COST-TOPROF

WG 3 (Microwave Radiometers)

J-CAL (Joint Calibration Effort) Lindenberg

Bernhard Pospichal
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1 Joint calibration experiment

Ground-based passive microwave radiometers (MWR) are becoming more and more widely used in atmospheric remote sensing and start to be routinely operated by national weather services. However, common standards for calibration of these radiometers and a detailed knowledge about the error characteristics is needed, in order to assimilate the data into models.

In the frame of the COST-TOPROF action, the joint calibration experiment (J-CAL) will make an effort towards establishing protocols for providing quality controlled (QC) MWR data and their uncertainties. To this end, standardized calibration routines for MWR will be developed, by jointly performing calibration experiments and establishing standards for error characterization.

The focus of J-CAL will lie on the performance of the two main instrument types which are currently used operationally. These are the MP-Profiler series by Radiometrics Corporation (Ware et al., 2003) as well as the HATPRO series by Radiometer Physics GmbH (Rose et al., 2005).

The overall goals of J-CAL can be summarized under the following three topics:

- **Calibration, Operation**
  Review protocols for calibration, scanning and maintenance. Develop quality control procedure for calibration, standardized calibration procedures

- **Data quality control**
  Automatic methods for filtering spurious data. Calculated spectra vs. observed spectra allow filter out rainy situations
  for RPG-HATPRO: SPC-files containing spectra are being developed

- **Error characteristics**
  Assess total uncertainty of MWR data (correlations/covariances, theoretical error of brightness temperatures, different retrieval types). How to deal with uncertainties in gas absorption models that lead to biased products? How large are these errors?

1.1 Field experiment in Lindenberg

Intercomparisons of calibrations performed by different MWRs have rarely been performed. Therefore, a calibration experiment in Lindenberg is suggested in order to assess uncertainties and differences between various instruments. Furthermore, a standardized calibration procedure should be developed by interaction between MWR operators and manufacturers.

When and where:

25-29 August 2014, Meteorological Observatory Lindenberg (DWD)

- 2 Radiometrics MWRs are operating in Lindenberg
- 3 HATPROs from different series will be brought to Lindenberg (Cologne, Warsaw, RPG)
- homogeneous conditions by parallel calibration of different MWRs
- intercomparison with radiosondes possible (standard sondes every 6 hours, how many extra sondes will be available?)

Calibrations using LN2 should be performed during 2-3 days by several experienced people, adding high-quality radiosondes if possible. After the LN2 calibrations, the instruments shall run continuously for several weeks (with optimized automatic calibration settings).

1.1.1 Proposed actions

- **Stability of MWR receivers, Covariances**
  continuous observation of ambient load and LN2 load during 1 hour (minimum), possibly with and without gain calibrations
- **Noise level of MWR observations (absolute accuracy of BTs)**
  How large are the variances? How do the variances differ between different instruments (see e.g. in Fig. 3?
- **Quality assessment of LN2 calibration with radiosondes**
  Comparison of MWR brightness temperatures after calibration with clear sky radiosondes
- **HATPRO: Standing waves at LN2 calibration**
  Does a standing wave pattern appear when looking at external target with LN2? Examples for this phenomenon at LACROS are shown in Fig. 7 and Fig. reffig:ex8
- **HATPRO: Performing absolute calibrations with different integration times**.

- Clear sky comparison of brightness temperatures over longer time (minimum one night).

- **Long-term stability**
  2-3 weeks of co-located, unattended operation of the instruments after LN2 calibration. Are there any instrument drifts?

1.2 Review of current operation strategies

As a preparation for the J-CAL experiment, a review among MWR operators concerning their operation strategies is:

- Review among MWR operators concerning current calibration cycles

- Which instruments are operated? Which construction year (e.g. HATPRO G1, G2, G3 have quite different performance parameters)

- Which type of retrieval algorithm is used? (Statistical, neuronal network, combined, other?)

- How often are gain/noise diode/sky tipping/LN2 calibrations performed?

