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

NASA Langley Research Center

Atmospheric SCIENCES

Instrument Working Group Personnel

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 Edmonds

S/C Integration & Test

- Roy Zalameda -
Mike Tafazoli
Eugene Sutton
Gene Andrews

Significant increases were necessary to implement new FM5 and FM6 work

Instrument Working Group Personnel - latest addition

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

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 - 12/07
	ERBE-like	Edition1	Yes	2/00 - present
		Edition2	Yes	2/00 - 12/07
Aqua	BDS	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 - 12/07
	ERBE-like	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 - 12/07

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

CERES Flight Schedule

Enabling Climate Data Record Continuity

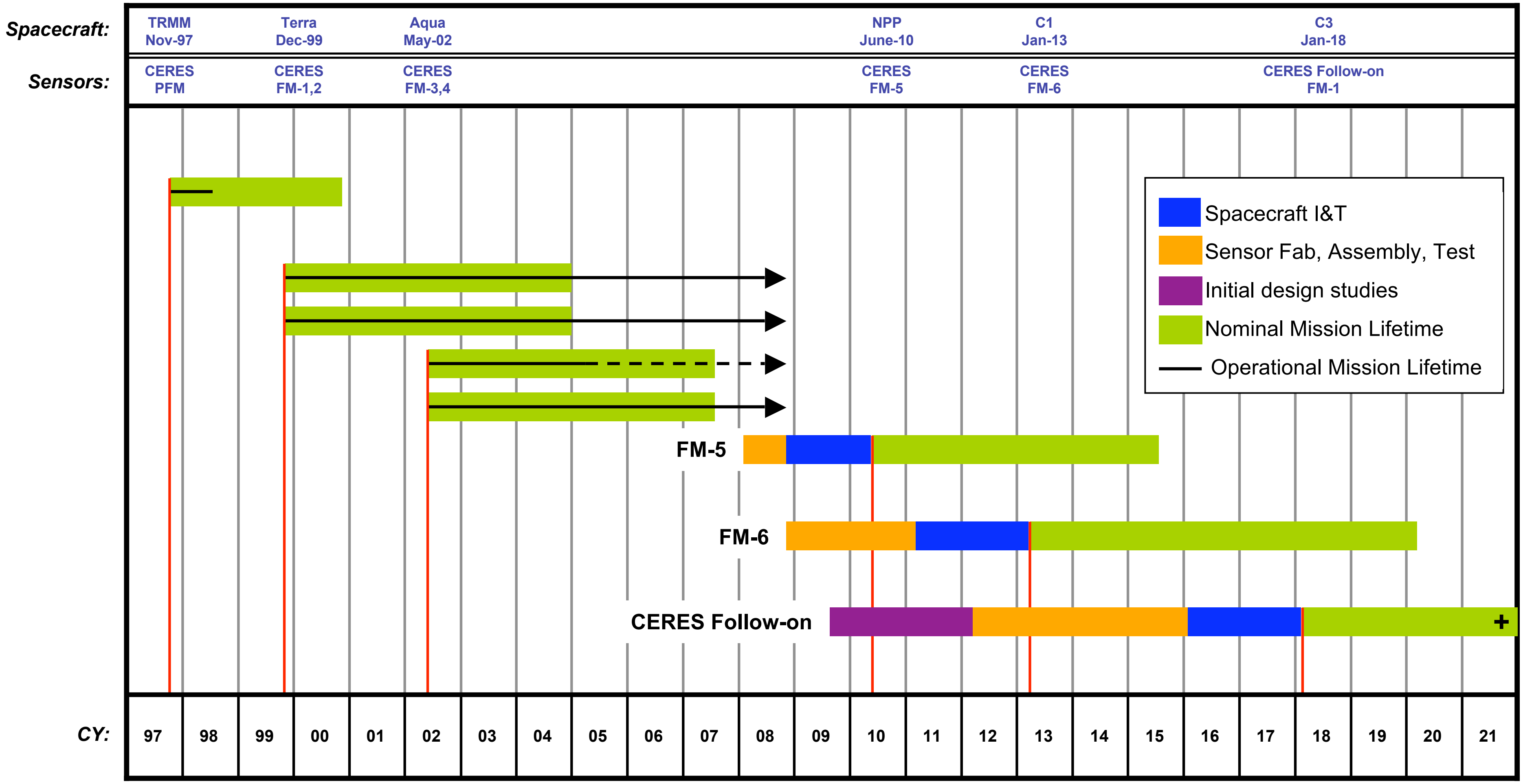
Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	98 +
Aqua	FM3, FM4	5/02	6/02	71 +
NPP	FM5	June 2010	-	-
NPOESS C1	***FM6***	***January 2013***	-	-
NPOESS C3	***CERES follow-on***	***January 2018***	-	-

31 Instrument Years of Data

CERES Flight Schedule

CERES

Enabling Climate Data Record Continuity



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

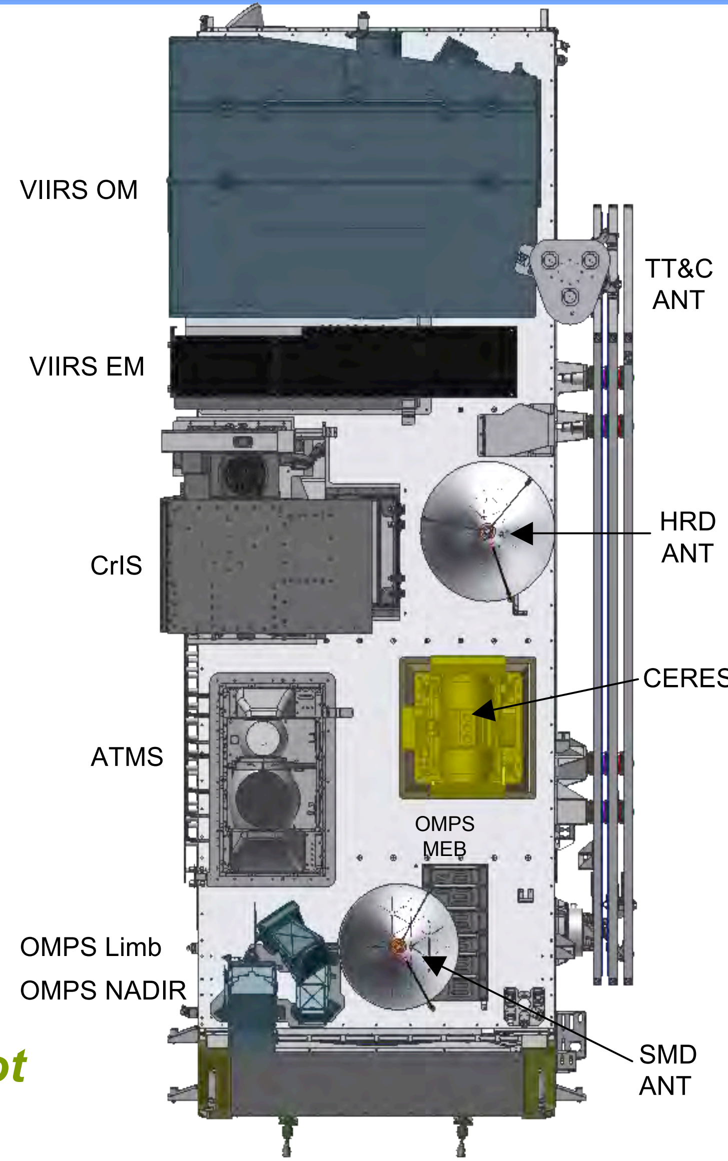
* Updated shortwave requirements based on improved understanding of reflected spectrum from CERES experience

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

CERES Authorized for Flight on NPP

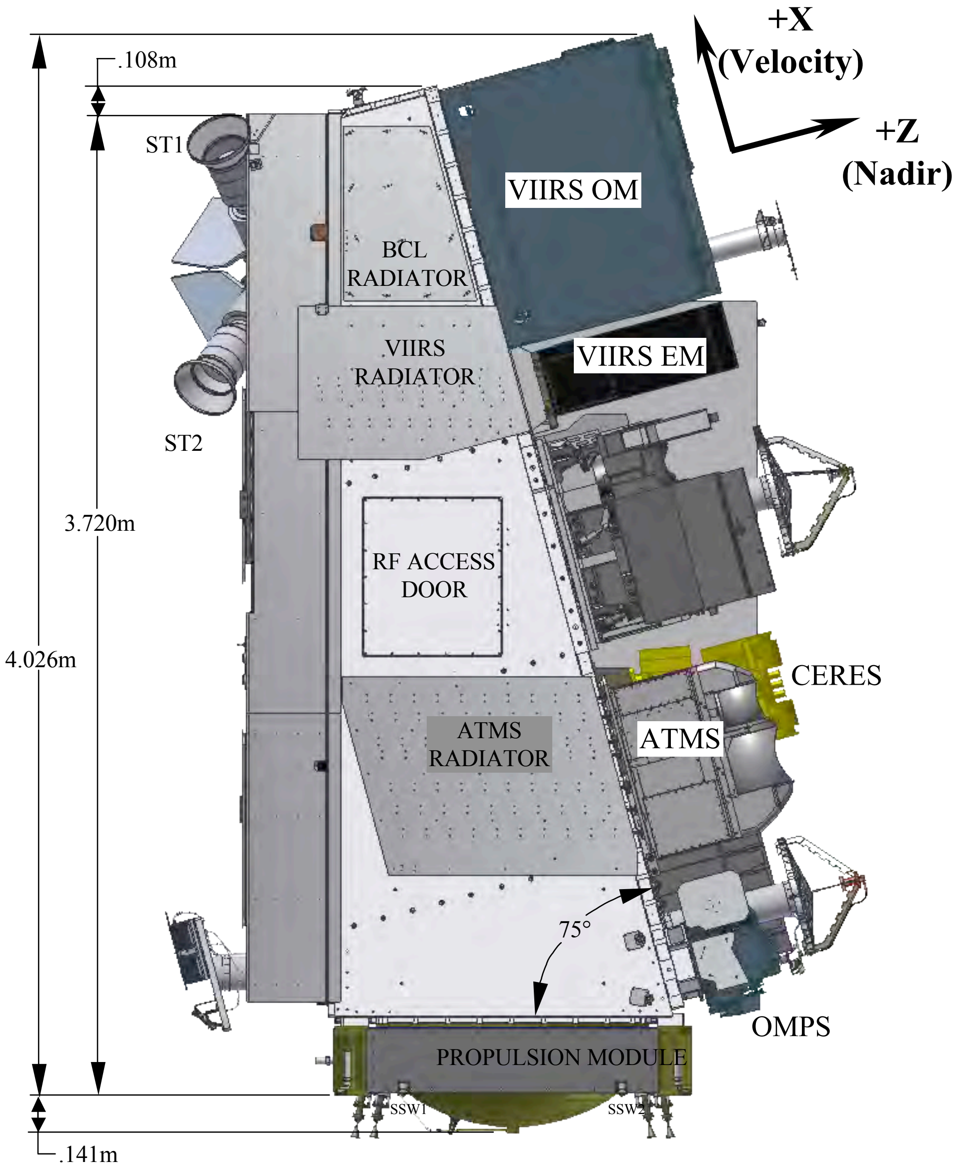
NASA HQ authorized multi-phase study in 2007 to assess feasibility of adding CERES back on NPP

