CERES Instrument and Calibration Status

~ The entire Instrument Working Group Team ~

Earth Radiation Budget Workshop 2010

École Normale Supérieure (ENS)

Paris, France

September 13, 2010

NASA Langley Research Center
Atmospheric SCIENCES

Outline

CERES FM1-FM6 Instrument Status Report (Priestley)

- EOS Flight Hardware Performance & Status
- EOS Data Product Status
- Climate Data Record Continuity Path Forward
  - FM5 on NPP
  - FM6 on JPSS - 1
  - ERBS on JPSS -2

Edition 3 Results for Validation & Testing (Thomas)

- CERES FM1-FM4 Edition3 Radiometric Calibration Update
- Edition3 Spectral Darkening Correction & Validation, Results for Terra

Instrument Working Group Personnel

Science

- Susan Thomas -
Audra Bullock
Janet Daniels
Phil Hess
Suzanne Maddock
Mohan Shankar
Nathan Smith
Nitchie Smith
Peter Szewczyk
Robert Wilson

Data Management

- Denise Cooper -
- Dale Walikainen -
Mark Bowser
Thomas Grepiotis
Jeremie Lande
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Mark Timcoe

Mission Operations

- Bill Vogler -
- James Bailey -
Christopher Brown
Jim Donaldson
John Butler
William Edmonds
Kelly Teague

S/C Integration & Test

- Roy Zalameda -
Mike Tafazoli
Eugene Sutton
Gene Andrews

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

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….

Why is CERES Climate Quality Calibration so difficult?

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

- Calibrated 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)

Design weaknesses and failures in onboard calibration hardware

- full spectral range of observations not covered by cal subsystems

Complicates separation of instrument 'artifacts' from natural variability.

Edition3 reprocessing of the first 10 years of radiances allows a more rigorous identification and separation of instrument artifacts and climate signals.

Enabling Climate Data Record Continuity

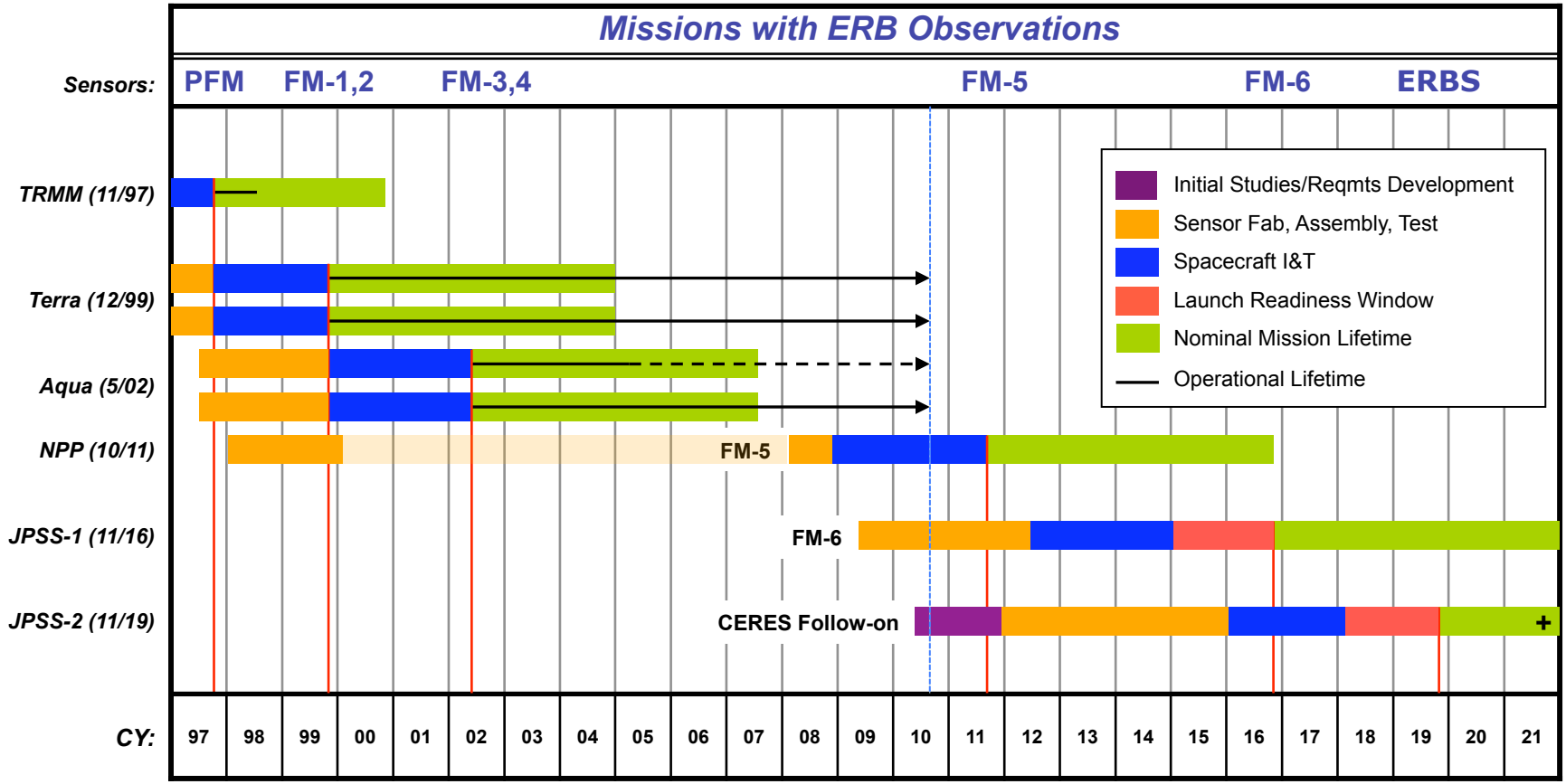
CERES Flight Schedule

Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	122 +
Aqua	FM3, FM4	5/02	6/02	95 +
NPP	*FM5*	*9/11*	-	-
JPSS - 1	*FM6*	*2016*	-	-
JPSS - 2	*ERBS*	*2019*	-	-

39 + Instrument Years of Data

Enabling Climate Data Record Continuity

CERES Flight Schedule



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
JPSS-1	FM6	***NOAA***	***TBR***	NASA Procurement	***TBR***
JPSS-2	CERES follow-on	***NOAA***	***TBR***	NASA Procurement	***TBR***

EOS Status

CERES/EOS 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	122 +
Aqua	FM3, FM4	5/02	6/02	95 +
NPP	*FM5*	*9/11*	-	-
JPSS - 1	*FM6*	*2015*	-	-
JPSS - 2	*ERBS*		-	-

37 + Instrument Years of Data

Terra/Aqua Instrument and ERBE-Like 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 – 8/10
		Editon3	Yes	2/00 – 3/09
	ERBE-like	Edition1	Yes	2/00 - present
		Edition2	Yes	2/00 – 8/10
		Editon3	In Production	2/00 – 3/09
Aqua	BDS	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 – 8/10
		Editon3	ASDC Testing	2/00 – 3/09
	ERBE-like	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 – 8/10
		Editon3	ASDC Testing	2/00 – 3/09

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

Cal/Val Protocol Overviews

Edition1_CV - Static Algorithms and coefficients - baseline product used in cal/val protocol

Edition2 - Utilizes temporally varying coefficients to correct for traceable radiometric drift. All spectral changes are broadband and 'gray'.

Edition3 - Accounts for temporally varying spectral artifacts in the SW and LW measurements.

User Applied Revisions - Advance capabilities to the users prior to the release of the next Edition.

Edition2 products lag Edition1 by a minimum of 6-12 months

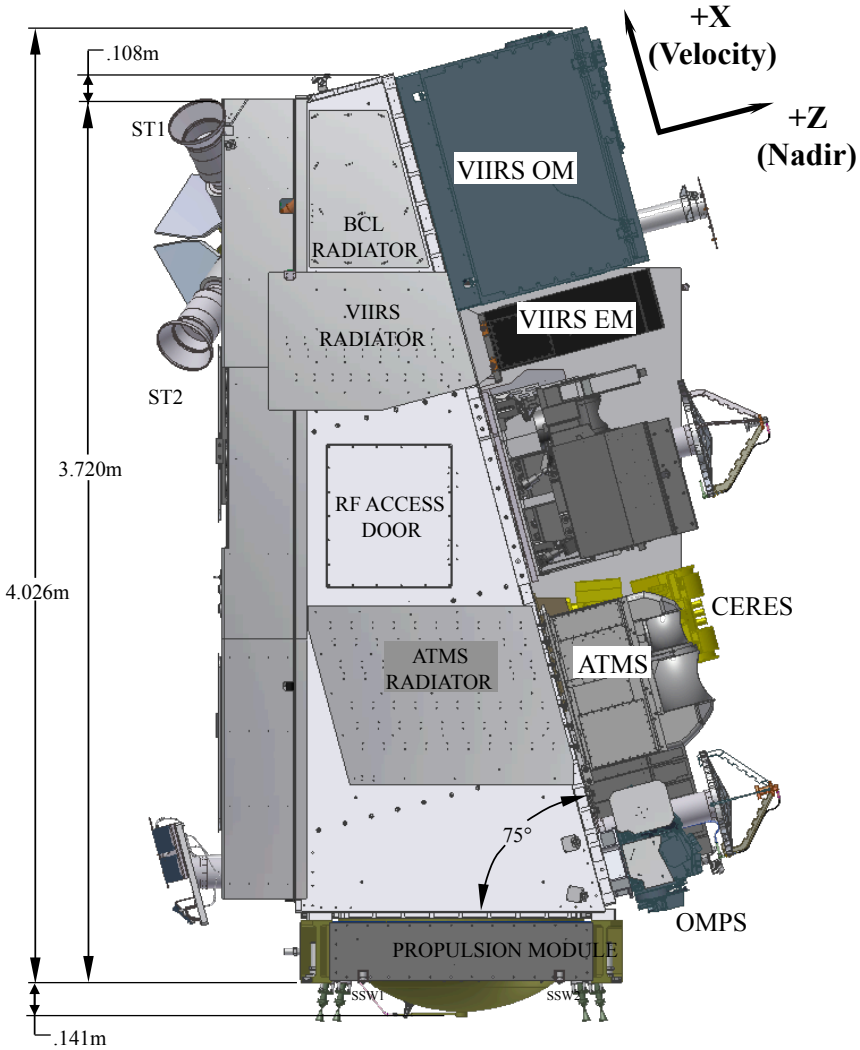
CERES Calibration Input Parameters

Coefficients updated in Cal/Val Protocols Traceability Matrix

Category	Parameter	Edition1	Edition2	Edition3
Radiometry	Gain	Static	Piecewise linear ~ 6 month intervals	Continuous, based upon ICS
	Spectral Response	Static	Gray Changes	Wavelength Dependent Changes
	Scan Dependent Offsets	Ground	Ground	Terra - DSCAL Aqua -TBD
	2nd Time Constant	Ground	Ground	Flight
	Thermal Correction	Common Correction	Common Correction	Instrument Specific
	IBB PRT Coefficients	Static	Static	Static
Pointing	Alignment	Static	Static	Static
	Gimbal Offsets	Static	Static	Static
	Time Response	Static	Static	Static

FM-5 Status

CERES Compatibility with NPP Spacecraft



Observatory Information

- Launch Readiness - September, 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**
- ***Observatory Pre-environmental Test Readiness Review 9/20-21/10***
- ***Spacecraft Environmental Campaign 11/10-4/11***
- ***NPP 'Official' Launch Readiness Date is currently September, 2011***
  - *Initial NPP launch date was mid-2006*

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 – September 28, 2010***
  - ***Delivery – July 2012***
  - ***Launch Readiness Date of Jan, 2015***
  - ***Launch Date of Oct. 2016***

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 - Unstable Reference Detector	**- Addition of source in blue region** - New Reference Detector identified	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

Green : Funding not currently available

NASA Recommended Implementation

Both the MAM improvement (with reference detector) and SWICS improvement (blue source) are required to meet performance requirements:

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

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

Current Implementation : Funding Limited

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 Observational requirements will not be met.**

Result

CERES Project Office has no choice but to move forward with the legacy EOS on-board SW calibration sources as the baseline design for FM-6.

CERES Follow-on status

Currently known as 'Earth Radiation Budget Sensor', or ERBS

CERES Follow-on Status & Near-Term Activities

- NOAA Sponsored a workshop on 'Continuity of Earth Radiation Budget (CERB) Observations: Post-CERES Requirements'
  - Asheville, North Carolina, July 13-14, 2010
- Draft workshop report currently in circulation
- Instrument Break-Out group endorsed performance requirements specified in earlier multi-agency workshops
  - Achieving Satellite Instrument Calibration for Climate Change (ASIC3)
- Nominal Schedule
  - Contract in place FY'12
  - Delivery of first flight Model FY'16

Proposed ERBS Radiometric Performance Requirements

CERES vs. ERBS

Parameter	Spectral Band	CERES	ERBS
Accuracy (%/decade)	SW	2.0	1.0
	TOT	1.0	0.5
	LW	1.0	0.5
Stability (%/decade)	SW	1.4	0.3
	TOT	1.0	0.3
	LW	1.0	0.3

- **Proposed requirements for ERBS are more stringent than CERES by a factor of 2-5**

Calibrate, Calibrate, Calibrate….

