Ground Based Microwave Sounding Radiometers:
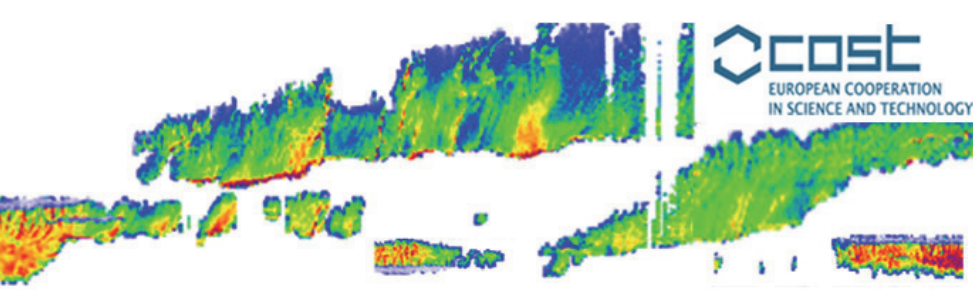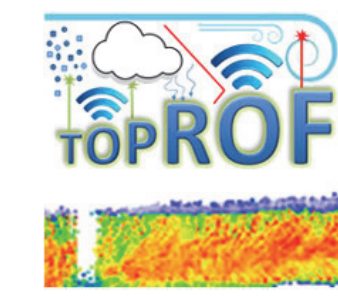## Noise Performance, Calibration, Quality Control, Data Formats for DA

Radiometer Physics
A Rohde & Schwarz Company

Harald Czekala, Gerrit Maschwitz, Emilano Orlandi, Thomas Rose [1]
Ulrich Löhnert, Susanne Crewell [2]
Nico Cimini [3] [4], **Francesco De Angelis** [4]

Introduction: RPG-HATPRO-G5 - Humidity And Temperature PROfiler („Sounder")

Direct Detection Filter-Bank Design
7 channel water vapour band (22 to 31.4 GHz)
7 channel oxygen band (51 to 58 GHz)
All channels parallel @1s res. (100% duty cycle)

