MICROWAVE RADIOMETER INTER-CALIBRATION USING THE VICARIOUS CALIBRATION METHOD

Darren McKague
Chris Ruf
John J. Puckett

University of Michigan

1. INTRODUCTION

The primary goal of NASA's Global Precipitation Measurement (GPM) mission is to improve the accuracy, sampling, and coverage of global precipitation measurements. This will be accomplished, in part, with a constellation of satellite-borne microwave radiometers. Each radiometer will have its own set of radiometric characteristics (viewing geometry, bandwidth, center frequency, for example) and its own error sources. For precipitation estimates from each to be consistent, differences in these radiometric characteristics and error sources must be well known. The goal of the GPM Inter-Calibration Working Group (ICWG) is to understand and quantify, and correct for these differences.

The ICWG is currently focusing on developing the techniques of radiometer inter-calibration through comparison of data from four radiometers currently on-orbit: the Defense Meteorological Satellite Program Special Sensor Microwave/Imager (SSM/I) on the F13 and F14 satellites, the Naval Research Lab WindSat radiometer, and NASA's Tropical Rainfall Measurement Mission Microwave Imager (TMI). The groups within the ICWG are independently developing methods for producing inter-calibrated measurements for a common data set from these four radiometers. By comparing the data from each radiometer, as well as comparing the different methods of inter-calibration, the working group will develop a method of producing consistent calibrated measurements amongst the radiometers that will comprise the GPM constellation. Preliminary results for the ICWG group from the University of Michigan (U of M) were shown at IGARSS in 2008 [1]. This presentation will show updated results including vicarious cold and hot reference inter-calibration of the ICWG radiometers.

2. BASIS OF VICARIOUS CALIBRATION METHOD

The U of M approach to radiometer inter-calibration is to adapt the vicarious calibration techniques developed for previous spaceborne radiometers (SSM/I, TOPEX, GEOSAT Follow-On, Jason and WindSat) and apply them to the suite of radiometers expected to comprise the GPM constellation (SSM/I, AMSR, WindSat, CMIS, and others) [2, 3]. The vicarious calibration technique provides a means to transfer main beam brightness temperature calibration standards between spaceborne radiometers that operate at different frequencies, incidence angles, polarizations and/or orbit geometries. Using the technique, absolute calibration of the sensors has been demonstrated to 1K. Relative calibration between sensors, as well as stabilization of a sensor's calibration over time periods of ten years or more, has been demonstrated to 0.3 K [4].

2.1 Vicarious Cold Reference

The manner in which the microwave brightness temperature (T_B) of the ocean varies as a function of sea surface temperature (SST), salinity (SSS), near surface wind speed (u) and atmospheric opacity can be taken advantage of as a source of vicarious calibration for an orbiting microwave radiometer. For every microwave frequency, polarization and incidence angle there is a unique combination of SST and SSS at which the T_B of an ideal, flat ocean surface is a minimum. Departures of SST and SSS from that point, as well as all variations in u and atmospheric opacity, will tend to increase the T_B observed by a downward looking radiometer in Earth orbit above its theoretical minimum. An inverse cumulative distribution function (ICDF) for T_B can be constructed which has the property that

$$\mathrm{ICDF}(x) = T_B \text{ for } 0 \le x \le 100\%$$

provided x% of the measurements have values below T_B. The ICDF is the inverse of the standard cumulative distribution function (CDF, the definite integral of the probability density function for T_B). The ICDF can be used to solve for the highest T_B for which x=0% - the vicarious cold T_B. This vicarious cold T_B has been successfully used as a calibration reference for the TOPEX Microwave Radiometer (TMR) with channels of 18, 21 and 37 GHz at a nadir angle of incidence [4]. It has been found to be repeatable to better than 0.3K RMS over a 6 year period.

2.1 Vicarious Hot Reference

The dynamic range of T_Bs that an Earth observing radiometer will encounter is approximately 120 K – 310 K over the range 18 – 40 GHz and 0 – 55^o incidence for either vertical or horizontal linear polarization. The vicarious cold reference discussed above can be used to calibrate the T_B at the cold end of the range. There remains a need for a reliable on-Earth hot calibration reference target. An ideal target would be a large isothermal blackbody extending over the mainbeam of the Earth pointing antenna. Heavily vegetated regions of South American and African rainforest can provide a viable approximation to a blackbody target [5]. Using a parameterized model, observations of these regions from one radiometer with a given Earth incidence angle (EIA) can be extended to different EIAs and center frequencies for comparison to additional radiometers. This is the basis for the vicarious hot reference. Taken together, the minimum ocean and hot rainforest T_Bs provide reference calibration targets at the high and low end of a radiometer's dynamic range that can be used to verify (and correct if necessary) the end-to-end calibration accuracy of a spaceborne microwave radiometer.

3. ICWG VICARIOUS CALIBRATION RESULTS

At IGARSS 2008, preliminary results were shown for the vicarious cold calibration of the ICWG data. These data showed significant scan position dependent biases for TMI (as large as 1K) and WindSat (as large as 5 K). Scan position dependent biases in SSM/I data were removed prior to processing. These biases are thought to be due to obstructions in the edge of scan field of view from the given instrument and its spacecraft. WindSat vertically polarized data also show a linear decrease in vicarious cold calibration brightness temperatures with scan position, while horizontally polarized data show a linear increase with scan position. Both are consistent with a .5° EIA offset from one end of the scan to the other due to spacecraft attitude errors as noted by Betttenhausen [6].

This presentation focuses on the completion of the ICWG vicarious cold calibration and shows results for the vicarious hot reference. For the cold reference, the results shown previously are corrected for atmospheric effects. With the addition of this correction, the ICWG radiometers can be inter-calibrated. For the hot reference, the method of Brown and Ruf is adapted for ICWG use using TMI as the reference radiometer.

[1] McKague, Darren, C. Ruf, J. Puckett, "Vicarious Calibration of Global Precipitation Measurement Microwave Radiometers," *Proc. IEEE International Geoscience and Remote Sensing Symposium*, Boston, MA, USA, July 7-11, 2008.

[2] Ruf, C.S., Y. Hu and S.T. Brown, "Calibration of WindSat Polarimetric Channels with a Vicarious Cold Reference," *IEEE Trans. Geosci. Remote Sens.*, 44(3), 470-475, 2006.

[3] Ruf, C.S. "Detection of calibration drifts in spaceborne microwave radiometers using a vicarious cold reference," *IEEE Trans. Geosci. Remote Sens.*, 38(1), 44-52, 2000.

[4] Ruf, C.S., "Characterization and Correction of a Drift in Calibration of the TOPEX Microwave Radiometer", *IEEE Trans. Geosci. Remote Sens.*, 40(2), 509-511, 2002.

[5] Brown, S., and C. Ruf, "Determination of a Hot Blackbody Reference Target over the Amazon Rainforest for the On-orbit Calibration of Microwave Radiometers," *AMS J. Oceanic Atmos. Tech.*, 22(9), 1340-1352, 2005.

[6] Bettenhausen, Michael H., Elizabeth Twarog and Peter Gaiser, "On-Orbit Calibration of WindSat Brightness Temperatures," *Proc. IEEE International Geoscience and Remote Sensing Symposium*, Barcelnona, Spain, July 23-27, 2007.