RBI is a New Instrument Developed as a Follow-on to CERES Flown on TRMM, EOS, NPP, and JPSS-1

Radiation Budget Instrument (RBI)

Partnerships and Teams

• NASA/NOAA Partnership
  – NOAA provides JPSS-2 satellite for accommodation of RBI
  – NASA provides RBI instrument and support through spacecraft I&T and launch/activation
  – NASA funds radiation budget science data analysis and generation of science products (RBM Project)

• 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)
  – Hand-over and release of RBI instrument ownership by RBI Project occurs at the JPSS-2 Operational Hand-over Review (OHR). For Phase E, the Langley Science Directorate (SD) Radiation Budget Measurement (RBM) Project assumes responsibility for RBI for mission planning and operations

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

• JPSS-2 Spacecraft and Mission Interface
  – Interface Control (ICD & MICD) and Data Format

RBI scanning radiometer measuring three spectral bands at top of Atmosphere (TOA)

• Total 0.3 to >50+ µm
• Shortwave 0.3 to 5.0 µm
• Longwave 5.0 to 50+ µm

Science Goal

• To continue the measurements from the last two decades in support of global climate monitoring.
• RBI extends the Earth radiation budget measurements of the Earth Observing System (EOS) and Joint Polar Satellite System (JPSS)

• Phase: Formulation (C)
• Risk: 7120.5E, Category 2; 8705.4 Payload Risk Class B
• Flight Instrument Delivery: March 2019
• JPSS-2 On-dock Delivery Date: April 2019
• Life: 7 years

RBI is a CERES Data Continuity Mission
Partnerships and Teams

[Logo images of Harris, NASA, Space Dynamics Laboratory, NASA Jet Propulsion Laboratory, L-1, Sierra Nevada Corporation, and General Dynamics Global Imaging Technologies]
## RBI Baseline and Threshold Requirements

<table>
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<tr>
<th>Key Performance Requirements</th>
<th>Baseline Science Requirements</th>
<th>Threshold Science Requirements</th>
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<tr>
<td>Total Spectral Range</td>
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<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>
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<td>Total Channel Absolute Radiometric Accuracy</td>
<td>( \leq ) Larger of 0.575 W/m²-sr or 0.5% (( k = 1 ))</td>
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<td>Total Channel Radiometric Precision</td>
<td>( \leq ) 0.2 W/m²-sr + 0.1% (( k = 3 ))</td>
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<td>( \leq ) 2.5 W/m²-sr</td>
</tr>
<tr>
<td>Shortwave Channel Linearity</td>
<td>( \leq ) 1.28 W/m²-sr</td>
<td>( \leq ) 2.13 W/m²-sr</td>
</tr>
<tr>
<td>Longwave Channel Linearity</td>
<td>( \leq ) 0.54 W/m²-sr</td>
<td>( \leq ) 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>
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RBI Baseline Science Requirements Match CERES
JPSS-2 Instrument Complement

- Radiation Budget Instrument (RBI)
- Advanced Technology Microwave Sounder (ATMS)
- Cross-track Infrared Sounder (CrIS)
- Visible Infrared Imagining Radiometer Suite (VIIRS)
- Ozone Mapping and Profiler Suite (OMPS)

JPSS-2 Observatory

- Nominal Altitude: 824 km ± 17 km
- Ground Track Repeatability Accuracy: ±20 km at the equator
- Ground Track Repeat Cycle: <20 days
- Nominal Ascending Equator Crossing Time: 1330 (local time) ± 10 min

Spacecraft design and Instrument locations are notional and representative of JPSS-1
JPSS-2 configuration has not been determined
Instrument Overview

- Instrument Design Overview
  - Instrument Features
  - ConOps Overview
  - Module Overviews
- Performance Overview
- Engineering Development Unit Overview
## Science and Continuity Drive
### Key Features of RBI Design

