ACTRIS

CCRES

MWR Data Processing and Quality Control

CCRES Meeting, SIRTA, France – November, 14-15, 2022

This project receives funding from the European Union's Horizon
2020 research and innovation programme under grant agreements No 871115

CCRES MWR Central Facility - Status & Updates

- **Python based processing software under development**
  - started with operational test run for Jülich
  - more stations will follow soon

- **In the process of acquiring 2 additional RPG MWRs**
  - low humidity (90 / 183 GHz)
  - replacement for operational MWR (G5 K / V Band)

- **Organized workshop on MWR operation and calibration in Jülich** (Bernhard Pospichal, Tobias Marke, Lukas Pfitzenmaier, Rainer Haseneder-Lind, Tobias Böck)

ACTRIS
CCRES

ACTRIS-CCRES / PROBE
Workshop on microwave radiometer operation and calibration
31 August – 2 September 2022, Jülich, Germany

- 9 participants from MWR operating institutions
- Background of microwave radiometry
- Data processing / quality control
- Hands-on calibration with liquid nitrogen
- Exchange of experiences between users and with manufacturer (RPG)
- Within ACTRIS-CCRES regular workshops for instrument operators are planned

ACTRIS CCRES

Goals in the ACTRIS MWR network

- **Homogenized data streams from all sites, including common:**
  - data formats, file contents and metadata
  - quality control / flagging
  - retrieval development and application
  - data quicklooks of level1 and level2 products

- **Continuous near real time processing of raw data from MWRs of different manufacturers (mainly RPG)**

- **Recommendations and minimum requirements for operators concerning measurement setup, calibration, maintenance, ...**

ACTRIS CCRES

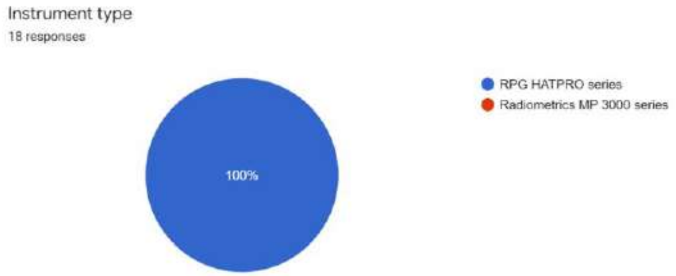
Standard Operating Procedures

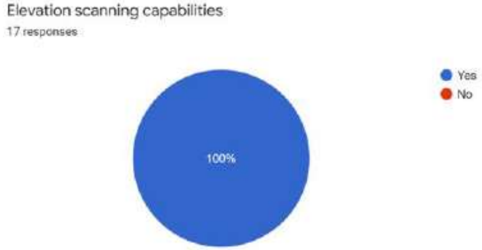
Microwave radiometer

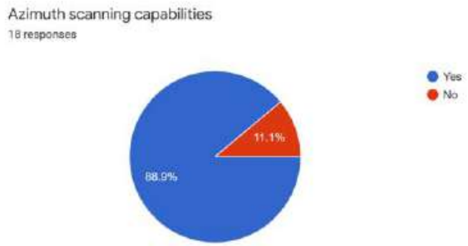
This document describes the **Standard Operating Procedures (SOPs)** that must be applied to all Microwave radiometers contributing measurements to the ACTRIS Cloud Remote Sensing Data Centre.

I. Site requirements

1	Operation area : environment surrounding the instrument	Open view to horizon, preferably in northern direction to perform elevation scans.
2	Specific points of attention	Easy access for site visits (esp. for liquid nitrogen calibrations and radome exchange) is required
3	Comply with local Safety and Security Rules	Respect safety regulations when handling liquid nitrogen







Goals in the ACTRIS MWR network

- **Homogenized data streams from all sites, including common:**
  - data formats, file contents and metadata
  - quality control / flagging
  - retrieval development and application
  - data quicklooks of level1 and level2 products
- **Continuous near real time processing of raw data from MWRs of different manufacturers (mainly RPG)**
- **Recommendations and minimum requirements for operators concerning measurement setup, calibration, maintenance, …**
- **Potential of synergistic products within CCRES**
- **Operational support, workshops and hands-on training regarding calibration and data handling**

ACTRIS CCRES

Data Stream - Overview

Data handling will be performed by the Cloud remote sensing data centre unit (CLU)

CLU performs data versioning, data provision and archiving

Station operators are required to transfer the raw data to CLU at least once per day
Required files for RPG instruments (binary files) are:

- BRT: Brightness temperatures (single angle)
- BLB / BLS: Brightness temperatures from multi-angle elevation scans
- HKD: Housekeeping data
- IRT: Infrared radiometer brightness temperatures
- MET: Meteorological sensor data

– preliminary also SPC, LWP files should be transferred until retrievals are developed.
– alternatively RPG retrieval coefficients can be applied.

Therefore, no data format conversion should be performed using the instrument software.

In addition, calibration LOG files (ABSCAL.HIS, CAL.LOG, CovMatrix.DAT) are needed; Centralized data base at CLU:

ACTRIS CCRES

Data Format

Common MWR data format being developed in the EUMETNET E-Profile network

- Will be used also in ACTRIS for a better cross network compatibility
- RPG binary files are converted into Level 1 NetCDF files and are not needed anymore for Level 2 products

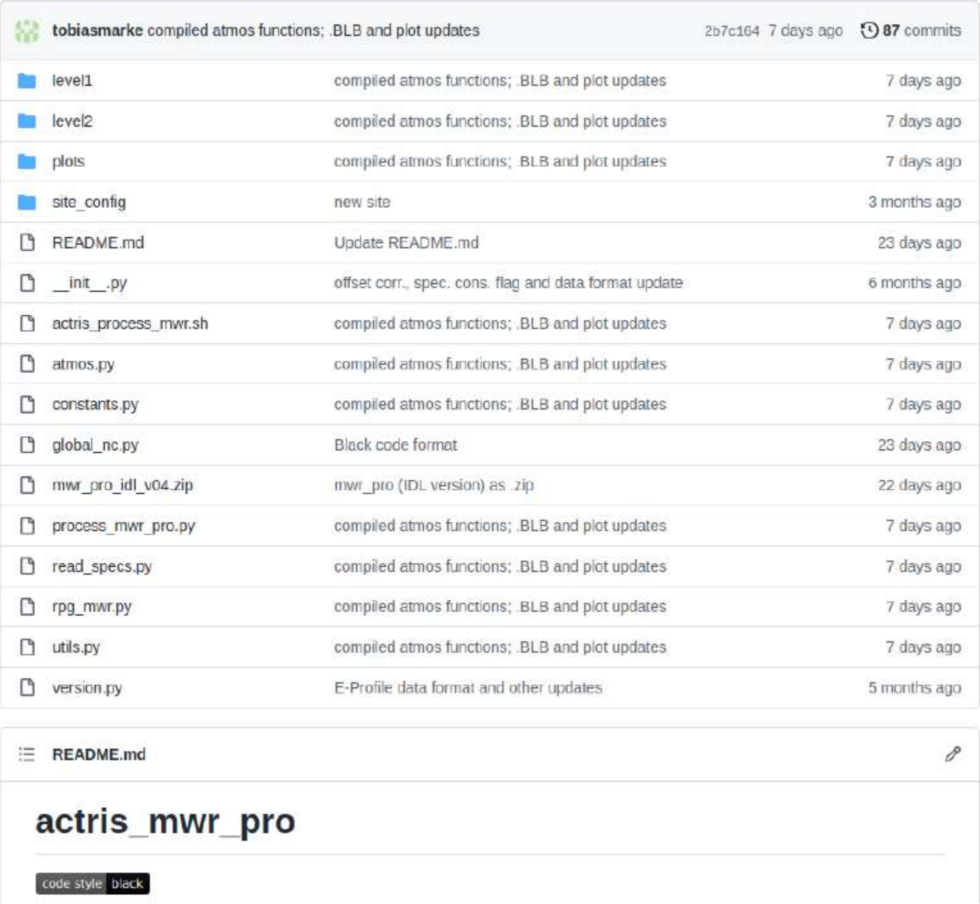
File name convention:

- 1B01 for MWR TB, 1B11 for IR, 1B21 for meteorological data, and 1C01 co-located
- 2IXX for integrated quantities (e.g. 2I01 for LWP)
- 2PXX for profiles (e.g. 2P01 temperature profiles)

Alternative variable names according to ACTRIS vocabulary will be provided

ACTRiS CCRES

Data Processing


tobiasmarke compiled atmos functions; .BLB and plot updates — 2b7c164 7 days ago — 87 commits

level1	compiled atmos functions; .BLB and plot updates	7 days ago
level2	compiled atmos functions; .BLB and plot updates	7 days ago
plots	compiled atmos functions; .BLB and plot updates	7 days ago
site_config	new site	3 months ago
README.md	Update README.md	23 days ago
__init__.py	offset corr., spec. cons. flag and data format update	6 months ago
actris_process_mwr.sh	compiled atmos functions; .BLB and plot updates	7 days ago
atmos.py	compiled atmos functions; .BLB and plot updates	7 days ago
constants.py	compiled atmos functions; .BLB and plot updates	7 days ago
global_nc.py	Black code format	23 days ago
mwr_pro_idl_v04.zip	mwr_pro (IDL version) as .zip	22 days ago
process_mwr_pro.py	compiled atmos functions; .BLB and plot updates	7 days ago
read_specs.py	compiled atmos functions; .BLB and plot updates	7 days ago
rpg_mwr.py	compiled atmos functions; .BLB and plot updates	7 days ago
utils.py	compiled atmos functions; .BLB and plot updates	7 days ago
version.py	E-Profile data format and other updates	5 months ago