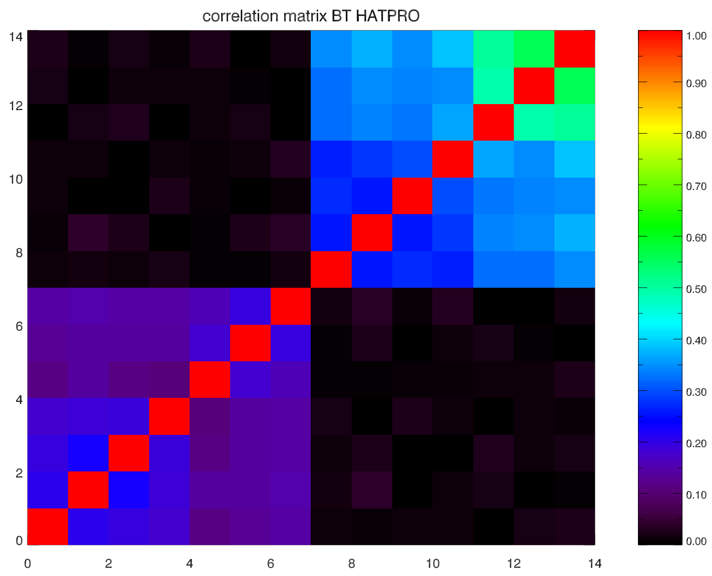
- Which thresholds are used?

- Are any quality control measures taken (e.g. compare to radiosondes, model, etc.)

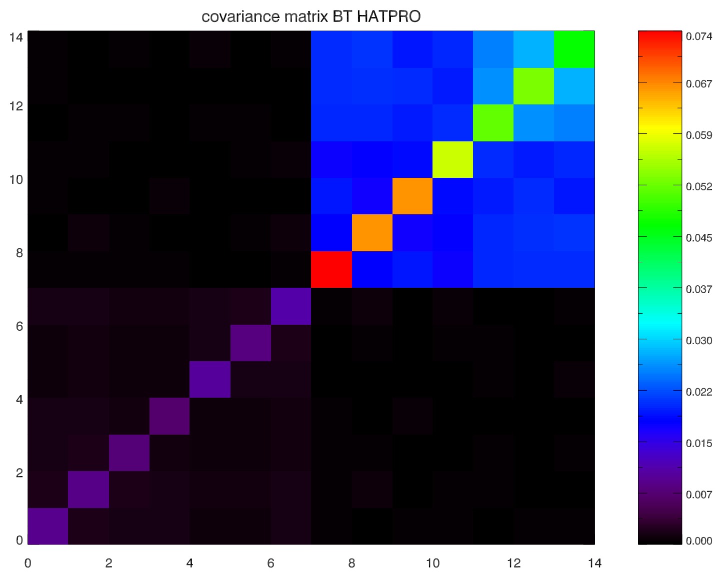
1.3 Error characteristics

The total random error for each frequency is determined by the brightness temperature variance, but also by the covariance to the other channels. An error estimate can be obtained by computing correlation and covariance matrices from blackbody (internal target) observations. The errors differ for every single instrument and therefore these matrices should be determined for every instrument to get the individual error characteristics.

Fig. 1 presents an example for correlation and covariance matrices for three hours of HATPRO blackbody observations at Leipzig. Note that the variances and covariances are higher for the V-band channels (8-14).



(a)



(b)

Figure 1: (a) Correlation matrix and (b) Covariance matrix for all 14 channels of HATPRO. Data were retrieved by 3 hours of observation of the internal target.

2 Radiometer calibration methods

2.1 Introduction

An accurate calibration of microwave radiometers is crucial, since calibration errors are the biggest source of uncertainty in radiometer observations. A short overview of calibration methods for MWR is given in Westwater et al. (2005). Maschwitz et al. (2013) present many details on MWR calibration and their possible error contributions with a special focus on liquid nitrogen calibrations.

When relating the total noise power P to the detector voltage U_d, the following unknown terms in Eq. 1 have to be determined: the gain factor (G) and the non-linearity α.

$$U_d = G\,P^{\alpha} \tag{1}$$

The total system noise power P can be expressed as noise temperature T_{sys} which is composed of two components, the atmospheric brightness temperature (scene temperature) T_A and the noise temperature of the radiometer system T_R.

$$U_d = G\,(T_R + T_A)^{\alpha} \tag{2}$$

Eq. 2 has now three unknown parameters G, T_R and α which have to be determined during the calibration process.

Several methods are used to calibrate radiometers, which can be described as absolute (all three calibration parameters are determined) or relative (only one or two parameters are updated, the rest is assumed to be constant).

