ACTRIS

CCRES Cloud Radar Calibration Strategy

CCRES Workshop – September 21, 2021

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

Introduction

- One of CCRES objectives is to guarantee the quality of all cloud radar measurements in the ACTRIS network

- However, cloud radars are complex instruments with intensive calibration needs

- Hence, it is necessary to develop a strategy to:
  - Calibrate the Cloud Radars of the ACTRIS infrastructure
  - Track the measurement quality of every instrument in the network
  - Manage the resources available for these tasks

- This presentation reviews recently developed calibration methodologies and proposes a first strategy that could be implemented in the ACTRIS network

Contents

Calibration tracking based on disdrometer measurements

Disdrometer calibration tracking

- **Objective** : develop a method to compare reflectivity (Ze) (1) measured by the Doppler Cloud Radar (DCR) with (2) derived from disdrometers to frequently monitor in time shifts, drifts and deviations of the DCR Calibration Constant (CC)
- **Instrumental setup** :

Disdrometer (DD) : measure the rain drop size distribution and fall velocity to derive the reflectivity (Ze) at the surface

Rain-Gauge (RG) : check the DD measurement and detect start/end of the rain event

Doppler Cloud Radar (DCR) : measure profile of Ze (between some tens of meters and several km) with an « a-priori » Calibration Constant that will be checked

: already analyze with python code developped by MA. Drouin

: to be done

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Disdrometer calibration tracking

- **Questions and assumptions**
  - **Disdrometer representativity compared to the Doppler Cloud radar**
    - Delay between DCR Ze sampling and the DD retrievals : use of the DCR fall velocity ;
    - Volume sampling/Heterogeneity of the precipitation : use of a long lasting rain event and of the first reliable gate of DCR (<200m) ;
    - Heterogeneity of sensors and DSD uncertainty / truncation : compare consistency between sensors (DD vs RG and DD vs DD), use specific rain event (RR range, cumulated rain)
  - **Doppler Cloud radar assumptions/corrections**
    - Rain attenuation correction along the vertical : parametrical correction can be applied
    - To be considered when defining "closest" reliable DCR gate for comparison : near field effects, overlap corrections, Transmitter-Receiver interferences (cross-talk)
    - Wet radome attenuation correction : use a very efficient blower until a certain rain rate to have a dry radome... but how to validate?, or use parametrical correction to account for the drop on the radome

Disdrometer calibration tracking

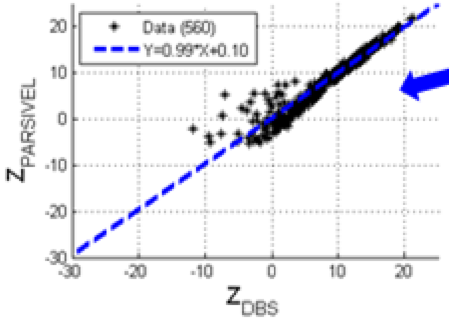
- **Method**

Select precipitation event (RR range, cumul., duration, Ta_{min}, min and max WS etc.)

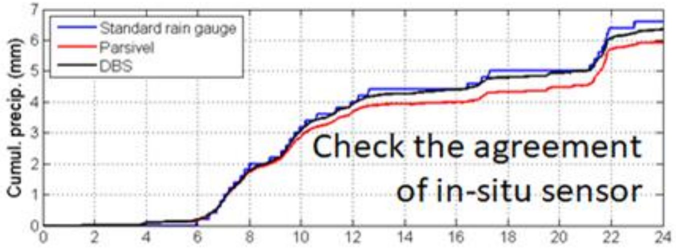
SPEED_MEAN_MAX	7 m/s
SPEED_MAX	10 m/s
TEMPERATURE_MIN	2 °C

	Minimum time between two events	Minimum rain sum	Number_of_events
31	1 hour	0 mm	390
32	1 hour	1 mm	140
33	1 hour	1.5 mm	101
34	1 hour	2 mm	83
35	1 hour	2.5 mm	68
36	1 hour	3 mm	59
37	1 hour	3.5 mm	50
38	1 hour	4 mm	48
39	1 hour	4.5 mm	39
40	1 hour	5 mm	38

Validate the DD measurement (relation fall velocity vs size, DD vs RG, DD vs DD)



Check the agreement of DD



Ze processing with DSD (generic Python code dev. by MA. Drouin, raw data -> netcdf, data & metadata

$$Z = \frac{\lambda^4}{|K_W|^2 \pi^5} 10^{18} \int N(D) \sigma_{bsc}(\lambda, D, \rho) dD$$

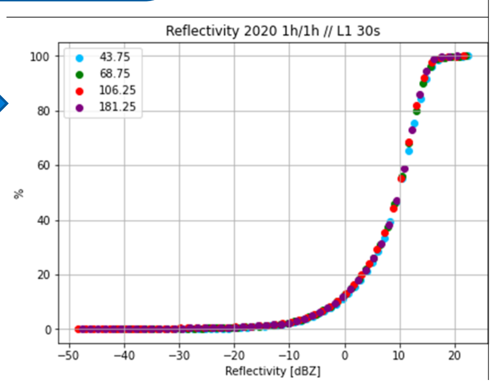
Drop size distribution N(D) is derived from **DBS2** and **Parsivel** measurements

Backscatter coefficients are derived with different assumptions:

- Rayleigh (not valid @ 95GHz)
- Mie (consider drops as sphere)
- **T-Matrix** (oriented spheroid, flatness information)

Leinonen, J., *Python code for T-matrix scattering calculations*
Mishchenko, M. I. and L. D. Travis, T-matrix computations of light scattering by large spheroidal particles, *Opt. Commun.*, vol. 109, 16-21 (1994)

Closest and reliable gate for DCR



Comparison for each "good" Rain event (median, mean, slode, R^2, RMSE)

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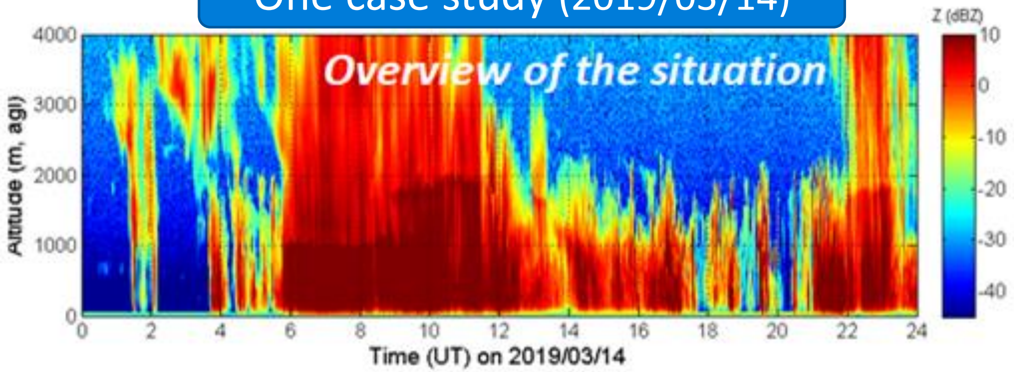
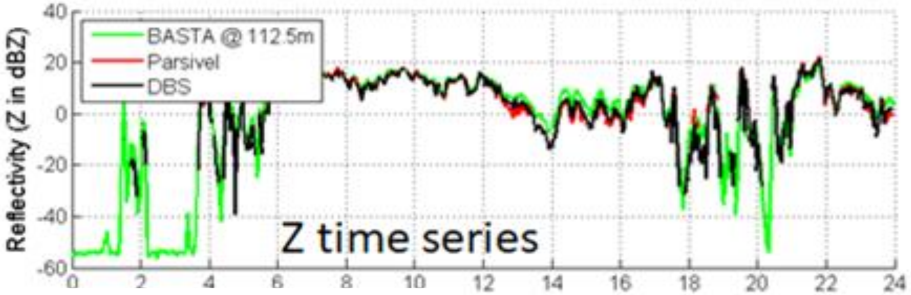
Disdrometer calibration tracking

- **Results**

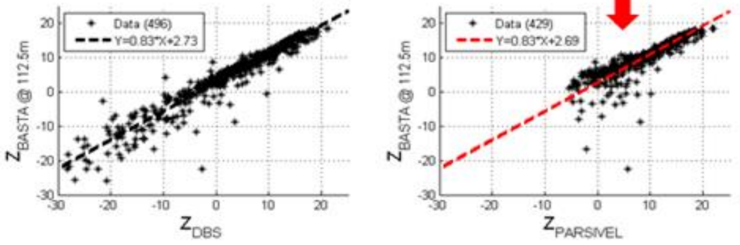
One case study (2019/03/14)



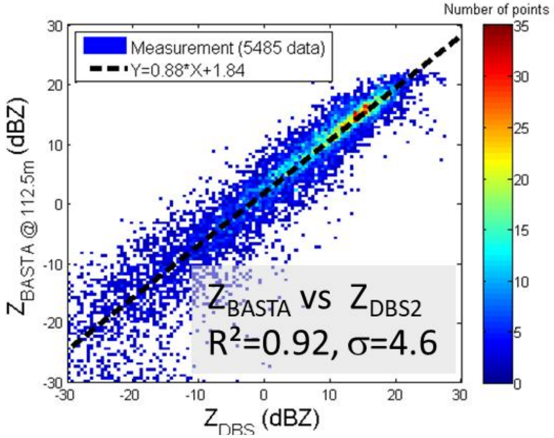


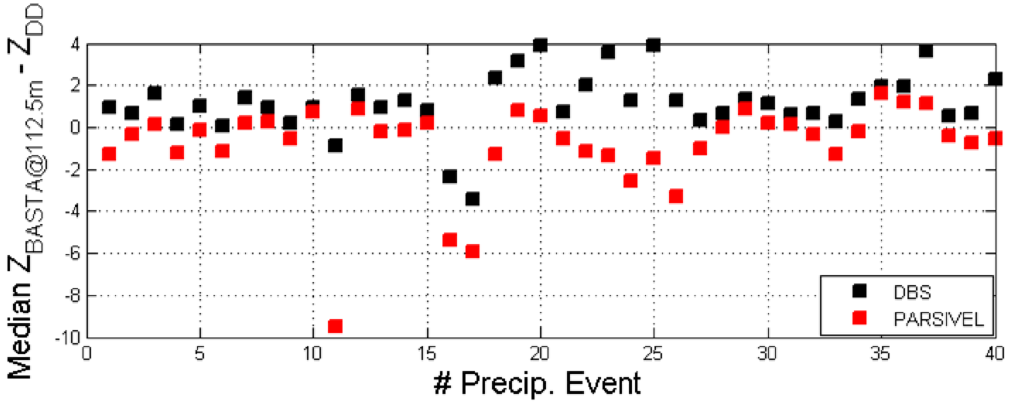
Relation Z_{BASTA} / Z_{DBS2}

Relation Z_{BASTA} / $Z_{Parsivel}$



Statistical results for 2019



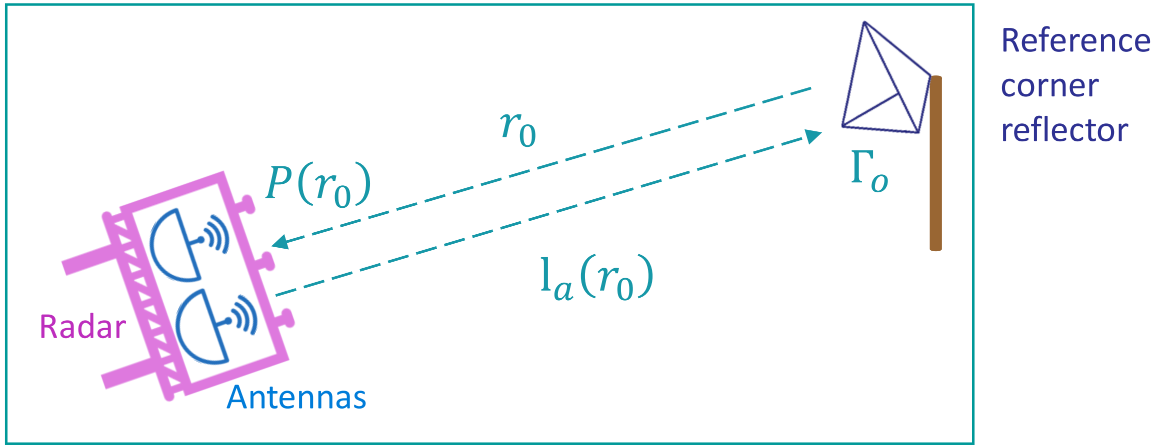


Absolute calibration method based on corner reflectors

Absolute calibration using corner reflectors

- Method developed during 2017, 2018 and 2019 cloud radar calibration campaigns
- Uses **corner reflectors** as **absolute references** to retrieve the radar **calibration constant**
- Current version of the method enables the **identification** and **quantification** of most **bias** and **uncertainty** sources

Calibration setup



Calibration constant (C.C.) retrieval based on an absolute reference

$$C.C. = \underbrace{\frac{8 \ln 2 \ \lambda^4 10^{18}}{\theta^2 \pi^6 K^2 \delta r}}_{\text{Radar Parameters}} \underbrace{\frac{\Gamma_0}{l_a^2 r_0^4 \mathrm{P_r(r_0)}}}_{\text{Calibration variables}}$$

