Radiometric Characterisation of the UK Met. Office Microwave Airborne Radiometer Scanning System (MARSS)

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INTRODUCTION

Since 1990, the Met. Office has operated a scanning microwave radiometer aboard its C-130 research aircraft. This instrument, known as MARSS (Microwave Airborne Radiometer Scanning System) originally operated on two channels [1]. In early 1999 it was upgraded (in conjunction with Rutherford Appleton Laboratories) to incorporate three additional channels. The five channels now available correspond closely to those of AMSU-B (channels 16 to 20), at frequencies of 89GHz, 157GHz and three channels at 183GHz [2]. This allows intercomparison with the satellite-borne instrument for ground truthing, as well as validation of radiative transfer models.

Stronger atmospheric absorption in the new channels means zenith views at high altitude can no longer be relied on as a calibration reference. It was therefore necessary to accurately characterise of the instrument on the ground. In September 1999 a thorough radiometric characterisation of the MARSS system was undertaken using the thermal vacuum test facility at DERA Farnborough. This facility is also used for the characterisation of the AMSU instruments [2].

INSTRUMENT DESCRIPTION

The configuration of the radiometer system is shown in Fig.1. The radiometer receiver (Front End Receiver Assembly or FERA) is mounted inside the aircraft fuselage, and uses a quasi-optic telescope with PTFE lenses to view a rotating stainless steel scan mirror located in an external pod. Each channel is detected in a single linear polarisation. In a 3 second scan, the rotating mirror provides nine upwards scene views, nine downwards scene views and views of two black-body targets. Each of the twenty view positions is held for a 100ms radiometer integration.

Calibration of the radiometer is maintained by reference to the observed brightness of the two black-body targets. One of these targets (the *hot* target) is heated, while the other (the *cold* target) is uncontrolled, and hence close to ambient temperature. Each target is fitted with an array of PRT temperature sensors to determine its physical temperature. At altitude, this arrangement can result in a target temperature contrast approaching 100K.

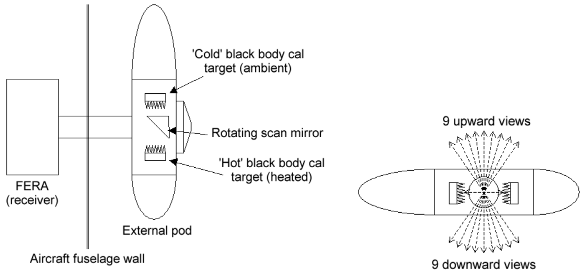

Figure 1 MARSS configuration. Inside the aircraft, the FERA views the environment via a rotating scan mirror mounted in an external pod. The scanning mirror also provides views of black-body calibration targets, one at ambient temperature and one heated.

TARGET THERMOMETRY CALIBRATION

Accurate knowledge of the temperature of the radiometric surfaces of the black-body calibration targets is essential for an accurate calibration of MARSS. These targets are observed regularly by the radiometer, and its calibration is maintained continuously by fitting an assumed linear detector response to the two reference points provided by these targets. Errors in the knowledge of temperature of either target are propagated to recovered brightness temperatures, with such error increasing with the difference between the temperature of the scene and that of the targets.

Each of the black-body calibration targets consists of an aluminium substrate with a radiometric surface shaped as an array of pyramids, covered with a 1mm layer of Eccosorb CR114. Ten PRT temperature sensors are embedded at varying depths within the target, one of these inside the tip of one of the pyramids. In order to calibrate these PRTs, precision reference PRTs were secured to the base and radiometric surface of the targets. The MARSS system was run, logging the target temperatures but without heating the *hot* target, for extended periods of time in thermally stable conditions over a range of ambient temperatures between approximately -20°C and +30°C. This procedure eliminated thermal gradients in the targets and established the calibration of the PRTs and the associated measurement system. A linear calibration for the A-D system measuring the resistance of the PRTs was established, and corrections obtained to recover the PRT temperatures to an accuracy of approximately 100mK.

Several techniques were used to assess the magnitude of thermal gradients between the target substrate and radiometric surface. Thermographic imaging of the heated target gave clear indications of gradients in the surface temperature of several Kelvin from the base to the tips of the pyramids. Comparison of MARSS' zenith measurements with modelled brightness temperatures allowed microwave radiometric measurement of target surface temperature when flying in the lower stratosphere. Study of the PRT measurements from differing depths within the target substrate, particularly during periods of rapid temperature change in flight, gave an understanding of the dominant heat transfer mechanisms and the gradients set up within the targets. These techniques allowed quantification of a scaling factor to apply to the gradients within the target substrate, to extend the directly measured gradients to the radiometric surface. Typically, this required a correction of the *hot* target temperature by –1.2K during straight and level flight with a target temperature contrast of 90K.

