Validation of Microwave Radiometer Measurements in Clear Air

Tim Hewison, Catherine Gaffard, John Nash

Absract

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 reduced. Biases were also found in the water vapour channels around 23 GHz, partly due to a dry bias in the RS80H radiosonde.

Introduction

Ground-based microwave radiometry can potentially retrieve:
- Temperature profiles
- Humidity profiles
- Liquid water cloud

- In the lower troposphere
- At high tempororal resolution

Exploiting features of microwave absorption spectrum:
- 22.235 GHz water vapour line
- Oxygen complex of lines centred on ~60 GHz
- Intermediate frequencies are 'windows', dominated by
  – water vapour continuum absorption in clear air
  – or liquid water cloud

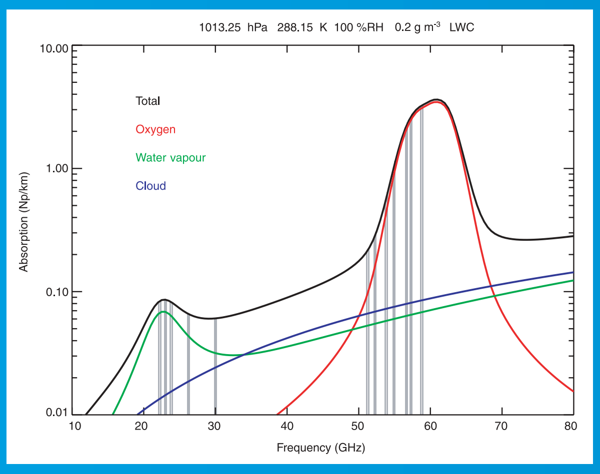

Figure 1. Microwave Absorption Spectrum

The Radiometrics MP3000 microwave radiometer


Figure 2. Radiometrics MP3000 Microwave Radiometer

12 channels:
- 5 for water vapour/cloud 22-30 GHz
- 7 for oxygen (temperature) 51-59 GHz
- All double sideband ±(40-190) MHz
- Centre frequencies given in Table 1
- All channels currently sampled sequentially
- (Takes ~40 s – under revision)

Internal calibration:
- ambient black body target and
- a noise diode, which needs absolute calibration

Observation cycle:
- Includes zenith view for retrieval
- Black body view
- Tip curve calibration at 5 elevation angles
- Originally ~14-minute cycle
- Now 200 seconds, after software revision

Integrated sensors:
- Ambient temperature, humidity & pressure
- Infrared radiometer to measure cloud base temperature
- Rain sensor – for quality control

Provides real-time retrievals by neural network

External calibration

Water vapour channels calibrated by tip curve:
- Scan five elevation angles: 30°, 45°, 90°, 135°, 150°
- Every few minutes
- Calculates opacity, τ, and fits to theoretical sec(θ) dependence
- Gives absolute reference: brightness temperature at zenith
- Need stratified conditions – only 35% of attempts at Camborne pass QC
- Noise dominated by atmospheric variability
- Bias dominated by sidelobe contamination due to finite beam efficiency causing sensitivity to emission from the surface at low elevation angles. This factor is not accounted for in the analysis of Han & Westwater [1].

Oxygen channels use a liquid nitrogen calibration target:
- Performed every few months
- Black body at known temperature (~79 K)
- Noise dominated by radiometer drift since last calibration
- Accuracy limited by thermal emission from the polystyrene.
- Uncertainty in reflections in the polystyrene-cryogen interface

Figure 3. Liquid nitrogen calibration target [Courtesy of Radiometrics]

Both calibration methods have been analysed by the authors [2]. The resulting random noise and systematic uncertainties introduced by calibration are given for nominal zenith scenes in Table 1.

Evaluation trial at Camborne

- Operated at Camborne, SW England
- From February 2002 to October 2003
- Operational RS80 radiosonde launches 2-4 per day, providing validation of retrieved profiles
- 915 MHz wind profiling radar – Radian LAP3000 – evaluating signal power to improve vertical resolution
- Extensive surface meteorological sensors

Radiometer random noise

Observation error covariance matrix needed for variational assimilation of data into NWP.
It determines whether the data will have an impact on the model background field.

