Update : CERES/EOS, FM-5, 6 Status
Terra/Aqua Edition3 Calibration Results

Kory Priestley
~ The entire Instrument Working Group Team ~

CERES Science Team Meeting
Colorado State University
Fort Collins, CO
November 3, 2009

NASA Langley Research Center
Atmospheric SCIENCES

Outline

CERES FM1-FM6 Instrument Status Report - K. Priestley

- EOS Flight Hardware Performance & Status
- EOS Data Product Status
- Climate Data Record Continuity Path Forward
  - FM5 on NPP
  - FM6 on NPOESS C1
- Summary and Selected Results of Edition3 Calibration

Edition 3 Release Details

- CERES FM1-FM4 Edition3 Radiometric Calibration Update – S. Thomas
- Edition3 Spectral Darkening Correction & Validation, Results for Terra - N. Smith
- CERES FM1-FM4 Beginning of Mission Spectral Response Functions – M. Shankar
- Establishing a common CERES Radiometric Scale – P. Szewczyk

Instrument Working Group Personnel

Science

- ***Susan Thomas*** -
Phil Hess
Suzanne Maddock
Mohan Shankar
Nitchie Smith
Peter Szewczyk
Robert Wilson

Data Management

- Denise Cooper -
- Dale Walikainen -
Lisa Coleman
Dianne Snyder
Mark Timcoe
Thomas Grepiotis
Mark Bowser

Mission Operations

- Bill Vogler -
James Bailey
Janet Daniels
Jim Donaldson
John Butler
William Edmonds

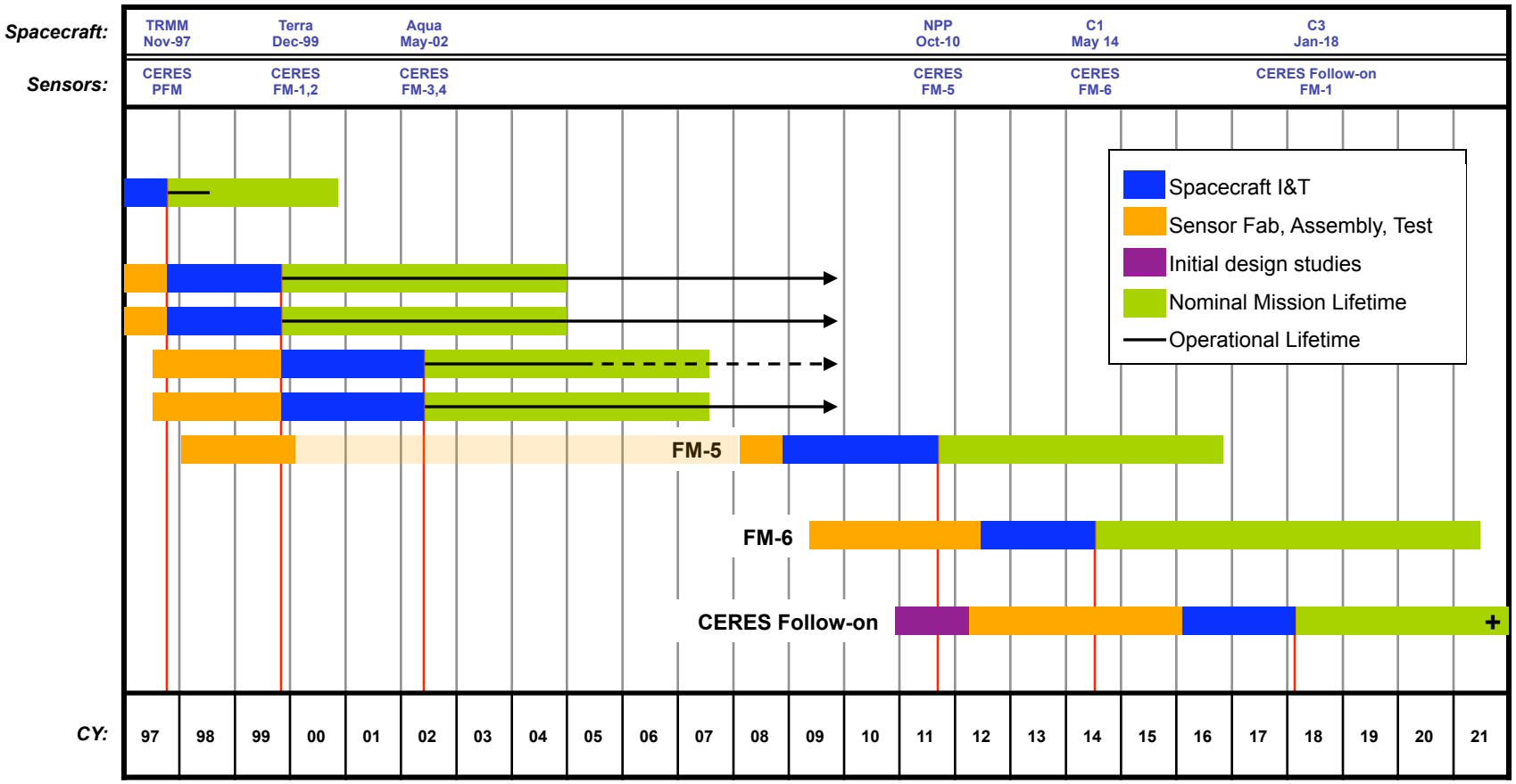
S/C Integration & Test

- Roy Zalameda -
Mike Tafazoli
Eugene Sutton
Gene Andrews

Significant increases have been necessary to implement new FM5 and FM6 work

CERES Flight Schedule

Enabling Climate Data Record Continuity



Enabling Climate Data Record Continuity

Agency Roles and Responsibilities

Mission	Instruments	Responsible Agency ($$ in budget)		Implementation	
		Hardware	*Science, Data Processing*	*Hardware*	*Science, Data Processing*
EOS	PFM-FM4	NASA	NASA	NASA Procurement	NASA Science Team
NPP	FM5	NASA/***NOAA***	NASA	NASA Procurement	NASA Science Team
NPOESS C1	FM6	***NOAA***	***NOAA***	NASA Procurement	***TBR***
NPOESS C3	CERES follow-on	***NOAA***	***NOAA***	***TBR***	***TBR***

EOS Status

CERES Operational History

With the exception of the SW channel on the CERES/Aqua FM-4 Instrument, the CERES Terra/Aqua instruments are functioning nominally…

Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	119 +
Aqua	FM3, FM4	5/02	6/02	90 +
NPP	*FM5*	*2011*	-	-
NPOESS C1	*FM6*	*January 2013*	-	-