- **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

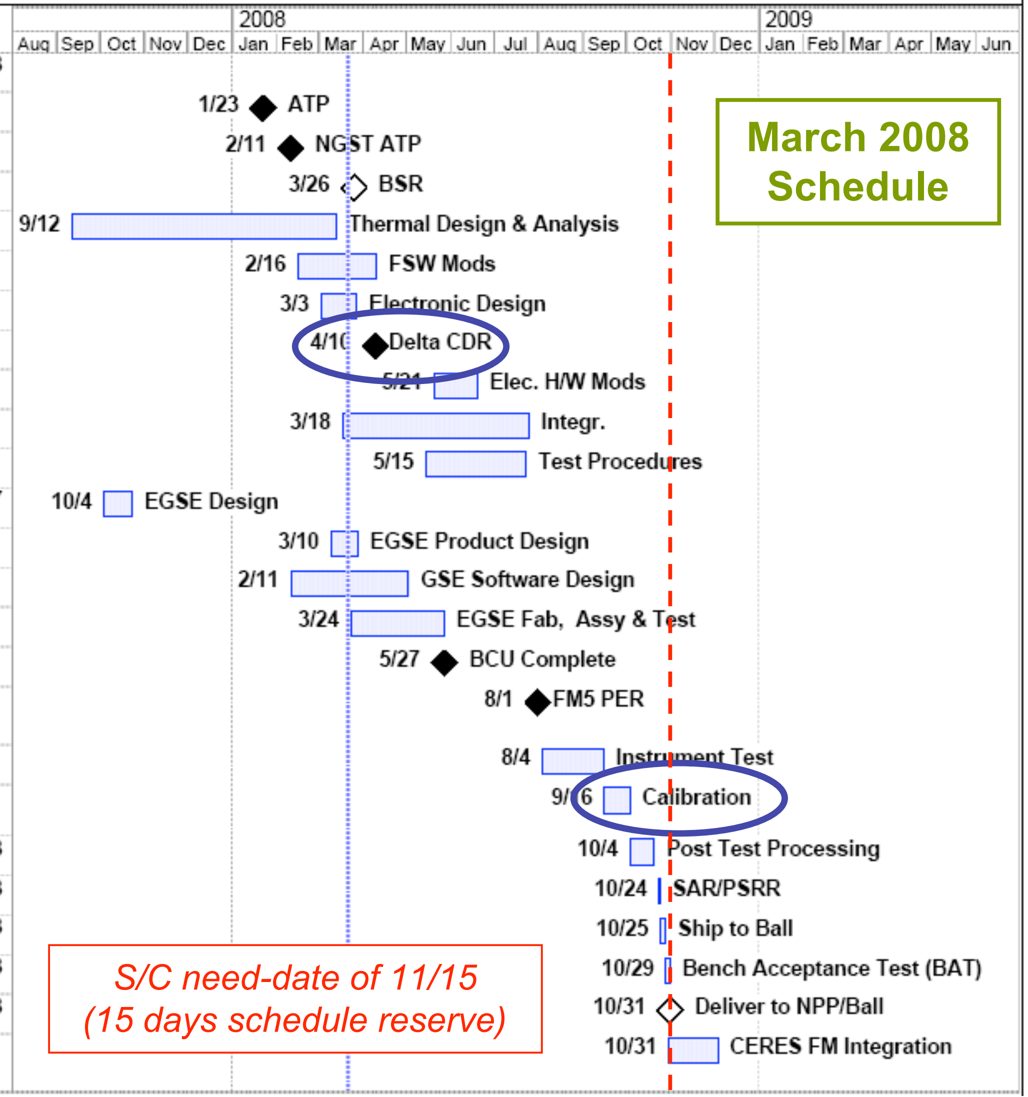


Observatory Information

- 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

ID	UID	IMS UID	Task Name	Dur	Start	Finish
332	4833	6	CERES FM5 Refurbishment	287 d	9/12/07	10/31/08
333	5050	LaRC	ATP	0 d	1/23/08	1/23/08
334	5049	NGST	NGST ATP	0 d	2/11/08	2/11/08
335	5058	LaRC	Baseline Status Review	0 d	3/26/08	3/26/08
336	5060	472	Thermal Design & Analysis	123 d	9/12/07	3/13/08
359	5069	309,510	Flight Software Mods	39 d	2/16/08	4/10/08
370	5064	313	Electronic Design	19 d	3/3/08	3/27/08
378	5055	485	FM5 Delta CDR	1 d	4/10/08	4/10/08
380	4871	15	Electronics Hardware Modifications	21 d	5/21/08	6/19/08
385	4872	361(part)	FM5 Instrument Integration	92 d	3/18/08	7/25/08
398	5070	370	Test Procedures	48 d	5/15/08	7/23/08
399	5078	335	EGSE Design	14 d	10/4/07	10/23/07
400	5079	338	EGSE Product Design	15 d	3/10/08	3/28/08
401	5080	450	GSE Software Design	60 d	2/11/08	5/2/08
402	5081	346,444	EGSE Fab, Assy & Test	46 d	3/24/08	5/27/08
403	5082	444	BCU Complete	0 d	5/27/08	5/27/08
404	4848	416	Conduct FM5 Pre-Environmental Review (PER)	2 d	8/1/08	8/2/08
405	5089	sum	Instrument Env. Test	30 d	8/4/08	9/15/08
415	4875	398	**FM5 Calibration (7d/wk)**	**18 d**	**9/16/08**	**10/3/08**
419	5088	sum	Post Test Processing	17 d	10/4/08	10/20/08
427	4864	39	Pre-Ship Readiness Review (PSRR)	1 d	10/24/08	10/24/08
428	4866	411	FM5 Transport Time to Ball	3 d	10/25/08	10/28/08
429	4867	31	Ball Bench Acceptance Test (BAT)	3 d	10/29/08	10/31/08
430	5083		Deliver to NPP/Ball	0 d	10/31/08	10/31/08
854	4595	591	CERES FM - On the Hook & Integration	22 d	10/31/08	12/3/08



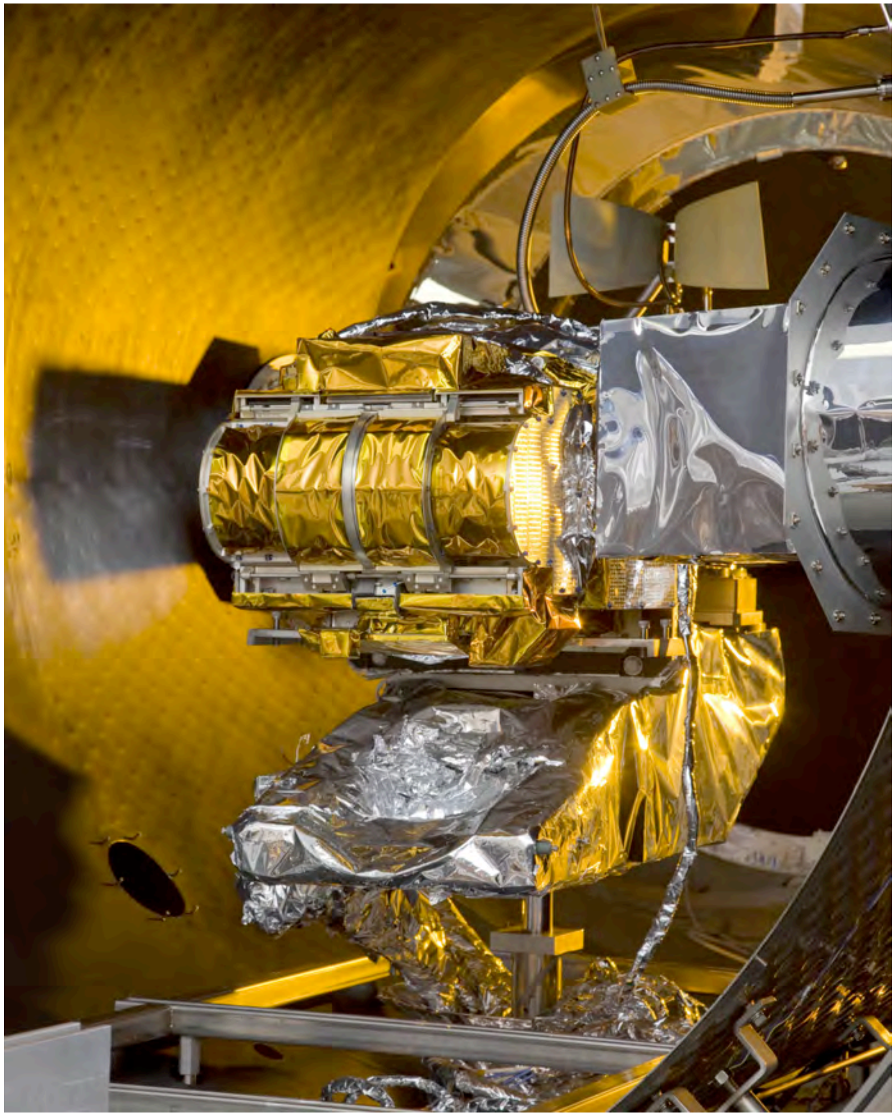
~ FM-5 Instrument will be delivered on 11/7, a week ahead of schedule ~

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 Complete

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

Path to ERB CDR Continuity

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* Updated shortwave requirements based on improved understanding of reflected spectrum from CERES experience

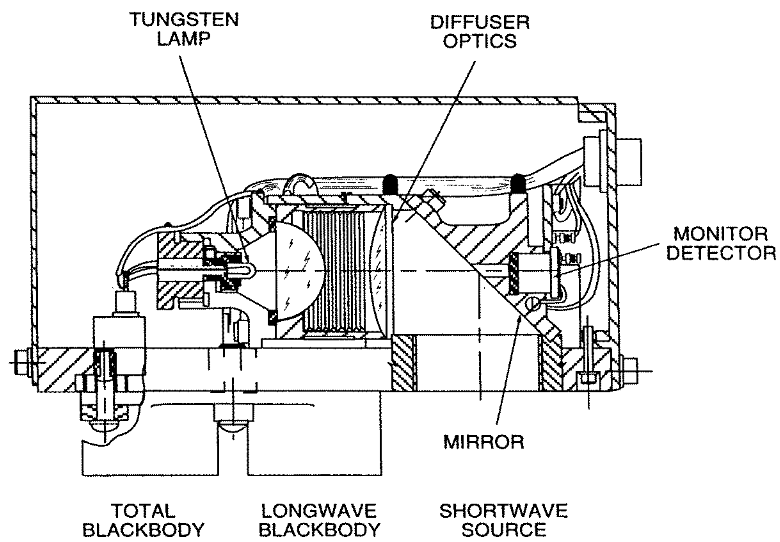
** Nominal improved FOV, final requirement set as part of CERES follow-on instrument study

CERES FM6 Status & Near-Term Activities

- 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

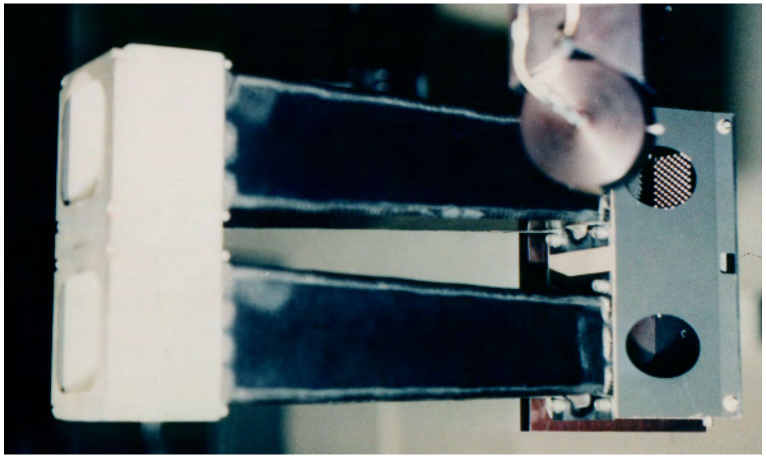
CERES FM6 Onboard SW Calibration Equipment