Summary

BACK-UP SLIDES

Radiometric Performance Requirements

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5-year design Lifetime

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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	
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EOS Calibration Report

CERES Unfiltered Radiance Summary

•Cal/Val Protocol demonstrates radiometric stability of the data products through 12/2009 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**

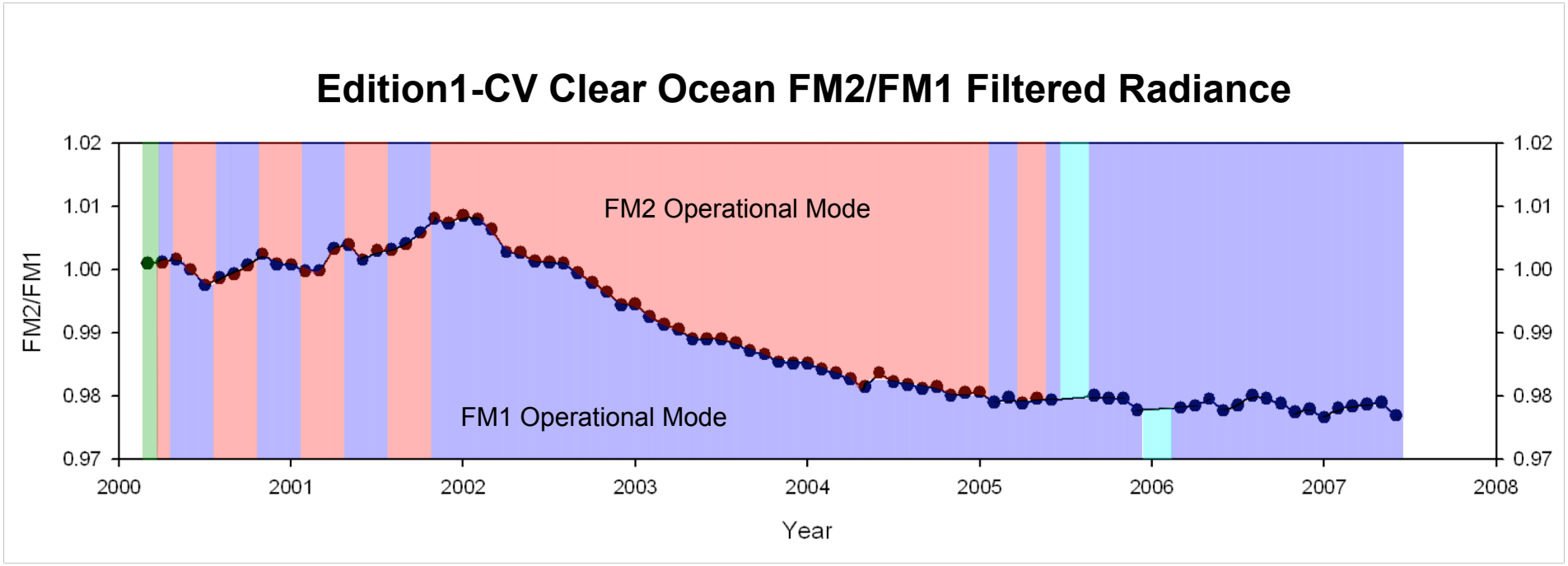
Occurs on all four CERES EOS sensors to varying degrees

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 coverage in the onboard SW sources greatly complicates the characterization and removal of this phenomena

Operational Mode and Direct Compare



Bi-axial (RAPS)

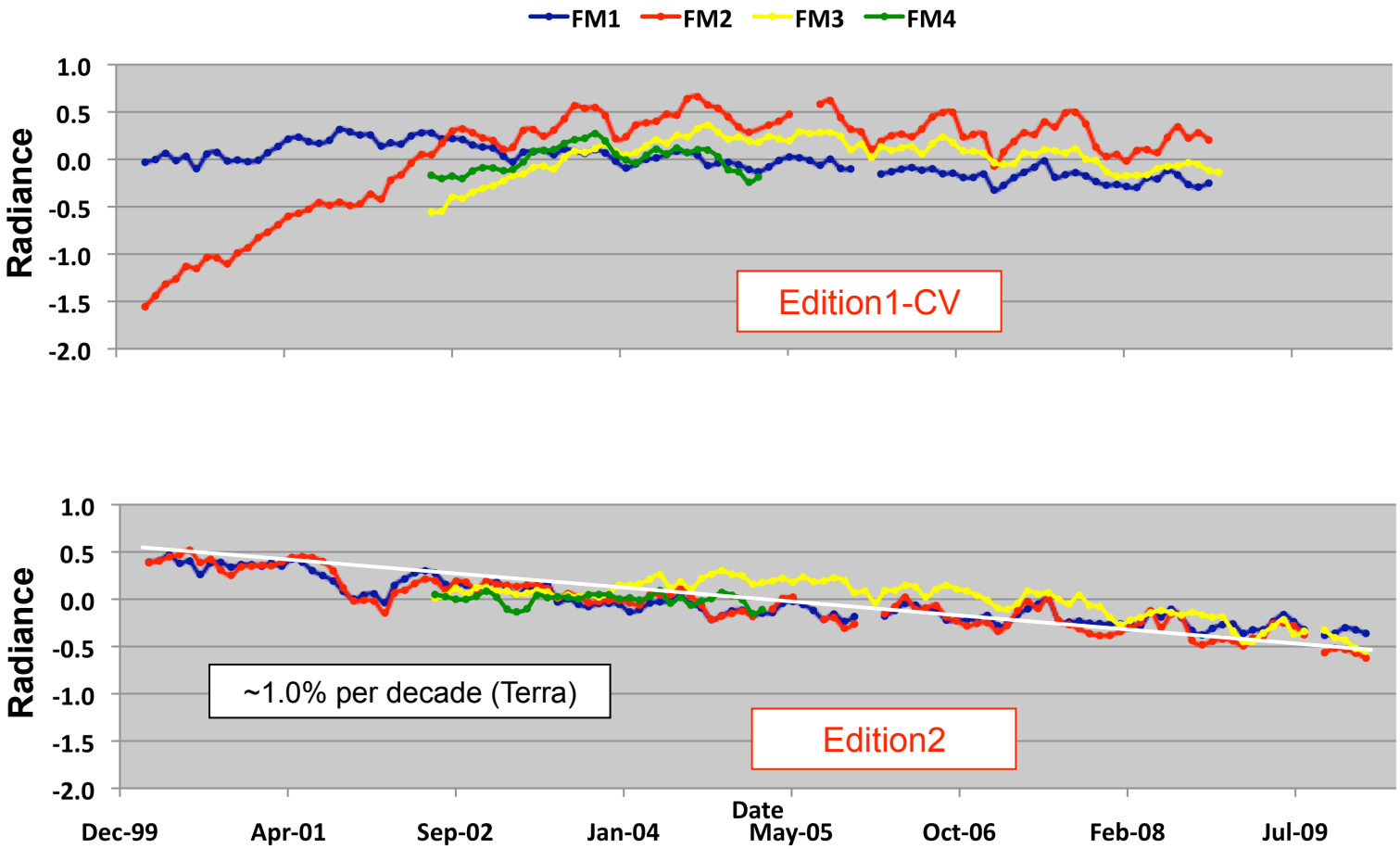
Crosstrack (FAPS)

Stowed

Mixed Crosstrack/Biaxial

Instrument operating in RAPS mode drops in SW response relative to instrument operating in cross-track mode.

OLR Day Night Difference Trends : Tropical Mean



Data Set

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

CERES Edition3 Calibration Report

Edition3 Calibration Protocol : Updates

Re-Analysis of Ground Calibration Data

- Update uncertainty analysis
- Verify at-launch Radiometric Gains
- Verify at-launch Spectral Response Functions

In-Flight Radiometric coefficient updates

- Gain
- Offsets
- 2nd Time Constant
- Thermal Correction

Establish a common Radiometric Scale across all CERES Sensors

- Flight Model 1 chosen as the standard

Determine optimal Spectral Response Functions to account For spectral darkening in the reflected solar bands.

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Determination of ***Filtered*** Radiances

Determination of ***Unfiltered*** Radiances

CERES : At-Launch Uncertainty Analysis

Introducing wavelength dependent uncertainties to classify confidence as a function of scene type

	Designation	Error W/m^2 -sr	Error %	Reference
Shortwave Channel Accuracy		**0.750**	**1.00%**	**4.2.4.3 Shortwave Channel Accuracy. The allocation of shortwave**
Ground Errors	**A1**	**0.48**	**0.64%**	**SQRT((Cal Process)^2+(Cal Facility)^2+(Instrument)^2)**
Calibration Process	***A11***	***0.18***	***0.25%***	***4.2.4.3.1.1 Calibration Process (A11). The ground calibration process, which inclu***
Spectral Knowledge	A111	0.075	0.100%	
NFBB Aperature	A112	0.008	0.010%	
Data Reduction	A113	0.075	0.100%	
TACR Transfer	A114	0.008	0.010%	
SA Thermal Model	A115	0.150	0.200%	
CSR Radiance	A116	0.002	0.002%	
Calibration Facility	***A12***	***0.38***	***0.50%***	***4.2.4.3.1.2 Calibration Facility (A12). The ground calibration facility shall cause sl***
NFBB	A121	0.075	0.100%	
Cold Space Reference	A122	0.015	0.020%	
Carousel Assembly	A123	0.075	0.100%	
Albedo Plate	A124	0.038	0.050%	
Test Baffle	A125	0.038	0.050%	
Alignment	A126	0.075	0.100%	
ARMS	A127	0.225	0.300%	
SWRS	A128	0.188	0.250%	
TACR	A129	0.188	0.250%	
Instrument	***A13***	***0.23***	***0.31%***	***SQRT(J25^2+J26^2+J27^2+J28^2) (RSS of lower terms)***
Sensor Assembly	A131	0.150	0.200%	4.2.4.3.1.3 Sensor Assembly (A131). The shortwave sensor assembly shall cause shortwav
Pointing Subsystem	A132	0.113	0.150%	4.2.4.3.1.4 Pointing Subsystem (A132). The biaxial scan assembly and its related position
Electrical Subsystem	A133	0.075	0.100%	4.2.4.3.1.5 Electronics Subsystem (A133). The electronics subsystem (less position control
In-flight Calibration	A134	0.113	0.150%	4.2.4.3.1.6 In-Flight Calibration (A134). The in-flight calibration subsystem shall cause sho
Flight Errors	**A2**	**0.57**	**0.75%**	**SQRT((Cal Process)^2+(Orbital Effects)^2+(Instrument)^2)**
Calibration Process	***A21***	***0.19***	***0.25%***	***4.2.4.3.2.1 Calibration Process (A21). The flight calibration process, which include***
Spectral Knowledge	A211	0.075	0.100%	
Data Reduction	A212	0.090	0.120%	
Out of Field	A213	0.150	0.200%	
Orbital Effects	***A22***	***0.25***	***0.34%***	***4.2.4.3.2.2 Orbital Effects (A22). The orbital environment shall cause shortwave c***
Environment	A221	0.113	0.150%	
Off-axis Sources	A222	0.225	0.300%	
Instrument	***A23***	***0.47***	***0.63%***	***SQRT(J39^2+J40^2+J41^2+J42^2) (RSS of lower terms)***
Sensor Assembly	A231	0.263	0.350%	4.2.4.3.2.3 Sensor Assembly (A231). The shortwave sensor assembly shall cause shortwav
Pointing Subsystem	A232	0.075	0.100%	4.2.4.3.2.4 Pointing Subsystem (A232). The biaxial scan
Electrical Subsystem	A233	0.075	0.100%	4.2.4.3.2.5 Electronics Subsystem (A233). The electron
In-flight Calibration	A234	0.375	0.500%	4.2.4.3.2.6 In-Flight Calibration (A234). The in-flight ca
Margin	**A3**	**0.11**	**0.16%**	**Remaining Margin given allocated values for Total Channel Accuracy Error. Calculat**

Lead : Nathan Smith

Spectral Response Function Evaluation

Reanalysis of ground test data to determine the optimal At-launch Spectral Response Function (SRF) for CERES sensors.

