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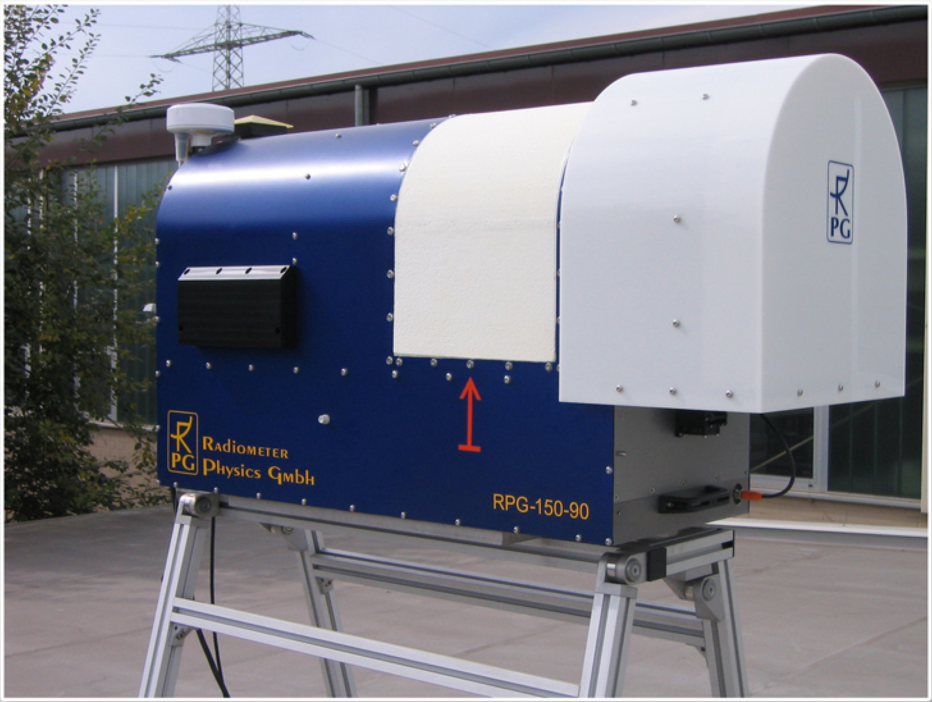
Microwave Radiometer – High Frequency HANDBOOK



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Microwave Radiometer – High Frequency (MWRHF) Handbook

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1.0 General Overview

The 90/150-GHz Vapor Radiometer provides time-series measurements of brightness temperatures from two channels centered at 90 and 150 GHz. These two channels are sensitive to the presence of liquid water and precipitable water vapor.

2.0 Contacts

2.1 Mentor

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2.2 Vendor / Instrument Developer

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53340 Meckenheim, Germany
www.radiometer-physics.com

3.0 Deployment Locations and History

Table 1. Status and location of the MWRHF.

Serial Number	Property Number	Location	Date Installed	Date Removed	Status
001		SGP/C1	2006/10/18		operational
002		AMF1	2007/06/08		operational

4.0 Near-Real-Time Data Plots

Plots of near-real-time data can be viewed at the DQHands (Data Quality Health and Status) system accessible through the web site: http://dq.arm.gov/. Click on “QC Metrics and Plots” and select the desired site and datastream. The MWRHF is located at the sites “SGP” and AMF1, the datastream is “sgpmwrhfC1.b1” and the facility is “C1”.Data Description and Examples

4.1 Data File Contents

Datastreams available from the ARM Archives are named: **xxxmwrhfSS.b1** and contain calibrated brightness temperatures. Raw data files are available upon request, and they are named xxxmwrhfSS.00.YYYYMMDD.HHMMSS.raw.YYMMDDHH.LV0.NC, where xxx is the site name (sgp, grw,…) and SS indicates the facility (C1, M1, …).

4.1.1 Primary Variables and Expected Uncertainty

The primary variables measured by the MWRHF are brightness temperatures at 90 and 150 GHz.

Table 2. Primary variables.

Variable Name	Quantity Measured	Unit	Uncertainty
Tbsky90	90 GHz sky brightness temperature	K	1 K
Tbsky150	150 GHz sky brightness temperature (filtered)	K	1 K

4.1.2 Secondary / Underlying Variables

Table 3. Secondary variables.

Variable Name	Quantity Measured	Unit	Uncertainty
time	Time offset from midnight	s	
temp	Ambient temperature	C	0.5
pressure	Pressure	KPa	2
rh	Relative humidity	%	5
Rain_flag	Rain flag	N/A	N/A

4.1.3 Diagnostic Variables

Table 4. Diagnostic variables.