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

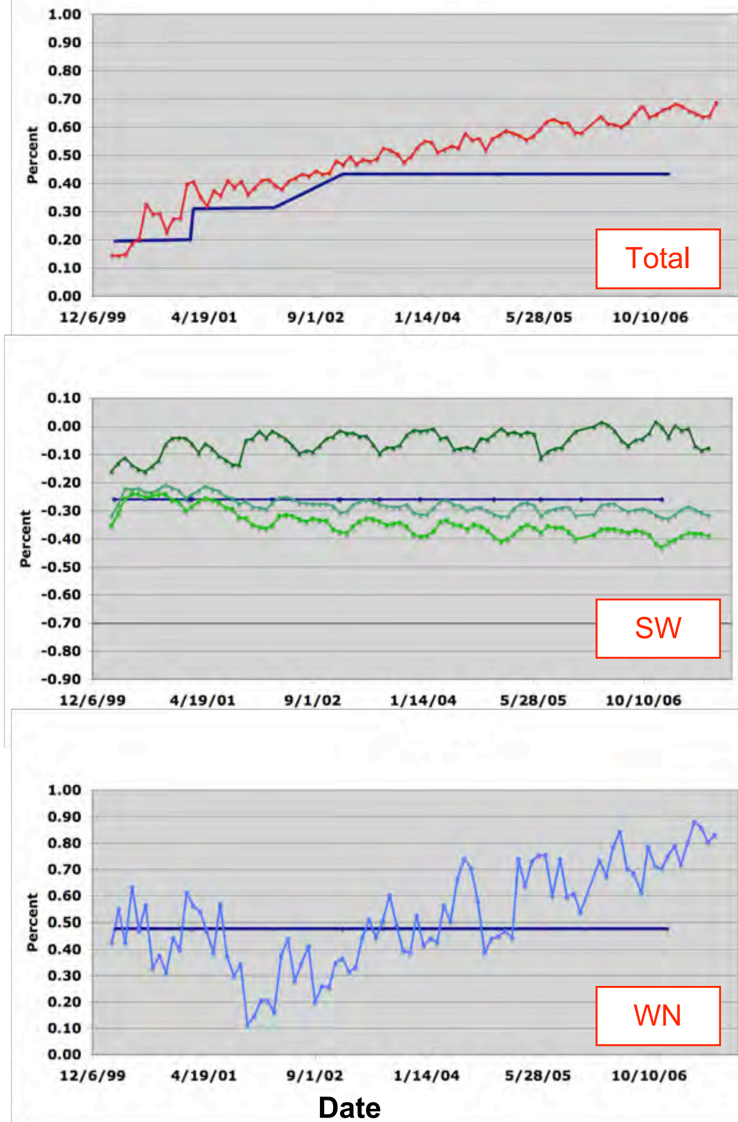
- Beta Angle
- Earth Sun Distance
- Orbital shifts
- Instrument Operational modes (I.e RAPS vs. Xtrack)

Complicates separation of instrument 'artifacts' from natural variability.

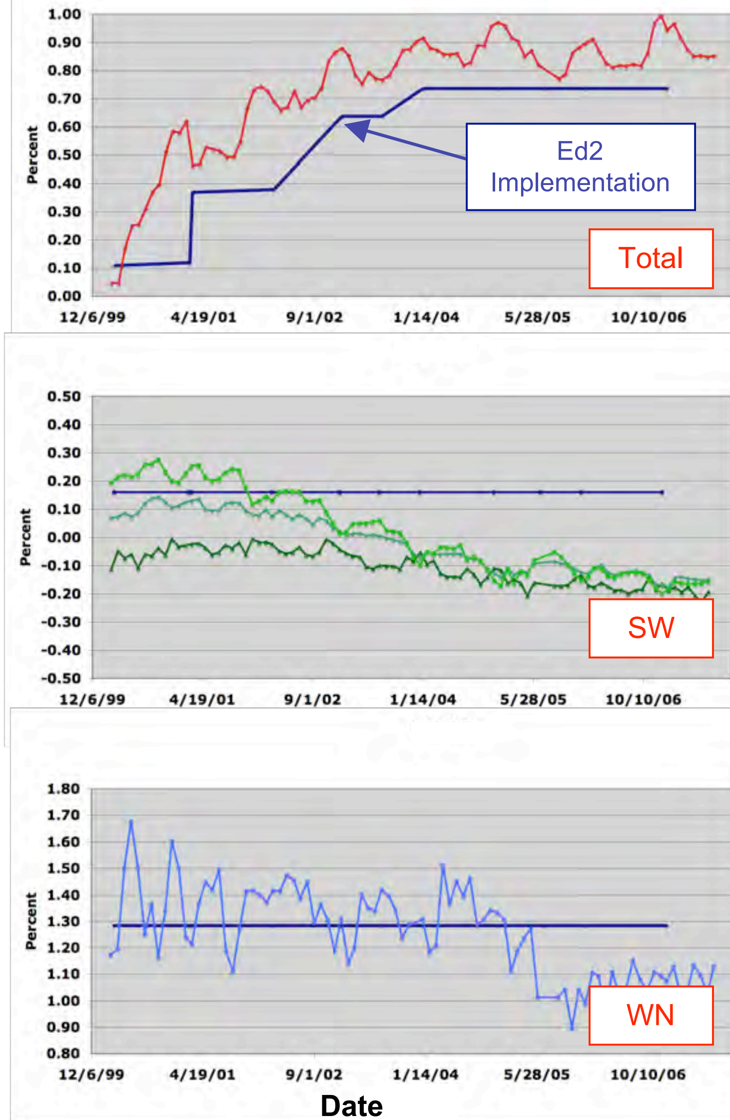
Edition3 reprocessing of the first 5 years of CERES radiances allows a much more rigorous identification and separation of instrument artifacts and true climate signals.