Individual Band-Passes
200 MHz – 2000 MHz
→ optimized TB sensitivity

Network Suitable
TCP/IP interface, internal monitoring, house-keeping data, sanity checks, automatic alerts
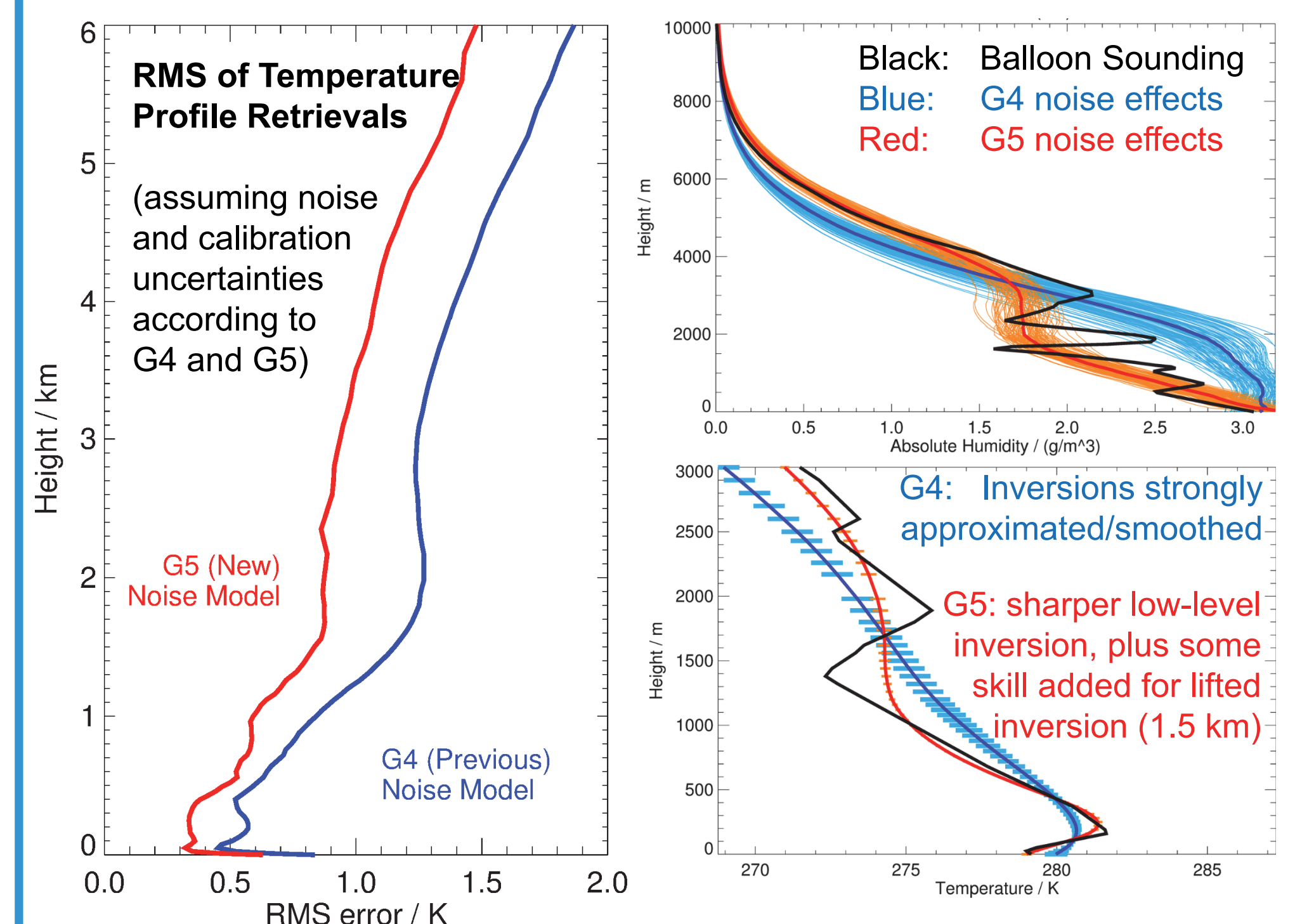