README.md

actris_mwr_pro

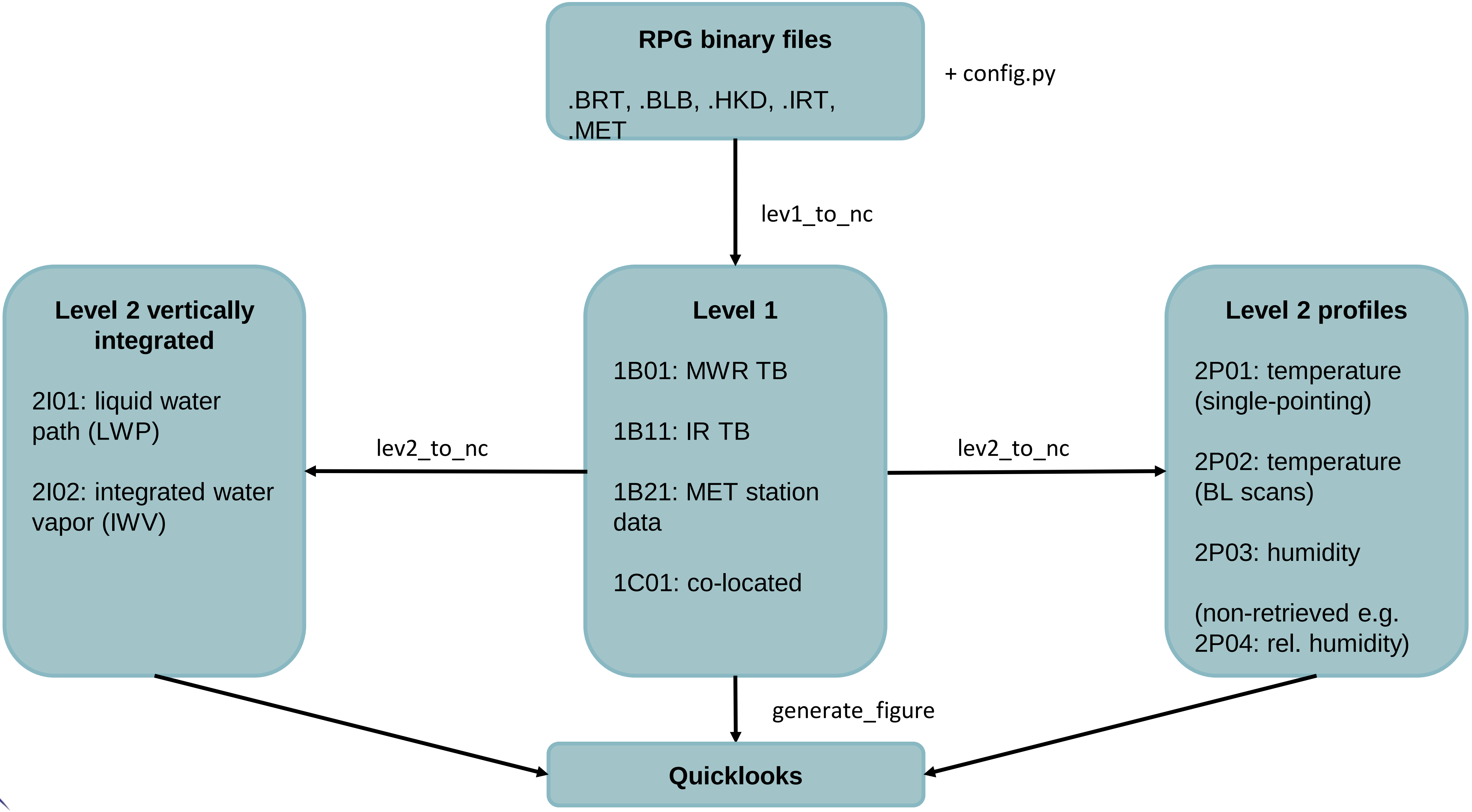
code style black

Python code under development and maintained on github (not public yet)

- Based on IDL routines of "MicroWave Radiometer PROcessing" (mwr_pro)
- Developed at University of Cologne and applied successfully to RPG data over years at different stations
- Planned to also run outside of the ACTRIS network
- Discussion on implementation into CloudnetPy framework needed

ACTRIS CCRES

Code Description



Site Specific Configuration

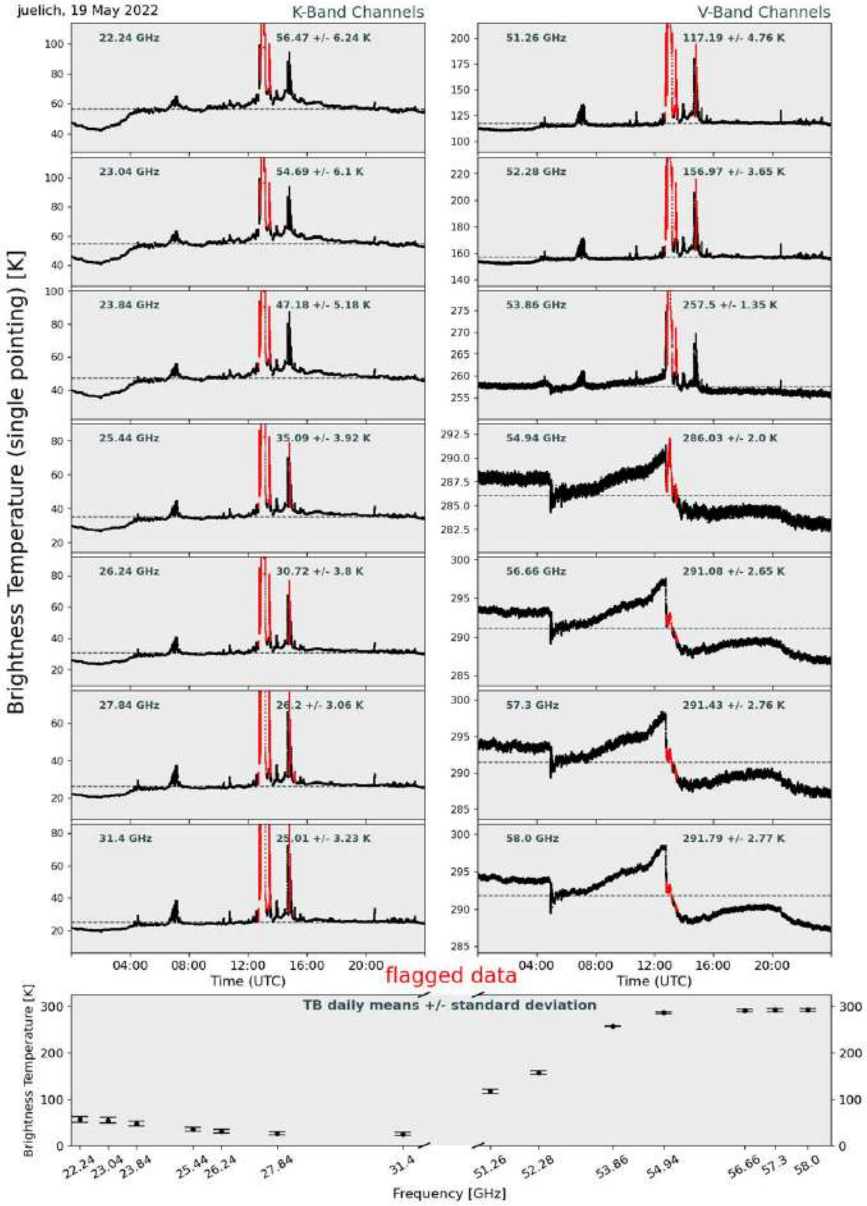
config.py contains site and instrument specific information for processing purposes and metadata generation

```
    # integration time of measurements in seconds
    'int_time': 1,

    # receiver information
    'receiver_nb': np.array([1, 2]),
    'receiver': np.array([1, 1, 1, 1, 1, 1, 1,
                          2, 2, 2, 2, 2, 2, 2]),

    # bandwidth of the central frequency in GHz (center frequency of single of upper side-band)
    'bandwidth': np.array([230., 230., 230., 230., 230., 230., 230.,
                           230., 230., 230., 230., 600., 1000., 2000.]),

    # 56.xx +/- X +/- Y
    'n_sidebands': np.array([1, 1]),
    'sideband_IF_separation': np.array([0., 0., 0., 0., 0., 0., 0.,
                                        0., 0., 0., 0., 0., 0., 0.]),
```

```
global_specs = {
    # Name of the conventions followed by the dataset
    'conventions' : 'CF-1.8',

    # A succinct description of what is in the dataset, composed of instrument type and site name
    'title' : 'HATPRO G5 MWR at Juelich, Germany',
```

ACTRIS CCRES

Level 1 - Brightness Temperatures / Spectrum



ACTRiS CCRES

Quality Flag

Quality flag for level 1 data

Bit 1: **missing_tb**

Bit 2: **tb_below_threshold** — TB values are being checked

Bit 3: **tb_above_threshold**

Bit 4: **spectral_consistency_above_threshold** → Comparison: retrieved & observed TB

Bit 5: **receiver_sanity_failed** → Receiver & ambient target stability + noise diode status

Bit 6: **rain_detected** → Rain sensor

Bit 7: **sun_in_beam** → Calculate sun position for site location (relevant for scans)

Bit 8: **tb_offset_above_threshold** Not implemented

Quality Flag

Quality flag for level 1 data

Bit 1: **missing_tb**

Bit 2: **tb_below_threshold** TB values are being checked

Bit 3: **tb_above_threshold**

Bit 4: **spectral_consistency_above_threshold** → Comparison: retrieved & observed TB

Bit 5: **receiver_sanity_failed** → Receiver & ambient target stability + noise diode status

Bit 6: **rain_detected** → Rain sensor

Bit 7: **sun_in_beam** → Calculate sun position for site location (relevant for scans)

Bit 8: **tb_offset_above_threshold** Not implemented

ACTRIS CCRES

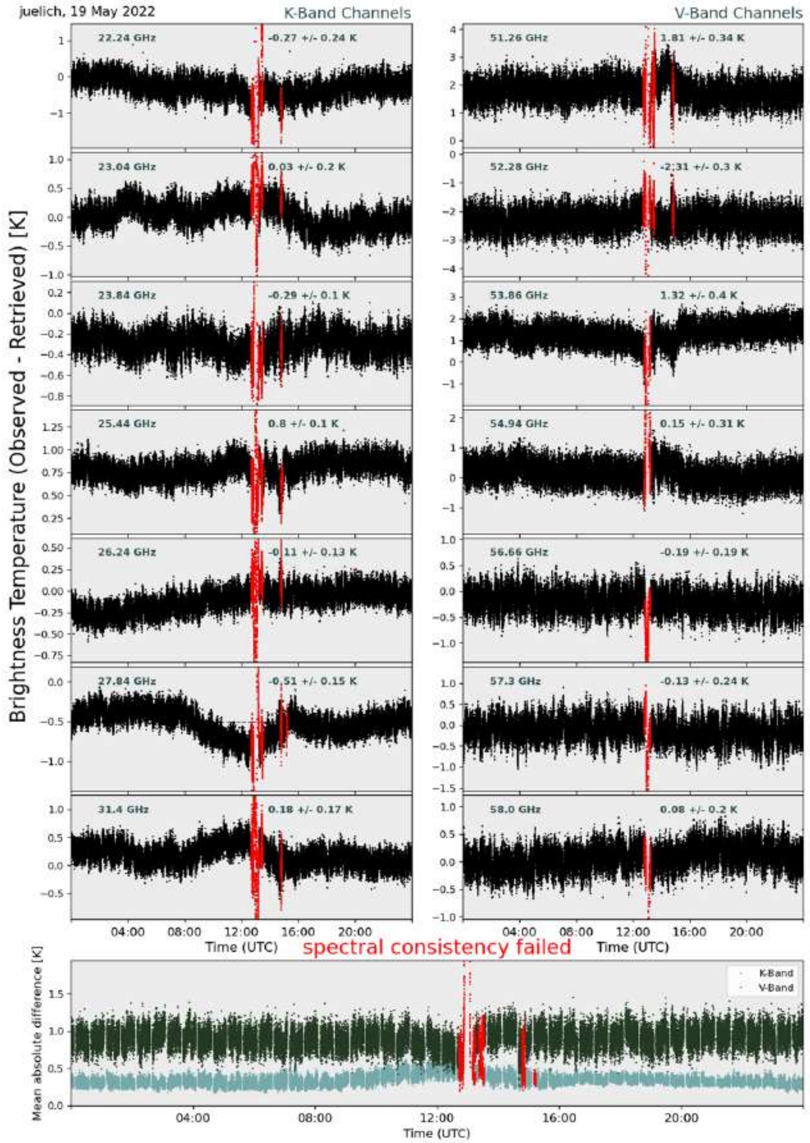
Spectral Consistency

Can the observed spectrum be explained by real atmospheric conditions?