Terra Monthly Average ICM Results

FM1

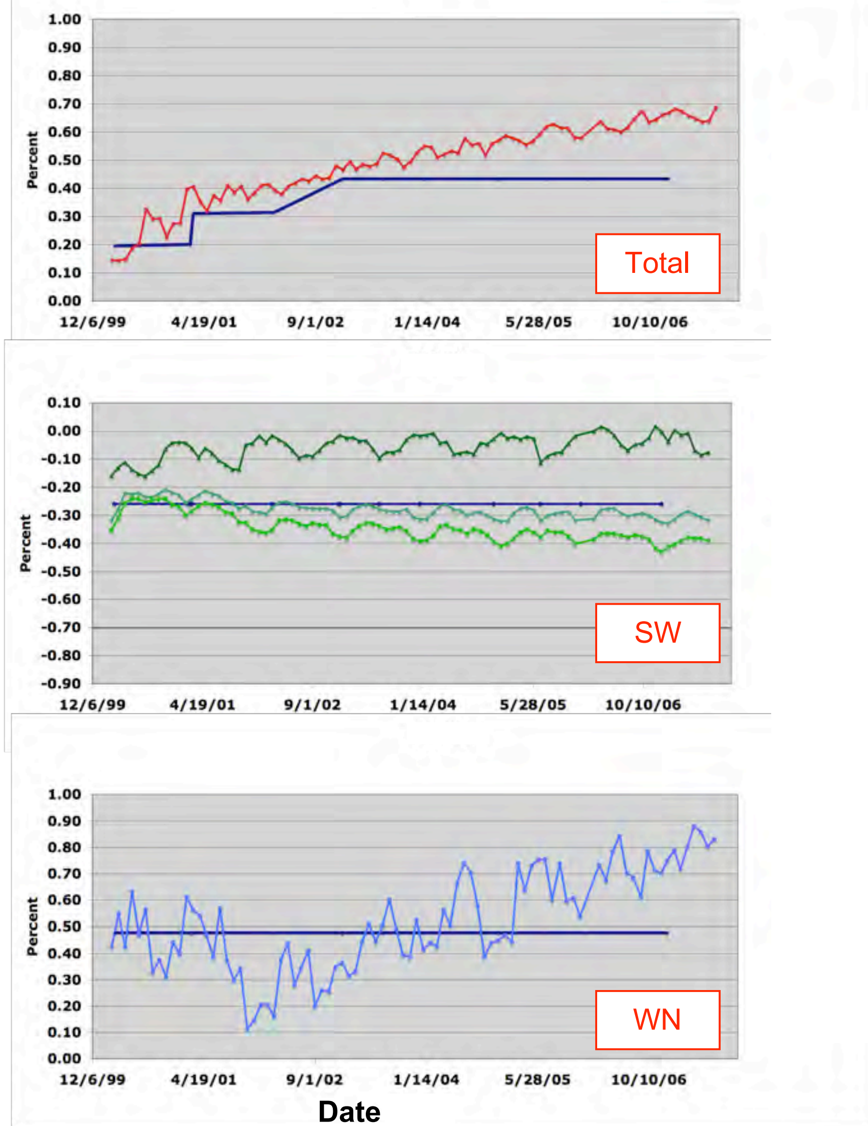


FM2

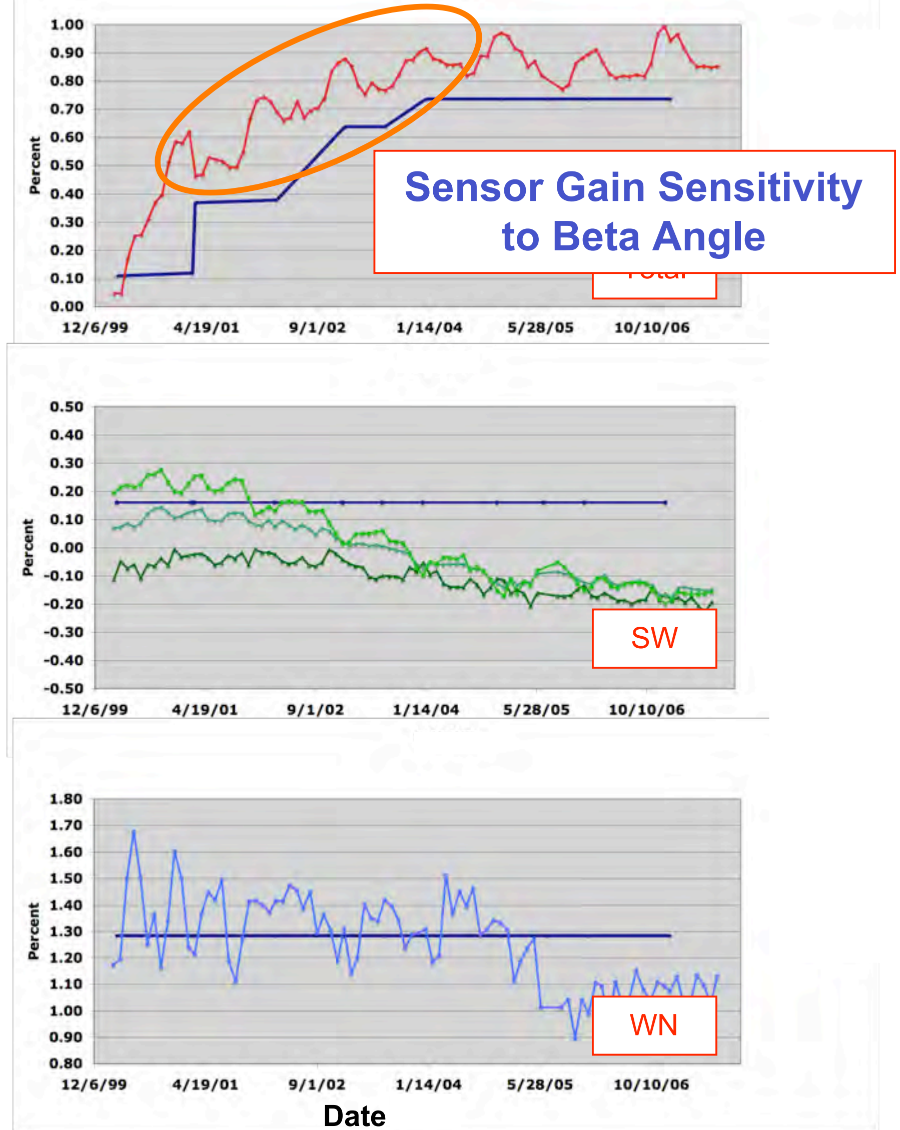


Terra Monthly Average ICM Results

FM1

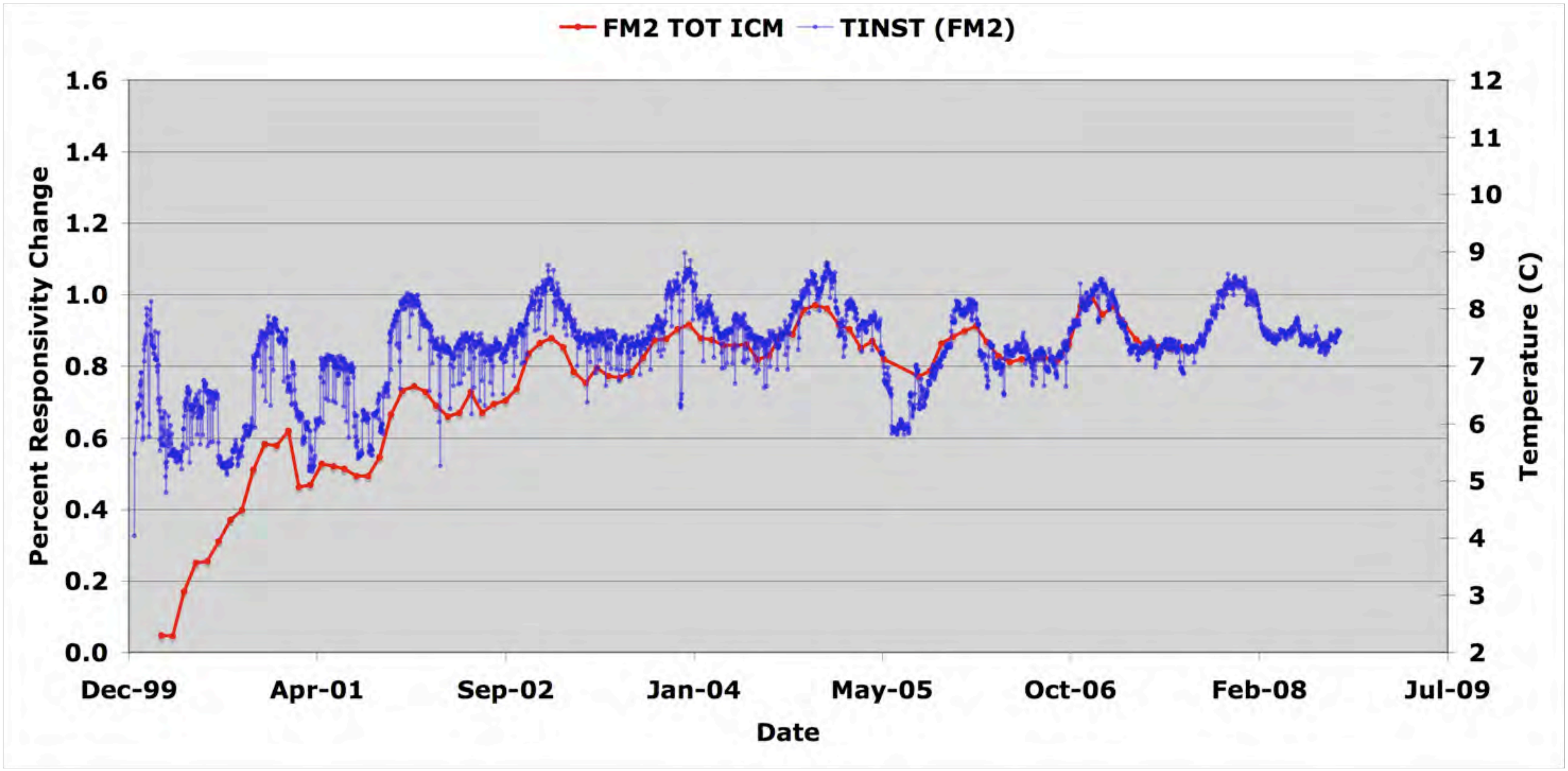


FM2



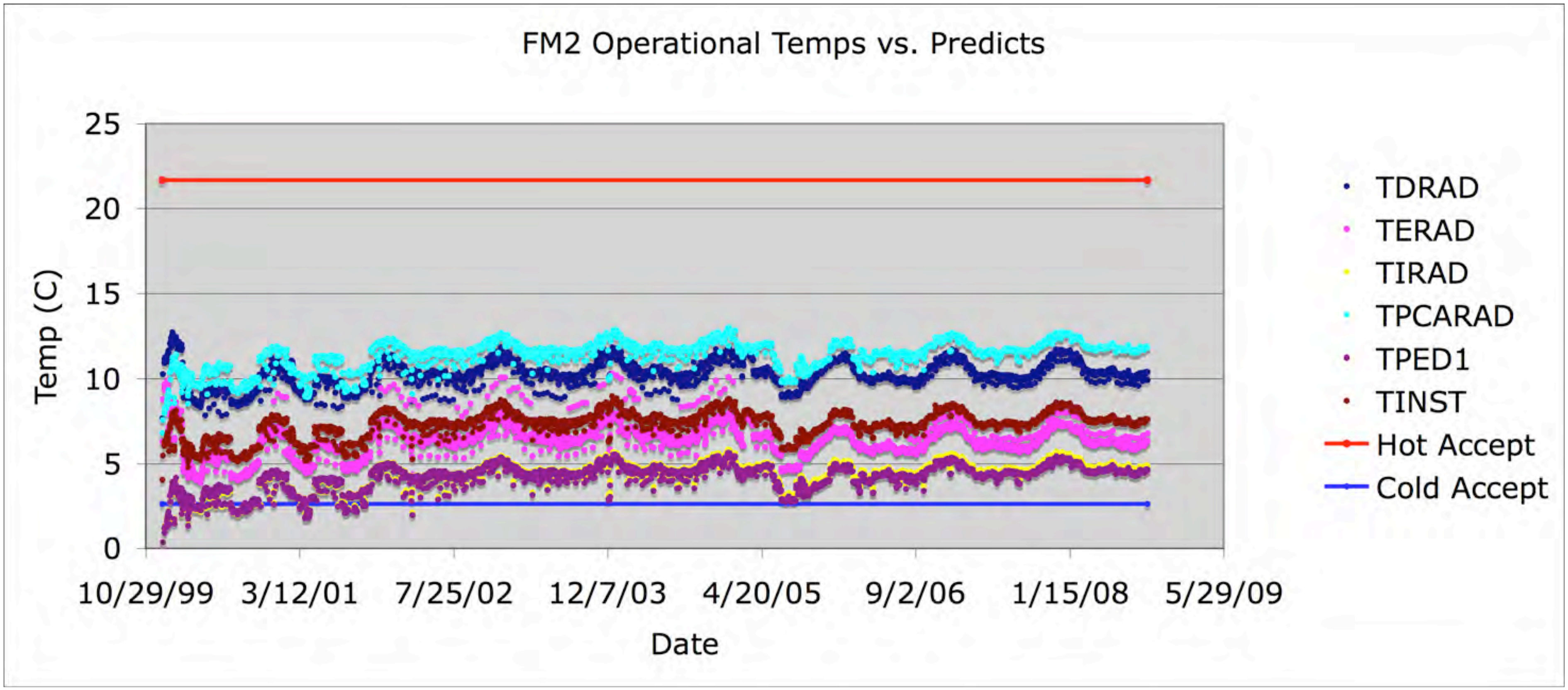
FM2 Total Channel Monthly Average ICM Results

Sensor Responsivity is highly correlated with instrument operating temperature



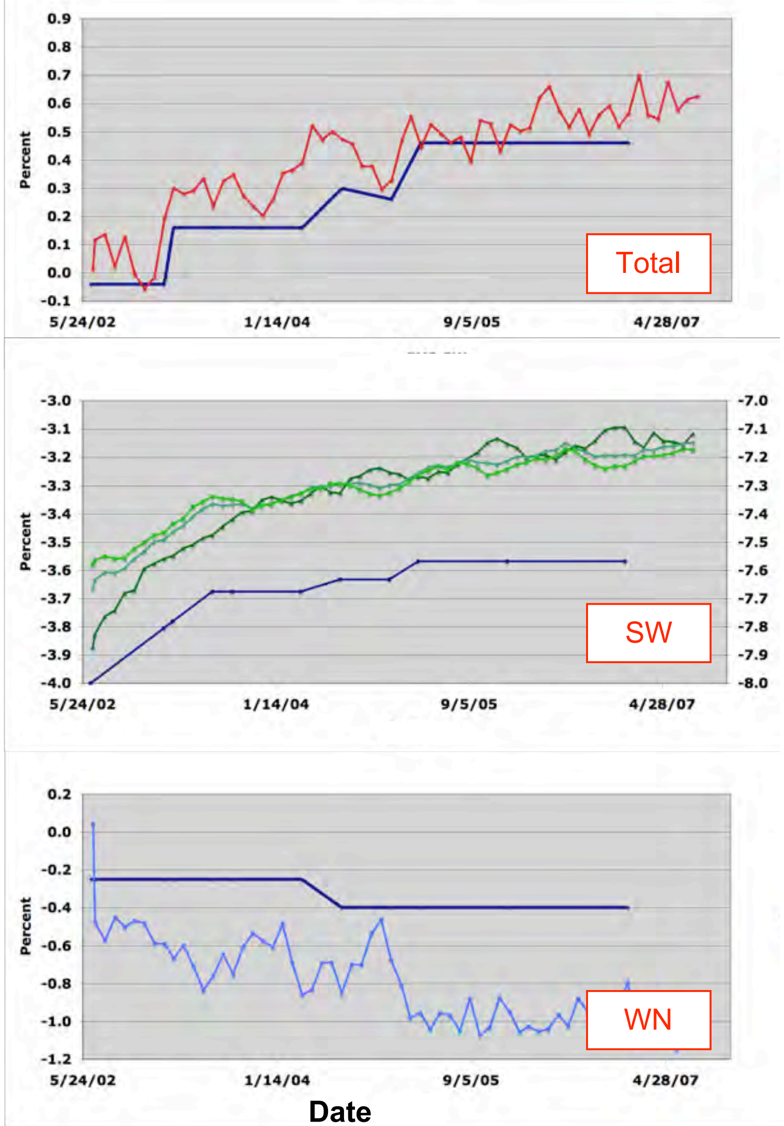
FM2 Operational Temperatures vs. Predicts

