The CLARREO Climate Benchmarking Mission: The Absolute Radiance Interferometer (ARI) is a proven prototype for the Infrared portion of the full observing capability.

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University of Wisconsin-Madison
Space Science and Engineering Center

2015 Sun-Climate Symposium
Savanna, Georgia, 10-13 November 2015
Introduction to CLARREO

- **CLARREO** (Climate Absolute Radiance & Refractivity Observatory) a 2007 Decadal Survey Tier 1 mission
  - IR & Reflected Solar spectra coupled with GPS RO offer (1) **unprecedented** measurement accuracy, 0.1 K IR brightness $T$, 0.4 % RS radiance, and 0.1 % GPS RO refractivity 5-20 km (all 3-sigma, **proven on orbit with SI standards**), (2) unbiased spatial and temporal sampling, and (3) much higher climate change sensitivity than existing climate records (from total integrated IR & Solar data)
  - Metrology lab on-orbit serves as “**NIST in orbit**”

- **CLARREO** to Benchmark Earth’s climate
  - Analogous to marking a glacier’s current extent

- **CLARREO** as an Inter-calibration Standard
  - **GSICS** (Global Space-based Inter-Cal System)
  - e.g. Greatly enhancing the value of the climate record from high spectral resolution IR sounders starting in 2002 (AIRS, IASI, CrIS) and RS sensors
NASA CLARREO Timelines
(Climate Absolute Radiance and Refractivity observatory)

• **2008-2010 CLARREO** – following the DS, NASA assigned mission responsibility to Langley Research Center (LaRC)
  – A Science Team was formed and detailed mission definitions debated (Pre-Phase A activities)
  – Mission Confirmation Review (MCR) passed successfully in November 2010
  – IR and Reflected Solar instrument development conducted under NASA Instrument Incubator Program (IIP) and calibration system studies

• **2011 CLARREO** – funding profile removed from the president’s budget on 14 February

• **2011-15 CLARREO** – Science Team Pre-Phase A studies continue, resulting in Wielicki et al., BAMS publication and cover in Oct 2013

• **2012-2014 New Instrument Technologies**
  - Achieved TRL 6 under NASA Instrument Incubator Program (IIP) / ESTO support of LASP for RS and UW-SSEC & Harvard for the IR

Wielicki et al.
Includes a Pathfinder mission to kickoff CLARREO! (Climate Absolute Radiance and Refractivity Observatory)

• “The CLARREO Pathfinder mission will demonstrate essential measurement technologies; validate the high accuracy radiometry required for long-term climate studies in support of other Decadal Survey and land imaging missions; and initiate measurements that will benchmark the shortwave reflectance and infrared climate record.“

• “NASA plans to host the two CLARREO Pathfinder instruments, Reflected Solar (RS) and Infrared (IR) spectrometers, on the International Space Station in FY 2019.” (budget $77 M)
NASA PPBE Milestone Accomplished
(Planning, Programming, Budgeting, and Execution)

• Approach and Grass Roots Cost Estimates for the IR from U of Wisconsin-SSEC and RS inputs from U of Colorado LASP (who conducted NASA IIP developments) were provided in support of a credible plan to perform the Pathfinder ISS mission under assumed constraints and budget.

• The NASA PPBE Milestone qualifies the LaRC CLARREO project to implement the Pathfinder, if it is part of the final FY2016 appropriations.
NASA PPBE Process Diagram

**ANNUAL PPBE PHASES AND STEPS**

**PLANNING**
- Internal/External Studies and Analysis
- NASA Strategic Plan
- Annual Performance Goals
- Implementation Planning
- Strategic Planning Guidance

**PROGRAMMING**
- Program and Resource Guidance
- Program Analysis and Alignment
- Agency Issues Book
- Program Decision Memoranda

**BUDGETING**
- Programmatic and Institutional Guidance
- OMB Submit
- President’s Budget
- Appropriation

**EXECUTION**
- Operating Plan and Reprogramming
- Funds Distribution and Control
- Analysis of Performance
- Reporting Requirements
- Performance and Accountability Report

Pathfinder now here
Topics

1) History (IR & Wisconsin slant)
2) ISS Pathfinder for CLARREO
3) Absolute Radiance Interferometer (ARI) CLARREO IR Prototype update

