Quality Assessment of HATPRO Microwave Radiometers Measurements and Calibrations

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1. Motivation and Goals

- The atmospheric boundary layer (ABL) is the most important under-sampled part of the atmosphere. Top-priority atmospheric variables for numerical weather prediction (NWP) applications like temperature (T) and humidity (H) profiles are currently not adequately measured.
- Ground-based microwave radiometers (MWRs) like HATPRO (Humidity And Temperature PROfiler) are particularly well suited to obtain such profiles.
- MWR data are not yet routinely assimilated into operational NWP:
  → The German Weather Service (DWD) investigates the potential of MWR networks for improving short-term weather forecasts over Germany.
  → Uncertainty Assessment for MWRs is needed for data assimilation (DA) into NWP systems

GOALS:
- **Define & apply procedure for MWR measurement uncertainty characterization**
- **Store all error types into level 1 (lv1) files for each channel after each calibration**

2. HATPRO Microwave Radiometer

Humidity and Temperature PROfiler:
- Measures thermal emissions from the atmosphere in brightness temperatures (TBs) in 14 different channels/frequencies within the K- and V-band
- Allows investigation of: T- and rudimentary H-profiles, liquid water path (LWP) and integrated water vapour (IWV)

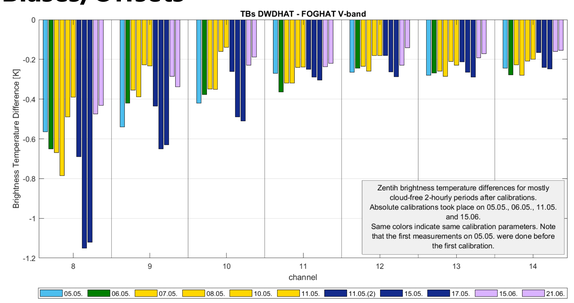
***Fig.1**: HATPROs on the roof of the DWD.*

3. Calibration and Measurement Errors

The following errors were characterized through coordinated experiments at the JOYCE site in Jülich (TOPHAT) and during a calibration campaign at FESSTVaL 2021 with 4 HATPROs (FOGHAT, SUNHAT, DWDHAT and HAMHAT) on the roof of DWD in Lindenberg:
- systematic errors:
  absolute liquid nitrogen (LN2) **calibration errors, biases/offsets**
  drifts (instrument stability, TB leaps between calibrations)
- random errors:
  radiometric noise (via covariance matrices)
- **repeatability of calibrations**

4. Results (Plots Overview)

Biases/Offsets



Here: systematic differences between two instruments

***Fig.2**: 2 hours averaged zenith TB differences of DWDHAT and FOGHAT in the V-band channels. Same colors indicate same LN2 calibration parameters.*

Drifts

Changes to an abs. reference over time

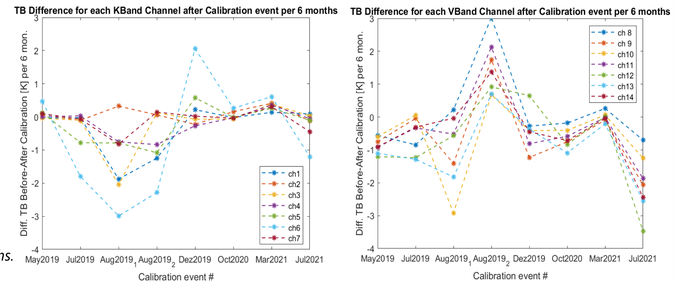
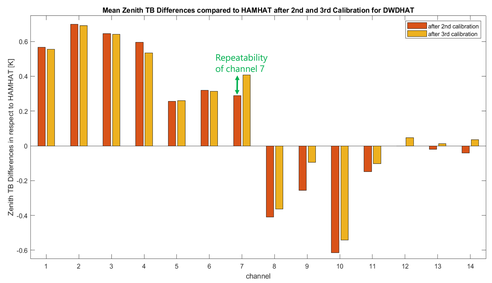


***Fig.3**: Leaps in TBs of TOPHAT before and after a LN2 calibration event normed to 6 months.*

Repeatability



Changes to a reference after two immediate calibrations

***Fig.4**: Mean zenith TB differences of DWDHAT in respect to HAMHAT measurements after the 2nd and 3rd calibration round from the FESSTVaL calibration campaign. Averaging time was around 15 min. Repeatability is the difference between these differences (see green arrow as an example).*

Noise

variance or standard deviation

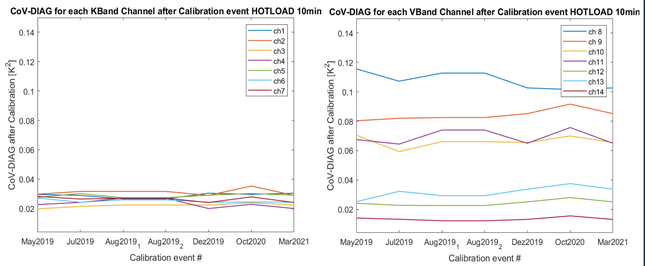


***Fig.5**: Hotload noise levels of TOPHAT via covariance matrix diagonal after calibration events. The square root yields the standard deviation.*

5. Summary and Conclusions

Type of Error	Typical Error Values K-band	Typical Error Values V-band	Determined via
Biases/Offsets	usually ≤ 0.3 K (up to 0.48 K)	usually ≤ 0.5 K (up to 1.15 K)	Zenith measurement differences between two MWRs
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
Calibration Repeatability	≤ 0.12 K	≤ 0.16 K	Leaps to zenith reference measurements after two immediate calibrations
Noise Levels (3min coldload – 10 min hotload)(1s)	≤ 0.11 K – 0.19 K	≤ 0.28 K – 0.42 K	Standard deviation

Noise and drifts cannot directly be influenced by the operator, these are instrument specific. However, these are the only two errors which can and should be tracked by the operator.

- Comparison to previous studies/manual:
  Maschwitz et al. (2013): LN2 calibration blackbody uncertainty of ±0.3 to ±1.6 K (old target)
  Küchler et al. (2016): LN2 calibration blackbody uncertainty of ±0.5 (newer target)
  RPG manual for Gen5 HATPROs: absolute TB uncertainty 0.5 K, noise 0.10 to 0.15 K
- Suggestion for total maximum error per channel:
  Bias mean + Drift + Repeatability
  (for retrievals noise is also important)
  For minimal error: only repeatability

6. Next Steps

- Define lv1 files with all uncertainties for each HATPRO after each calibration in detail
- Precise guidance for operators (e.g. DWD, ACTRIS, COST action PROBE) on how to operate and calibrate HATPROs and how to avoid mistakes
- Location characterization (radio frequency interference and obstacles): Sensitivity experiments with a radiative transfer model to analyze from where/how far signals come from

References:
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