Experiments using CERES observations of the moon to supplement the Cal/Val protocol

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CERES Instrument Working Group

CERES Science Team Meeting
Virtual
October 13, 2021
Primary CERES Flight Radiometric Validation Protocol Activities

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At the end of the presentation we will compare results of the Internal Calibration Module and Lunar Observations.
Executive Summary

The moon is NOT an adequate standalone calibration target for Spectrally broadband, Wide Angular Field of View, Absolute Radiometry sensors such as CERES.

However… It does play a role in the overall CERES Post Launch Cal/Val protocol

It presents itself as a highly unstable reflector (spatially nonuniform with insufficient spectral knowledge) calibration target that ‘wobbles’ in a galactic ‘optical bench’ where the key distances and illumination angles between source, reflector and measurement system vary rapidly and out of phase.

However… ROLO has, and ArcStone will in the future make important advances in characterizing these instabilities in the coming decade

Fully interpreted/corrected Lunar observations are consistent with all other elements of the cal/val protocol

1) Pointing Knowledge (supplements coastline detection experiment)
2) Co-alignment of the three science channels
3) Spatial/Angular uniformity of dynamic response in the sensor assemblies
4) Decadal trends consistent with those measured by onboard calibration sources (blackbodies and lamps)
Lunar Cal Phenomena to be Untangled

Sun Moon Distance varies (+ - 3% effect)
Sat. Moon Distance varies (+ - 15% effect)
Libration/Wobble (+ - 2% effect)
Phase Angle (+ - 2% effect)
Solar Constant (<1% effect)

ArcStone will address some of these

Variation of illumination path lengths and angles

Mismatch of Lunar Disk Target Size to Optical system

- Moon fills 7.4% of ceres FOV at perigee and 9.7% at apogee
  - yields time varying Solid angle of source illumination.
  - >90% System etendue is 2K deep space background.
  - Yields Very low signal

Variation of Illumination Path Lengths and Angles all Have Unique Periodicity

The Sidereal and Synodic Months. The sidereal month is the time the Moon takes to complete one full revolution around the Earth with respect to the background stars. Thus, the synodic month, or lunar month, is longer than the sidereal month. A sidereal month lasts 27.322 days, while a synodic month lasts 29.531 days.

Presents Minimal Variation in Integrated Spectral Radiance

2-point Calibration cannot distinguish between a gain, spectral, or offset change in sensor assembly throughput

~ A Case Study in how not to design a calibration experiment ~
Lunar Observation Experimental Design

Objective: Utilize the moon as a quasi-point source to complete a near steady-state raster scan across the CERES FOV to support Cal/Val activities

Goals

• Validate pre-launch alignment measurements (dedicated observations began in April 2001) (Ipod released May 2001)
• Measure inter-channel relative pointing accuracy, (i.e. co-registration of telescopes)
• Map out system level spatial non-uniformities in the CERES Optics/Detectors
  • Detector Requirement is +10% from raster scan focused spot across the detector (component test)
  • This type of mapping is not performed under vacuum prior to launch
• Develop data set for long term stability measurements utilizing lunar radiances (stable protocol since 3/2006)

By combining knowledge of the motion of the moon relative to the spacecraft and the programmability of the CERES Instruments we obtain....

Detectors view of the moon passing through the FOV
Elevation Gimbal is fixed at one of three pre-determined angles above the earth’s limb.

Lunar Observation Experimental Design

Elevation Gimbal completes an out and back rotation in 6.6 second data packet.

Operation is completed for the five orbits before and after full moon each lunar month.
Lunar Scanning Results – CERES Optical Transfer Function

Monte-Carlo Ray Trace (FELIX)

Confirms alignment and co-registration

FM-2 Total

Displays non-uniformity in Response

FM-2 Shortwave

How accurately can this be accomplished with sparsely sampled data?

Integrating across the transfer function provides an estimate of full-field lunar signal
Lunar Observation Angular Sampling Study

Study to quantify the impact of sampling pattern on estimating equivalent full field lunar radiance

Error in the process of Estimating equivalent Full Field Observed Radiance from a sub Full Field Raster Scan

\( \sim +0.3\% \ (k = 1) \)
Moon presents itself to CERES as a time varying target of $\sim+/-20\%$

Once Fully Interpreted Variability is at $\sim+/-1\%$
Normalized Lunar Radiance
Correct Lunar Observations to an 8-deg Lunar Phase Angle

