CALIBRATION OF THE REFLECTED SOLAR INSTRUMENT FOR THE CLIMATE ABSOLUTE RADIANCE AND REFRACTIVITY OBSERVATORY

Kurtis Thome[1], Robert Barnes[2], Rosemary Baize[3], Joseph O'Connell[3], Jason Hair[1]

[1]NASA, Goddard Space Flight Center; [2]Science Applications Int'l. Corp.; [3]NASA Langley Research Center

1. INTRODUCTION

The Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission addresses the need to observe high-accuracy, long-term climate change trends and to use decadal change observations as the most critical method to determine the accuracy of climate change projections such as those in the IPCC Report[1]. A rigorously known accuracy of both decadal change observations as well as climate projections is critical in order to enable sound policy decisions. The CLARREO Project will implement a spaceborne earth observation mission designed to provide rigorous SI traceable observations (i.e., radiance, reflectance, and refractivity) that are sensitive to a wide range of key decadal change variables, including:

- Surface Temperature and Atmospheric Temperature Profile
- Atmospheric Water Vapor Profile
- Far Infrared Water Vapor Greenhouse
- Aerosol Properties and Anthropogenic Aerosol Direct Radiative Forcing
- Total and Spectral Solar Irradiance
- Broadband Reflected and Emitted Radiative Fluxes
- Cloud Properties
- Surface Albedo

There are two methods the CLARREO mission will rely on to achieve these critical decadal change benchmarks: direct [2] and reference inter-calibration. A quantitative analysis of the strengths and weaknesses of the two methods has led to the recommended CLARREO mission approach. The project consists of two satellites launched into 90-degree, precessing orbits separated by 90 degrees. The instrument suite receiver on each spacecraft includes one emitted infrared spectrometer, three reflected solar spectrometers: dividing the spectrum from ultraviolet through near infrared, and one global navigation receiver for radio occultation. The measurements will be acquired for a period of three years minimum, with a five-year lifetime goal, enabling follow-on missions to extend the climate record over the decades needed to understand climate change.

2. REFLECTED SOLAR INSTRUMENT DESCRIPTION

The basis of the design of the RS sensor is the retrieval of an at-sensor reflectance over the spectral range from 320 to 2300 nm with 500-m GIFOV and a 100-km swath width. Reflectance is obtained from the ratio of measurements of radiance while viewing the earth's surface to measurements of irradiance while viewing the sun. The need to measure the energy leaving the earth's surface as well as the solar irradiance means that signals vary by factors of 2 to 10 due to multi-dimensionality of the problem caused by:

- Surface reflectance changes
- View/solar geometry (seasonal and geographic)
- Atmospheric effects
- Spectral variation

The RS instrument must be designed to account for these effects as well as include a calibration approach that allows accurate retrieval of the reflectance traceable to SI standards at a level better than 0.2% in the mid-visible. Such a required accuracy provides a data set that when collected globally reduces sampling biases for climatologically significant spatial and temporal averages over annual means [3].

The calibration approach taken in order to achieve the ambitious 0.2% absolute calibration uncertainty is predicated on a reliance on heritage hardware, reduction of sensor complexity, and adherence to detector-based calibration standards. One design being evaluated currently for the reflected solar instrument is based on an Offner spectrometer which is capable of limiting spectral smile on the focal plane. The design relies on three separate focal planes each with its own entrance aperture and grating to permit the use of single order diffraction gratings. The three separate focal planes cover spectral ranges of 320-640, 600-1200, and 1150-2300 nm implemented as three individual spectrometers.

3. CALIBRATION OVERVIEW

The system design currently being evaluated relies on a direct solar view as the primary calibration approach. The data from a solar view are coupled with the earth view data and knowledge of the sensor optical geometry to retrieve at-sensor reflectance. The method is similar in concept to past sensors that rely on solar diffuser data to derive reflectance. One reason for adopting a reflectance philosophy is it reduces the need for elaborate onboard calibration sources. Conversion of the reflectance to an absolute radiance will rely on access to an appropriately accurate solar irradiance.

Reliance on a direct solar view requires that the sensor to reduce the incident solar energy to a level comparable to the earth-viewing energy, approximately a factor of 50,000. The approaches being evaluated are a single pinhole aperture, neutral density filters, a collection of pinhole apertures, and combinations of these three. The attenuators require extremely careful evaluation during ground testing, but are also a source of uncertainty on orbit if the attenuators degrade in some fashion. Evaluation of the attenuators on orbit takes place through coordinated views of the sun and the moon. The brightness of the moon is low enough to permit measurements without the attenuators allowing the coupled lunar/solar views to determine if the attenuators are operating properly.

The reason that three attenuator approaches are currently under study is that an additional goal of CLARREO calibration is to rely on multiple and independent calibration approaches. Thus, other on-orbit validation approaches such as aircraft underflights and ground validation sites are planned. Multiple calibration pathways during preflight characterization including solar-like sources and a hyperspectral image projector will be used.

4. ERROR BUDGET ANALYSIS

Preliminary error budget analyses led to uncertainty estimates in excess of 1.5% in the mid-visible. The dominant error source identified in that original analysis was stray light that behaves differently between the solar and the terrestrial views. The use of a three-aperture, three-grating design reduces stray light which has been identified as one of the largest errors sources in preliminary error budget analyses. Revised error analysis including traceability to the electrical Watt (the SI quantity) using tunable laser sources and detector-based standards approaches the required 0.2% uncertainty. Calibration systems, such as NIST’s Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) facility, provide such standards and a capability to understand stray light, spectral response, and polarization sensitivity at the level necessary for CLARREO [4].

5. CONCLUSIONS

The goals of CLARREO including the reflected solar instrument are daunting but achievable. Characterization of the reflected solar instrument relies on improvements to currently-available calibration approaches. Careful sensor design to limit stray light and polarization sensitivity also is critical to achieving the needed accuracy. In the end, adherence to these basic design and characterization principles will provide data at the accuracy required to provide the basis for a set of data records needed to understand the earth’s climate.

6. REFERENCES

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