Update: CERES FM-5, 6 & CERES follow-on Terra/Aqua Edition3 Studies

Kory Priestley
~ The entire Instrument Working Group Team ~

CERES Science Team Meeting
Goddard Institute for Space Studies
New York, NY
October 27, 2008
**Science**  
- Susan Thomas  
  Melody Avery  
  Phil Hess  
  Suzanne Maddock  
  Peter Szewczyk  
  Robert Wilson  
  Mohan Shankar

**Data Management**  
- Denise Cooper  
  - Dale Walikainen  
  Lisa Coleman  
  Ashley Alford  
  Dianne Snyder  
  Mark Timcoe  
  Thomas Grepiotis  
  Mark Bowser

**Mission Operations**  
- Bill Vogler  
  James Bailey  
  Janet Daniels  
  Jim Donaldson  
  John Butler  
  William Edmond

**S/C Integration & Test**  
- Roy Zalameda  
  Mike Tafazoli  
  Eugene Sutton  
  Gene Andrews

*Significant increases were necessary to implement new FM5 and FM6 work*
Succession plan for follow-on missions

Name: Tyler James Maddock (T. J.)
Born: 14 October 2008 (3:32pm EST)
Weight: 9 lbs, 5.6 oz.
Length: 20.5 in
## Terra/Aqua Edition2 Availability

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<thead>
<tr>
<th>Spacecraft</th>
<th>Product</th>
<th>Version</th>
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<th>Months Processed</th>
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<td>1/98 - 8/98, 3/00</td>
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<td></td>
<td>Edition2</td>
<td>Yes</td>
<td>6/02 - 12/07</td>
</tr>
</tbody>
</table>

Note: Red text indicates months are in final validation prior to public release.
# CERES Flight Schedule

## Enabling Climate Data Record Continuity

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Instruments</th>
<th>Launch</th>
<th>Science Initiation</th>
<th>Collected Data (Months)</th>
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<tbody>
<tr>
<td>TRMM</td>
<td>PFM</td>
<td>11/97</td>
<td>1/98</td>
<td>9</td>
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<tr>
<td>Terra</td>
<td>FM1, FM2</td>
<td>12/99</td>
<td>3/00</td>
<td>98 +</td>
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<tr>
<td>Aqua</td>
<td>FM3, FM4</td>
<td>5/02</td>
<td>6/02</td>
<td>71 +</td>
</tr>
<tr>
<td>NPP</td>
<td>FM5</td>
<td>June 2010</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>NPOESS C1</strong></td>
<td><strong>FM6</strong></td>
<td><strong>January 2013</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>NPOESS C3</strong></td>
<td><strong>CERES follow-on</strong></td>
<td><strong>January 2018</strong></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**31 Instrument Years of Data**
# CERES Flight Schedule

## Enabling Climate Data Record Continuity

<table>
<thead>
<tr>
<th>Spacecraft:</th>
<th>TRMM Nov-97</th>
<th>Terra Dec-99</th>
<th>Aqua May-02</th>
<th>NPP June-10</th>
<th>C1 Jan-13</th>
<th>C3 Jan-18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors:</td>
<td>CERES PFM</td>
<td>CERES FM-1,2</td>
<td>CERES FM-3,4</td>
<td>CERES FM-5</td>
<td>CERES FM-6</td>
<td>CERES Follow-on</td>
</tr>
</tbody>
</table>

| CY: | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Spacecraft I&T |               |               |               |       |       |               |               |               |       |       |               |               |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Sensor Fab, Assembly, Test |               |               |               |       |       |               |               |               |       |       |               |               |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Initial design studies |               |               |               |       |       |               |               |               |       |       |               |               |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Nominal Mission Lifetime |               |               |               |       |       |               |               |               |       |       |               |               |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Operational Mission Lifetime |               |               |               |       |       |               |               |               |       |       |               |               |       |       |       |       |       |       |       |       |       |       |       |       |       |

- **CERES Follow-on FM-1**:
- **FM-5**:
- **FM-6**:

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*NASA Langley Research Center / Science Directorate*
# Path to ERB CDR Continuity

