Calibrating Ground-Based Microwave Radiometers: Uncertainty and Drifts

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1. MiRaCalE

The Microwave Radiometer Calibration Experiment (MiRaCalE) took place in fall 2014. Ten “Liquid Nitrogen Calibrations” and 2841 “Tipping Curve Calibrations” were performed with a state-of-the-art microwave radiometer to assess **calibration uncertainties** and instrument **drifts**.

Fig. 1: HATPRO at the NSSL, Oklahoma, USA.

Humidity And Temperature Profiler (HATPRO)

- 7 channels between 22 and 31 GHz (humidity + liquid water)
- 7 channels between 54 and 58 GHz (temperature)
- 1 second temporal resolution

2. Calibration Techniques

Liquid Nitrogen Calibration (LN2cal)

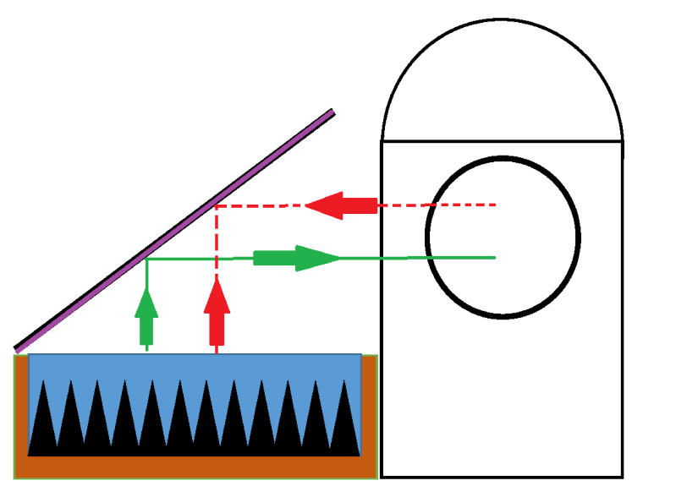

Fig. 2: Sketch of „cold“ load observation (green) with reflection of receiver's signal (red).

- LN2-cooled blackbody at ≈ 77 K as „cold“ load
- Ambient temperature blackbody at ≈ 300 K as „hot“ load
- Internal noise source added to „cold“ and „hot“ signals

Tipping Curve Calibration (TCC)

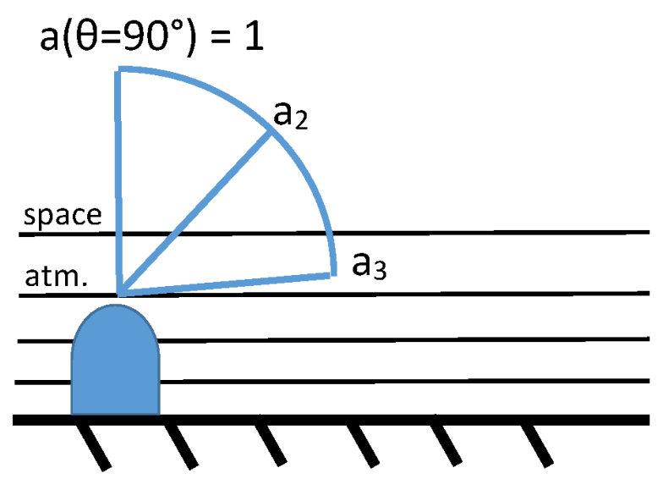

Fig. 3: Observing the homogeneously stratified atmosphere at several elevation angles.

Zenith radiances (B^{zen}) as „cold“ load:

1) Opacity-airmass pairs at several elevation angles
2) Linear regression of pairs provides zenith opacity

→B^{zen} from radiative transfer equation without scattering

The relation between the detected voltage U_{sc} and the scene radiance B_{sc} is determined by the instrument's **gain** *g*, the **receiver's equivalent noise** radiance B_R and the instrument's **non-linearity** *α* :

$$U_{sc} = g(B_{sc} + B_R)^{\alpha} \qquad (1)$$

The three unknowns (α, g, B_R) are determined by observing two calibration references both with and without an **additional, constant noise** signal B_N leading to f**our unknowns** and **four calibration points**.