International Space Station

ARI Lab Prototype
Earth Radiation Budget, *the old way*

13 Oct 1959-Feb 1960 Explorer 7

The 1st meteorological satellite instrument to observe the Earth

- Radiometer designed by Verner Suomi & Robert Parent
- Omni-directional spheres
- 3-color (black, white, gold)

Spectrally integrated obs continue today

Spheres also on TIROS 3, 4, 7
1961-63

* The right way then!
Many flights carried Suomi/Parent Radiometers

- ESSA 3, 5, 7, 9 spinners, 1966-69
- ITOS 1, 1970
- NOAA 1, 1970

1966-1972 Black and White Flat Plate Radiometers followed for flux measurements of the Earth Radiation Balance
Active Cavity Radiometer, 1975-8

• Developed for UW ERBOS* mission
• Electrical Substitution Cavity Radiometer chosen to improve flux accuracy
• Designed with fast time constant response (15 ms) for scanning the Earth from a spinner
• This UW program was cancelled, but the approach of measuring the total integrated Solar Reflected and Earth Emitted fluxes for studying Earth’s Climate continues today

- Current US Earth Radiation Budget measurements from CERES followed those from ERB and ERBE.
- New NASA Radiation Budget Instrument (RBI) is planned

* Earth Radiation Budget Observing System, not selected
Fourier Transform Spectro-radiometer

- 1978-1985: Designed high spectral resolution instrument for “Sounding” [T(p), WV(p)] from GEO leading to High-resolution Interferometer Sounder (HIS) aircraft sensor
- Flew on high altitude NASA U2/ER2 aircraft 1985-1998
- 3-17 µm at 0.34 cm\(^{-1}\) resolution (Resolving power > 1700)
- First demonstration of high vertical resolution sounding (2.5-3 times improvement) from high spectral resolution IR
- Significant contribution to improved spectroscopy from accurately calibrated, long path atmospheric spectra

We learned the virtues of high spectral resolution for improving absolute accuracy — *uncertainties reduced from degrees to tenths of degrees!*
Scanning HIS Aircraft Instrument
(Scanning High-resolution Interferometer Sounder, HIS; 1998-present)

Uplooking and Downlooking Spectra for Remote Sensing

Michelson Interferometer

Satellite Sensor Validation

Proteus

AIRS
1993-CLIMSAT: Jim Hansen, NASA GISS

- Spectrally resolved IR and solar proposed to measure forcings & feedbacks - 3 instruments:
  - **MINT**: 6-40 µm Michelson Interferometer
  - **EOSP**: 0.4-2.25 µm Earth Observing Scanning Polarimeter
  - **SAGE III**: 0.29-1.02 µm Stratospheric Aerosol and Gas Experiment

- Two Spacecraft for adequate sampling
- Emphasized precision/self calibration
- But expected to rely on observations from subsequent S/C having temporal overlap to achieve 2-decade observing goal
1996-Arrhenius: Jim Anderson, Harvard

- Proposed observing system based on IR Spectrally resolved Radiances (6-44 µm) with 0.1 K 3-sigma accuracy, *demonstrated on-orbit*

- Sampling studies showed importance of multiple, carefully chosen orbits

- Evolved to add reflected solar and GPS Radio Occultation for Decadal Survey White Paper in 2005
  (Harvard teamed with UW-SSEC, NIST, U of Colorado, SwRI, U of Graz)
• We have a fundamental responsibility to future generations to put in place a climate record that is accurate in perpetuity, testable by scientists from any nation at any time in the future, and is global in coverage.

• Long-term climate forecasts that are tested, trusted and systematically improved.

• **Eloquently supporting the argument that on-orbit accuracy verification & testing is a crucial requirement**
Achieving Satellite Instrument Calibration for Climate Change (ASIC³)

Report of a Workshop Organized by

National Oceanic and Atmospheric Administration
National Institute of Standards and Technology
National Aeronautics and Space Administration
National Polar-orbiting Operational Environmental Satellite System-Integrated Program Office
Space Dynamics Laboratory of Utah State University

At the National Conference Center, Lansdowne, VA, May 16-18, 2006

Edited by George Ohring

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Center for Satellite Applications and Research
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
CM2 25-yr Annual Mean Trends
Yi Huang thesis (Ramaswamy, advisor), 2008