Standardization Efforts
Within COST action TOPROF: Joint calibration campaigns (JCAL), format requirements, forward operator (RTTOV-gb), O-B statistics
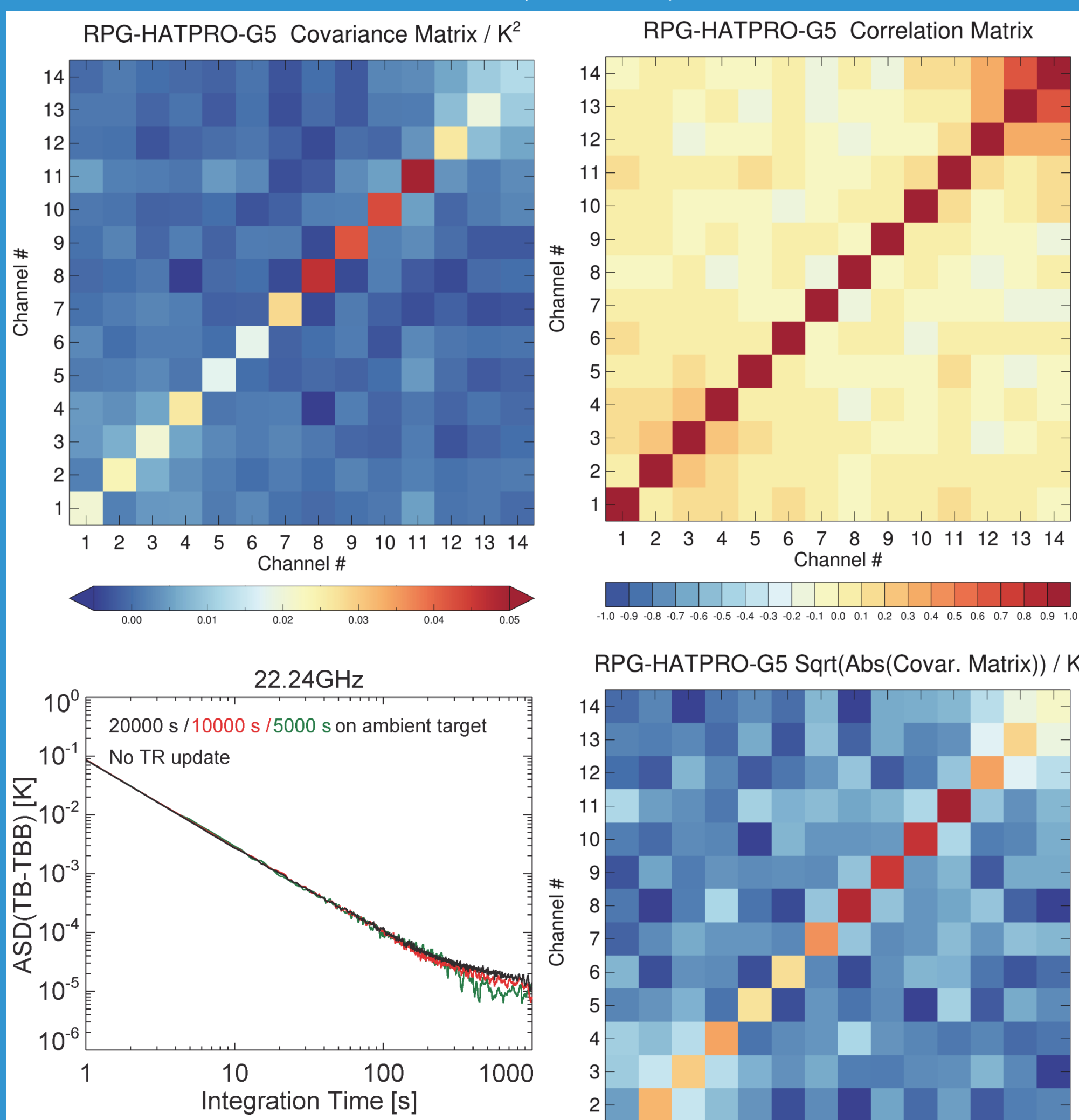