Ground Calibration typically conducted at Hot Acceptance Temperatures

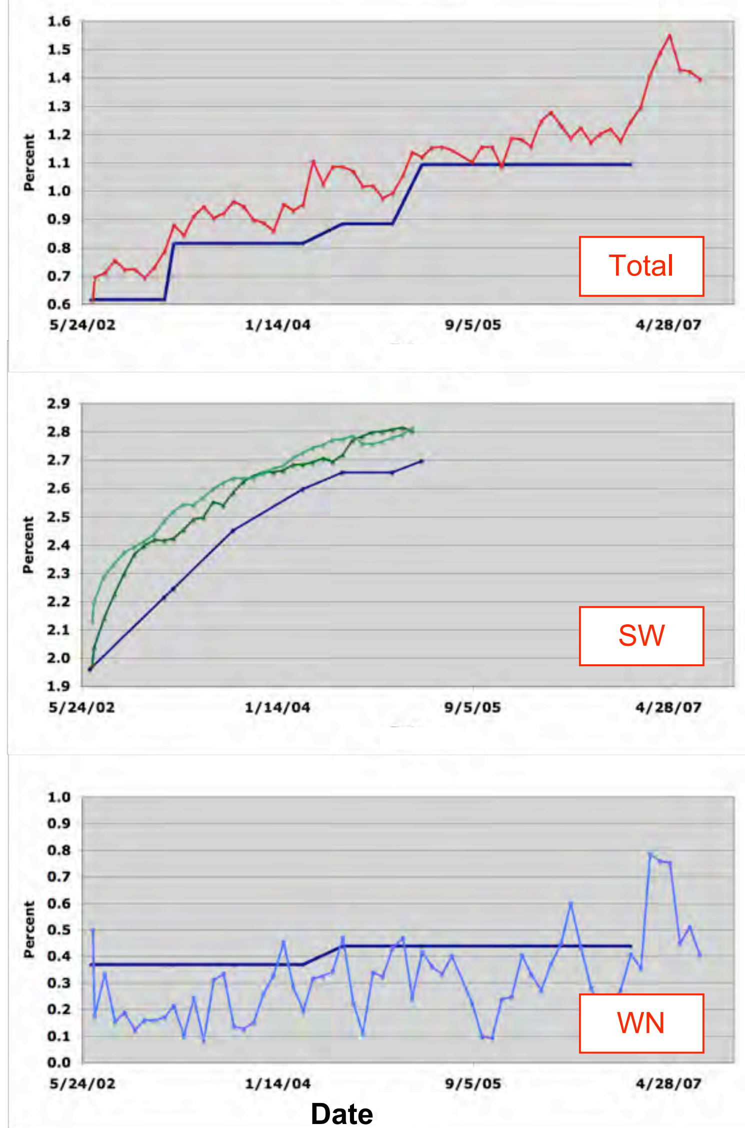


Aqua Monthly Average ICM Results

FM3



FM4



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**
- **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**

Deseasonalized SW Anomalies : Terra

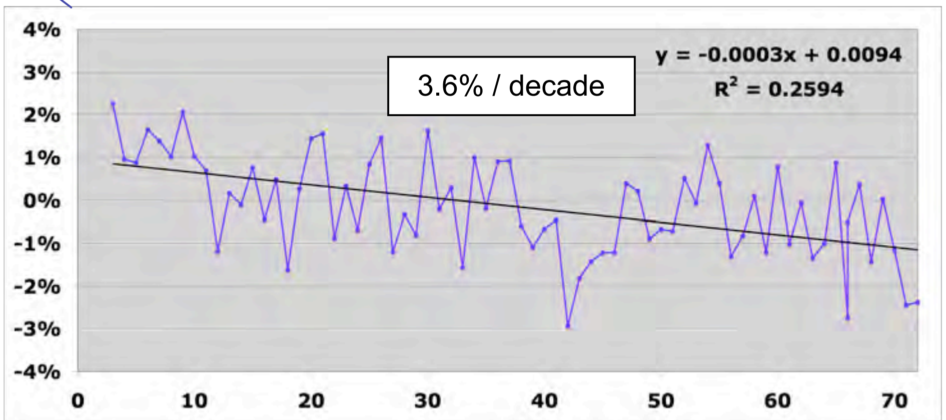
Scene Type

Operational Mode

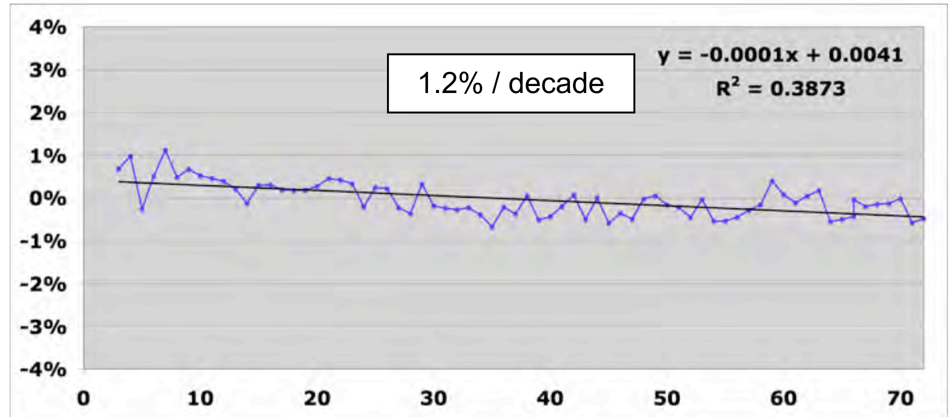
ClrOcn

DCC

Xtrack

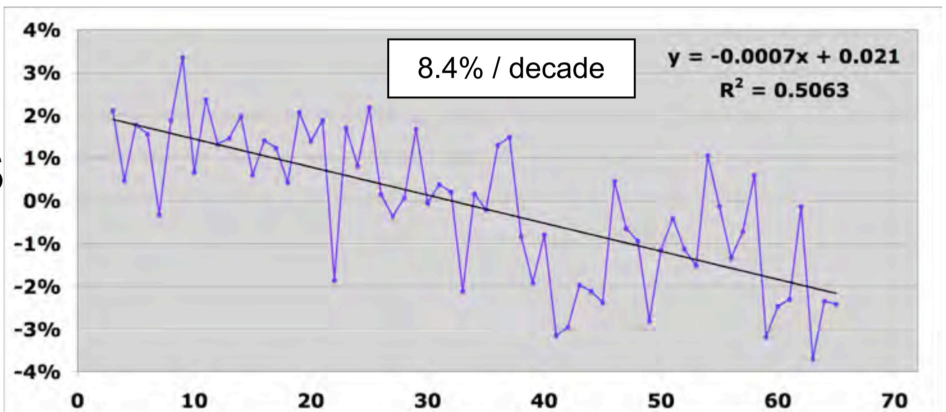


Months in Mode

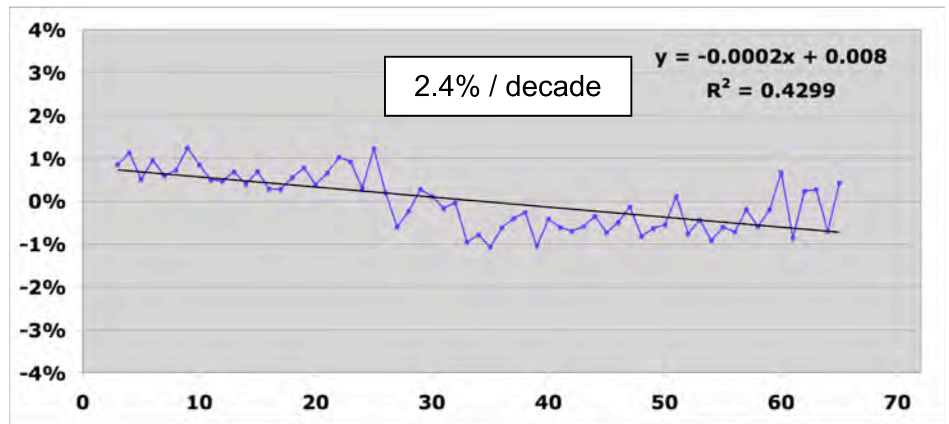


Months in Mode

RAPS



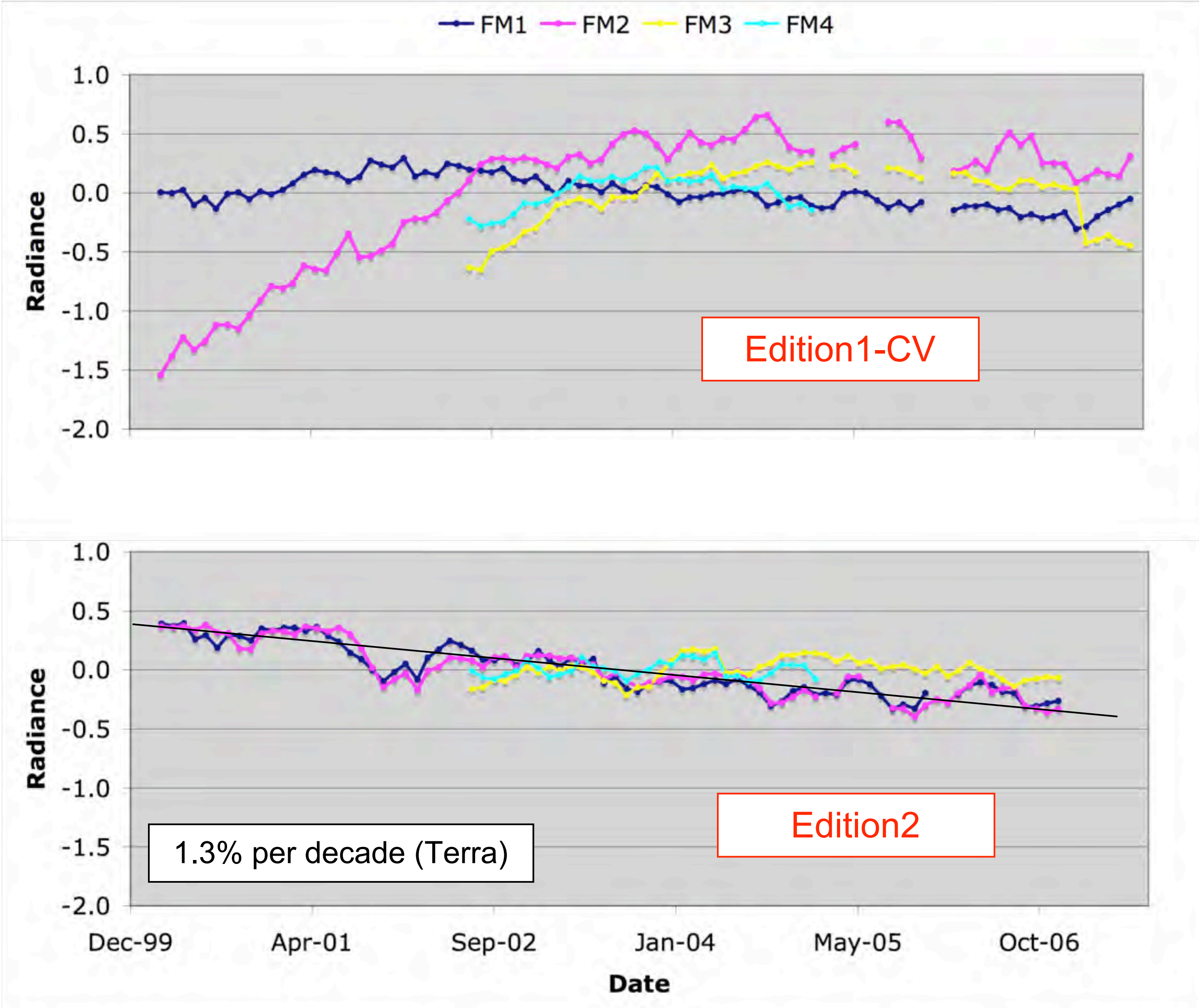
Months in Mode



Months in Mode

Note: Unfiltered SW radiance measurements sorted into Angular bins (I.e. VZA and RAZ) and averaged on a monthly basis