FM1 Total Channel: 2006 to 2021

Shortwave Channel Sensitivity to Lunar Phase Angle 2X Total and Longwave

Correct Lunar Observations to an 8-deg Lunar Phase Angle
Correct Lunar Observations to an 8-deg Lunar Phase Angle

Shortwave Channel Sensitivity to Lunar Libration 2X Total and Longwave

Note: Longitude Correction Not Shown
Mission Year

**FM-1 Lunar and Internal Calibration**

**Normalized Trend Comparison (%)**

**Orbital and Lunar Monthly**

**Internal and Lunar Calibrations : Monthly**

**Total**

Slope = 0.01152 % change / year

**Shortwave**

Slope = -0.0144 % change / year

**Window**

Slope = 0.02949 % change / year

Results display instrument artifacts that have been removed in the Edition-4 Products
Mission Year
Orbital and Lunar Monthly

Internal and Lunar Calibrations: Monthly

Total
Slope = 0.00888 % change / year

Shortwave
Slope = -0.0291 % change / year

Window
Slope = 0.04486 % change / year

Results display instrument artifacts that have been removed in the Edition-4 Products.
FM-3 Lunar and Internal Calibration
Normalized Trend Comparison (%)

Orbital and Lunar Monthly

Internal and Lunar Calibrations: Monthly

Total

Slope = 0.01641 % change / year

Shortwave

Slope = 0.00135 % change / year

Window

Slope = -0.0111 % change / year

Results display instrument artifacts that have been removed in the Edition-4 Products
FM-4 Lunar and Internal Calibration
Normalized Trend Comparison (%)

Orbital and Lunar Monthly

Internal and Lunar Calibrations: Monthly

Total
Slope = 0.00806 % change / year

Shortwave
Slope = -0.0096 % change / year

Window
Slope = -0.0096 % change / year

Results display instrument artifacts that have been removed in the Edition-4 Products
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Back-up
Still not corrected for:
- Spectral variation
- Lunar Observations
- Solar Calibrations
- Internal Calibration Sequence

Flight Cal/Val Locations

Aqua

Terra

Legend:
- Lunar Observations
- Solar Calibrations
- Internal Calibration Sequence
**FM-2 Window Channel**

- One quadrant of detector has an extremely high responsivity
- Probably due to localized delamination of detector due to air-bubbles in the lower Epoxy layers.
  - Consistent with known fabrication problems at the time these detectors were made.
- The resulting void would provide a higher local thermal impedance
  - Inducing higher temperatures in thermistor layer
  - Result in a slower time constant
  - Much longer air-to-vacuum stabilization time

**Very stable radiometric performance on orbit!!!!!**
Lunar Scanning Results – CERES Optical Transfer Function

Monte-Carlo Ray Trace (FELIX)

FM-1 Total

FM-1 Shortwave

FM-1 Window
• No longer have working group meetings at Science Team so thought we would initiate individual focused presentations on each of the cal val activities
• Recognize arcstone selection
• Provide inputs to costy and Cindy on CERES perspective
• Timeline of when and why we executed lunar scanning

• Wide field telescope introduces it’s own uniqueness vs imagers with much smaller IFOV

• Phases of experiment
• Operations to sample
• Analysis of collected data (Arcstone may help here)
• Comparison to other cal/val experiment results

• Lunar reflectance plot
  
  Time scales.... Lunar is one data point per month
• See calcon plot for where calibrations occur
• The moon is okay for what it is, but it’s really only one element in an overall cal/val protocol
FM1 Lunar and Internal Calibration Trend Comparison (%)

Orbital and Lunar Monthly

Total

Slope = 0.01152 % change/year

Shortwave

Slope = -0.0144 % change/year

Window

Slope = 0.02949 % change/year

Internal and Lunar Calibrations : Monthly

Normalized to In-Flight Data

Mission Year
Moon presents itself to CERES as a time varying target of $\sim+20\%$.

To be useful peak to peak variability/noise must be reduced to better than $+1\%$. 

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**Graphs:**

1. **Normalized detector signal**
   - FM1 Total Channel: 2006 to 2013
   - Data adjusted for EM
   - Earth-Moon distance overlay
   - Days since January 1, 2000

2. **Distance in AU**
   - 3.00e-3
   - 2.75e-3
   - 2.50e-3
   - 2.25e-3

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Fig. 11. CERES FM-1 detector response before lunar phase angle adjustment.

Fig. 12. CERES FM-1 detector response after lunar phase angle adjustment.
Fig. 14. FM-1 detector output versus lunar libration latitude.

Fig. 15. FM-3 detector output versus lunar libration latitude.