35 + Instrument Years of Data

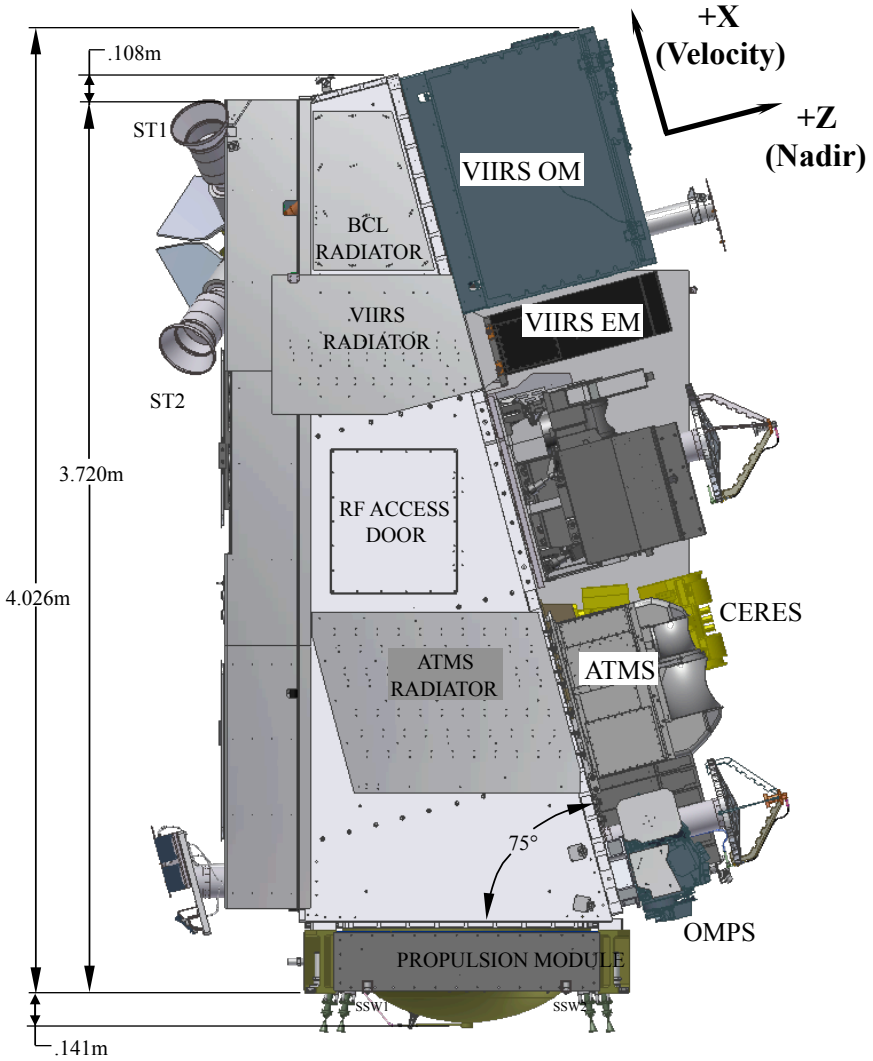
Terra/Aqua Edition2 Availability

Spacecraft	Product	Version	Available	Months Processed
TRMM	BDS	Edition1	Yes	1/98 - 8/98 , 3/00
	ERBE-Like	Edition1	Yes	1/98 - 8/98 , 3/00
		Edition2	Yes	1/98 - 8/98 , 3/00
Terra	BDS	Edition1	Yes	2/00 - present
		Edition2	Yes	2/00 - 06/09
	ERBE-like	Edition1	Yes	2/00 - present
		Edition2	Yes	2/00 - 06/09
Aqua	BDS	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 - 06/09
	ERBE-like	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 - 06/09

Note: Red text indicates months are in final validation prior to public release.

FM-5 Status

CERES Compatibility with NPP Spacecraft



Observatory Information

- Launch Readiness - NST March, 2011
- 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 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**
- **Shipped to BATC on 11/2/09**
- **Mechanical/Electrical Integration to NPP spacecraft completed 11/11/08**
  - **P12 Connector Replacement completed 1/27/09**
- **System End-to-End Test completed 2/12-26/09**
- **Ground Calibration TIM at NGST 3/26/09**
- ***Spacecraft Environmental Campaign 11/10-4/11***
- ***NPP 'Official' Launch Readiness Date is currently NST March 2011***
  - *Initial NPP launch date was mid-2006*
  - *Earliest 'feasible' launch date is October, 2011*

FM-6 Status

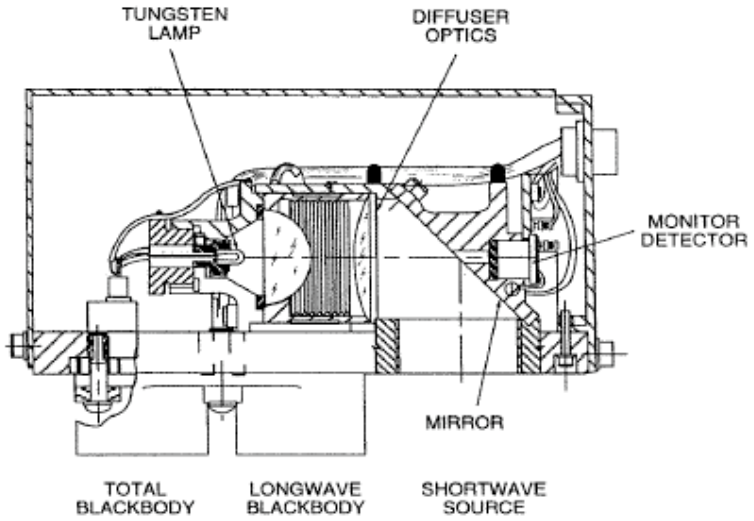
CERES FM6 Status & Near-Term Activities

- Project received ~$5M for FM6 in CY08
- Allowed for enhanced study phase only, start 11/08
  - review of legacy processes and procedures
  - Initial Spacecraft/sensor ICD development
  - *Upgraded on-board calibration equipment design studies (ASIC3 Report)*
- Long Lead item procurements authorized 3/09
- Contract negotiations completed 4/23/09
- Key Milestone Dates (Preliminary)
  - Authority To Proceed – 5/1/09
  - Systems Readiness Review – 9/22/09
  - Delta Preliminary Design Review – January 2010
  - Delta Critical Design Review – July 2010
  - Delivery – July 2012
  - Launch Readiness Date of May 2014

Legacy CERES SW Onboard Calibration Sources

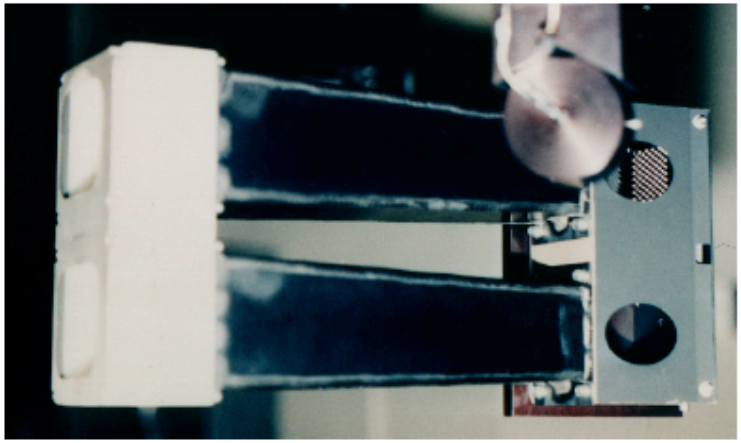
Shortwave Internal Calibration Source (SWICS)

- Evacuated Quartz tungsten lamp operated at 3 Levels (2100, 1900, 1700 K spectrums) **(Insufficient Spectral Coverage)**
- Silicon Photodiode (SiPd) reference detector ***(Failed part)***
- Design specification is +-0.5% stability over 5-years
- Designed primarily to transfer SW channel Ground Cal measurements to orbit



Mirror Attenuator Mosaic (MAM)