- Liquid nitrogen calibration (absolute), see section 2.2
- Tipping curve calibration (absolute), see section 2.3
- Noise injection calibration (relative), see section 2.4
- (Hot Load) Gain calibration (relative), see section 2.5

These calibration methods will be described briefly in the following, and some open issues are discussed.

2.2 Liquid Nitrogen Calibration

By using liquid nitrogen (LN_2) and an additional internal noise diode with a noise temperature T_n, four unknowns can be determined (G, T_R, α, and T_N). Measurements against black body targets with different well-known physical temperatures (boiling point of LN_2, and ambient temperature) are performed. In addition, the internal noise diode is switched on and off, resulting in four calibration points for four unknowns.

2.2.1 Challenges, Issues

- Uncertainties due to pressure dependency of LN_2 boiling temperature
- Refractive index of LN_2 surface not exactly known
- Standing wave patterns between receiver and LN_2 surface
- How often should the LN_2 calibration be performed?
- ... see also Maschwitz et al. (2013)

2.3 Tipping curve calibration

An alternative to the LN_2 calibration in section 2.2 is the so-called tipping curve calibration which can be used to calibrate low-opacity radiometer channels. The general idea is to replace the LN_2 target by the cold clear sky. The method uses opacity - air-mass pairs under different elevation angles. Assuming clear sky conditions and a homogeneously stratified and non-opaque atmosphere, the opacity scales linearly with the air mass for low optical depths along the slant path. Han and Westwater (2000) discuss this method in detail and specify an absolute calibration accuracy of better than 0.5K for K-band channels.

2.3.1 Challenges, Issues

- Atmosphere is never perfectly homogeneous, therefore quality thresholds that guarantee the goodness of the fit have to be used. Which ones? How strict?
- Lower angles lead to higher accuracy, but also potentially to a very low number of good calibrations.

- Repeatability of tipping curve calibrations?
- applicable only at low humidity, not possible under tropical conditions.
- no tip calibration during daytime due to convective atmosphere?
- ...

2.4 Noise diode calibration

After a successful LN_2 calibration, the temperature T_N from a well burned-in 245 noise diode is stable enough to serve as a secondary calibration standard during operation. Therefore, from Eq. 2, G and T_R can be determined by measuring on the internal target, once with and once without additional noise.

2.4.1 Challenges, Issues

- Stability of noise diode between LN2 calibrations?

2.5 Gain (Hot load) calibration

This calibration type uses the ambient hot load target as a reference. The hot load temperature T_H is known from a precision in-situ measurement within the target itself. In order to correct for significant changes in HATPRO-G2's detector gain that occur on time scales longer than 5min, the hot load target is reviewed every 5min with an integration time of 4s. For the V-band channels, G is known from continuous noise switching (Sec. 3.3) and thus T_n is used to update T_R during every hot load target calibration.

2.5.1 Challenges, Issues

- How accurate is temperature measurement of hot load target?
- How often should the gain calibration be performed?

3 Examples for calibration evaluation

Some examples for calibration evaluation are presented here, mostly from two Leipzig radiometers (HATPRO G1, G2).

In the summer of 2011, two radiometers were operated next to each other which allowed an intercomparison of the data. Results of mean daily differences are presented in Fig. 2. After a ship campaign, the OCEANET instrument was restarted without a LN_2 calibration. After a calibration on 10 June 2011, most differences disappeared. However, in the course of three months, several channel drifts could be observed again.

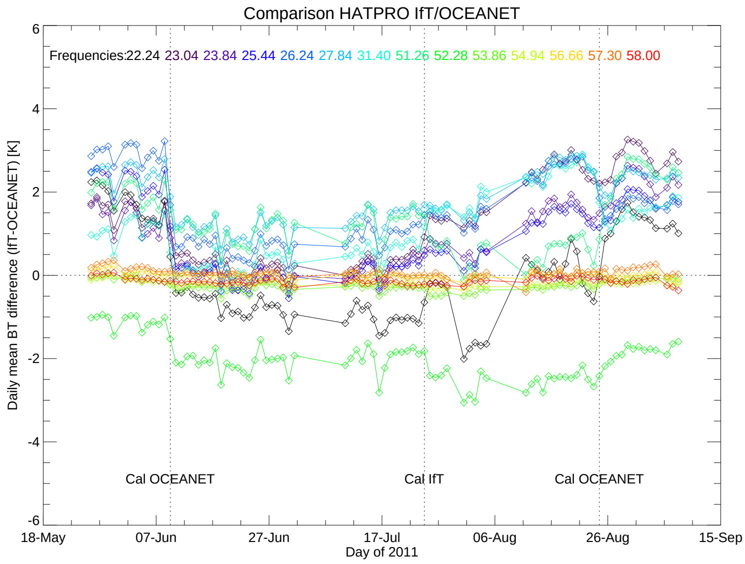
Fluctuations on small time scales can be seen in Fig. 3. As an example, 10-minute mean and standard deviation of brightness temperatures for two frequencies are presented. Raw data for both instruments are with a resolution of 1 second. Note the different variances, especially for the 54.94 GHz channel!