THERMAL VACUUM TEST FACILITY

The thermal vacuum test facility at DERA Farnborough consists of a vacuum chamber lined with a temperature-controlled shroud. The UKMO test rig used for the AMSU satellite instrument was used to support the MARSS FERA and pod assembly inside the chamber. This test rig provides two black-body targets and differential heating panels [2]. Only one of the rig's black-body targets was used for the MARSS characterisation. Referred to as the *Earth* target, this large target is mounted on a remotely controlled arm that swings about the instrument's scan axis. The Earth target temperature can be controlled between 90K and 330K and its temperature is monitored for stability and absolute accuracy.

The MARSS characterisation in the chamber was carried out in a back-filled atmosphere of dry nitrogen, mainly at a pressure near 300hPa. This is a pressure similar to that experienced in operation, and eliminates any effects of water vapour or oxygen emission and absorption.

LINEARITY

To quantify the linearity and accuracy of each channel, the Earth target was set to temperatures between approximately 100K and 310K, while close-coupled to the MARSS pod to minimise scene contamination by other radiating surfaces within the chamber. MARSS observations of the Earth target brightness temperature, derived using an assumption of linear detector response, are shown in Fig.2 as a function of earth target temperature for all five channels. A clear variation of bias with scene temperature is seen for channel 16 (89GHz), leading to errors near 5K for a scene temperature near 100K.

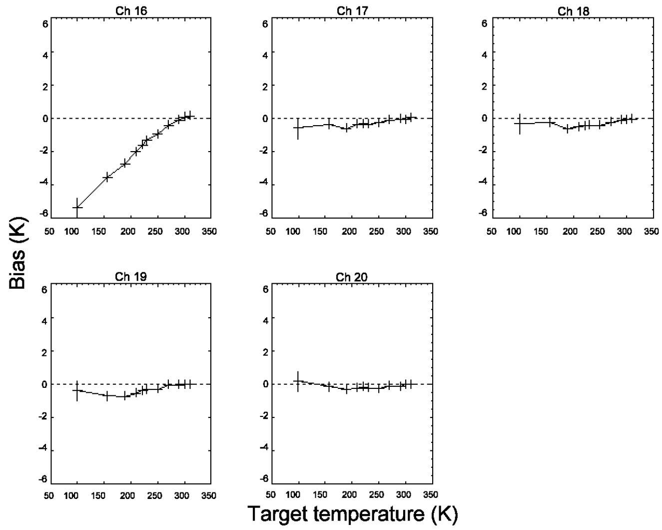

Figure 2 Residual error in MARSS observations of earth target temperature, as a function of earth target temperature. Note channel 16 non-linearity leads to errors near 5K for scene temperatures of 100K.

An assumption of a quadratic rather than a linear detector response leads to a correction to recovered brightness temperature of the form:

$$\Delta T = \gamma(C_H - C_E)(C_C - C_E) \tag{1}$$

where γ is a constant, and C_H, C_C and C_E are the radiometer detector outputs to the *hot* target, *cold* target and observed scene respectively. Application of such a correction to channel 16, with the γ constant obtained by a least squares linear fit to the data shown in Fig.2, brings the residual bias to zero, within the error bars which have a width of approximately 1.2K at an earth target temperature of 100K.

Knowledge of this non-linearity therefore leads to a corresponding improvement of system accuracy for observation of scenes of low brightness temperatures by Channel 16. Other channels were found to be linear.

VIEW DEPENDENCE

The reflectivity of the stainless steel mirror varies with the polarisation angle, p_0 for radiation incident at angle, θ=45° from $\Gamma_{//}$=0.991 to $\Gamma_{\perp}$=0.995 at 183GHz according to (2). This implies that the reflectivity varies with scan position, resulting in contamination of the reflected brightness temperature. Given the instrument configuration, it was expected that this would be the only cause of scan dependence in the instrument, and these tests confirmed this.

$$\Gamma(\theta) = \Gamma_{//}.\cos^2(\theta + p_0) + \Gamma_{\perp}.\sin^2(\theta + p_0) \tag{2}$$