<table>
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<tr>
<th>RBI Science Needs</th>
<th>RBI Design Feature to Fulfill Science Need</th>
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<tbody>
<tr>
<td><strong>Low Shortwave Radiometric Uncertainty</strong></td>
<td><em>VCT</em> containing Electrical Substitution Radiometer (ESR) provides stable SW reference radiance over life</td>
</tr>
<tr>
<td><strong>Low Total and Longwave Radiometric Uncertainty</strong></td>
<td>Heated high-emissivity <em>ICT</em> with well-calibrated temperature sensors provide on-orbit reference for Total and LW channels</td>
</tr>
<tr>
<td><strong>Accurate Knowledge of Relative Spectral Response Over Life</strong></td>
<td>6-diode <em>VCT</em> provides multispectral RSR characterization with absolute stability provided by the ESR</td>
</tr>
<tr>
<td><strong>Radiometric Calibration Consistency Between Channels</strong></td>
<td>All channels view the same <em>VCT, ICT</em> and <em>SCT</em>.</td>
</tr>
<tr>
<td><strong>Stable Radiometric Response</strong></td>
<td>Effective temperature stability of telescope and detectors</td>
</tr>
<tr>
<td><strong>Point Spread Function (PSF) Closely Matches Heritage CERES</strong></td>
<td>RBI uses an IFOV size/shape and scan rate that are nearly identical to heritage CERES. PSF closely matches CERES.</td>
</tr>
<tr>
<td><strong>Radiometric Verification Via Solar Calibration</strong></td>
<td><em>SCT</em> containing multiple Spectralon surfaces. Pristine surfaces are used to detect degradation of primary surface.</td>
</tr>
<tr>
<td><strong>Multiple Observation Modes (crosstrack, bi-axial, user defined)</strong></td>
<td>3 telescopes (one for each band) provide best operational flexibility and continuity. Uploadable scan pattern.</td>
</tr>
<tr>
<td><strong>Reliable Science Data</strong></td>
<td>Completely redundant instrument, including detectors and electronics</td>
</tr>
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*VCT* = Visible Calibration Target  
*ICT* = Infrared Calibration Target  
*SCT* = Solar Calibration Target
RBI ConOps Provides Operational Flexibility

- Earth observations: Crosstrack and Biaxial scanning
- Calibration
  - Every scan line: space look
  - Daily: single point gain response using VCT and ICT
  - Monthly
    - Spectral calibration using VCT
    - Linearity measurement using VCT and ICT
- User-defined modes for operational flexibility
  - Earth target for validation campaigns
    - Includes cross-correlations with CERES by viewing the same earth location
  - Solar observations via diffuse target
  - Lunar observations
Field of Regard Obtained by Mounting Orientation & Two-Axis Pointing

Cross-track Scan Module (CSM) enables swath mode views of the Earth, internal calibration targets, and space views.

Azimuth Rotation Module (ARM) enables biaxial-mode for views of the Earth to support Angular Distribution Models (ADM), direct Lunar calibration, and indirect Solar calibration using the Solar Calibration Target (SCT).
Cross-Track Scan is Primary Operational Mode

- **Constant 63.1 deg/sec rate over full Earth; 6.6-sec cycle time**
During a Bi-axial scan the instrument is commanded to rotate both the azimuth and Elevation gimbals.

- Data is used to validate and refine Angular Distribution Models used to convert RBI radiances into fluxes at top of atmosphere.

- Elevation scan rate is 63.1 deg/sec with a +/- 70 deg rotation.

- Azimuth scan rate is 0.5 to 6.0 deg/sec with a +/-90 deg rotation.