Absolute calibration using corner reflectors

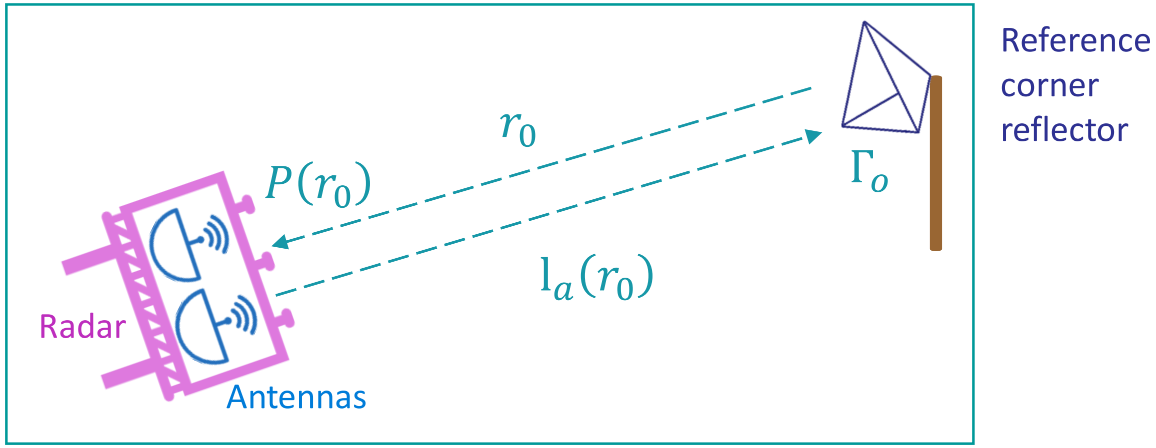
- A typical setup involves the installation of a low cross-sectional mast several hundred meters away from the radar
- Relatively controlled conditions enable the quantification and estimation of bias and uncertainty sources

Absolute calibration using corner reflectors

Uncertainty sources

$$C = \underbrace{\frac{8\ln 2\ \lambda^4 10^{18}}{\theta^2\pi^6 K^2 \delta r}}_{\text{Radar Parameters}} \underbrace{\frac{\Gamma_0}{l_a^2 r_0^4 \mathrm{P_r}(\mathrm{r_0})}}_{\text{Calibration variables}}$$

Calibration setup



Uncertainty sources:

Antennas properties
- Beam lobe shape
- Beam overlap
- Beam width

Radar

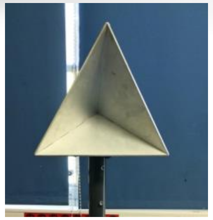
Radar gain variations
- Impact of temperature
- Non ideal IF filters

$P(r)$: Sampled power
- Receiver compression

Reference corner reflector

Γ_o: Reference target Radar Cross Section (RCS)
- Theoretical value
- Clutter
- Alignment

Calibration using corner reflectors: Uncertainty Characterization

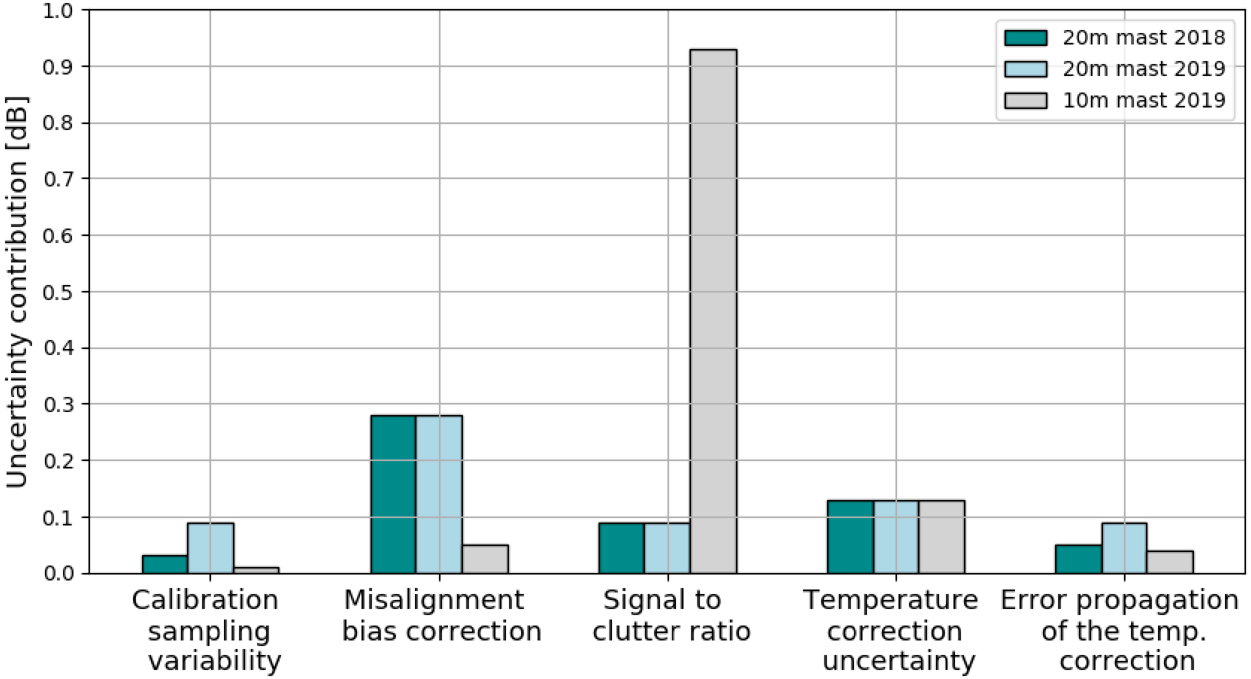


BASTA-mini Cloud Radar

10 m mast + 10 cm corner reflector

20 m mast + 20 cm corner reflector

Uncertainty budget for three different experiments



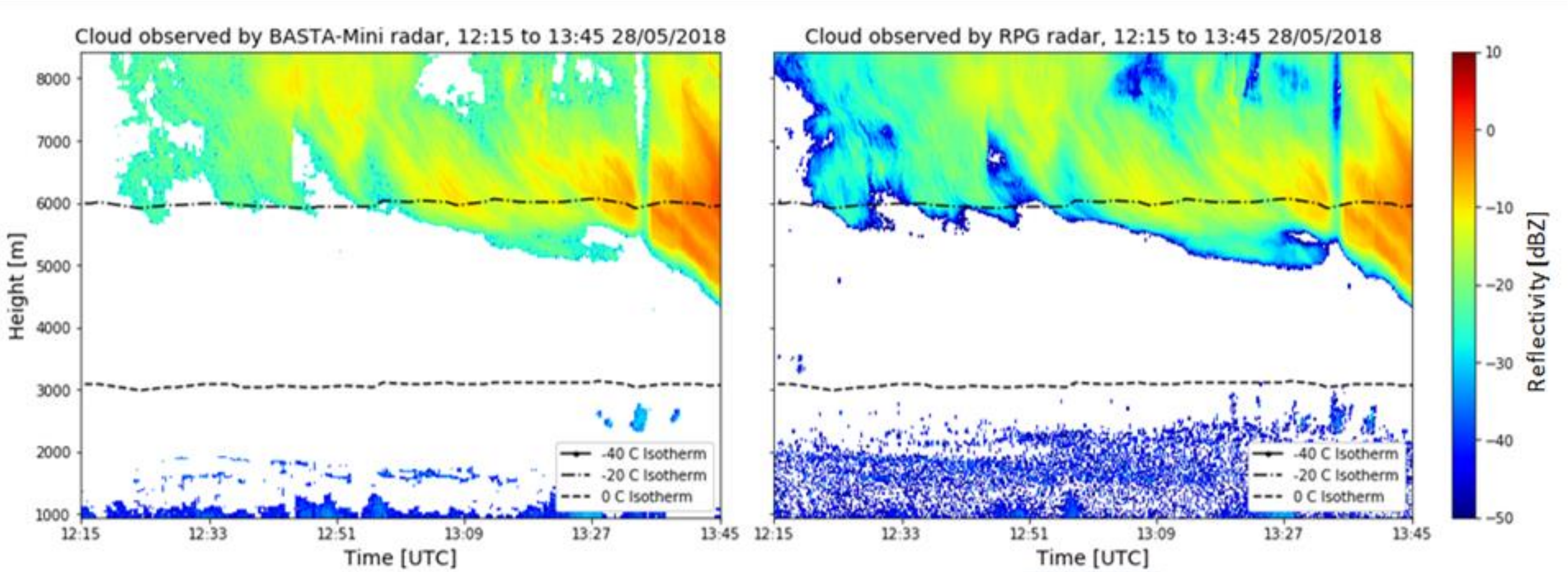
Calibration transfer by simultaneous sampling of clouds

Calibration Transfer

- Objective: To correct the measurements of a cloud radar based on a reference instrument:

$$Z^{uncalib}(r) + K = Z^{corrected}(r)$$

- Method: The comparison of simultaneous cloud measurements



In this example:
Reference radar: 95 GHz BASTA-Mini
Uncalibrated radar: 94 GHz RPG

Reference radar

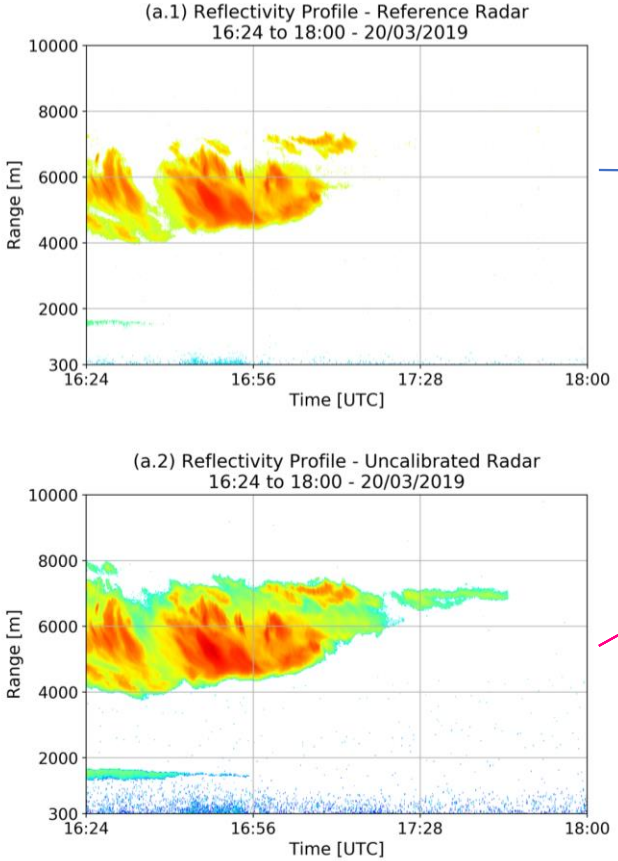
Uncalibrated radar

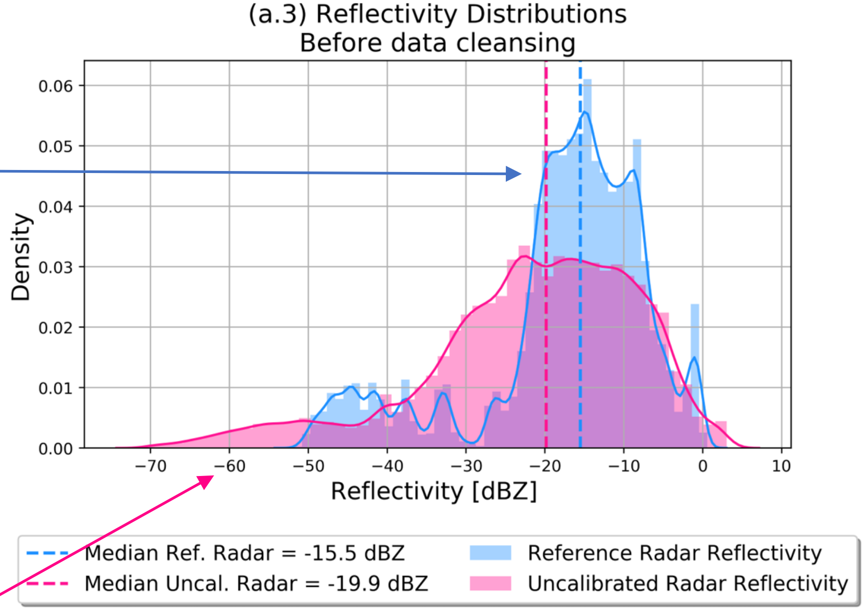
Calibration Transfer

- When radars do not have the same sensitivity, data comparison is not straightforward

Reference radar

Uncalibrated radar





Differences between the instruments
→ Reflectivity distributions do not have the same shape

Reflectivity distributions cannot be directly compared, data must be processed

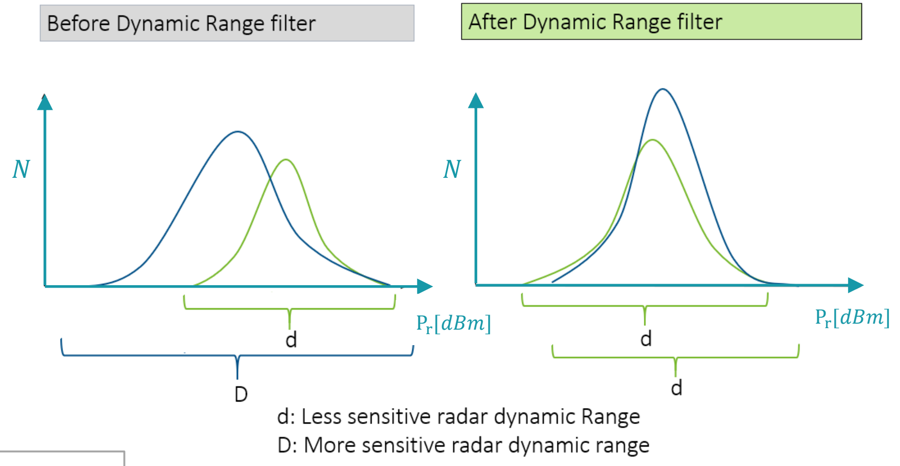
Calibration Transfer: Methodology

0. Cloud period selection → No precipitation / Dry radome

1. Boundary Layer Removal → Source of highly variable, inhomogeneous data (airbone plankton)

2. Three-sigma filter

3. Dynamic Range Filter → Filter data from the most sensitive radar to match the dynamic range of the less sensitive one

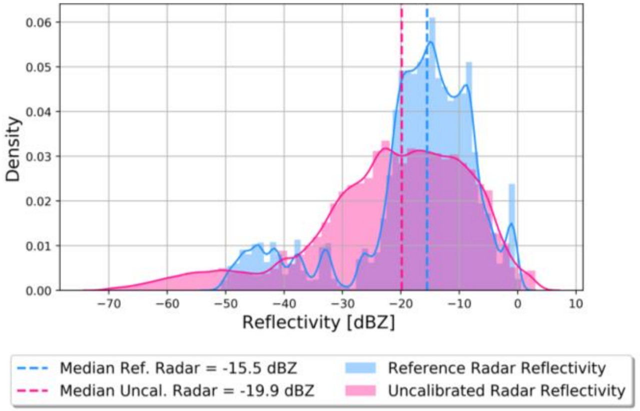


4. Interpolation → Uncalibrated radar data is interpolated to match the reference radar grid

5. Quality Control (Q-Q plot) → Compares the resulting distributions to decide if they are comparable (R^2 score better than 0.8)