3. Drifts

Frequent calibrations of the parameters in eq. (1) are necessary to **ensure measurement accuracy**:

Figure 4 shows how **drifts** of the calibration parameter B_R **influence** the **retrieval of** cryogenic load **radiances** by solving eq. (1) for B_{sc} (shown in the temperature regime as T_C) using a reference voltage signal and TCCs that were performed at different times.

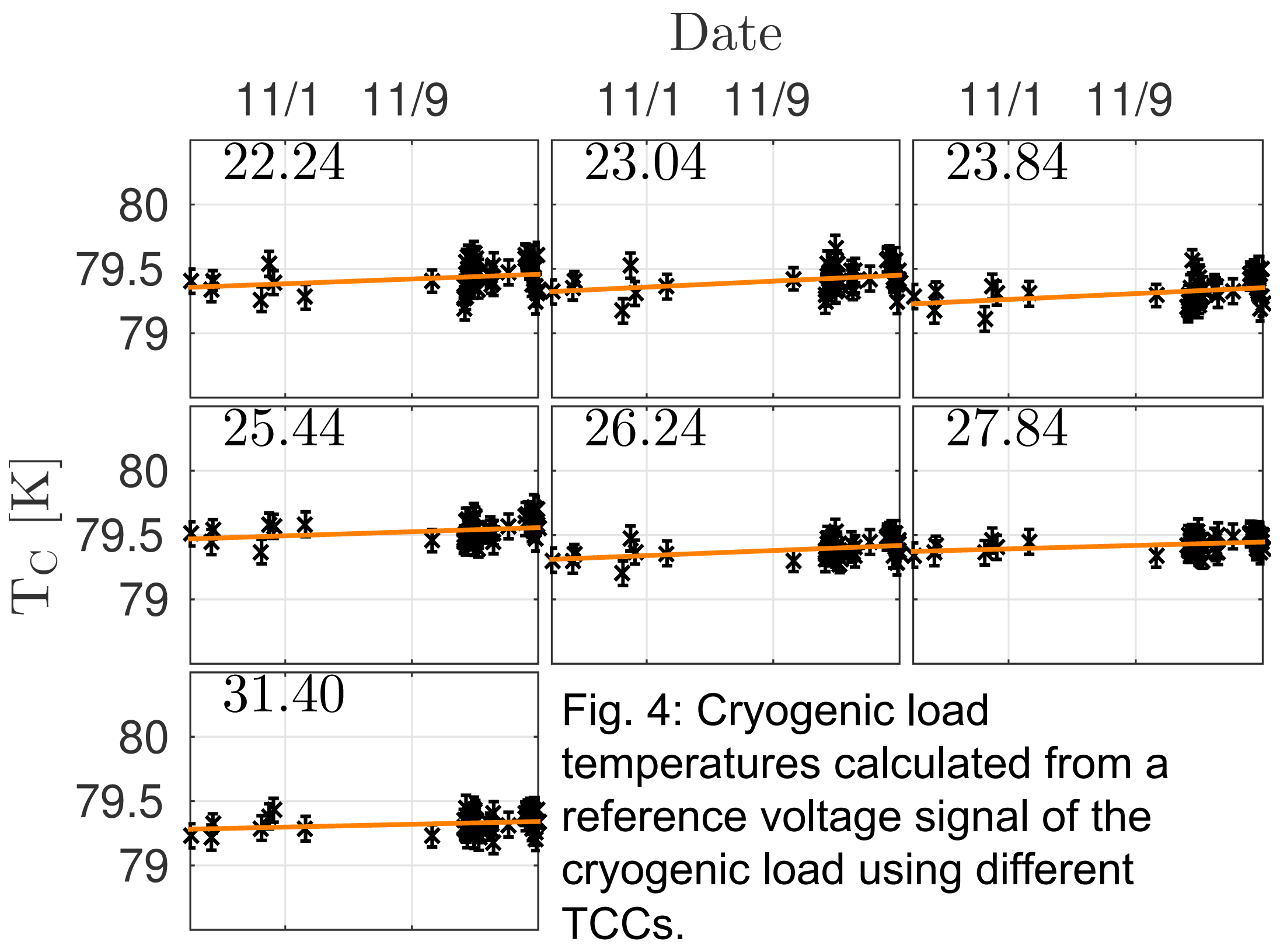

Fig. 4: Cryogenic load temperatures calculated from a reference voltage signal of the cryogenic load using different TCCs.