Variable Name	Quantity Measured	Unit	Uncertainty
tnd90med	90 GHz median noise diode temperature from tip curves	K	5 K
tnd150med	150 GHz median noise diode temperature from tip curves	K	5 K
tnd90i	90 GHz instantaneous noise diode temperature from tip curves	K	1.5 K
tnd150i	150 GHz instantaneous noise diode temperature from tip curves	K	2.5 K

4.1.4 Data Quality Flags

Data quality flags are named qc_'fieldname' (i.e. qc_tbsky90). Possible values for qc_flags are: 0 (value is within the specified range), 1 (missing value), 2 (value is less than the specified minimum), 4 (value is greater than the specified maximum), and 8 (value failed the valid "delta" check). Specified maximum and minimum values are shown in Table 5.

Table 5. Data quality thresholds.

Field Name	Min	Max
Tbsky90	0	310
Tbsky150	0	310
pressure	80	110
temp	-49	50
rh	1	110

4.1.5 Dimension Variables

Table 6. Dimension variables.

Field Name	Quantity	Unit
base_time	Base time in Epoch	seconds since 1970-1-1 0:00:00 0:00
time_offset	Time offset from base_time	s
lat	north latitude	degrees
lon	east longitude	degrees
alt	altitude	meters above Mean Sea Level

4.2 Annotated Examples

In this section are some examples of data. Figure 1 shows a comparison of measured and modeled brightness temperatures collected during winter 2008–2009 at the SGP/C1. Figure 2 is an example of one day of calibrated brightness temperatures collected at the Mobile facility GRW/M1 during February 2010.

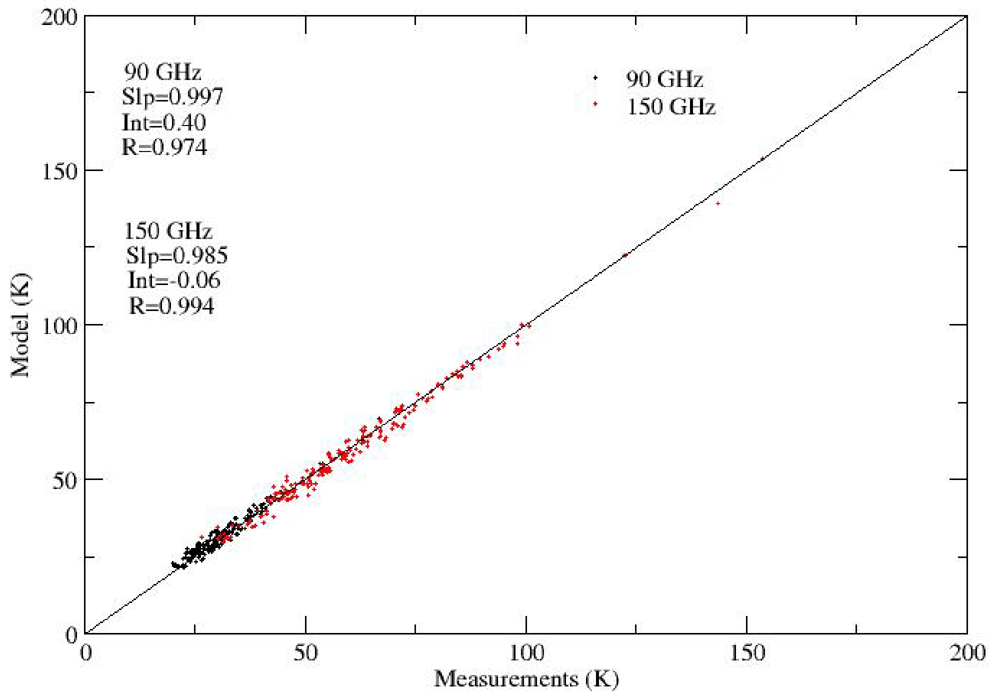

Figure 1. Comparison of measured and modeled brightness temperatures, data collected at the SGP (2008–2009), N=197 points.

