The University of Wisconsin Space Science and Engineering Center Absolute Radiance Interferometer (ARI): Demonstrated Radiometric Performance

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Abstract: A summary of the Absolute Radiance Interferometer (ARI) radiometric performance demonstrated during vacuum testing at the University of Wisconsin Space Science and Engineering Center (UW-SSEC) is presented.
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1. Introduction

Spectrally resolved infrared radiances measured from orbit with extremely high absolute accuracy are a critical observation for climate benchmark measurements. For the infrared radiance spectra, it has been determined that a measurement accuracy, expressed as an equivalent brightness temperature error, of 0.1 K (k = 3) confirmed on orbit is required for signal detection above natural variability for decadal climate signatures [1, 2].

The University of Wisconsin Space Science and Engineering Center (UW-SSEC), with funding support from the NASA Earth Sciences Technology Office (ESTO) developed the Absolute Radiance Interferometer (ARI). The ARI is designed to meet the uncertainty requirements needed to establish spectrally resolved thermal infrared climate benchmark measurements from space, and utilizes a design with a short path to flight qualification, long life, and is reasonably small, simple, and affordable.

2. Climate Benchmark Measurements from Space

The climate benchmark measurement concept and accuracy requirement for the infrared (IR) and far-infrared (FIR) is defined in the ASIC3 (Achieving Satellite Instrument Calibration For Climate Change) report [2], and the US National Research Council Decadal Survey recommended Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission [1].

A simple instrument design is key to achieving the ultra-high absolute accuracy requirements associated with the infrared spectral radiances. The required simplicity is possible due to the large differences in the sampling, spatial coverage, and noise requirements for the benchmark climate measurement from those of the typical remote sensing infrared sounders for weather research or operational weather prediction. Studies show that for the climate benchmark measurement paradigm, which emphasizes high absolute accuracy information content, the key climate information can be obtained with nadir only, relatively large footprints (<100 km), and modest requirements on noise performance [3, 4]. The goal is to achieve extremely low combined measurement and sampling biases for the climate product, which consists of annual averages of nadir radiance spectra over large 15^{o} zonal regions. The SI traceable infrared radiances will also provide a source of on-orbit absolute calibration for a wide range of Earth observing sensors, greatly increasing their value for climate monitoring.

3. The UW-SSEC Absolute Radiance Interferometer (ARI)

The ARI development is a component of a larger project funded by a NASA Instrument Incubator Program (IIP) grant "A New Class of Advanced Accuracy Satellite Instrumentation (AASI) for the CLARREO Mission". The NASA Earth Sciences Technology Office provided further support for the vacuum testing of the ARI and its integrated calibration verification system. This development effort combined the development of fundamentally new devices including (1) the On-orbit Absolute Radiance Standard (OARS), a high emissivity blackbody source that uses multiple miniature phase-change cells to provide a revolutionary in situ standard with absolute temperature accuracy proven over a wide range of temperatures [5, 6]; (2) On-orbit Cavity Emissivity Modules (OCEMs), providing a source (quantum cascade laser (QCL) or "Heated Halo") to measure any change in the cavity emissivity of the OARS and calibration reference sources [7-9]; (3) an On-orbit Spectral Response Module (OSRM), a source for spectral response measurements using a nearly monochromatic QCL source configured to uniformly fill the sensor field-of-view, and (4) the Absolute Radiance Interferometer (ARI) for measuring spectrally resolved radiances with a spectral coverage of 200 – 2500 cm^{-1} at 0.5 cm^{-1} spectral sampling and a radiometric accuracy of < 0.1 K, k = 3, brightness temperature at scene temperature [10-14]. Details of the sensor prototype design, operational concept, and key trade-studies are presented in other papers [10, 12, 13].

4. Radiometric Performance: Calibration Accuracy

The complex calibration method is used for radiometric calibration of the ARI measurements [15]. The uncertainty associated with the calibrated radiance may be estimated by evaluating the combined uncertainty [16] for the complex calibration equation. The on-orbit, vacuum, and laboratory environments each present unique uncertainty conditions. Meeting the combined calibration and calibration verification uncertainty in the respective laboratory or vacuum calibration reference configurations and environments demonstrates the capability to meet the 0.1 K (k = 3) uncertainty requirement on-orbit. The details of the radiometric calibration and uncertainty analysis are presented in separate papers [10, 12].

Calibration verification was successfully completed in both the laboratory and vacuum calibration configuration and environment. Vacuum calibration verification was completed using the OARS verification source at temperature setpoints of approximately 216K, 233K, 253K, 273K, 293K, 313K, and 333K. Results of the calibration verification at 800 cm^{-1} (700 – 900 cm^{-1} average), expressed as differences in observed and predicted brightness temperatures for the LW MCT detector with nonlinearity correction, and the DTGS detector are shown in Figure 1 and Figure 2, respectively. Detailed results are presented by Taylor in a separate paper [10].