Calibration Transfer: Methodology

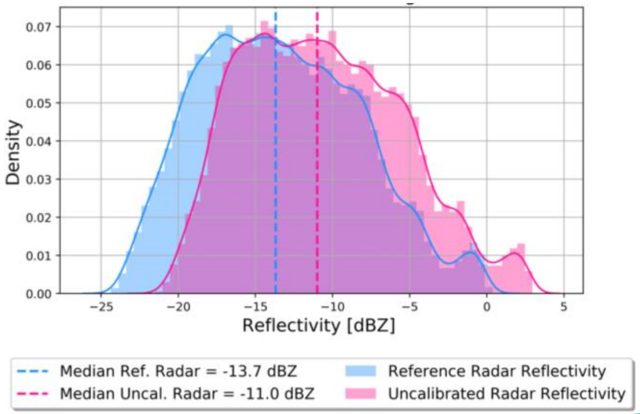
Original reflectivity distributions (different shape)



$\text{median}(Z^{ref})\text{-median}(Z^{uncal}) = 4.4\ dB$

Data processing to remove non comparable measurements

Reflectivity distributions are now comparable



$\text{median}(Z^{ref})\text{-median}(Z^{uncal}) = -2.7 \pm 0.6\ dB$

$= K_i \pm \sigma_{K_i}$ correction coefficient sample

Using N cloud periods

Correction coefficient $K = \overline{K_i} \pm \delta K$

$$Z^{corrected}(r) = Z^{uncalib}(r) + K$$

Standard error

Error propagation from each K_i

Reference radar calibration uncertainty

$$\delta K = \sqrt{\frac{\sigma_{\overline{K_i}}^{2}}{N} + \left(\frac{1}{N^2}\sum_{i=1}^{N} {\sigma_{K_i}}^2\right) + {\sigma_r}^2}$$

Calibration Strategy

First ACTRIS Cloud Radar network calibration strategy

Central facilities

- Absolute calibration of a portable **reference radar**
- **Transportation of the reference radar to the NFs**, to calibrate their instruments using the **calibration transfer** method

All facilities

- **Calibration tracking** using disdrometers on site
- Provide infrastructure to install the reference radar close to their instruments
- Implementation of absolute calibration methods is optional

Research and perspectives

Research and perspectives

Some limitations have been identified from the results of our calibration experiments:

- There is a need for an absolute characterization of the reference reflector, **to reduce the uncertainty of the reference radar**

- Calibration transfer works between radars on the same frequency band:
    - Need for calibration transfer methodologies for radars in different frequency bands (Ka to W band and vice-versa), **to calibrate all radar types**

- Need for new absolute calibration methods with lower infrastructure requirements, **to enable absolute calibration experiments at NFs**

- Antenna pointing and alignment characterization must be improved

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Reference Reflector Characterization

- Corner reflectors have an RCS that depends on the beam incidence angle and the signal frequency
- At present, calibration experiments use its theoretical value, calculated using geometric equations

10 cm corner reflector used in the calibration experiments

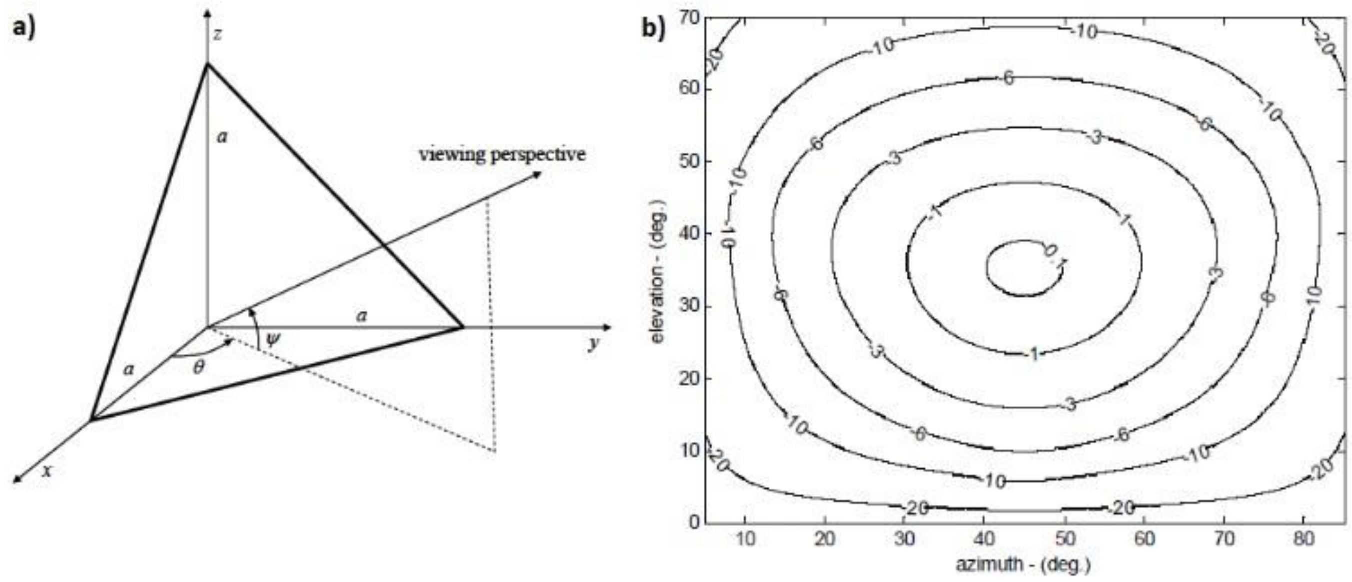
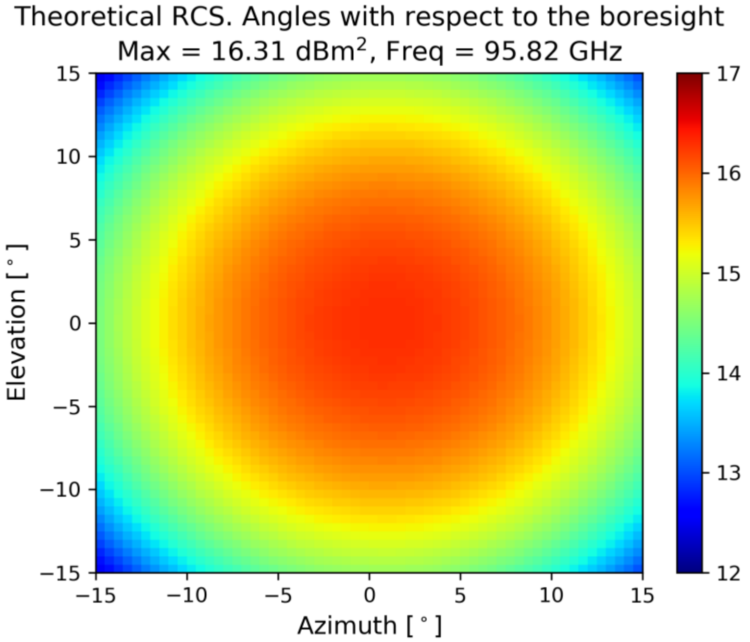


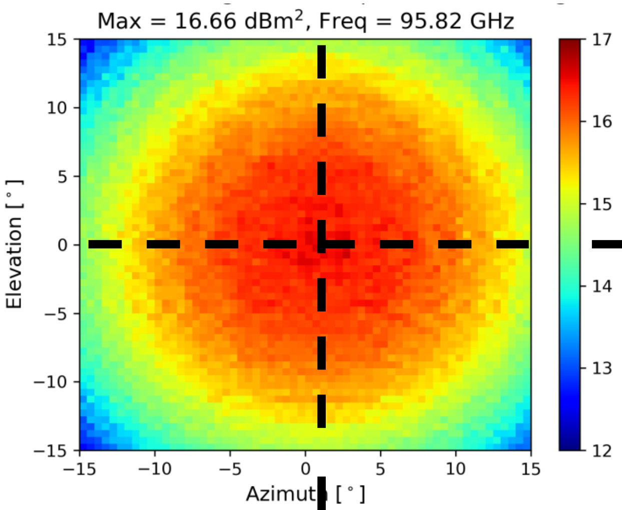
Figure 2.7: a) Viewing geometry of a trihedral CR at boresight. b) The RCS response of a triangular trihedral CR as a function of azimuth (θ) and elevation (ψ) angle relative to the peak RCS. a is known as the inner leg dimension. After Doerry and Brock [2009].

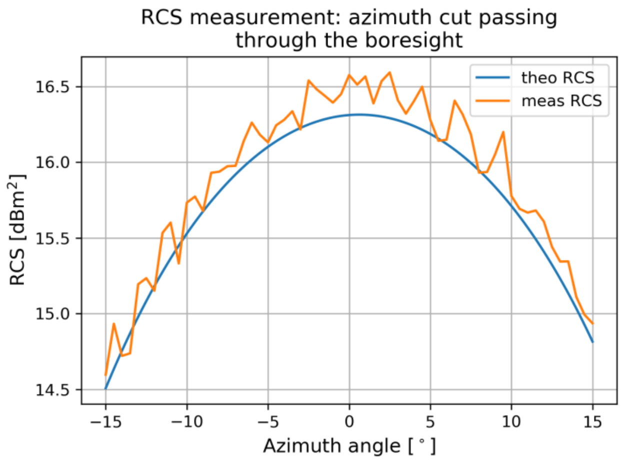


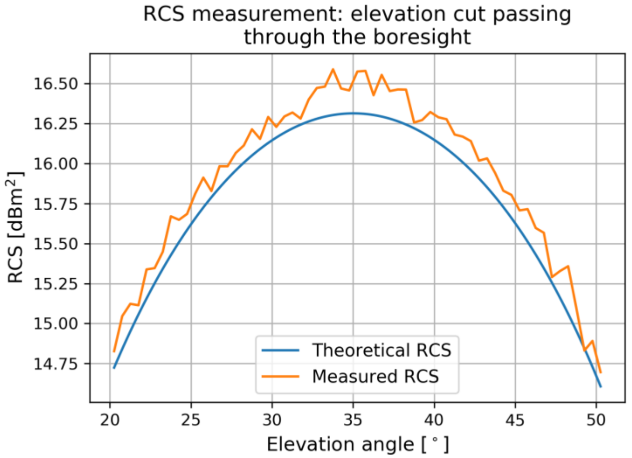
Reference Reflector Characterization

- First characterization of the 10 cm corner reflector in an anechoic chamber (University of Rennes)
- Identified a slight misalignment of 0.6° corrected using the theoretical model
- Measured RCS is ~0.4 dB above the theoretical value
- The measured curve shape matches the theoretical RCS with an RMSE of 0.2 dB
- The difference between the measured and theoretical RCS is within the [-0.25, 0.43] dB range