In order to assess the calibration quality, co-located radiosondes can be used to calculate virtual brightness temperatures. In Fig. 4, one example for absolute brightness temperatures, as well as their differences is presented. Note that the use of different gas absorption models can significantly influence the quality of the retrieval. Fig. 5 shows the mean differences for 30 sondes on a Polarstern cruise between Cape Town and Bremerhaven (different climate zones!)

In order to analyze favorable skytip conditions, optical thicknesses were calculated from elevation scan brightness temperatures (Fig. 6). It can be seen that already slight differences in optical thickness lead to high chi-square values.

At calibrations with liquid nitrogen, standing wave features occur for some HATPRO instruments. Fig. 7 presents time series of brightness temperature observations of the LN_2 surface. A distinct periodic pattern can be seen, until the LN_2 has evaporated and the temperatures were rising. With the first derivative in Fig. 7(b), the wave pattern can be well identified. The period of the wave depends on the microwave frequency (wavelength) as well as the evaporation rate. In Fig. 8, the wave periods for two days with different evaporation rates are shown as a function of wavelength.

With long-term observation of calibration parameters changes of radiometer components can be detected. Calibration parameters for a whole year are presented in Fig. 9.



(a)

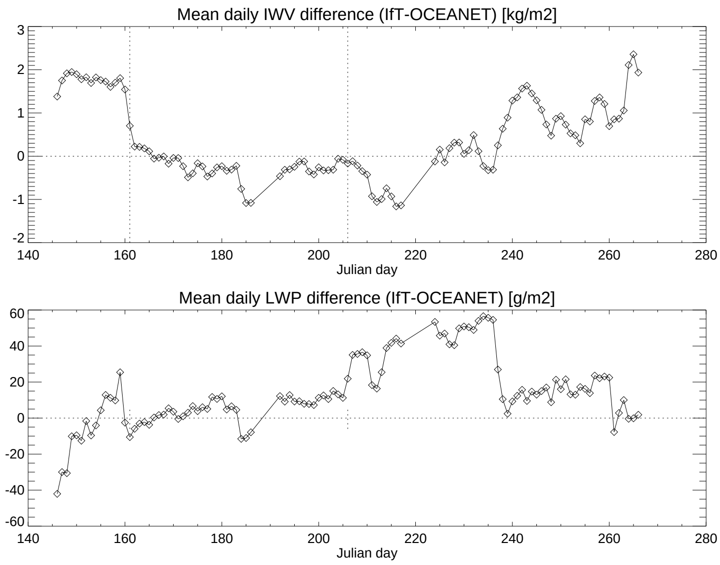
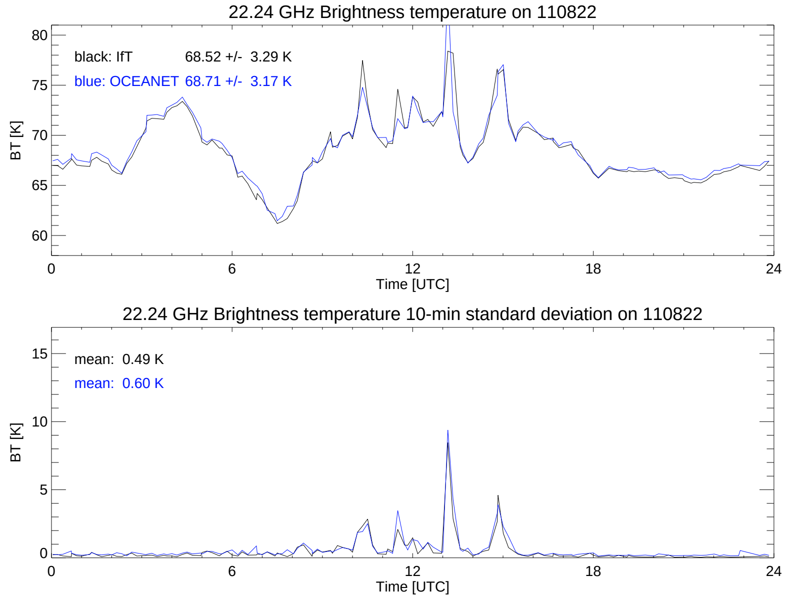
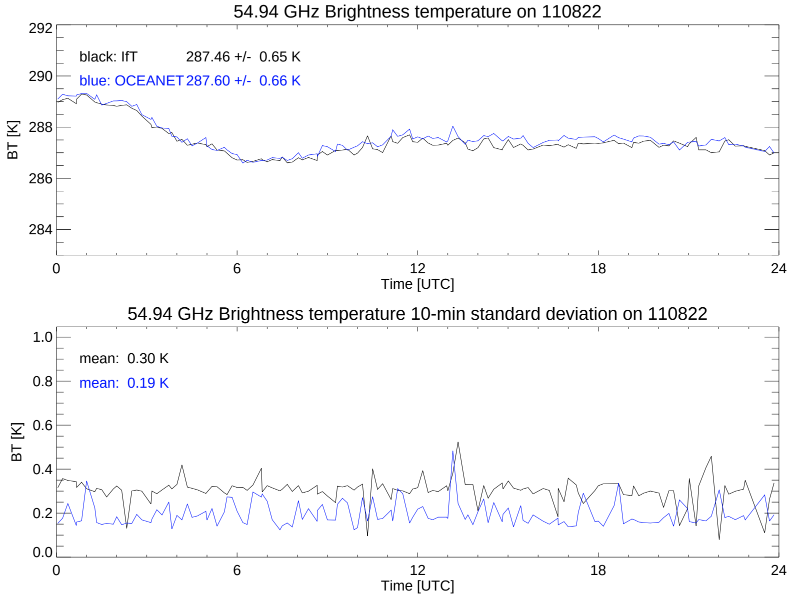