5. Summary

The UW-SSEC ARI and On-orbit Test and Verification (OTV) module have demonstrated the technology necessary to measure infrared spectrally resolved radiances (3.3 – 50 µm) with ultra high accuracy (< 0.1 K, k = 3 brightness temperature at scene temperature) required for a benchmark climate mission. The UW-SSEC ARI and OTV subsystems have been selected and developed to provide an instrument prototype with a clear path to space, and the prototype has received a NASA technological readiness level (TRL) rating of 6.

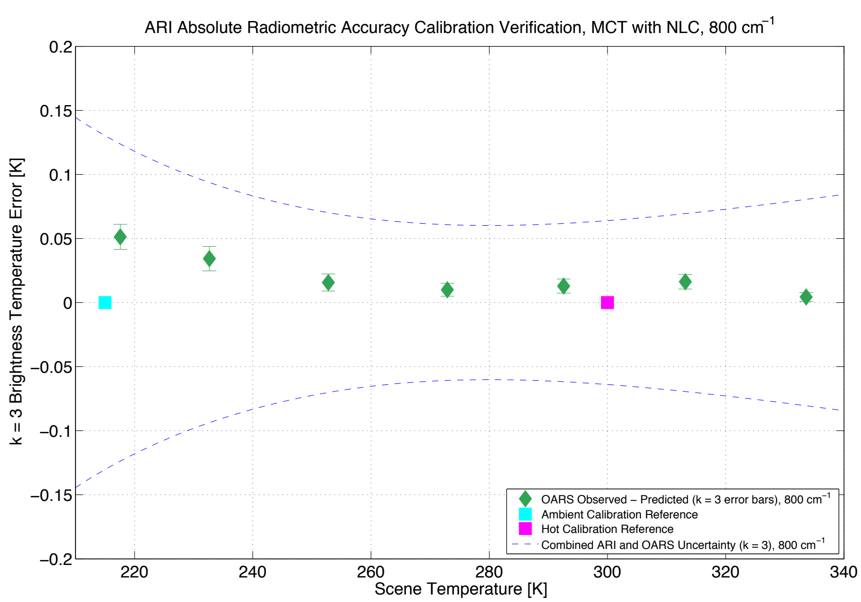

Figure 1: ARI calibration verification (800 cm^{-1}) for the LW MCT detector (with nonlinearity correction). Meeting these uncertainty bounds in the vacuum environment demonstrates the capability to meet the 0.1 K (k = 3) uncertainty requirement on-orbit.

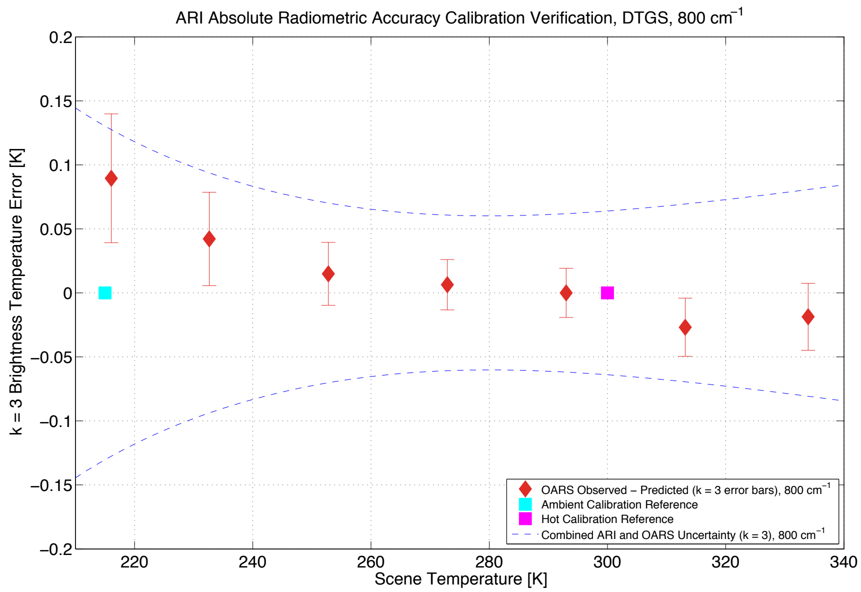

Figure 2: ARI calibration verification (800 cm^{-1}) for the DTGS detector. Meeting these uncertainty bounds in the vacuum environment demonstrates the capability to meet the 0.1 K (k = 3) uncertainty requirement on-orbit.

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