Reflected Solar Bands:

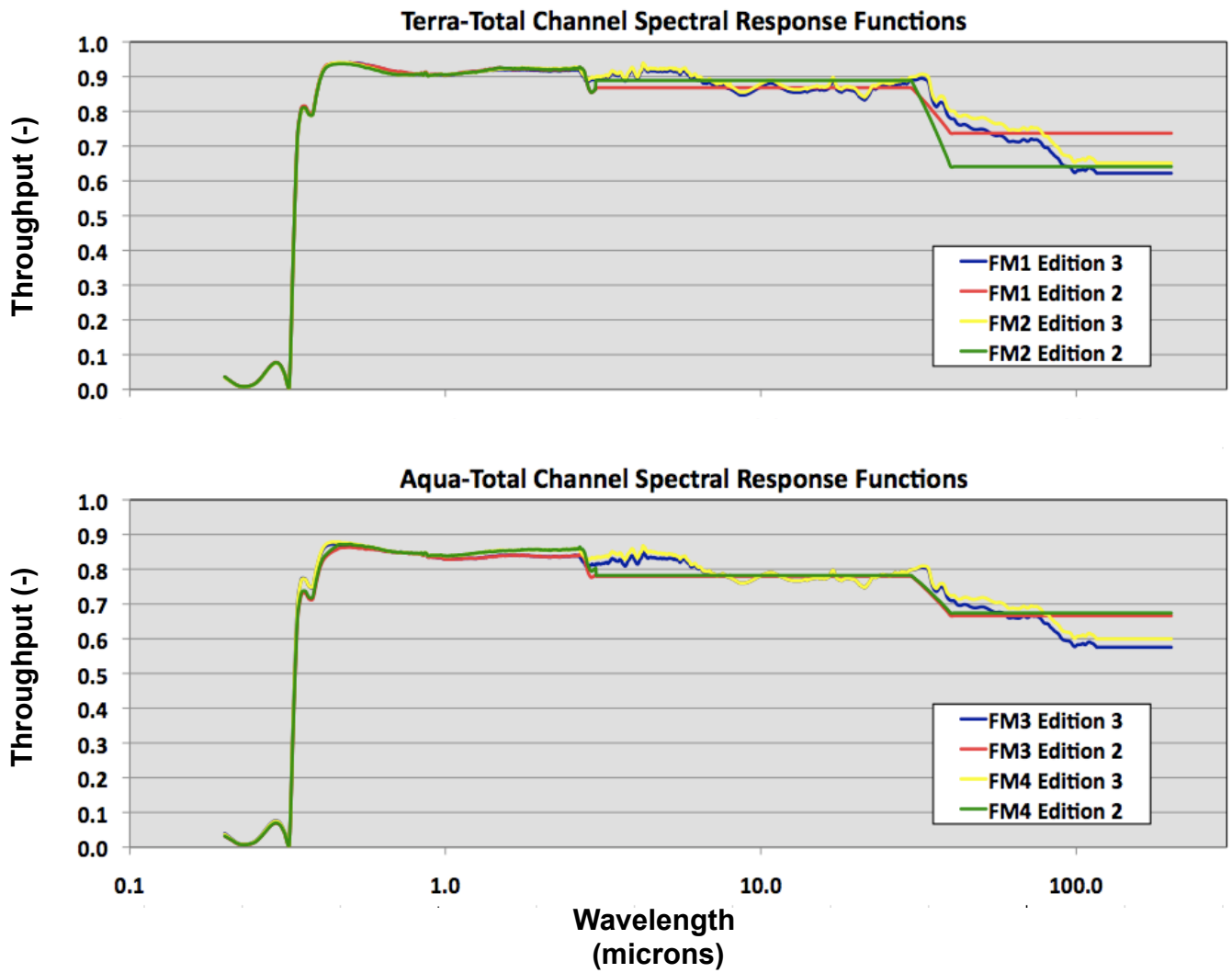
- Component measurements re-evaluation: Silver data from different coating runs.
- Impact of shortwave source spectral throughput on the band-pass filters used in the determination of Gain/SRF.

Emitted Thermal bands:

- Incorporated Fourier Transform Spectrometer (FTS) measurement analysis to determine the SRF in the Longwave region.

Lead : Mohan Shankar

Total Channel Spectral Response Functions



TERRA Radiance Comparison : March 2000

Edition2 and Edition3 Spectral Response Function

ALL SKY Global Flux Results for March 2000

	FM1			FM2			FM1-FM2	
	Edition3 Wm-2	Edition2 Wm-2	Ed3-Ed2	Edition3 Wm-2	Edition2 Wm-2	Ed3–Ed2	Edition2	Edition3
LWday	230.74	228.91	0.80%	230.74	229.91	0.36%	-0.43%	0%
LWnite	224.99	224.15	0.37%	224.36	223.82	0.24%	0.15%	0.28%
SW	255.96	255.84	0.05%	255.89	255.70	0.07%	0.03%	0.05%

Notes : ERBE-Like ES-8 NADIR data
Matched Footprints
Each sensor on native radiometric scale
Ed3 or Ed2 Gains
New BOM SRF
Ground to Flight Shift
Edition3 Thermal

Lead : Dale Walikainen

CERES Edition3 Calibration Report

Edition3 Calibration Protocol : Updates

Re-Analysis of Ground Calibration Data

- Update uncertainty analysis
- Verify at-launch Radiometric Gains
- Verify at-launch Spectral Response Functions

In-Flight Radiometric coefficient updates

- Gain
- Offsets
- 2nd Time Constant
- Thermal Correction

Determination of ***Filtered*** Radiances

Establish a common Radiometric Scale across all CERES Sensors

- Flight Model 1 chosen as the standard

Determine optimal Spectral Response Functions to account For spectral darkening in the reflected solar bands.

Determination of ***Unfiltered*** Radiances

Ground to Flight Shift Analysis for Edition3

IBB and SWICS Pre-Launch and Post-Launch calibration data re-evaluated to quantify ground to flight changes in sensor gains.

Ground to Flight change in sensor responsivity :

	Total	Window	Shortwave
FM1	-0.13%	0.40%	-0.50%
FM2	-0.21%	1.61%	-0.01%
FM3	0.04%	0.25%	8.00%
FM4	-0.62%	0.37%	-1.96%

Note: Terra shifts incorporated in Edition3
Aqua shifts included in Edition1-CV

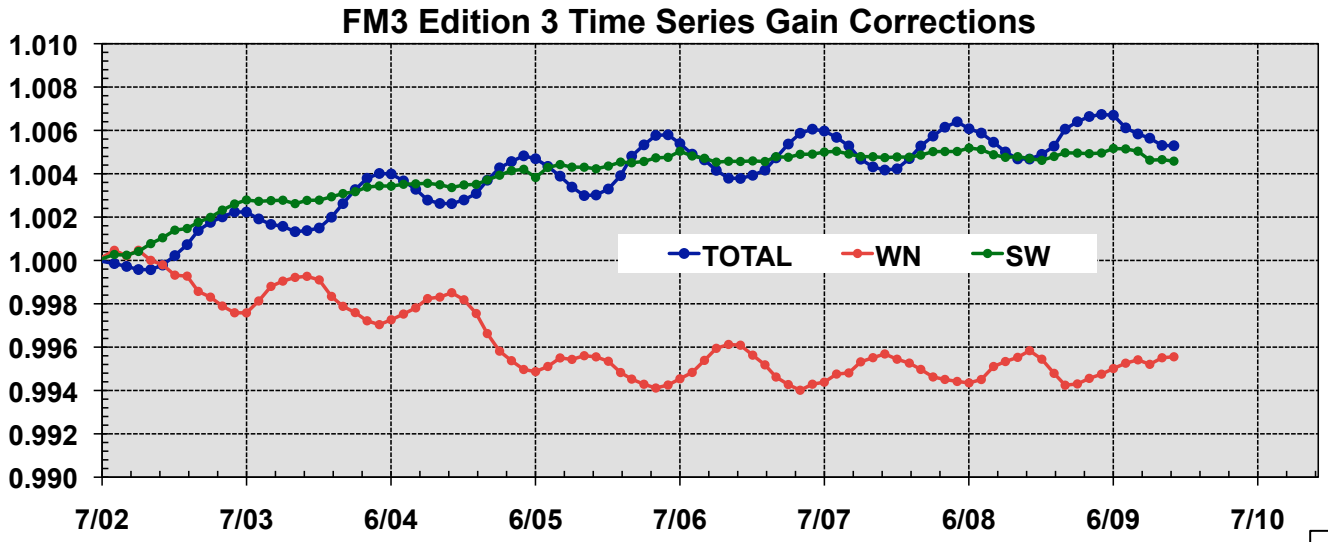
Lead : Susan Thomas

In-Flight Gain Analysis for Edition3

In-flight gain updates determined using the Internal Calibration Source (ICS)

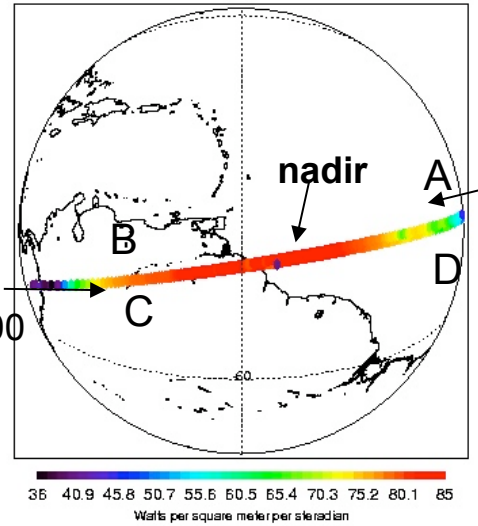
- **Internal Blackbody (IBB) – *Total, Window***
- **Shortwave Internal Calibration Source (SWICS) - *Shortwave***

Monthly variation in the Total and Window sensor gain observations filtered with a five month running mean.



Lead : Phil Hess

Scan Angle Dependent Offset Stability Verification

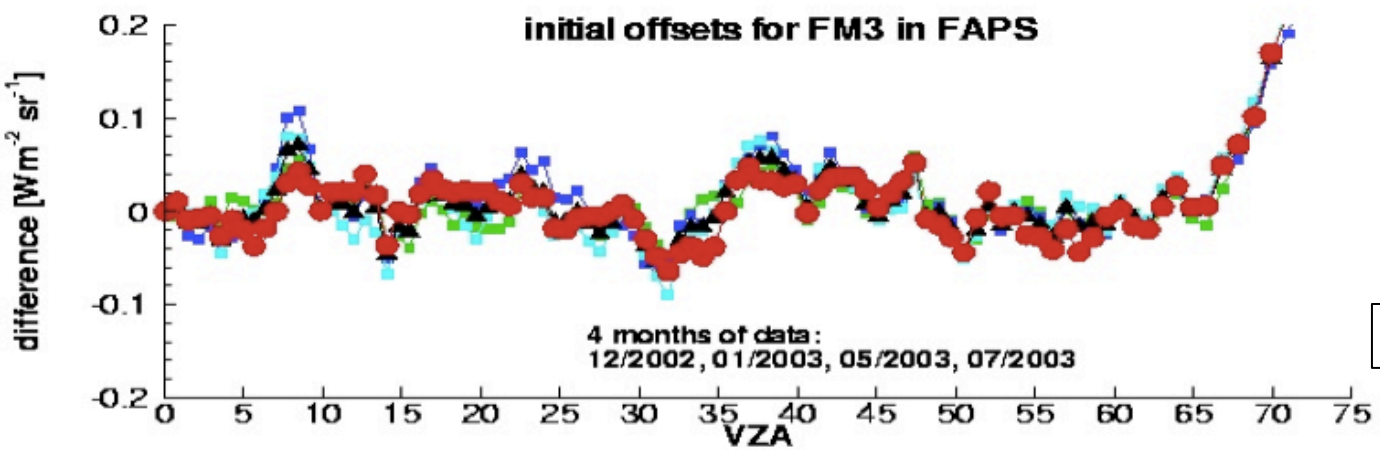


Space look samples:1→ 60 & 600 → 660

Space look & internal calibration samples: 260 →400

Analysis of nighttime Earth viewing data combined with Limb Darkening model, offset stability verified at the 0.05 Wm-2 level

Pattern Recognition in Reducing Bias of CERES Radiometeric Measurements; Z. Peter Szewczyk, AIAA-2008-884, 46th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, Jan. 7-10, 2008

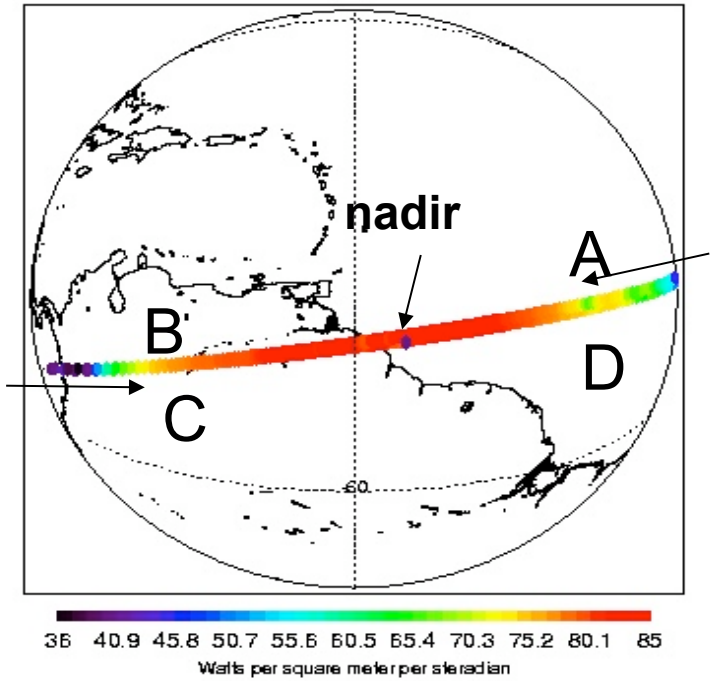


Lead : Peter Szewczyk

2nd TC Verification/update in flight Total Channel

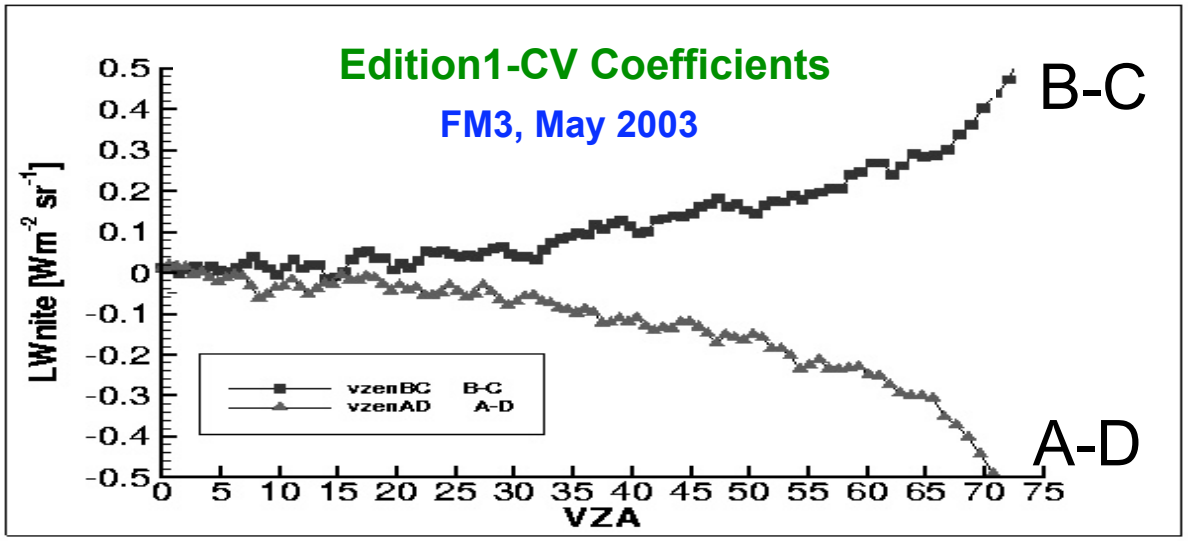
- **Edition 1&2 filter parameters were determined using internal calibration data**
  - analyzing the difference between calibration signal and radiometer response
- **Edition 3 filter parameters are set based on analyzing Earth viewing data**
  - measurements of nightime tropical mean tropics at night for total channel (LW)