Radiometer noise:
- Evaluated viewing ambient black body
- Covariance is ~diagonal
- Channels independent (good for assimilation)
- Low noise: NEΔT~0.1K
- But does not include noise added by calibrations…

Calibration noise:
- Increases diagonal terms by a factor of ~2-10
- Adds off-diagonal terms to water vapour channels
- Degrades vertical resolution of profiles
- Could be improved by QC on tip curve calculations

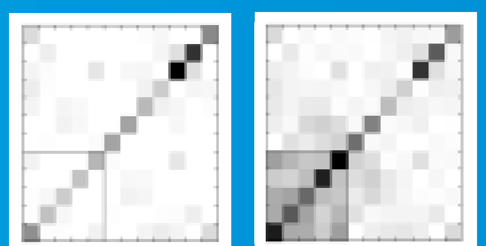
Figure 4. Error covariance matrices;
Left panel: excluding calibration noise;
right panel: including calibration noise.
For 12 channels: 22 GHz lower left, 59 GHz upper right. Scale: white ≤0 K^2, black=0.1 K^2.

Table 1. Summary of radiometer random noise including calibration and model comparison

Frequency (GHz)	Nominal zenith brightness temperature, T_b (K)	Radiometric sensitivity NEΔT (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	0.27	0.52	0.38	0.45
23.035	27.0	0.10	0.26	0.40	0.38	0.45
23.835	24.0	0.10	0.25	0.40	0.34	0.41
26.235	17.1	0.10	0.31	0.29	0.22	0.38
30.000	15.0	0.09	0.29	0.21	0.16	0.32
51.250	105.5	0.13	0.26	1.06	0.19	0.31
52.280	148.9	0.10	0.21	0.89	0.15	0.24
53.850	248.6	0.08	0.14	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	0.28	0.22	0.13	0.30
58.800	284.1	0.09	0.14	0.22	0.14	0.20

Running radiative transfer models with radiosonde profiles

- Comparison restricted to clear sky conditions to minimise the uncertainty in the forward model. Extinction by clouds/precipitation sensitive to microphysical parameters for which no *in situ* data are available

Input to radiative transfer models:
- Radiosondes profiles of temperature and humidity used at high resolution (~10 m)
- Radiosondes from Camborne typically reach altitudes >30 km (~10 hPa).
- 'Topped-up' with a standard atmosphere, as there is finite emission from atmosphere above (small, insignificant difference for the 22.235 GHz channel only)

Selected *effective monochromatic frequencies* to represent each channel:
- Frequencies selected to produce zenith brightness temperatures most closely matching the average of a combination of 22 frequencies spread over the pass band of each channel
- Tuning repeated for 12 profiles, ranging from cold and dry to warm and humid
- Models run at the *effective monochromatic frequency* agree within r.m.s. difference of <0.05 K of full combination

Absorption models used in this study:
Δ = MPM87 [3], ◊ = MPM89 [4], X = MPM93 [5] and + = Rosenkranz98 [6]

Random uncertainty in radiosonde measurements:
- Temperature: ± 0.2 K
- Humidity: ± 3% RH
- Each of 40 layers of standard atmosphere perturbed independently
- Estimates uncertainty on modelled brightness temperatures, propagated through model, see Table 1.