Note OLR Insensitivity to the trends in Ts, Atmospheric T, WV, and Clouds

Black dots indicate changes > 3 x standard deviation of unforced means
High Spectral Resolution Infrared Sounding from Polar Orbit for operational weather

1978- HIRS (20 ch)
1986- HIS, S-HIS, NAST-I
1990/91 ITS (~CrIS) UW-SSEC led Design
2002- AIRS (2378 ch)
2006- IASI (8461 ch)
2011- CrIS (2211 ch)
1330 Suomi-NPP (NOAA/NASA)
0930 EUMETSAT METOP
1330 NASA Aqua

Stepping stones
Topics
1) History (IR & Wisconsin slant)
2) ISS Pathfinder for CLARREO
3) Absolute Radiance Interferometer (ARI) CLARREO IR Prototype update

International Space Station

ARI Lab Prototype
Value of an ISS Pathfinder Mission

An IR Prototype on ISS will provide, not only a tech demo for CLARREO cost and technical risk reduction, but also the start of an accurate climate benchmark, identified as critically important in the 2007 Decadal Survey.

The key components supporting the above are

• **Measurement Accuracy:** ARI has demonstrated the ability to fully meet the CLARREO 0.1 K 3-sigma requirement over the required spectral range, including the Far IR out to 50 microns.

• **Sampling Requirements:** Needs for an initial benchmark (unbiased temporal and spatial sampling) are met by ISS below 52 degrees latitude.

• **Intercalibration:** Use of the AIRS (on EOS Aqua) and CrIS (on Suomi NPP) at 0130/1330 local times, IASI (on EUMETSAT MetOp A and B) at 0930/2130 local times, and likely the Chinese sounder on (FY3E) at 0530/1730, provide good sampling to extend the benchmark to high latitudes for all but the Far IR portion of the spectrum.

• **Lifetime:** No fundamental life limiting components are required for the sensor, and with ISS life extended until 2024 there is a good chance of creating the 5 year record needed for a credible benchmark.
Current Sounders Show Significant Differences

Mean Simultaneous Nadir Overpass (SNO) differences for 910-930 cm\(^{-1}\)

SNOs: AIRS-IASI-A, CrIS-IASI-A, AIRS-IASI-B, CrIS-IASI-B

ARI would establish an absolute reference to better than 0.1K!
Current Approach to absolute assessment:
SNPP Calibration Validation Campaign 2015

- Seven ER-2 science flights were conducted during the March 2015 airborne calibration validation campaign. Flights were based out of Keflavik Iceland with flights over the Greenland ice sheet.
- The Scanning-HIS has a clear calibration traceability to NIST and many valuable satellite underflight datasets were collected.

---

**Specifications**

- **IFOV:** 100 mrad (2km @ 20km, nadir)
- **Scene Coverage:** Programmable 45° scene mirror nadir ± 40° typical
- **Spectral Coverage:**
  - LW (HgCdTe), 580 - 1180 cm⁻¹
  - MW (HgCdTe), 1000 - 1820 cm⁻¹
  - SW (InSb), 1750 - 3000 cm⁻¹
- **Spectral Resolution:** 0.5 cm⁻¹
PRELIMINARY LW window differences

SNAP2015, 850–900 cm$^{-1}$

Brightness Temperature Difference from SHIS

- CrIS
- IASI-A
- IASI-B
- AIRS

Brightness Temperature

0.6 K
Achieving Climate Change Absolute Accuracy in Orbit,

Example with ~ factor of 2 shorter Time to Detect

Wielicki et al., BAMS, 2013
Topics

1) History (IR & Wisconsin slant)
2) ISS Pathfinder for CLARREO
3) Absolute Radiance Interferometer (ARI) CLARREO IR Prototype update
**Key Instrument Performance Specifications**

