Radiation Budget Instrument Status

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Discussion Topics

- RBI Goals, Objectives, Mission Success
- Key requirements for RBI Mission
- RBI Overview and Scope
- Instrument Architecture
- EDU Bench Test Results
- Predicted Performance
- RBI Summary
Missions for which LaRC is responsible for ERB Mission Operations and Data Analysis (MO&DA)

<table>
<thead>
<tr>
<th>Sensors</th>
<th>PFM</th>
<th>FM-1,2</th>
<th>FM-3,4</th>
<th>FM-5</th>
<th>FM-6</th>
<th>RBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRMM (11/97)</td>
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<td>Terra (12/99)</td>
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<td>JPSS-2 (11/21)</td>
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We now have over 65 years of flight experience with the CERES instruments
RBI Goals, Objectives, and Success

- **Project Goal**
  - Provide an instrument that enables continuity of Earth Radiation Budget (ERB) observational record.

- **Science Objectives**
  - Collect the observations necessary to seamlessly continue the ERB Climate Data Record (CDR) by:
    - Measuring the temporal and spatial distribution of outgoing thermal and reflected solar radiation from the Earth, allowing investigation of the Earth’s radiation budget when combined with measurements of solar irradiance
    - Tying the RBI observations to those of CERES through intercalibration while aiding in the development of a quantitative understanding of the links between the radiation budget and the properties of the atmosphere and surface that define it, and improve models of Earth’s climate system

- **Mission Success**
  - RBI provides measurements of the reflected solar and emitted radiances from the top of the Earth’s atmosphere that continue for at least six (6) years post launch, with accuracy, precision, extent, and frequency sufficient to continue this radiation budget climate data record with similar accuracy and precision

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**RBI is a Data Continuity Mission**
### Key Performance Requirements

<table>
<thead>
<tr>
<th>Key Performance Requirements</th>
<th>Baseline Values</th>
<th>Threshold Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Spectral Range</td>
<td>0.3 to 100+ microns</td>
<td>0.3 to 50+ microns</td>
</tr>
<tr>
<td>Shortwave Spectral Range</td>
<td>0.3 to 5 microns</td>
<td>0.3 to 5 microns</td>
</tr>
<tr>
<td>Longwave Spectral Range</td>
<td>5 to 50+ microns</td>
<td>5 to 35+ microns</td>
</tr>
<tr>
<td>Total Channel Absolute Radiometric Accuracy</td>
<td>≤ Larger of 0.575 W/m²-sr or 0.5% (k = 1)</td>
<td>≤ Larger of 0.575 W/m²-sr or 0.75% (k = 1)</td>
</tr>
<tr>
<td>Shortwave Channel Absolute Radiometric Accuracy</td>
<td>≤ Larger of 0.75 W/m²-sr or 1.0% (k = 1)</td>
<td>≤ Larger of 0.75 W/m²-sr or 1.25% (k = 1)</td>
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<tr>
<td>Longwave Channel Absolute Radiometric Accuracy</td>
<td>≤ Larger of 0.575 W/m²-sr or 0.5% (k = 1)</td>
<td>≤ Larger of 0.575 W/m²-sr or 0.75% (k = 1)</td>
</tr>
<tr>
<td>Total Channel Radiometric Precision</td>
<td>≤ 0.2 W/m²-sr + 0.1% (k = 3)</td>
<td>≤ 0.2 W/m²-sr + 0.1% (k = 2)</td>
</tr>
<tr>
<td>Shortwave Channel Radiometric Precision</td>
<td>≤ 0.2 W/m²-sr + 0.1% (k = 3)</td>
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</tr>
<tr>
<td>Longwave Channel Radiometric Precision</td>
<td>≤ 0.2 W/m²-sr + 0.1% (k = 3)</td>
<td>≤ 0.2 W/m²-sr + 0.1% (k = 2)</td>
</tr>
<tr>
<td>Total Channel Linearity</td>
<td>≤ 1.5 W/m²-sr</td>
<td>≤ 2.5 W/m²-sr</td>
</tr>
<tr>
<td>Shortwave Channel Linearity</td>
<td>≤ 1.28 W/m²-sr</td>
<td>≤ 2.13 W/m²-sr</td>
</tr>
<tr>
<td>Longwave Channel Linearity</td>
<td>≤ 0.54 W/m²-sr</td>
<td>≤ 0.9 W/m²-sr</td>
</tr>
<tr>
<td>Point Spread Function</td>
<td>Within 95% of CERES</td>
<td>Within 90% of CERES</td>
</tr>
</tbody>
</table>