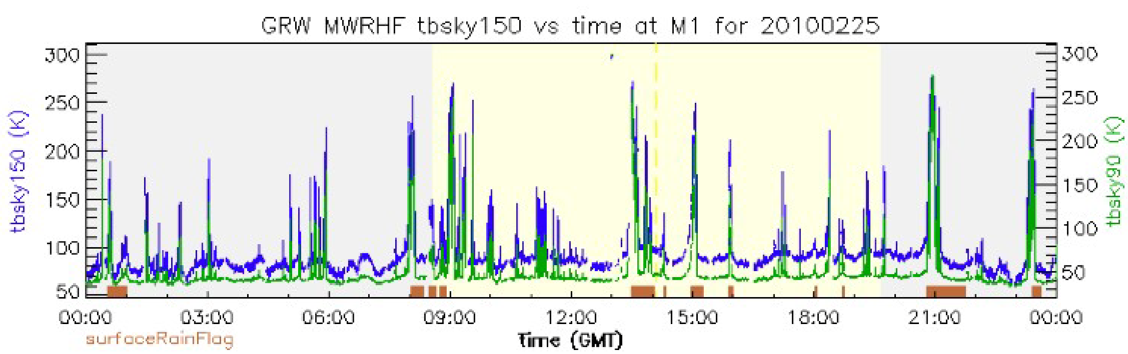

Figure 2. Example of a time series of brightness temperatures at 90 and 150 GHz collected at the M1/GRW site in February 2010.

4.3 User Notes and Known Problems

The calibration of the MWRHF has been re-written to be more consistent with the calibration of the 2 channel MWR radiometers. Therefore the calibrated brightness temperatures are not produced with the software provided by the vendor. A description of the calibration algorithm is provided in this handbook.

4.4 Frequently Asked Questions

This section is not available.

5.0 Data Quality

5.1 Data Quality Health and Status

Daily quality check on this data stream can be found at the DQHands page: http://dq.arm.gov/. Click on “QC Metrics and Plots” and select the desired site and datastream. For example, for the MWRHF located at the site “SGP”, the datastream is “sgpmwrhfC1.b1” and the facility is “C1”.

5.2 Data Reviews by Instrument Mentor

The instrument mentor submits a monthly summary report IMMS accessible from the instrument web page. Some of the general checks performed by the instrument mentor are shown below.

1. In general, the brightness temperature time series should be smooth and with low noise levels.
2. Brightness temperatures should be greater than 2.75 K and less than approximately 310 K.
3. External temperature readings can be compared to tower measurements. The agreement should be +/- 2 K.
4. External pressure readings can be compared to tower measurements. The agreement should be +/- 5 KPa.
5. External relative humidity readings can be compared to tower measurements. The agreement should be +/- 5%
6. Measured brightness temperatures are also compared with model computations as a general quality check.

5.3 Data Assessments by Site Scientist / Data Quality Office

The Data Quality office daily data assessment can be viewed at the DQHands web page.

5.4 Value-Added Procedures and Quality Measurement Experiments

No value-added products are available at this stage.

6.0 Instrument Details

6.1 Detailed Description

The MWRHF measures sky radiances at two frequencies 90 and 150 GHz. Radiance measurements are converted to "equivalent brightness temperatures" through the calibration procedure. Below is detailed description of the instrument components.

6.1.1 List of Components

- RF section: Radiometer RPG-150-90.
- Desktop PC host computer with monitor, keyboard, and mouse
- Radiometer stand
- Blower assembly
- Cables
- Heater unit

6.1.2 System Configuration and Measurement Methods

In this section we give a brief description of the MWRHF hardware configuration. The material in this section can be found in [1]. Refer to the same reference and to [2] for further details on this instrument.

The radiometer has two direct detection receiver units. An off-axis paraboloid mirror is used to focus microwave radiation onto a corrugated feed horn. The microwave radiation entering the instrument is first decomposed in two beams through a wire-grid beam splitter. Each beam is directed in a feed horn to generate a beam of the desired divergence (~3° HPBW). At each receiver input, a Dicke Switch periodically switches the receiver inputs to an internal black body with known brightness temperatures. This is used to continuously determine the system noise temperature of the radiometers. A 40-dB low noise amplifier (LNA) boosts the input signal before it is filtered and boosted again by another 20-dB amplifier. The waveguide band pass filters bandwidths, and center frequencies are listed in Table 7. All channels are detected and integrated simultaneously. The receivers are based on the direct detection technique, where the signal is directly amplified, filtered, and detected.

The radiometer receivers are thermally stabilized to an accuracy of ± 0.02 K. Due to this extremely accurate stability, the instrument can run without gain calibration for about 30 minutes, maintaining a radiometric accuracy of ± 0.3 K. A block diagram of the instrument is shown in Figure 3. The instrument located at the SGP does not have the noise diode after the Dicke switch and relies on the Dicke switch for calibration. The radiometer is configured for 1s integration time at each frequency.