4. Accuracy of the Cryogenic Load

Uncertainty sources:

- Resonant effects [Pospichal et al. 2012]
- Entrainment of oxygen [Paine et al. 2014]
- Uncertainty of the refractive index of LN2 [Maschwitz et al. 2013].

We found a total **uncertainty of 0.5 K for the LN2 cooled blackbody** by using TCCs to retrieve the cold load's temperature (Fig. 5). Drifts of B_R were taken into account.

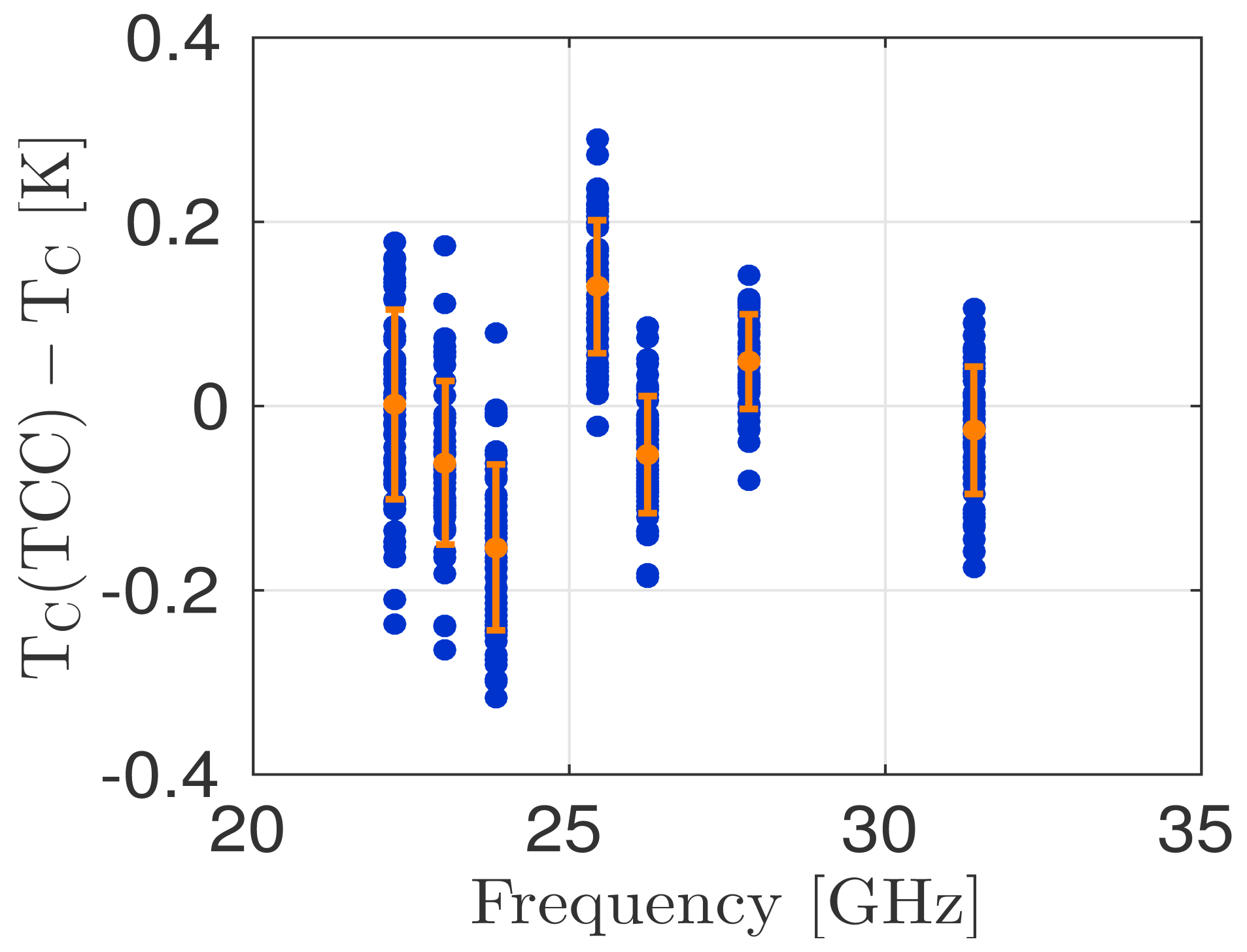

Fig. 5: Deviation of cryogenic load temperature T_c(TCC) derived from TCCs from the truth T_c.