7 channel V-band filter-bank

HATPRO V-band Receiver
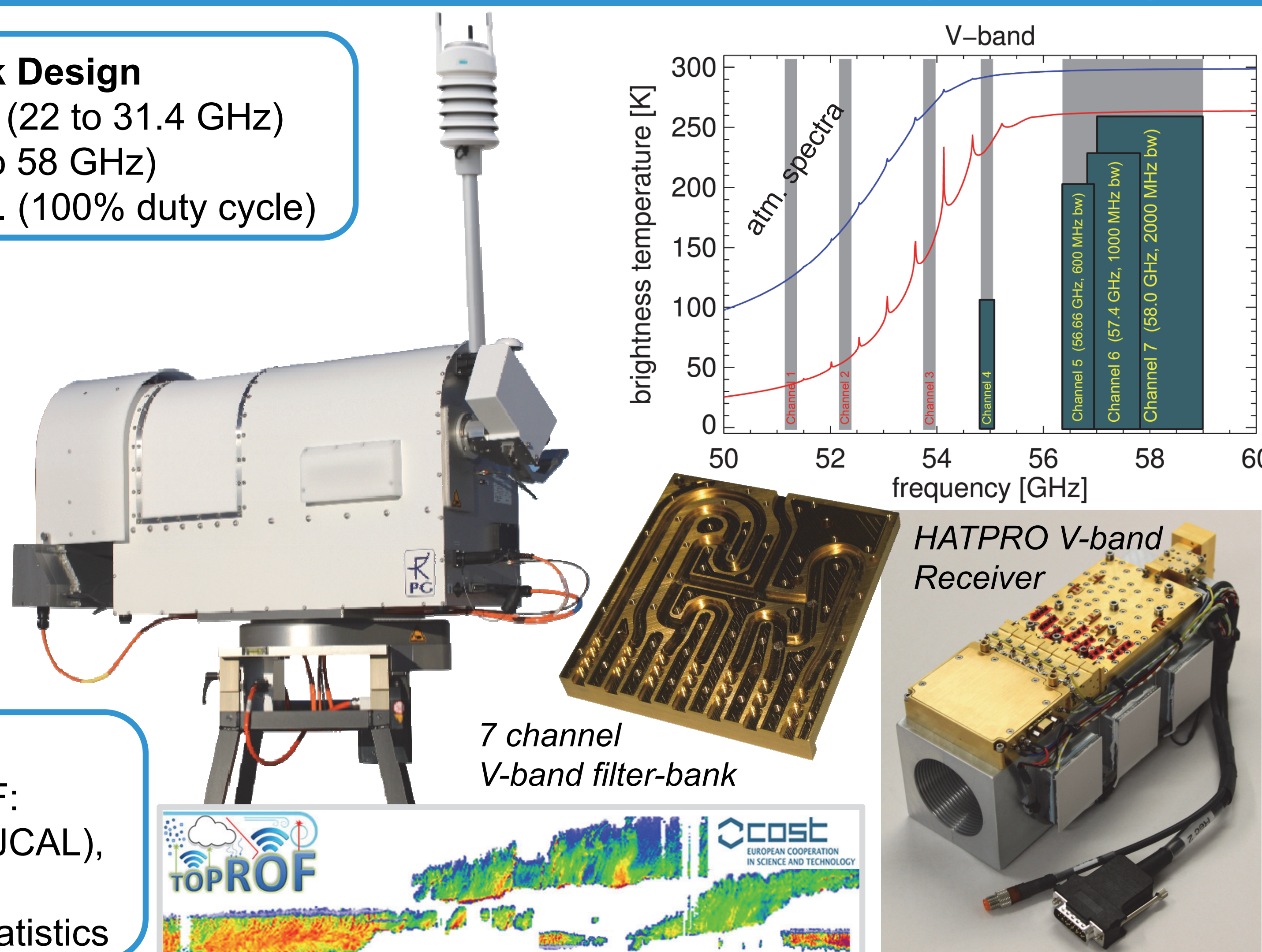
Generation 5 (G5) Improvements

- 40 times higher data sampling rate
- Rapid noise switching (64 Hz) at all channels
  - → Improved noise performance ($\leq$0.05 K RMS @10s integration time)
  - → Improved radiometric stability
  - → retrievals profit in RMS (plus added features)

RMS of Temperature Profile Retrievals
(assuming noise and calibration uncertainties according to G4 and G5)

G5 (New) Noise Model
G4 (Previous) Noise Model

Black: Balloon Sounding
Blue: G4 noise effects
Red: G5 noise effects

G4: Inversions strongly approximated/smoothed
G5: sharper low-level inversion, plus some skill added for lifted inversion (1.5 km)

Receiver Covariance, RMS, Allan Std.-Dev.

RPG-HATPRO-G5 Covariance Matrix / K²
RPG-HATPRO-G5 Correlation Matrix

22.24GHz
20000 s / 10000 s / 5000 s on ambient target
No TR update

RPG-HATPRO-G5 Sqrt(Abs(Covar. Matrix)) / K

Analyse time series of TB:
- Collected on cold load
- Collected on hot load
→ Test systems, provide input for forward-model


Automatic Quality Checks → Blacklisting

Using spectral retrieval $TB_{INS} = f(TB_{measured})$
- Calculate instrument's TB_{INS} spectrum using
  - Finite band-passes (integrate TB within filter)
  - Finite beam effects
  - Covariance and calibration errors
- Deviations (measured TB versus INS-spectrum):
  - → **problem with hardware or model statistics**
- **Automatic checks in server software**