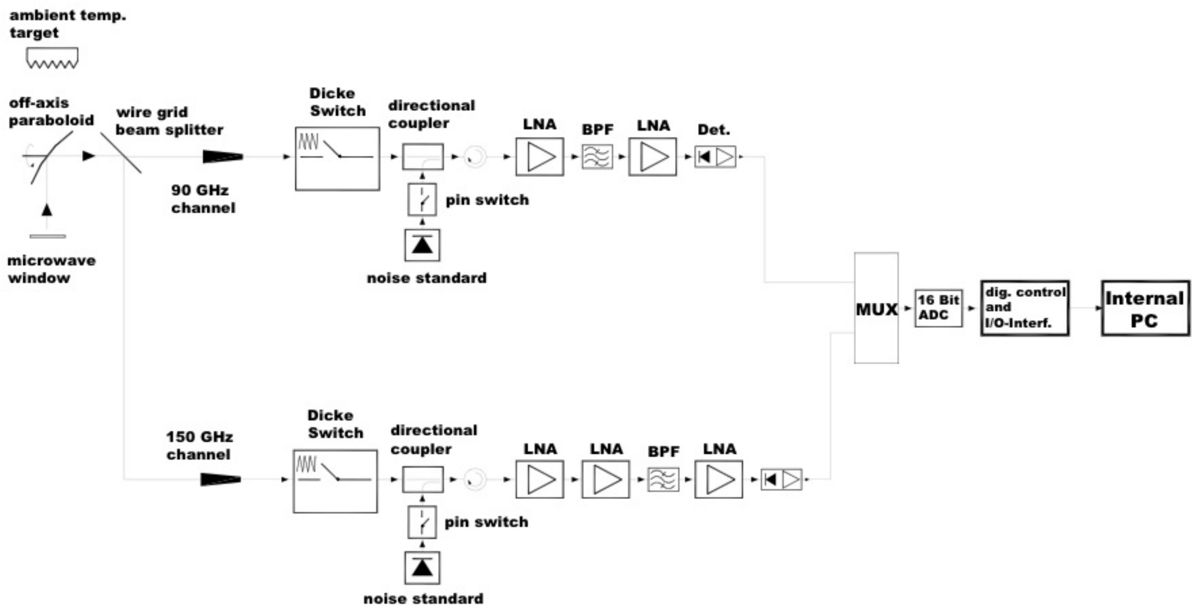

Figure 3. MWRHF simplified component level block diagram.

6.1.3 Specifications

Table 7. Instrument specifications.

Parameter	Value
Receiver noise temperature 90 GHz	< 750 K
Receiver noise temperature 150 GHz	< 1650 K
Channel bandwidth	2000 MHz
Absolute system stability	1 K
Radiometric resolution	0.2-0.4 K RMS@1 s integration time
Receiver and antenna thermal stabilization	< 0.05 K
Integration time	>=1 s
HPBW 90-GHz channel	1.8°
HPBW 150-GHz channel	1.5°
Temperature range	-30 to +45 C (Environmental Chamber tested)
Power consumption	< 150 W, Max 350 W without dew blower

6.2 Theory of Operation

The MWRHF measures brightness temperatures from two channels centered at 90 and 150 GHz. These two frequencies are located in the so-called window region of the microwave spectrum, and they are sensitive to cloud liquid water. The water vapor contribution at these frequencies comes from the water vapor continuum region. Figure 4 shows the contribution of various atmospheric gases to the opacity as a function of frequency. The two vertical yellow lines indicate the location of the two MWRHF channels.

Since the cloud liquid water contribution to the microwave signal increases roughly with the square of the frequency, the window regions above 90 GHz are more sensitive to cloud liquid than the region below 45 GHz.

Simulations show that by adding measurements at 90 and 150 GHz to measurements at 23.8 and 31 GHz (from the microwave dual-channel radiometer MWR), it is possible to reduce by approximately 50 % the root mean square error of the retrieved liquid water path (LWP).

6.3 Calibration

6.3.1 Theory

The MWRHF absolute calibration is conducted using two calibration targets. Occasionally a cryogenic reference target is used to perform absolute calibration and determine the equivalent noise temperature of the diode. During absolute calibration, the receiver gain coefficient, G, the system noise equivalent temperature, T_{sys}, and a non-linearity coefficient, α, are determined. Liquid nitrogen calibrations are usually performed at the beginning of a new deployment or when the radiometer has been out of service or moved. Additional LN2 calibrations may be performed when considered necessary. However, after the initial cryogenic calibration, the routine calibration of the radiometer relies on tip curves.

