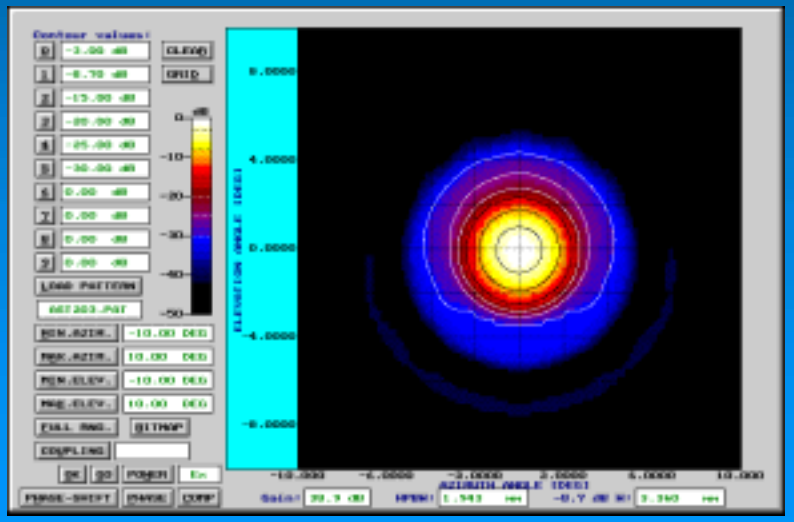


Optical Performance







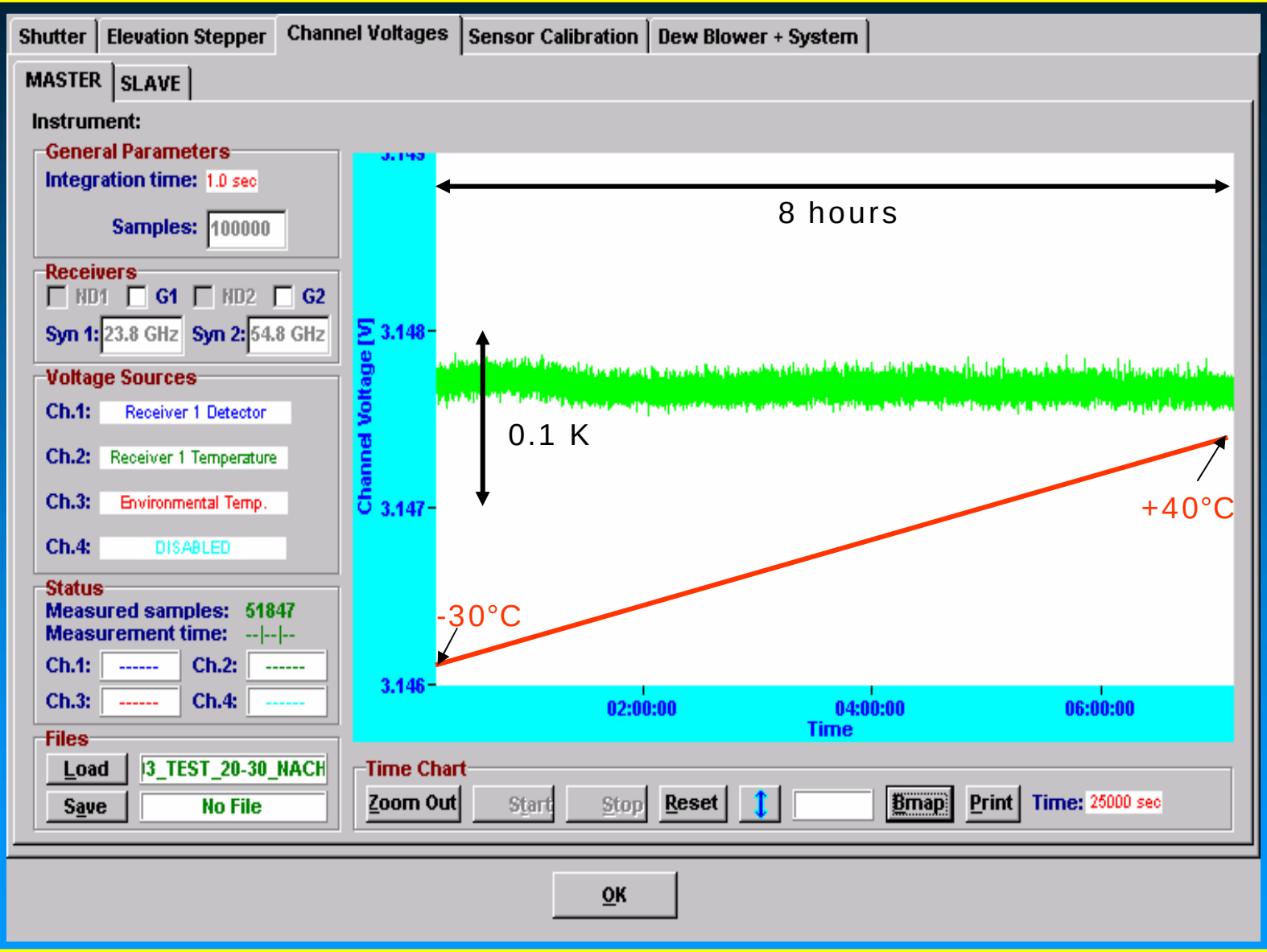


23.8 GHz, HPBW = 3.9°, Sidelobes: <-30 dB

55.0 GHz, HPBW = 1.9°, Sidelobes: <-30 dB

Receiver Thermal Stabilization

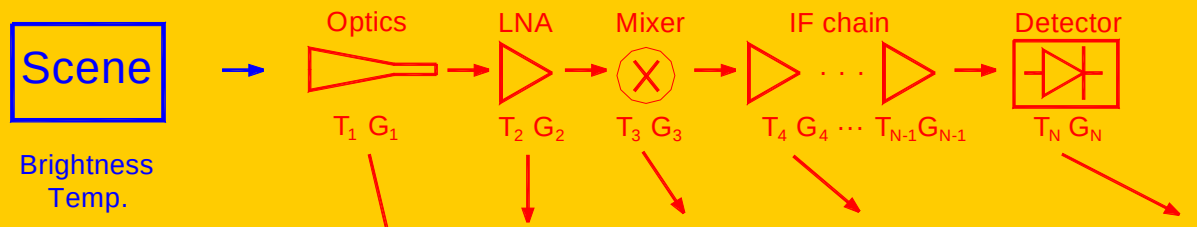
Receiver Thermal Stabilization



Calibration and Error Sources

ALL lossy receiver components should be thermally stabilized!

Receiver Noise Errors



$$T_{total} = T_B + \left(T_{sys} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \frac{T_4}{G_1 G_2 G_3} \cdots \frac{T_N}{G_1 \cdots G_{N-1}} \right)$$

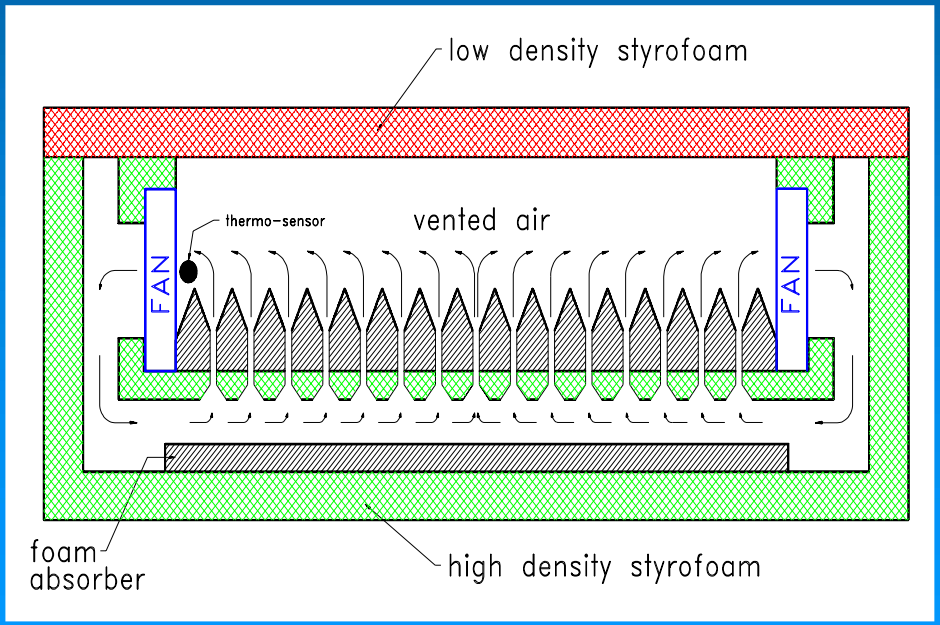
$$T_1 = T_{physical} \left(\frac{1}{G_1} - 1 \right)$$

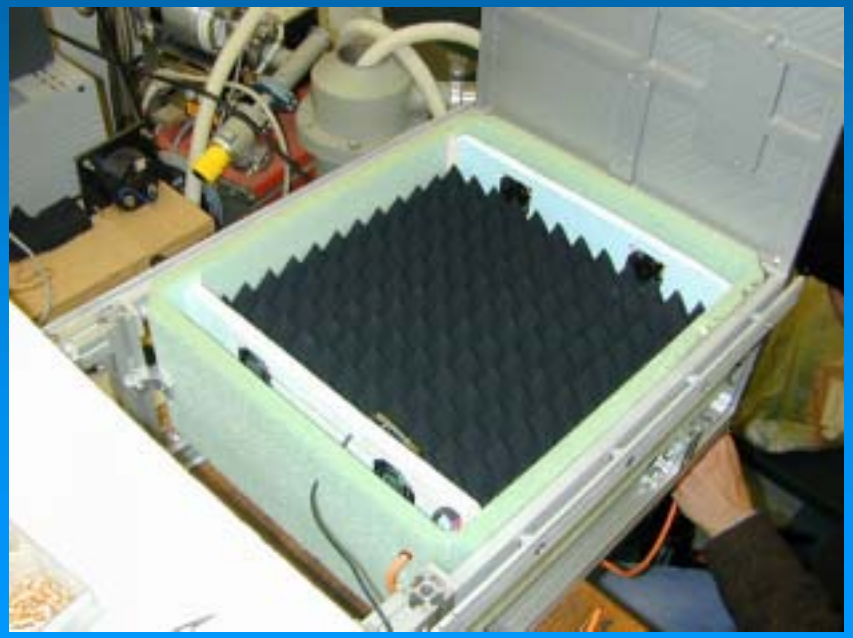
typical optical Losses:
G_1 = -1.0 dB = 0.8 (20%) → $\triangle T_{physical} = 10\ °C \Longrightarrow \triangle T_1 = 2.5\ °C$!!