<table>
<thead>
<tr>
<th>Capability</th>
<th>FM-5</th>
<th>FM-6</th>
<th>CERES Follow-on</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lineage</strong></td>
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<td>Build to Print, with modest upgrades, Technology Bridge</td>
<td>New Design</td>
</tr>
<tr>
<td><strong>Flight Software</strong></td>
<td>Bug fixes, minimal functionality improvements</td>
<td>Bug fixes, minimal functionality improvements</td>
<td>Bug fixes, Full functionality improvements</td>
</tr>
<tr>
<td><strong>New Solar Calibration</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MAM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Shortwave Internal Cal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Source Upgrade</strong>*</td>
<td></td>
<td>Minimal Spectral Capability</td>
<td>Multi-spectral Capability</td>
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<tr>
<td><strong>Replace 8-12 μm Channel</strong></td>
<td></td>
<td>5 - 100 Micron</td>
<td>5 - 100 Micron</td>
</tr>
<tr>
<td><strong>New Detectors</strong></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>“10 km” FOV</strong></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ground Calibration</strong></td>
<td>Re-verify sources, revisit procedure</td>
<td>Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW</td>
<td>Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW</td>
</tr>
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* Updated shortwave requirements based on improved understanding of reflected spectrum from CERES experience

** Nominal improved FOV, final requirement set as part of CERES follow-on instrument study
CERES Authorized for Flight on NPP

NASA HQ authorized multi-phase study in 2007 to assess feasibility of adding CERES back on NPP

• Phase 1: Initial Feasibility Study (February – May 2007)
  – Passed the sanity test
  – Recommended progression to Phase 2

• Phase 2: Detailed Analysis and Engineering design
  (June 1, 2007 – September 14, 2007)
  – Identified instrument, spacecraft & ground system modifications
  – No technical or schedule barriers identified
  – Results indicated CERES could be accommodated without impacting Sept. 2009 (now 6/10) Launch Readiness Date

• Phase 3: Implement CERES Accommodation on NPP
  (October 15, 2007 – July 2008)
  – Sensor ATP granted 1/23/08

CERES originally carried as part of NPP mission but not approved at Mission Confirmation Review in Nov 03.
CERES Compatibility with NPP Spacecraft

Observatory Information
- Launch Readiness - June, 2010
- Location - Vandenberg AFB
- Launch Vehicle - Delta II
- Altitude - 824 Km
  - CERES FOV increases to ~ 24Km
- Inclination - Sun-Synch, 98.7-deg
- Crossing Time - 1:30pm, Ascending
- Payload -
  - CERES
  - VIIRS
  - OMPS
  - CRIS
  - ATMS
CERES FM-5 Instrument Baseline Schedule

### FM-5 Instrument Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>UID</th>
<th>IMSS UID</th>
<th>Task Name</th>
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<th>Start</th>
<th>Finish</th>
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<td>332</td>
<td>4603</td>
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<td>359</td>
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<td>10/28/08</td>
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<td>564</td>
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<td>501</td>
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<td>22d</td>
<td>10/31/08</td>
<td>12/3/08</td>
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</table>

**S/C need-date of 11/15 (15 days schedule reserve)**

**March 2008 Schedule**

~ FM-5 Instrument will be delivered on 11/7, a week ahead of schedule ~

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NASA Langley Research Center / Science Directorate
CERES FM5 Hardware Status & Near-Term Activities

- Fabrication, Assembly and Test Program is complete
- Ground Calibration was most extensive to date in the CERES Program
  - 33 days under continuous vacuum
  - 6 supplemental tests beyond legacy procedure
  - NGST Test Team did an outstanding job...
- System Acceptance Review 10/30 at NGST
- Ship FM-5 to BATC on 10/31
- Instrument Integration Readiness Review 11/7 at BATC
- Mechanical/Electrical Integration to NPP spacecraft begins 11/12
- NPP Launch Readiness Date is currently June 2, 2010
  - Initial NPP launch date was mid-2006
  - Earliest ‘feasible’ launch date is Jan. 2011
  - Realistic launch date is late 2011
Radiometric Calibration Facility
NPP Program Status

- All of the NASA elements (i.e. launch vehicle, spacecraft, CERES, ATMS) of the program are on schedule...