### Calibrated Fourier Transform Spectrometer (CFTS)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bands</td>
<td>3.5 - 5.5 μm</td>
<td>InSb</td>
</tr>
<tr>
<td></td>
<td>5.5 - 9 μm</td>
<td>MCT</td>
</tr>
<tr>
<td></td>
<td>9 - 15 μm</td>
<td>MCT</td>
</tr>
<tr>
<td></td>
<td>10 - 50 μm</td>
<td>Pyroelectric</td>
</tr>
<tr>
<td>NEDT (Far-Infrared) @290K</td>
<td>4.0 K</td>
<td>(350-1,000 cm⁻¹)</td>
</tr>
<tr>
<td>NEDT (Mid-Infrared) @290K</td>
<td>0.3 K</td>
<td>(700-2,000 cm⁻¹)</td>
</tr>
<tr>
<td>Spectral Resolution (Δν)</td>
<td>0.625 cm⁻¹</td>
<td>Unapodized</td>
</tr>
<tr>
<td>Radiometric Accuracy</td>
<td>0.07 K (3σ)</td>
<td></td>
</tr>
<tr>
<td>Spectral Calibration @ 735 cm⁻¹</td>
<td>≤1 ppm</td>
<td>(Verified on orbit using atmos. line)</td>
</tr>
<tr>
<td>Instrument Lineshape width</td>
<td>&lt;1% Δν knowledge</td>
<td></td>
</tr>
<tr>
<td>Ground Footprint</td>
<td>40 km</td>
<td>For 390 km orbit</td>
</tr>
<tr>
<td>Field-of-View</td>
<td>104 mrad</td>
<td>Ifr divergence as mrad</td>
</tr>
<tr>
<td>Viewing Geometry</td>
<td>Nadir</td>
<td></td>
</tr>
<tr>
<td>Optical Throughput</td>
<td>0.0084 cm²·sr</td>
<td></td>
</tr>
<tr>
<td>Maximum OPD</td>
<td>± 0.8 cm</td>
<td>Two-sided interferogram</td>
</tr>
<tr>
<td>OPD Scan Rate</td>
<td>0.4 cm/second</td>
<td></td>
</tr>
<tr>
<td>Metrology Laser Wavelength</td>
<td>1.55 μm</td>
<td></td>
</tr>
<tr>
<td>Samples per Interferogram</td>
<td>10323</td>
<td></td>
</tr>
<tr>
<td>Bits per Sample</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Mean Data Rate</td>
<td>0.132 Mbps</td>
<td>33 Kbps/band X 4 bands</td>
</tr>
<tr>
<td>Time per Interferogram</td>
<td>2-4 sec</td>
<td></td>
</tr>
<tr>
<td>Scan Mirror Retrace</td>
<td>1 second</td>
<td></td>
</tr>
<tr>
<td>Time per Sequence</td>
<td>20 seconds</td>
<td>ABB, Space, Earth, OVTS</td>
</tr>
<tr>
<td>Ground Sample Spacing</td>
<td>145 km</td>
<td></td>
</tr>
<tr>
<td>ABB Temperature Range</td>
<td>268 to 303K</td>
<td>3σ</td>
</tr>
<tr>
<td>ABB Temperature Uncertainty</td>
<td>&lt;45 mK (3σ)</td>
<td></td>
</tr>
<tr>
<td>ABB Cavity Max Temp. Gradient</td>
<td>0.1 K</td>
<td></td>
</tr>
<tr>
<td>ABB Emissivity</td>
<td>0.999</td>
<td></td>
</tr>
<tr>
<td>ABB Emissivity Uncertainty</td>
<td>&lt;0.001 (3σ)</td>
<td></td>
</tr>
</tbody>
</table>

