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Benchmark measurements for achieving societal objectives

John A. Dykema[1†], Robert E. Holz[2], David C. Tobin[2], Daniel B. Kirk-Davidoff[3], P. Jonathan Gero[1], Stephen S. Leroy[1], Fred A. Best[2], Joseph K. Taylor[2], Robert O. Knuteson[2], Henry E. Revercomb[2], and James G. Anderson[1]

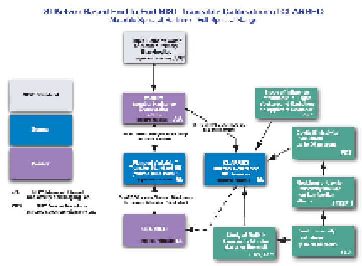
[1]School of Engineering and Applied Sciences, Harvard University; [2]Space Science and Engineering Center, University of Wisconsin; [3]University of Maryland

Abstract

The recent Interagency Achieving Satellite Calibration for Climate Change (ASIC-3)[1] report highlighted the importance of benchmark measurements with highly accurate calibration for climate and weather applications. Similarly, the National Research Council (NRC) report entitled "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond"[2] addressed the need for new benchmark measurements, tied to international standards and tested for systematic errors on-orbit. The NRC Decadal Survey explicitly addressed the critical need for benchmark measurements in addressing societal objectives. The Executive Summary of the Decadal Survey delineated the CLimate Absolute Radiance and Refractivity Earth Observatory (CLARREO) mission, which includes a constellation of three small satellites flying benchmark infrared interferometers. CLARREO is designed to provide robust documentation of future climate suitable for quantifying human influence and test and improving climate models. The interferometers include novel technology to tie the instrument calibration to the International System of Units (SI) and test for systematic error on-orbit, and cover the far infrared (to at least 200 cm^{-1}) with a spectral resolution better than 1.0 cm^{-1}. This constellation provides measurements at six local times per day, providing very accurate sampling of the diurnal and semidiurnal cycles. Recent work shows that this constellation is capable of accurate intercalibration (to 0.1 K) of a weather sounder in sun-synchronous orbit on time periods of months using methods envisioned for the Global Space-based Inter-Calibration System (GSICS). In this way, the calibration of the future operational sounder network can be improved, while CLARREO can take advantage of the dense spatial sampling of the sounder network for a wide variety of process studies. The modest weight and power envelope of a CLARREO interferometer with its calibration hardware also allows its inclusion on a future sounder satellite as an option for improved sounder accuracy.

SI Traceability

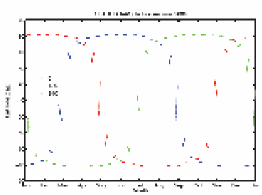
•Demonstrating that the on-orbit calibration of a sounder is traceable to the International System of Units (SI) according to the principles in the literature[3,4] and the ASIC-3[1] report achieves the goal of testing for systematic error on-orbit and tying the calibration to international standards.



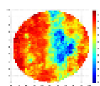
Orbits and Intercalibration

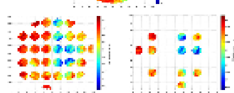
•Here we present a case study[5] where 3 CLARREO satellites[6] in 90° polar orbits offset by 60° are used to transfer the calibration to a sounder in sun-synchronous orbit.

•The results are believed to be very credible as they are based an entire year of MODIS Earth observations and represent the actual spatial variability of the atmosphere and a realistic sampling approach.

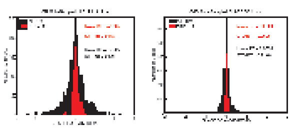


One year of intersections for the three CLARREO satellites and the Aqua orbits leads to thousands of overlapping footprints.



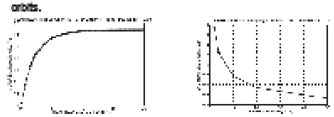


The 11 μm MODIS BT (1 km resolution) is used to sub-sample the CLARREO field-of-view (FOV). The 3x3 array of CrIS dectectors samples 55% of the Earth's area whereas the 2x2 array of IASI detectors only sample about 18% of the Earth's area.