TBs for a certain channel are derived via statistical retrieval from other channels (atmospheric information is not independent, and only certain atmospheric spectra are physically possible)

Retrieved TBs for all channels are then compared to measurements (data flagging is based on thresholds depending on channel retrieval uncertainty)

Possible to judge radome quality
(duration of inconsistency after rain w.r.t. atmospheric conditions)



Quality Flag

Quality flag for level 1 data

Bit 1: **missing_tb**

Bit 2: **tb_below_threshold** → TB values are being checked

Bit 3: **tb_above_threshold**

Bit 4: **spectral_consistency_above_threshold** → Comparison: retrieved & observed TB

Bit 5: **receiver_sanity_failed** → Receiver & ambient target stability + noise diode status

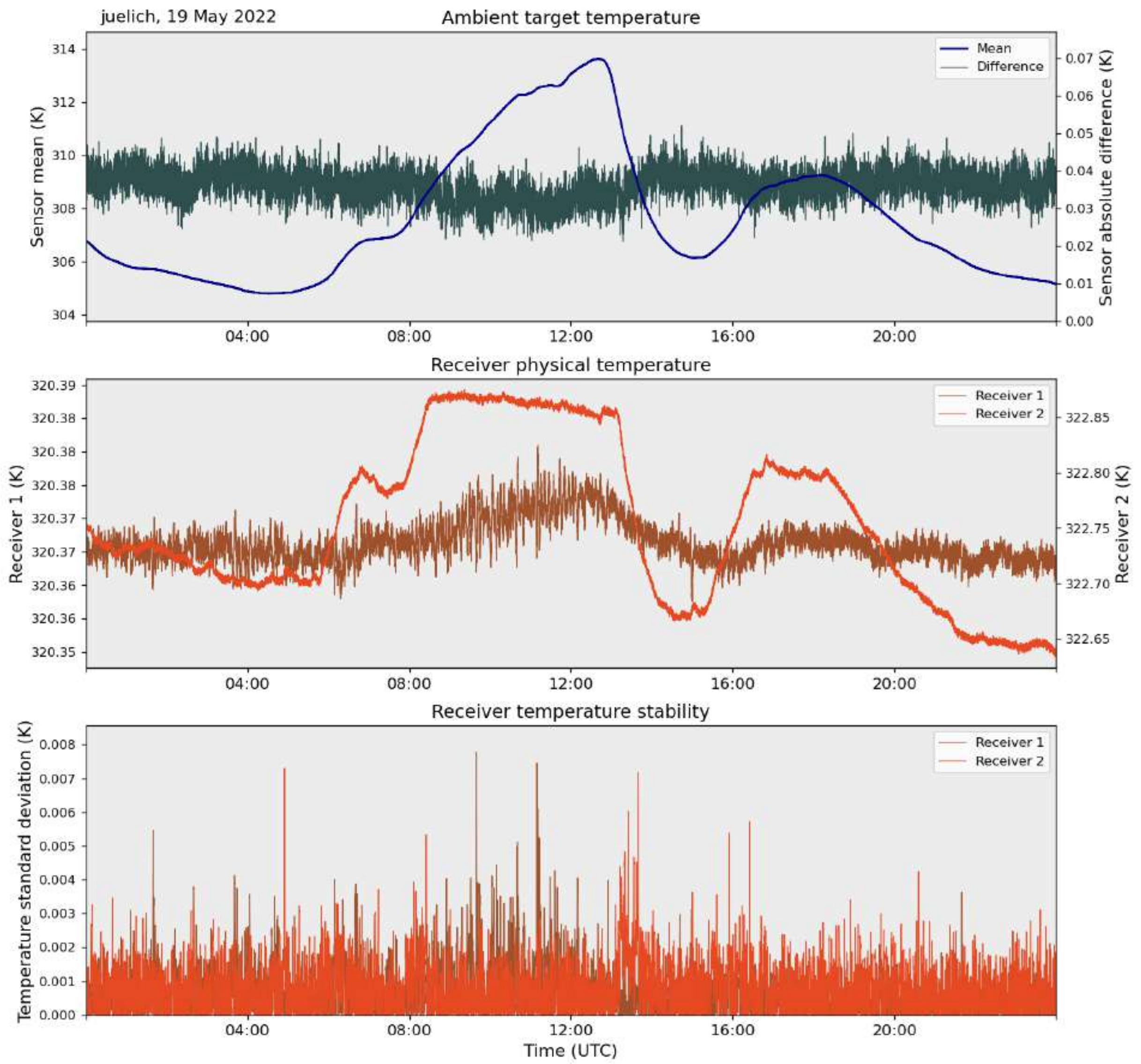
Bit 6: **rain_detected** → Rain sensor

Bit 7: **sun_in_beam** → Calculate sun position for site location (relevant for scans)

Bit 8: **tb_offset_above_threshold** Not implemented

ACTRIS CCRES

Level 1 - HKD



Visualization of housekeeping data within CLU?

Quality Flag

Quality flag for level 1 data

Bit 1: **missing_tb**

Bit 2: **tb_below_threshold**   TB values are being checked

Bit 3: **tb_above_threshold**

Bit 4: **spectral_consistency_above_threshold** → Comparison: retrieved & observed TB

Bit 5: **receiver_sanity_failed** → Receiver & ambient target stability + noise diode status

Bit 6: **rain_detected** → Rain sensor

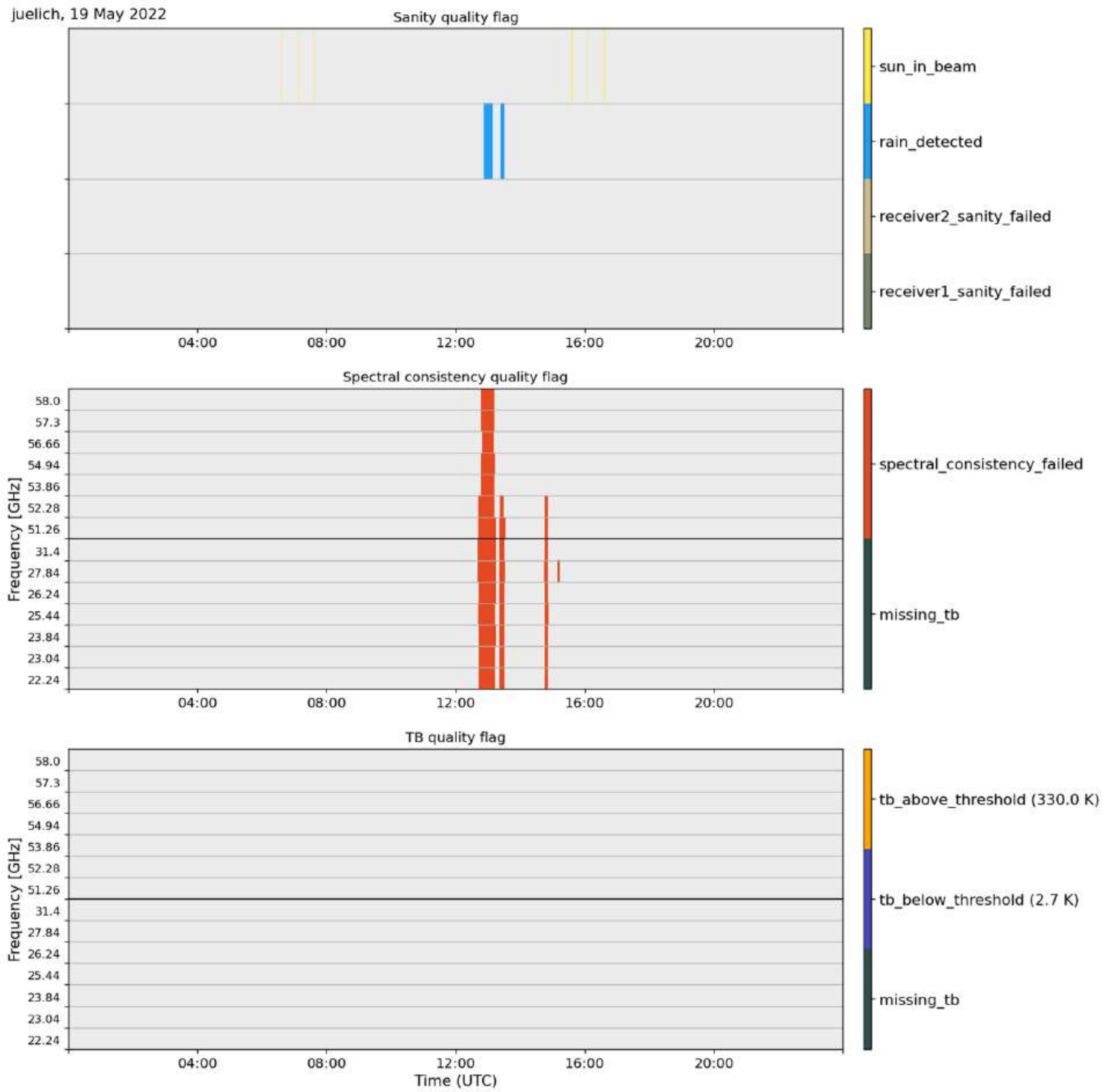
Bit 7: **sun_in_beam** → Ca[illegible]ate sun position for site location (relevant for scans)