Tip curves are collected hourly to determine the system noise temperature and gain. A linear regression is performed between the optical thickness and the air mass. The straight line is extrapolated to zero air mass. The detector reading at this point corresponds to a radiometric temperature, which equals the system noise temperature plus 2.7 K. A second detector voltage is measured with the radiometer pointing at the ambient temperature with known radiometric temperature.

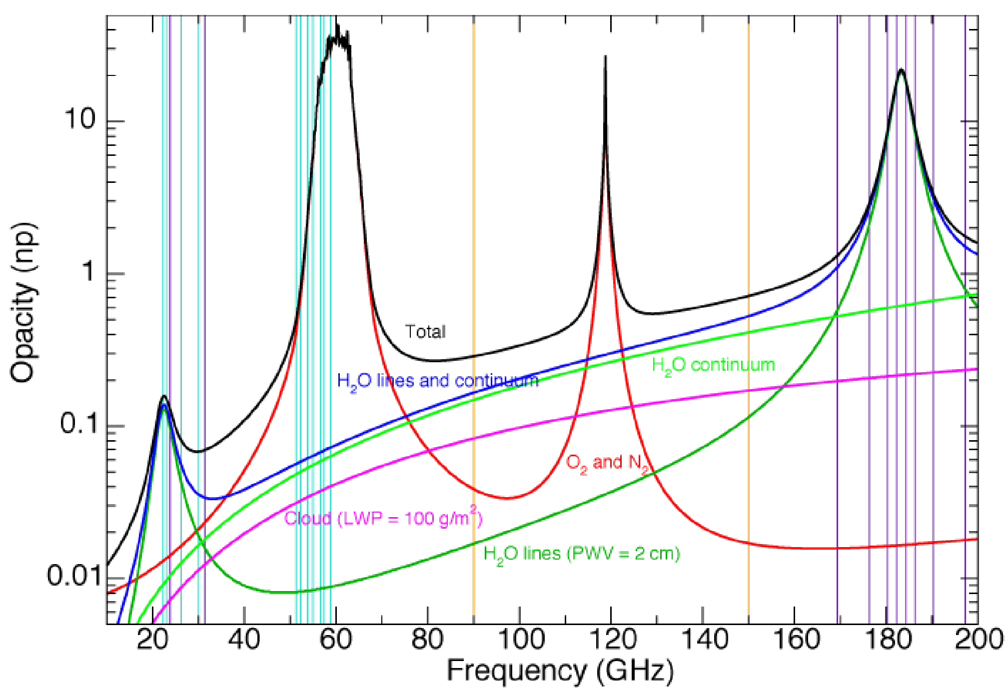

Figure 4. Atmospheric opacity as function of frequency.

6.3.2 Procedures

The calibration algorithm is based on the assumption that although noise diodes are known to be stable over time, the effective noise diode injection temperature as determined from tip curves will eventually show some drift over a period of a few months. The radiometer equation used in the algorithm is:

$$T_{sky} = T_{bb} + (V_{sky} - V_{bb})/G \tag{1}$$

where V_{sky} is the signal recorded when the reflector is oriented towards the sky, V_{bb} is the signal recorded while looking at the black body target, G is the gain, and T_{bb} is the physical temperature of the black body target. Equation 1 is the basic equation that is used in the calibration. The radiometer performs absolute calibrations by conducting tip curves every hour and gain calibrations every 5 minutes. During tip calibrations, the radiometer scans on both sides of the window and acquires black body readings. During gain calibration the radiometer acquires only black body readings.

The gain G is determined by:

$$G = (V_{bb+nd} - V_{bb}) / T_{nd}, \tag{2}$$

where V_{bb+nd} is the signal associated to the black body with the noise diode on and T_{nd} is defined as:

$$T_{nd} = \frac{T_{sky} - T_{bb}}{V_{sky} - V_{bb}} (V_{bb+nd} - V_{bb}). \tag{3}$$

To have an estimate of T_{nd}, it is necessary to acquire an independent T_{sky} value. This is achieved through hourly tip curves. In the tip curve procedure, the opacity (τ) computed at each elevation angle is plotted as a function of airmass and the slope of the regression (τz) is computed. T_{sky} is then determined as:

$$T_{sky} = 2.73e^{-\tau z} + T_{mr}(1 - e^{-\tau z}) \tag{4}$$

where T_{mr} is the atmospheric mean radiating temperature. This T_{sky} value is then substituted in (3) to determine the *instantaneous* value of T_{nd} that will be called $T_{nd}I$. Scanning on both sides of the window, although it increases the time necessary for the calibration, helps to minimize the errors due to misalignment. Notice that only the slope (and not the intercept) is determined in the tip curve process.