Side-by-Side comparison at 1 s sampling
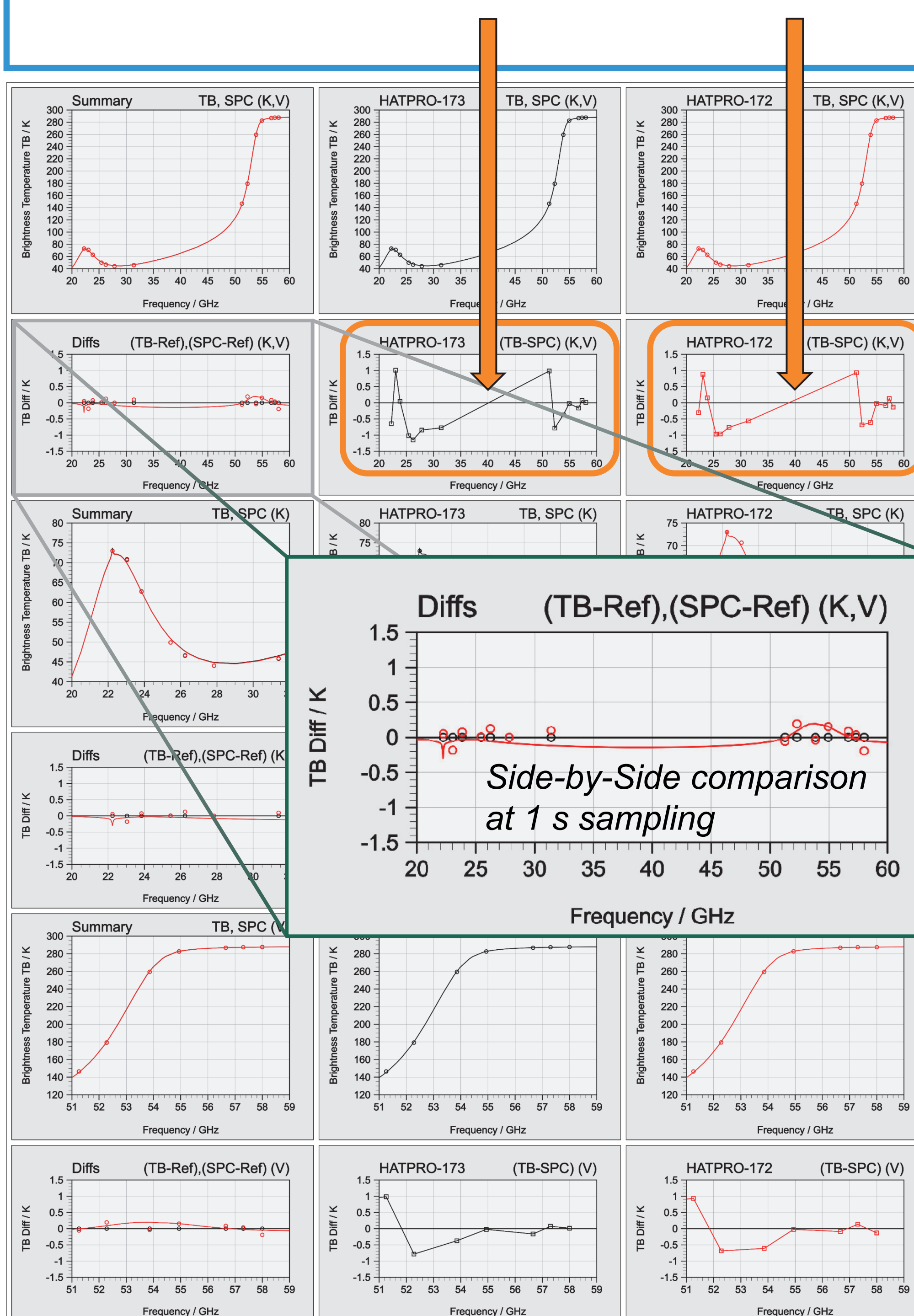
G5 Calibration Procedures