### On-Orbit Verification and Test System (OVTS)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>On-Orbit Absolute Radiance Standard (OARS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blackbody Radiance Uncertainty</td>
<td>&lt;0.07 K</td>
<td>3σ</td>
</tr>
<tr>
<td>Aperture Diameter</td>
<td>30 mm</td>
<td></td>
</tr>
<tr>
<td>Temperature Range</td>
<td>228 to 313K</td>
<td></td>
</tr>
<tr>
<td>Temperature Stability</td>
<td>50 mK/min</td>
<td>While viewing</td>
</tr>
<tr>
<td>OARS Cavity Max Temp. Gradient</td>
<td>0.1 K</td>
<td></td>
</tr>
<tr>
<td>Absolute Temp Calibration</td>
<td>29.76 °C</td>
<td>Gallium (302.41K)</td>
</tr>
<tr>
<td></td>
<td>0.00 °C</td>
<td>Water (273.15K)</td>
</tr>
<tr>
<td></td>
<td>-38.83 °C</td>
<td>Mercury (234.32K)</td>
</tr>
<tr>
<td>Melt Temperature Calibration Uncertainty</td>
<td>5 mK</td>
<td>3σ</td>
</tr>
<tr>
<td>Emissivity</td>
<td>&gt;0.999</td>
<td>3-50 μm</td>
</tr>
<tr>
<td>Emissivity Uncertainty</td>
<td>&lt;0.0006</td>
<td>3σ</td>
</tr>
<tr>
<td>Heated Halo Emissivity Meas. Uncertainty</td>
<td>&lt;0.0006</td>
<td>3σ</td>
</tr>
<tr>
<td>Heated Halo Temperature</td>
<td>343K</td>
<td></td>
</tr>
<tr>
<td>Heated Halo Temperature Knowledge</td>
<td>&lt;268K</td>
<td></td>
</tr>
<tr>
<td>View Factor (Cavity to Halo)</td>
<td>F&gt;0.6</td>
<td></td>
</tr>
<tr>
<td><strong>Quantum Cascade Laser (QCL) for Emissivity &amp; Instrument Line Shape (ILS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILS Measurement Uncertainty (Dv/ν)</td>
<td>2 ppm</td>
<td>3σ</td>
</tr>
<tr>
<td>QCL Wavelength</td>
<td>9.5 μm</td>
<td></td>
</tr>
<tr>
<td>QCL Linewidth</td>
<td>0.001 cm⁻¹</td>
<td></td>
</tr>
<tr>
<td>QCL Wavelength Stability</td>
<td>0.1 ppm</td>
<td></td>
</tr>
<tr>
<td>QCL Emissivity Meas. Uncertainty</td>
<td>&lt;0.001</td>
<td>3σ</td>
</tr>
<tr>
<td>QCL Power Meas. Uncertainty</td>
<td>5%</td>
<td>Using calorimetry</td>
</tr>
</tbody>
</table>

**CLARREO IR Pathfinder**
Spectral Coverage & Resolution:
3-50 \( \mu \text{m} \) or 200-3000 cm\(^{-1} \) with \( \Delta \nu = 0.5 \text{ cm}^{-1} \)
(includes Far IR to capture most of the information content and emitted energy, & instrument independent scale)
**CLARREO IR Accuracy**

**Radiance Accuracy:** <0.1 K 2-sigma brightness $T$ for combined measurement and sampling uncertainty (each <0.1 K 3-sigma) for annual averages of large regions (to approach goal of resolving a climate change signal in the decadal time frame)

![Graph showing CLARREO 3-sigma Requirement](image)
Absolute Radiance Interferometer (ARI): Definitions of key components of prototype instrument

- **Calibrated Fourier Transform Spectrometer (CFTS):**
  - FTS with strong flight heritage from ABB/Bomem, Inc.
  - 3 Spectral bands covering 3-50 µm
  - 2 Cavity Blackbody References for Calibration (1 + Space On-orbit)

- **On-orbit Verification and Test System (OVTS):**
  - 1. **On-orbit Absolute Radiance Standard (OARS) cavity blackbody** using three miniature phase change cells to establish an accurate temperature scale from -40, to +30 C
  - 2. **On-orbit Cavity Emissivity Module (OCEM)-Heated Halo** using a blackened, Heated Halo source that allows the FTS to measure the broadband spectral emissivity of the OARS to better than 0.001
  - 3. **OCEM-QCL** using a quantum cascade laser source to monitor changes in the mono-chromatic cavity emissivity of the OARS
  - 4. **On-orbit Spectral Response Module* (OSRM)** using the same QCL to measure the FTS instrument line shape

*Not fully implemented in prototype—demonstrated separately
Absolute Radiance Interferometer (ARI) Prototype

with a short upgrade path to flight

ABB Bomem Interferometer
Modulator “Wishbone”

Calibrated FTS

- Corner-cube interferometer used in 4-port to avoid double pass; Strong flight heritage
  - 0.5 cm\(^{-1}\) resolution (± 1 cm OPD)
  - 1.55 µm diode laser for interferogram sample control & fringe counting
  - 10 cm CsI single-substrate beamsplitter

- Fore optics designed to
  - minimize polarization effects
  - minimize sizes of calibration/verification BBs & reflectivity sources
  - minimize stray light by providing effective field and aperture stops
  - maximize energy throughput