A tip curve is considered good if the correlation coefficient of the regression is higher than a predefined threshold of 0.999. An example of tip curve result is shown in Figure 5.

The variability in the instantaneous values $T_{nd}I$ is such that it is not desirable to introduce these single values directly in the calibration algorithm (2) and (1). Instead, the following procedure is adopted: instantaneous values $T_{nd}I$ are collected and stored in a circular array of 50 (or more) points, and the median value of the array is computed. Every time a new tip is collected, the elements of the array are shifted off one position and the newest tip is stored as the last element of the array. A new median value of the array is then computed. The two channels are updated independently from each other.

In Figure 6, the instantaneous tip curves $T_{nd}I$ (black points), the 50-point running median values (green line), and the values derived from repeated LN2 calibrations (red line) are shown.

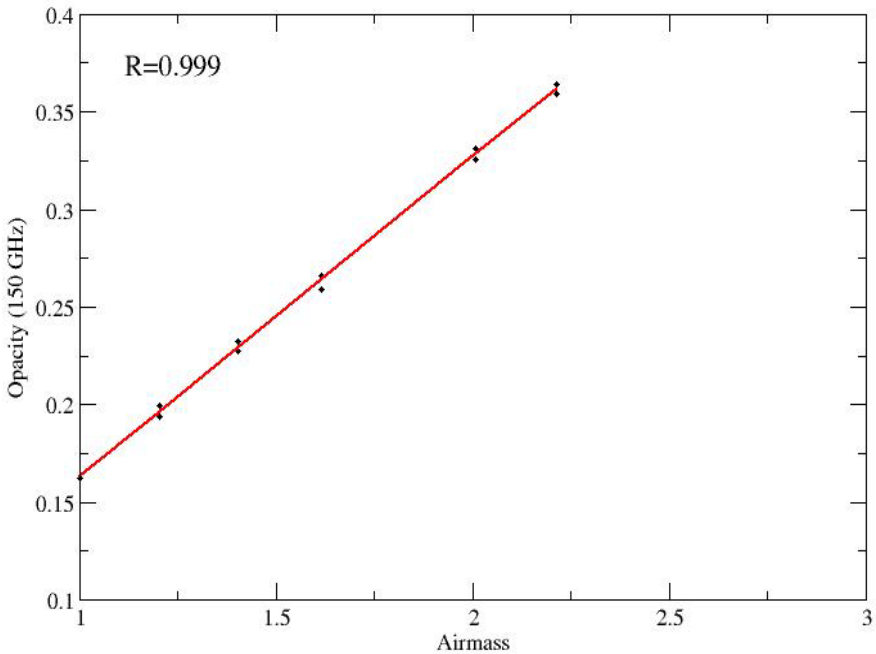

Figure 5. One example of successful tip curve (R > 0.999) collected on January 31, 2008 (150 GHz).

Error budget of calibration equations

For a typical estimated uncertainty of the slope δτz ~ 0.002 the estimated error on T_{sky} is (4):

$$\delta T_{sky} = (T_{mr} - T_c)e^{-\tau z}\delta\tau z \sim 0.4K \tag{5}$$

From this we can estimate the error on the instantaneous $T_{nd}I$:

$$\delta T_{nd}I \sim T_{nd}I/(T_{sky} - T_{bb})\delta T_{sky} \sim (T_{nd}I/250)\delta T_{sky} \tag{6}$$

For a typical $T_{nd}I$ ~ 900 K at 90 GHz and 1000 K at 150 GHz, this results in an uncertainty of ~ 1.5 K in the estimation of $T_{nd}I$ in both channels.

Conversely, an error of 1 K on T_{nd} will produce a ~ 0.3 K error in T_{sky}. For a typical standard deviation of the instantaneous $T_{nd}I$ of 5 K at 90 GHz and 8 K at 150 GHz, the calibration uncertainty can be estimated to be ~ 1 K at both frequencies.

Implementation

The calibration algorithm reads the LV0 files containing the raw data. It first determines if previous calibration values are stored in an external calibration file. If they are found, the most recent median value T_{ndmed} is used as a starting point. Upon reading the LV0 file the software determines whether or not a tip curve and gain calibrations are present. If a new tip curve is found that passes the correlation threshold, the software computes a new $T_{nd}I$ value, updates the calibration array, computes a new T_{ndmed}, and uses this last value to calibrate the data that follows.

If a tip curve is not found, the software only updates the gain calibration every 5 minutes by using the most recent black body readings and the old T_{ndmed} values. The chart in Figure 7 shows the algorithm implementation.