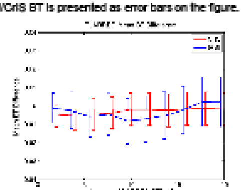


The difference between the mean IAI or CrIS brightness temperature and the CLARREO mean brightness temperature is computed to characterize the sampling error due to incomplete spatial sub-sampling.

Using the results of the CLARREO/Aqua sampling study, these figures investigate the CLARREO noise requirements such that the total uncertainty in the monthly mean bias was 0.03K using 10 K as the maximum allowable BT STD within the CLARREO FOV. The requirements for CLARREO single channel noise are presented as a function of CLARREO sampling interval and scene BT standard deviation assuming 3 CLARREO satellites in 90° orbits.



The mean monthly BT difference are presented. The uncertainties in the mean BT differences between the fully sampled CLARREO 100 km field of view and the sub sampled IASI/CrIS BT is presented as error bars on the figure.



†corresponding author: postal address 12 Oxford Street, Cambridge, MA 02138 USA
Phone: +1 617 495 5922
Email: dykema@huarp.harvard.edu

Technological Innovation (Detectors)

•CLARREO provides a platform for the development of single-element far-infrared detectors.
•Currently, thermal detectors lack speed, while photon detectors lack spectral range.

Detector Property	Available	Ideal
Cut-on	10 μm/1000 cm^{-1}	3 μm/3300 cm^{-1}
Cut-off	25 μm/400 cm^{-1}	50 μm/200 cm^{-1}
Nonlinearity	1%	0.01%
Imaging	N/A	N/A
Operating Temperature	80 K	140 K
Dynamic Range[1]	300-700 W/m²	N/A
Sensitivity (D*)	$5x10^9$ cm-$Hz^{1/2}$ W^{-1}	BLIP
Modulation speed	>10 kHz	>10 kHz

[1] onto a detector with Ø=1-2 mm

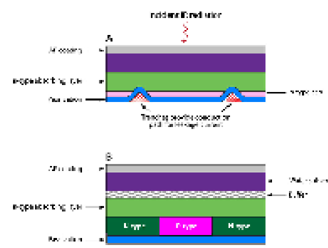
Three material systems are capable of observing below 600 cm^{-1} (> 16 μm)[9]:

•InGaAs/InSb superlattice detectors,

•GaAs/AlGaAS quantum well infrared photo-detectors (QWIPs), and

•HgCdTe photodiodes.

Far-infrared photodiodes



Panel A: mesa-type photodiodes; Panel B: planar-type photodiodes. Planar devices have the greater potential for climate and weather applications.

•Far-infrared photodiodes offer the potential for substantially improved linearity over current state-of-the-art photoconductive detectors[11].

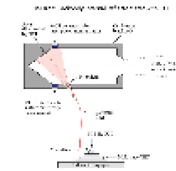
•Planar devices reduce dark currents relative to mesa devices, improving sensitivity and simplifying preamplifier design[10].

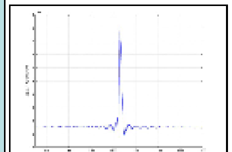
Technological Innovation (Spectral Calibration)

•Fourier Transform Spectrometers (FTSs) have the useful property that the same few parameters (including detector size, shape, and centration) determine the instrument lineshape (ILS) for all lines in the spectrum[8].

•This property may be exploited for on-orbit spectral calibration through the use of new technology: high power, miniaturized mid-infrared lasers.

•Based on new developments in semiconductor growth and processing, quantum cascade lasers (QCLs) can provide over 100 mW of narrow linewidth power in the near infrared.





The result of coupling a 30 mW, 8 μm QCL into a Lambertian cavity is single line with its lineshape determined by the optical properties of the measuring FTS.

•By coupling a QCL into a cavity with a diffuse reflecting surface, a uniform source of mono-chromatic light is created: ideal for spectral lineshape characterization[8].

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