Bit 8: **tb_offset_above_threshold**   Not implemented

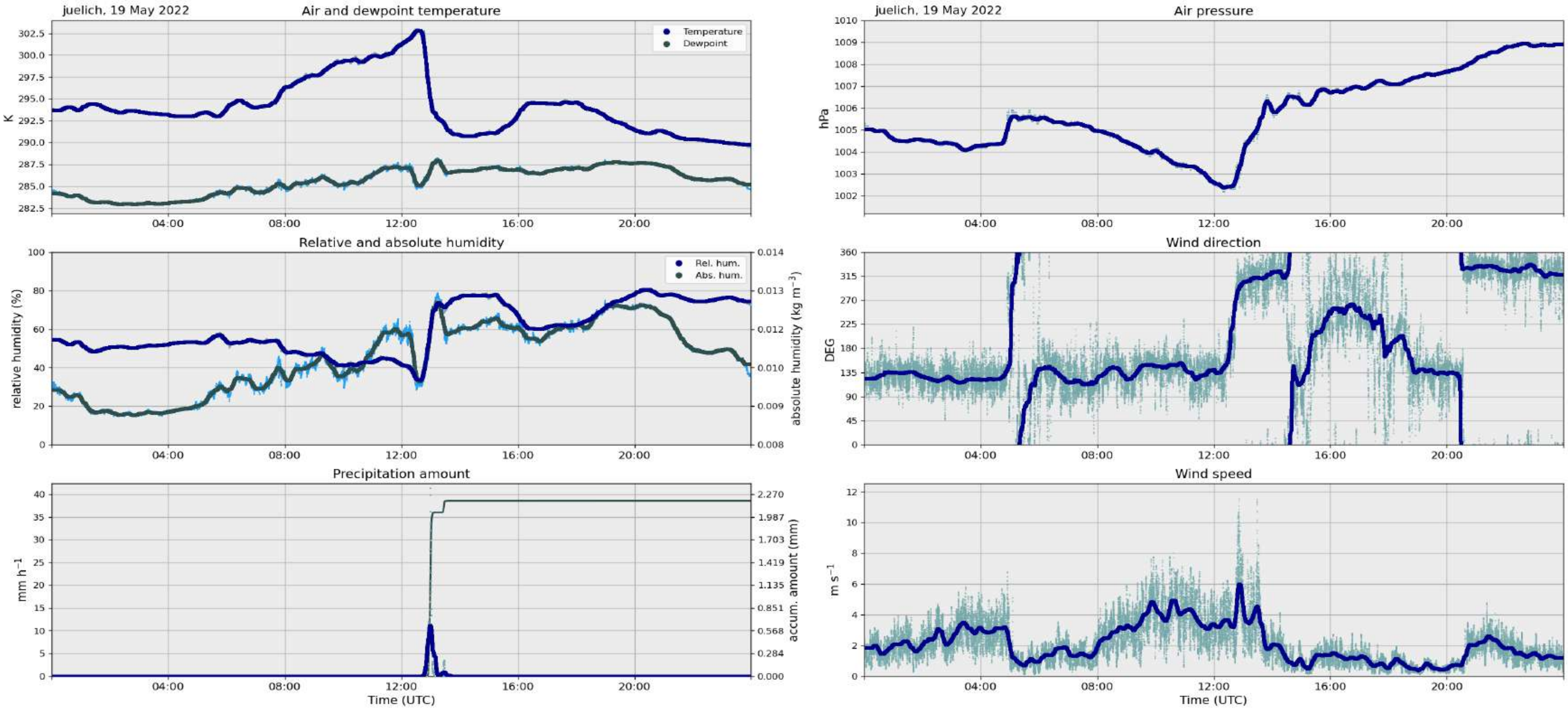
ACTRIS CCRES

Quality Flag Quicklook

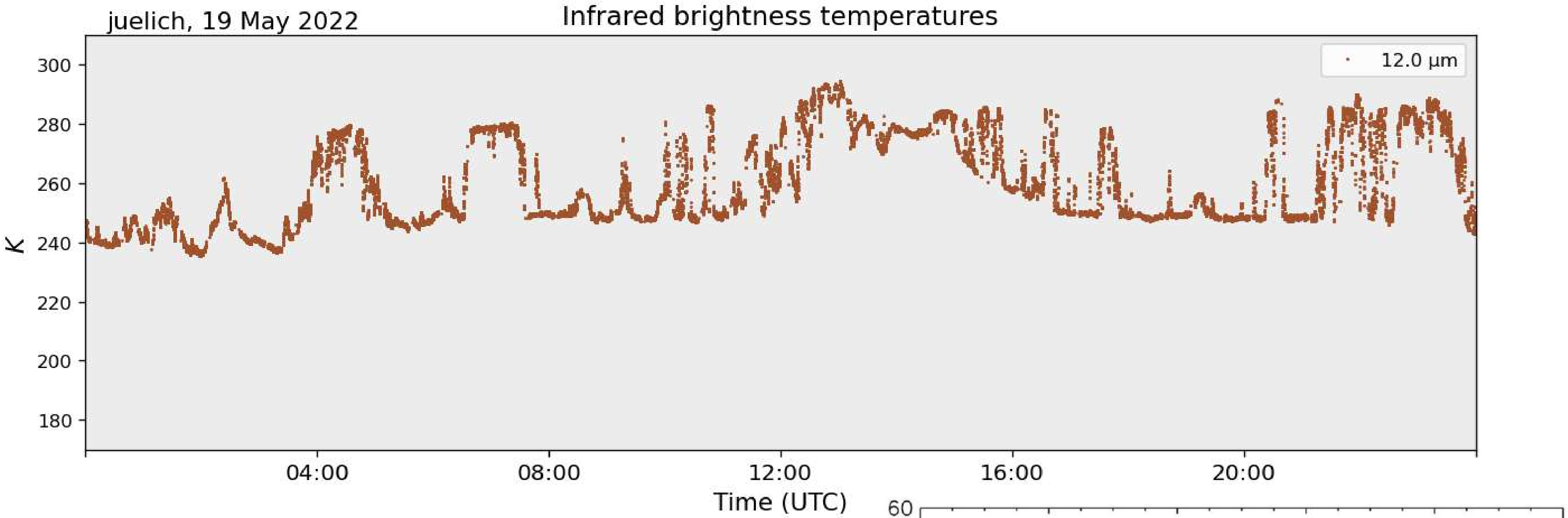
- **Individual channels / receivers are flagged**
- **Helps to detect malfunctions in long-term deployments**
- **Statistical evaluation is performed for the labeling process, including at least 2 successful liquid nitrogen absolute calibrations**



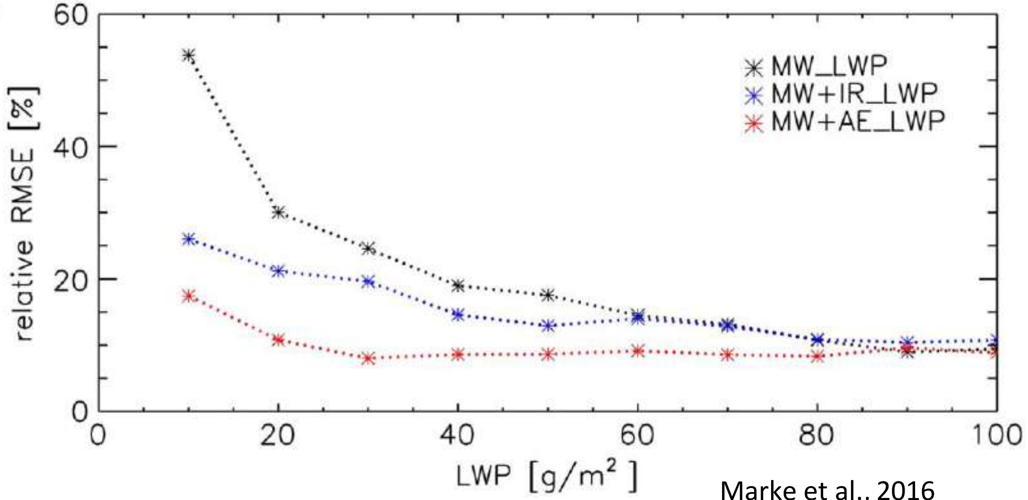
Level 1 - MET station



Level 1 - IRT

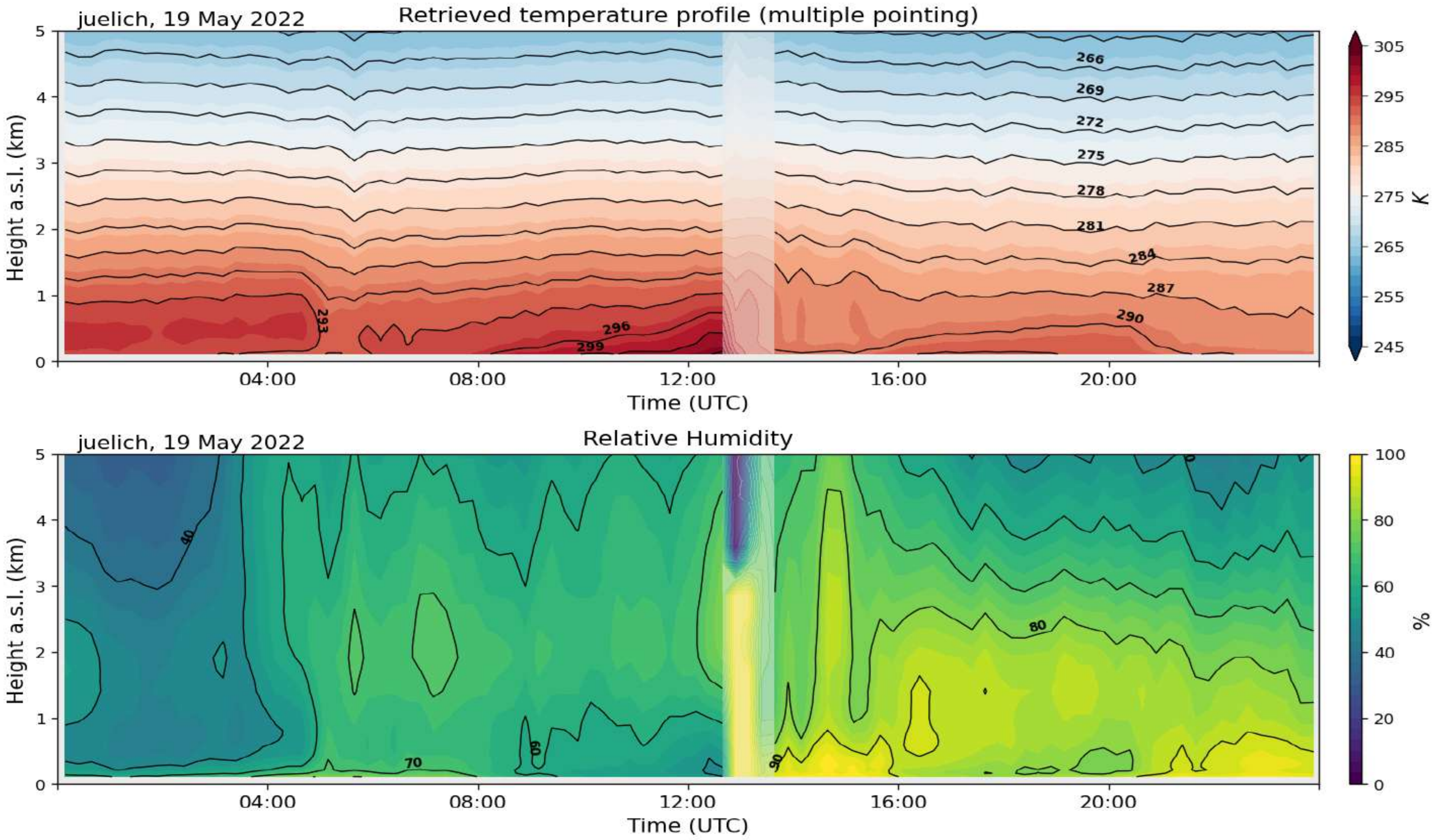


Synergy with IRT helps reduce LWP retrieval uncertainty in the case of low-LWP clouds compared to MWR only