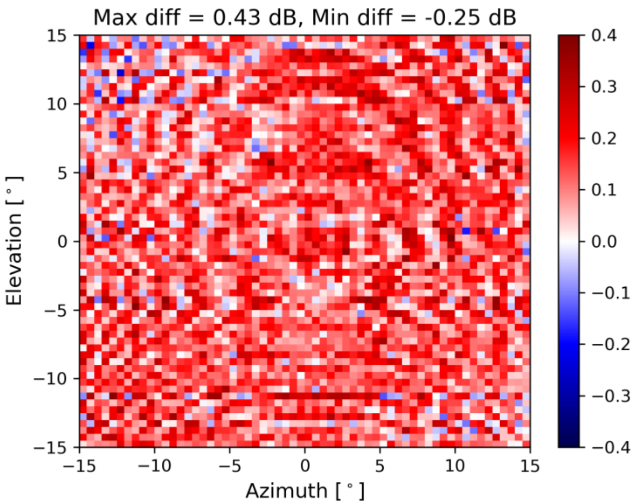
Measured RCS







Measured - Theoretical RCS



Research and perspectives

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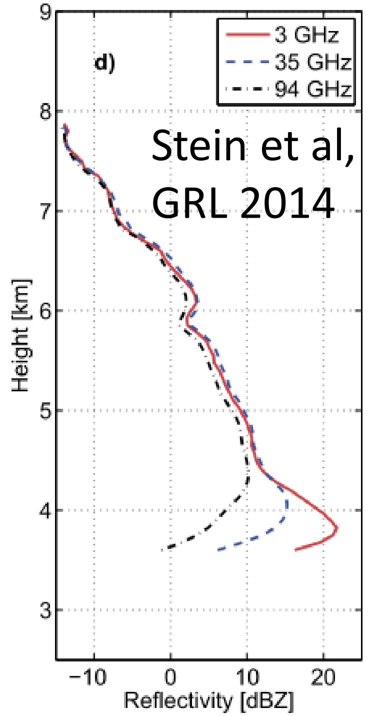
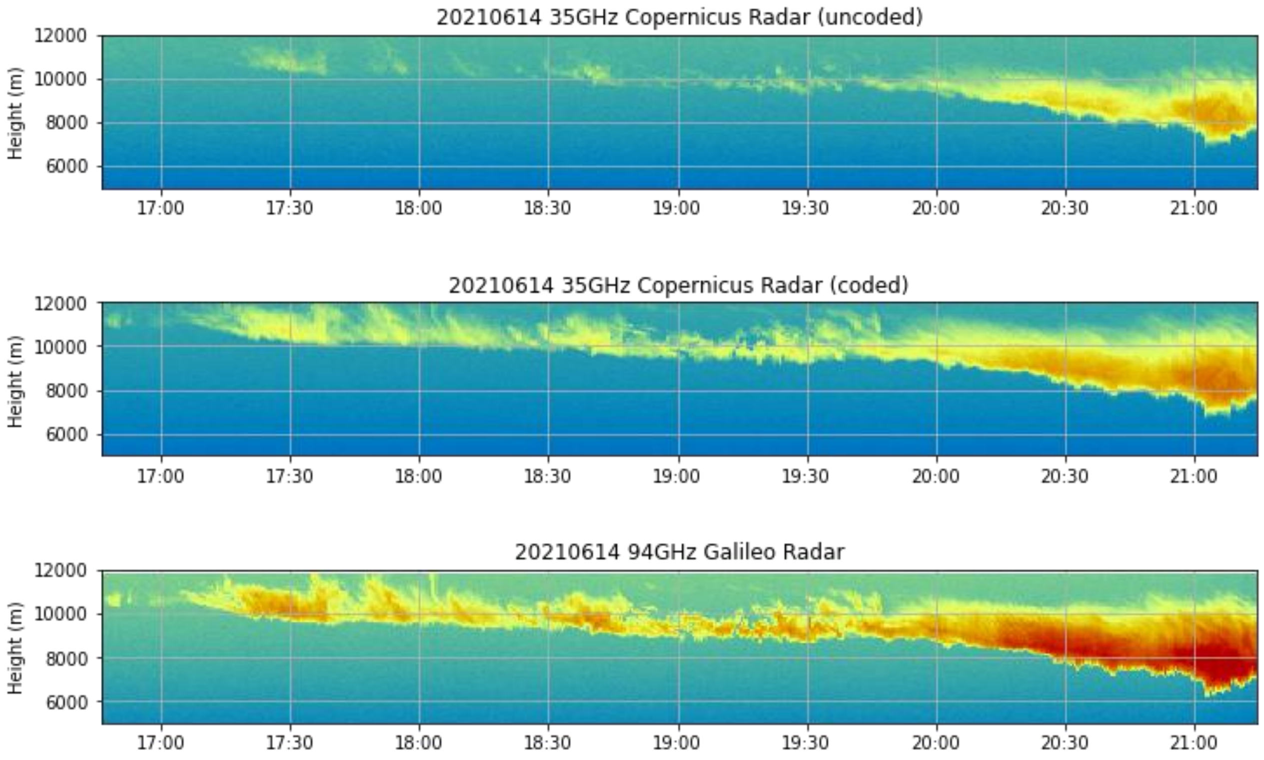
    - Need for calibration transfer methodologies for radars in different frequency bands (Ka to W band and vice-versa), **to calibrate all radar types**
- Need for new absolute calibration methods with lower infrastructure requirements, **to enable absolute calibration experiments at NFs**
- Antenna pointing and alignment characterization must be improved

35-94 GHz calibration transfer

Work in progress

- Methodology based on **matching reflectivity for Rayleigh scattering particles** near the **top of ice clouds.**
- Chilbolton work draws on previous calibration transfer methods (S-band to Ka- and W-band) developed at University of Reading [Nicol, Westbrook, Stein, Illingworth]

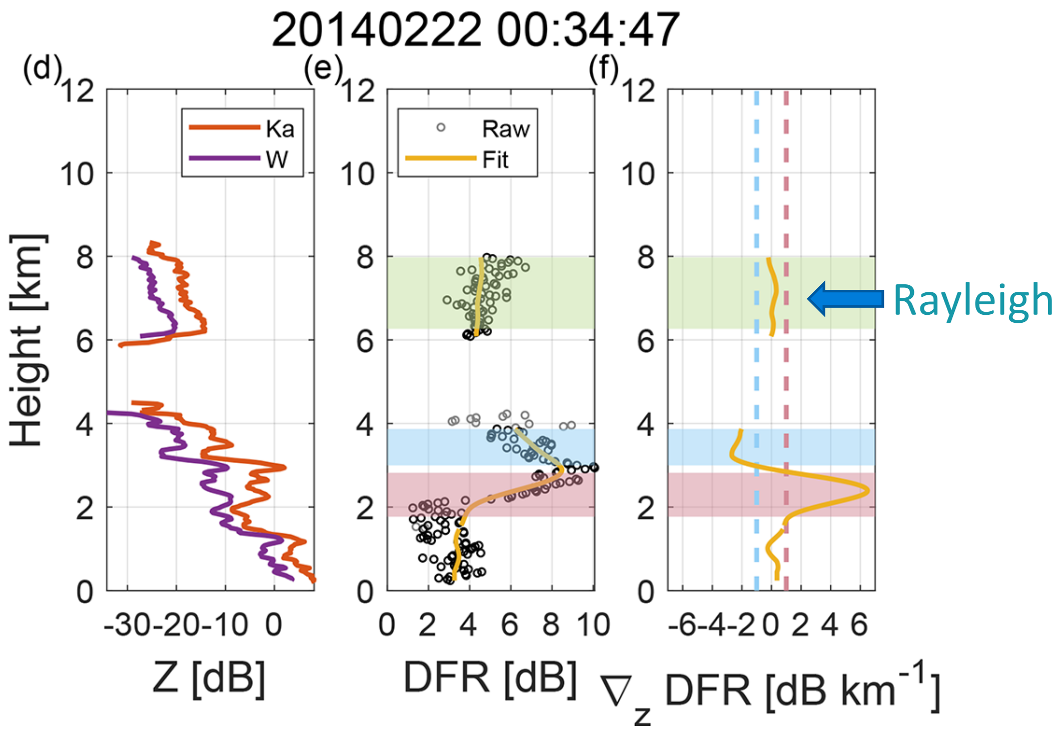




35-94 GHz calibration transfer

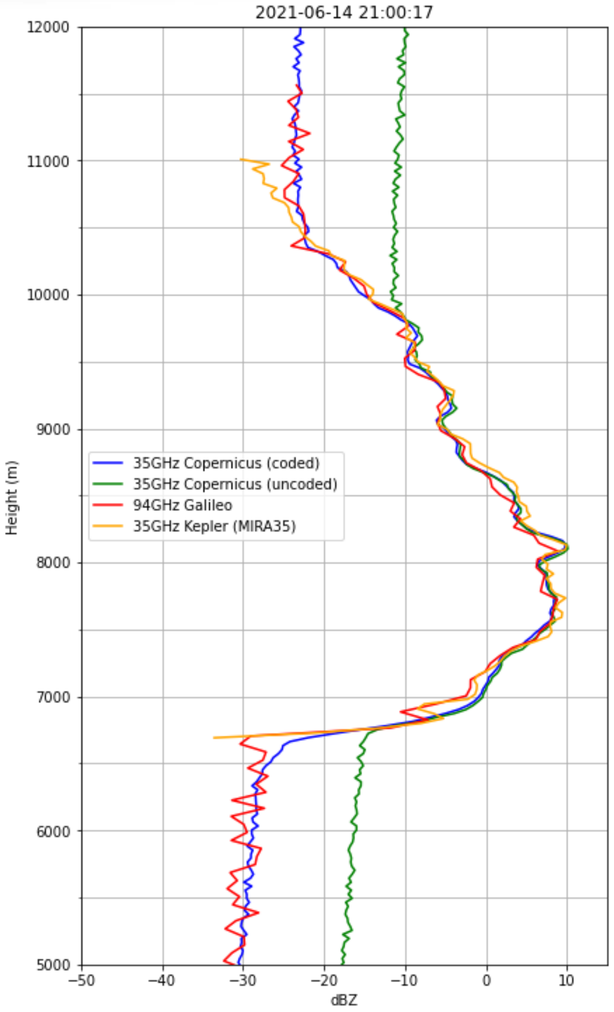
- **Points for attention**:
  - How to identify Rayleigh scatterers?
    - Simple reflectivity thresholding (such as $-10<dBZ_{94}<5$) can be problematic –
      e.g. low concentrations of larger particles can give similar reflectivity.
    - Use of velocities to assist in identifying the slowly falling smallest particles requires accurate zenith alignment to avoid bias from horizontal winds.
      Ties in with antenna pointing calibration work.
    - Potential to explore use of Dual Frequency Ratio (DFR) plateau method (Tridon et. al, AMT, 2020) for selection of Rayleigh regions.

Tridon, Battaglia & Kneifel, AMT, 2020



35-94 GHz calibration transfer

- **Points for attention**:
  - Need to account for two-way attenuation from liquid water and water vapour which differs for each frequency.
    - Standardization – Draw on CCRES experience with MWR and code base development in CLU.
  - Need to consider spatial separation of radars and determine time lags to synchronize cloud returns.
    - Ideally radars will be close together.
  - Need to consider dwell time and averaging times.
  - Need to consider relative sensitivity of the radars.



35-94/95-GHz Calibration Transfer

Workflow to be evaluated

0. Cloud period selection → No precipitation / Dry radome

1. Boundary Layer Removal → Source of highly variable, inhomogeneous data (airborne plankton)

2. Three-sigma filter

3. Dynamic Range Filter

4. Synchronization and range alignment → Uncalibrated radar data is interpolated to **fine time and range grid** with **rolling mean** to match the reference radar range bins and averaging/dwell times. → Lags in **time** and **range** identified to maximize correlation, and applied to uncalibrated radar data.

5. Interpolation → Synchronized and range aligned data from uncalibrated radar interpolated onto grid of calibrated radar.

6. Identification of Rayleigh scattering region

7. Quality Control → Compares the resulting distributions to decide if they are comparable

Research and perspectives

Some limitations have been identified from the results of our calibration experiments:

- There is a need for an absolute characterization of the reference reflector, **to reduce the uncertainty of the reference radar**

- Calibration transfer works between radars on the same frequency band:
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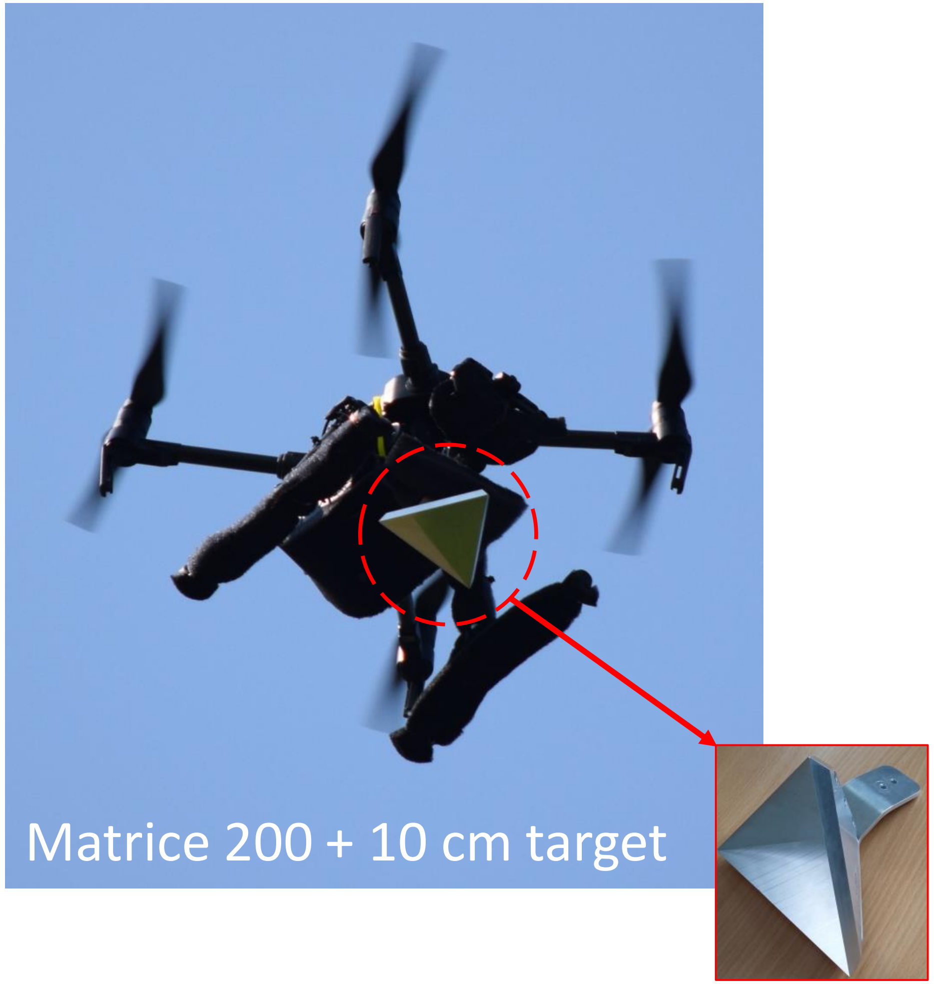
- Need for new absolute calibration methods with lower infrastructure requirements, **to enable absolute calibration experiments at NFs**