**RBI Baseline Science Requirements Match CERES**
Enabling Inter-mission Continuity

- **Earth Target**
  - Tracking Capability

- **Fixed (FAPS)**
  - Nominal Science Mode

- **Programmable (PAPS)**
  - Programmable Azimuth Plane Scan
  - Targeted Campaigns

- **Rotating (RAPS)**
  - Rotating Azimuth Plane Scan
  - Increased angular sampling
CERES-Like Point Spread Function Supports Data Continuity

- Use of CERES-shaped detector and heritage scan rate provides best PSF match
- RBI PSF is required to be smaller than CERES, referenced to 95% energy contour
  - i.e., over 95% of RBI energy must be within the CERES 95% energy contour
- Close match to CERES PSF supports data continuity value

95.2% of RBI Energy Falls Within the Heritage CERES Contour (Worst-Case)
Partnerships and Teams

• **NASA/NOAA Partnership**
  - NOAA accommodates RBI on the JPSS-2 satellite
  - NASA provides RBI instrument and support through spacecraft I&T and launch/activation

• **NASA Langley**
  - Manages prime contractor development of RBI instrument, provides management, technical, and mission assurance insight and oversight; provides support to spacecraft I&T thru launch and early on-orbit checkout (thru Phase D); develops L0-L1 science algorithms
  - Hand-over and release of RBI instrument ownership by RBI Project occurs at the JPSS-2 Operational Hand-over Review (OHR)

• **Harris**
  - RBI prime contractor with sub-contractors providing key elements and support (SDL for Calibration, JPL for Thermopile Detectors, Sierra Nevada for Azimuth Rotation Module)

### RBI Overview and Scope

RBI scanning radiometer measuring three spectral bands at top of Atmosphere (TOA)
- Total 0.3 to > 100+ μm
- Shortwave 0.3 to 5.0 μm
- Longwave 5.0 to 50+ μm

### Science Goal
- Provide an instrument to support global climate monitoring by continuing the sequence of Earth Radiation Budget (ERB) measurements obtained by NASA and NOAA over the past thirty years

- **Phase:** Final Design and Fabrication (C)
- **Critical Design Review:** 9/26-28/2017
- **Flight Instrument Delivery:** Q3 FY19
- **JPSS-2 Launch:** Q4 FY21
- **Life:** 7 years
Radiation Budget Instrument

- Collects upwelling earth radiance over a wide spectral range
  - Ultraviolet to far-infrared (100um)
  - Continuous cross-track scans

- Three spectral bands
  - Shortwave: reflected solar energy
  - Longwave: emitted earth energy
  - Total: Sum of reflected and emitted
  - One telescope per band simplifies detectors and operations

- Very precise calibration
  - Extensive ground calibration program sets the calibration
  - Multiple onboard targets maintain calibration over mission life
RBI’s Modular Architecture
Clouds and the Earth’s Radiant Energy System

Optical Module and Targets Designed for Stability and Accuracy

Thermal Shrouds to Minimize Temperature Drifts

Heated, High-Emissivity ICT

SCT With 3 Protected Spectralon® Surfaces

Low-NEP Thermopile Detectors; Shape Provides Heritage PSF

VCT With 6-Wavelength LED’s and ESR for Absolute Reference

Earth Limb +62.3°

Space Look +70°

NADIR (0°)
Optical Module Overview

- Focuses photons on the detector and converts to bits
- Minimizes stray light
- Provides low noise linear conversion of radiance to bits
- Athermalized design provides a stable uniform environment for low noise detectors
- Provides spectral selection into three bands
- Thermal control provides for long term stable environment
Visible Calibration Target (VCT)
Provides Radiance Standard for Reflected Solar Bands

- Provides 6 narrow band Laser-diode sources: 375, 405, 445, 680, 915, 1470 nm for the TOT and SW channels
- Si and InGaAs photodiodes monitor sources and provide quick radiance reference
- Electrical Substitution Radiometer (ESR) provides stable, long term, absolute, NIST-traceable measurements
  - Used monthly to calibrate monitoring photodiodes
- Neutral density filters mounted in filter wheel enable flux level adjustment
- Thermal stability achieved by remotely locating and fiber coupling the laser diodes
Solar Calibration Target (SCT) Provides Indirect Solar Illumination to RBI