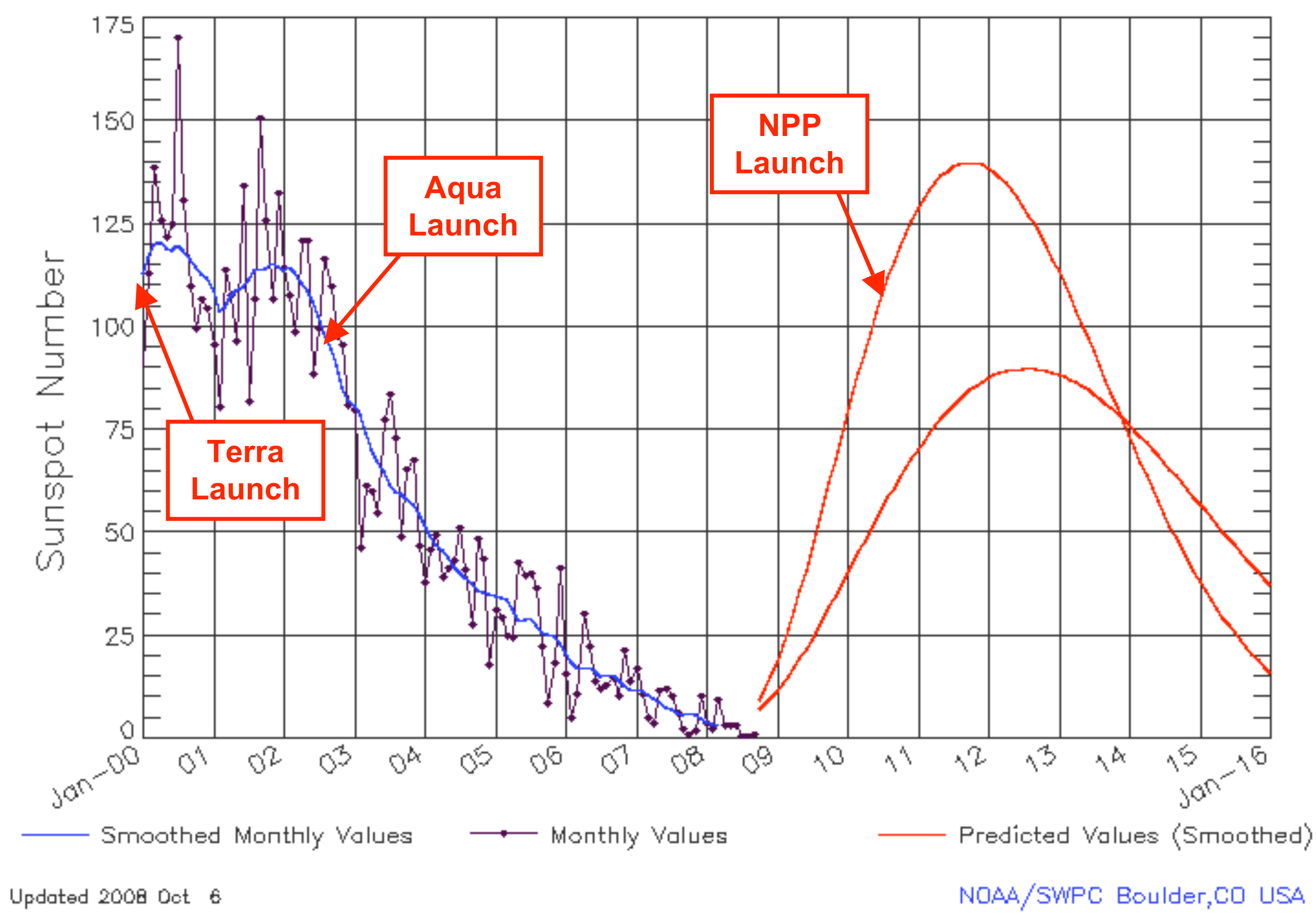
Tropical Mean : LW Day Night Difference Trends



Data Set

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

Solar Cycle Sunspot Number



Edition3 Studies : Status

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 thoughput 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

Edition3 Studies : Status

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-dependencies
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

Edition3 Studies : Path Forward

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 enviroment, Edition 3 Gain and Spectral Response functions by April 2009.

Edition3 Studies : Path Forward

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.

Edition3 Studies : Path Forward

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 -

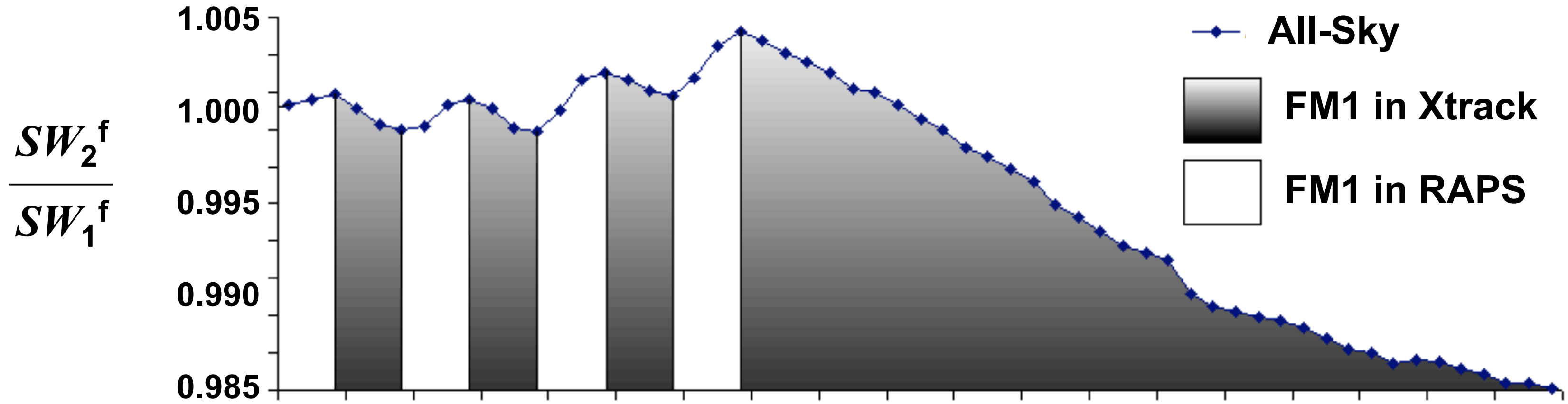
On a month-by month basis -

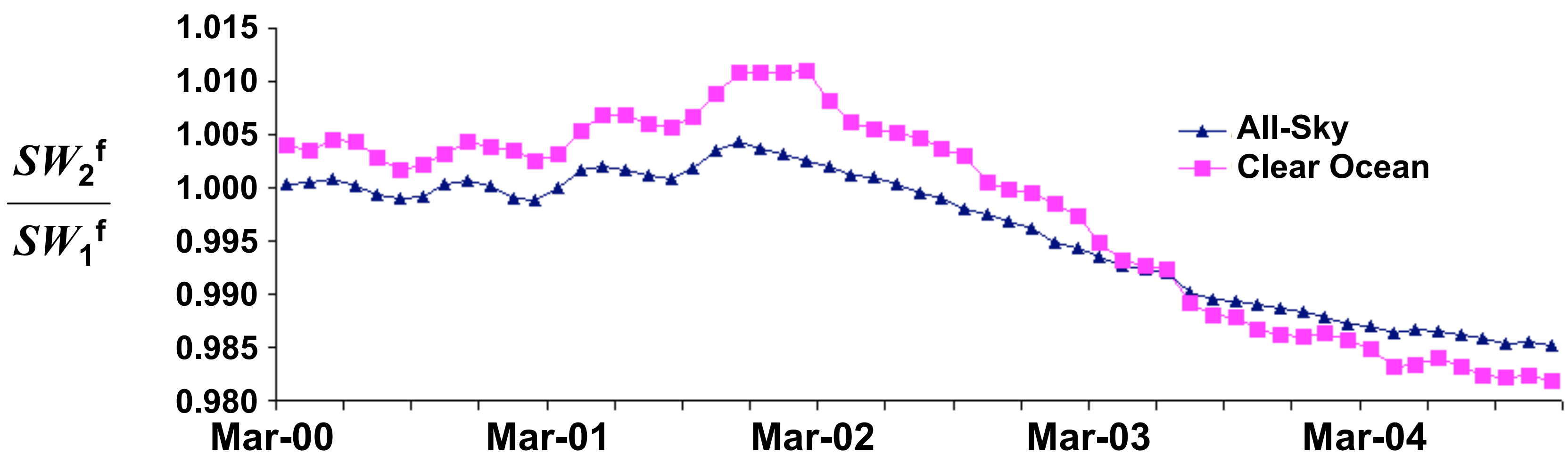
- Apply gains provided in Effort (1) to XTRACK and RAP instruments.
- Unfilter XTRACK instrument with previous month's SRF. Unfilter RAP instrument (or instrument last in RAP mode) with all candidate SRFs.
- Identify the RAP SRF that minimizes the XTRACK-RAP nadir radiance difference. For every footprint, the ufiltering subroutine is run once for the XTRACK instrument and for all candidate SRFs for the RAP instrument.