- Azimuth scan rate and rotation are commanded from ground.
Modular Design Simplifies Integration

- Radiation Budget Instrument
- Modular Design
- Simplifies Integration

- ESR Electronics
- Solar Calibration Target (SCT)
- Cross-Track Scan Module (CSM)
  - Twist Capsule Mounting Bracket
  - Twist Capsule
  - Optical Module (OM)
  - CSM Assembly
- Electronics Unit (EU)
- Bench Shroud
- Infrared Calibration Target (ICT)
- Azimuth Rotation Module (ARM)
- Laser Diode Assembly
- External Filter Module
- Thermal Mounting Feet
- Visible Calibration Target (VCT)
- Twist Capsule Mounting Bracket
- Optical Module (OM)
Optical Modules and Targets Designed for Maximum Stability and Accuracy

- **ICT**: Heated, High-Emissivity
- **SCT**: With 3 Protected Spectralon® Surfaces
- **VCT**: With 6-Wavelength Radiance Output and ESR for Absolute Reference
- **Thermal Shrouds Minimize Temperature Drifts**
- **Telescope Baffling Minimizes Stray Light**
- **Thermopile Detectors; Shape Provides Heritage PSF**

Diagram showing the Radiation Budget Instrument with labeled components and a marked NADIR 0° (+Z) orientation.
Optical Module Controls Stray Light While Providing a Stable Thermal Environment

Extensive Telescope Baffling Minimizes Stray Light

Fore-Baffles

Telescope Mirrors

Filter

JPL Thermopile Detector

One Telescope Per Band Simplifies Detector Design

Rear Enclosure Provides Thermally Stable Environment

Materials Minimize Thermal Gradients
Uncooled thermopile detectors with Gold-Black coating are responsive over the full RBI spectral range from UV to far-infrared

- Scene radiance is measured by detecting small changes in temperature of the detector material

- Detectors are highly linear, stable, low noise, and fully redundant

- Heritage: MCS/Diviner (15 years of flight ops)
ICT is a Thermal Infrared Radiance Source for Precise Calibration

- Provides IR calibration source for LW and Total channels
- Harris-patented Specular Trap design provides >0.995 emissivity in a compact, easy to manufacture package
- PRTs are carefully calibrated to NIST standard on the ground prior to installation
- Heaters enable linearity measurements while on-orbit
- Beryllium minimizes thermal gradients
- Flight heritage design from CrIS and AHI-8
Visible Calibration Target Provides Reflected Solar Band Calibration Standard

- VCT provides 6 laser diode sources
  - 375, 405, 445, 690, 915, 1470 nm
  - Radiometric calibration uses 915nm laser only
  - RSR characterization uses all 6 wavelengths sequentially
- Si and InGaAs photodiodes provide short-term radiance reference
- ESR provides stable absolute radiance traceable to NIST
  - Used monthly to calibrate photodiodes and SW / Total channels
- Laser diodes are remotely located, fiber coupled, providing thermal stability of diodes and sphere
Solar Cal Target Provides Additional Independent Check of SW/Total Calibration

♦ SCT contains three protected Spectralon® solar diffusers for on-orbit calibration checks
  ▪ Targets are in a cube orientation within a sealed enclosure, which protects them from solar degradation
  ▪ At least one surface can be maintained in a pristine condition to track and correct for changes in the “daily” surface
  ▪ The 4th face blocks incoming solar radiation and contamination when the SCT not in use

♦ SCT mechanism is space-qualified
♦ Proven Spectralon® solar diffuser material, also used by ABI, AHI, COMS, and GOSAT programs
CSM Provides Low-Jitter Cross-Track Scanning of Optical Module

- Designs leverage heritage motor/encoder designs
- Design optimizes OM thermal performance
- Twist flex design provides redundant OM connections
- $H$ infinity control optimizes response and provides robustness to external disturbances
- Heritage bearing system has proven long life on CrIS
Azimuth Rotation Module Provides Reliable Bi-Axial Scan Capability

- Provides azimuth rotation of upper half of instrument
  - Rate of 0.5-6.0 deg/sec
- Open-loop stepping system with simple and reliable control process
- Resolver feedback in telemetry provides confirmation of positioning
- Leverages many assemblies with flight heritage
  - Gearbox, resolvers, hybrid stepper motor, Electronic Control Unit, launch lock

Gray = Stationary (Tied to Spacecraft)
Blue = Rotating With RBI Bench
Orange = Combination
Instrument Overview