- Antenna pointing and alignment characterization must be improved

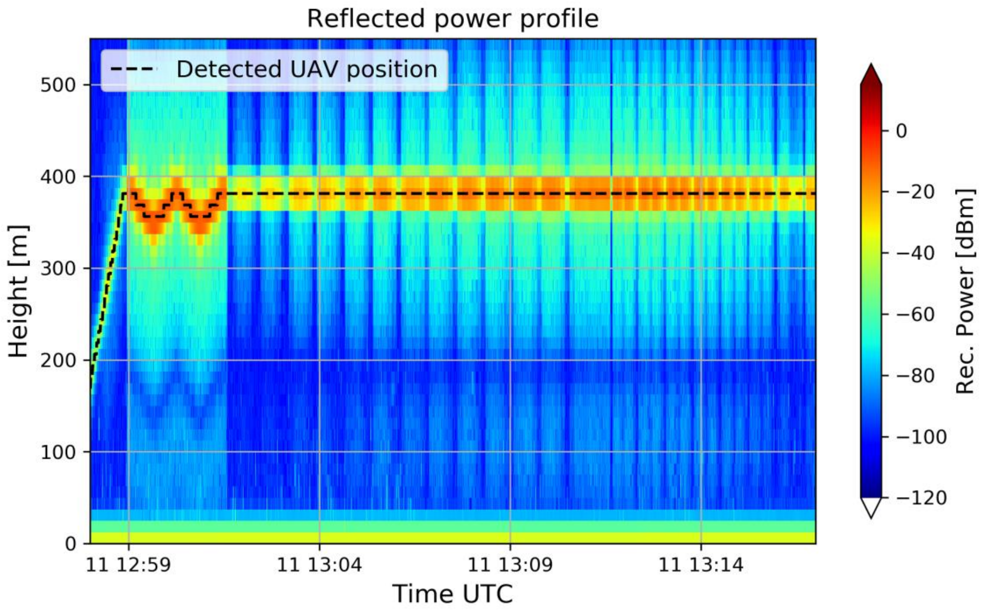
Calibration with UAV and corner reflectors

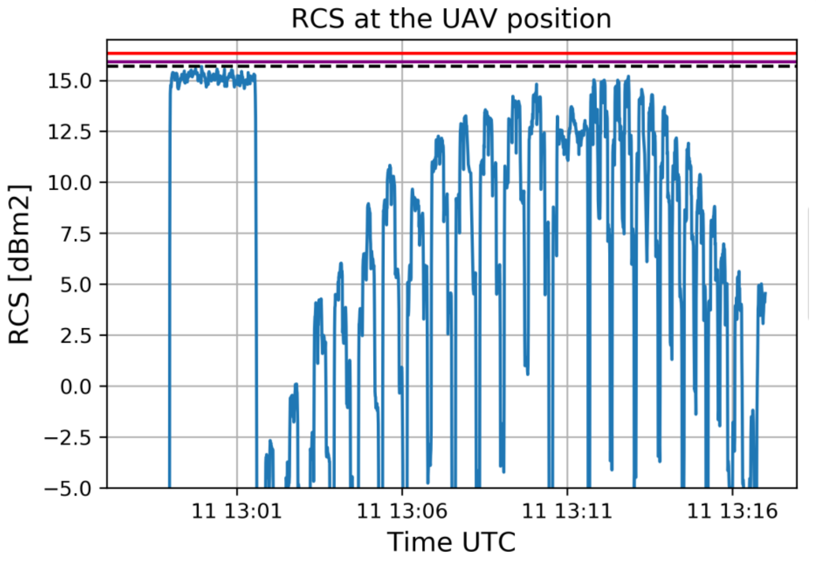
- UAV flies with the corner reflector above a vertically pointing radar
- Tested with the BASTA-mini radar in 2019 calibration campaign
- Main constrain: minimum distance to the radar.
  - Saturation
  - Antenna overlap
  - Antenna near field
- The UAV flew ~400 m above the radar to avoid these issues (safe distance)

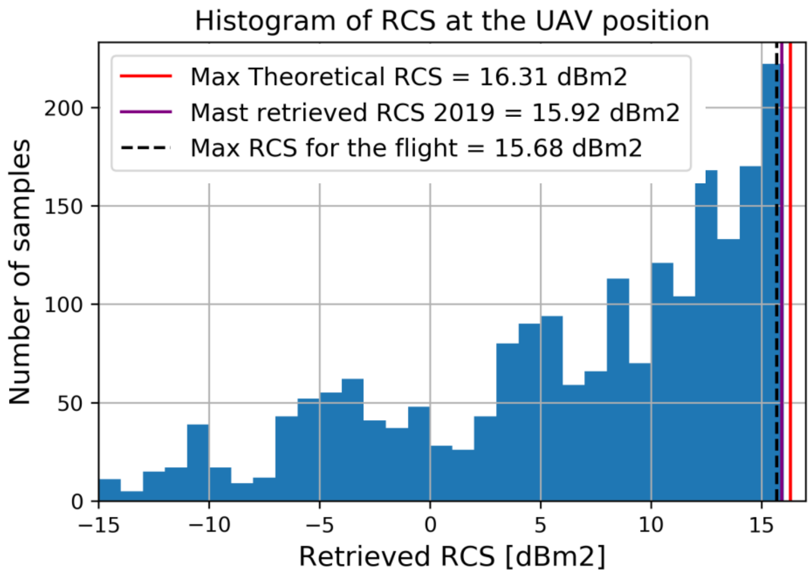


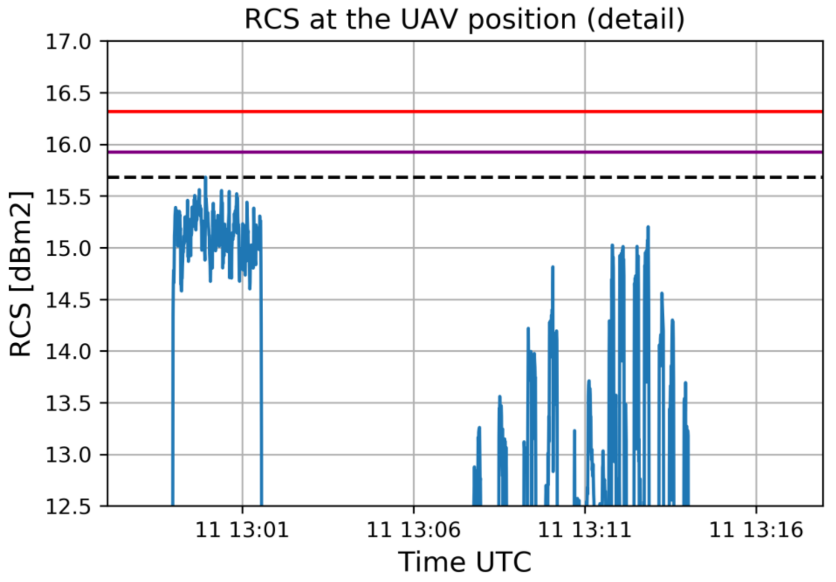
RCS sampling of the 10 cm target: UAV flying 400 m above the radar

- RCS is retrieved using the 20 m mast calibration (best)
- Measured **RCS** for the **10 cm target** on the **10 m mast = 15.9 ±0.9 dBm2**
- **7 flights** provided a maximum observed **RCS = 15.4 ± 0.2 dBm2** (range [15.1, 15.7])
- The method enables a consistent retrieval of the target RCS -> the setup can be used for calibration









RCS sampling of the 10 cm target: Clutter

- Signal to clutter ratio (SCR) indicated the uncertainty introduced by reflections on objects other than the target

- The drone base was covered with absorbing material to reduce its RCS (clutter)

- SCR without absorber = 13.8 dB
  - Introduces $[-2,+1.6]$ dB of uncertainty

- SCR with absorber = 19.0 dB
  - Introduces $[-1.0,+0.9]$ dB of uncertainty

UAV calibration with corner reflectors: conclusions

- The sampling of the 10 cm target on the UAV matches previous observations done on top of the 10 m mast

- The repeatability of the result indicates that this is a feasible calibration method

- Signal to clutter ratio (SCR) should be improved by a few dB.
  - 3 more dB of SCR would reduce uncertainty contrib. to ± 0.7 dB
  - Absorbing material shows promising results.
  - Bigger targets at farther distances are also an option

Research and perspectives

Some limitations have been identified from the results of our calibration experiments:

- There is a need for an absolute characterization of the reference reflector, **to reduce the uncertainty of the reference radar**

- Calibration transfer works between radars on the same frequency band:
    - Need for calibration transfer methodologies for radars in different frequency bands (Ka to W band and vice-versa), **to calibrate all radar types**

- Need for new absolute calibration methods with lower infrastructure requirements, **to enable absolute calibration experiments at NFs**

- Antenna pointing and alignment characterization must be improved (presentations of Lukas Pfitzenmaier et al., Matthias Bauer et al.)

Cabauw Cloud Radar Calibration Campaign 2021

To be held in Cabauw, The Netherlands on October 2021

Topics:

- Calibration tracking using disdrometers
- Testing of the Corner Reflector calibration technique on RPG Cloud Radars
- Closure study between corner reflector and calibration transfer methods
- Calibration transfer between different radar frequencies:
    - 1 RPG W band
    - 1 RPG W/Ka band
    - 1 BASTA-mini W band

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Calendar of future activities

Calendar

- Cabauw cloud radar calibration campaign 2021
- Implement disdrometer calibration tracking by 2022
  - Communicate disdrometer data by 2022
- Operational proof of concept of the calibration strategy by 2022
  - Calibrate 1-2 NF other than CCRES centers
- Calibrate ~5 NF per year by ~2024 (continuous operation)

CCRES Calibration Strategy

ACTRiS

Microwave radiometer calibration

Bernhard Pospichal,
Tobias Böck

CCRES Workshop – September 21, 2021

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

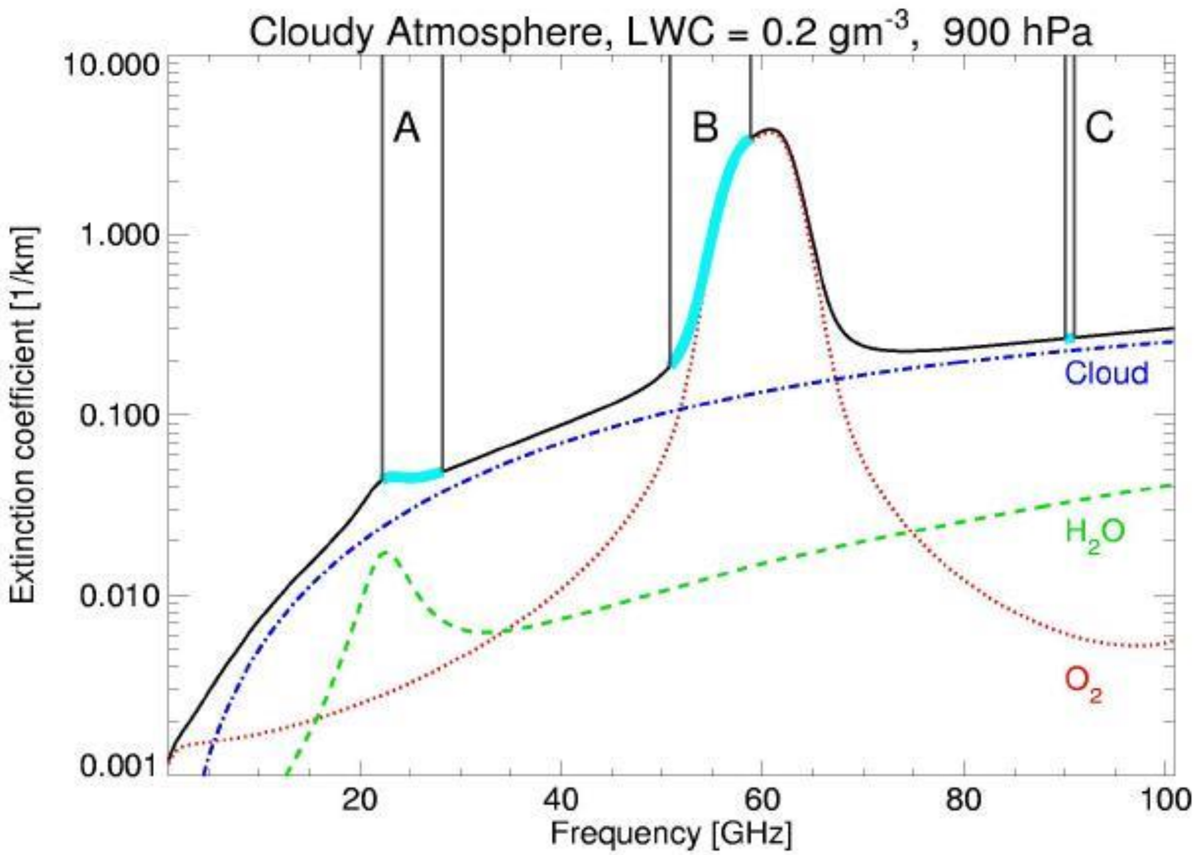
Ground-based microwave radiometry

- Overview
- Microwave radiometer (MWR) introduction
- MWR calibration
- Calibration campaign Lindenberg May 2021

What does a MWR „see“?

Measurement of downwelling radiation usually in one to three frequency ranges between 20-100 GHz (example RPG-HATPRO)

- A: 22.235 –31.4 GHz, 7 channels on the upper wing of the water vapor line as well as window channels
- B: 51.26 – 58.0 GHz, 7 channels along the 60 GHz oxygen absorption complex
- Some radiometers have only one band, some measure also at higher frequencies (for low-humidity conditions)

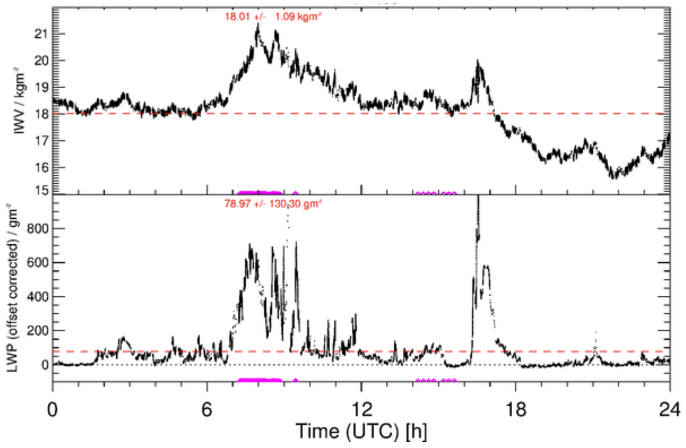


Measured radiances are expressed in „brightness temperature“

What do we want to get from a MWR?