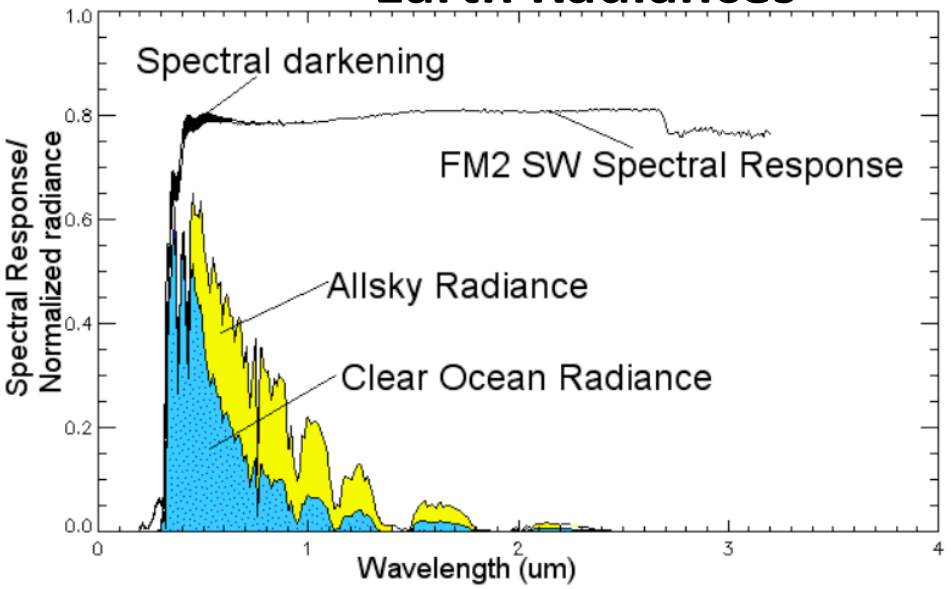
- Solar Diffuser plate attenuates direct solar view (~5800 K Spectrum)
- Nickel substrate with Aluminum coated spherical divots
- ***No independent reference detector***
- Provides a relative calibration of the Shortwave and Total channel
- Designed to provide a long-term on-orbit SW calibration source
- ***Solar Cal results to date are invalid due to large drifts in MAM surface reflectances***



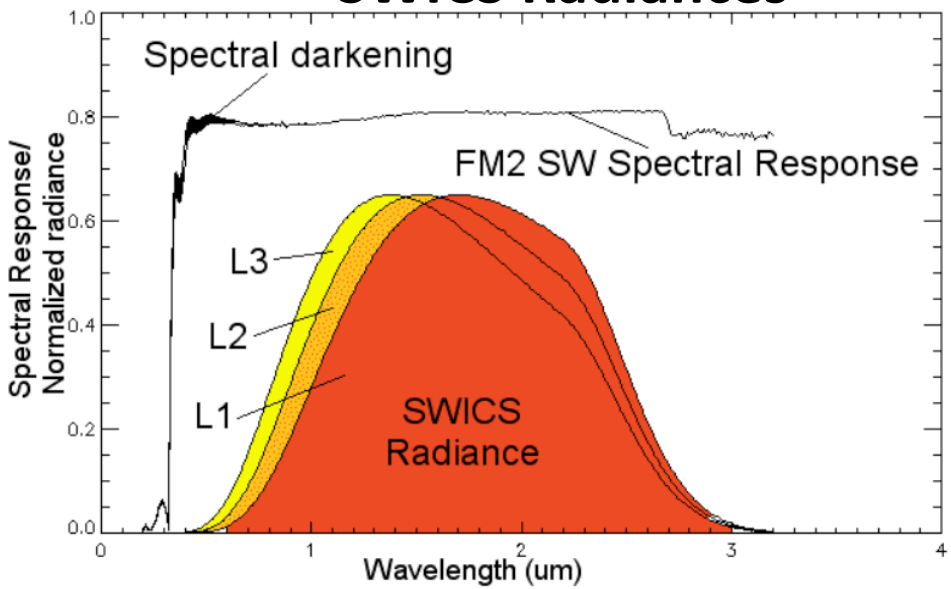
Legacy SWICS Calibration Source Spectral Content

- SWICS insensitive to blue end of CERES SW Spectral Response Function
- Significant contribution in this region from Earth scenes (e.g., clear ocean)
  - ⇒ ***Lamps cannot detect changes at shorter wavelengths***

Earth Radiances



SWICS Radiances



EOS Results

- SWICS suggested SW channels were stable to 0.1%
- Earth viewing measurements showed scene-dependent decreases
  - ⇒ Bluer scenes (clear ocean) had larger changes than white scenes (deep conv clouds)

Proposed Implementation Strategy to Address CERES/EOS Calibration Subsystem Design Weaknesses and Failures

Recommended Improvements to CERES FM6

Capability	PFM through FM-5	FM-6	Rationale for Change
Longwave /Window Channel	*8-12 micron*	5 – 100 Micron	- Risk Reduction -Improved 3-Channel Consistency Test
New Solar Calibration MAM	Surface Reflectance Instability	- Improved Coating - Enhanced Screening - **Stability Monitor**	Need for functional stability monitor
Shortwave Internal Cal Source Upgrade	Lack of sensitivity in blue region	**Addition of source in blue region**	Requirement for ability to detect changes in spectral response function.
Blackbody Temperature Range	Minimum internal blackbody set point temperature too warm (290-320 K).	Lower Internal blackbody set point temperatures to be consistent with Earth Temp's (270-320 K)	Eliminates second-order effects caused by blackbody being warmer than Earth

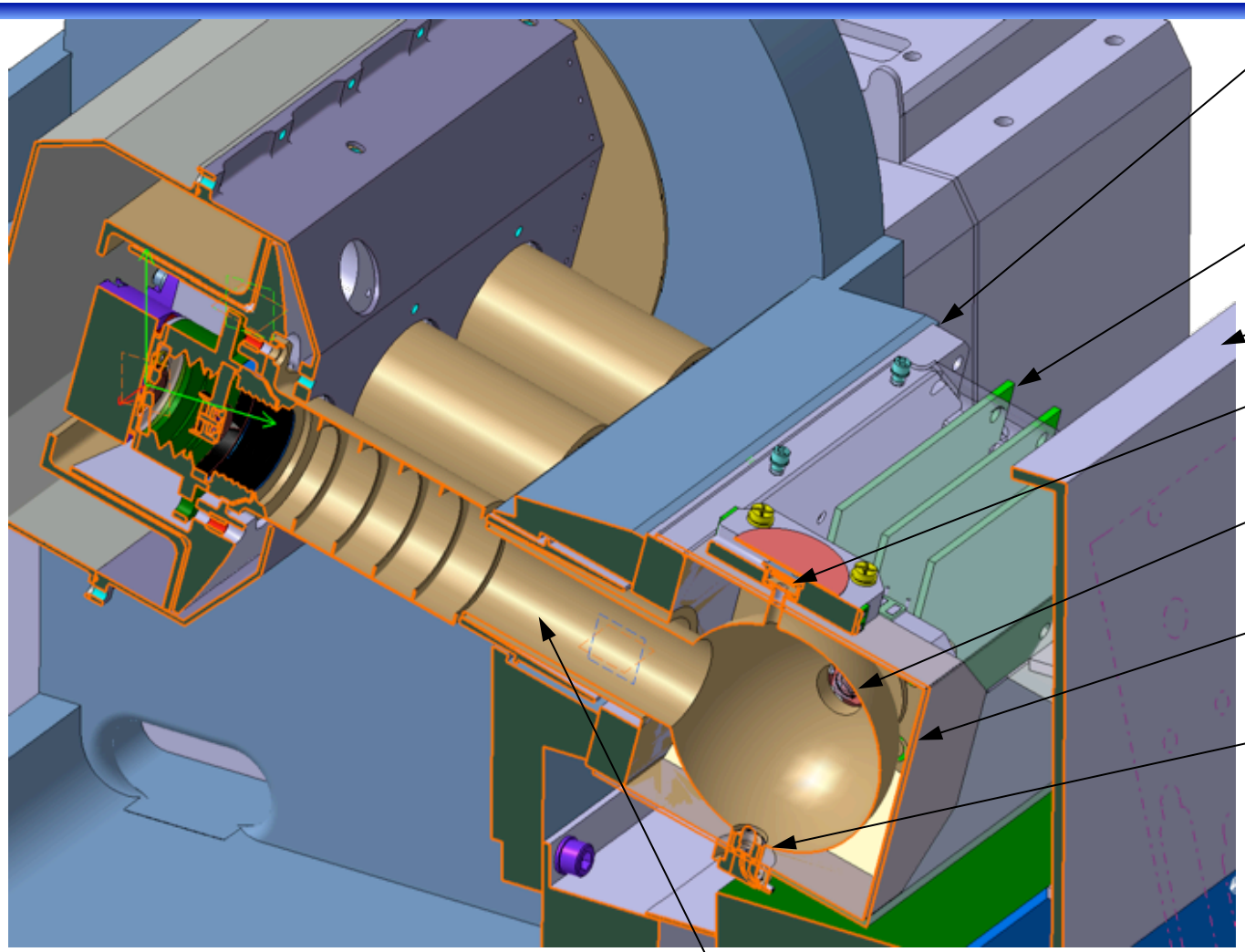
Red: Recommendation not currently funded by NOAA