Figure 2: (a) Time series of daily mean brightness temperature differences between two co-located HATPRO MWRs during June-September 2011 in Leipzig. (b) IWV and LWP differences derived for similar period as in Fig. 2(a)



(a)



(b)

Figure 3: (a): Time series of brightness temperatures (22.24 GHz) from two co-located HATPRO instruments on 22 August 2011 in Leipzig, and 10 minute standard deviation of brightness temperatures. (b) same for 54.94 GHz frequency

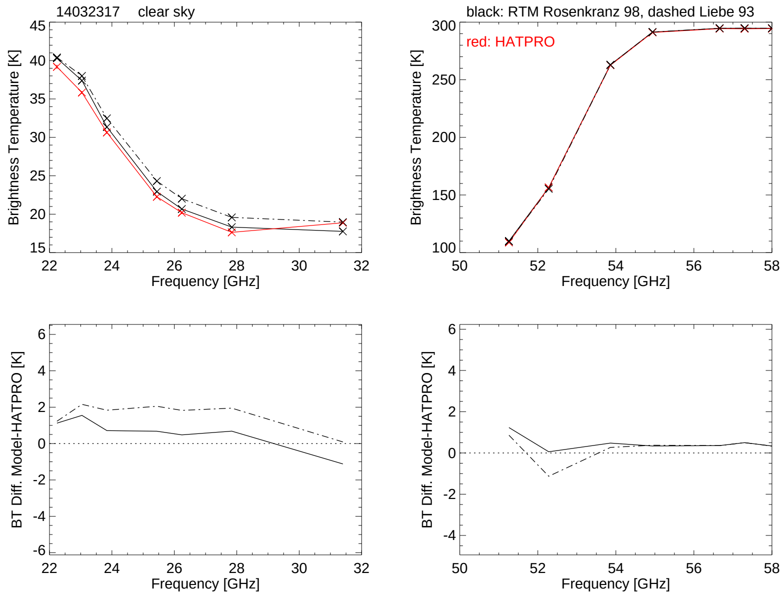


Figure 4: Measured and modeled brightness temperatures on 23 March 2014, 17 UTC on Polarstern research vessel (clear sky conditions)