Results

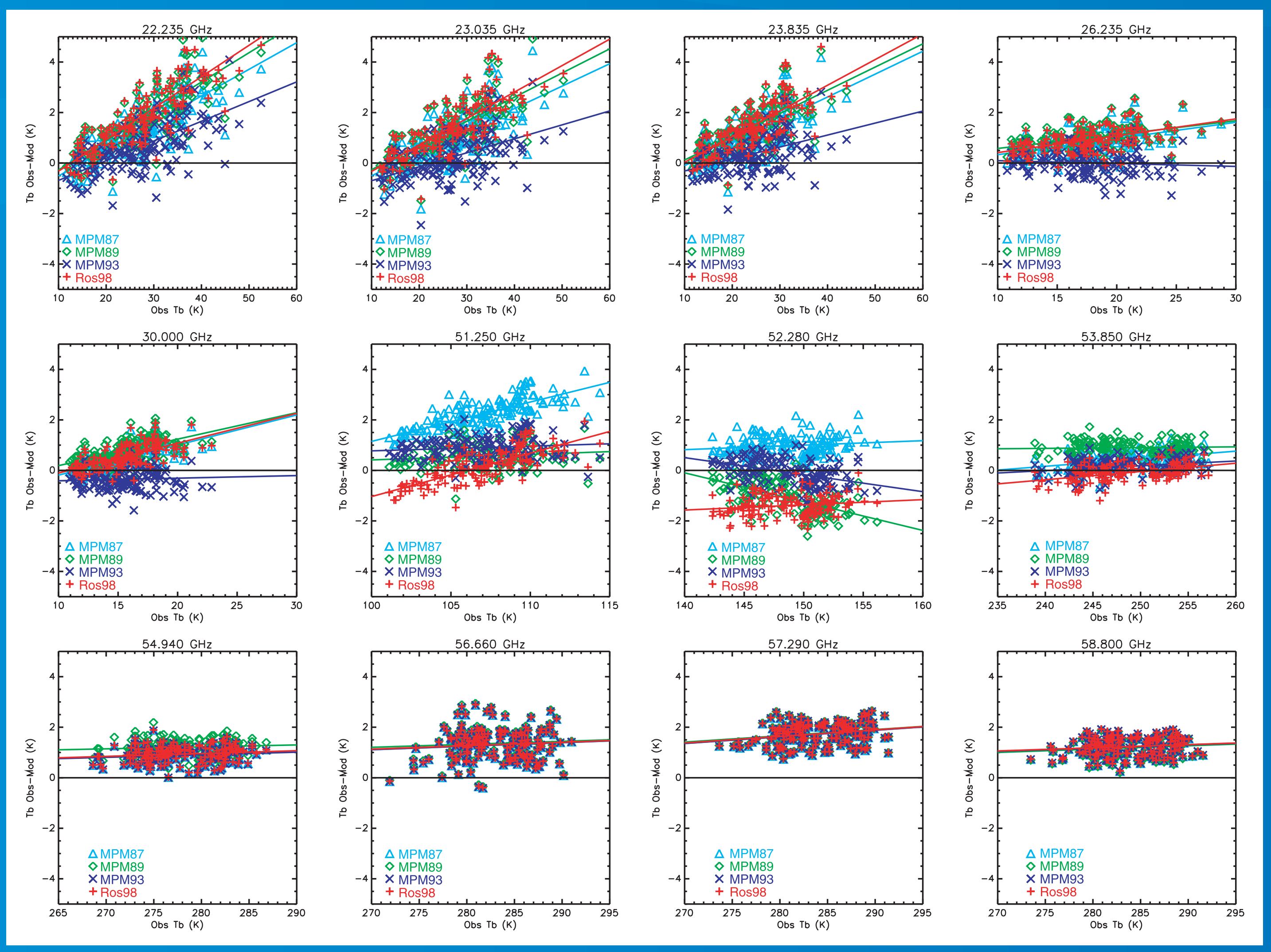

Figure 5. Bias in observations of microwave radiometer with respect to forward models based on 145 uncorrected RS80H radiosondes with ≤1/8 low cloud, 22/2/02-3/2/03, Camborne, UK.

- At *high frequencies* >55 GHz all models agree
- Positive bias in observations at high frequency channels >54 GHz – due to bias in radiometer. Bias now reduced by software revision (low frequencies unchanged)

- At *low frequencies* models diverge, due to different water vapour continuum and lines

- *Low frequency* observations fit models well in dry conditions, but are biased when warm/humid
- Partly explained by dry bias of humidity sensor in RS80H radiosonde - reads 97.0% RH in low cloud
- Can correct for sonde dry bias by scaling vapour pressure by 1.03
  - But all models still underestimate observations at 22.235 GHz
  - MPM93 then overestimates strength of water vapour continuum at 26-30 GHz in humid conditions

References

1. Y.Han and E.R.Westwater, 2000: "Analysis And Improvement Of Tipping Calibration For Ground-Based Microwave Radiometers," IEEE-TGARS, Vol.38, No.3, 2000, pp.1260-1276.
2. T.J.Hewison and C.Gaffard, 2003: "Radiometrics MP3000 Microwave Radiometer Performance Assessment", Met Office (OD) Technical Report 29, Available from National Meteorological Library, UK.
3. Liebe, H.J and D.H.Layton, 1987: "Millimeter-Wave Properties Of The Atmosphere: Laboratory Studies And Propagation Modeling", NTIA-Report 87-224, Natl. Telecommun. And Inf. Admin, Boulder, CO.
4. Liebe, H.J., 1989: "MPM - An Atmospheric Millimeter Wave Propagation Model, Int. J. Infrared and Millimeter Waves", Vol.10(6), pp.631-650.
5. Liebe, H.J., G.A.Hufford and M.G.Cotton, 1993: "Propagation modeling of moist air and suspended water/ice particles at frequencies below 1000GHz", AGARD 52nd Specialists' Meeting of the Electromagnetic Wave Propagation Panel, Ch3.
6. Rosenkranz, P.W., 1998: "Water Vapor Microwave Continuum Absorption: A Comparison Of Measurements And Models", Radio Science, Vol.33, No.4, pp.919-928.

Met Office University of Reading Meteorology Building 2U08 PO Box 243 Earley Gate Reading RG6 6BB UK
Tel: +44 (0)118 378 7830 Fax: +44 (0)118 378 8791
E-mail: tim.hewison@metoffice.com www.metoffice.com