VICARIOUS CALIBRATION OF GLOBAL PRECIPITATION MEASUREMENT MICROWAVE RADIOMETERS

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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. This presentation will detail the progress to-date of the ICWG group from the University of Michigan (U of M).

2. VICARIOUS CALIBRATION

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) [1, 2]. 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 [3].

The vicarious calibration technique consists of three principle steps. First, calibration algorithms are coded up for each sensor. These algorithms convert raw (Level 0) radiometer digital counts into Level 1 radiometric antenna temperatures – by correcting for on board calibration and other instrumental effects – and then into Level 2 main beam averaged brightness temperatures – by correcting for antenna pattern and spacecraft attitude effects. The algorithms will at first be based on the Algorithm Theoretical Basis Documents (ATBDs) that were developed by the cognizant instrument developers and will be adapted and corrected as needed. Step 2 involves the assembly of external, vicarious calibration measurements. For these measurements, certain statistical properties of the brightness temperature measurements made over specific classes of radiometrically cold ocean and warm land regions can be predicted with high accuracy and extremely high precision [4, 5]. The vicarious calibration data allows for the identification of errors in sensor calibration. The third step involves characterization of the calibration errors, typically by appropriate sorting and binning of the results of Step 2, followed by
an iterative refinement of the Level 1 and Level 2 algorithms to remove the errors. Adequate characterization of the errors is critical in order to determine which part(s) of the algorithms should be adjusted.

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

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\text{ICDF}(x) = T_B \text{ for } 0 \leq x \leq 100\%
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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 [3]. 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_B's that an Earth observing radiometer will encounter is approximately 120 K – 310 K over the range 18 – 40 GHz and 0 – 55° 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 the Amazon rainforest can provide a viable approximation to a blackbody target. Taken together, the minimum ocean and hot Amazon 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.

A parameterized model has been developed for an Amazon hot calibration reference target [5]. It has been tuned to specific regions of the Amazon rainforest. The model is physically derived and tuned to measurements made by SSM/I. For this reason, the models should be considered as a method for transferring the calibration accuracy of SSM/I to other instruments. SSM/I calibration performance has been extensively evaluated and is widely regarded as extremely stable over time and between different units on orbit [6]. However, it should be noted that the detailed quantitative behavior of the results is dependent on the accuracy of SSM/I calibration. The models are adjustable in frequency over the range from 18 to 40 GHz and in incidence angle from nadir to 55°. The specific Amazon regions that have been selected are effectively unpolarized, so these models can be used for any linear or circular polarized channel. The model is intended for investigations in which SSM/I measurements of the Amazon regions are available that are roughly coincident in time with those of another radiometer under test. The model parameterizes the extrapolation from SSM/I T_B measurements, at SSM/I frequencies and incidence angle, to the T_Bs that would have been observed at other frequencies and incidence angles.