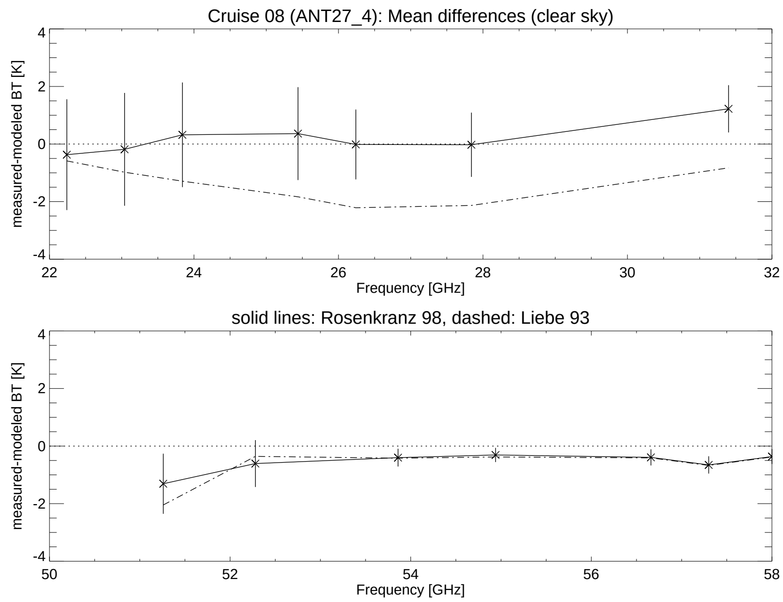


Figure 5: Differences between measured and modeled brightness temperatures at clear sky conditions. Polarstern cruise ANT–XXVII/4 (Cape Town–Bremerhaven, 20 April–20 May 2011). The modeled data are based on radiosondes, two different water vapor absorption models were used (Liebe, Rosenkranz)

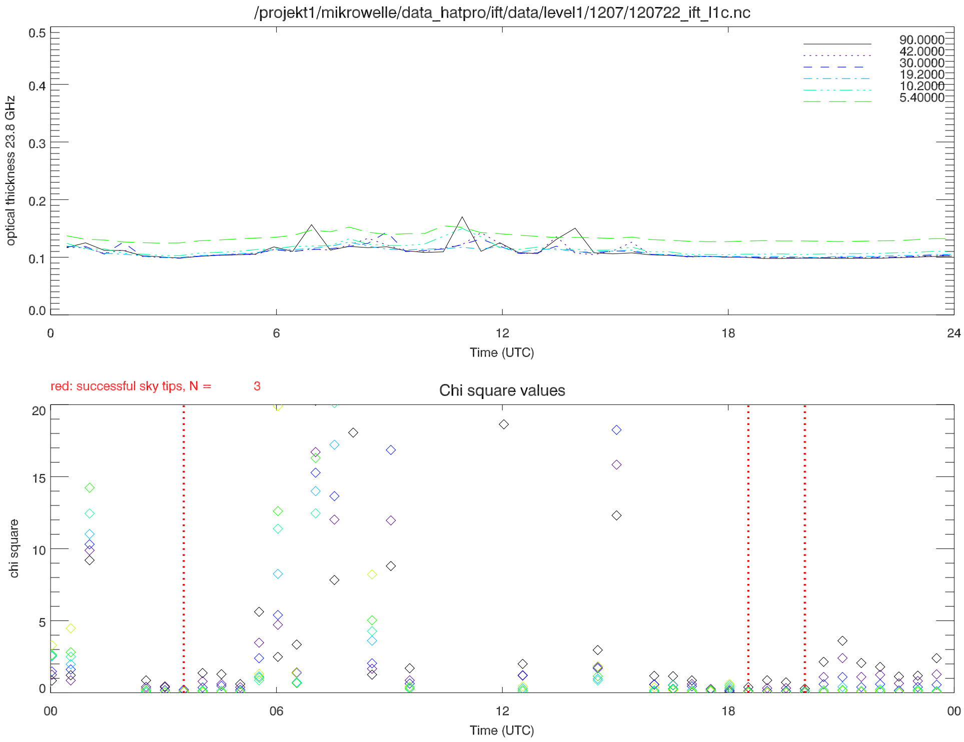
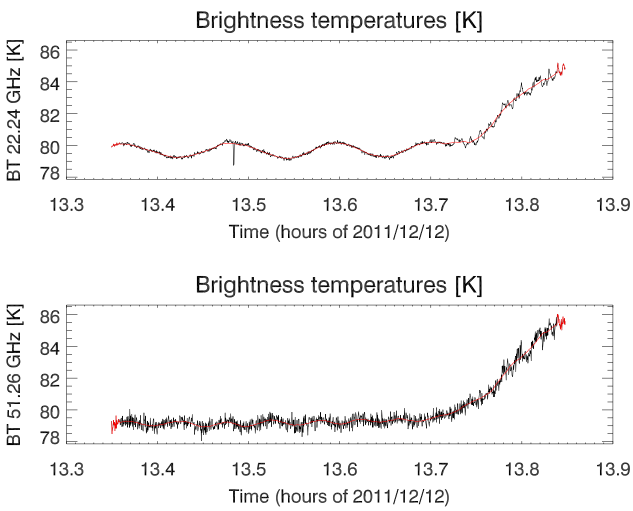
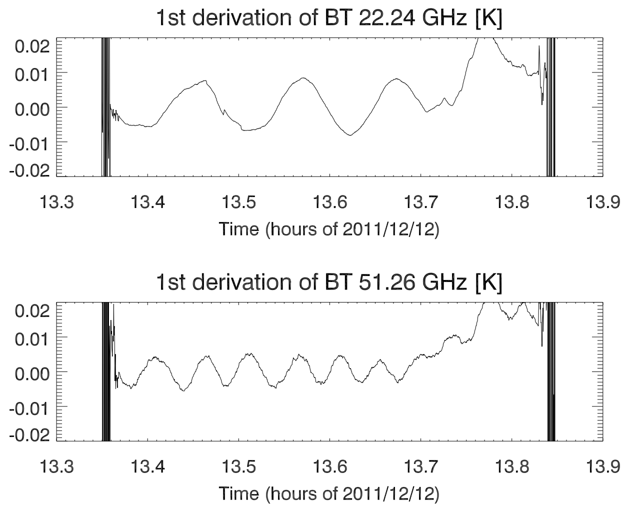


