Calibration Methods for Climate Change Measurement and Modeling

Calibration methods and techniques to help ensure the designed sensor meets the stringent climate change measurement and modeling requirements for precision and accuracy to achieve climate-quality measurement results

Results of the SI-Traceable Space-based Climate Observing System (SITSCOS) Workshop

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ABSTRACT: The SI-Traceable Space-based Climate Observing System (SITSCOS) Workshop was hosted by the National Physical Laboratory in London, UK, 9-11 September 2019 with the purpose of defining climate-research measurement requirements and the current capabilities from the reflected-solar through the thermal-infrared spectral regions. Approximately 100 attendees represented the international community of climate researchers, satellite-instrument designers, data users, metrologists, and space agencies with expertise across a breadth of applications and technologies. A resulting 17 journal articles were published in a “Remote Sensing” Special Issue titled, “The Needs and Path Toward an SI-Traceable Space-based Climate Observing System,” and a 224-page Workshop Report was produced, summarizing current capabilities and providing recommendations to achieve the climate-driven measurement requirements.

The Workshop Report consolidates published values of current measurement capabilities and compares those to the climate-observing-system accuracies required to discern results on decadal timescales. Containing inputs from 80 contributing authors, the Report describes climate-science accuracy requirements, progress on laboratory metrology, SI traceability of satellite instruments, GISCS inter-calibration methods, CEOS Cal/Val activities, and estimates of the economic value from a space-based climate-observing system achieving the needed accuracies. The workshop concluded that current climate-observation accuracies are typically 2 to 10 times less than required and recommended on-orbit reference SI-Traceable Satellite (SITSat) spectrometers capable of calibration transfer to other space-based assets as the most robust and cost-efficient method to achieve climate-change calibration capabilities. The initial such SITSats are planned for launch this decade, including NASA’s CLARREO Pathfinder, ESA’s TRUTHS and FORUM, and the Chinese Space Agency’s LIBRA.

In this presentation, we summarize the Workshop Report, the current state of climate-measurement capabilities, the needed accuracies, the economic cost benefits of a focused SI-traceable space-based climate-observing system, and the recommended approach of implementing that system.

OCO-3 Inflight Radiometric Performance

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ABSTRACT: NASA’s OCO-3 instrument onboard the International Space Station (ISS) was launched on May 4th 2019. The primary objective of its three-year nominal mission is to measure the column-averaged dry-air mole fraction of carbon dioxide. It consists of three long slit imaging grating spectrometers with resolving powers around 20,000, observing in three near infrared spectral channels centered at 0.765, 1.61, and 2.06 microns. Each of the three channels collects 1016 spectral samples in eight spatial footprints, yielding 24,384 samples. OCO-3 was radiometrically calibrated prior to launch at NASA’s Jet Propulsion Laboratory using an integrating sphere source calibrated with respect to NIST reference standards. Its radiometric calibration is frequently updated inflight to account for both continuous and sometimes abrupt changes in instrument response, which introduce spectrally-dependent changes within the bands. These are caused by the accumulation of contaminants and their subsequent removal after scheduled decontamination events and also by flips of the overall gain state of the two longest wavelength bands, related to instrument resets. Due to limitations stemming from its position onboard the ISS, OCO-3 was not given the capability to observe the Sun. As a result, inflight updates to its calibration are currently based solely on OCO-3’s three on-board calibration lamps. Initial difficulties with pointing accuracy, now resolved, delayed intercomparison with the OCO-2 instrument, lunar, and vicarious calibration, all of which are currently in progress. OCO-3’s lamps are observed with different frequencies and thus degrade at different rates. The current algorithm used in the inflight relative calibration of OCO-3 combines information from all three lamps to provide high temporal resolution and, at the same time, minimize the impact of lamp aging on the 24,384 inflight coefficients that describe changes in the radiometric response of the instrument. We used thousands of clear ocean science soundings during periods of high and low contamination to assess the relative calibration within each spectral channel and inform the next data version. Here we present the algorithm developed to perform OCO-3's inflight relative radiometric calibration and discuss the current state of the calibration.

Refined Spatial Response Functions for OCO-3

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ABSTRACT: The Orbiting Carbon Observatory 3 (OCO-3) has been collecting high-resolution spectra of sunlight reflected by Earth in three near-infrared spectral channels since 2019. An external payload on the International Space Station, it uses the spare instrument from the OCO-2 mission, which continues to collect data as a dedicated satellite. The three individual long-slit imaging grating spectrometers have their own focal plane arrays and share a common entrance telescope. The OCO-3 telescope was modified to have a 1.8˚ field of view to yield a similar ground footprint size from the 400-420 km altitude ISS orbit as OCO-2 obtains with its 0.8˚ field of view from its 705km altitude orbit. During preflight testing, the OCO-3 instrument was illuminated by a collimator with slit and pinhole targets in front of a quartz tungsten halogen lamp. The slits and pinholes were scanned across the field of view using a two-axis stage to determine the field of regard, coalignment of the three spectrometers, and the 2D spatial response of each footprint. The initial Ancillary Geometric Product, containing the centers and widths of each footprint, was calculated using an average of columns in the spectral dimension. Subsequently, a defocus was identified that varies significantly in the spectral dimension. As a result, the widths of the along-slit footprints are much larger at one end of the spectral band than at the other. The effect is strongest for the "Strong CO2" channel with a center wavelength of 2.06 microns. An improved characterization of the column-dependent spatial response is key for absolute calibration using the Moon, and important for determining which science scenes are sufficiently uniform to allow good quality atmospheric retrievals. Here, we will summarize recent progress in characterization and its impacts on the OCO-3 data products.

Libera Planned On-orbit Calibration

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ABSTRACT: Libera is a next generation scanning radiometer that will fly as a rideshare on the Joint Polar Satellite System-3 (JPSS-3), which is set to launch in late 2027. Libera will provide continuity of the Clouds and Earth's Radiant Energy System (CERES) Earth radiation budget observations, advance the development of a self-contained observing system, and provide enhanced observing capability to further support earth radiation budget science goals. Data collected by Libera will be used by the earth radiation budget community to continue the long-term measurements of radiation being reflected and emitted by Earth. The Libera science channels include shortwave (SW; 0.3-5 μm) to measure solar radiation reflected by the Earth, longwave (LW; 5-50 μm) to measure IR radiation emitted from Earth, and total (TOT; 0.3-100+ μm) to measure the total radiation being reflected and emitted by Earth. In addition to these three channels shared with CERES, there will be a new science channel, the split short-wave channel (SSW; 0.7-5 μm) to further quantify the shortwave energy deposition in the Earth system, and a wide field of view camera for scene identification and split-SW angular distribution model development.

On-board calibration sources will be used to track changes in the science radiometers over the planned five-year mission. These calibration sources include a short-wave LED-based calibration system and a reflective Spectralon solar diffuser, used to track degradation of all four science channels. A black body source will be used to track degradation of the LW and TOT channels. In addition to the on-board sources, Libera will use the moon 8-12 times per year as an independent calibration check. Each calibration source has independent traceability. Drifts among the sources will not be correlated and stability across the sources will verify the stability of the science radiometers. This paper highlights the planned on-orbit calibration operations including a detailed discussion of the different calibration targets.