Validation of Microwave Radiometer Measurements in Clear Air

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ABSTRACT

An independent validation of the performance of a microwave radiometer is presented. Observed brightness temperatures are compared with radiative transfer models, based on coincident radiosonde profiles in clear sky conditions. Biases were identified in the radiometer, which caused biases in the retrieved temperature profile. These have now been corrected. Biases were also found in the water vapour channels around 23 GHz, partly due to a dry bias in the RS80H radiosonde.

Keywords: Validation, remote sensing instruments, microwave radiometer, temperature, water vapour, radiosonde.

1. INTRODUCTION

The Met Office procured a microwave radiometer to evaluate its abilities to retrieve information on temperature and humidity profiles in the lower troposphere. This was operated at Camborne, in south-west England from February 2002 to March 2003. During this period, radiosondes were regularly launched to provide co-incident *in situ* data to validate the radiometer's measurements. This comparison is restricted to clear sky conditions to minimise the uncertainty in the forward model, as extinction by clouds and precipitation is sensitive to microphsyical parameters for which no *in situ* data is available.

2. THE RADIOMETRICS MP3000 MICROWAVE RADIOMETER

The Radiometrics MP3000 radiometer has 12 channels: 5 in the 22-30 GHz band dominated by water vapour and 7 in the 51-59 GHz oxygen band. It is calibrated against an ambient internal black body target and a noise diode. Each channel detects radiation in a double sideband ±(40-190) MHz centred on the frequencies given in **Table 1**. This also shows the radiometric resolution of each channel before calibration. The channels were sampled sampled sequentially, as part of a ~14 minute observation cycle that includes zenith views, black body views and tip curves [see Section 4].

Table 1 - Summary of Radiometer Random Noise including Calibration and Model Comparison

Frequency (GHz)	Nominal Zenith Brightness Temperature, T_b (K)	Radiometric Sensitivity $NE\Delta T$ (K)	Random Noise on T_b including Calibration (K)	Systematic Uncertainty on T_b from Cal. (K)	Random Error on Model from Sonde inputs (K)	Total Random Error on Obs-Model (K)
22.235	27.5	0.11	0.24	0.52	0.38	0.45
23.035	27.0	0.10	0.24	0.40	0.38	0.45
23.835	24.0	0.10	0.23	0.40	0.34	0.41
26.235	17.1	0.10	0.30	0.29	0.22	0.38
30.000	15.0	0.09	0.28	0.21	0.16	0.32
51.250	105.5	0.13	0.24	1.06	0.19	0.31
52.280	148.9	0.10	0.19	0.89	0.15	0.24
53.850	248.6	0.08	0.13	0.38	0.06	0.15
54.940	278.7	0.08	0.13	0.24	0.08	0.16
56.660	283.4	0.24	0.35	0.22	0.12	0.37
57.290	283.8	0.19	0.27	0.22	0.13	0.30
58.800	284.1	0.09	0.14	0.22	0.14	0.20

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Absolute calibration of the noise diode for the water vapour band is provided by regular tip curves. However, this technique cannot be applied to the optically thick channels in the oxygen band, so an external liquid nitrogen target is used to provide absolute calibration every few months. Both calibration methods have been ananlysed by the authors [1]. The tip curve calibration method is found to be limited by the instruments' beam efficiency, which causes sensitivity to emission from the surface at low elevation angles. This factor is not accounted for in the analysis of Han & Westwater [2]. The accuracy of the liquid nitrogen calibration is limited by thermal emission from the polystyrene, and uncertainty in the amplitude of reflections in the polystyrene-cryogen interface. The resulting random noise and systematic uncertainties introduced by calibration are given for nominal zenith scenes in **Table 1**.

3. RUNNING RADIATIVE TRANSFER MODELS WITH RADIOSONDE PROFILES

High resolution (~10 m) profiles of temperature and humidity are used as input to the radiative transfer models to minimise any errors introduced by layering the data. Radiosondes from Camborne typically reach altitudes of >30 km (~10 hPa). However, there is still a finite emission from atmosphere above this altitude, so the radiosonde profiles are 'topped-up' with a standard atmosphere. This makes a small, insignificant difference for the 22.235 GHz channel only.

The radiative transfer models are run at a single frequency to represent each channel. These frequencies were selected to produce zenith brightness temperatures that most closely matched the average of a comb of 22 frequencies spread over the passband of each channel. This tuning was repeated for 12 profiles, ranging from cold and dry to warm and humid. The models run at the *effective monochromatic frequency* agreed with an r.m.s. difference of <0.05 K of the full comb. The following absorption models were used in this study: MPM87 [3], MPM89 [4], MPM93 [5] and Rosenkranz98 [6].

The random uncertainty on the radiosondes measurements of temperature (±0.2 K) and humidity (±3 %RH) are propagated through the radiative transfer model to estimate the uncertainty on the modelled brightness temperatures, shown in **Table 1**. This is done by perturbing each of 40 layers of a standard atmospheric profile independently.

4. RESULTS

Figure 1 shows the difference between observed and modelled brightness temperatures, plotted against the observed value. The lowest frequency channels show a strong slope, with all models showing a significant bias in humid conditions. The RS80H radiosondes used at Camborne are known to have a dry bias due to sensor contamination and solar heating. The average maximum relative humidity measured in low cloud during this period was 97.0 %RH. If the profiles input to the radiative transfer model are corrected by increasing the vapour pressure by a factor of 1.03, the difference between observations and model decreases, but a positive bias remains for all models. MPM93 then remains the closest model to the observations, although it overestimates the strength of the water vapour contiuum at 26-30 GHz.