♦ Instrument Design Overview
  ▪ Instrument Features
  ▪ ConOps Overview
  ▪ Module Overviews

♦ Performance Overview

♦ Engineering Development Unit Overview
CERES-Like Point Spread Function (PSF) Provides Important Data Continuity

- RBI detector shape mimics the CERES precision aperture, and heritage scan rate and time constant 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 enhances data continuity
Knowledge of Relative Spectral Response Ensures Accurate Observations

- VCT detects changes in Relative Spectral Response (RSR) over life allowing corrections to be implemented
- SCT can also support corrections

VCT Measures Responsivity Changes at 6 Wavelengths, Allowing RSR Changes to Be Corrected

Preliminary RSR Curves Use Measured Data From Prototype Parts
Radiometric Performance Expected to Meet Requirements

- Radiometric repeatability and uncertainty are expected to meet requirements
- Accurate radiance measurements are critical to the ERB CDR
### Key Performance Requirements vs. Baseline Science Requirements

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<td>0.18 W/m²-sr</td>
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<td>&gt;95% of CERES</td>
<td>95.2% of CERES, Worst Case</td>
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Instrument Overview

♦ Instrument Design Overview
  ▪ Instrument Features
  ▪ ConOps Overview
  ▪ Changes Since SRR
  ▪ Module Overviews

♦ Performance Overview

♦ Engineering Development Unit Overview
EDU is a pathfinder for calibration
- Design is quite similar to RBI flight design
- Manufacturing processes are validated
- Radiometric performance requirements are demonstrated
- Calibration approach is demonstrated

EDU is a pathfinder for test execution
- “Dry Run” of the Flight pre-launch calibration campaign
- Limited environmental tests bring confidence to design robustness

EDU TVAC Testing Scheduled for Summer 2017
- Provides first opportunity to correlate end-to-end radiometric model
EDU is a Representation of Flight Design

- EDU is not electrically redundant
- Multiple aluminum substitutions to enable faster build and test
- Static ARM enables faster build
- Optical modules fail stray light requirements
- Quality standards are specific to EDU-type build

Multiple Aluminum Substitutions to Enable Faster Build and Test

Static ARM Enables Faster Build

Optical Modules fail stray light requirements

EDU Is Not electrically redundant

EDU
Summary

♦ RBI design is optimized for its mission
♦ RBI provides valuable data continuity with CERES
♦ Operations are highly flexible to support science needs
♦ Design utilizes heritage sub-assemblies to minimize development risk and schedule
♦ Performance expected to meet requirements
♦ RTM and EDU provide early risk mitigation
Modular Design Simplifies Integration

- Electronics Unit (EU)
- Solar Calibration Target (SCT)
- Cross-Track Scan Module (CSM)
- Twist Capsule Mounting Bracket
- Optical Module (OM)
- CSM Assembly
- Azimuth Rotation Module (ARM)
- Infrared Calibration Target (ICT)
- Laser Diode Assembly
- Twist Capsule
- External Filter Module
- Thermal Mounting Feet
- Visible Calibration Target (VCT)
- Bench Shroud
Instrument Design Addresses Mission Needs

♦ Design features maximize mission performance
  ▪ Stable thermal environment
  ▪ Comprehensive suite of calibration targets
  ▪ High-performance detectors
  ▪ Flexible operational strategy
  ▪ PSF closely matched to CERES for best data continuity

♦ Design uses flight heritage, as able, to reduce development risk
Radiation Budget Instrument is Designed to Meet Mission Needs

- Measures upwelling earth radiance over a wide spectral range
  - Ultraviolet to far-infrared (100um)
  - Continuous cross-track scans
- Three spectral bands
  - Shortwave (SW): reflected solar energy
  - Longwave (LW): emitted earth energy
  - Total: reflected solar plus emitted thermal energy
- Very precise calibration
  - Extensive ground calibration program establishes radiometric traceability
  - Multiple onboard targets hold calibration over mission life