- Provides a secondary calibration monitor for reflected solar bands (TOT & SW channels)
- Three Spectralon diffusers used with different frequencies to monitor reflectance degradation over mission life
  - Bi-weekly, Quarterly, & Yearly
- Shroud encapsulates and protects Spectralon surfaces from contamination
- Provides a full aperture source of diffusely reflected solar spectral irradiance
Infrared Calibration Target (ICT) Provides Radiance Standard for Infrared Bands

- Onboard infrared radiance standard for LW and Total channels
- Geometry and optical surface ensure a highly, stable emissivity that, when combined with known surface temperature, provides a stable, known radiance, resulting in low radiometric uncertainty
- Heaters provide an accurate, stable and controllable (23-42ºC) source for daily calibration and monthly linearity testing
- NIST traceable standards
  - Platinum Resistance Thermometers (PRTs) calibrated to ITS-90 scale
  - ICT paint calibrated to gold reference standard
Daily: quantify short-term repeatability
• Total and SW channels view VCT (single LD, one illumination level)
• Total and LW channels view ICT (fixed point temperature)

Bi-weekly: quantify short-term repeatability
• Total and SW channels view SCT

Monthly: quantify long-term uncertainty
• Multiple illumination (ND filter) levels using one laser diode source are used to characterize linearity/gain for Total and SW
• Laser diodes at multiple wavelengths are used to characterize the spectral response of the Vis/NIR portion of the Total and SW
• ESR calibrates Photodiodes in VCT
• Multiple ICT temperature levels used to characterize linearity/gain for Total and LW
EDU is a pathfinder for:

- Calibration
  - Radiometric design is virtually identical to RBI flight design
  - Manufacturing processes are validated
  - Performance requirements are demonstrated
  - Calibration approach is demonstrated

- Test execution
  - “Dry Run” of TVAC test program/GSE

- Flight build and test
  - Design team has incorporated all EDU lessons learned in the flight design

- EDU TVAC testing is underway
VCT Performance Is As Expected

Photodiode radiance agrees very well with TOT and SW

All measured responses are as expected
Linearity Performance Is As Expected Using ICT

Instrument Response is Very Linear

<0.5 Wm\(^{-2}\)sr\(^{-1}\) (3-sigma) Agreement is Very Good
Estimated Radiometric Performance Meets Requirements with Margin

Margin using allocations: use RHS scale

- Requirement
- Current Best Estimate
RBI Summary

- PDR was held May 2016, KDP-C approved July 2016
- CDR occurring currently
- Flight delivery in mid-2019
- Instrument flies on JPSS-2, launch 2021

- RBI will continue the important ERBE and CERES data records
  - PSF and spectral coverage traceable to CERES
  - RBI has an enhanced shortwave calibration source providing accurate multi-wavelength sources with a NIST-traceable reference detector

Program is on Track for Successful Delivery of RBI FM1
Clouds and the Earth’s Radiant Energy System

EDU Bench Test Performance Indicates Readiness To Proceed to TVAC Testing

<table>
<thead>
<tr>
<th></th>
<th>TOT</th>
<th>SW</th>
<th>LW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsivity (DN / r.u.)</td>
<td>182*</td>
<td>282</td>
<td>272</td>
</tr>
<tr>
<td>Noise (DN) viewed at park</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>NER (r.u.) unfiltered at ambient</td>
<td>0.11</td>
<td>0.071</td>
<td>0.071</td>
</tr>
<tr>
<td>NER (r.u.) unfiltered expected**</td>
<td>&lt;0.19</td>
<td>&lt;0.12</td>
<td>&lt;0.12</td>
</tr>
<tr>
<td>NER (r.u.) unfiltered in TVAC (est.)</td>
<td>0.033</td>
<td>0.021</td>
<td>0.021</td>
</tr>
</tbody>
</table>

* Total channel intentionally has lower responsivity since it has a larger dynamic range requirement
** Based on RTM testing in TVAC and at ambient pressure

All measured responses and noise levels are as expected
Key Requirements Drive Calibration and Traceability to CERES

Radiometric Uncertainty (SW, LW and Total channels)