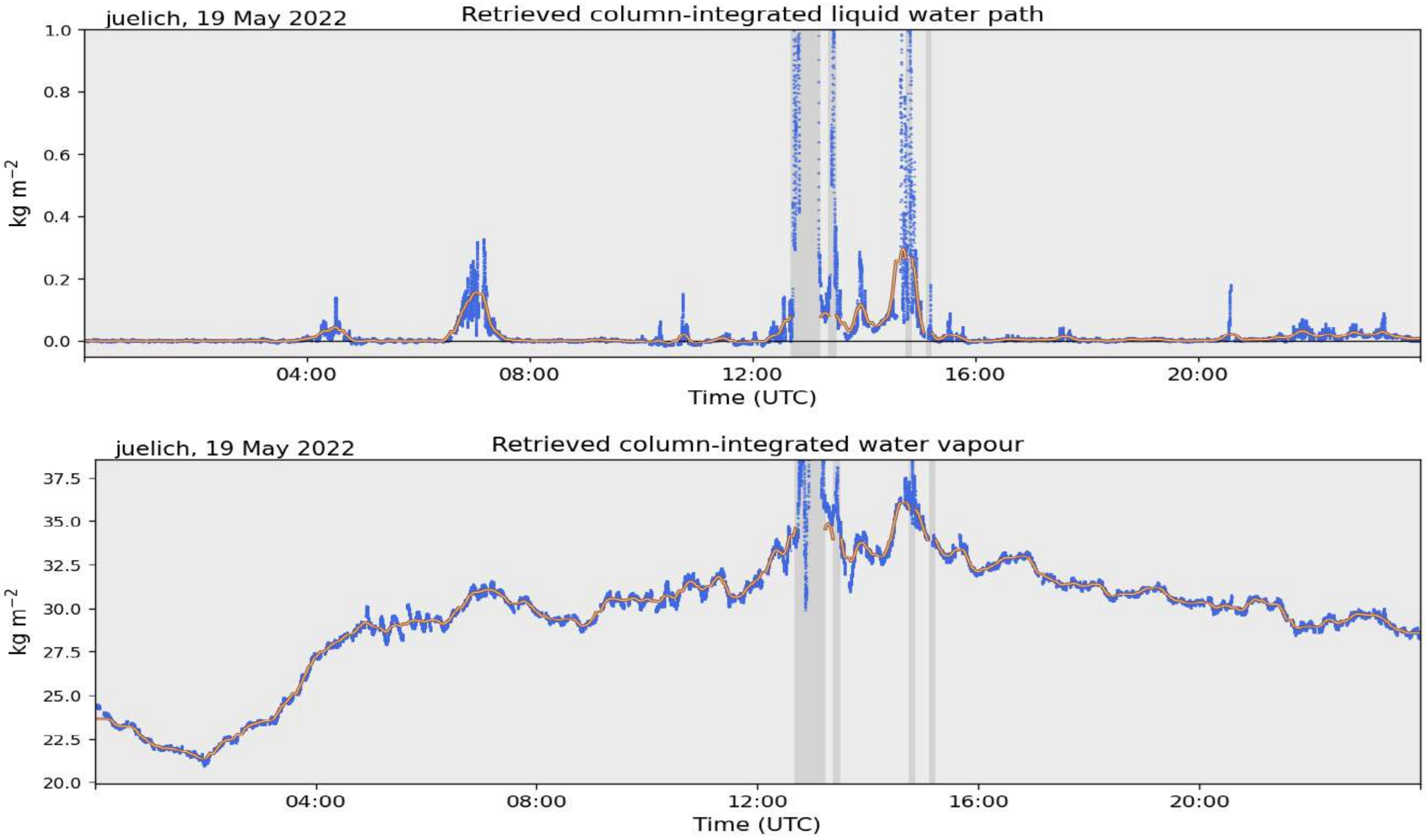


Marke et al., 2016

Level 2 - Multiple pointing



Level 2 - Vertically Integrated

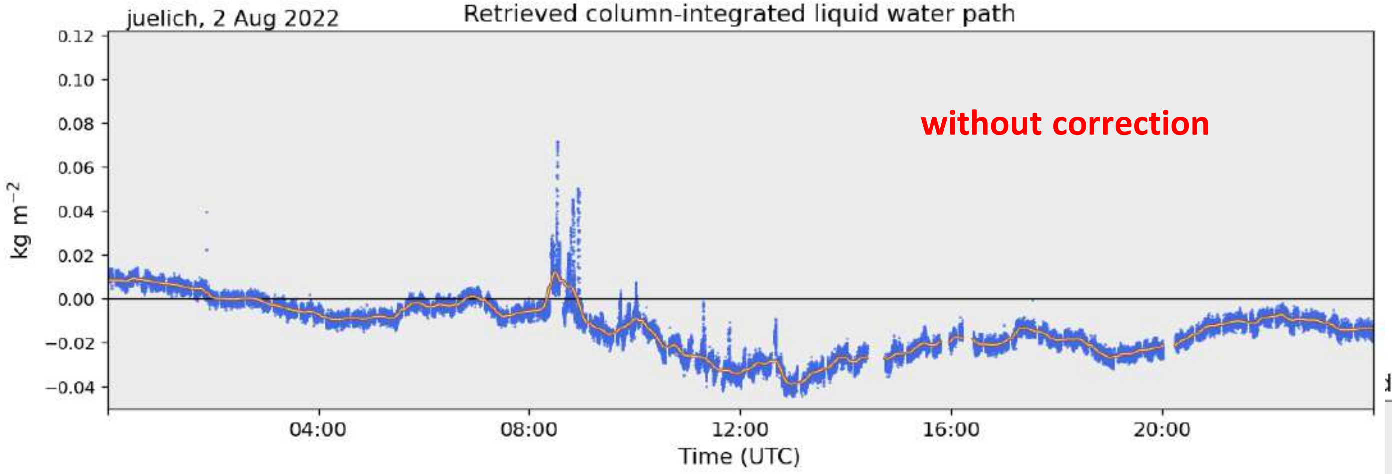


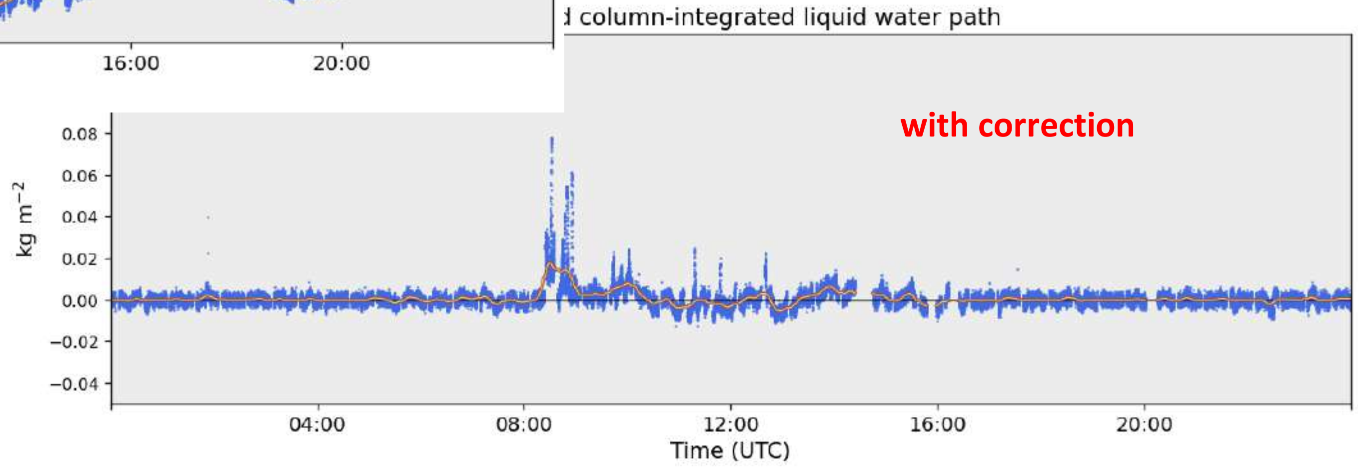
ACTRIS CCRES

LWP Offset Correction

When using statistical retrievals, spurious LWP values can exist in clear sky scenes

1) Identify clear sky scenes using 2 min TB standard deviation @ 31.4 GHz and IR temperature as additional check for liquid clouds
2) Subtract mean LWP bias for 20 min windows if threshold criteria are fulfilled





ACTRIS CCRES

ACTRiS

CCRES

Workshop on Ground-based Microwave Radiometry

MWR technical components, calibration

CCRES MWR Workshop Jülich, 31 Aug – 2 Sep 2022

Universität zu Köln

JOYCE

PROBE COST ACTION

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreements No 871115

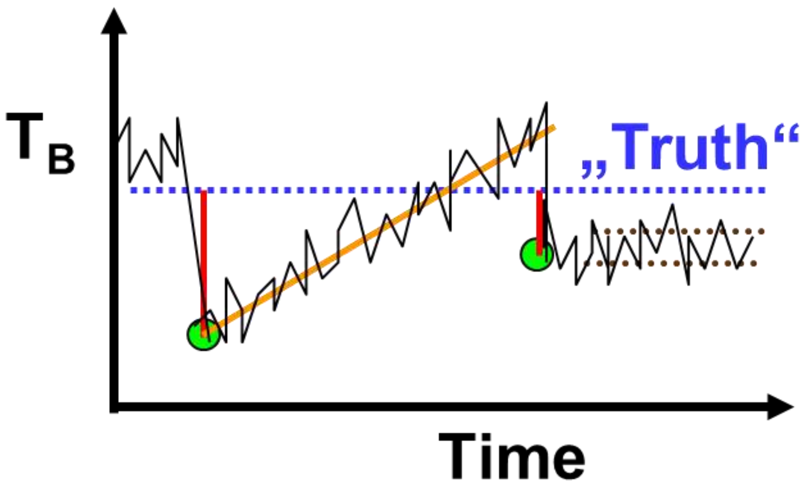
MWR calibration

- Regular calibration is vital for any microwave radiometer
- Uncalibrated radiometers do not produce any meaningful data
- MWR have several calibration types
  - absolute (using external blackbodies with well-defined temperatures)
  - relative (using secondary standards, such as noise diodes)

Radiometer calibration

Sources for measurement uncertainties:

- Random errors:
  - Instrument sensitivity (signal-noise ratio, detection limit)
- Systematic errors:
  - Instrument stability (drifts in signals)
  - Absolute accuracy
- Retrieval uncertainties:
  - Non-representative data for retrieval training
  - Measurement process not modelled correctly (noise levels, etc.)
  - Forward model uncertainties



Absolute radiometer calibration

- Absolute calibrations using liquid nitrogen (LN_2) have to be performed every 6 months or after relocation of the instrument

- If possible, perform calibrations at low relative humidity conditions (RH < 70%) to reduce the likelyhood of condensation

- Before and after a calibration take a short measurement sample at cold load in order to estimate the drift/offset since the last calibration

- Do not refill liquid nitrogen too often, in order to avoid oxygen to be mixed into LN_2 > causes change in boiling temperature and a wrong calibration. Same is valid for using non-pure LN_2

Absolute radiometer calibration

- Impressions from different calibration intercomparison campaigns
  Lindenberg 2014, 2021
  Meckenheim 2015
  Jülich 2019

ACTRIS

Universität zu Köln

Absolute radiometer calibration

Evolution of calibration targets at RPG

left: old load design
right: current load design

Old calibration load (with mirror) was produced until 2016. Disadvantages: standing waves, condensation, oxygen mixing into nitrogen

New target (PT-V1), since 2016, reduced these error sources drastically. Disadvantage: It has to be turned during calibration