Design Change - SWICS

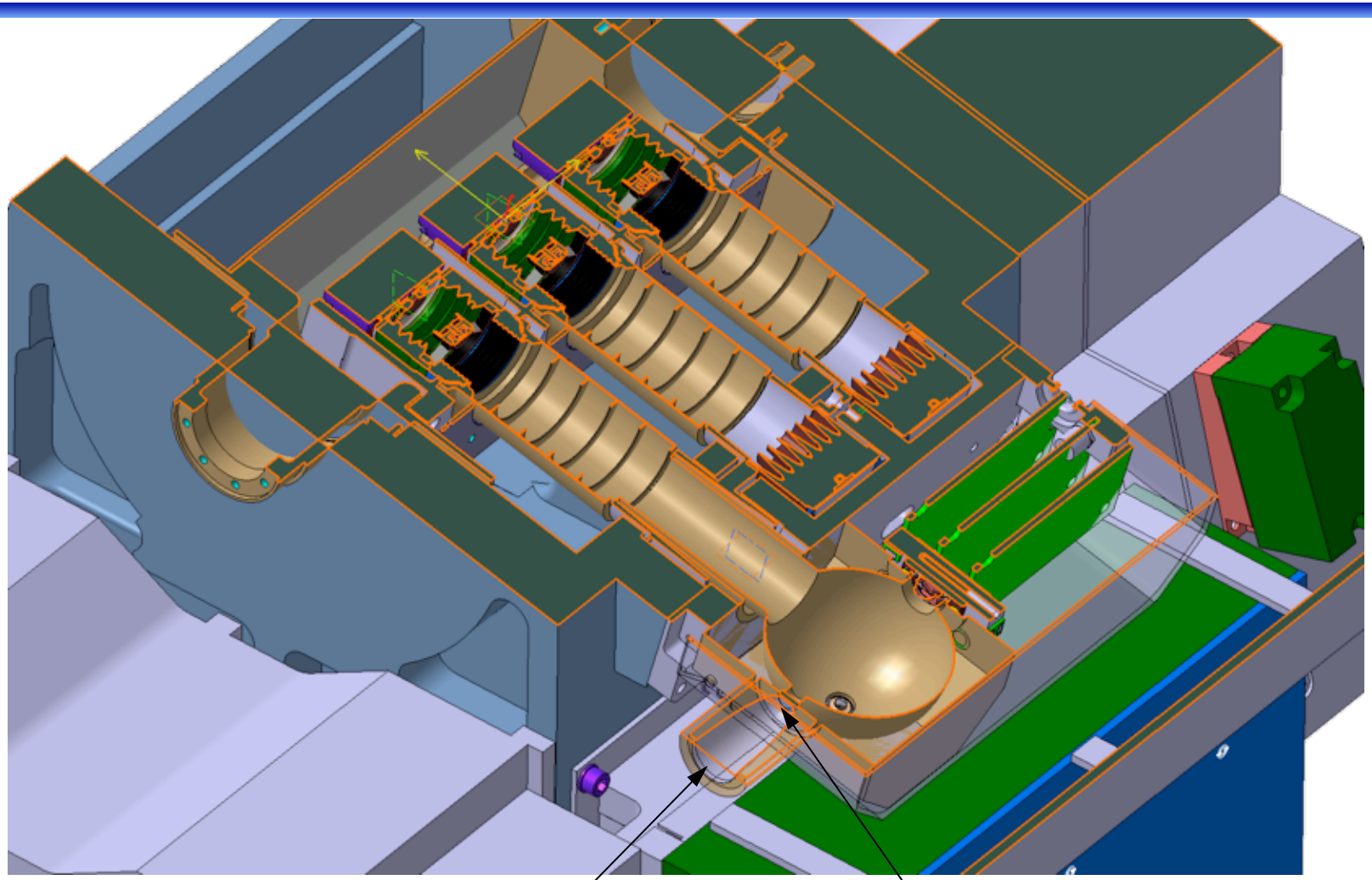
- **CERES uses a Short Wavelength In-flight Calibration Source (SWICS) to provide on-orbit traceability of the SW channel radiometric performance**
  - Heritage hardware design cannot characterize/correct for in-flight short wavelength losses in instrument observed on orbit (FM1-FM4)
    - Legacy lamp does not contain the proper spectral content to detect spectral changes
    - Reference detector failed to meet stability spec
- **FM6 SWICS Implementation Methodology**
  - Measurement requirement is a narrow band blue energy source to supplement the broadband legacy lamp output.
  - A series of trade studies and analyses to improve the SWICS performance has been completed. Northrop has proposed an improved SWICS design utilizing an integrating sphere with:
    - Blue Light Emitting Diode (LED)
    - Solar port with blue band-pass filter
    - Legacy tungsten lamp(s)
    - Functioning reference detector to provide independent check on sources

Currently Cancelled Per NOAA direction

SWICS: Integrating Sphere Design Concept



SWICS: Integrating Sphere Design Concept



Design Change – Mirror Attenuator Mosaic

- **CERES utilizes a Mirror Attenuator Mosaic (MAM) to attenuate solar irradiance allowing the sun to serve as the primary radiometric source for quantifying radiometric stability of SW and SW portion of TOT channels**
  - Changes in the MAM's effective surface reflectance of 3 to 7 percent on the CERES/EOS sensors have prevented the use of solar calibrations as a rigorous stability metric
  - Root cause of this change is two phenomena
    - Degradation of SiOx protective overcoat due to Atomic Oxygen (initial brightening)
    - Contamination on reflective surface causes decreased reflectance in blue region
- **FM6 Solar Attenuator Implementation Methodology**
  - Measurement requirement is rigorous knowledge of relative changes in the MAM's effective surface reflectance
  - Confidence in this knowledge is attained by…
    - Pre-flight verification of the hardware's stability over the life of the mission
      - Enhanced screening and acceptance/testing program
      - Specification of $Si0_2$ (as opposed to Si0x) for protective overcoat
    - Independent measurement of MAM reflectance
      - ***Implementation of stable reference detector***

Currently Cancelled Per NOAA direction

NASA Recommended Implementation

Both the MAM improvement (with reference detector) and SWICS improvement (blue source) should be implemented:

Impact

This will provide a robust onboard calibration system that can:

i) identify any changes in instrument gain;

ii) identify changes in the shortwave channel separately from the shortwave part of the total channel;

iii) provide a direct measure in the blue region to detect and correct for spectral darkening associated with molecular contamination;

iv) be able to correct for spectral degradation even if either the MAM or associated reference detector failed to meet the expected performance.

Conclusion

The improvements provide the minimal level of redundancy that *will ensure the CERES FM6 Level-1 requirements are met and rigorously verified*, given the expected operational environment.

NOAA Directed Implementation

No funding is available to implement either the MAM improvement (with reference detector) or SWICS improvement (blue source):

Impact

⇒ There will be no direct means of quantifying and correcting for expected measurement loss of sensitivity with time in the Reflected Solar Bands.

Conclusion

⇒ **High probability that CERES FM6 Level-1 requirements will not be met.**

Result

CERES Project Office (LaRC) has no choice but to move forward with the legacy EOS on-board SW calibration hardware as the baselined design for FM-6.

Discussions are ongoing to locate additional funding to implement the upgraded SW calibration sources.