5. Spectral Consistency

- Calibration **biases** can **differ between** radiometer **channels** (Fig. 6), which influence multi-frequency retrievals: Integrated water vapor (IWV) retrieval → **1 K offset** between two channels → **Error of 0.73 mm** (corresponds to 70 % of the diurnal cycle of IWV; Fig. 7).
- **Control measurements** (Fig. 6) can identify biased calibrations by testing for “spectral consistency”.

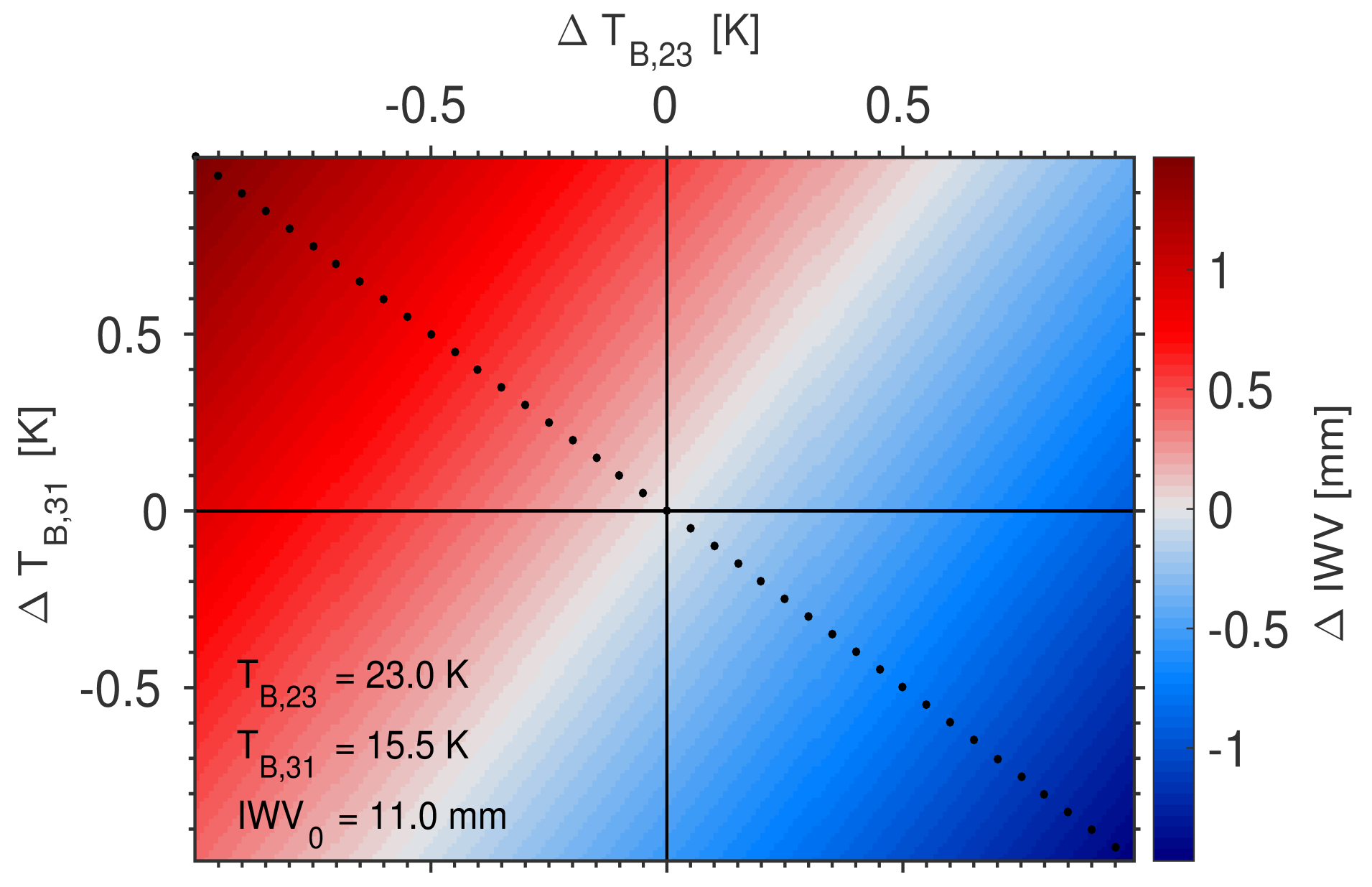

Fig. 7: Error of IWV retrieval due to biased brightness temperatures.