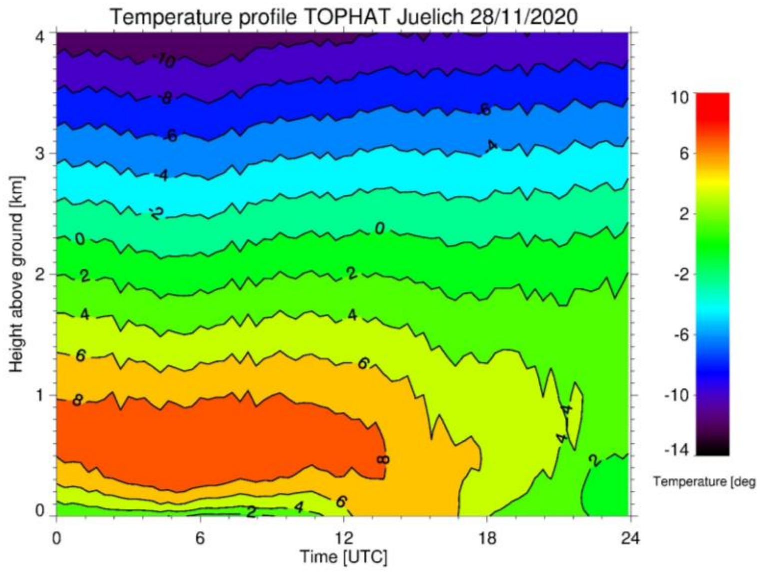
continuous data: resolution of seconds to minutes

path-integrated **cloud liquid water (LWP) and water vapor (IWV)**



low resolution **water vapor profile**, but excellent path-integrated values

temperature profile of the PBL, low resolution profile above



- level1: brightness temperatures (TB) → calibration dependent
- level2: atmospheric products → forward model and retrieval dependent

Ground-based microwave radiometers

Benefits

- Continuous long-term, unmanned observations on temporal scales down to seconds → fill gaps between radiosondes
- Measurements during both cloudy and clear air
- Commercial availability

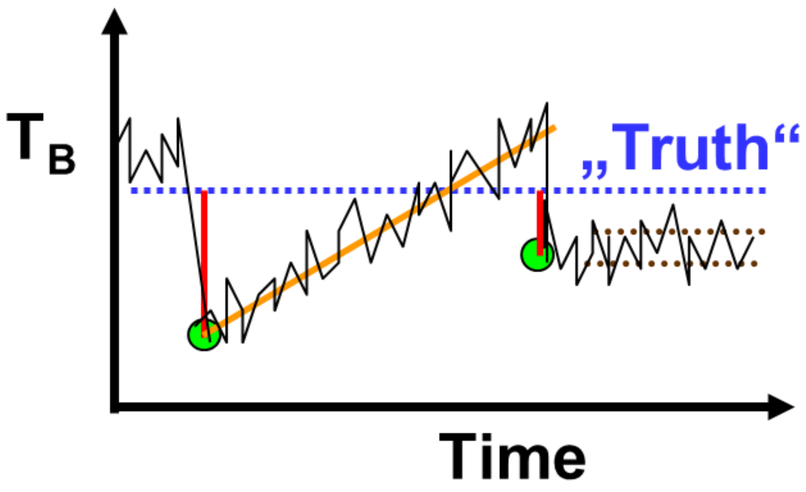
Limitations/Challenges

- Limited vertical resolution (2-4 deg. of freedom), declines with height
- Coordinated networks
- Calibration
- Absorption modeling
- Automatic data quality control (QC) systems

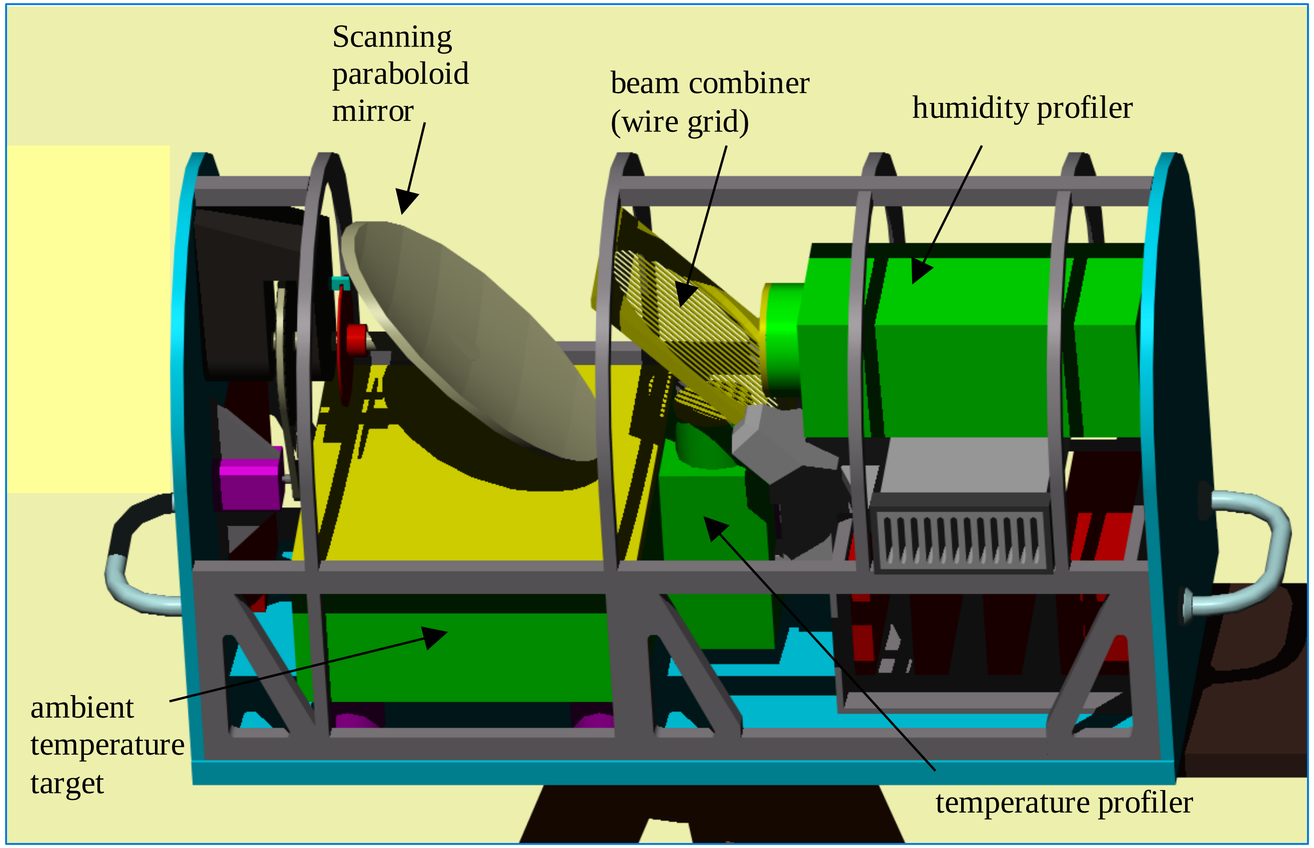
Radiometer calibration

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



MWR components (HATPRO)

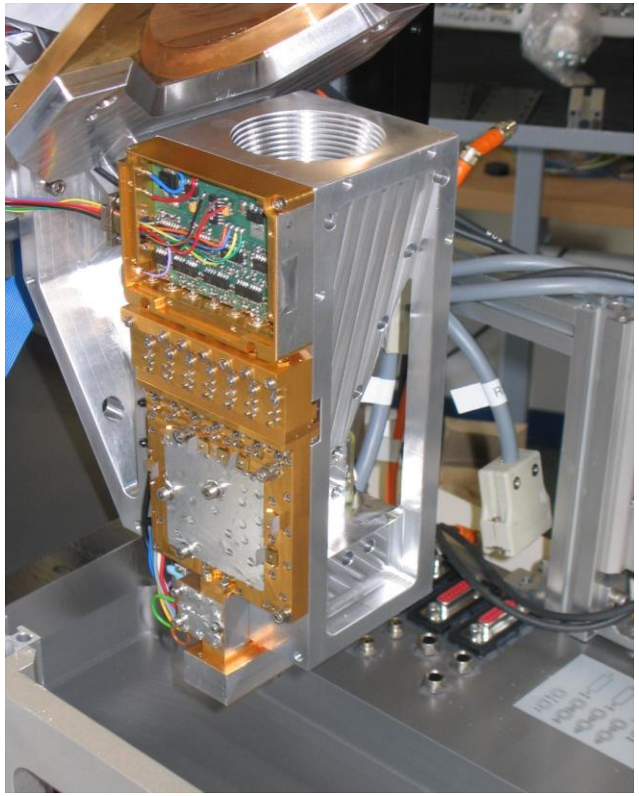


Radiometer formula

Detected receiver voltage has to be „translated“ into a brightness temperature. Relationship has to be determined with a calibration.

$$U_D = G \cdot T_{sys}{}^{\alpha} = G(T_R + T_A)^{\alpha}$$

T_{sys} System “noise“ temperature
T_R Receiver noise temperature (all instrumental noise sources combined)
T_A antenna temperature (atmospheric source)
G Gain [V/K] (proportionality factor)
α Non-linearity factor



For calibration purposes, a stable noise diode can be switched on to provide a constant additional signal (T_N)

Radiometer formula / automatic calibration

$$U_D = G \cdot T_{sys}{}^{\alpha} = G(T_R + T_A)^{\alpha}$$

Unknowns:
- G (Gain factor),
- T_R (system noise = contribution to signal by components),
- α (non-linearity factor)

- G, and T_{sys} have to be regularly calibrated (minutes to seconds)
- For most radiometers, G is updated by looking at a blackbody at ambient temperature or using a noise diode signal (T_N). For HATPRO G5, a stable noise diode is used that switches with a frequency of 50 Hz.
- T_{sys} is updated by looking at blackbody targets at ambient temperature (every 5-10 minutes)
- The frequency and integration time for automatic calibrations can be determined when defining a measurement (part of MWR SOPs in ACTRIS)

- α, and T_N are stable over long-term (months) and are only updated during absolute calibrations

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

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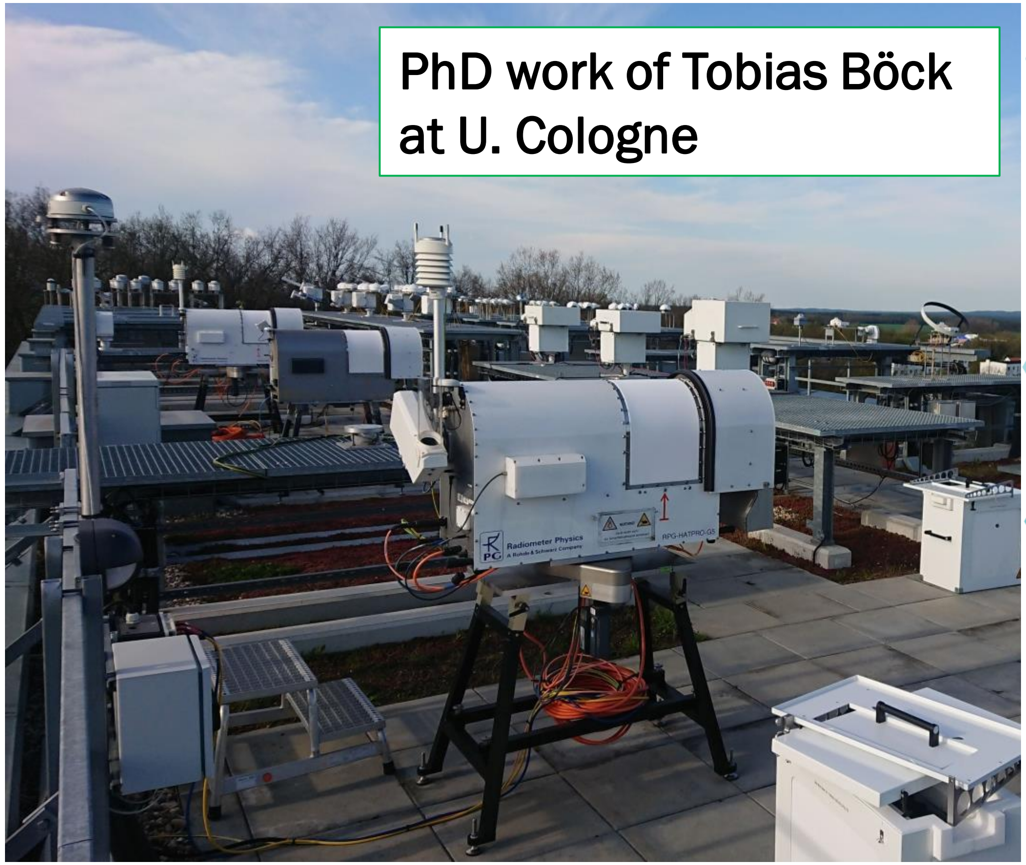
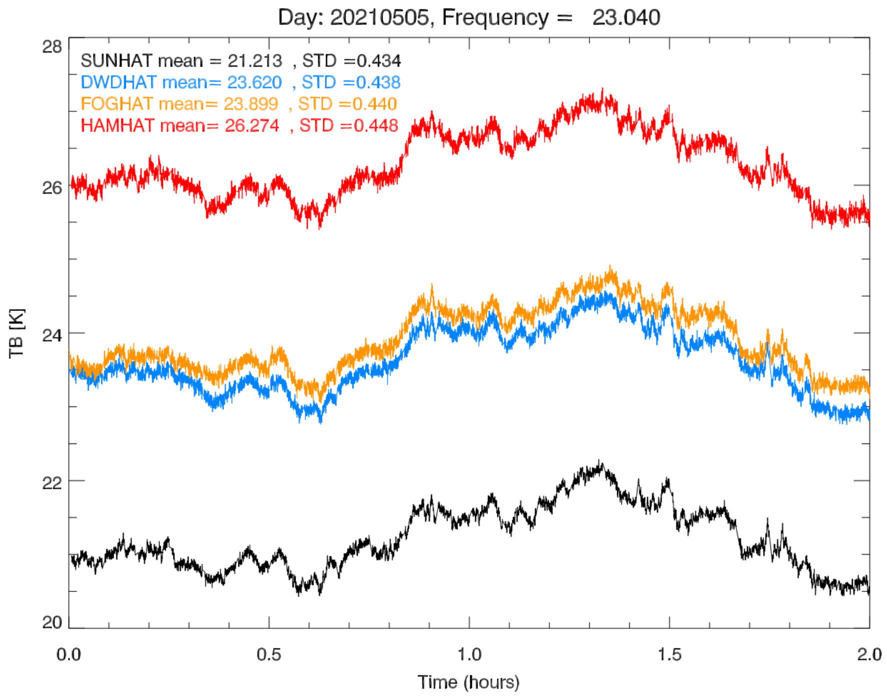
New results from calibration Campaign in Lindenberg