- Long Term Uncertainty
- Relative Spectral Response by channel
  - SW: 0.2 μm – 5 μm; LW: 5 μm – 50 μm; Total: 0.2 μm – 100 μm
- Point Spread Function (PSF) 95% match to CERES
- Channel to channel registration of 98%
- Calibration sources for SW, LW and solar calibration
Integrated Team Supports RBI Development

Clouds and the Earth’s Radiant Energy System

Cross-track Scan Module (CSM) and Encoder Electronics

Telescopes

Thermopile Detectors

Visual Calibration Target (VCT)

Azimuth Rotation Module (ARM)

Electronics Unit (EU) Power Supply

Electronics Unit (EU) Single Board Computer

TVAC and Calibration

BEI PRECISION SYSTEMS & SPACE COMPANY, INC.

GENERAL DYNAMICS Global Imaging Technologies

Jet Propulsion Laboratory California Institute of Technology

NASA

HARRIS

Space Dynamics Laboratory

Microsemi

Maxwell Technologies

Sierra Nevada Corporation

Space Systems

L-1
# Enhancements to RBI Design Since 2016

<table>
<thead>
<tr>
<th>PDR Design</th>
<th>CDR Design</th>
<th>Benefit of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDR Telescope Baffle Design</td>
<td>Improved Baffle Design; Z306 Paint With Micro-Balloons</td>
<td>Better Stray Light rejection. Improved radiometric uncertainty to allow compliance with margin.</td>
</tr>
<tr>
<td>Aperture stop at edge of primary mirror surface</td>
<td>Changed to physical baffle aperture (telescope metering structure T4) in close proximity to the primary mirror surface</td>
<td>Physical aperture is a more robust and controllable stop</td>
</tr>
<tr>
<td>Heritage Gold Black Coating</td>
<td>Improved Gold Black Deposition Process With Revised Thickness Spec</td>
<td>Improved repeatability and better resistance to solar glints. Also enables better electrical grounding.</td>
</tr>
<tr>
<td>CSM Bearing Fixture OM Restraint</td>
<td>CSM magnetic-lock launch restraint</td>
<td>Secure restraint of telescopes during launch and transfer orbit preventing solar exposure</td>
</tr>
<tr>
<td>No ICT Baffle</td>
<td>Thermally Isolated Baffle Added</td>
<td>Better thermal isolation from a potential space view. Black-painted baffle interior minimizes stray light</td>
</tr>
<tr>
<td>ICT Single-Piece Titanium Mount</td>
<td>Improved Mount Design Including Vespel Material</td>
<td>Design accommodates new baffle, reduces mass, and provides better thermal isolation</td>
</tr>
<tr>
<td>660nm VCT Diode</td>
<td>Changed to 680 nm</td>
<td>680 was chosen for its availability and offers improved radiometric uncertainty, spectral correction</td>
</tr>
<tr>
<td>ARM ECU</td>
<td>Revised FPGA Code and ECU design</td>
<td>Improved torque margin performance</td>
</tr>
</tbody>
</table>

Changes Improve Mission Performance, Reduce Complexity, and Better Support Spacecraft Interface
RBI’s Mission: Earth’s Radiation Budget Measurement Continuity
<table>
<thead>
<tr>
<th>Discovery</th>
<th>Changes to Design to Resolve Discovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPM to filter housing spacing</td>
<td>Change to Filter ring mount in Flight design</td>
</tr>
<tr>
<td>CSM free rotation</td>
<td>Magnetic launch lock design</td>
</tr>
<tr>
<td>FPGA sync, detector noise</td>
<td>Fix implemented on EDU</td>
</tr>
<tr>
<td>Flight SW elevation drop outs</td>
<td>Noise eliminated on EDU/Flight</td>
</tr>
<tr>
<td>SW integration, set points, coefficient and telemetry issues</td>
<td>Resolved Flight SW to EU/FPGA interfaces</td>
</tr>
<tr>
<td>Test processes/equipment debug and integration</td>
<td>Test procedures and work instructions are being updated and made ready for Flight</td>
</tr>
<tr>
<td>VCT temp sensitivity</td>
<td>Flight fix</td>
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<tr>
<td>MIL-STD-1553 test software implementation issue</td>
<td>Test set issue resolved to support EDU/Flight testing</td>
</tr>
<tr>
<td>ARM flex design issues</td>
<td>Flight fix</td>
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<tr>
<td>CSM control system</td>
<td>Optimized for requirements set</td>
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