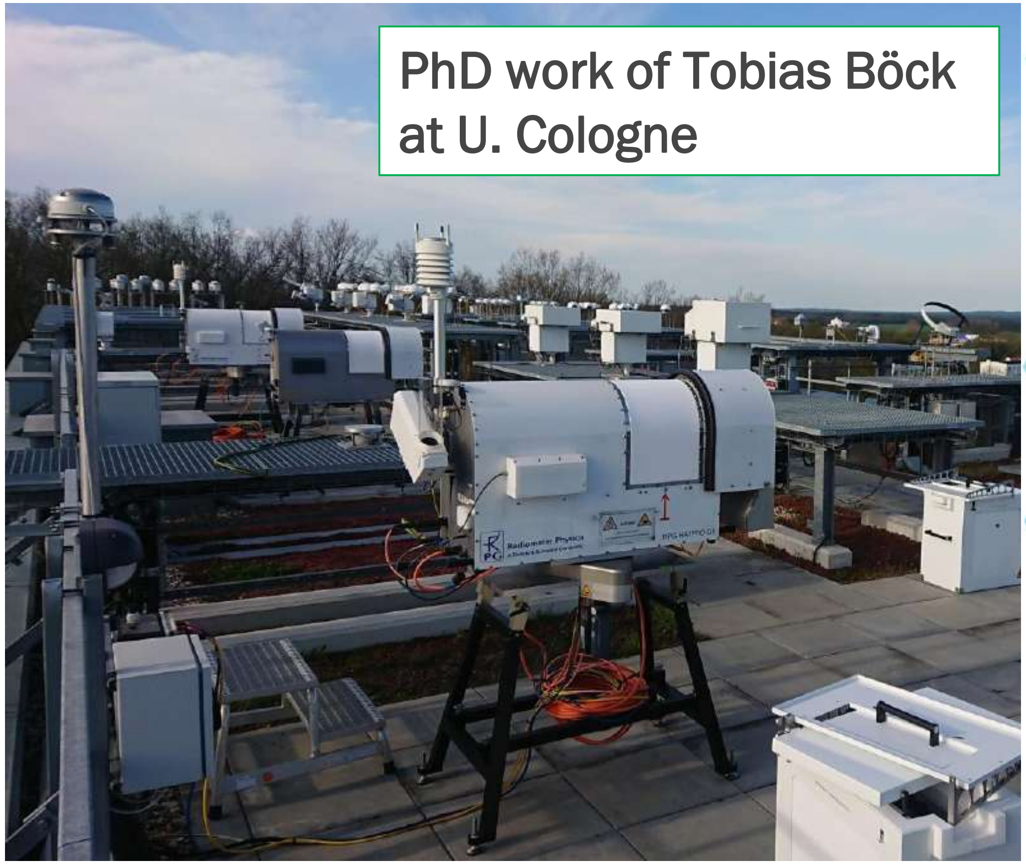
Upgrade of new target (PT-V2), since 2021: No turning necessary during calibration, less LN2 needed

ACTRIS

Universität zu Köln

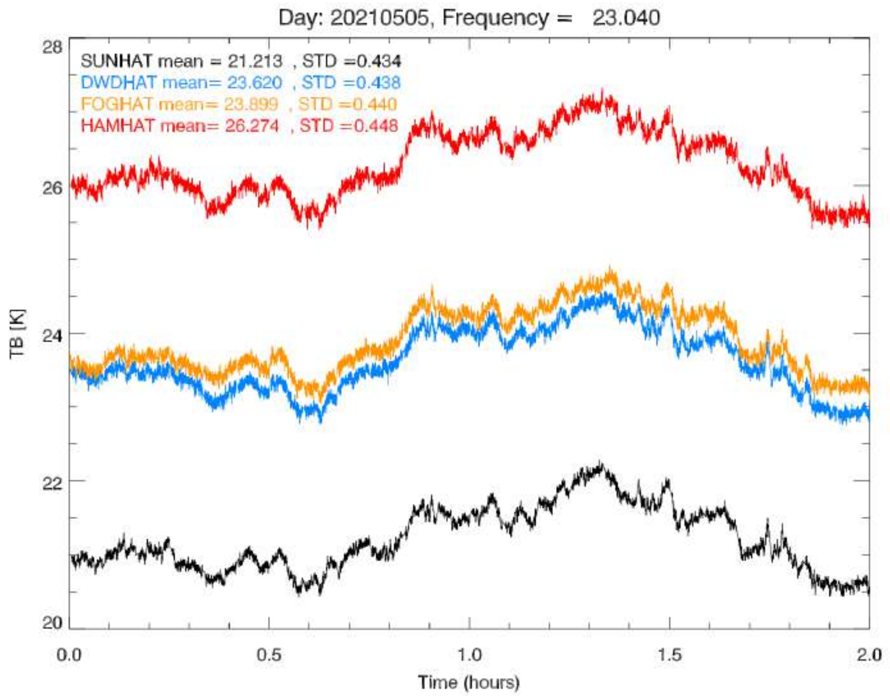
Results from calibration Campaign in Lindenberg

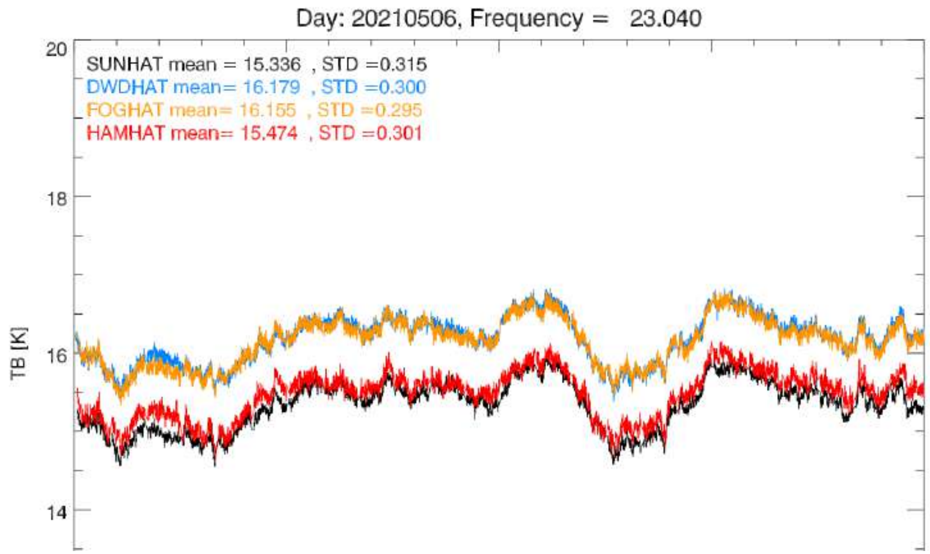
- **4 HATPROs** (FOGHAT G5, DWDHAT G5, SUNHAT G2, HAMHAT G2)
- Calibration campaign:
  - Calibrate all 3 HATPROs on the roof in a row for **three times** each with the standard procedure
  - **Zenith** measurements in between
  - 4th HATPRO nearby gets calibrated only once and then always measures zenith; is used as a reference later
    - First calibration round: May 5, 2021
    - Second and third calibration round: May 6, 2021
- Comparisons of zenith and blackbody measurements (to find out **biases**, **drifts/leaps**, **noise levels**, **repeatability**)

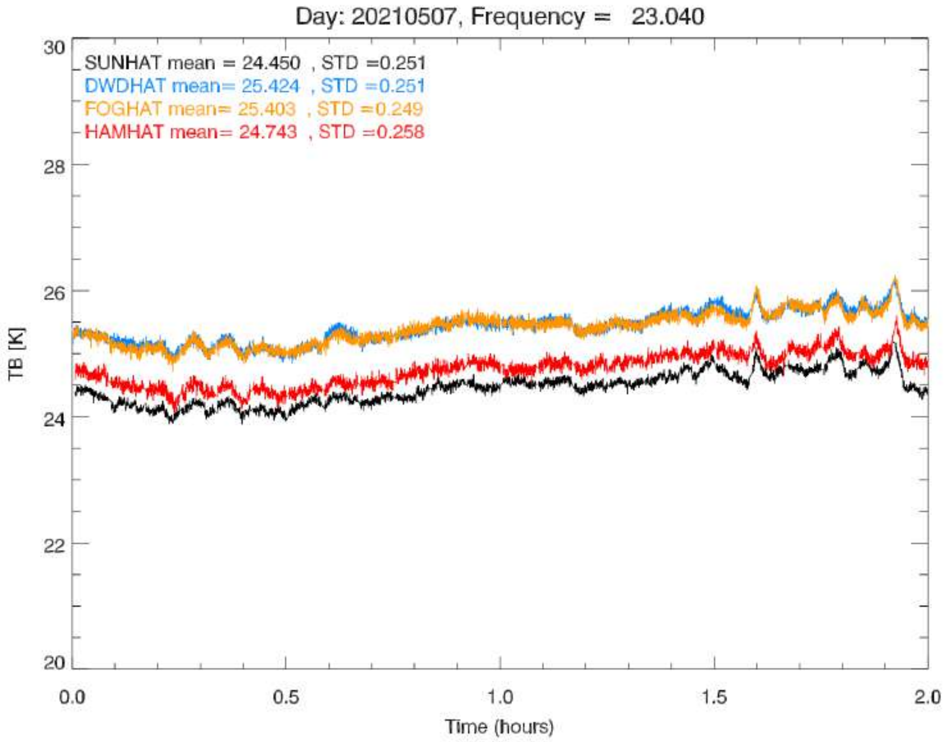


PhD work of Tobias Böck at U. Cologne

Zenith T_B comparisons before/after calibration







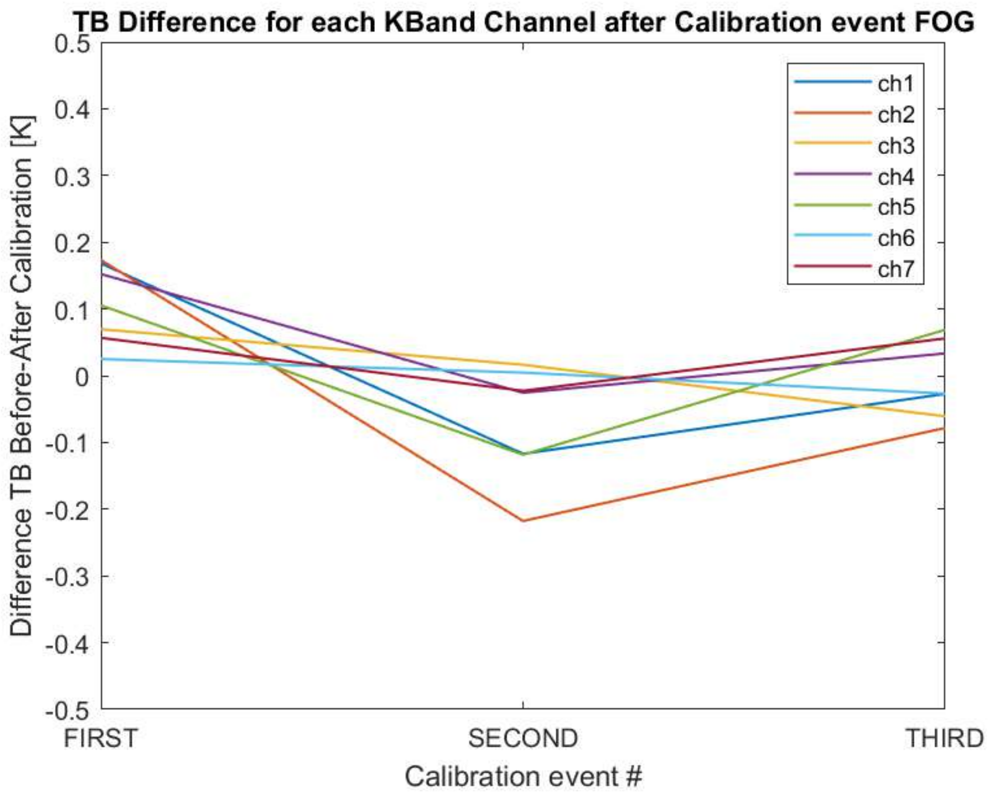
2 hours of clear sky zenith observations before the first calibration (left) and after calibrations (right).
Blue and yellow: G5 (new generation) HATPROs, red and black G1/G2 (>10 years old)