Edition3 Calibration : Summary and Selected Results

CERES Unfiltered Radiance Summary

•**Cal/Val Protocol demonstrates radiometric stability of the data products through 12/2008 of….**

	Edition1_CV				Edition2				Edition2_Rev1				Edition 3			
	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4
LW_{day}	.3	.6	.4	.4	.125	.125	.3	.3	.125	.125	.15	.15	<.1	<.1	<.1	<.1
LW_{night}	.1	.125	.125	.125	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	<.1	<.1
SW	.2	.4	.4	.5	.2	.3	.3	.4	<.1	<.1	.25	.25	<.1	<.1	<.1	<.1
WN	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	<.1	<.1

Note: **Values apply to all-sky global averages**
Units are in %/yr

CERES Edition2 Calibration Summary

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**
  - **User Applied Revision developed to correct All-sky and Clear Ocean Scenes**
- **Divergence between daytime and nighttime OLR records with time.**
  - **LW_{day} = Total - Shortwave**
  - **LW_{night} = Total**

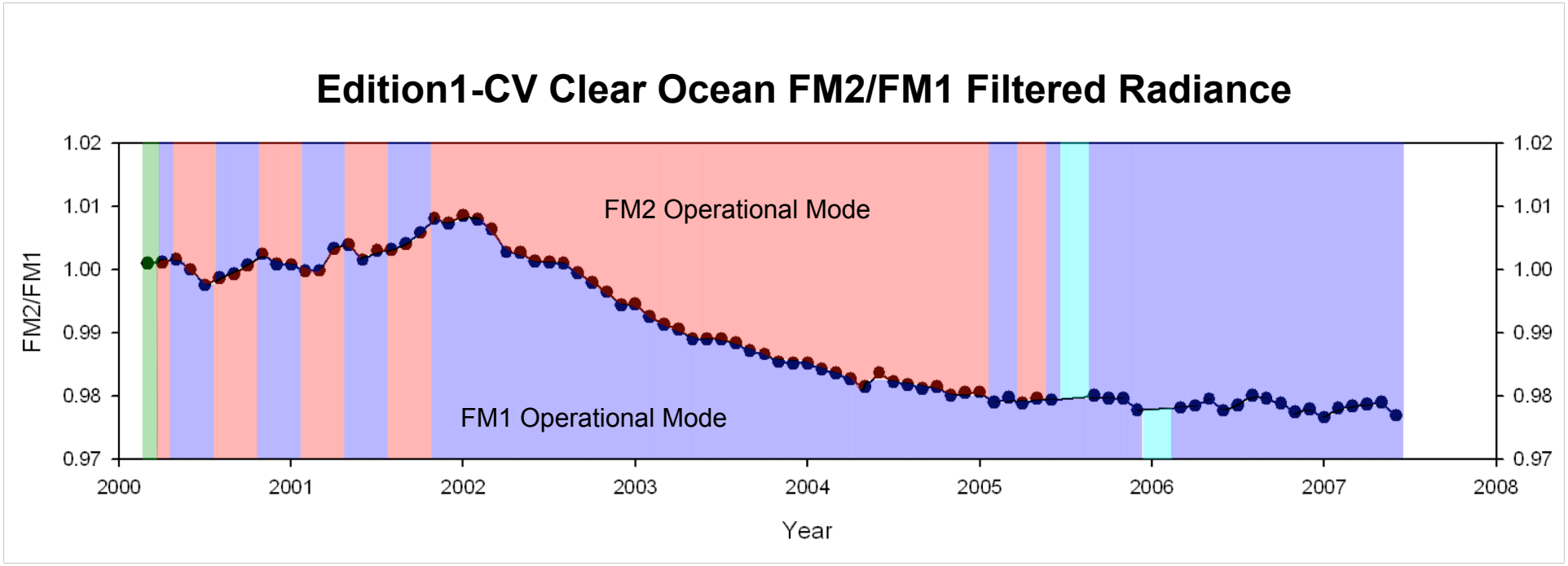
Occurs on all four CERES EOS sensors to varying degrees

Highly correlated to several factors

- **Operational Mode**
- **Solar Cycle**
- **Atomic Oxygen fluence levels**

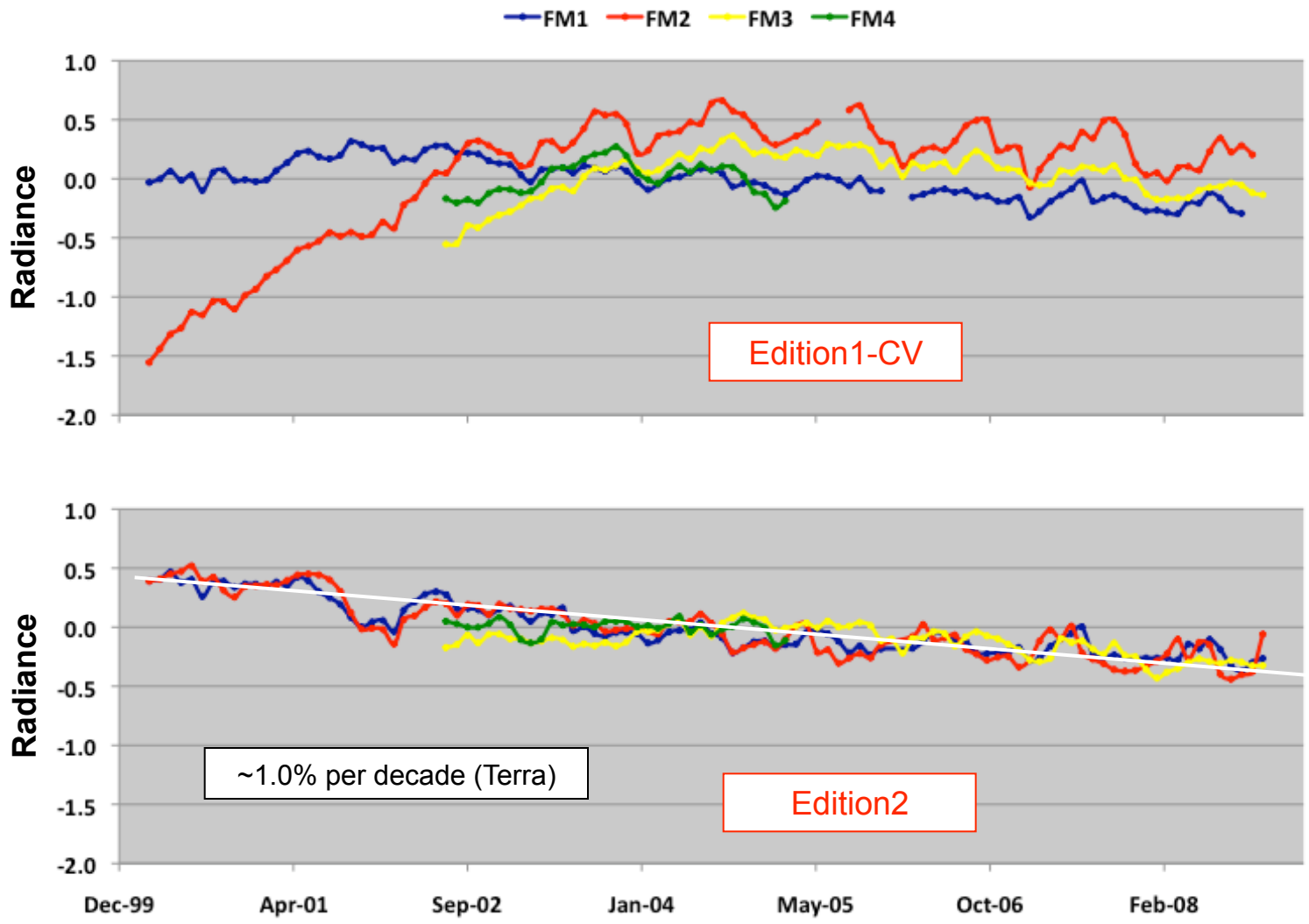
Instability of the Solar Diffusers (MAM's) and lack of adequate Spectral knowledge in the onboard SW sources greatly complicates the characterization and removal of this phenomena