Figure 6: Analysis of conditions favorable for skytip calibrations for data from Leipzig on 22 July 2012. Top: Optical thickness from elevation scan BT observations. Bottom: Chi square values from Sky tip calibrations.



(a)



(b)

Figure 7: (a) Brightness temperature observations of LN2 surface during calibration on 12 December 2011 in Leipzig. (b) 1st derivative of brightness temperature for same period.

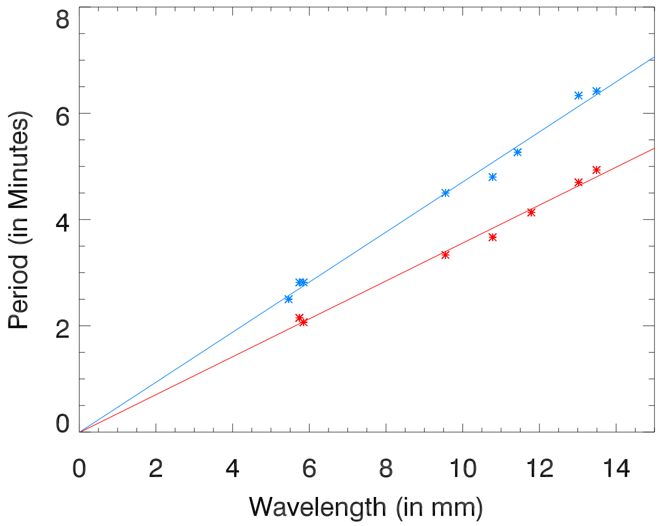


Figure 8: Correlation of standing wave period and wavelength for two different calibration events (colors).