hot to cold: B - C

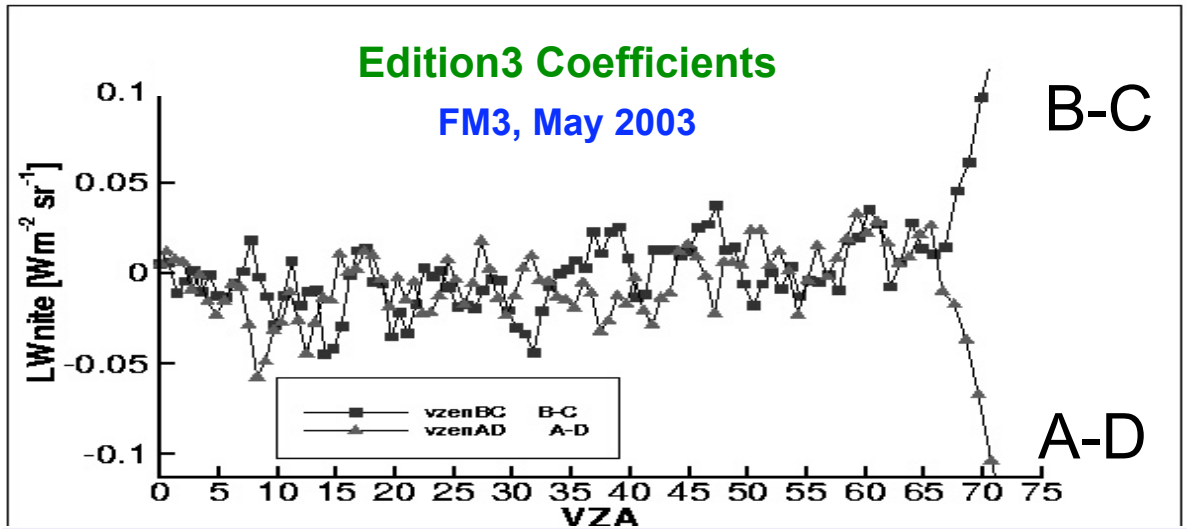


cold to hot: A - D

2nd TC Verification/update in flight Total Channel



	λ	c
FM1	7.60	0.008
FM2	7.60	0.014
FM3	3.0	0.0135
FM4	4.0	0.011



Slow mode of the CERES scanning radiometers; Szewczyk, Z. Peter, Remote Sensing of Clouds and Atmosphere XII, Proceedings of SPIE Vol. 6745, paper 6745-30, 2007

Lead : Peter Szewczyk

CERES Edition3 Calibration Report

Edition3 Calibration Protocol : Updates

Re-Analysis of Ground Calibration Data

- Update uncertainty analysis
- Verify at-launch Radiometric Gains
- Verify at-launch Spectral Response Functions

In-Flight Radiometric coefficient updates

- Gain
- Offsets
- 2nd Time Constant
- Thermal Correction

Determination of ***Filtered*** Radiances

Establish a common Radiometric Scale across all CERES Sensors

- Flight Model 1 chosen as the standard

Determine optimal Spectral Response Functions to account For spectral darkening in the reflected solar bands.

Determination of ***Unfiltered*** Radiances

CERES Edition3 Calibration Report

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Determine optimal Spectral Response Functions to account For spectral darkening in the reflected solar bands.

Determination of ***Unfiltered*** Radiances

Edition3 Spectral Darkening Correction & Validation Of CERES Reflected Solar bands (SW and SW/TOT channels)

Part 1

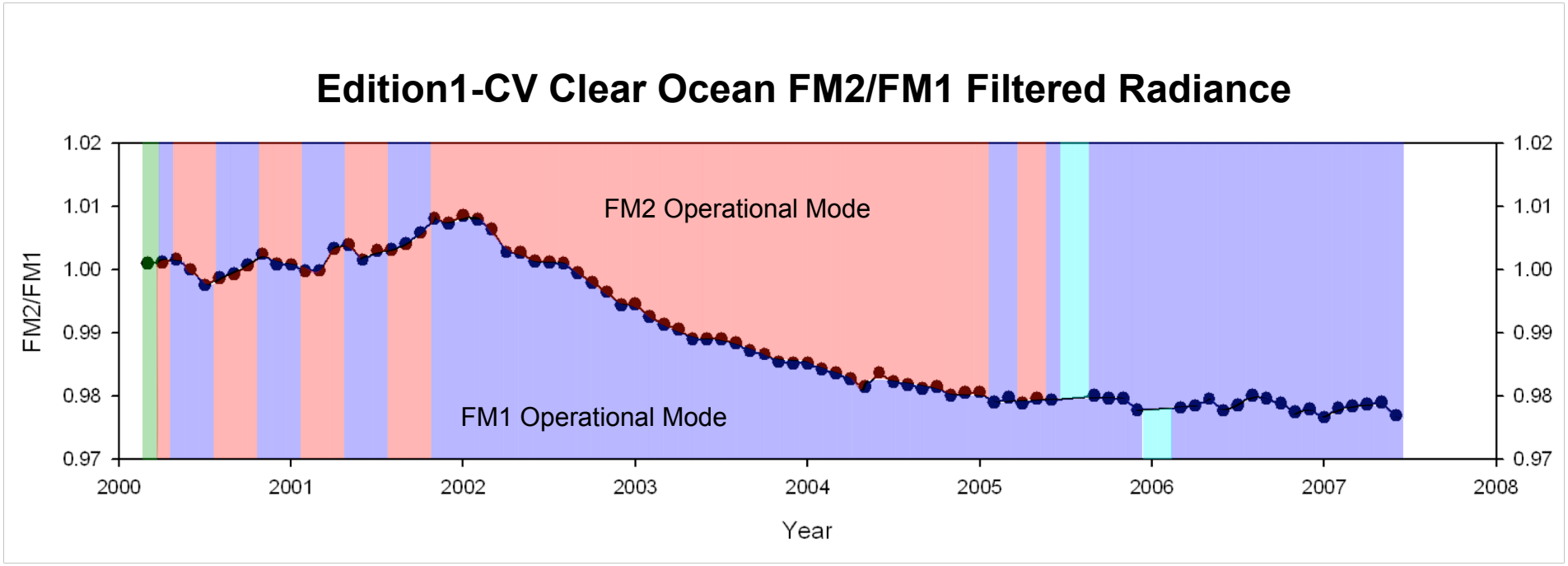
SW Channel

Strategy for Characterizing Spectral Degradation

Direct Nadir Radiance Comparison

- **Assumptions**
  - temporal variation in FM2/FM1 SW unfiltered radiance ratio (i.e. direct nadir radiance comparison) is due to spectral degradation
  - Spectral degradation occurs only on RAPS instrument
- **Compare monthly averaged spatially/temporally matched nadir FM1 and FM2 observations for specific scene types**
  - Clear ocean shows largest sensitivity to RAPS spectral darkening
- **Xtrack mode sensor - unfilter with previous month's SRF.**
- **RAPs mode sensor - Retrieve optimal SRF from a set of candidate SRFs with varying degrees of spectral darkening**
  - Optimal RAP SRFs ensure constant SW unfiltered FM2/FM1 radiance ratio throughout the mission.

Operational Mode and Direct Compare



Bi-axial (RAPS)

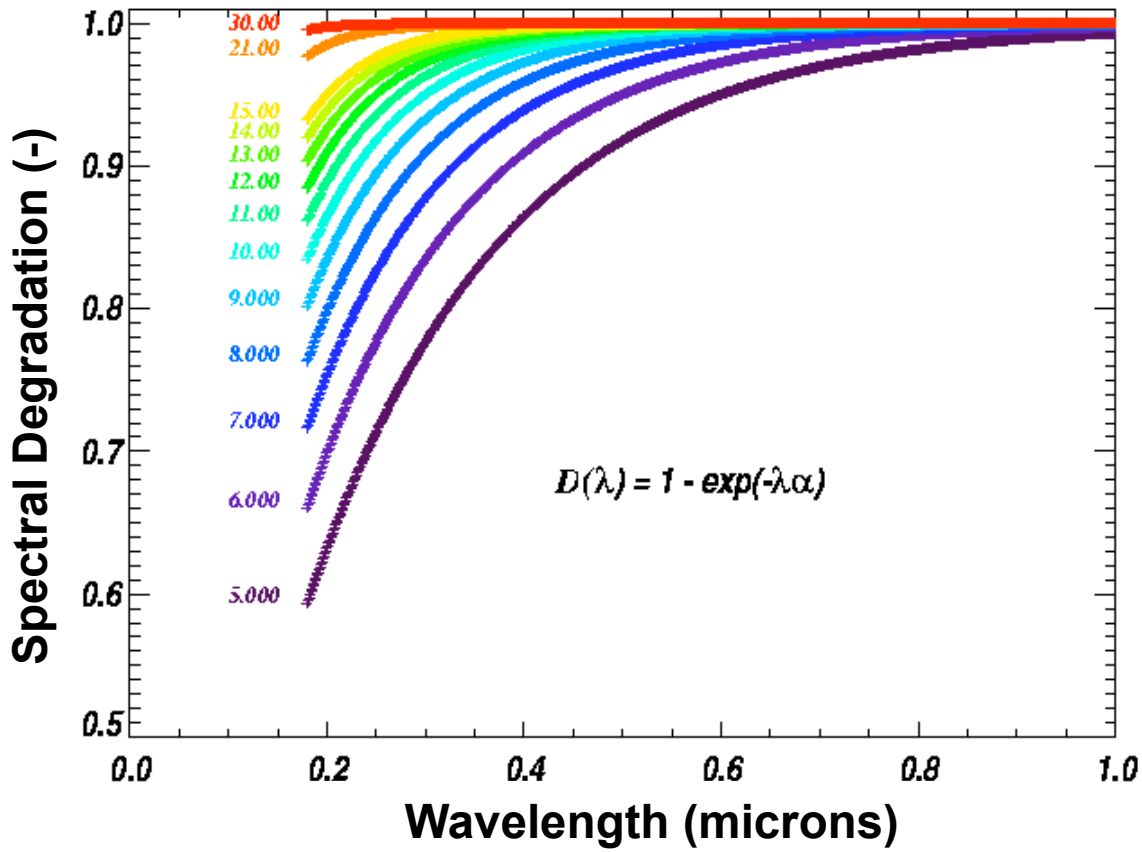
Crosstrack (FAPS)

Stowed

Mixed Crosstrack/Biaxial

Instrument operating in RAPS mode drops in SW response relative to instrument operating in cross-track mode.

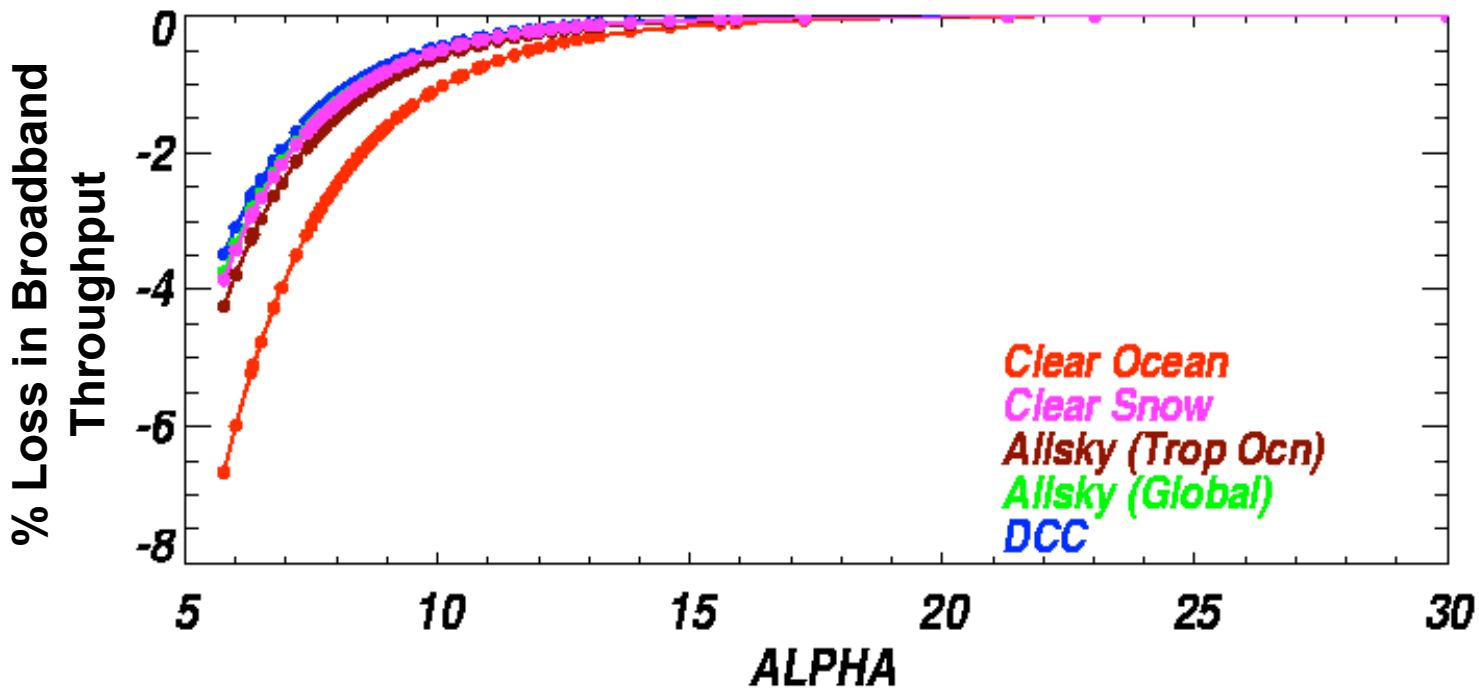
Candidate Spectral Darkening Curves



- *Functional form similar to that observed in other missions (e.g. GOME, LDEF)*
- *Spectral darkening increases with shorter wavelengths.*
- *Plot shown is only a subset of the 53 "candidate" curves.*