- 3-50 µm Spectral Coverage
  - Highly linear pyroelectric detector, all reflective aft optics: 10-50 µm
  - Cryo-cooler for MCT & InSb semiconductor detectors: 3-18 µm
FTS Flight Readiness for CLARREO-like Mission

- Flex Blade Mounted V-Shaped Scan Arm
- Voice Coil Actuator Driving Scan Arm Rotation (hidden)
- Circular CsI B/S
- Beamsplitter Wall Optical bench
- IR Beam IN
- IR Beam OUT
- Monolithic Cube Corner
- Metro Beam IN
- Metro Beam OUT
On-Orbit Verification and Test System

Calibrated Fourier Transform Spectrometer

Space

IR Spectrometer

Earth

Ambient Blackbody

Traditional Approach

On-Orbit Absolute Radiance Standard (OARS, with wide Temperature range)

OVTS Provides On-Orbit, End-to-End Calibration Verification & Testing Traceable to Recognized SI Standards
Absolute Radiance Interferometer (ARI) Prototype

*with a short upgrade path to flight*

On-orbit Verification and Test System (OVTS) Technologies

1. **On-orbit Absolute Radiance Standard** (OARS) cavity blackbody using three miniature phase change cells to establish the temperature scale from -40 to +30 °C to better than 10 mK

2. **On-orbit Cavity Emissivity Module** (OCEM) using Heated Halo source allowing the FTS to measure the broadband spectral emissivity of the OARS to better than 0.001

3. **OCEM-QCL** using a Quantum Cascade Laser source to monitor changes in the mono-chromatic cavity emissivity of the OARS & Cal BB to better than 0.001

4. **On-orbit Spectral Response Module** (OSRM) QCL used to measure the ILS

*QCL functions demonstrated by Harvard separately*

**All components at flight scale**
On-orbit Absolute Radiance Standard OARS

Heated Halo & Halo Insulator  Cavity  Inner Shield & Isolator

Assembly Diagram
Temperature Scale Established to < 10 mK on-orbit

Phase Change Cell (Ga, H₂O, or Hg)

Plateaus (shown in plots) provide known temperatures to better than 5 mK
Heated Halo Concept

\[ R_{\text{scene}} = B(T_{\text{BB}}) + (1-e) \left[ F \cdot B(T_{\text{Halo}}) + (1-F) \cdot B(T_{\text{room}}) \right] \]

**Radiance emitted from BB**

\[ \langle 1 - (t) \rangle_t = \begin{pmatrix} R_{\text{scene}}(t) & B[T_{\text{BB}}(t)] \\ R_{\text{background}}(t) & B[T_{\text{BB}}(t)] \end{pmatrix}_t \]
Blackbody Emissivity Measured to < 0.001 on-orbit

3-σ emissivity of 0.0006 uncertainty indicated by dashed lines applied to model

Good agreement with NIST measurements

Far IR tests with Graphene in Z306 are in progress

Graphene in Z306 expected to greatly increase Far-IR $\varepsilon$
CO₂ laser injected into gold integrating sphere

Harvard QCL to be used for flight design
**Measured ILS (red) Compared to Calculation**

ARI ILS (FIR); MOPD = 1.0 cm, iFOV = 0.0258 mrad, off-axis angle: 0.000 mrad, Line Source = 938.70 cm$^{-1}$

**Calculation assumes:**
- Expected angular field-of-view in interferometer
- Perfect alignment
- Perfect laser beam filling

**Measured Instrument Line Shape (ILS) is well understood**
Vacuum Testing Configuration
Brightness Temperature Accuracy Verified to < 0.1 K
(CFTS calibrated - OARS verification)

Correction of field stop problem removes this error

Error bars only include statistical error in measurement

ARI Calibration Verification Summary, Measured − Predicted Residual BT (Rolling Window Cal)

Original Vacuum Data Collect shown before

Spectral Averaging Bin Width is 5 cm$^{-1}$
Demonstration of Required Radiometric Accuracy, LW MCT