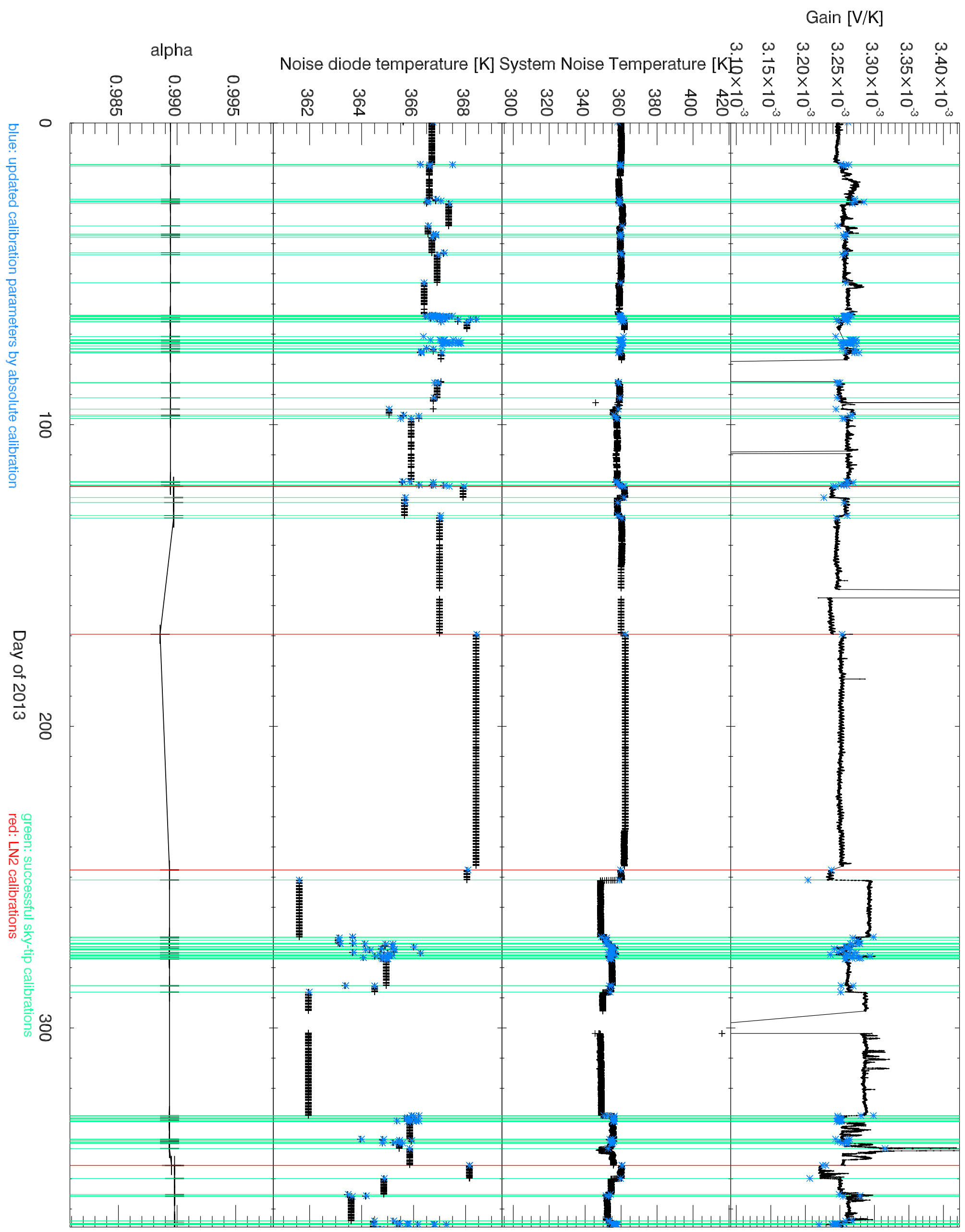


Figure 9: Variation of calibration parameters for 22.24 GHz channel of LACROS HATPRO during 2013.

References

Han, Y. and E. Westwater (2000). Analysis and Improvement of Tipping Calibration for Ground-Based Microwave Radiometers. *IEEE T. Geosci. Remote. 38*, 1260–1276.

Maschwitz, G., U. Löhnert, S. Crewell, T. Rose, and D. D. Turner (2013). Investigation of ground-based microwave radiometer calibration techniques at 530 hPa. *Atmos. Meas. Tech. 6*, 2641–2658.

Rose, T., S. Crewell, U. Löhnert, and C. Simmer (2005). A network suitable microwave radiometer for operational monitoring of the cloudy atmosphere. *Atmos. Res. 75*, 183–200.

Ware, R., R. Carpenter, J. Güldner, J. Liljegren, T. Nehrkorn, F. Solheim, and F. Vandenberghe (2003). A multichannel radiometric profiler of temperature, humidity, and cloud liquid. *Radio Sci. 38*, doi:10.1029/2002RS002856.

Westwater, E., S. Crewell, and C. Mätzler (2005). Surface-based Microwave and Millimeter wave Radiometric Remote Sensing of the Troposphere: a Tutorial. *IEEE Geoscience and Remote Sensing Society Newsletter March 2005*, 16–33.