Calibration and Error Sources

Ambient Temperature Calibration Target

- Cancellation of thermal gradients across the target in vertical and horizontal directions by venting
- Self-heating of temperature sensor avoided by airflow
- Precision calibrated temperature sensor

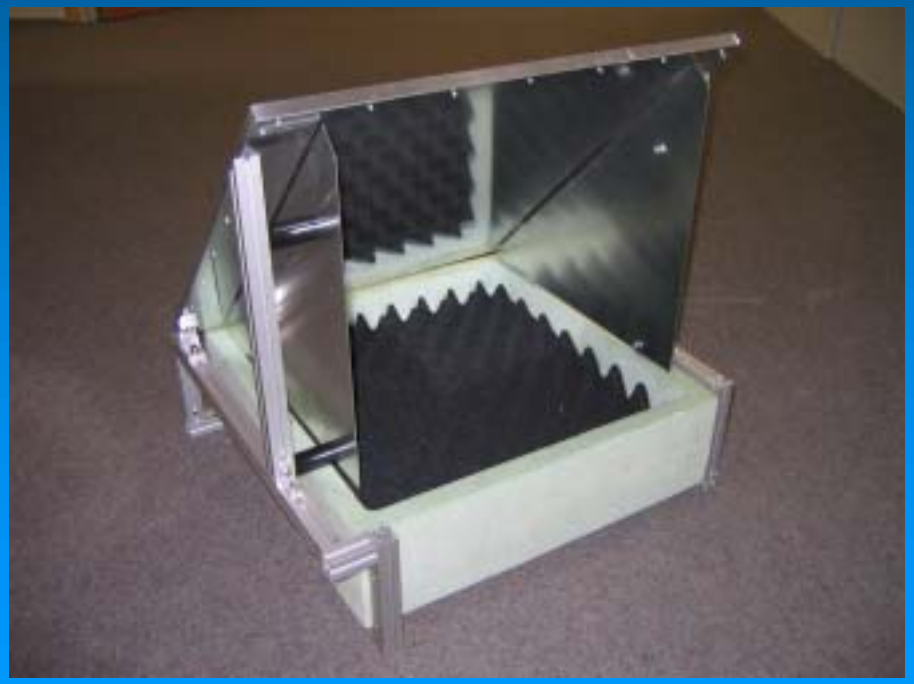




Calibration and Error Sources

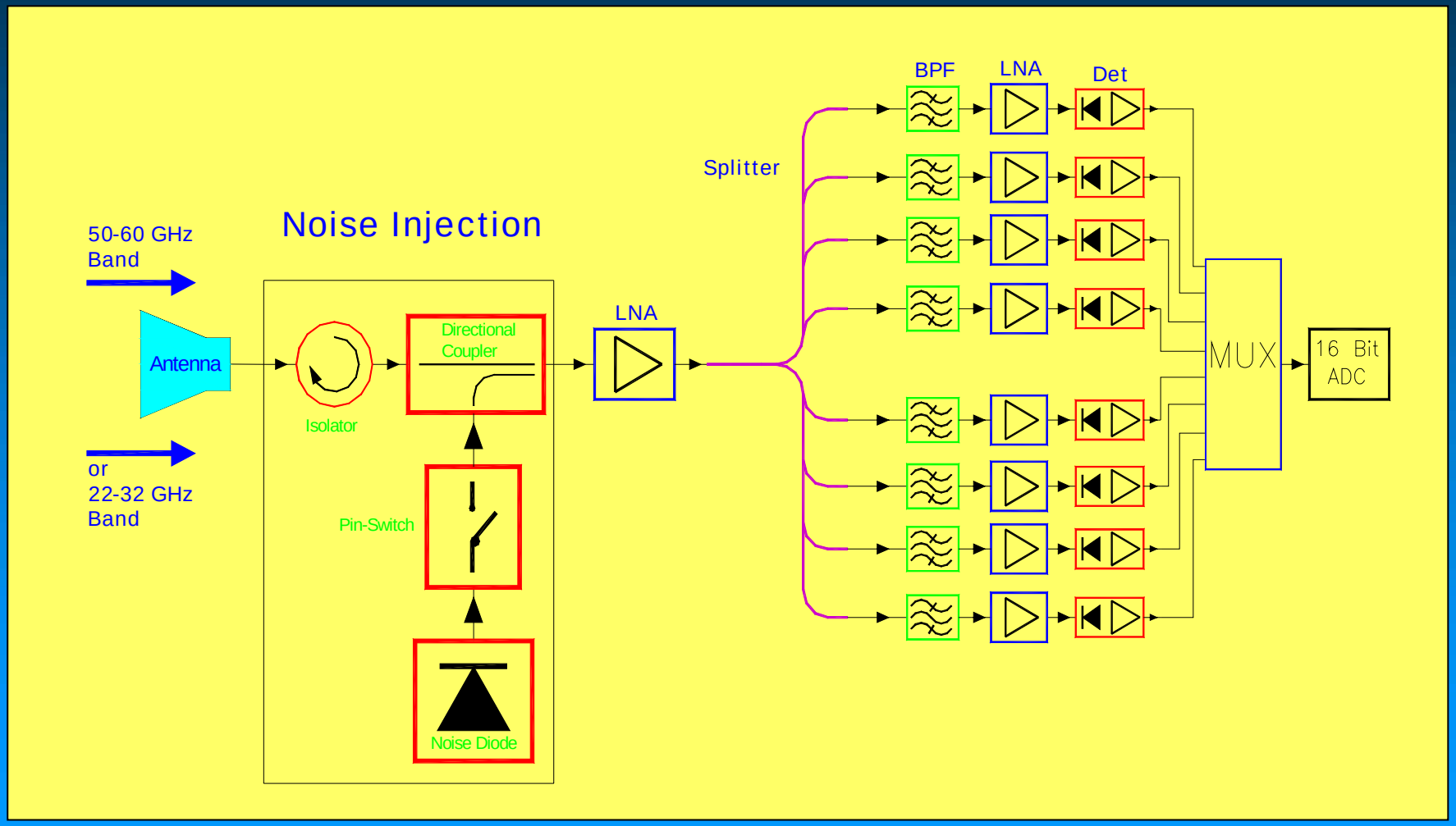
Liquid Nitrogen Cooled Calibration Target

- no humidity formation on styrofoam surfaces
- Calibration of reflector losses and reflection from liquid surface
- Barometric Pressure correction of boiling temperature



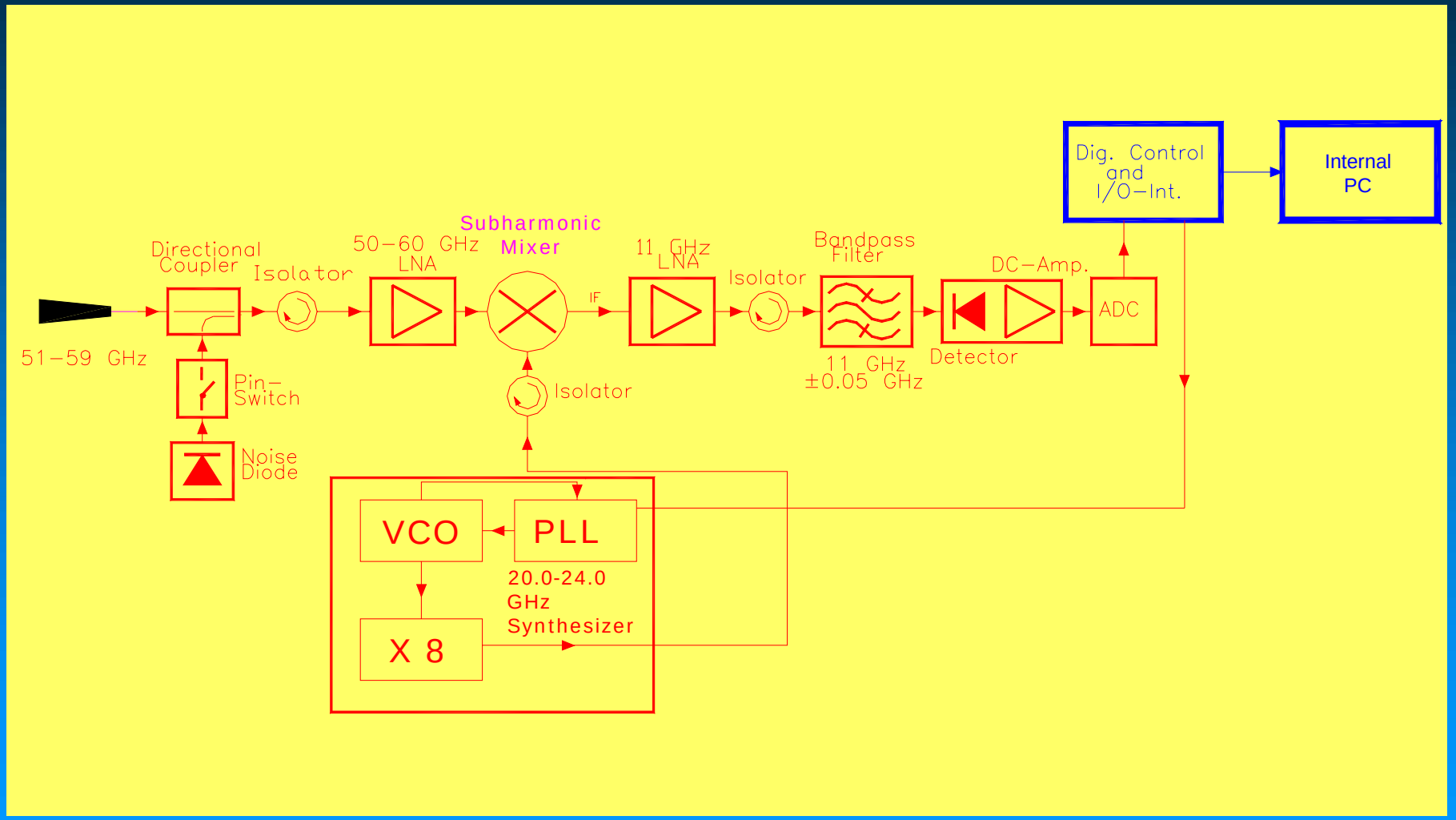
New HATPRO Receiver Design

Dual Profiler Direct Detection Filterbank Receivers based on MMIC Technology:



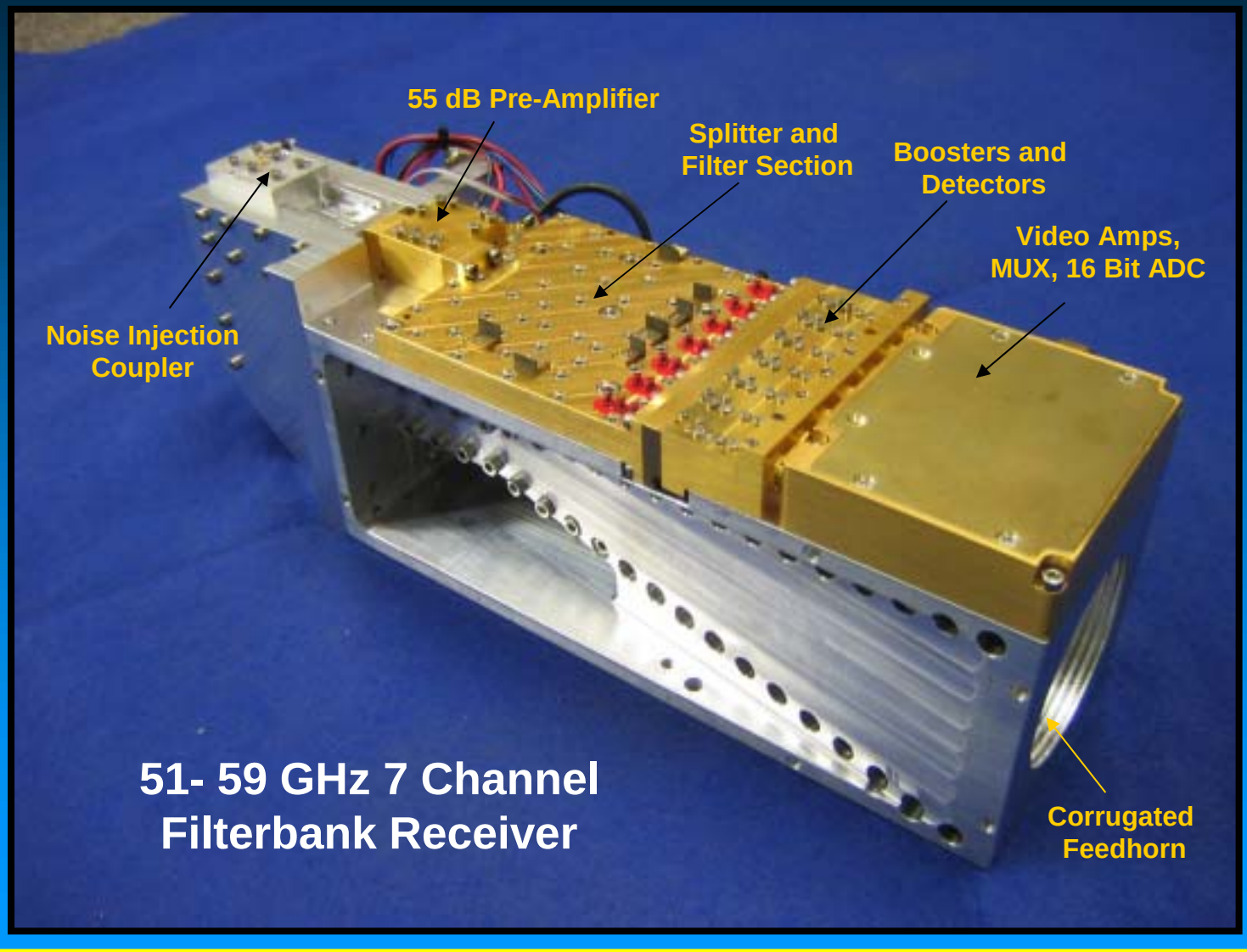
Conventional Frequency Sweeping

Based on Synthesizer sequential frequency sweeping ("Spectrum Analyzer"):



New HATPRO Receiver Design

Compact Layout



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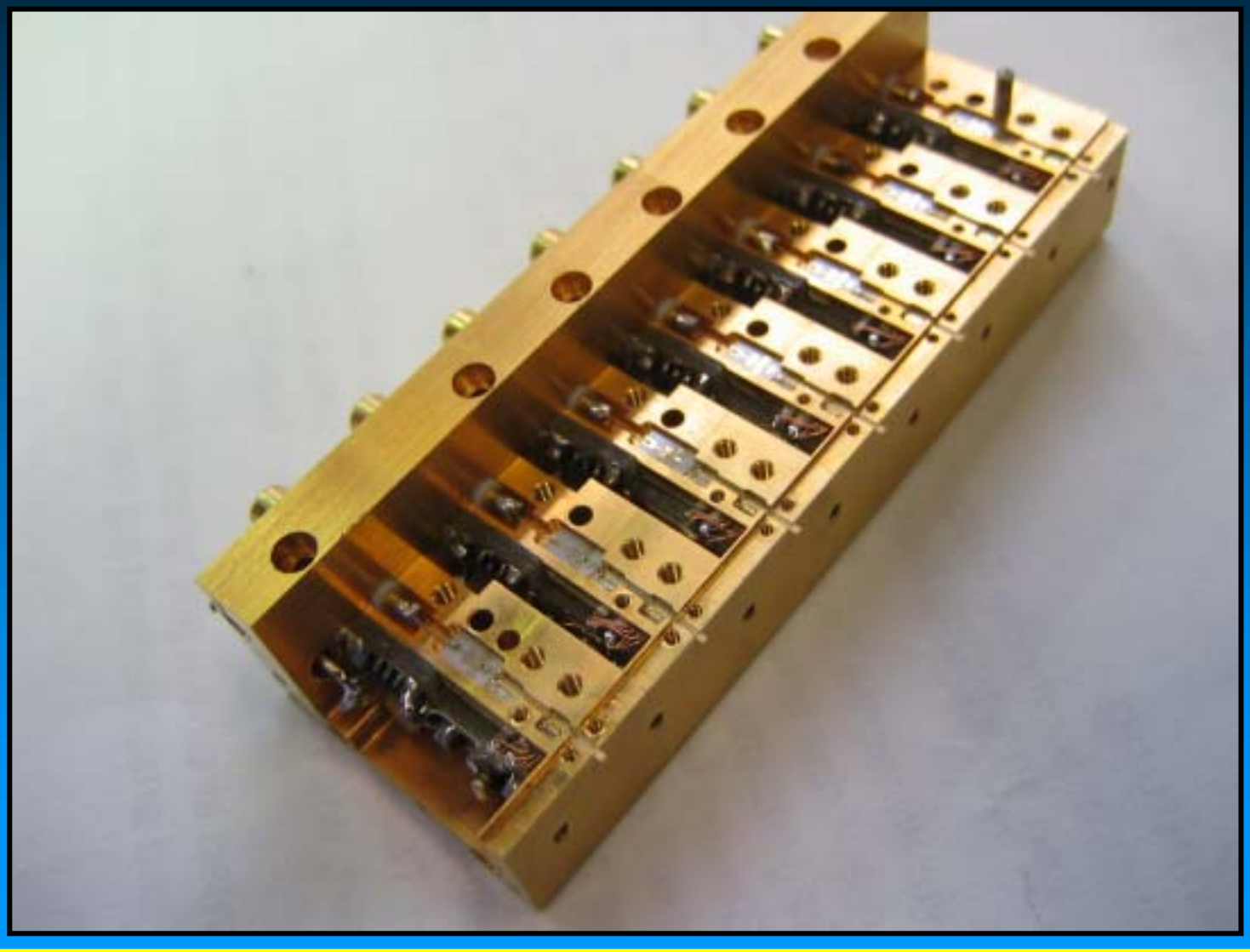
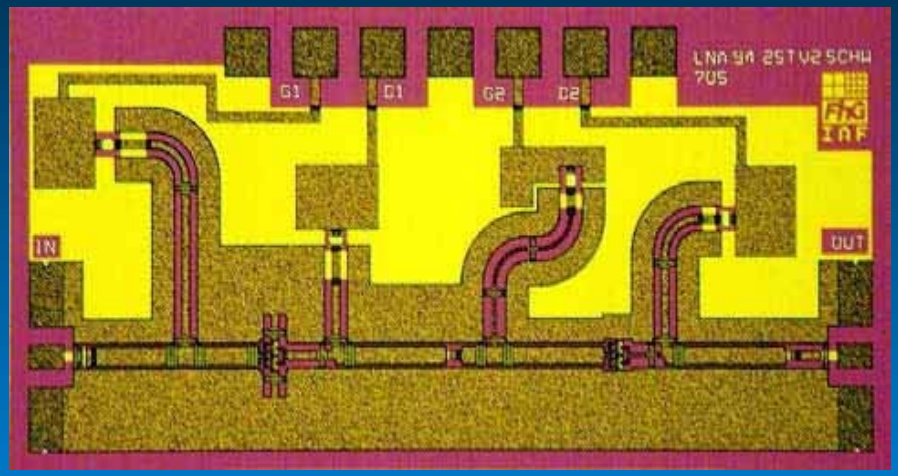
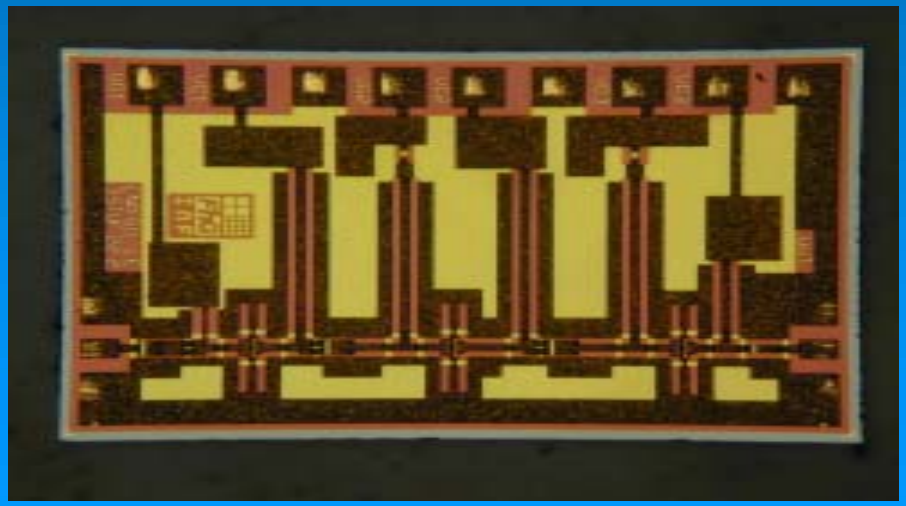