Original Vacuum Data Collect

LW ARI Calibration Verification Summary,
Measured and Predicted Residual BT (Rolling Window Cal)

\[
\begin{align*}
333.1 & \pm 0.2K \\
333.6 & \pm 0.2K \\
333.1 & \pm 0.2K \\
331.7 & \pm 0.2K \\
331.2 & \pm 0.2K \\
331.7 & \pm 0.2K \\
327.1 & \pm 0.2K \\
292.4 & \pm 0.2K \\
292.8 & \pm 0.2K \\
292.4 & \pm 0.2K \\
272.3 & \pm 0.2K \\
252.8 & \pm 0.2K \\
252.3 & \pm 0.2K \\
232.7 & \pm 0.2K \\
232.2 & \pm 0.2K \\
217.6 & \pm 0.2K
\end{align*}
\]

wavenumber (cm\(^{-1}\))

\[
\begin{align*}
\text{Obs} - \text{Pred} & \pm 0.1K \\
\text{Combined RU} & \pm 0.25K \\
\text{Residual} & \pm 0.5K
\end{align*}
\]

Stray light issue—Diagnosed & fixed during post vacuum testing
Demonstration of Required Radiometric Accuracy, LW MCT

New 2015 Data Collect – Dry Air Purge

LW ARI Calibration Verification Summary, Measured and Predicted Residual BT (Rolling Window Cal) ±0.5K

15 micron CO₂ band

Observed and Predicted

BT Obs – BT Pred

- Obs – Pred Combined RU – ± 0.1K

Conclusion

Introduction

Instrument Overview

Results

Summary and Outline

±0.25K

Measured – Predicted Residual BT (Rolling Window Cal), 5.0 cm⁻¹ bins

2015 Data Collect – Confirms small stray light issue diagnosed and fixed during post vacuum testing

The UW-SSEC ARI: Demonstrated Radiometric Performance (FW3A.3 – OSA FTS 2015)

3-March-2015

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Brightness Temperature Accuracy Verified to < 0.1 K
(CFTS calibrated - OARS verification)

ARI Calibration Verification Summary, Measured − Predicted Residual BT (Rolling Window Cal)

Error bars only include statistical error in measurement

Original Vacuum Data Collect shown before

Spectral Averaging Bin Width is 25 cm\(^{-1}\)

Bin averaged result subject to low SNR at band edges

200 cm\(^{-1}\)  →  1400 cm\(^{-1}\)
Demonstration of Required Radiometric Accuracy, DTGS

2015 Data Collect – Dry Air Purge

FIR ARI Calibration Verification Summary,
Measured and Predicted Residual BT (Rolling Window Cal)

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**Observed and Predicted**

- BT Obs (solid line)
- BT Pred (dashed line)

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**Low SNR effect – Not expected to be an issue for flight unit**

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The UW-SSEC ARI: Demonstrated Radiometric Performance (FW3A.3 – OSA FTS 2015)

3-March-2015

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FIR ARI Calibration Verification Summary, Measured and Predicted Residual BT (Rolling Window Cal), ±0.5K

15 micron CO₂ band

2015 Data Collect – Confirms small stray light issue diagnosed and fixed during post vacuum testing
ARI Technology Development

**Miniature Phase Change Cell (MPCC)**

**MPCC Component Integration, Characterization and Accelerated Life Testing**

**Heated Halo Generation-1 (Breadboard Halo, AERI BB with Scanning HIS Aircraft FTIR)**

**Absolute Radiance Interferometer (ARI) Breadboard**

**TRL 4**

**Integration of MPCC into Breadboard Blackbody for Thermal Testing**

**Heated Halo Generation-2 (Large Conical Halo, AERI BB with ARI Breadboard FTIR)**

**Absolute Radiance Interferometer Prototype**

**TRL 5**

**On-Orbit Absolute Radiance Standard: New 30 mm Aperture BB with MPCC integrated into cavity, and Heated Halo**

**ARI Prototype Tested in Vacuum**

**TRL 6**

**Ready for Flight Program**
CLARREO pathfinder on ISS would provide economical risk reduction for the full CLARREO mission and a chance to improve the overall accuracy of operational environmental satellite capabilities and leverage them to start a global benchmark record. And it is now in the FY2016 President’s Budget Request and satisfied the NASA PPBE process.

CLARREO IR Flight Prototype, ARI has passed ESTO TRL assessments and laboratory test results have demonstrated the capability to meet full CLARREO mission performance requirements.

US 2017 NRC Decadal Survey White Papers: Several white papers arguing for the importance of proceeding with the full CLARREO Mission are being submitted.

Let’s hope the Pathfinder stays in the FY2016 Budget and that a commitment is soon made to the full mission!