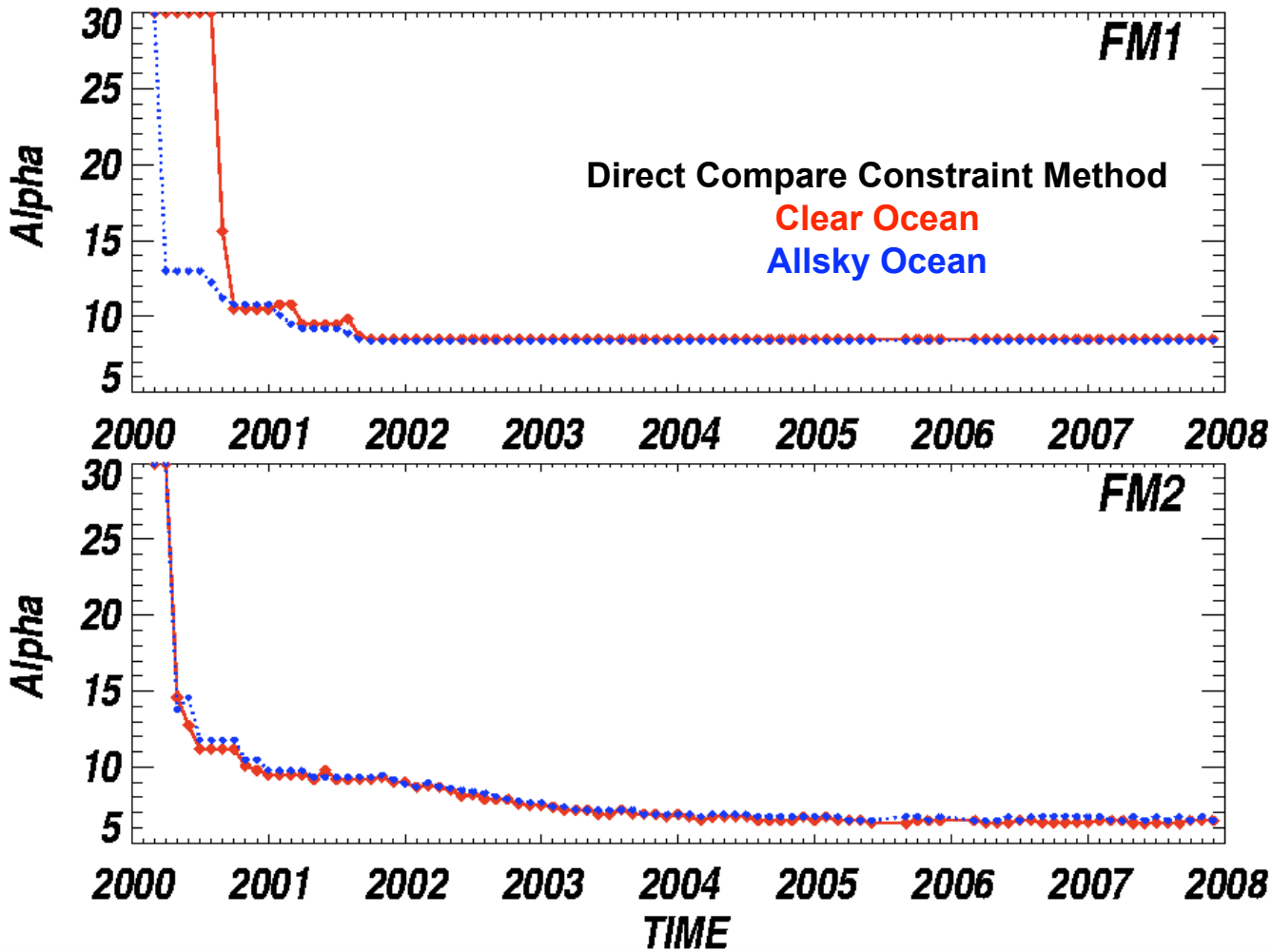
Impact to Observations of Typical Scenes

Approximate Relationship between Spectral Darkening Parameter and SW Radiance Changes since BOM (Terra)



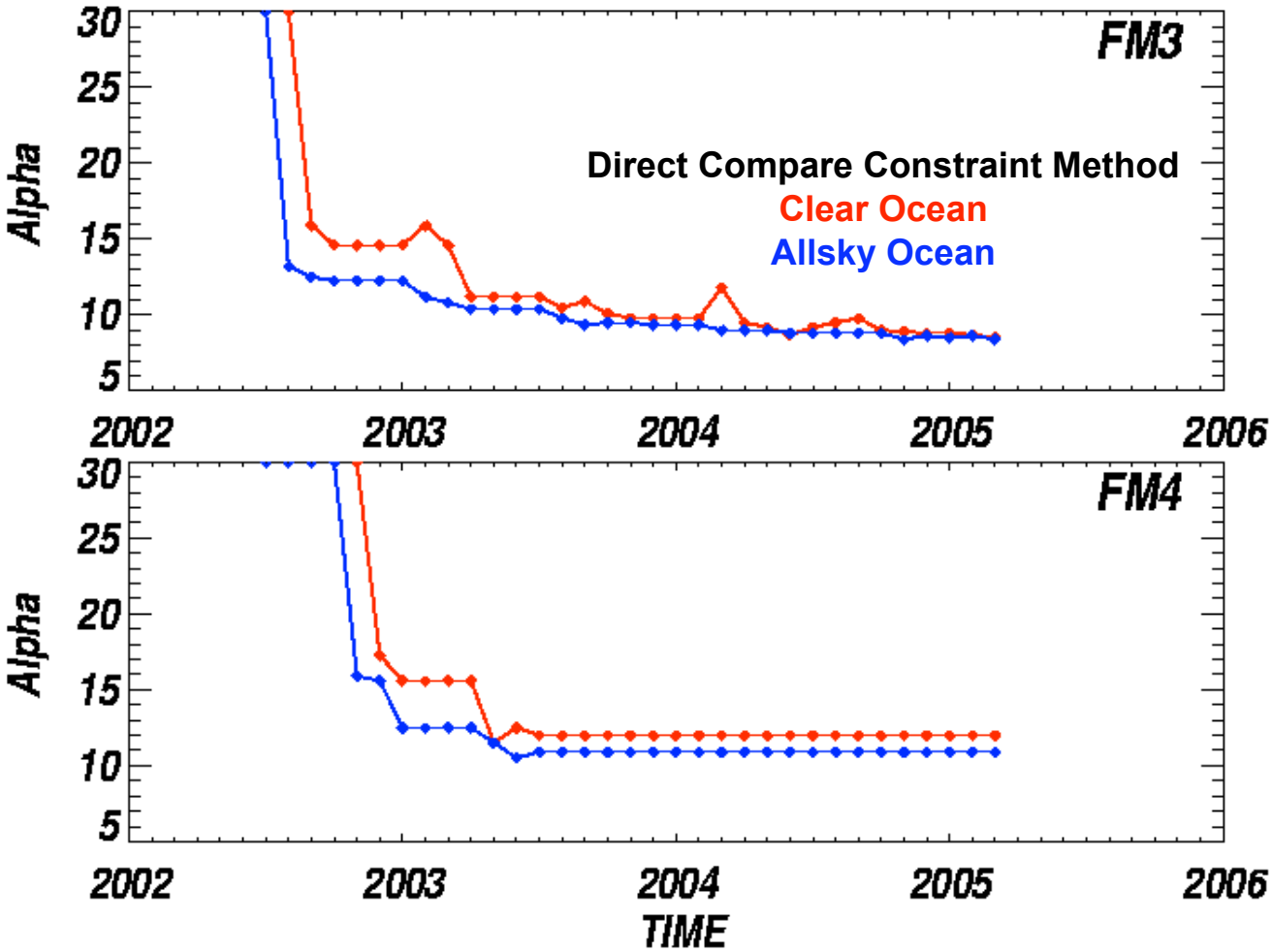
Retrieved SW Channel Degradation Parameter Alpha

Terra

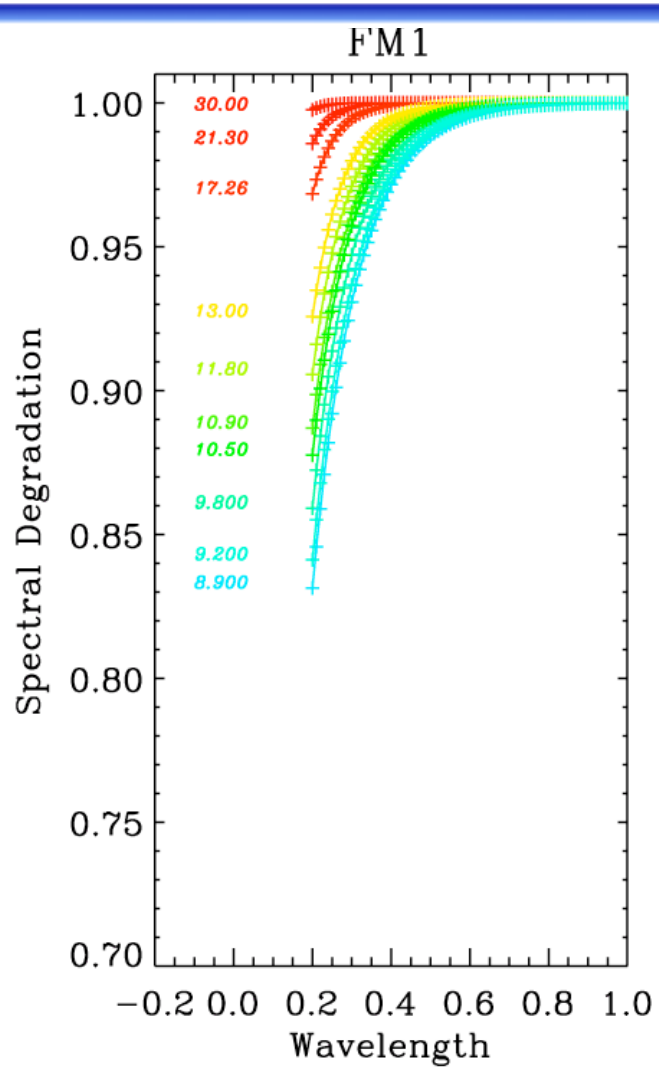


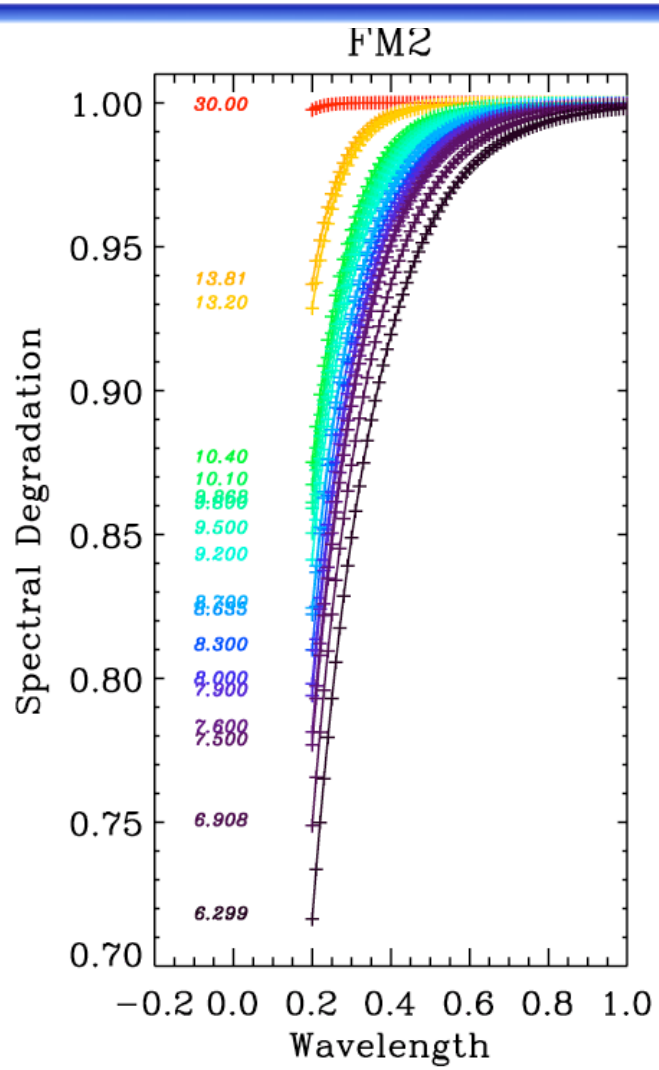
Retrieved SW Channel Degradation Parameter Alpha