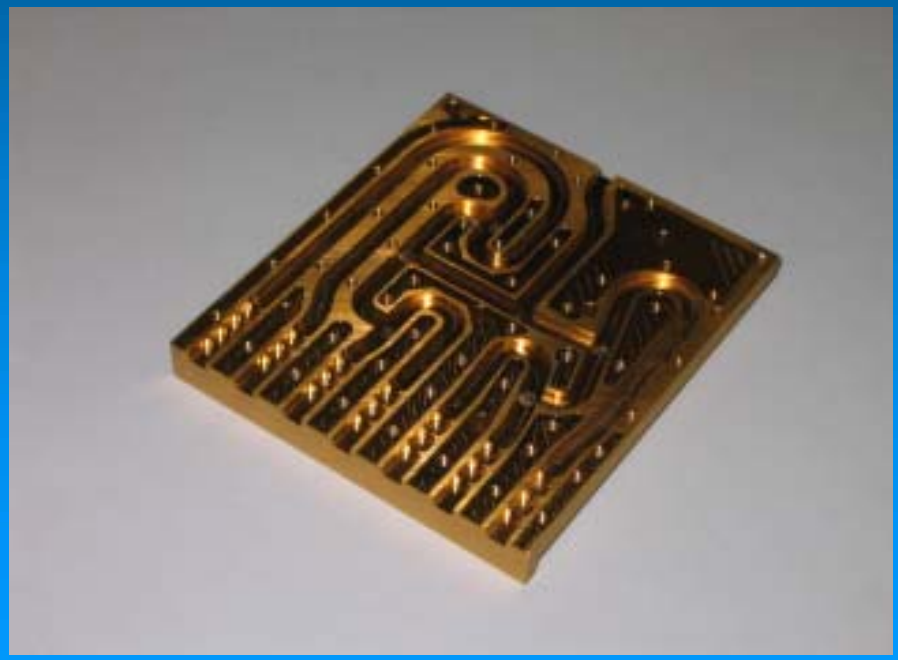
Direct Detection Receiver Components

45-65 GHz LNAs, 2.5 dB NF





Power Splitter + Bandpass-Filters



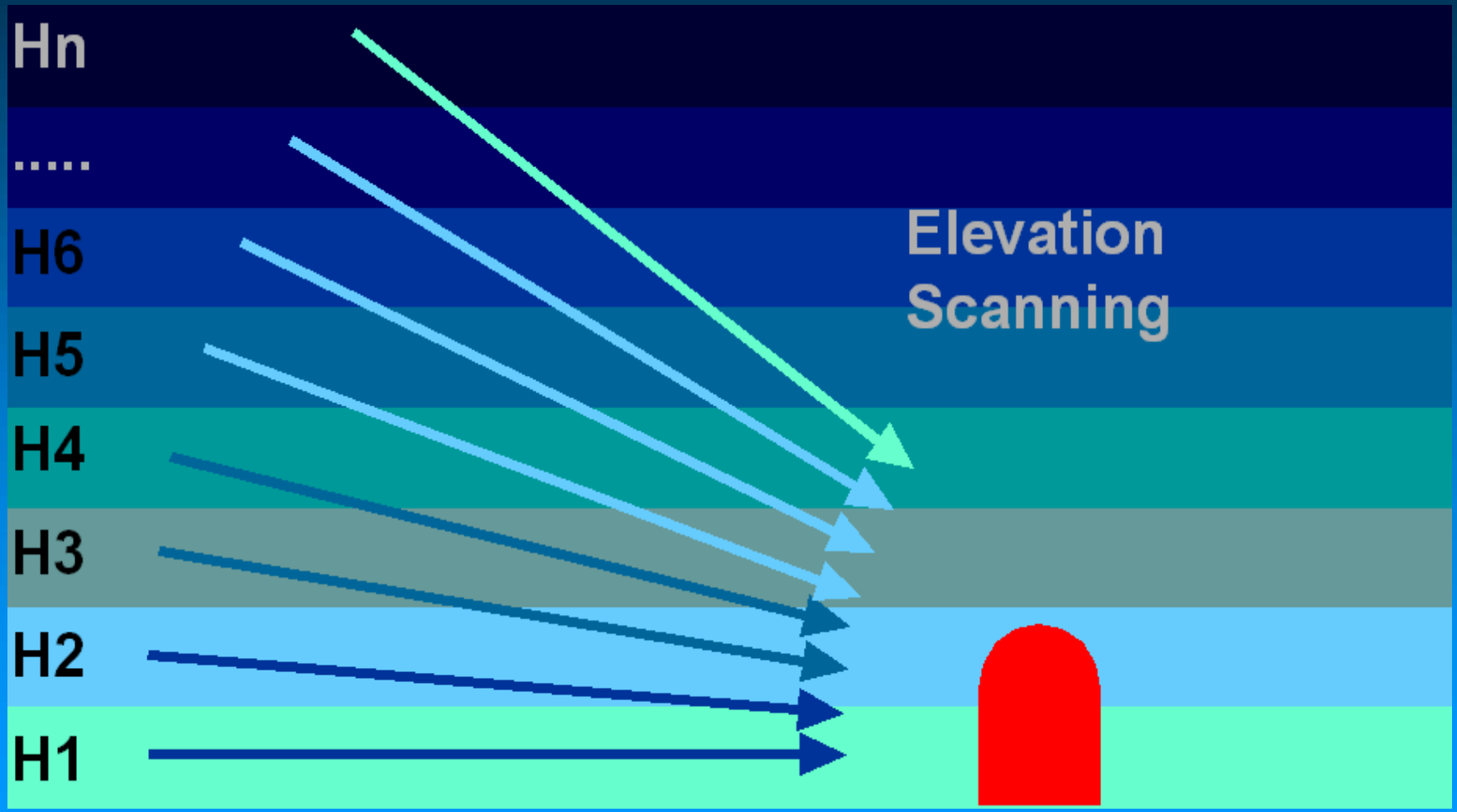
HATPRO Receiver Design

Summary of Benefits of Direct Detection Filterbank Design:

- Simultaneous measurements of all frequency channels
- Much higher temporal resolution for all products (LWP/IWV: 1sec, profiles: 20 sec) compared to single detection receivers
- 5 times faster calibration procedures than with sequentially scanning receivers
- Feasibility of individual channel bandwidth selection (important for boundary layer profiling). One broad band 58 GHz channel to give high radiometric accuracy for boundary layer profiling
- No mixer sideband filtering required, no LO drifts
- Reduced sensitivity to interfering external signals (mobile phones etc.) due to avoidance of frequency down conversion

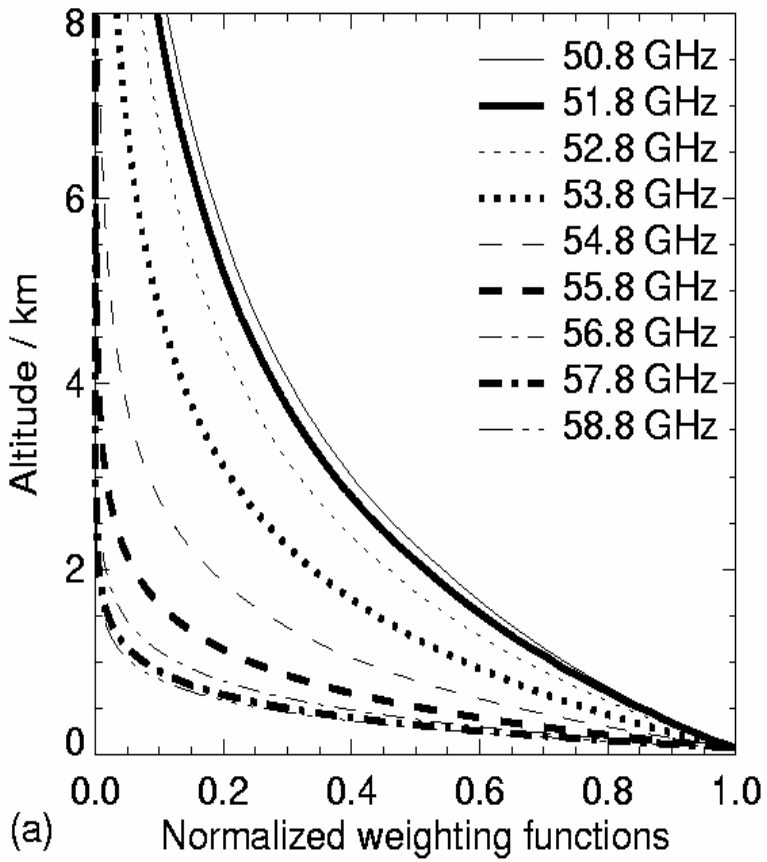
Accurate Boundary Layer Profiling

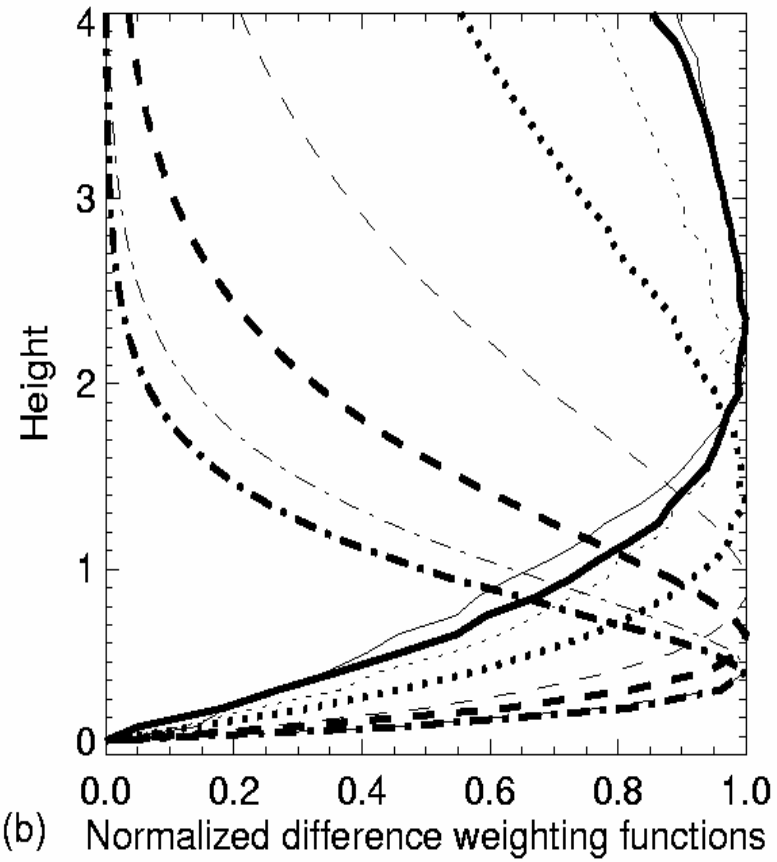
58/54.8 GHz Elevation Scanning



Accurate Boundary Layer Profiling

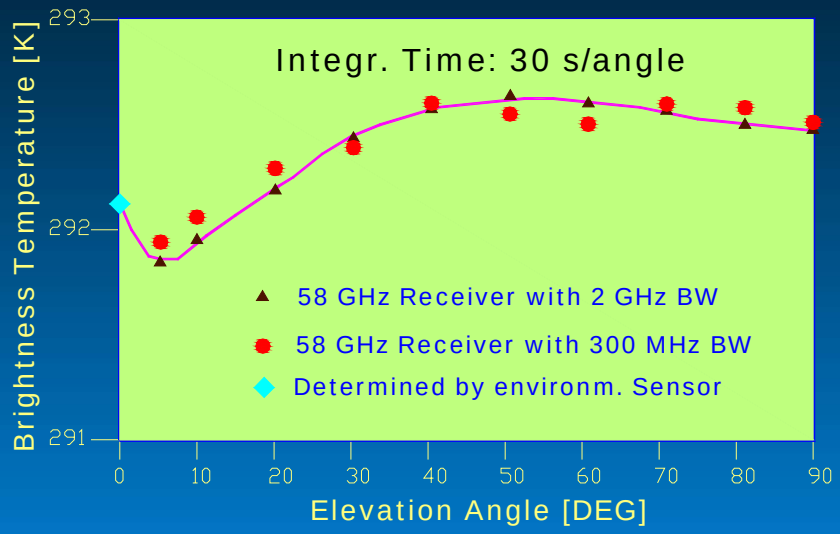
58/54.8 GHz is ideal for 0-1000 m range:

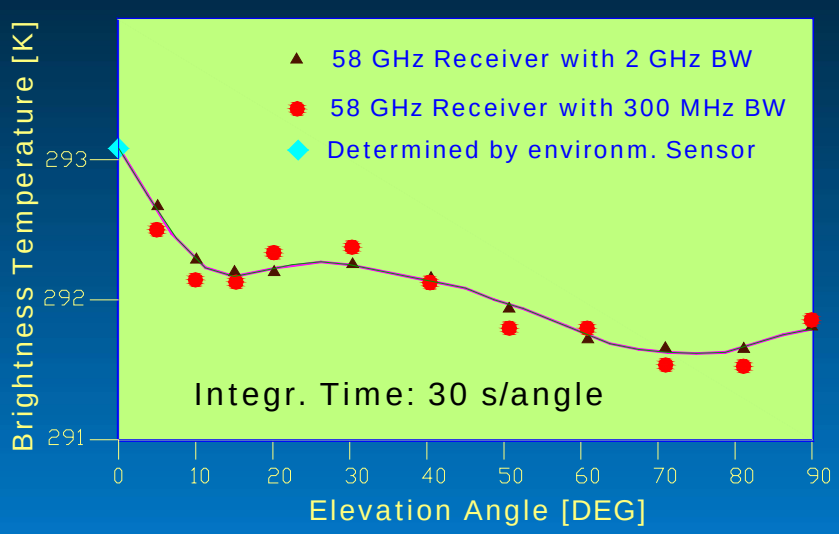


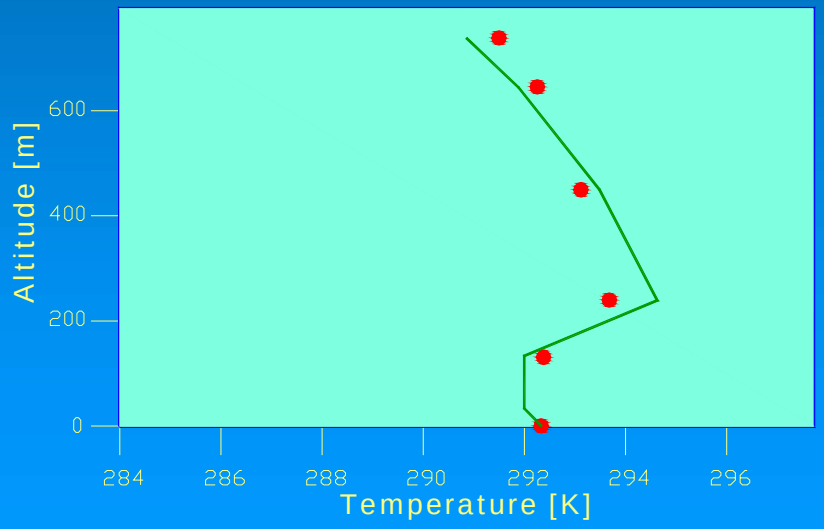


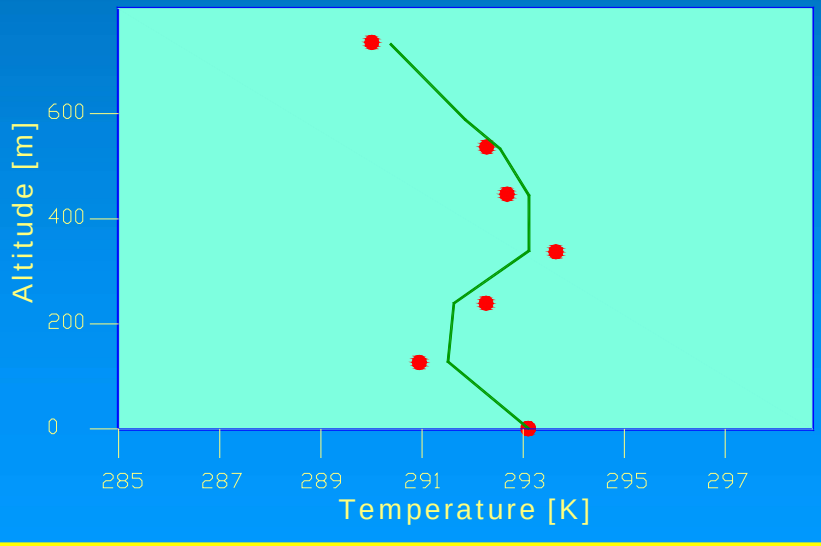
Boundary Layer Temperature Profiling

Influence of 58 GHz channel sensitivity

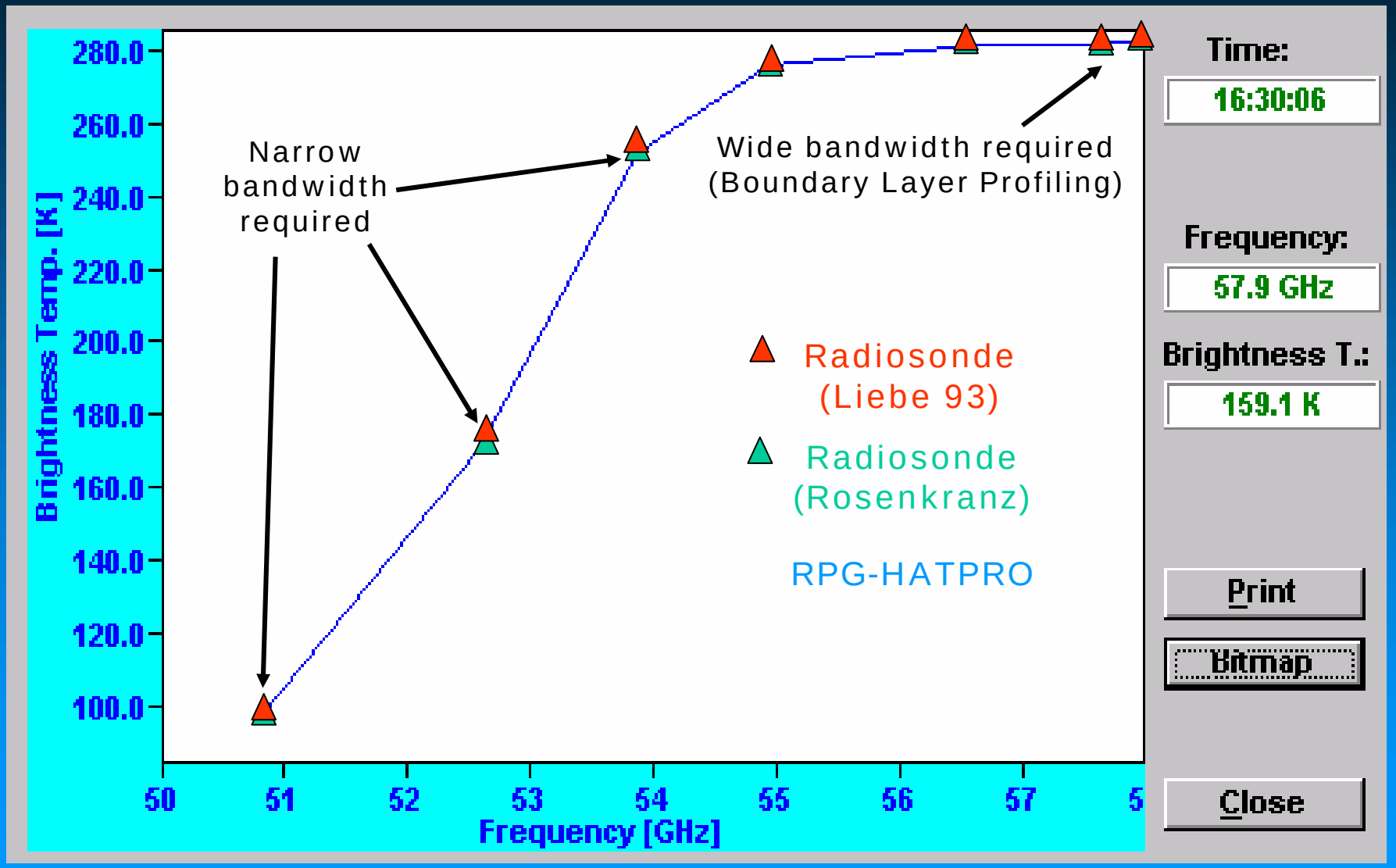








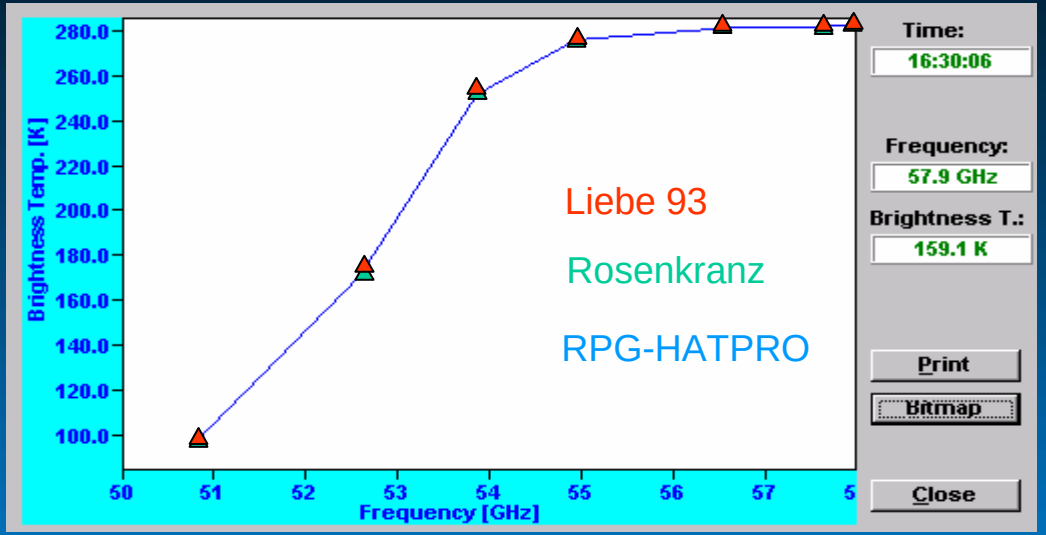
50-60 GHz Channel Bandwidth



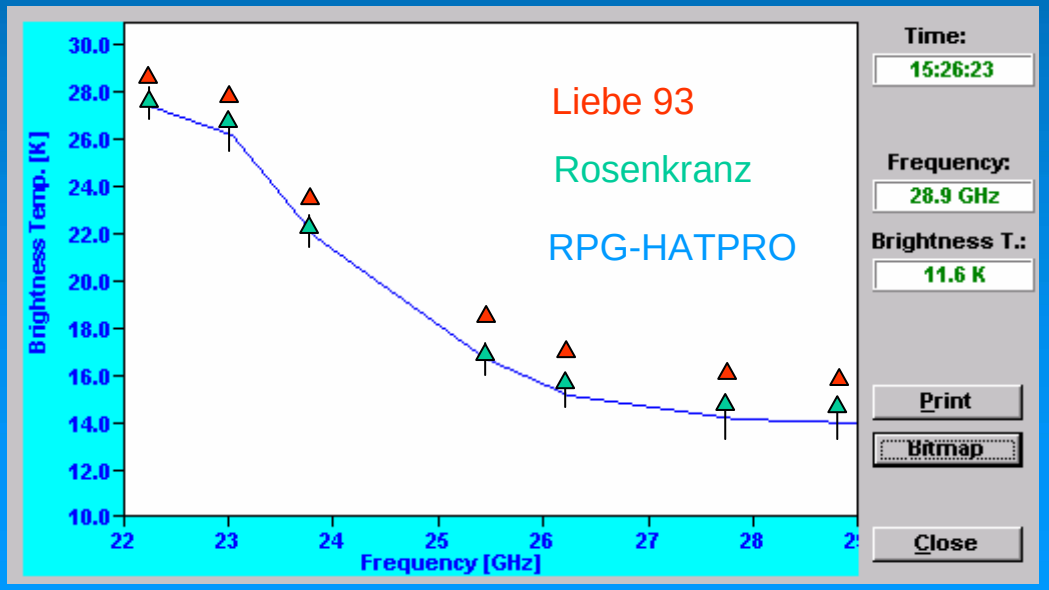
Verification with Radiosonde Data

BBC2 Measurement Campaign in Cabauw/NL (2.5.2003 – 23.5.2003)

Oxygen Line (Clear Sky)



Water Vapour Line (Clear Sky)