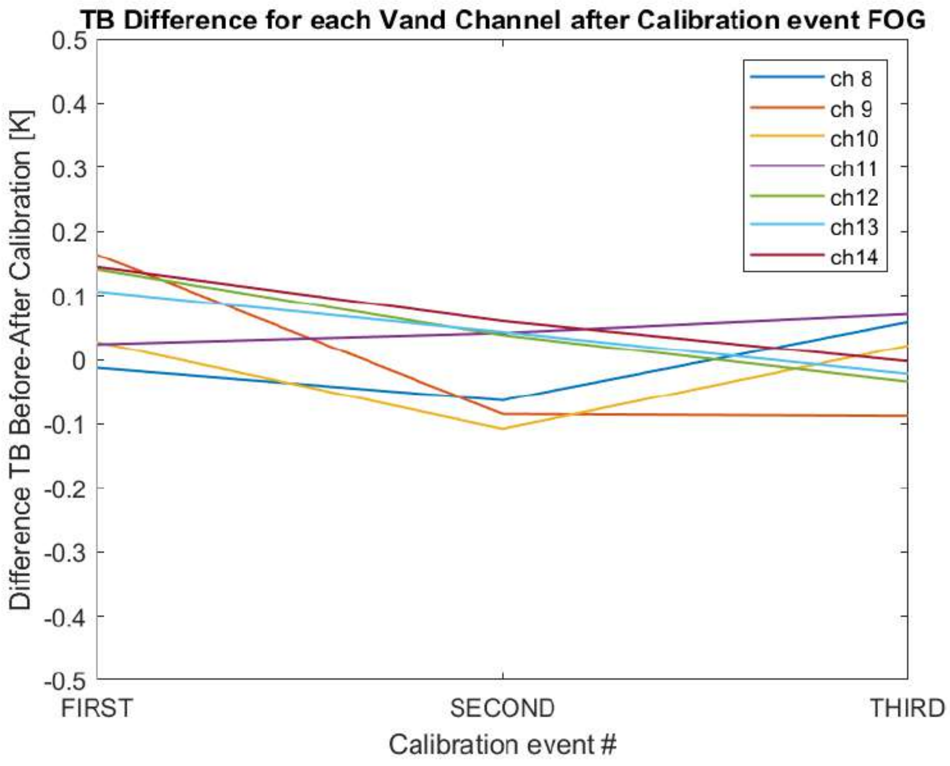
ACTRIS

Universität zu Köln

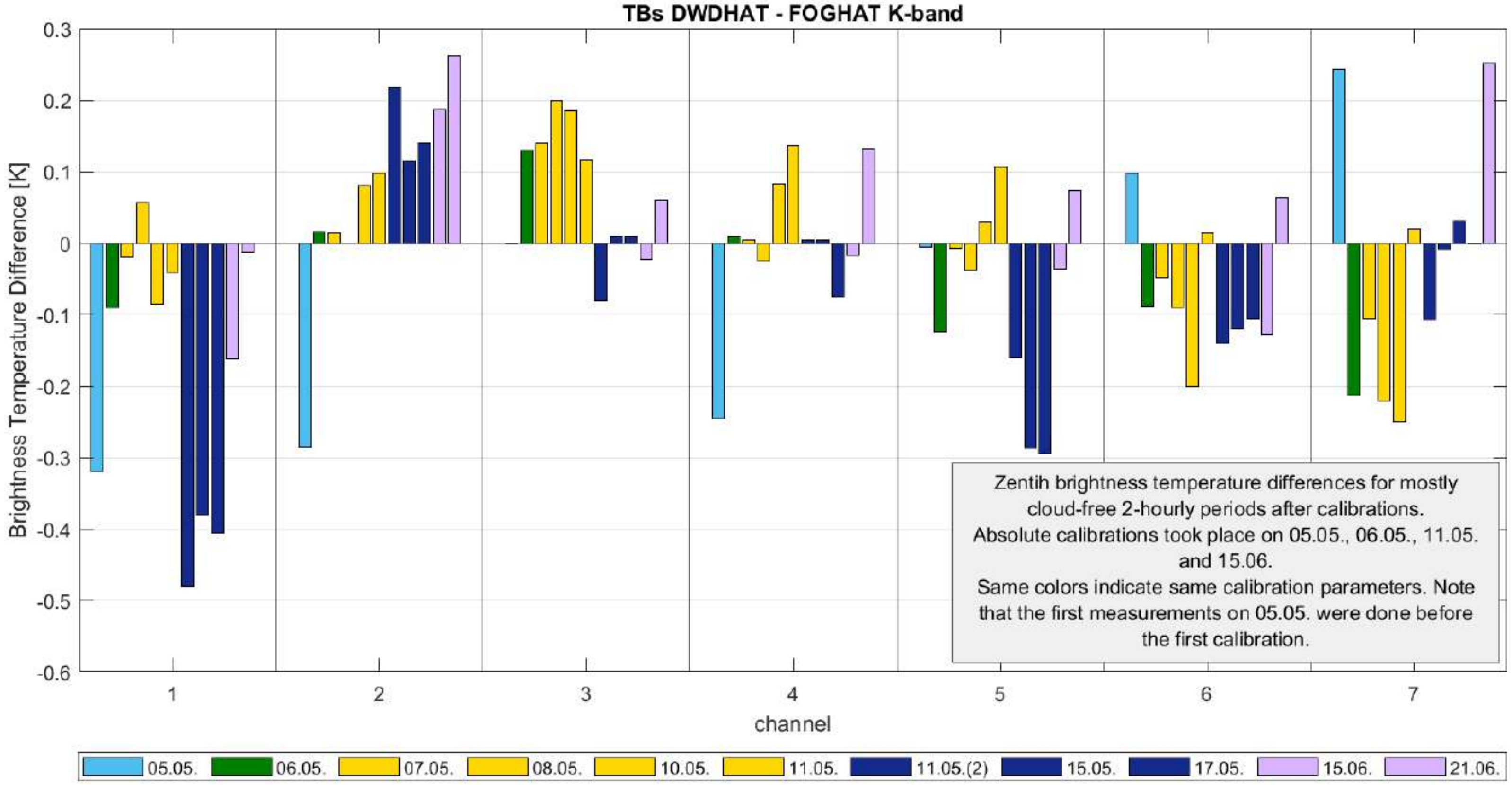
Repeatability of absolute calibrations

- Look at cold calibration target before and after calibration and determine difference (mean of 3 min observations)



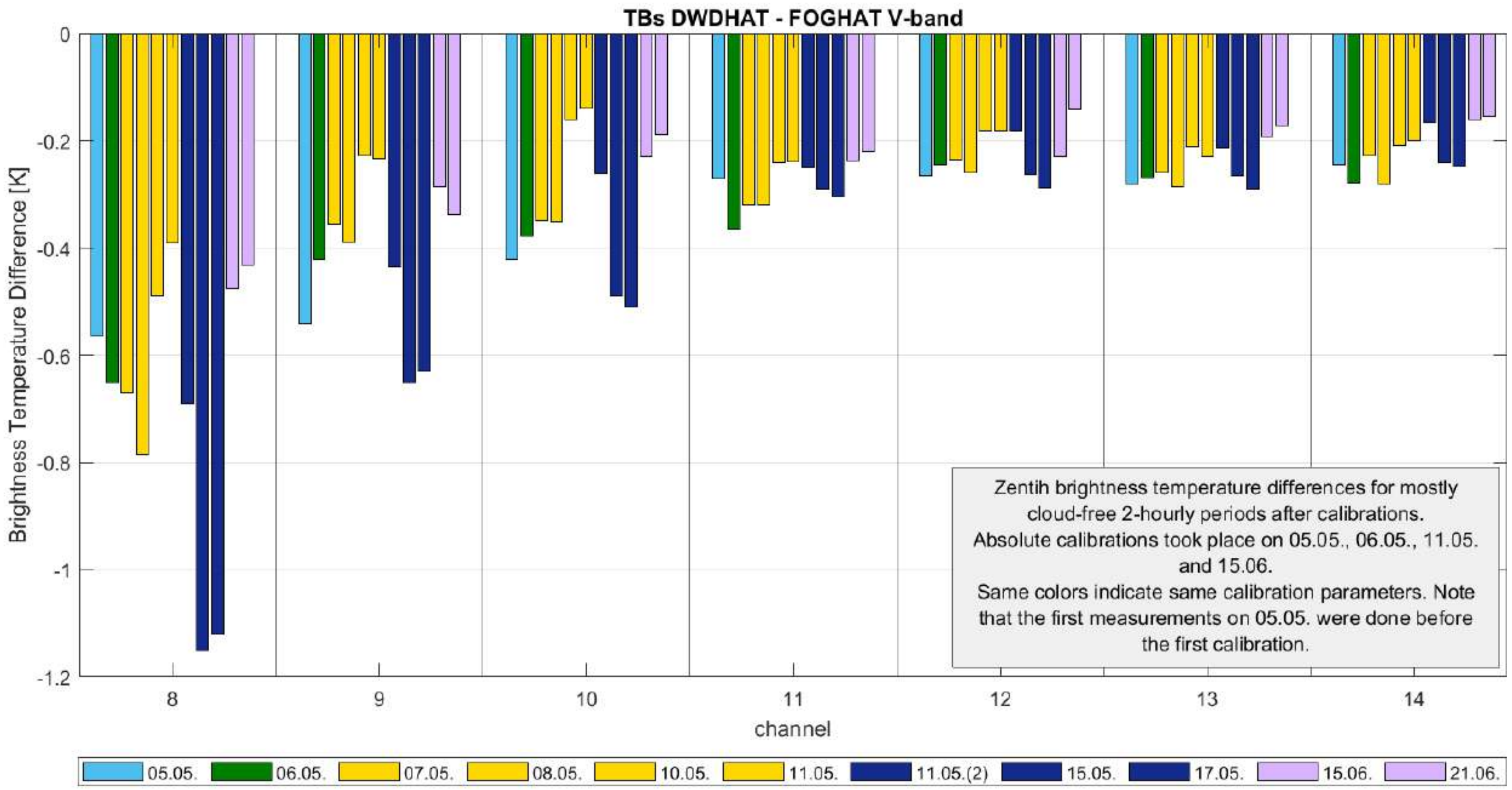


T_B Biases/Offsets via zenith comparisons



→ Two co-located G5 HATPROs looking zenith during several 2 hour clear-sky periods