Aqua

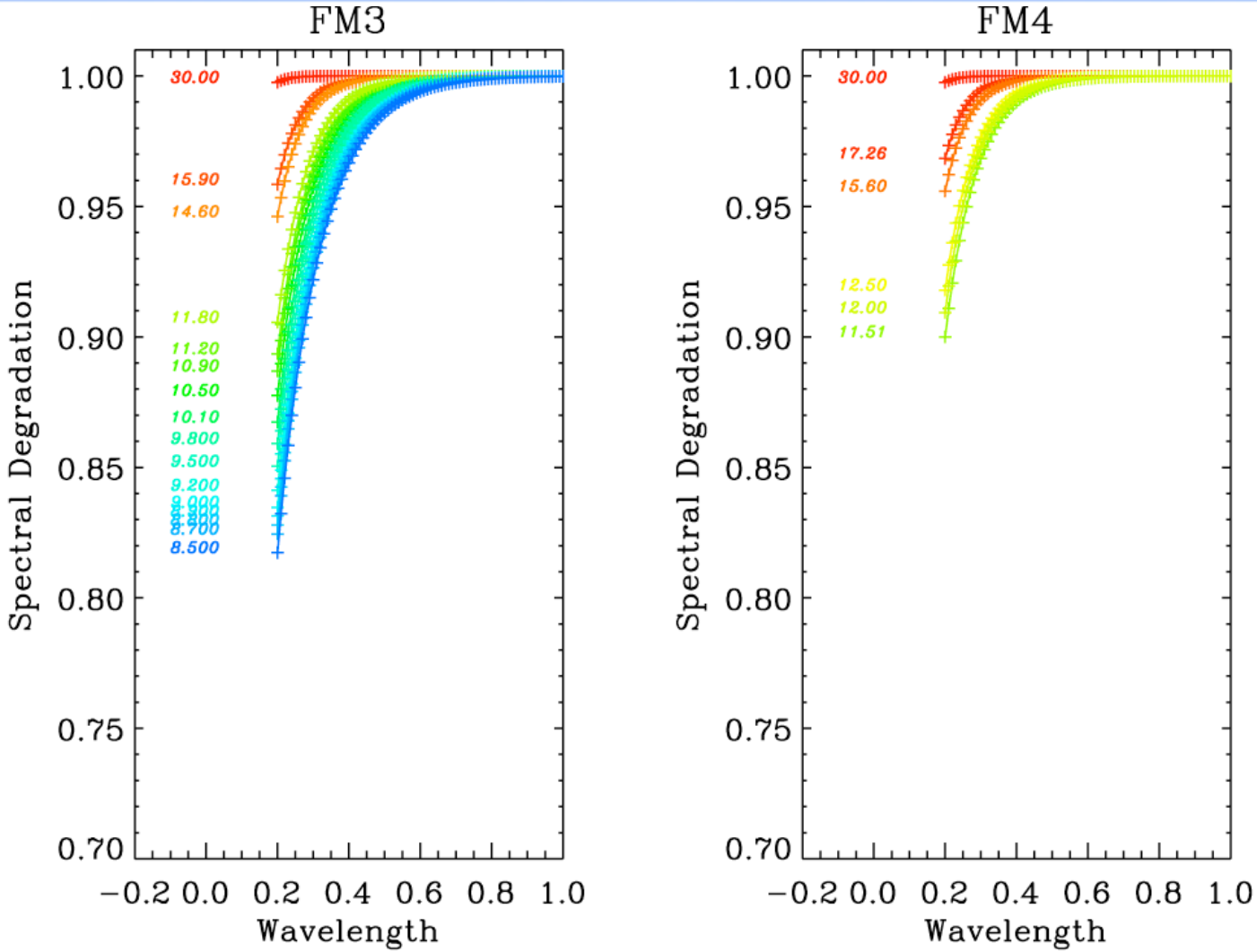


Alpha Retrieval Results : FM1 and FM2 SW Channels



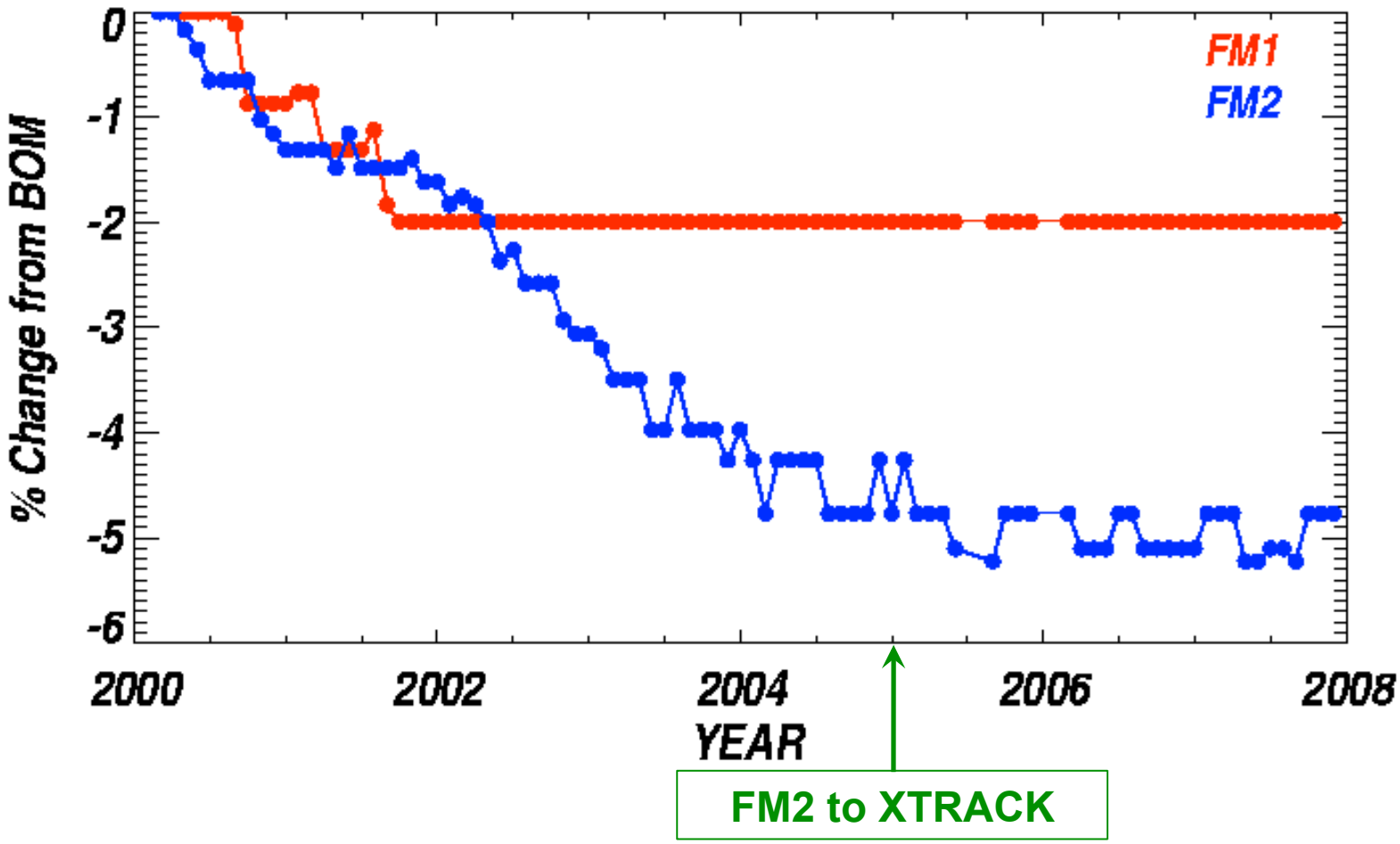


Alpha Retrieval Results : FM3 and FM4 SW Channels



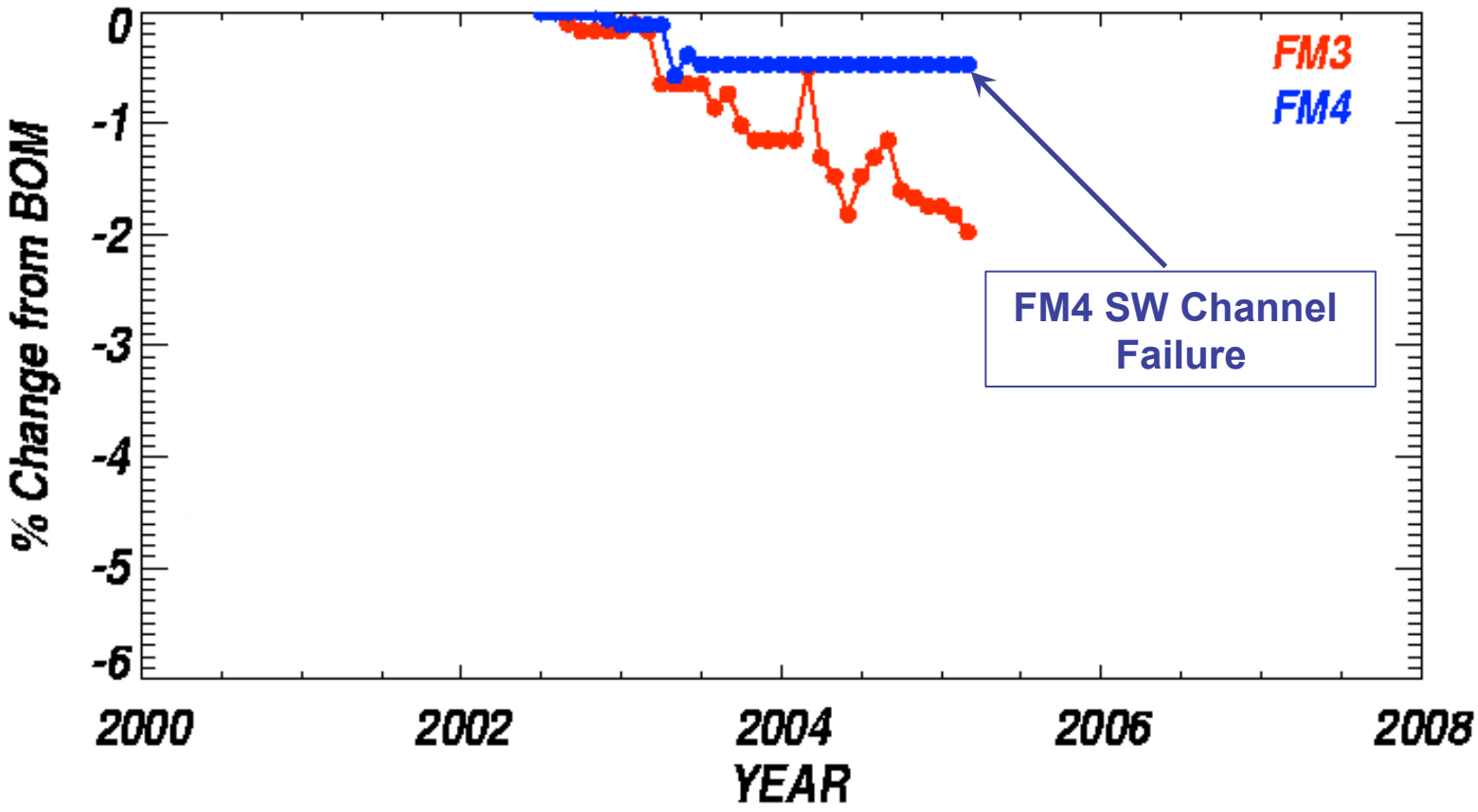
SW Channel Broadband Throughput Loss

Sciamachy Clear Ocean Spectra

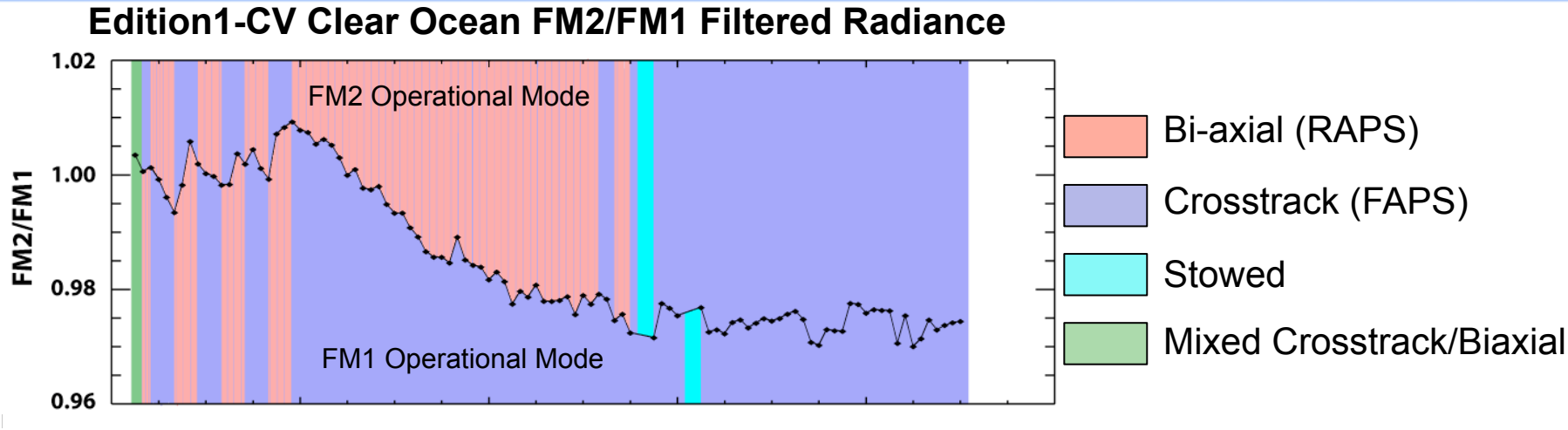


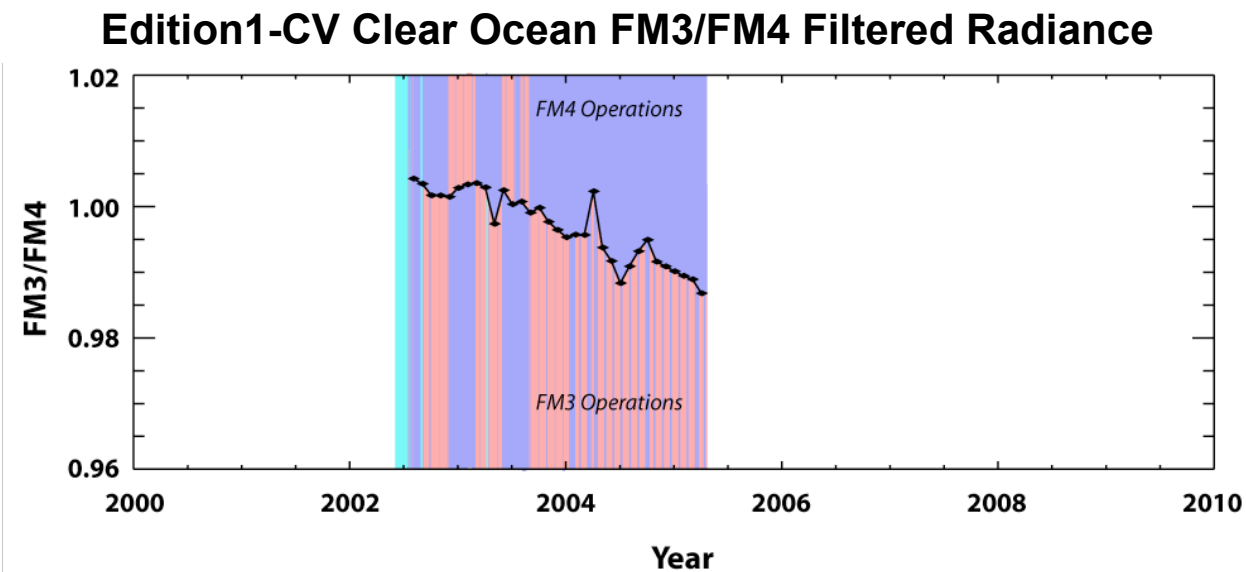
SW Channel Broadband Throughput Loss

Sciamachy Clear Ocean Spectra