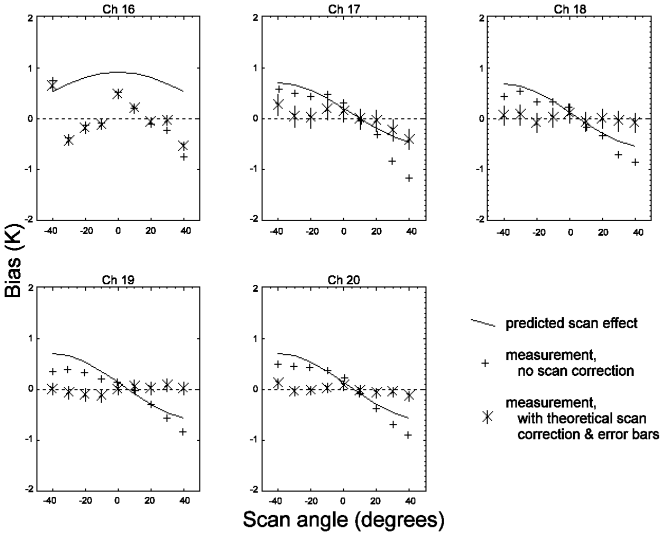

Figure 3 Residual bias from tipping curve calibration (lower stratosphere over the Baltic Sea) showing scan dependence.

The scan dependence was investigated in the chamber by moving the earth target, on its remotely controlled swinging arm, into the field of view of each of the nine downward-facing instrument scan positions, while keeping it at a constant temperature near 100K, and the instrument at a constant temperature near 300K. Scan dependence observed this way was small compared with the measurement uncertainty, which was dominated by Earth target instability.

Flight data collected in the lower stratosphere over the Baltic Sea in December 1999 allows a tipping curve calibration technique to be used for observation of any scan dependence. The zenith views in this case yield much lower brightness temperatures than available in the chamber (less than 10K), giving more contrast for the detection of scan dependence. Fig.3 shows the observed error with scan position in this case. It can be seen that a correction in accordance with the expected scan variation in reflectivity removes most of the observed scan dependence.

INSTRUMENT ENVIRONMENTAL SENSITIVITY

MARSS' FERA includes active temperature control of its IF amplifiers. Test sequences adjusting these set points showed that the channel gains are sensitive to IF amplifier temperature, but that the temperature controllers maintain good temperature stability, and restabilise in a matter of minutes after adjustments are made. Channel gains were found to be stable over a period of typically tens of minutes, and smoothing gains on this time-scale substantially reduces instrument noise when extrapolating the calibration to low scene temperatures as the gain noise is minimised.

Cooling and heating panels in the test rig gave substantial control over the temperature experienced by the FERA in the thermal vacuum chamber. Additional PRT temperature sensors associated with the AMSU test rig were used to monitor the FERA temperature. Although the IF amplifiers within the FERA are temperature controlled, the rest of the electronics are not, and a substantial dependency of receiver temperature was found in the linear calibration of the instrument. The FERA, however, has substantial thermal mass and its temperature only fluctuates over a long time-scale (minutes to tens of minutes). MARSS' self-calibration technique of continually monitoring the black-body calibration targets is therefore able to track such variation.

The thermal vacuum facility also provided the opportunity to confirm MARSS' insensitivity to pressure over its operating range between 300hPa and 1000hPa.

SUMMARY OF RESULTS

Table 1 summarises the radiometric sensitivity (NEΔT) and bias for each of MARSS' channels, averaged over the range of measured scene brighness temperatures, after correcting for thermal gradients in the black-body calibration targets, receiver non-linearity and scan dependence. These values of NEΔT are for 100ms integrations and are independent of scene temperature, thanks high gain stability.

Table 1 - Results of MARSS radiometric tests after all corrections

Channel	16	17	18	19	20	
Frequency	89	157	183 ± 1	183 ± 3	183 ± 7	GHz
NEΔT	0.23	0.72	0.62	0.42	0.33	K
Bias mean	-0.24	-0.27	-0.31	-0.32	-0.14	K
r.m.s.	0.44	0.34	0.36	0.40	0.19	K

The study of the radiometric temperatures of the black-body calibration targets was a very important feature in obtaining accurate measurements from the instrument. Radiometric characterisation of MARSS has helped resolve this effect and identify an important non-linearity in the response of channel 16. This is believed to be due to the high level of IF input power into the tunnel diode detector on this channel. Further, these series of tests verified the instrument's insensitivity to pressure and provided confirmation of a small correction for scan dependence on the basis of mirror reflectivity.

REFERENCES

[1] S.J.English, C.Guillou, C.Prigent and D.C.Jones, "Aircraft measurements of water vapour continuum absorption," Q.J.R. Meteorol. Soc., Vol.120, 1994, pp.603-625.

[2] R.W.Saunders, T.J.Hewison, S.J.Stringer and N.C.Atkinson, "The Radiometric Characterization of AMSU-B," IEEE Transaction on Microwave Theory and Techniques, Vol.43, No.4, 1995, pp.760-771.