There was a consistent, positive bias of 1-2 K at the highest frequencies. This has been identified as a instrument bias, and has subsequently been reduced by modification of the control software. The channels at intermediate frequencies (30-52 GHz) show significant differences between the models, where MPM93 provides the best fit to the observations, although there is a large systematic uncertainty (~1 K) in the observations at 51.250 GHz mostly due to the calibration.

The average bias is found to be significant (>2σ) for several channel/model combinations. The r.m.s. difference between the observations and the models is also significantly larger than expected if the unceratinties due to the calibration are combined with those due to the accuracy of the radiosonde measurements input to the models (as shown in the last column of Table 1). This is evidence that at least one component of the systematic uncertainty has been underestimated in the calibration analysis [1].

The radiometer's control software was revised by the manufacturers in February 2003. Since then, the bias in the high frequency channels has reduced. However, there is not sufficient data yet available to check the bias at the lowest frequencies in humid conditions, but this is not expected to change. This revision also reduced the observation cycle by a factor of ~4. This allows the radiometer to retrieve information on temperature and humidity profiles in the lower troposphere more quickly and with lower bias than was previously possible.

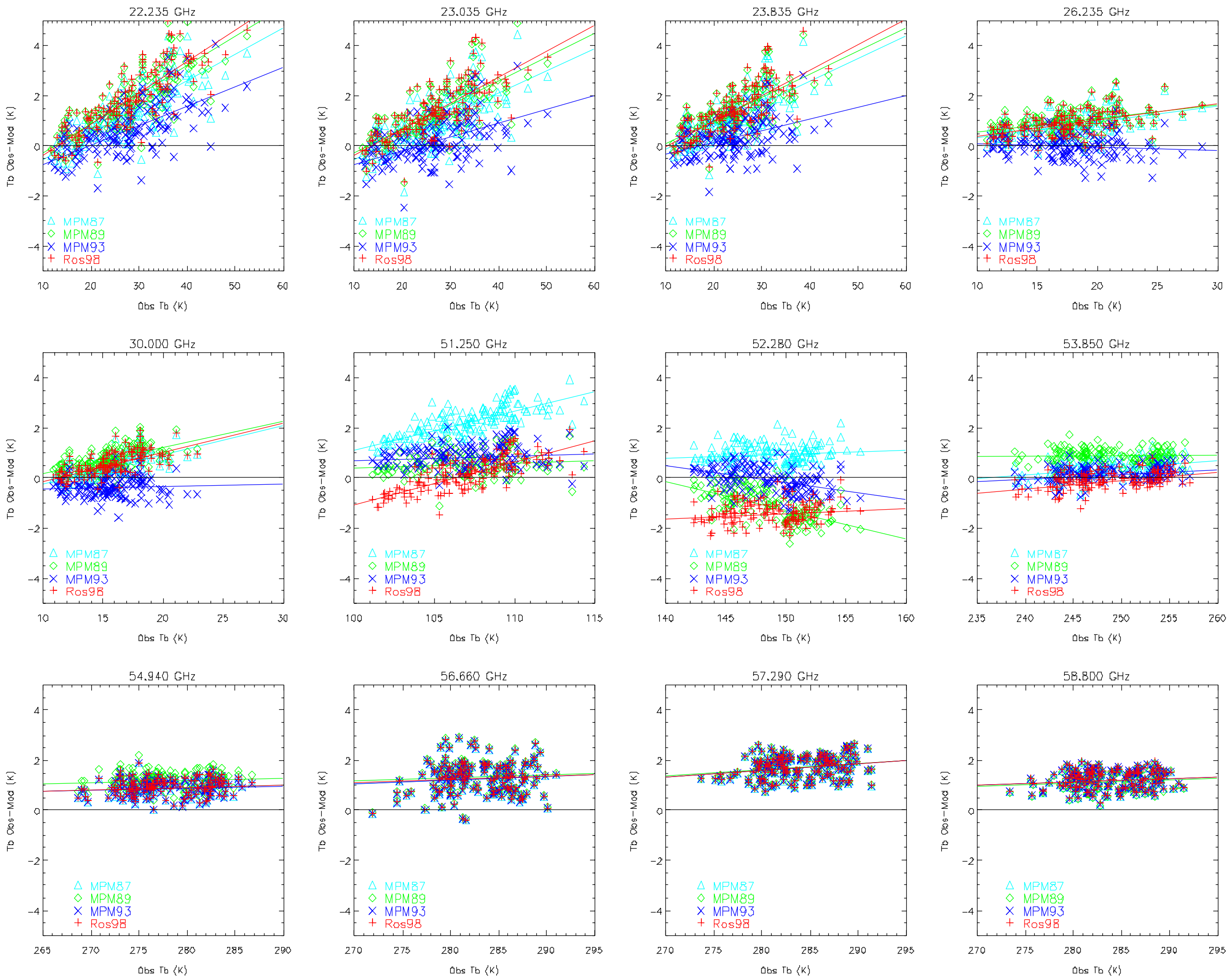

Figure 1 – Bias in Observations of Microwave Radiometer with respect to Forward Models
Based on 145 uncorrected RS80H radiosondes with ≤1/8 low cloud, 22/2/02-3/2/03, Camborne, UK.

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