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 profiles. 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 temporal resolution

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

The 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 channel currently sampled sequentially

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

Observation cycle:
- Includes zenith view for retrieval
- Black body view
- Tip curve calibration at 5 elevation angles
- Original ~14-minute cycle
- Now 202 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 sect(x) dependence
- Gains absolute reference: brightness temperature at zenith
- Need stratified conditions – only 33% of attempts at Camborne pass QC
- Noise dominated by atmospheric variability
- Bias dominated by sideband 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 & Hewison [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 polyethylene.
- Uncertainty in reflections in the polyethylene-oxygen interface

Both calibration methods have been analysed by the authors [2]. The resulting random noise and systematic uncertainties introduced by calibration are given for nominal in situ conditions 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
- 316 MHz wind profiling radar – Rapid LAD-9000 – 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
- Coherence is –diagonal
- Channels independent (good for assimilation)
- Low noise: Noise exacerbated by
- But does not include noise added by calibrations...

Calibration errors:
- Increases diagonal terms by a factor of ~2–10
- Adds off-diagonal terms to water vapour channels
- Doppler vector was not resolved
- Could be improved by QC on tip curve calculations

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:
- Radiosonde profiles of temperature and humidity used at high resolution (~10 m)
- Radiosonde from Camborne typically reach altitudes ~30 km (~70 hPa)
- ‘Topped up’ with a standard atmosphere, as there is finite emission from atmosphere above

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
- Models run at the effective monochromatic frequency agree within r.m.s. difference of ~0.05 K of full combination.

Abstraction models used in this study:
- MPM93 [3], MPM89 [4], MPM93 [1] 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

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 some 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