G5 receivers require more precise calibration

- New design for cold calibration (liquid nitrogen) target
- → No reflections at target
- → No standing waves
- → Minimized evaporation of LN2
- → Minimized entrainment of oxygen
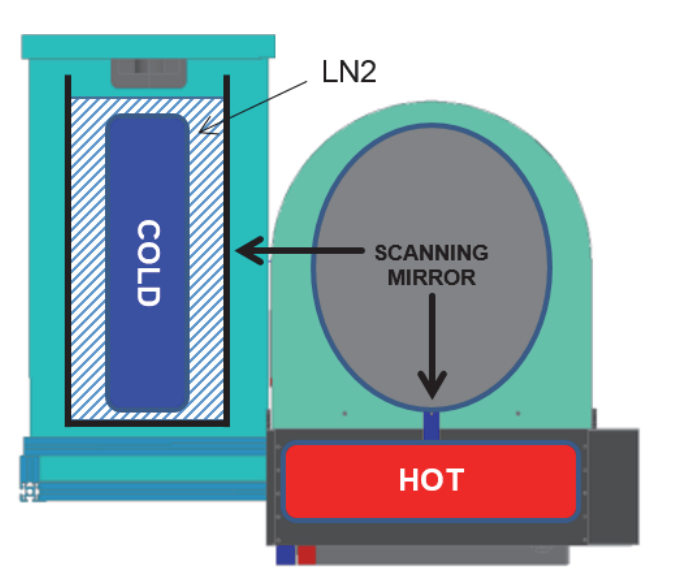
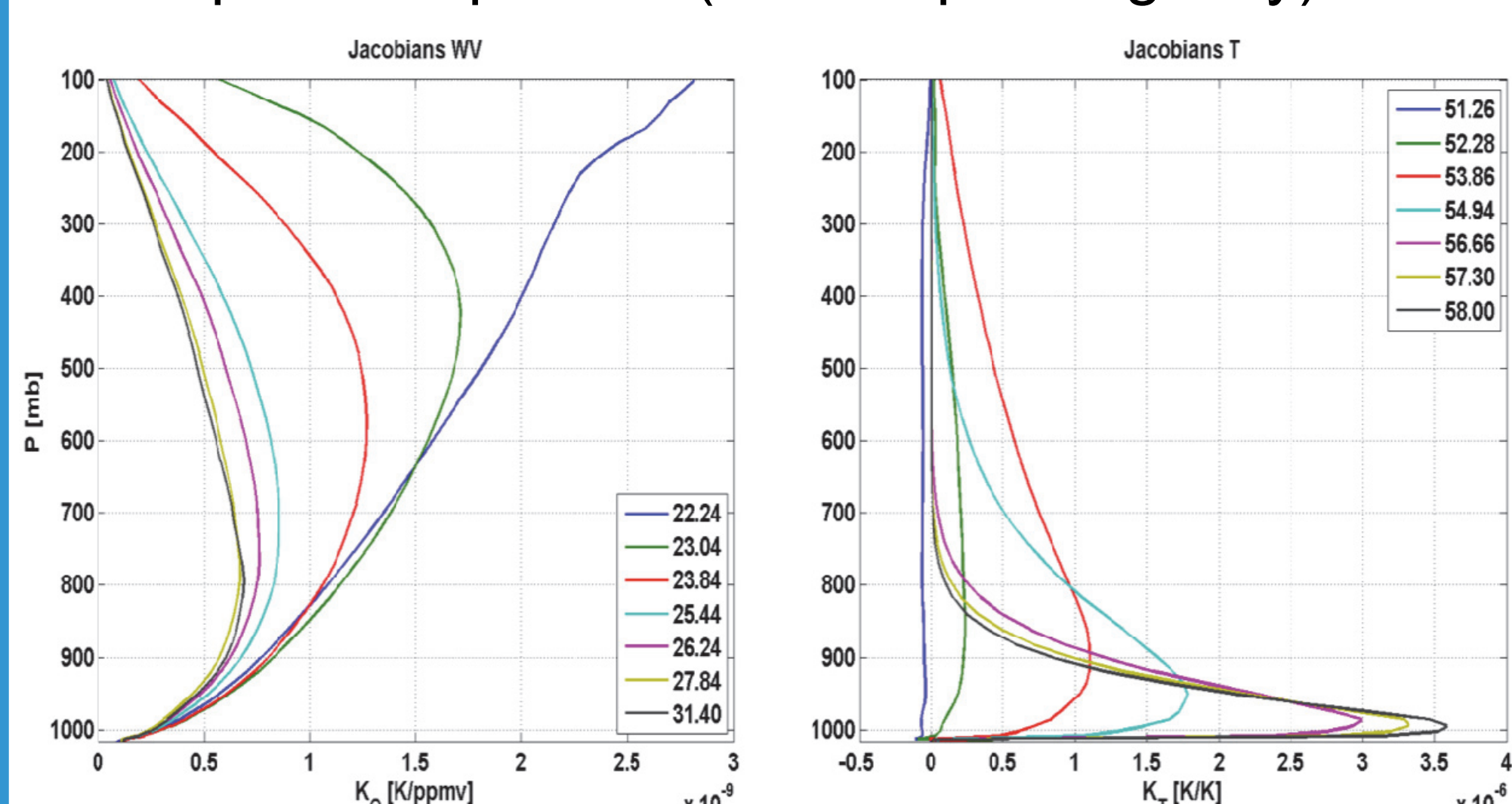**Absolute TB Accuracy / Repeatability ±0.15 K**