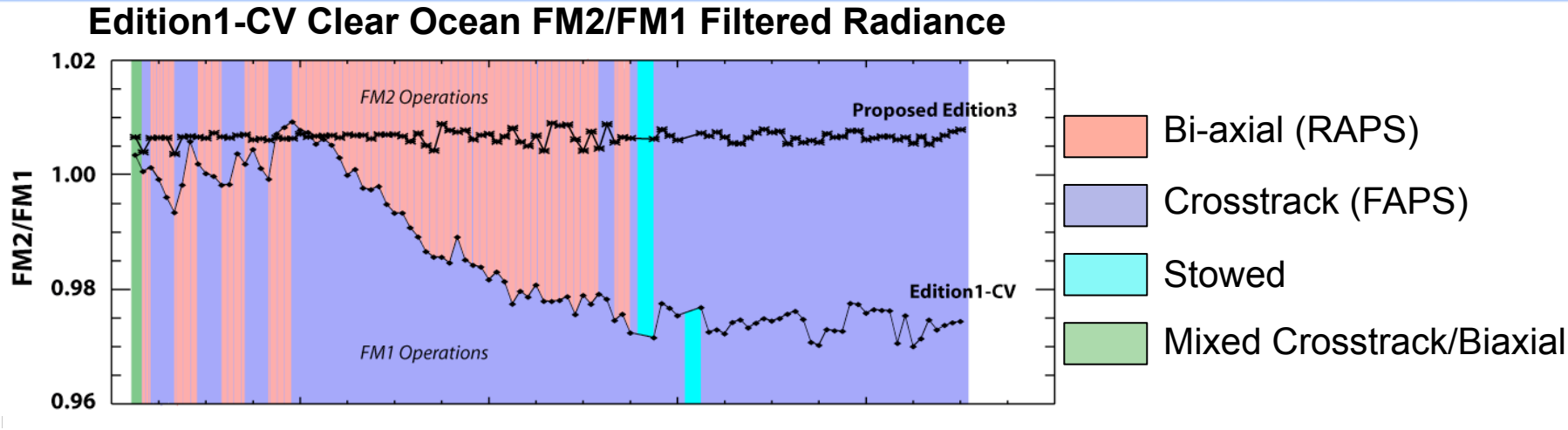
Operational Mode and Direct Compare

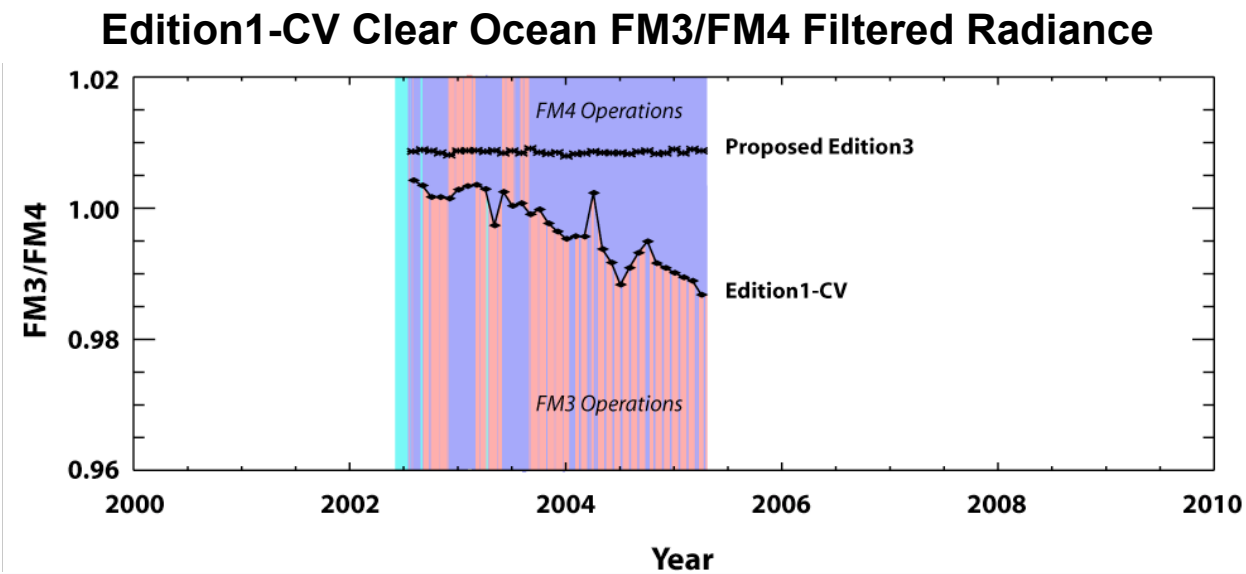




Instrument operating in RAPS mode drops in SW response relative to instrument operating in cross-track mode.

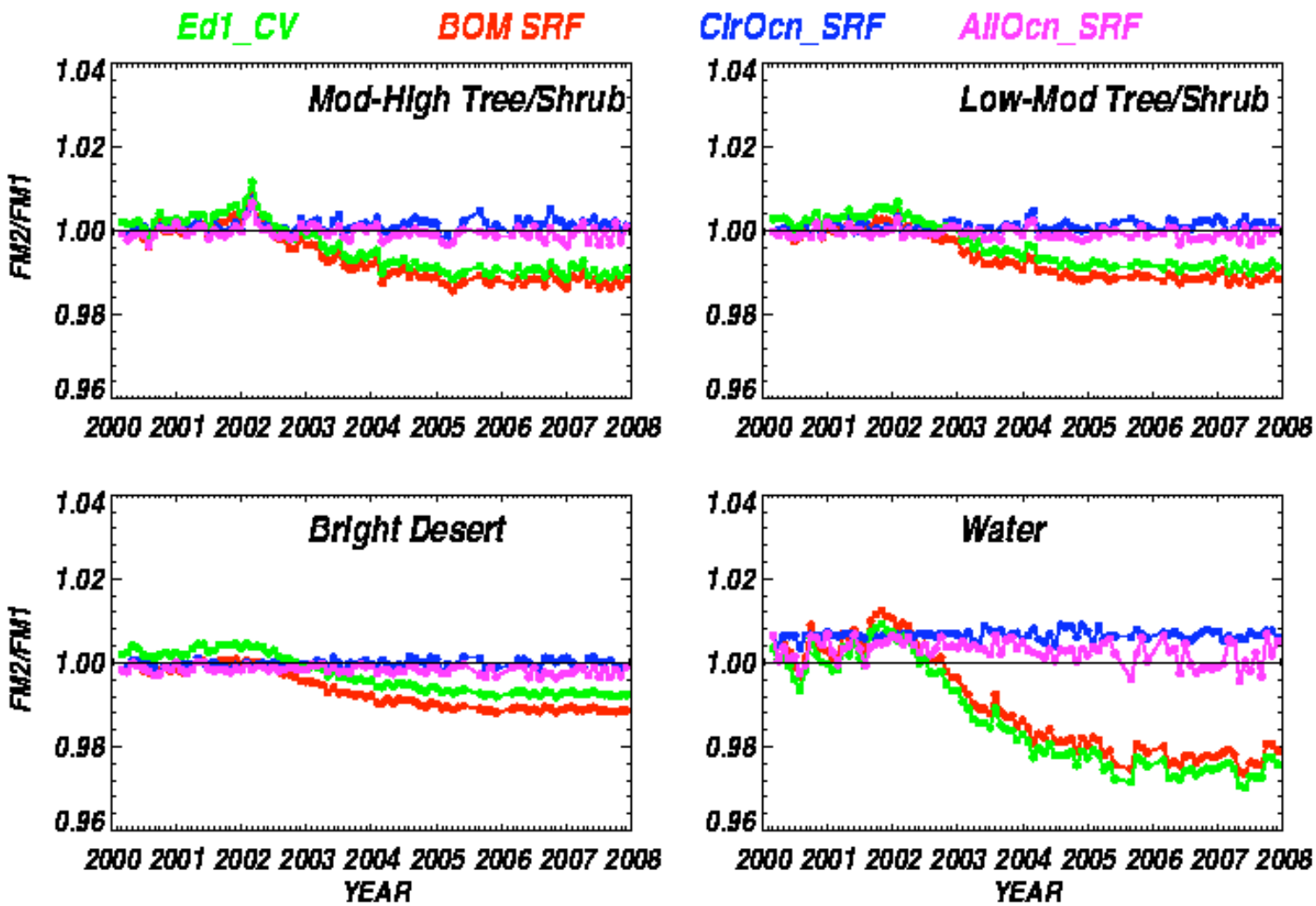
Operational Mode and Direct Compare



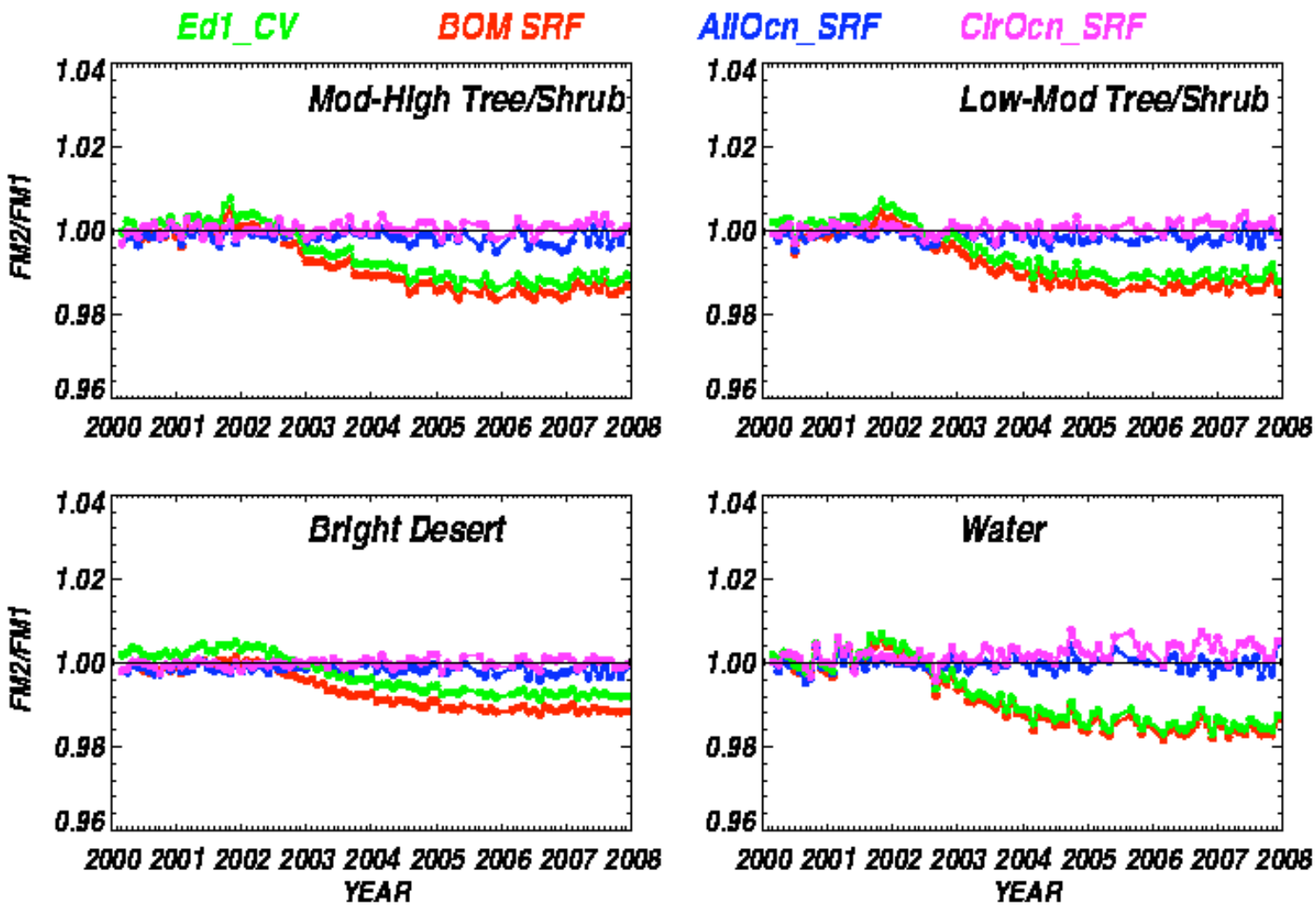


Instrument operating in RAPS mode drops in SW response relative to instrument operating in cross-track mode.