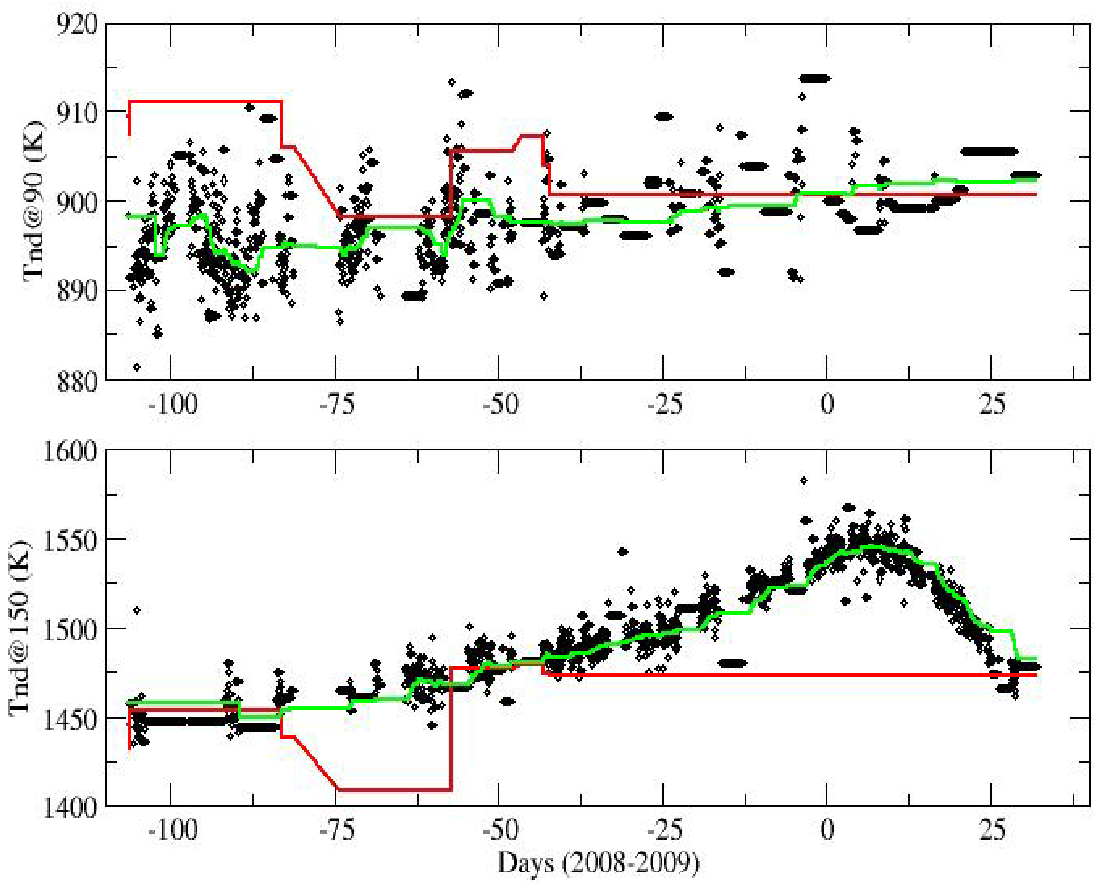

Figure. 6. Instantaneous $T_{nd}I$ values derived from tip curves (black points), running median values over 50 points (green line), Tnd values from LN2 calibration (red line). Top panel: 90-GHz channel; Bottom panel: 150-GHz channel.