Forward Operator: RTTOV-gb

Triggered by COST-TOPROF, adaption of RTTOV:
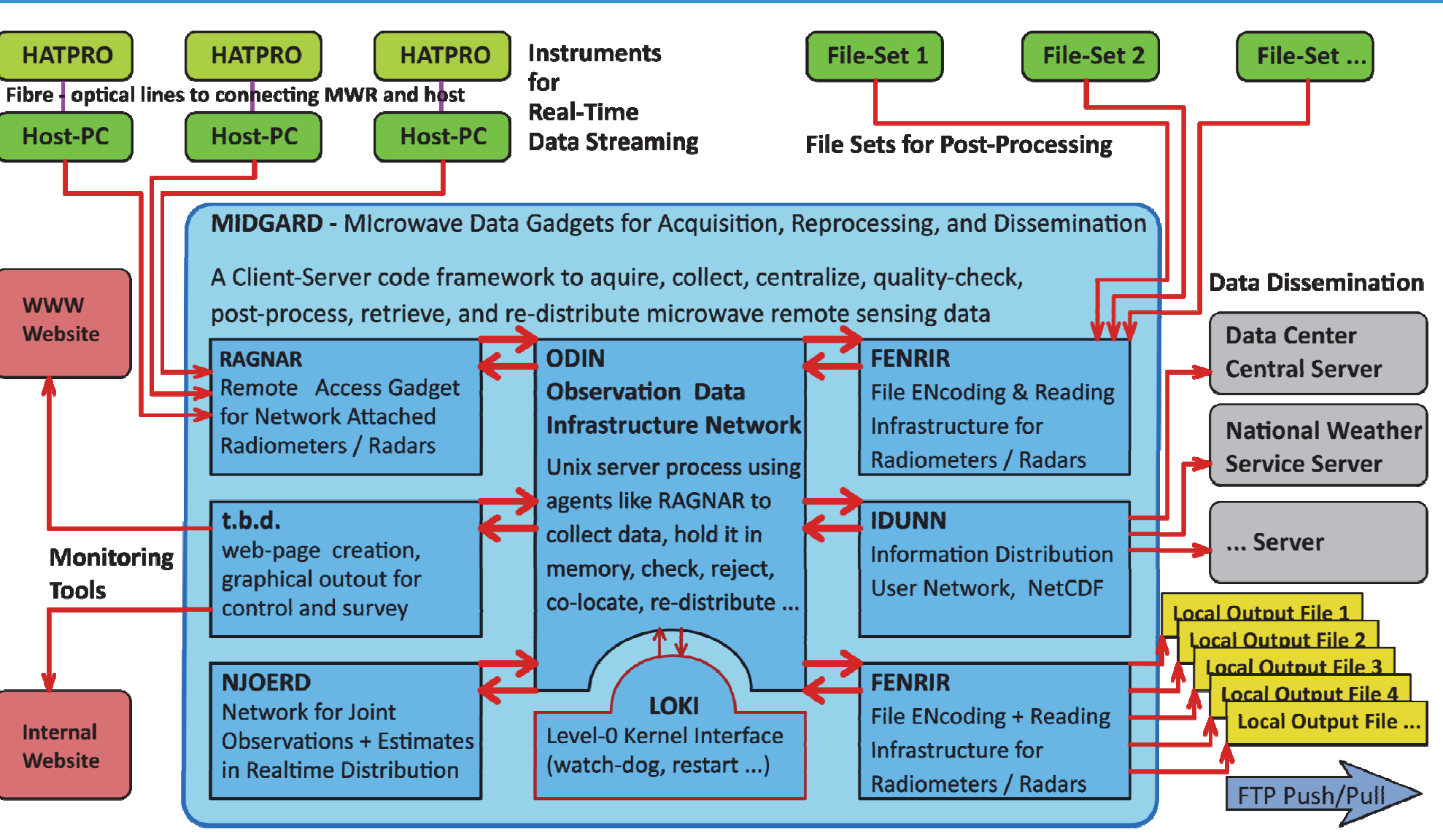*(De Angelis et al., Geoscientific Model Development, 2016)*