Back-up Slides

Terra Edition2 Nadir Direct Comparison

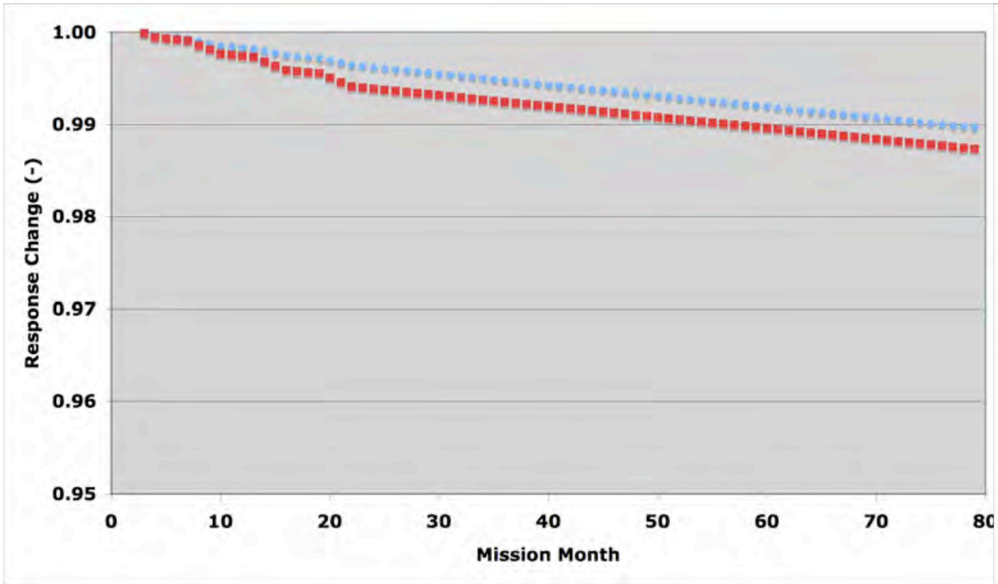
SW Nadir Radiances



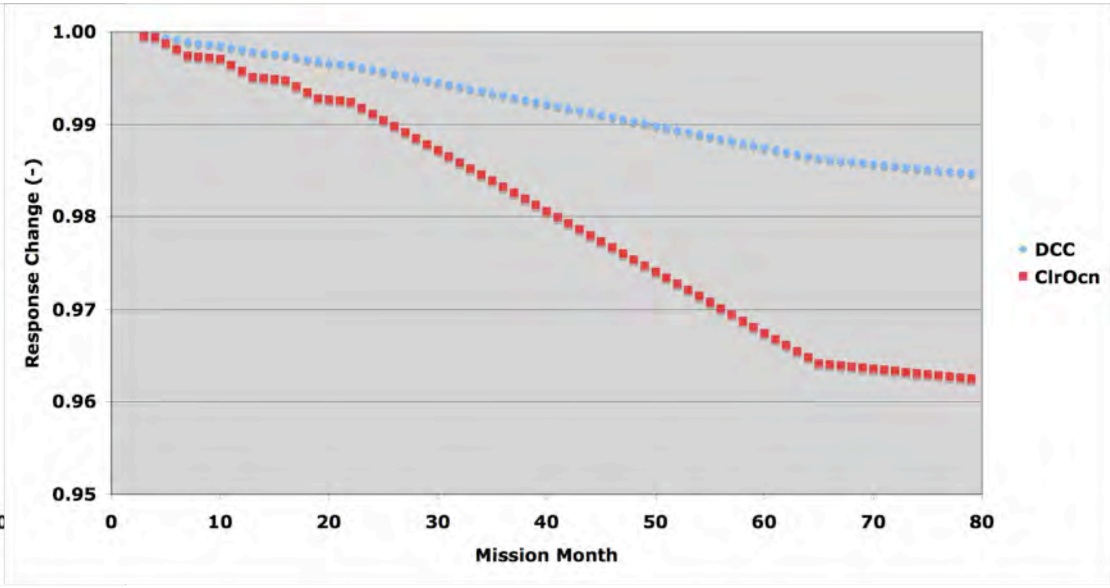


Spectral Drop for ClrOCn and DCC

FM1



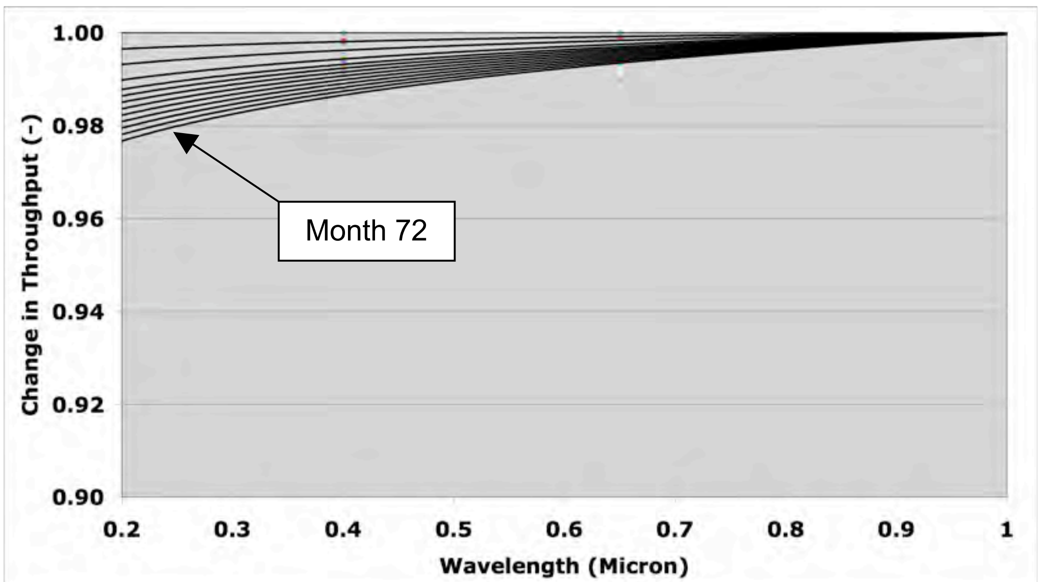
FM2



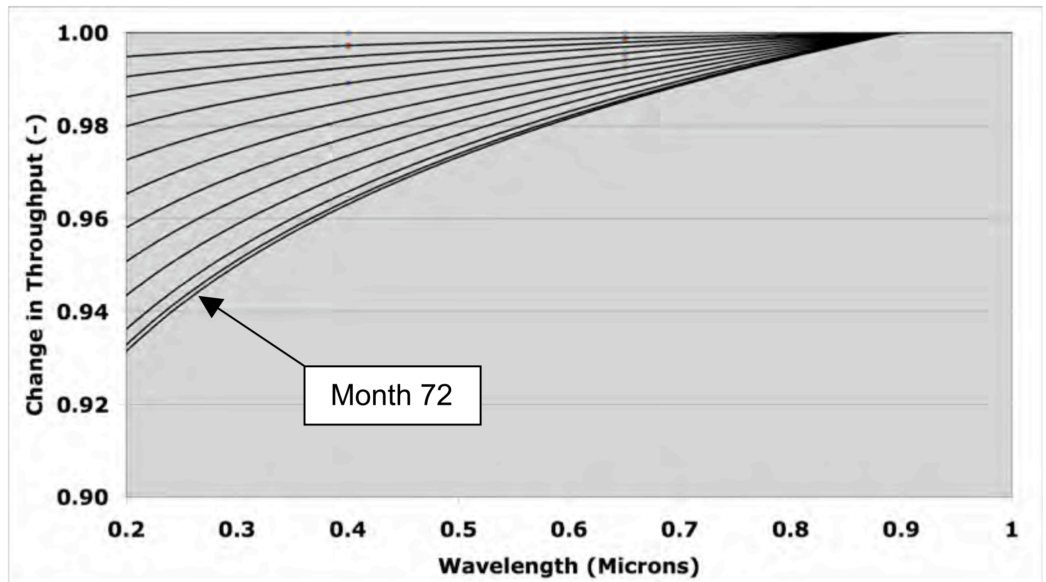
Spectral Response Degradation

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

FM1



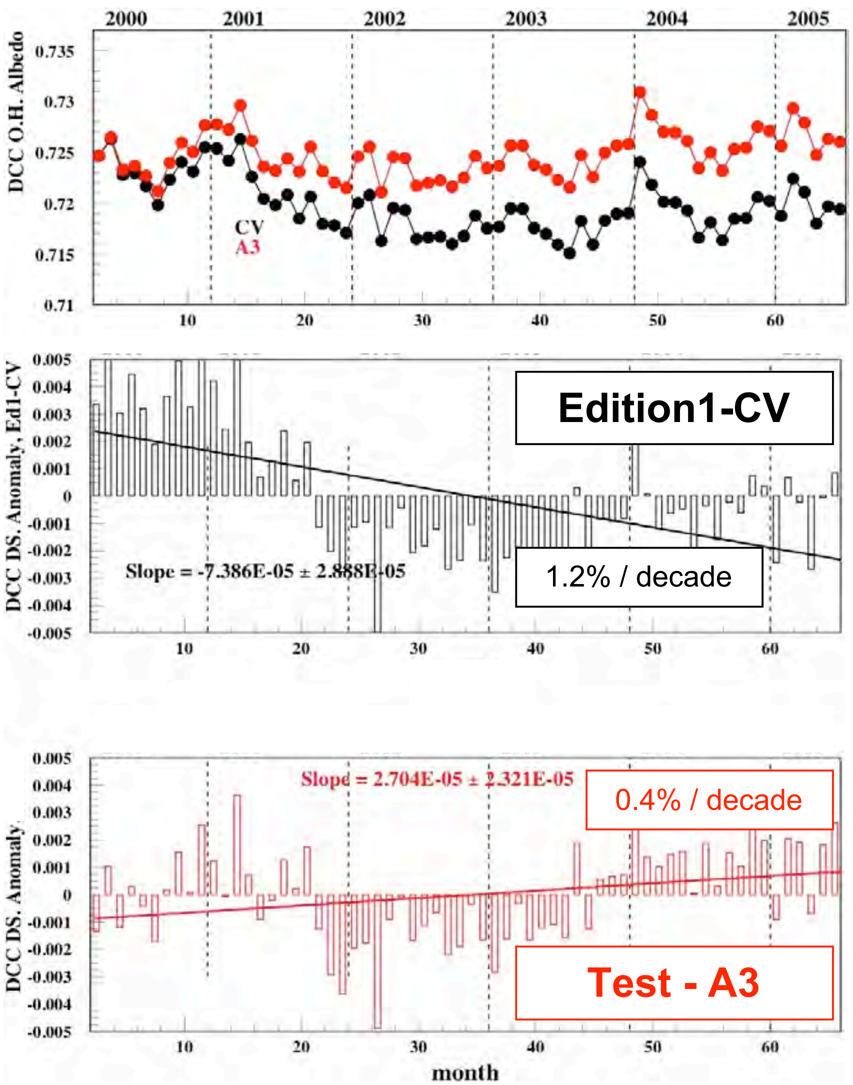
FM2



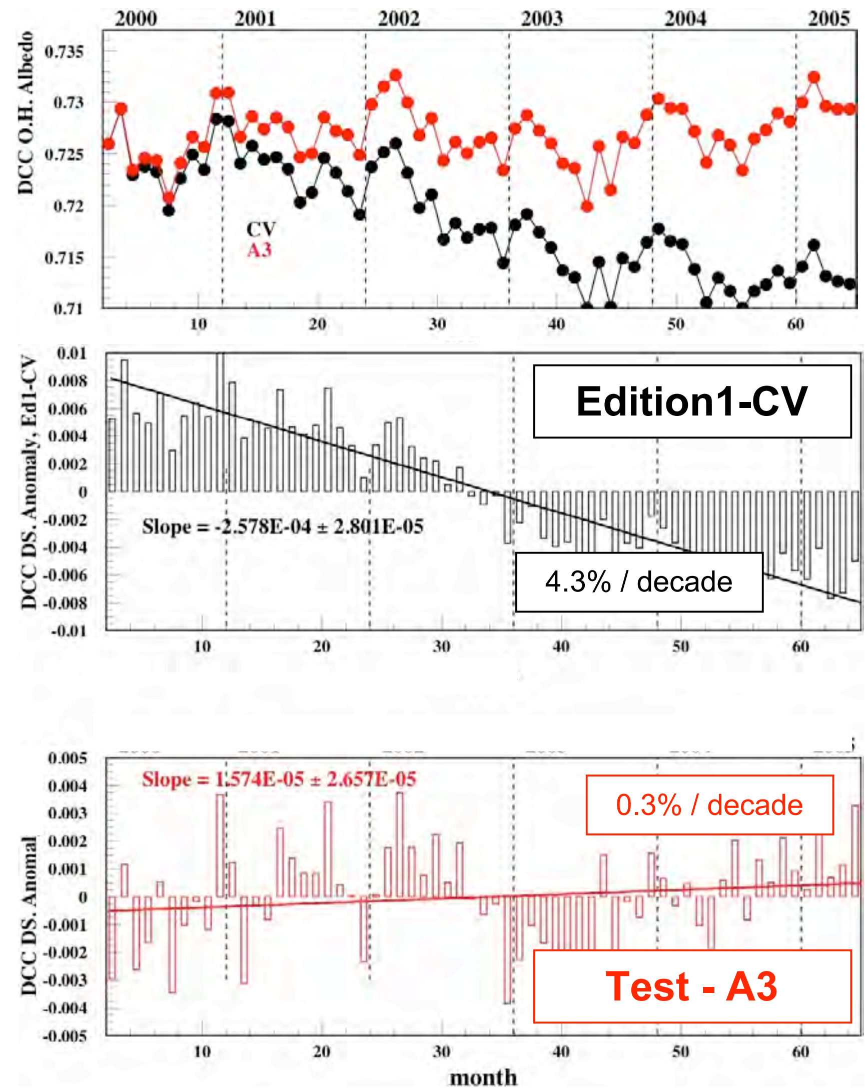
Note: Results shown for 6 month centers

Terra - Deep Convective Cloud Albedo

FM-1

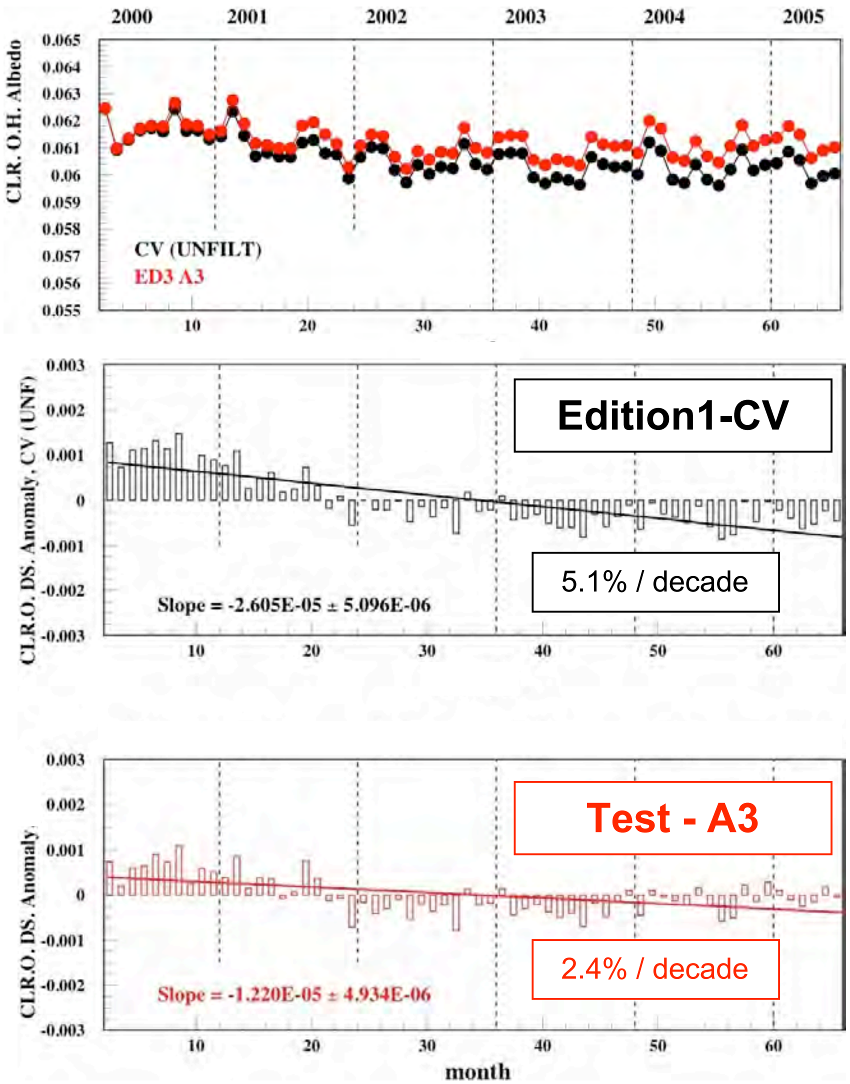


FM-2