- Due to significant delays with the NGST/NPOESS led procurement of the VIIRS sensor, and it’s resulting impact on the NPOESS program, everything with regard to NPP is now on the table...

- Scenarios being re-considered include:
  - Wait for VIIRS (fly as-is, less than fully functional)
    - Unknown schedule/cost impact
  - Replace VIIRS with AVHRR
    - Estimated 2-year schedule delay
  - Replace VIIRS with a cloud ‘camera’
    - Unknown delay
  - Fly with no imager
    - No schedule delay
  - Cancel NPP
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<tr>
<td><strong>New Solar Calibration MAM</strong></td>
<td>Yes + enhanced screening</td>
<td>Yes + enhanced screening</td>
<td>Yes + enhanced screening</td>
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<tr>
<td><strong>Shortwave Internal Cal Source Upgrade</strong>*</td>
<td>Minimal Spectral Capability</td>
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* Updated shortwave requirements based on improved understanding of reflected spectrum from CERES experience

** Nominal improved FOV, final requirement set as part of CERES follow-on instrument study
LaRC has created a dedicated FM-6 acquisition team

Center Commitment Review scheduled for 11/21

A complete RFP package will be released to NGST once full funding authority is granted to LaRC

NASA has received ~$5M for FM6 in FY09
  - roughly half of what was requested for the entire year

Allows for enhanced study phase only
  - test/characterize existing detectors
  - review of legacy processes and procedures
  - Initial Spacecraft/sensor ICD development
  - Upgraded internal calibration equipment design studies
Shortwave Spectral Internal Module (SSWIM)

- Either lamps with spectral filters or a series of monochromatic sources
- Ability to vary strength of source preserved
- Contains independent monitoring of source output
- Design specification is 0.1% stability over 5-year mission
- Designed primarily to spectrally resolve changes in optical transmission

Mirror Attenuator Mosaic (MAM) Solar Diffuser

- Solar Diffuser plate attenuates direct solar view (~5800K Spectrum)
- MAM is currently a Nickel substrate with Aluminum coated spherical cavities or divots
- Provides a Relative calibration of the Shortwave channel and the SW portion of the Total channel
- Designed to provide a long-term on-orbit SW calibration source.
Lessons Learned / Future Direction

In the future CERES will fly in a single orbit with one instrument per spacecraft, eliminating key Direct Comparison validation capabilities...

Programmatic Implementation
- Increase weighting/influence of Radiometric Performance in cost/schedule trades
- Maintain positive/open relationship with hardware provider. Avoid ‘Us’ vs. ‘Them’ mentality.
  - LaRC/NGST Team has proven track-record and experience

Ground Characterization Procedures
- Re-verify traceability of calibration targets
- Establish collaborations with NIST, other international agencies
- Implement automated Data Acquisition System on Calibration Chamber

Operational Mode
- Do not point optics in ‘forward’ looking direction
  - Strong Correlation to spectral darkening of SW channel optics

Onboard Calibration Hardware
- Provide additional SW spectral characterization capability
  - Stringent measurement requirements demand SW spectral capabilities

Handling Procedures
- Minimize possibility of contamination
- Develop Inspection and cleaning procedures
Why are CERES Edition2 radiances not perfect?

A question of time scales, experience and balancing accuracy with providing data products to the community.

- Edition2 Radiances have been released on ~6 month centers
- 6 months is just a blink of an eye when analyzing long term trends…

Same time scale as phenomena which influence instrument response
- Beta Angle
- Earth Sun Distance
- Orbital shifts
- Instrument Operational modes (i.e. RAPS vs. Xtrack)

Complicates separation of instrument ‘artifacts’ from natural variability.