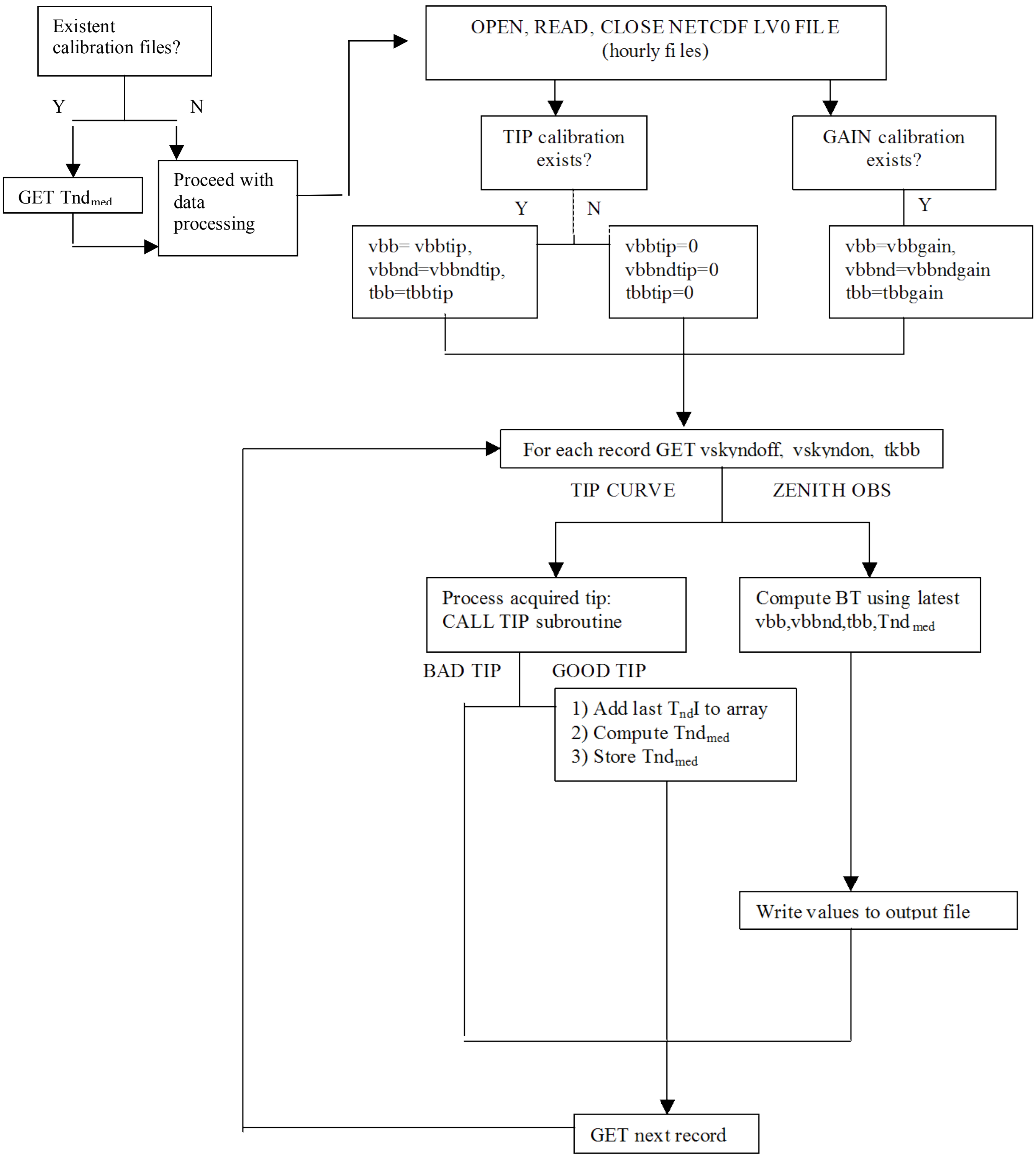

Figure 7. Diagram of the MWRHF calibration software.

6.3.3 History

- 2006–2007: The MWRHF was initially tested at the SGP/C1 site.
- 2007: Deployment of second unit with AMF1/FKB during the "Initiation of Convection and the Microphysical Properties of Clouds in Orographic Terrain" (COPS) campaign.
- 2008 (September): Deployment of modified unit at the SGP/C1 after hardware and software modifications.
- SGP data have the new calibration algorithm starting in September 2008.
- AMF1 data have new calibration algorithm starting in May 2009 (GRW deployment).

6.4 Operation and Maintenance

6.4.1 User Manual

See [1].

6.4.2 Routine and Corrective Maintenance Documentation

Available at the site operation web pages.

6.4.3 Software Documentation

Available through the Data Management Facility or instrument mentor.

6.4.4 Additional Documentation

N/A

6.5 Glossary

Uncertainty: We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error B and uncorrelated random errors characterized by a variance σ^2, the root-mean-square error (RMSE) is defined as the vector sum of these,

$$RMSE = \left(B^2 + \sigma^2\right)^{1/2}. \tag{7}$$

(B may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval, we use the Student's t distribution: $t_{n;0.025} \approx 2$, assuming the RMSE was computed for a reasonably large ensemble. Then the *uncertainty* is calculated as twice the RMSE.

6.6 References

[1] RPG-150-90 High Sensitivity LWP radiometers-Operating Manual, by T. Rose and H. Czekala.

[2] T Rose, S Crewell, U Lonhert, and C Simmer. 2005. "A network suitable microwave radiometer for operational monitoring of the cloudy atmosphere." *Atmospheric Research* 75: 183–200.

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