- From satellite perspective to ground-based
- Multiple elevation angles, RMS < 0.2 K
- Provides TB / Jacobians → Radiance Assimilation

Future distribution: usual RTTOV release channels

- Example of Jacobians for water vapour and temperature profiles (vertical pointing only).

Jacobians WV
Jacobians T

Data Streaming Software (Client-Server)

HATPRO — Instruments for Real-Time Data Streaming
File-Set 1, File-Set 2, File-Set ...
Fibre / optical lines to connecting MWR and host
Host-PC
File Sets for Post-Processing

MIDGARD - Microwave Data Gadgets for Acquisition, Reprocessing, and Dissemination
A Client-Server code framework to aquire, collect, centralize, quality-check, post-process, retrieve, and re-distribute microwave remote sensing data

WWW Website
RAGNAR Remote Access Gadget for Network Attached Radiometers / Radars
ODIN Observation Data Infrastructure Network Unix server process using agents like RAGNAR to collect data, hold it in memory, check, reject, co-locate, re-distribute ...
FENRIR File ENcoding & Reading Infrastructure for Radiometers / Radars
IDUNN Information Distribution User Network, NetCDF
Data Dissemination
Data Center Central Server
National Weather Service Server
... Server

Monitoring Tools
t.b.d. web-page creation, graphical outout for control and survey
LOKI Level-0 Kernel Interface (watch-dog, restart ...)
NJOERD Network for Joint Observations + Estimates in Realtime Distribution
FENRIR File ENcoding + Reading Infrastructure for Radiometers / Radars
Local Outout File 1, Local Outout File 2, Local Outout File 3, Local Outout File 4, Local Outout File ...
Internal Website
FTP Push/Pull

Data Files and Formats: NetCDF-CF 1.6

L1B: per Sensor, Microwave-TB, IRR-TB, …

L1C: co-located on time-grid

L1D: derived L1 like *cloud-removal* from TB

L2B: retrieved products (T, Q, IWV, LWP, …)

Meta-Data-L1: Covar-Matrix, calibrations, filters, …

Meta-Data-L2: Retrieval type, data source, RTM, …

Conclusions & Recommendations

Through joint efforts with the user community (COST-TOPROF), the latest Generation-5 MWR have reached maturity in precision, stability, robustness, and software tools.

MRW data assimilation can now start and close the observation gap in the boundary layer.

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