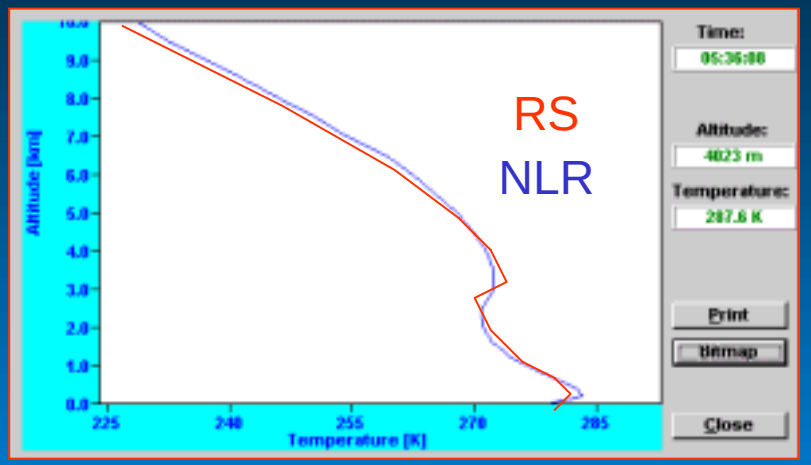


Verification with Radiosonde Data

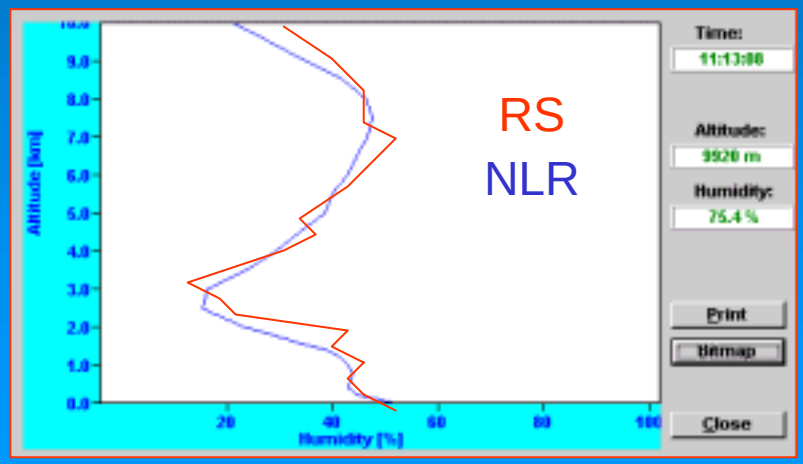
BBC2 Measurement Campaign in Cabauw/NL

Clear Sky Conditions

Temperature Profiles

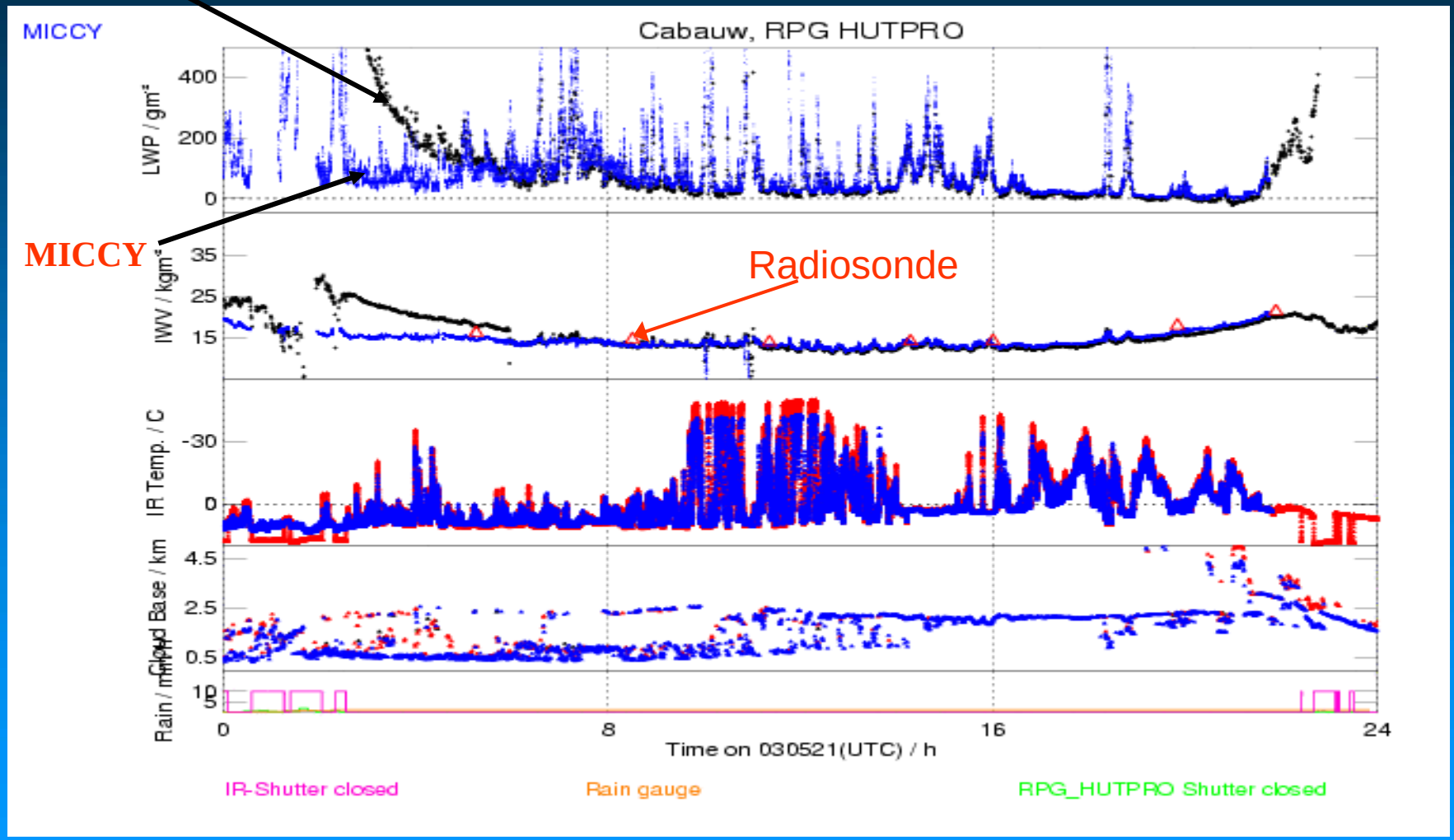


Humidity Profiles



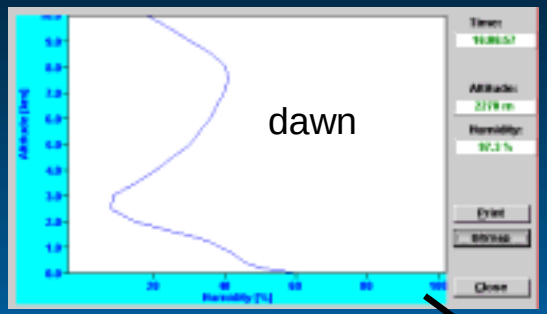
HATPRO LWP & IWV Charts

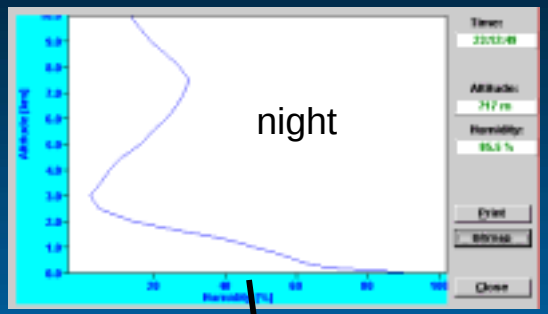
LWP-Time Series on 21 May 2003

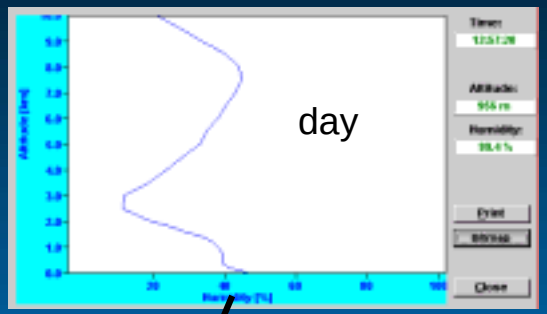


HATPRO Humidity Profile Charts

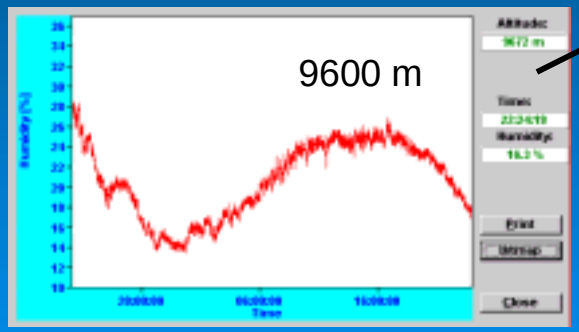
Humidity Profiles

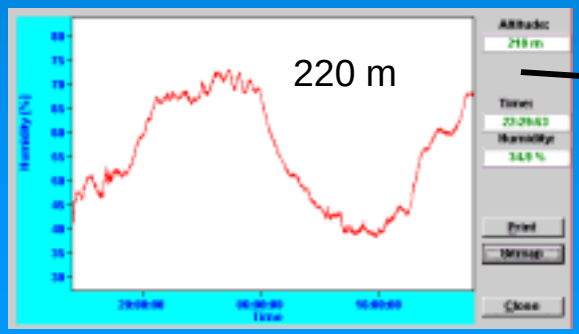


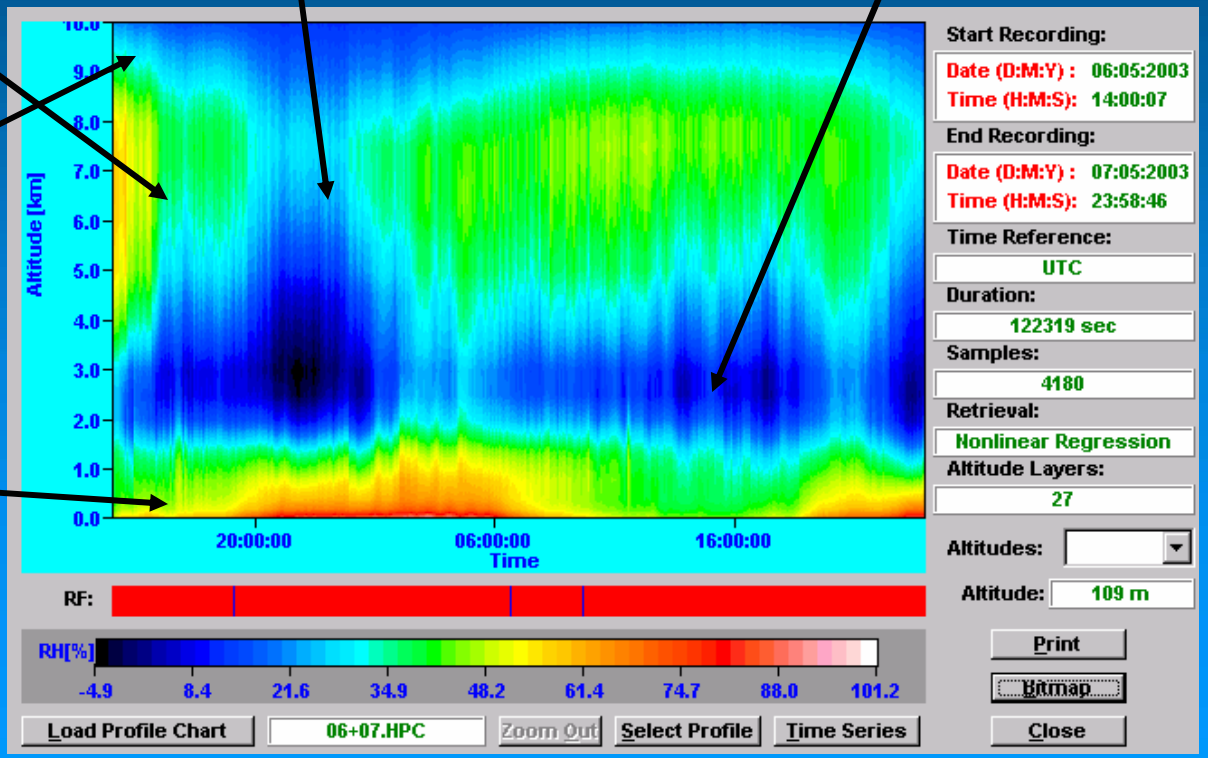




Time Series

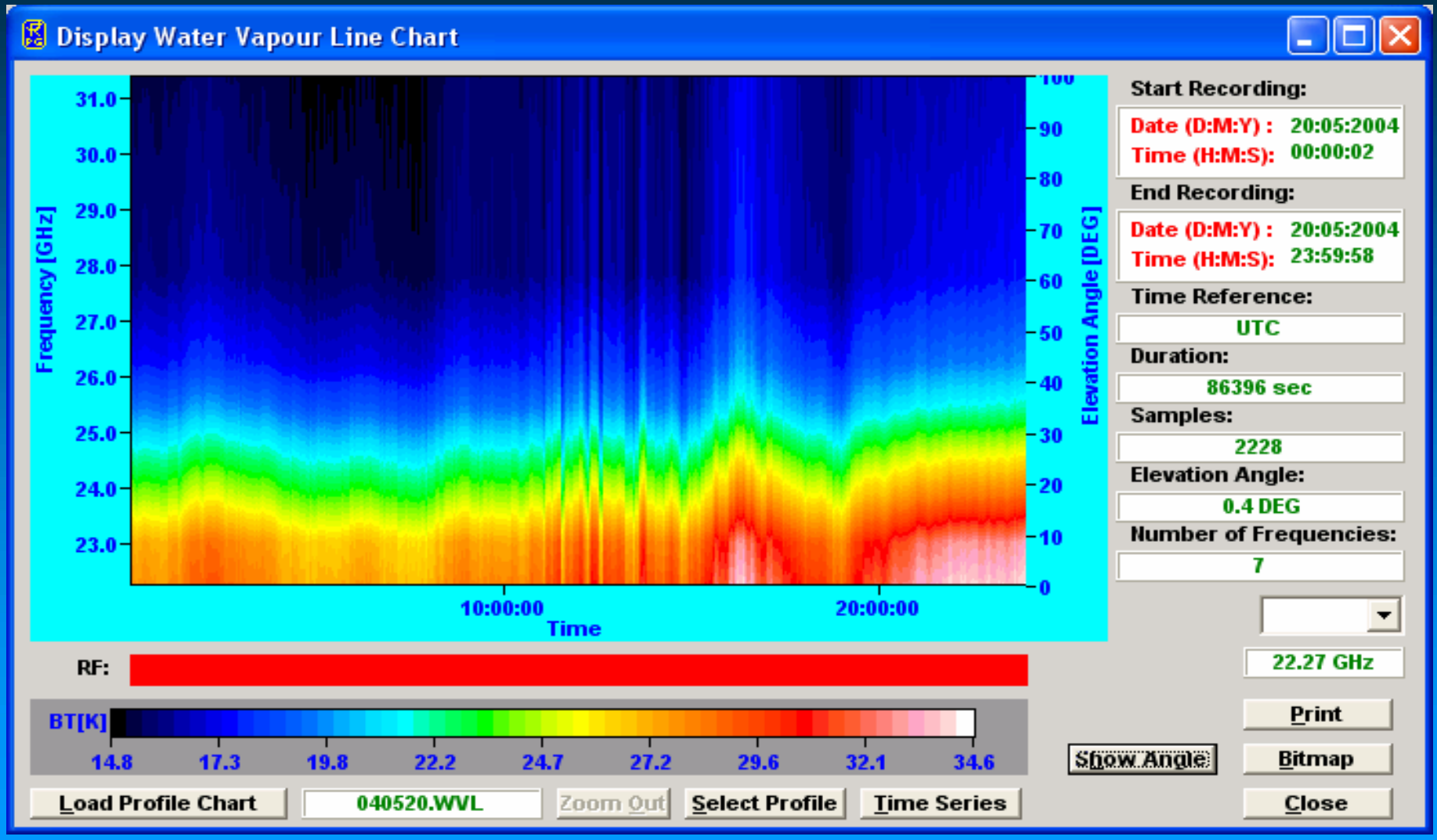






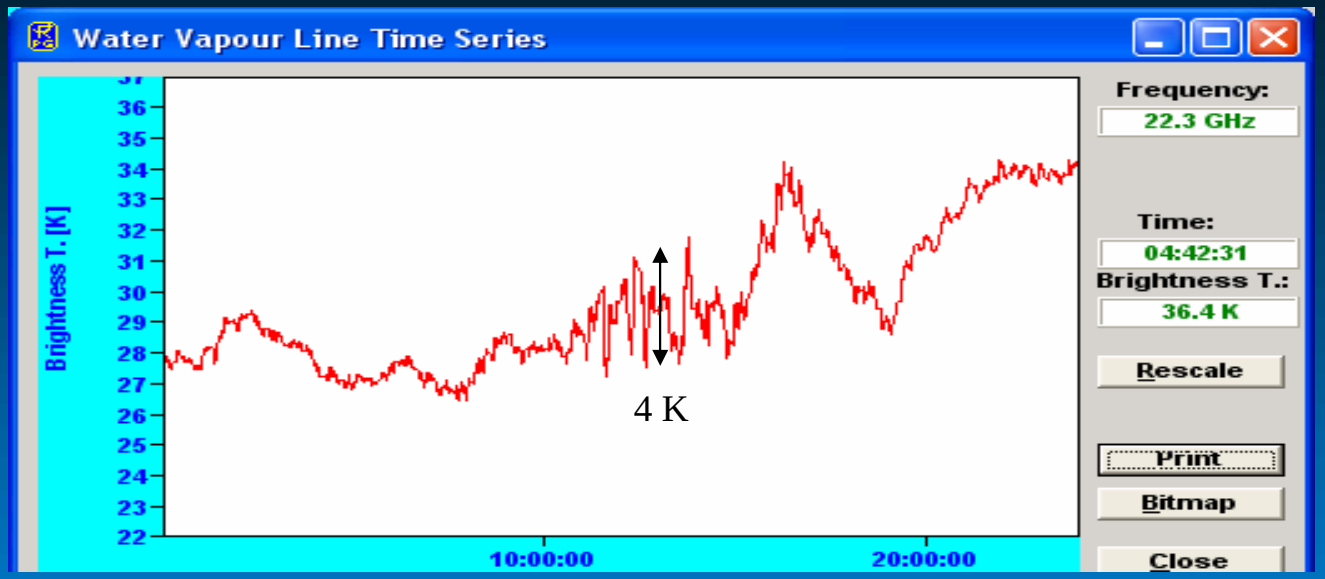
Humidity Fluctuations

VAPIC Campaign in Pallaiseau/France, May 2004

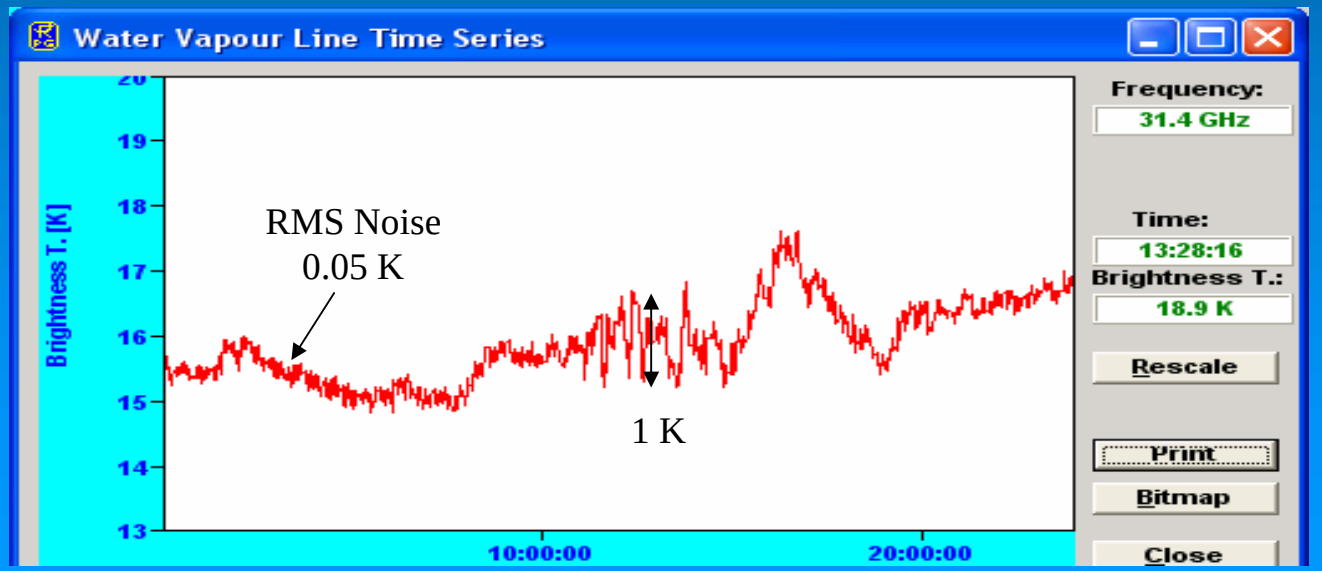


Humidity Fluctuations