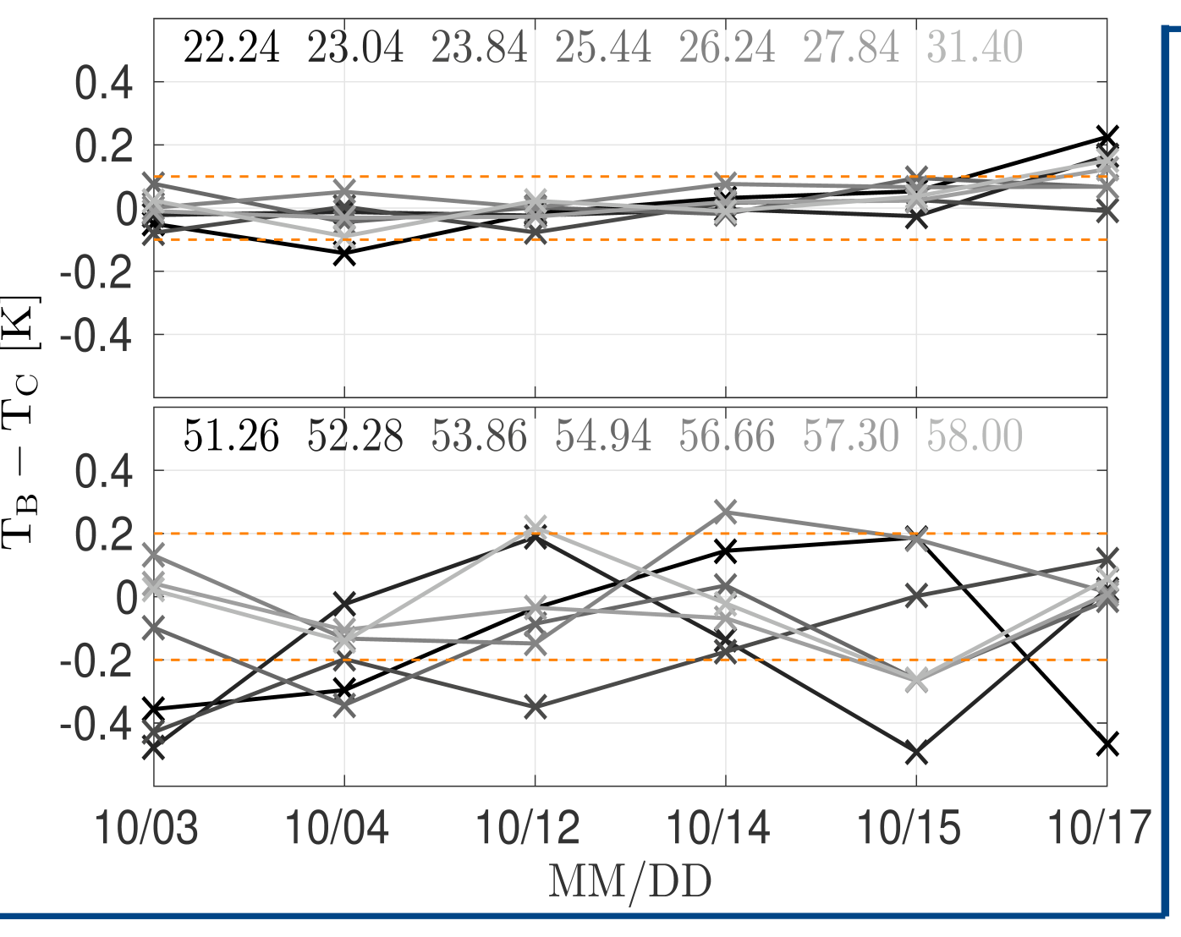

Fig. 6: Differences between cryogenic load temperatures observed directly after LN2cals and those temperatures used for calibration. Orange: Instrument's noise level provided by manufacturer.

6. Summary

- **Frequently updating** calibration parameters ensures stable long-term-measurements.
- The **spectral consistency** of control measurements is useful to estimate calibration accuracy.
- The brightness temperature of the **LN2-cooled load is accurate within 0.5 K.**

References

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