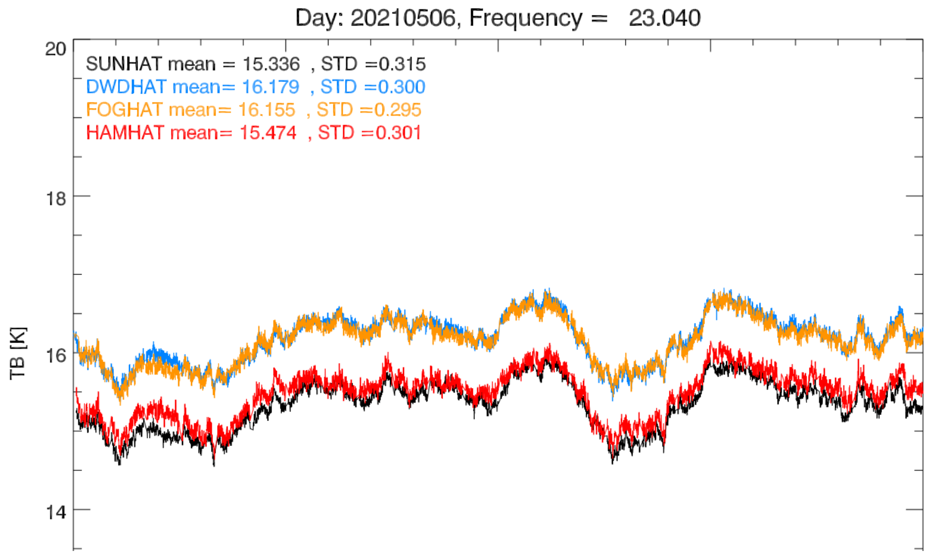
- **4 HATPROs** (FOGHAT G5, DWDHAT G5, SUNHAT G2, HAMHAT G2)
- Calibration campaign:
  - Calibrate all 3 HATPROs on the roof in a row for **three times** each with the standard procedure
  - **Zenith** measurements in between
  - 4th HATPRO nearby gets calibrated only once and then always measures zenith; 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**)

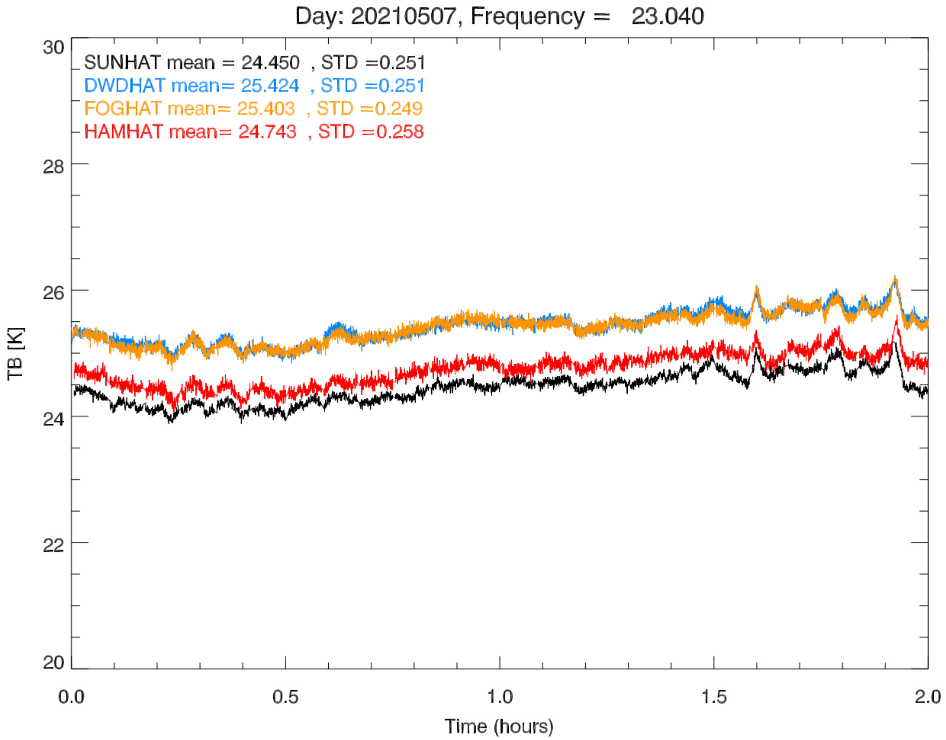


PhD work of Tobias Böck at U. Cologne

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)

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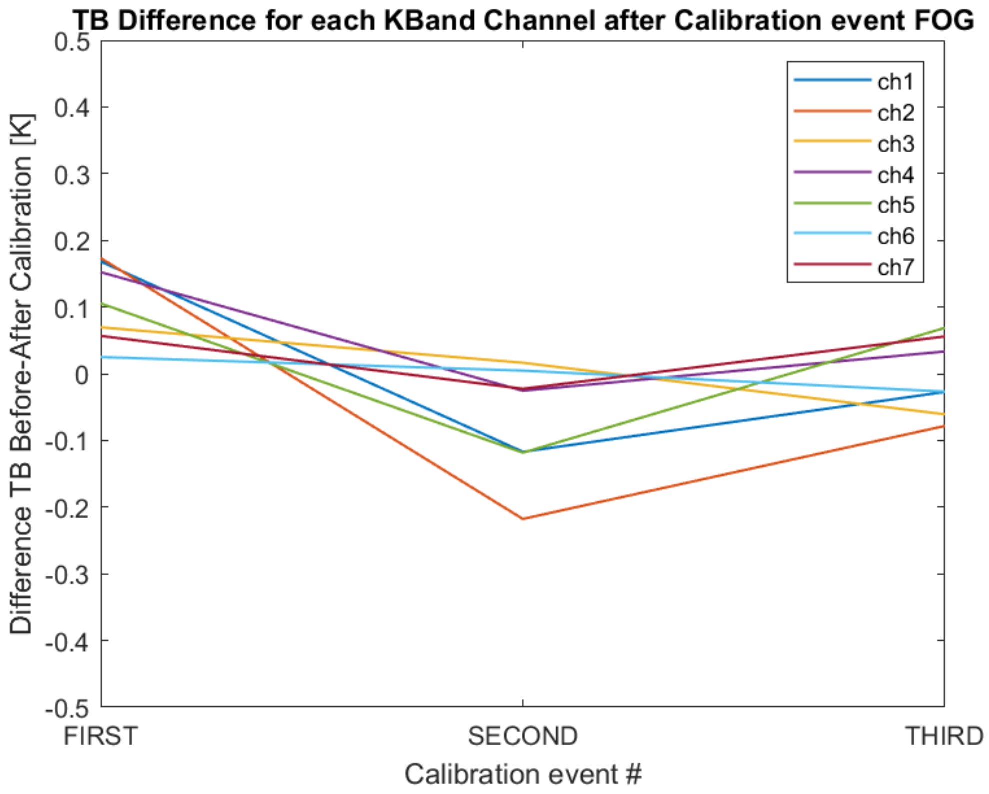
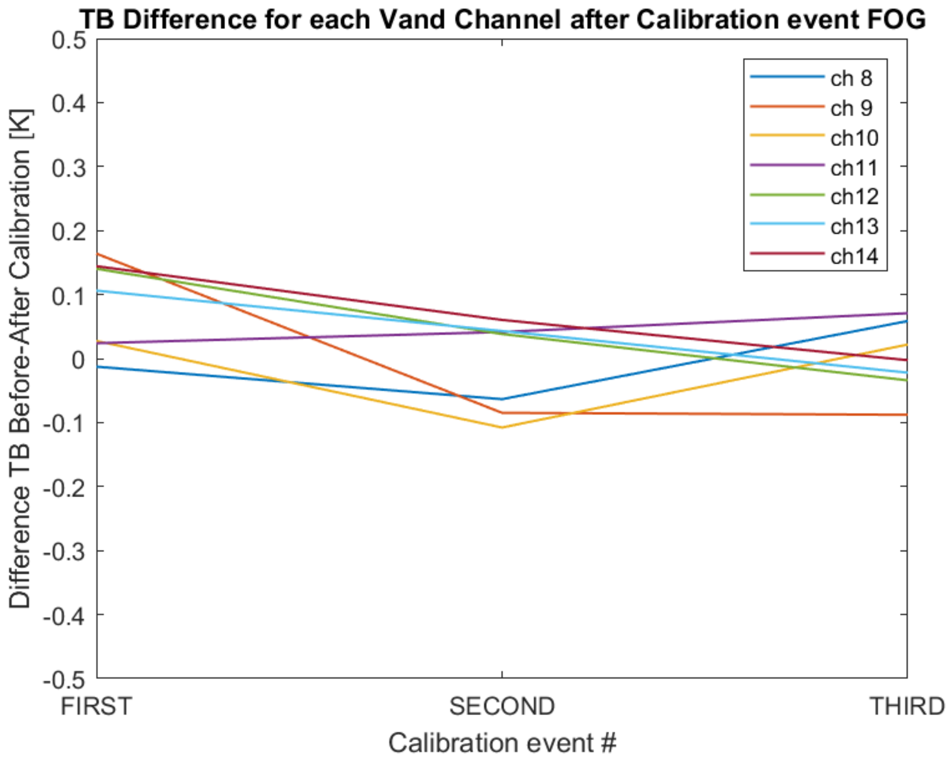
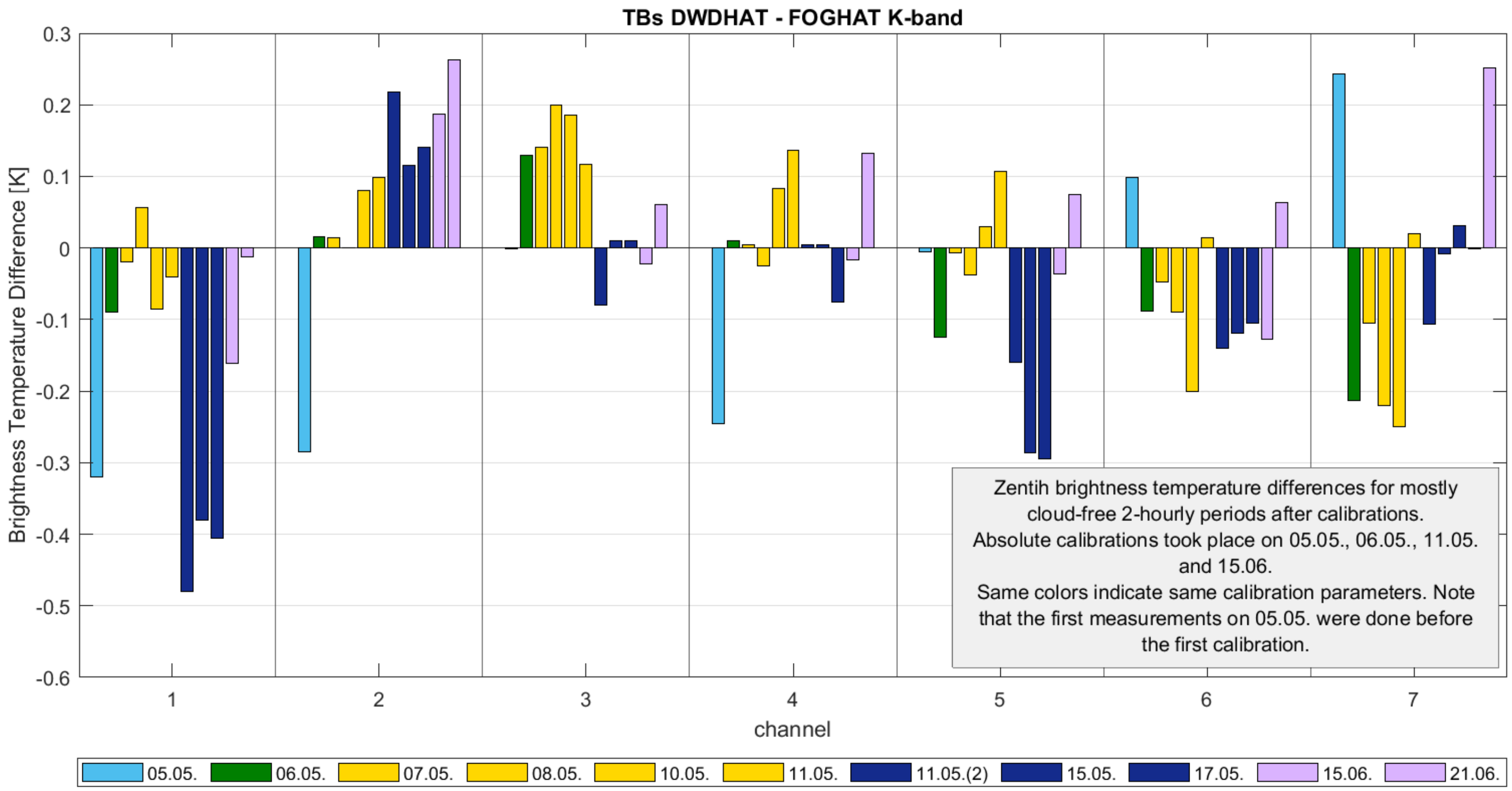
Repeatability of absolute calibrations