T_B Biases/Offsets via zenith comparisons

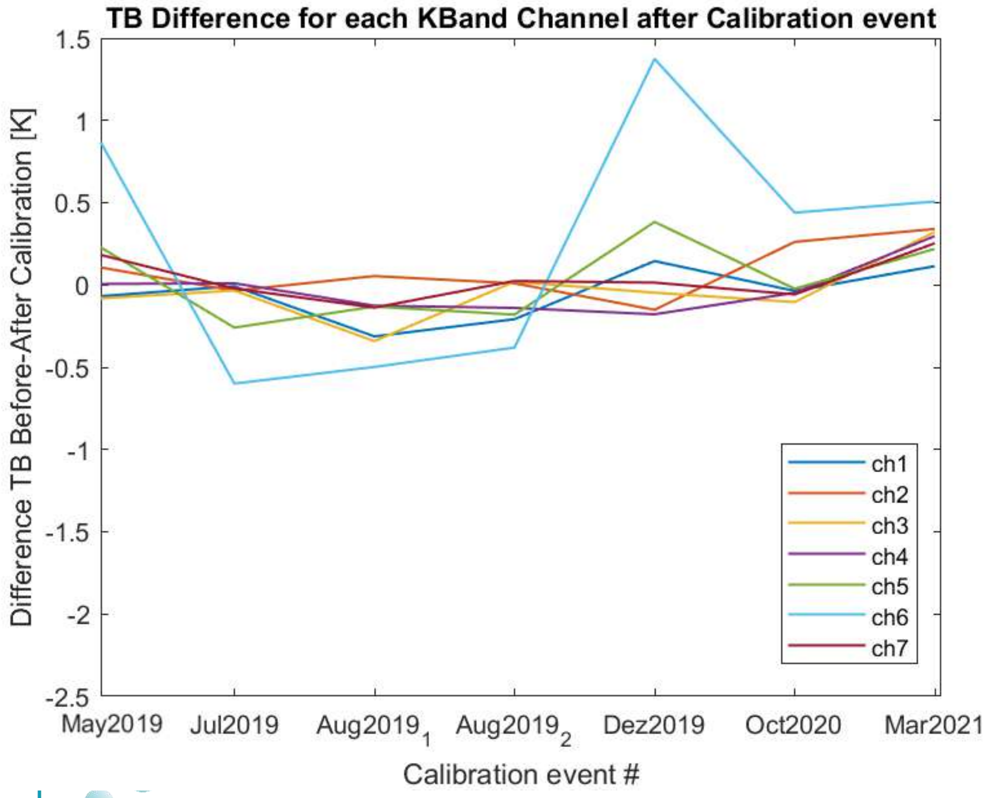


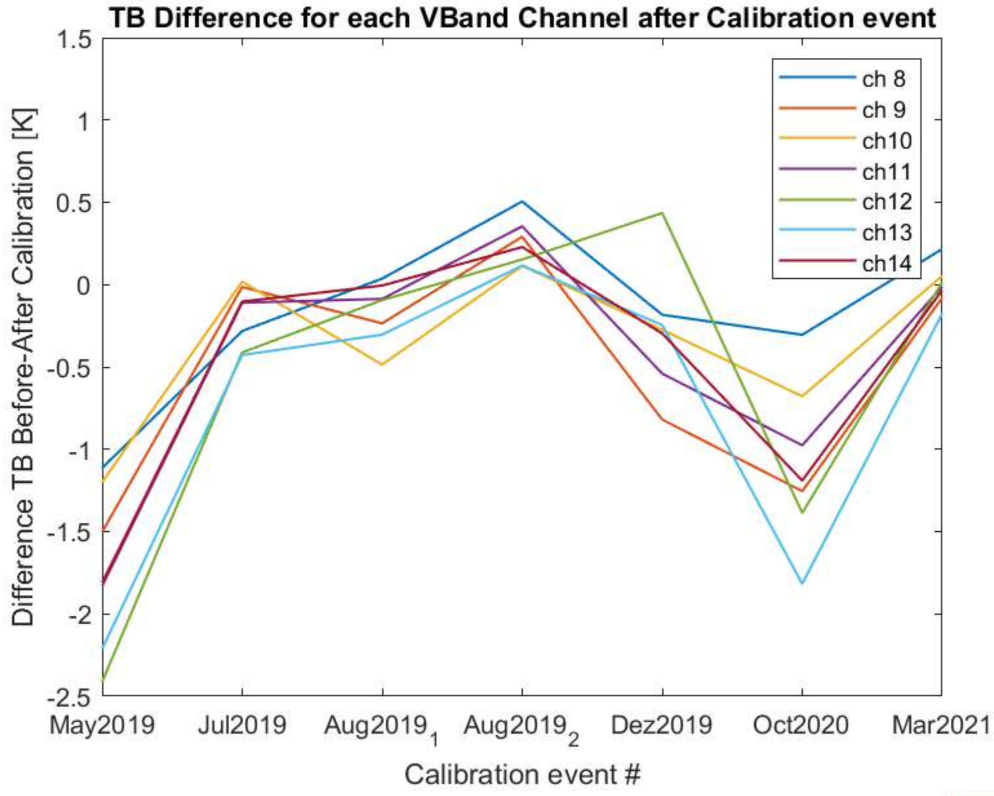
→ Biases/Offsets can be reduced by better LN2 calibrations, however some systematic differences remain, especially in V-Band

→ All errors are relative, there is no perfect absolute reference

Long-term drifts

- Calculated by looking at brightness temperature differences at one radiometer (TOPHAT) at JOYCE. Calibration frequency between 2 and 10 months. Can be determined at every LN2 calibration > will be monitored in ACTRIS



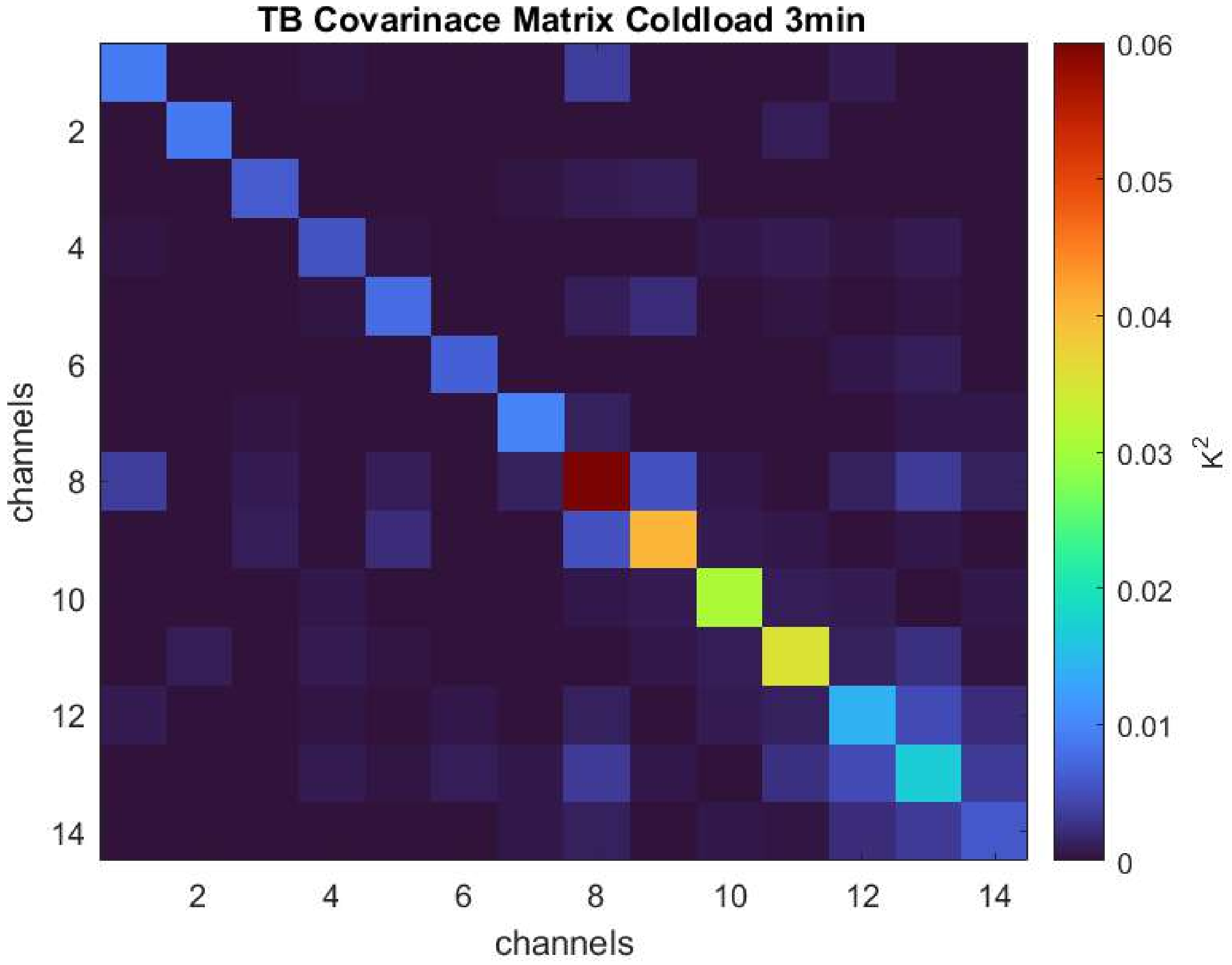


ACTRIS

Universität zu Köln

Channel covariances

- **Correlated radiometric noise** for all 14 channels (shows dependency of these channels)
- The radiometric noise for a single channel can be determined by calculating the variance when looking on a stable blackbody target
- Highly correlated channels are of little use for retrievals and data assimilations as they don't contain additional information



Universität zu Köln

Summary of uncertainties

Type of Error	Typical Error Values K-band	Typical Error Values V-band	Determined via	Error influenced by handling?	How to reduce error?
Biases/Offsets	**usually ≤ 0.3 K (up to 0.48 K)**	**usually ≤ 0.5 K (up to 1.1 K)**	Zenith measurement differences between two MWRs	yes	Quality of calibration
Drifts (over 6 months)	**usually ≤ 0.3 K (up to 0.6 K)**	**usually ≤ 0.8 K (up to 1.3 K)**	Leaps at coldload after calibration	no	Frequency of calibration
Calibration Repeatability	**≤ 0.12 K**	**≤ 0.24 K**	Leaps to zenith reference measurements after two immediate consecutive calibrations	yes	Quality of calibration
Noise Levels (coldload – hotload) (1s)	**≤ 0.11 K – 0.18 K**	**≤ 0.27 K – 0.35 K**	Standard deviation of hot/coldload observations	no	Not possible, instrument specific

HATPRO calibration strategy in ACTRIS

- Common standards for automatic calibration depending on instrument type and generation (MWR SOPs)
- Absolute calibration to be performed every 6 months
- Continuous performance monitoring at ACTRIS data centre
  - housekeeping parameters
  - calibration log-files
  - O-B statistics with model
  - spectral consistency checks

may determine and change calibration intervals

- Online: HKD data evaluation (temperature stability of receiver, ambient target temperature, etc.)

- Every absolute calibration:
  - Logbook entry by operator (still need to be defined)
  - HATPRO software will provide files with covariances and log-files for calibration and performance monitoring
  - *.LOG files from Calibration to be sent to Data Centre

ACTRIS

Universität zu Köln

Thank you