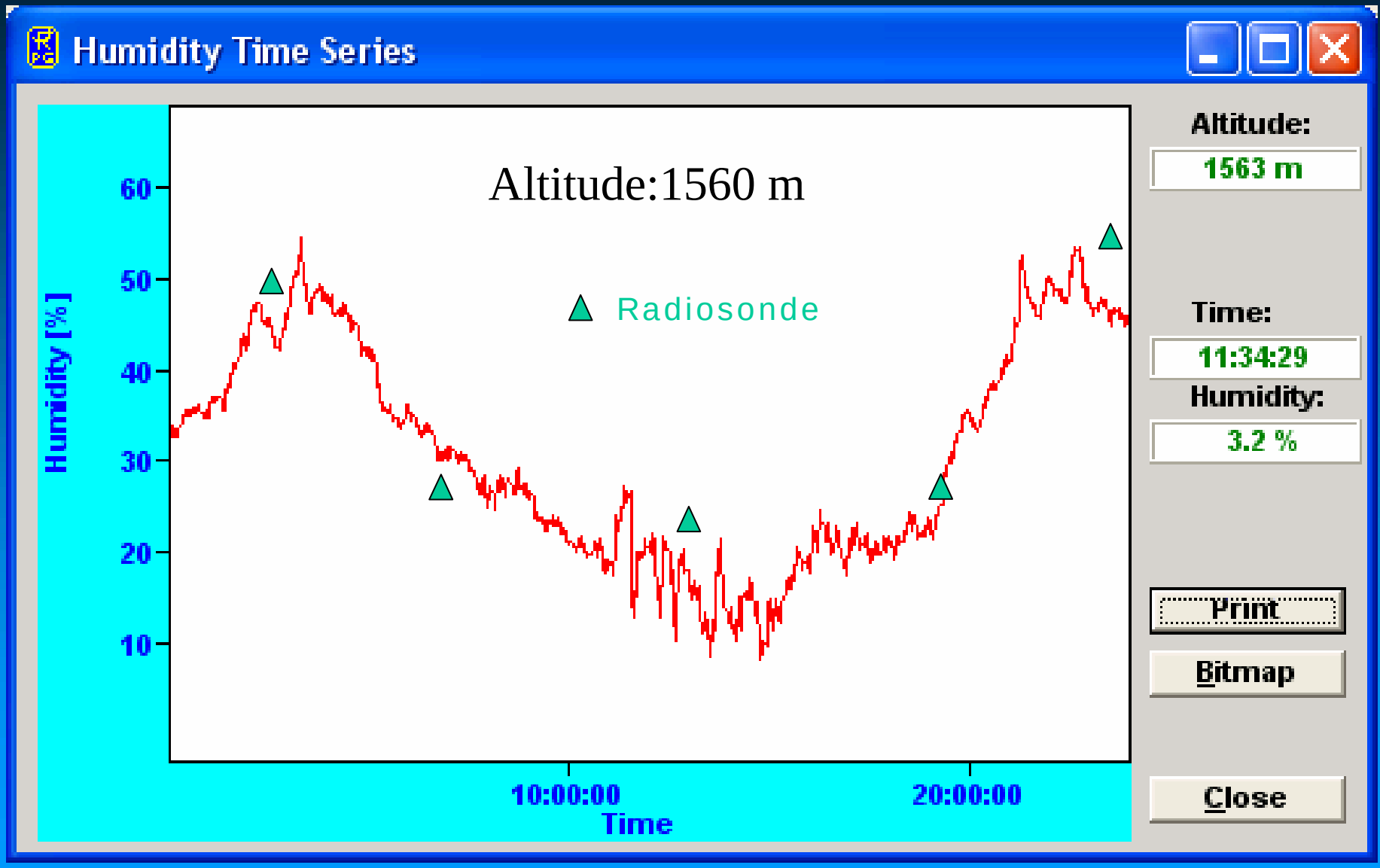
22.35 GHz



31.4 GHz

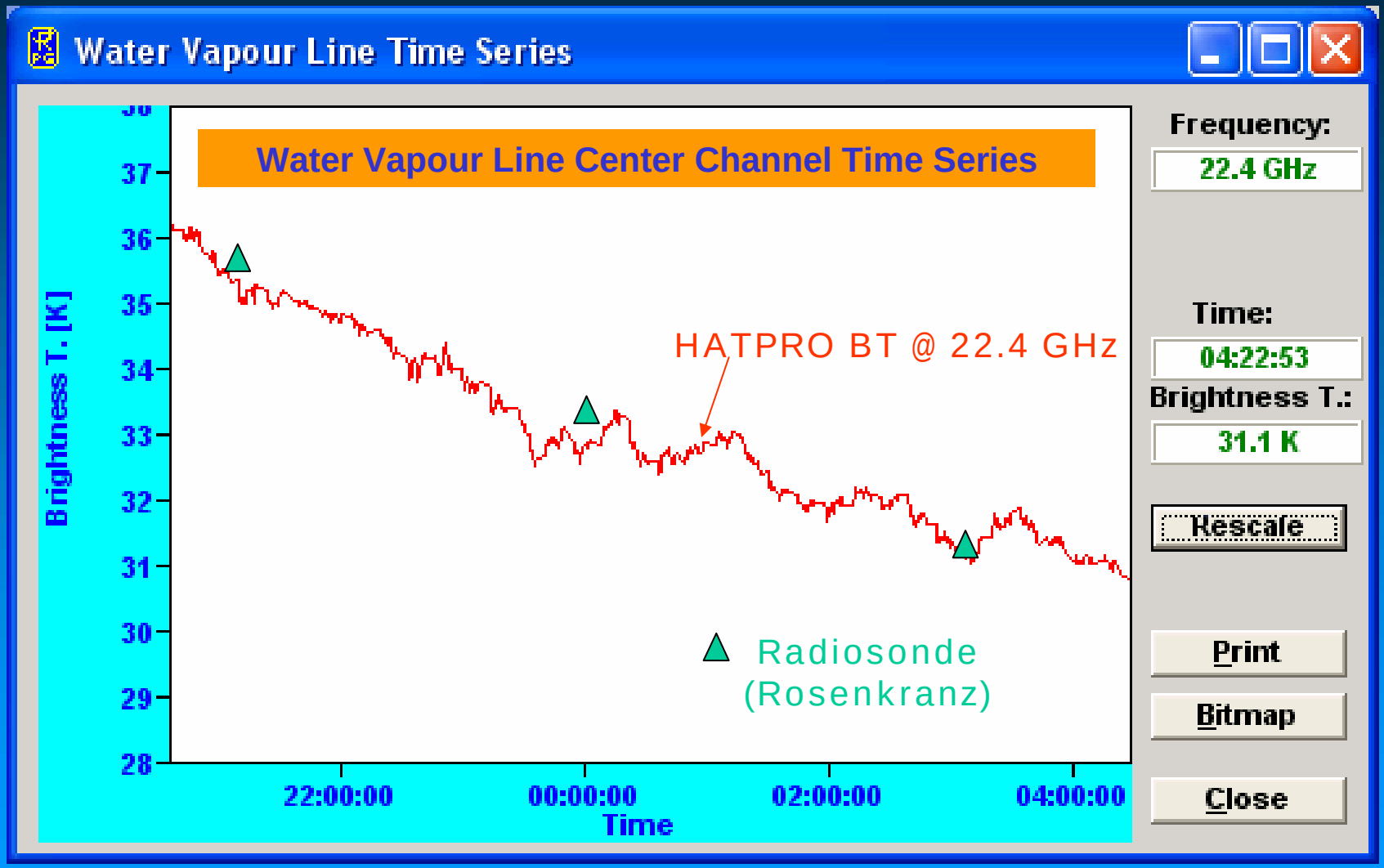


Humidity Fluctuations



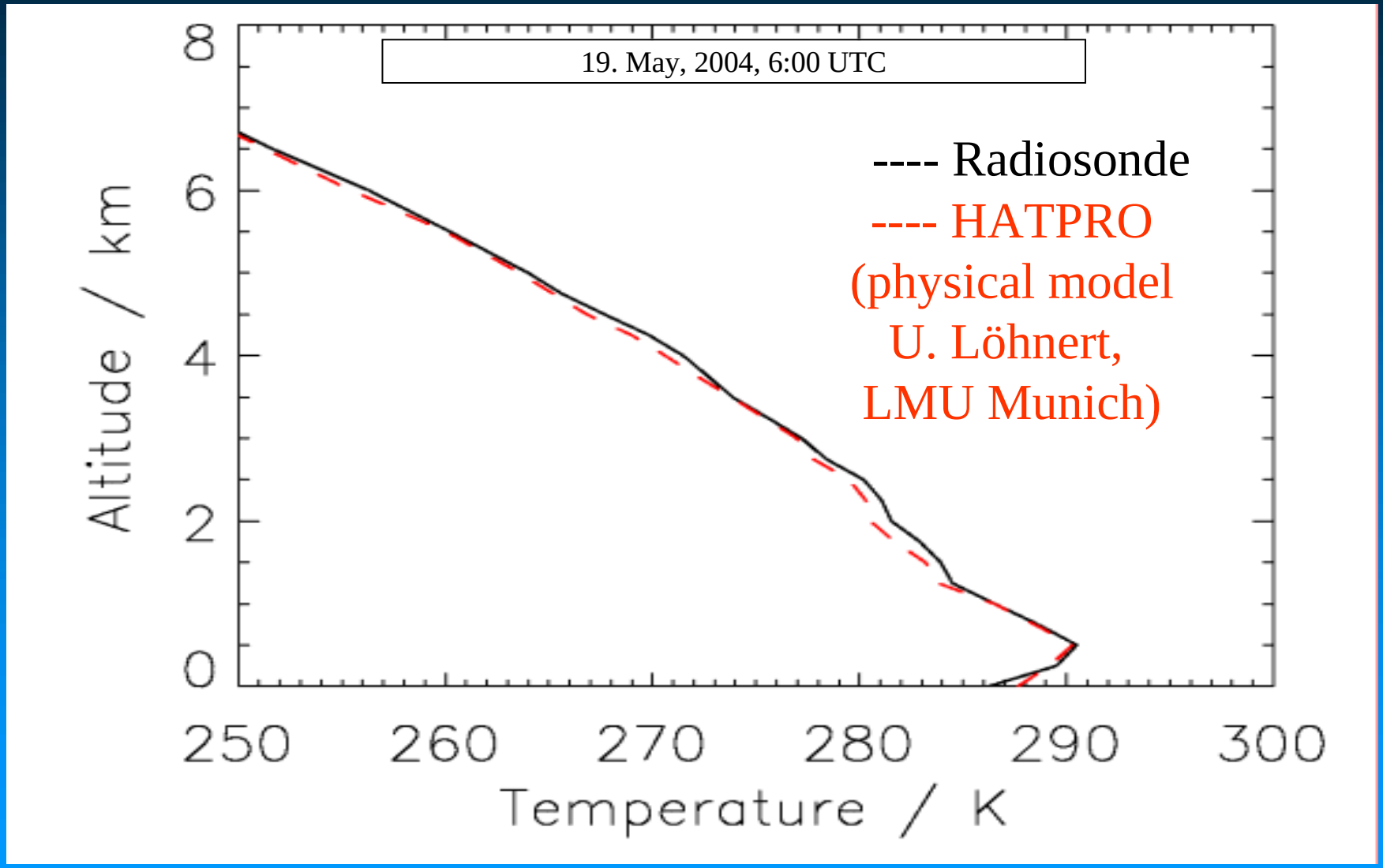
HATPRO Brightness Temp. Time Series

VAPIC Campaign in Pallaiseau/France, May 2004



Verification with Radiosonde Data

VAPIC Campaign in Pallaiseau/France, May 2004 (Clear Sky)



RPG Instruments for Atmospheric Remote Sensing

HATPRO Spin-Off Radiometer Models:

- **RPG-LWP:** **23.8 +31.4 GHz channels for LWP and IWV monitoring, Wet/Dry Delay** (available)
- **RPG-LWP-U:** **23.8 +31.4 + 90.0 GHz channels for improved LWP and IWV monitoring, Wet/Dry Delay** (available)
- **RPG-TEMP90:** **Tropospheric/Boundary Layer Temperature Profiler + 90 GHz channel** (available)
- **RPG-TEMPRO:** **Tropospheric/Boundary Layer Temp. Profiler** (available)
- **RPG-HUMPRO:** **Tropospheric Humidity Profiler, LWP, IWV, Wet/Dry Delay** (available)
- **RPG-HATPRO:** **Tropospheric/Boundary Layer Temp. Profiler + Tropospheric Humidity Profiler, LWP, IWV, Wet/Dry Delay** (available)
- **RPG-TEMP-BL:** **Boundary Layer Temperature Profiler based on 54.8, 58 GHz channels** (available)
- **(RPG-PRR):** **Polarized Rain Radiometer for Rain Remote Sensing, 19+37 GHz v/h Pol.** (under development, Nov. 2004)

Summary

- Direct Detection Filterbank Design offers superior performance for tropospheric and boundary layer profiling of atmospheric temperature
- High temporal and spatial resolution for LWP cloud observations
- 100% duty cycle for all channels
- Instrument optimized for operational networks in terms of maintenance level and operating temp. range
- Low Cost due to integrated receiver design

Detailed Instrument Description

Download of instrument manual available from:

www.radiometer-physics.com