Operational Mode and Direct Compare



- Bi-axial (RAPS)
- Crosstrack (FAPS)
- Stowed
- Mixed Crosstrack/Biaxial

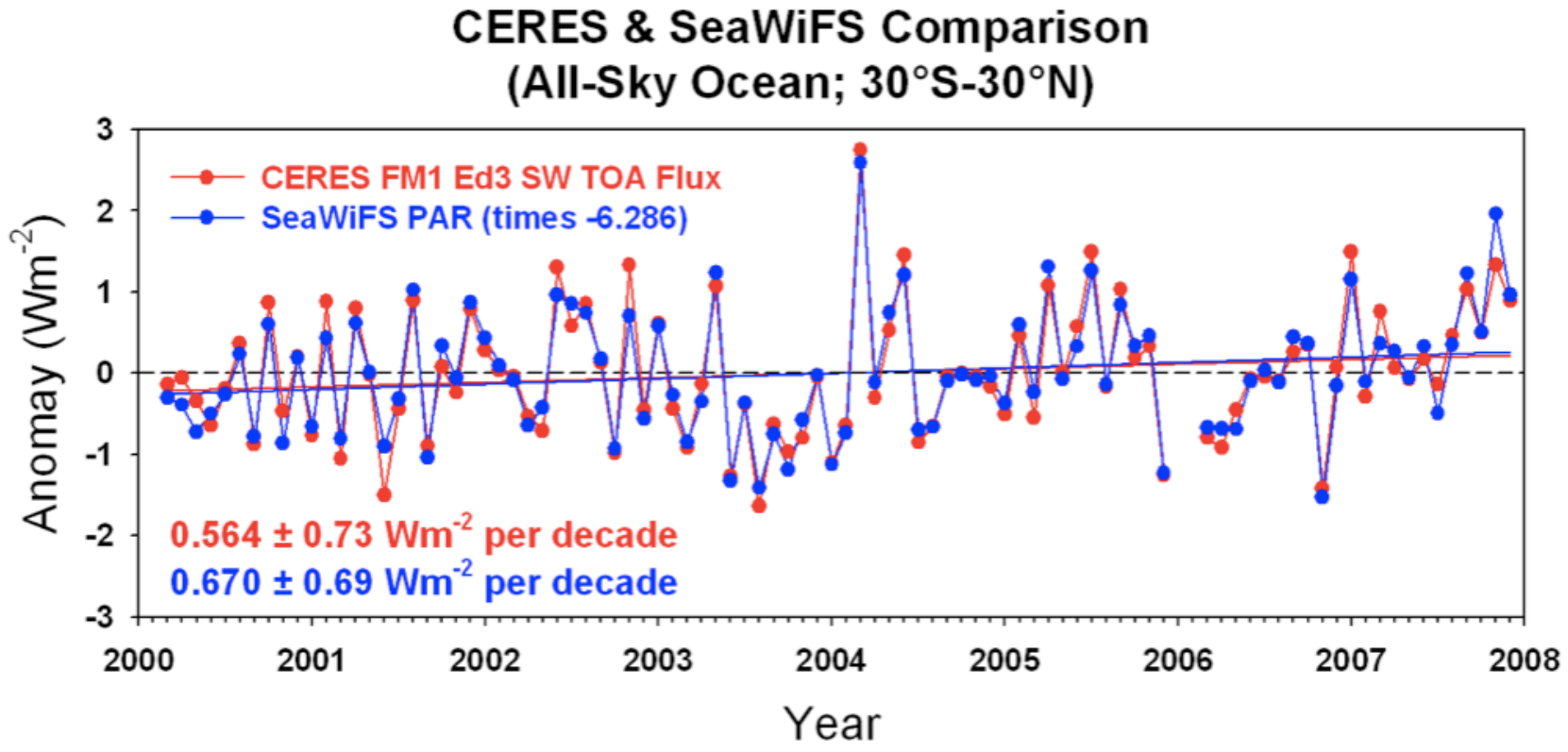
OLR Day Night Difference Trends : Tropical Mean



Data Set

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

Edition3 Validation : CERES to SeaWiFS



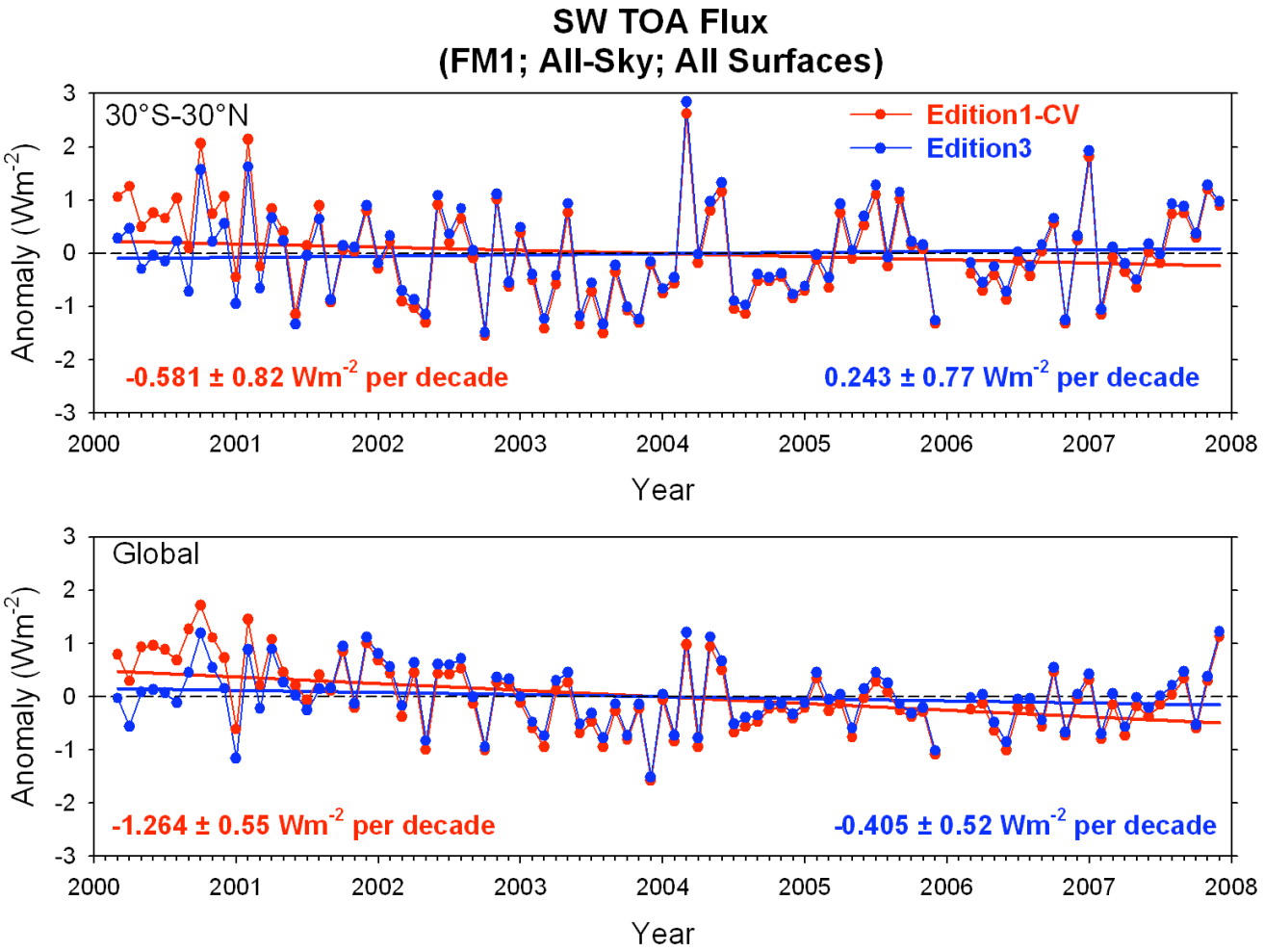
CERES Anom Minus SeaWiFS Anom: -0.106 ± 0.2 Wm^{-2} per decade