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



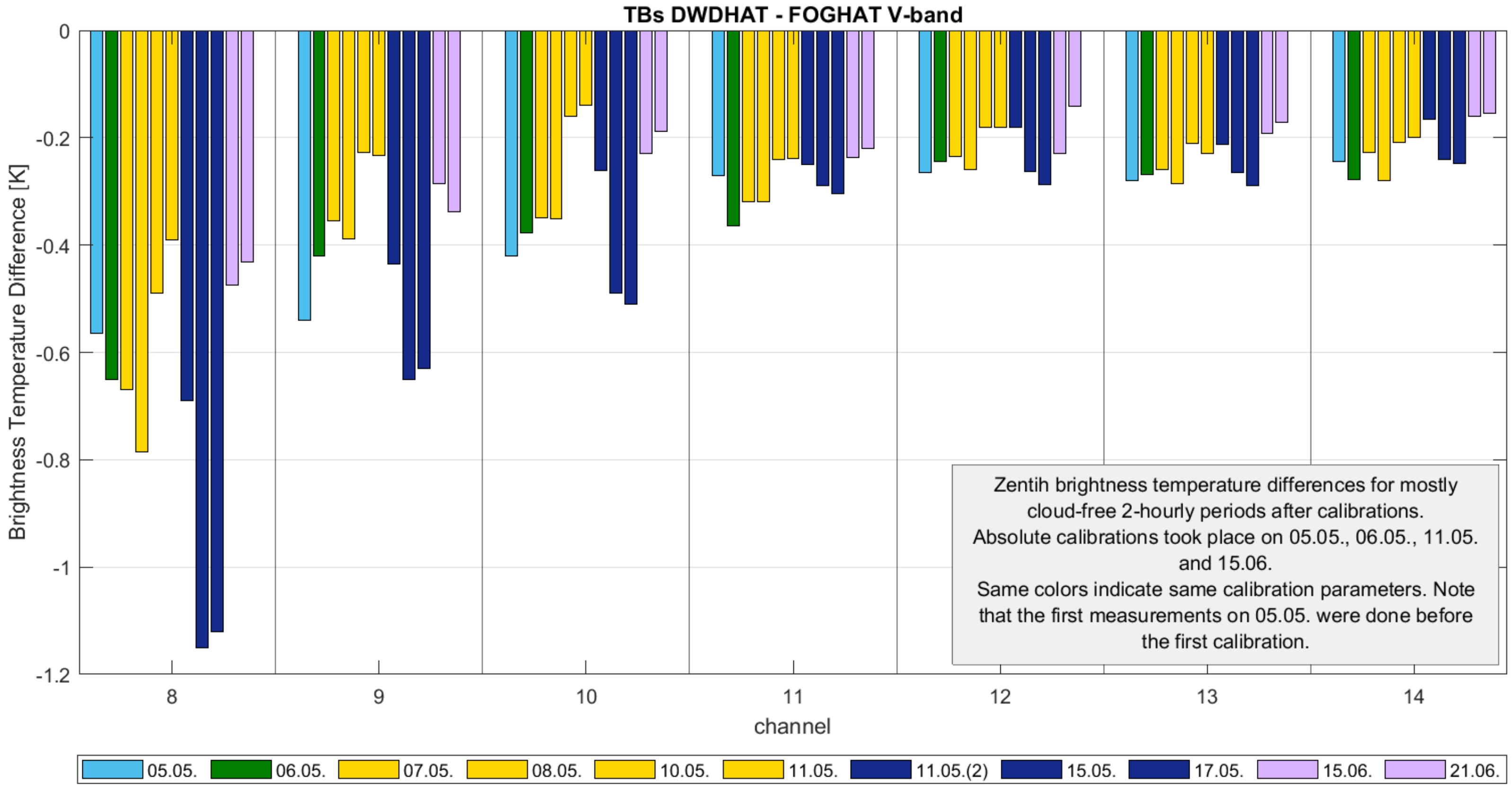


T_B Biases/Offsets via zenith comparisons



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

T_B Biases/Offsets via zenith comparisons

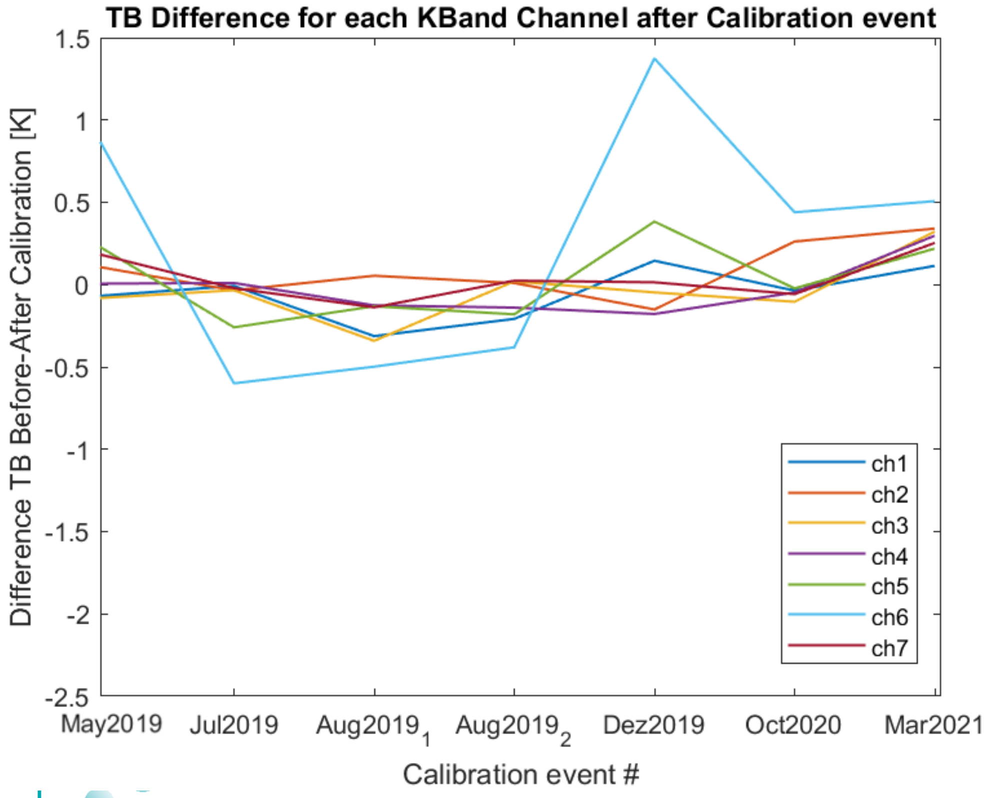


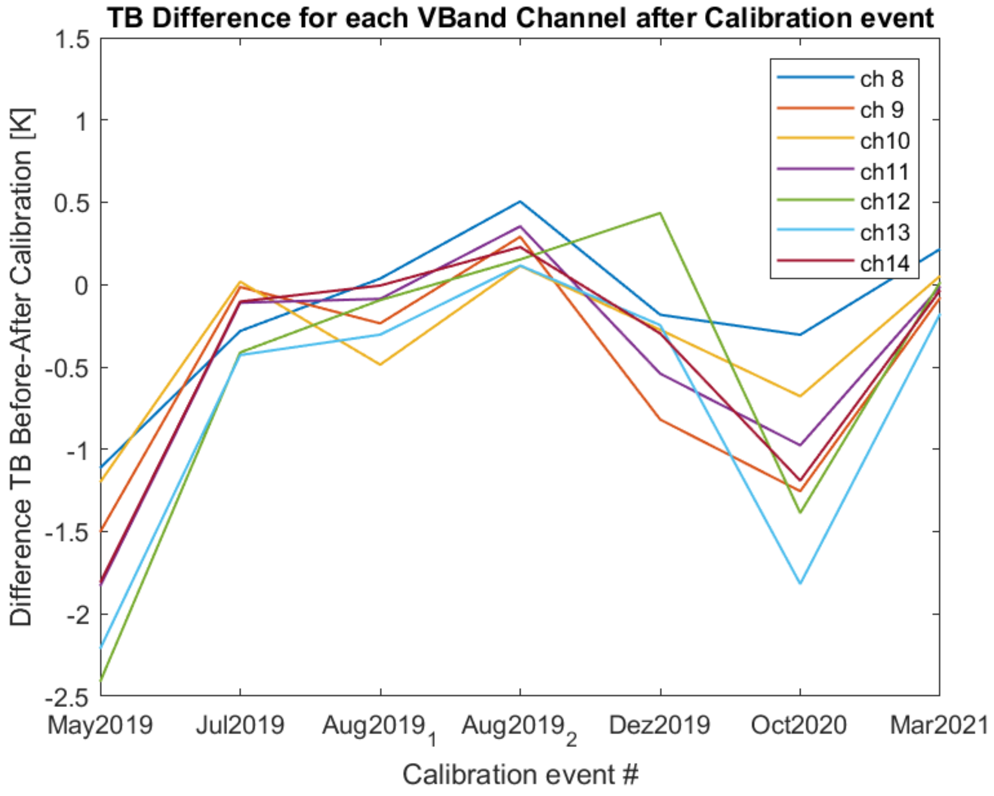
→ Biases/Offsets can be reduced by better LN2 calibrations, however some systematic differences remain, especially in V-Band

→ 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





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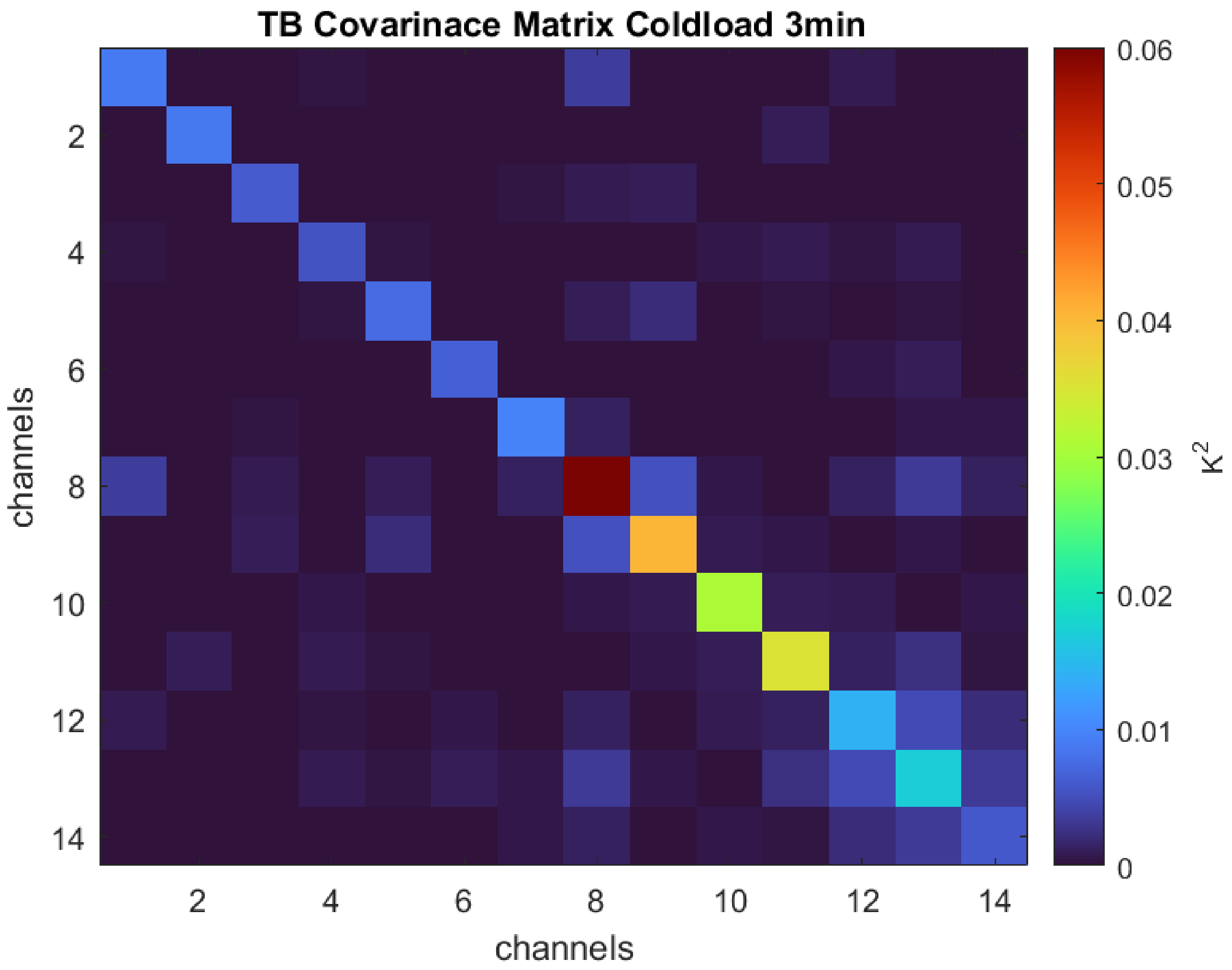
Channel covariances

- **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



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

- HATPRO software will provide files with brightness temperatures during calibration, as well as covariance matrices for calibration and performance monitoring
- New generation of calibration targets for HATPRO (since 2016) allows more accurate calibration > new further developments at RPG

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Thanks for your attention!

CCRES Workshop – September 21, 2021

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