Edition3 reprocessing of the first 5 years of CERES radiances allows a much more rigorous identification and separation of instrument artifacts and true climate signals.
Terra Monthly Average ICM Results

**FM1**

- **Total**
- **SW**
- **WN**

**FM2**

- **Total**
- **SW**
- **WN**

*Note: Ed2 Implementation*
Terra Monthly Average ICM Results

**FM1**

**FM2**

Sensor Gain Sensitivity to Beta Angle

**Date**

Sensor Gain Sensitivity to Beta Angle
Sensor Responsivity is highly correlated with instrument operating temperature.
Ground Calibration typically conducted at Hot Acceptance Temperatures
Aqua Monthly Average ICM Results

FM3

Total

SW

WN

FM4

Total

SW

WN
Residual calibration errors in CERES Edition2 data products are dominated by spectral degradation of sensor optics in the reflected solar bands. (SW and SW/TOT)

This results in

- Artificial decreasing trend in the reflected solar measurements
- Divergence between daytime and nighttime OLR records with time.
  - \( LW_{\text{day}} = \text{Total} - \text{Shortwave} \)
  - \( LW_{\text{night}} = \text{Total} \)

Occurs on all four CERES EOS sensors to varying degrees

Highly correlated to several factors

- Operational Mode
- Solar Cycle
- Atomic Oxygen fluence levels
Deseasonalized SW Anomalies: Terra

**Operational Mode**

**Scene Type**

**Xtrack**

**DCC**

**RAPS**

Note: Unfiltered SW radiance measurements sorted into Angular bins (i.e. VZA and RAZ) and averaged on a monthly basis.
Tropical Mean: LW Day Night Difference Trends

Data Set
- LW Unfiltered Radiance
- Nadir
- 20N - 20S
- Tropical Ocean
- All-Sky

1.3% per decade (Terra)

Edition1-CV
Instrument has pursued two independent paths to characterize spectral degradation

Path A: led by Peter Szewczyk (Presented at May, 2008 STM)

Premise: Trends explained solely by operational mode, not by sensor

- Sort Clear Ocean (ClrOcn) and Deep Convective Cloud (DCC) unfiltered SW radiance measurements into Angular bins (i.e. VZA and RAZ)
- Determine monthly mean SW measurements for each bin
- Calculate deseasonalized anomalies for Xtrack and RAPS time series
- Trends in ClrOcn and DCC deseasonalized anomalies define drops in spectral throughput at 0.4 and 0.65 microns respectively
  - DCC directly
  - ClrOcn, relative trend of RAPS to Xtrack measurements

Pros: simple, results appear robust for SW channel

Cons: Assumes DCC is absolutely stable, not applicable to SW/TOT
Instrument has pursued two independent paths to characterize spectral degradation

Path B: led by Grant Matthews (Presented at May & Nov 2007 STM’s, latest results presented today by SARB, TISA)

Premise: Optics contaminated on-orbit due to transfer of contaminants by Atomic Oxygen

- Spectral degradation is characterized by an 8 parameter exponential fit
- Deep Convective Cloud Albedo used as an absolute stability metric
- All sensor channels normalized to DCC Albedo on a monthly basis

Pros: Results appear consistent
- Passes all sanity checks
- Provides good engineering insight to possible physical processes

Cons: Too complicated with too many inter-depencies
- Assumes DCC is absolutely stable
- Requires non-physically based changes to spectral response function to resolve divergence in Day/Night OLR
- Assumes complete failure of the onboard SW calibration equipment
We are at the point where we can combine the best and most robust aspects of both paths into an operational scenario

Final Path: Coordinated by Melody Avery, teaming with bot Peter Szewczyk and Grant Matthews

Premise: Utilize all information/studies available to rigorously address spectral darkening, we are going to synthesize...

- What the IWG has learned from validation studies using Ed 2 +/- Rev 1
- What we learned from repeated and extended FM5 cals
- What Peter has learned from his approach
- What Grant has calculated with his approach
- What other physical insight we now have into the space environment (OMI, SBUV/2, SCIA, solar atmosphere) and spectral darkening modes
- Use new tools/data such as ability to spectrally unfilter the broadband Total Channel

Goal is to have validated results and deliver to the production environment, Edition 3 Gain and Spectral Response functions by April 2009.
The plan moving forward consist of 3 separate efforts

Effort 1 - Gain Adjustments

Instrument Group will incorporate all known, physically based changes in gain and other calibration coefficients for each instrument, and produce a new Level1 data set

- Use internal cals
- Thermal Environment impacts
- Incorporate Scan Dependent offset measurements determined on-orbit
- Apply Edition 2 Cal/Val protocol to the full 6-year dataset as opposed to 6 month intervals

Develop and implement a way of placing all CERES instruments on the same radiometric scale at mission start.