CERES Variability (1σ) = 0.79 Wm^{-2}

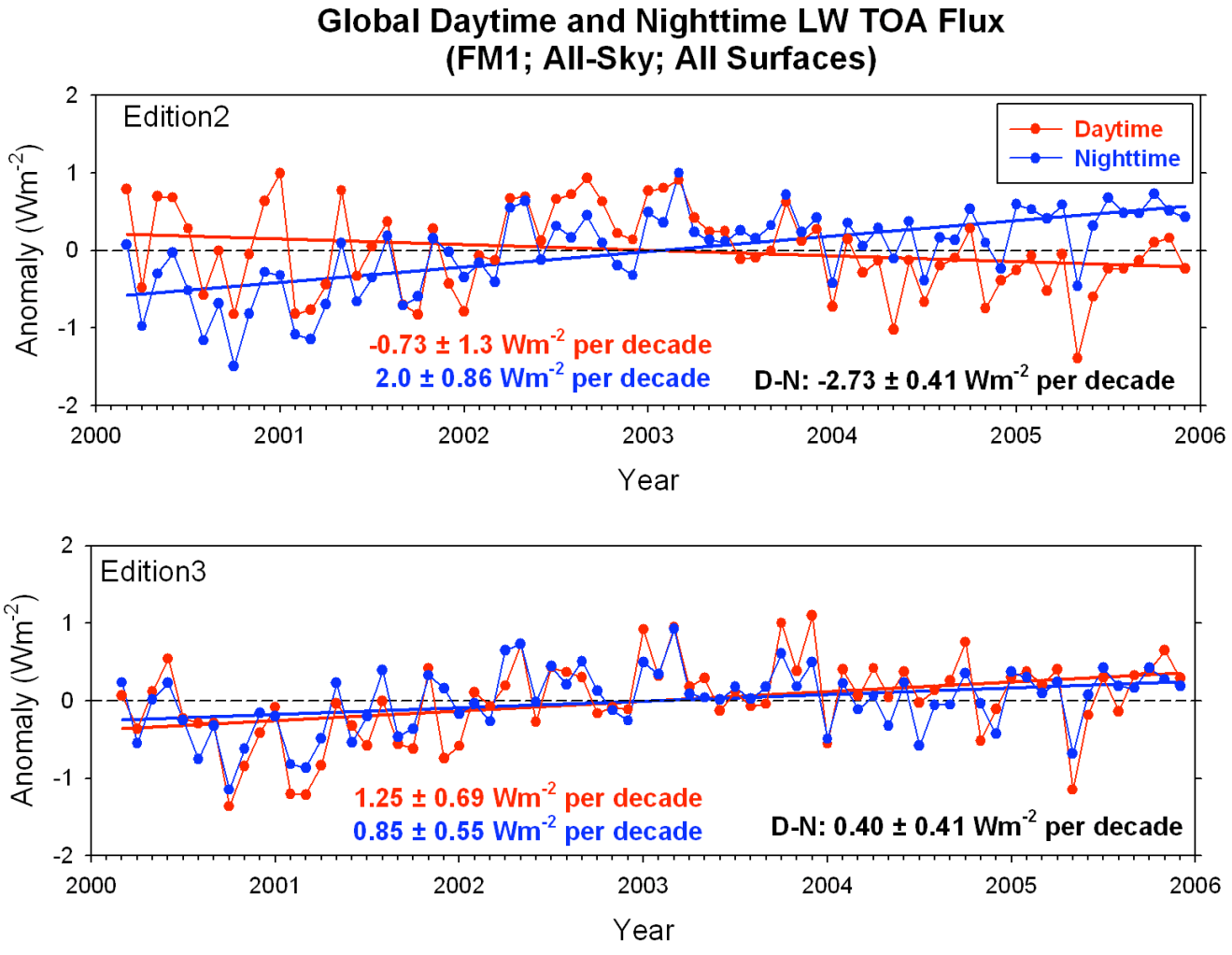
SeaWiFS Variability (1σ) = 0.76 Wm^{-2}

σ(CERES - SeaWiFS) = 0.21 Wm^{-2}

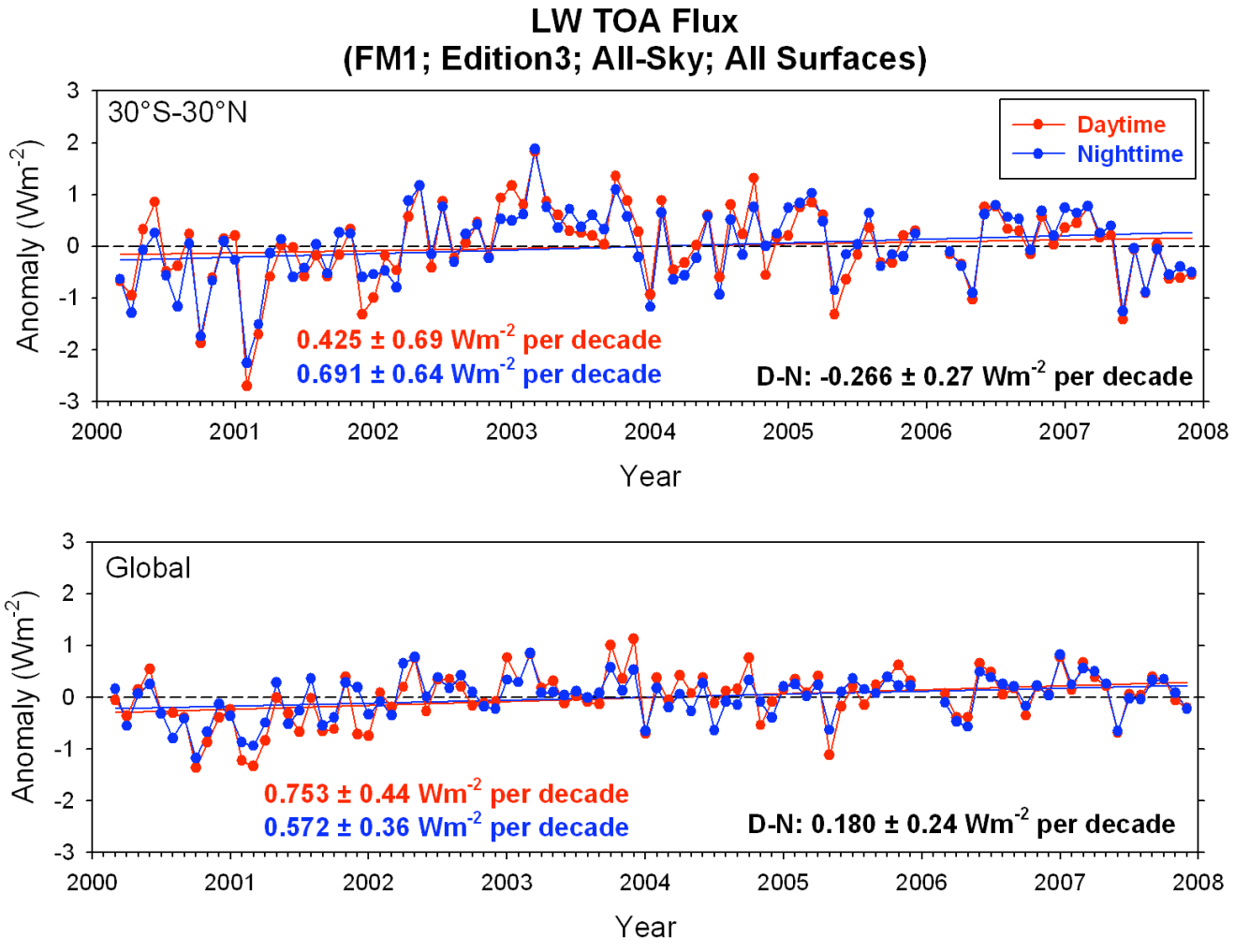
Edition3 Validation : SW TOA Flux



Edition 2 & 3 Day Night Comparison : LW TOA Flux



Edition3 Validation : LW TOA Flux



Back-Up Slides

Radiometric Performance Requirements

CERES is defined as a class 'B' Mission

5-year design Lifetime

Spectral Regions	Solar		Terrestrial		Atmospheric Window
Wavelengths	0.3 - 5.0 μm		5.0 - 200 μm		8 - 12 μm
Scene levels	<100 w/m^2-sr	>100 w/m^2-sr	<100 w/m^2-sr	>100 w/m^2-sr	All Levels
Accuracy Requirements	0.8 w/m^2-sr	1.0 %	0.8 w/m^2-sr	0.5 %	0.3 w/m^2-sr
SOW Stability Requirements		< 0.14%/yr		< 0.1%/yr	
Climate Stability Goals		< 0.6 w/m^2/dec < 0.03 %/yr		< 0.2 w/m^2/dec < 0.02%/yr	

- **Requirements for CERES are more stringent than ERBE's by a factor of 2**
- **Requirements per Ohring et. al. are more stringent than CERES by a factor of 3-5**

Calibrate, Calibrate, Calibrate….

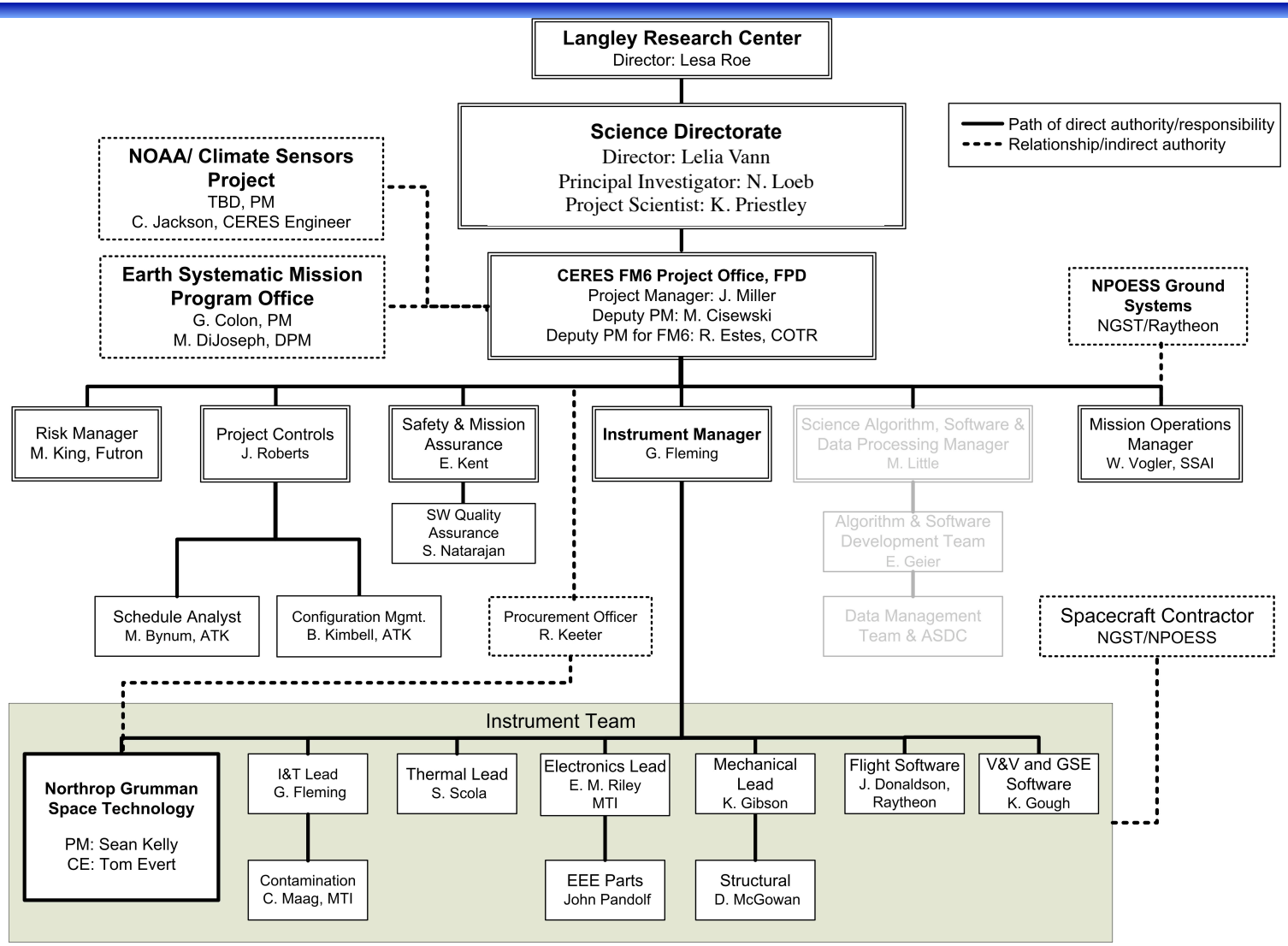
Path to ERB CDR Continuity

Capability	FM-5	FM-6	CERES Follow-on
Lineage	As-Built	Build to Print, with modest upgrades, Technology Bridge	New Design
Flight Software	Bug fixes, minimal functionality improvements	Bug fixes, minimal functionality improvements	Bug fixes, Full functionality improvements
New Solar Calibration MAM		Yes + enhanced screening	Yes + enhanced screening
Shortwave Internal Cal Source Upgrade*		Minimal Spectral Capability	Multi-spectral Capability
Replace 8-12 μm Channel		5 - 100 Micron	5 - 100 Micron
New Detectors			Yes
"10 km" FOV*			Yes
Ground Calibration	Re-verify sources, revisit procedure	Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW	Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW