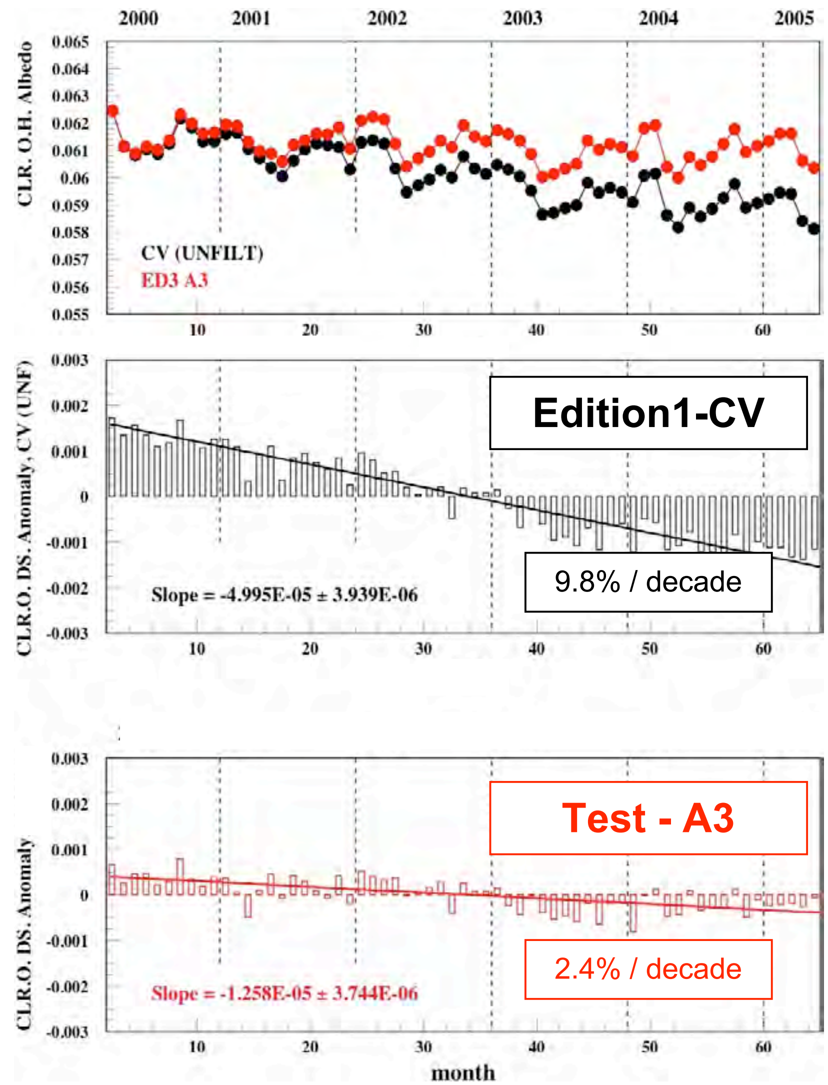


Terra - Clear Ocean Albedo

FM-1



FM-2



Terra/Aqua Edition3 Studies

- *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 thoughput 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

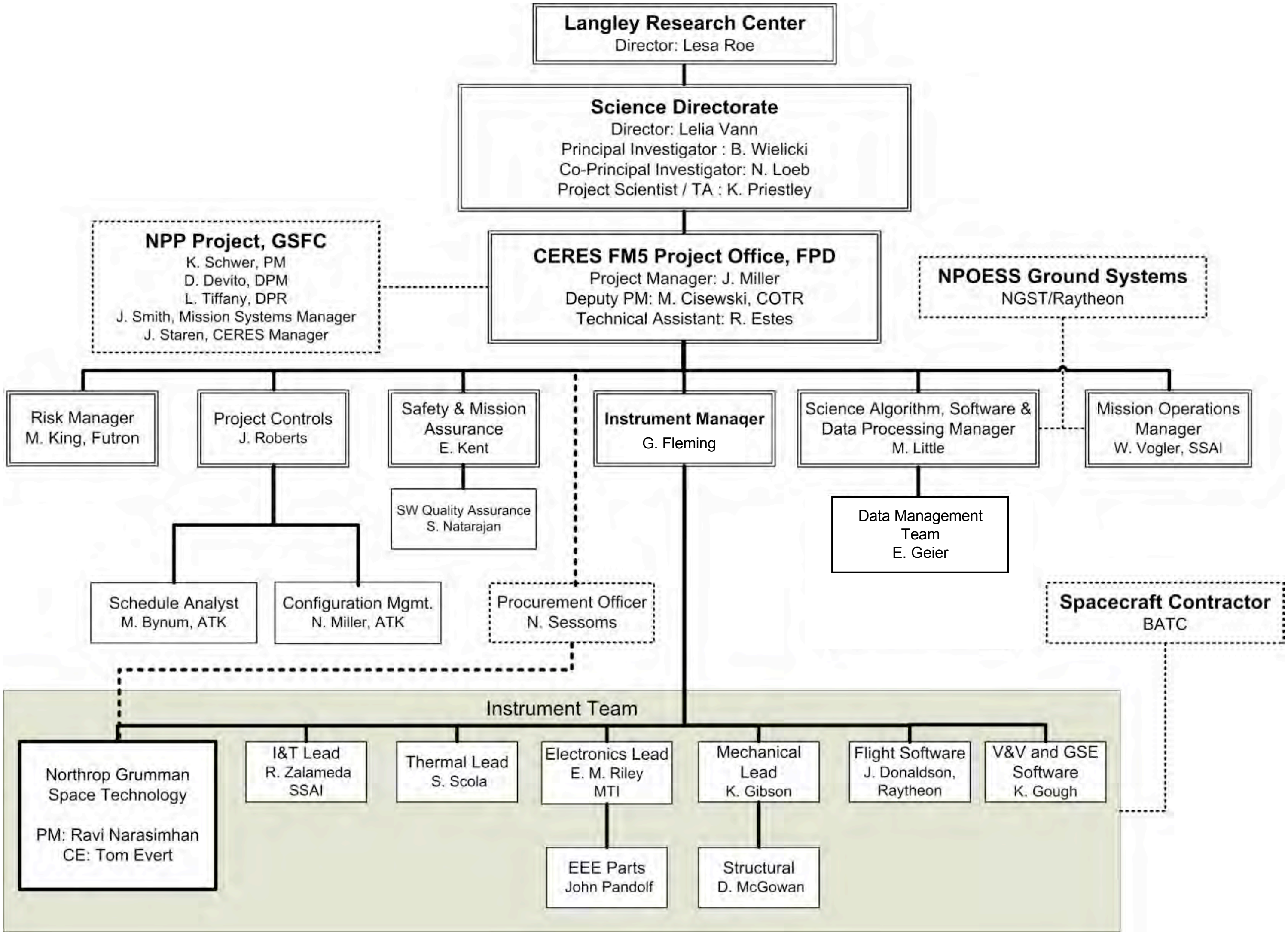
- **Limited Life articles**
  - Bearing lubrication
    - N_2 purged storage environment was optimal
    - No concern for limiting lifetime
  - Onboard Calibration lamps
    - No known mechanisms to reduce life expectancy

- **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.

CERES Project Organization



NPP S/C Layout - 1