- Reanalysis of Ground calibration data will yeild new atlaunch gains and Spectral Response function.
- Utilize satellite intercomparisons

This new Level1 dataset will be used in subsequent analyses to come up with spectral response functions (SRFs) for each month.
Effort (2) - Determine "Optimal" SRFs from Direct Compare approach.

- The concept is to "retrieve" RAP instrument SRFs each month from a pre-populated set of candidate SRF’s with varying degrees of spectral degradation.
- Nadir Direct comparisons are completed for each of the three channels for as many robust scene types as possible, not just DCC and Clear Ocean.
- "Optimal" SRF retrieval yields the smallest XTRACK-RAP "direct compare" nadir radiance difference in a given month.

Implementation concept -

On a month-by-month basis -

- Apply gains provided in Effort (1) to XTRACK and RAP instruments.

- Unfilter XTRACK instrument with previous month's SRF. Unfilter RAP instrument (or instrument last in RAP mode) with all candidate SRFs.

- Identify the RAP SRF that minimizes the XTRACK-RAP nadir radiance difference. For every footprint, the unfiltering subroutine is run once for the XTRACK instrument and for all candidate SRFs for the RAP instrument.
Spectral Drop for ClrOCn and DCC

FM1

FM2
Fit an exponential curve through the ClrOcn and DCC effective wavelengths of 0.4 and 0.65 microns on a monthly basis.

Note: Results shown for 6 month centers
Terra - Deep Convective Cloud Albedo

**FM-1**
- Edition1-CV
  - Slope = 7.386E-05 ± 2.883E-05
  - 1.2% / decade

**FM-2**
- Edition1-CV
  - Slope = -2.578E-04 ± 2.801E-05
  - 4.3% / decade

**Test - A3**
- Slope = 2.704E-05 ± 2.321E-05
- 0.4% / decade

- Slope = 1.574E-05 ± 2.657E-05
- 0.3% / decade
Terra - Clear Ocean Albedo

FM-1

Edition1-CV

5.1% / decade

Test - A3

2.4% / decade

FM-2

Edition1-CV

9.8% / decade

Test - A3

2.4% / decade
- Characterizes trends by Xtrack and RAPS mode, not by sensor

**Methodology**

Sort Clear Ocean (ClrOcn) and Deep Convective Cloud (DCC) unfiltered SW radiance measurements into Angular bins (i.e. VZA and RAZ)

Determine monthly mean SW measurements for each bin

Calculate deseasonalized anomalies for each time series

Trends in ClrOcn and DCC deseasonalized anomalies define drops in spectral throughput at 0.4 and 0.65 microns respectively

  - DCC directly
  - ClrOcn, relative trend of RAPS to Xtrack measurements
What is the impact of 8-years of storage?

Key Concerns are being addressed:

• Review of Electronic parts for age and radiation environment
  - NPP Orbit provides different radiation environment
  - Parts Review underway
  - No significant concerns identified

• Limited Life articles
  - Bearing lubrication
    - N₂ purged storage environment was optimal
    - No concern for limiting lifetime
  - Onboard Calibration lamps
    - No known mechanisms to reduce life expectancy

• Address on-orbit anomalies from Terra/Aqua
  - FM4 SW channel Sensor Electronics Assembly failure
    - Tiger Team reconstituted
    - 90 years of operational lifetime on circuit with one failure
    - Awaiting Recommendation
CERES FM5 Project Scope

- **Instrument**
  - Modify, test, calibrate, and deliver CERES FM5 to NPP spacecraft vendor
  - Update electrical GSE to support instrument development
  - Support spacecraft I&T

- **Mission Operations**
  - Support MO development (NPOESS)
  - Conduct early instrument MO and calibration/validation
  - Conduct instrument MO throughout NPP mission

- **Science Algorithms and Data Processing Software**
  - Develop and maintain FM5/NPP specific algorithms
  - Develop and maintain FM5/NPP specific production data processing software

- **Data Processing, Archival, and Distribution**
  - Integrate FM5 data into the production of EOS climate data records

- **Science**
  - Conduct science studies and review all data products.