* 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 FM6 Project Organization



Achieving Satellite Instrument Calibration for Climate Change (ASIC^3)

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

Contributors

James G. Anderson	Philip Ardanuy	Gail Bingham
James Butler	Changyong Cao	Raju Datla
John Dykema	William Emery	Lawrence Flynn
Gerald Fraser	Mitchell Goldberg	Greg Kopp
Toshio Iguchi	David Kunkee	Stephen Leroy
Laury Miller	David Pollock	Hank Revercomb
Scott Shipley	Karen St. Germain	Tom Stone
Joe Tansock	Alan Thurgood	David Tobin
Stephen Ungar	Bruce Wielicki	David Winker
Jack Xiong	Fuzhong Weng	

June 2007

ASIC^3 (2006) Workshop Recommendations

- Partially ***redundant on-board calibrations*** to improve knowledge of instrument stability. Improvements are needed in broadband MAM or diffuser designs to meet the new climate stability requirements.

- More ***careful attention be paid to potential contamination of optical surfaces*** for climate instruments during ground testing, as well as improving the technologies for measuring and correcting any potential contamination.

- Flight of the CERES FM-5 instrument use only the crosstrack scan mode to avoid in-orbit contamination of the SW channel optics. ***We also recommend that future calibration observatories in space be designed to explicitly account for expected in-orbit contamination***, even if its level is small.

- ***Future broadband instruments should examine the potential for 0.3 to 0.5 μm sources*** such as small nonlinear optics lasers to explicitly monitor throughput below 0.5 μm. This issue appears to exist for all instruments measuring solar radiation with wavelengths below 0.5 μm and should be accounted for in calibration system design.