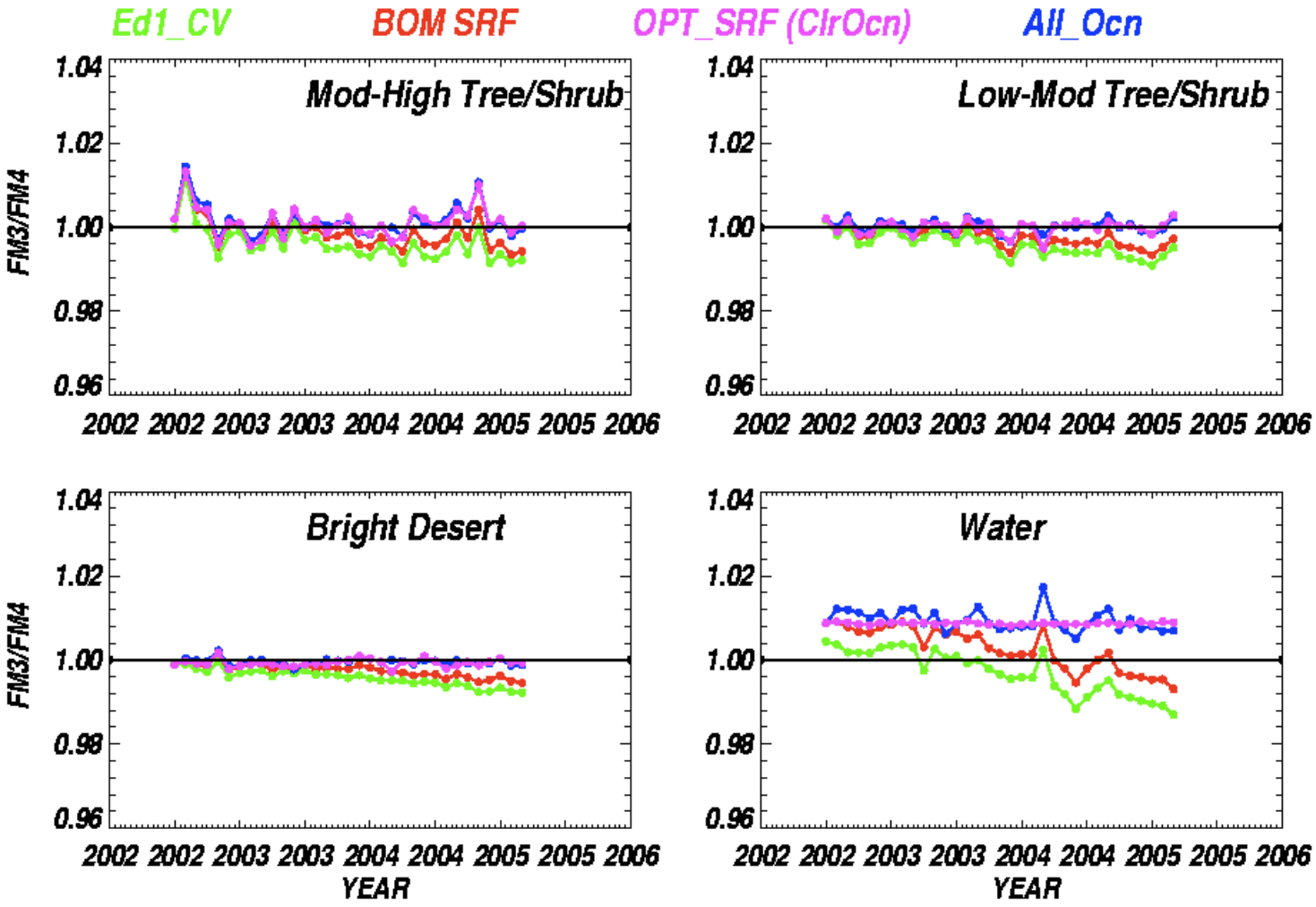
FM2/FM1 SW Unfiltered Radiance Ratio for *Clear Sky* Scenes



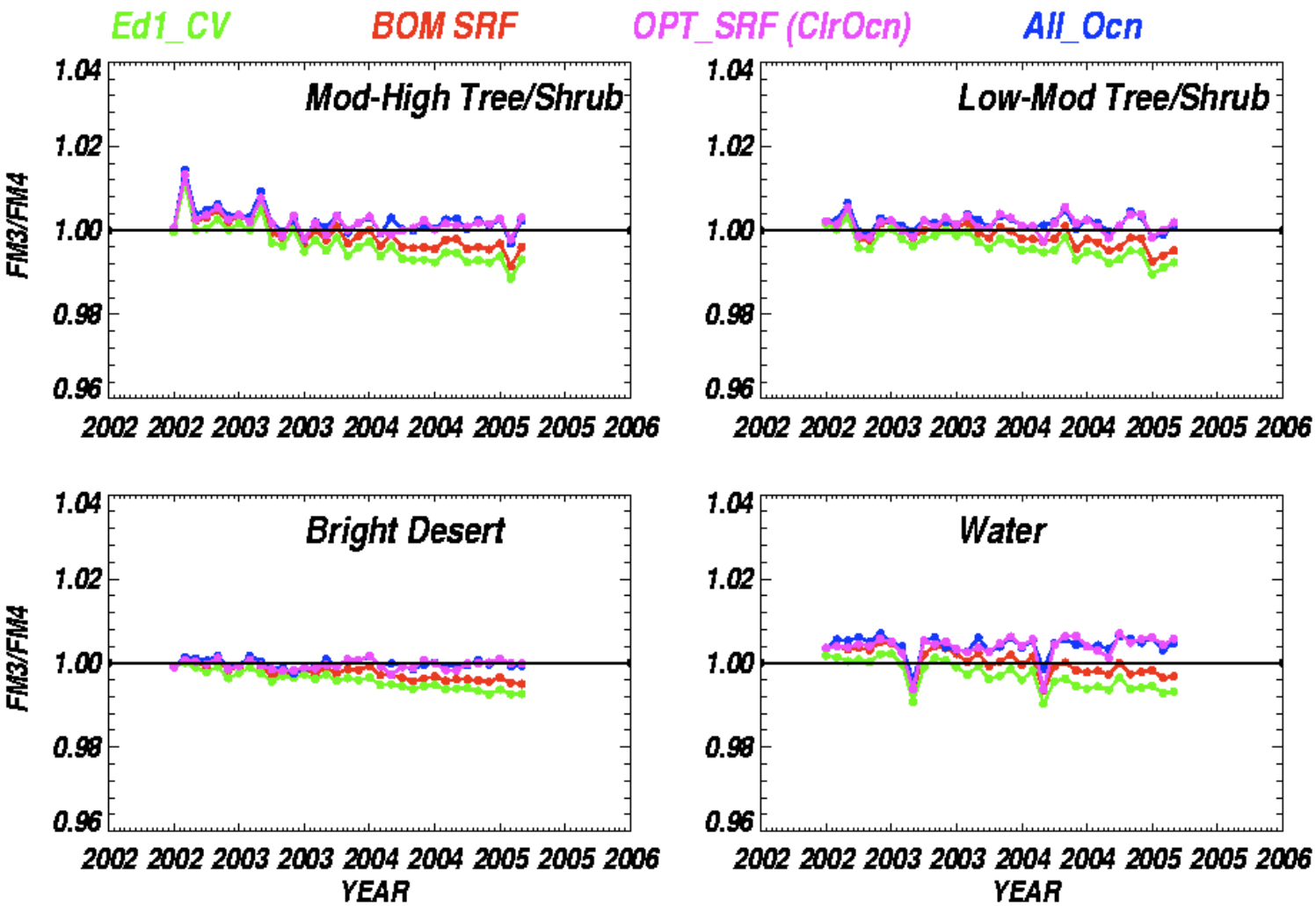
FM2/FM1 SW Unfiltered Radiance Ratio for *All Sky* Scenes



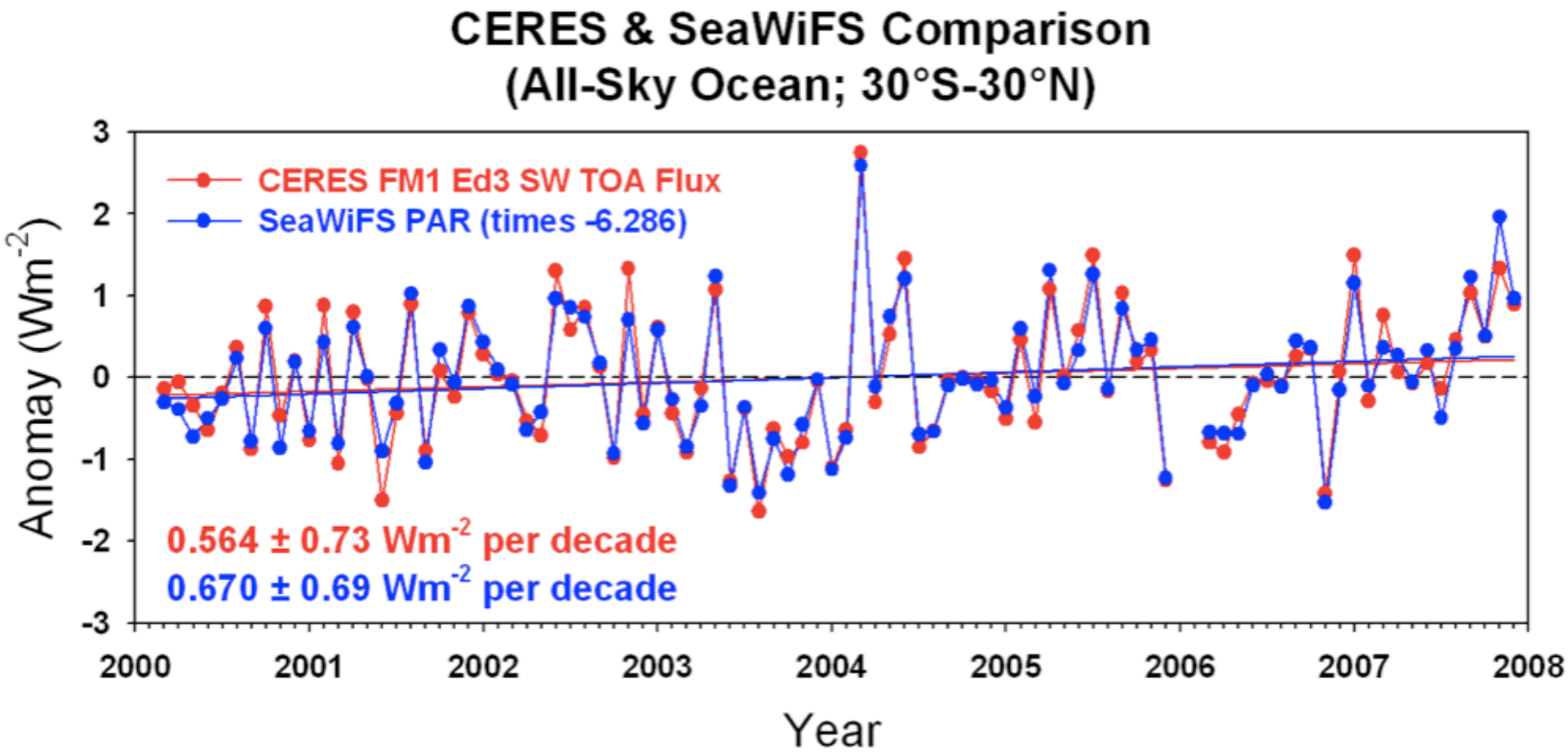
FM3/FM4 SW Unfiltered Radiance Ratio for *Clear Sky* Scenes



FM3/FM4 SW Unfiltered Radiance Ratio for *All Sky* Scenes



Edition3 Validation : CERES to SeaWiFS



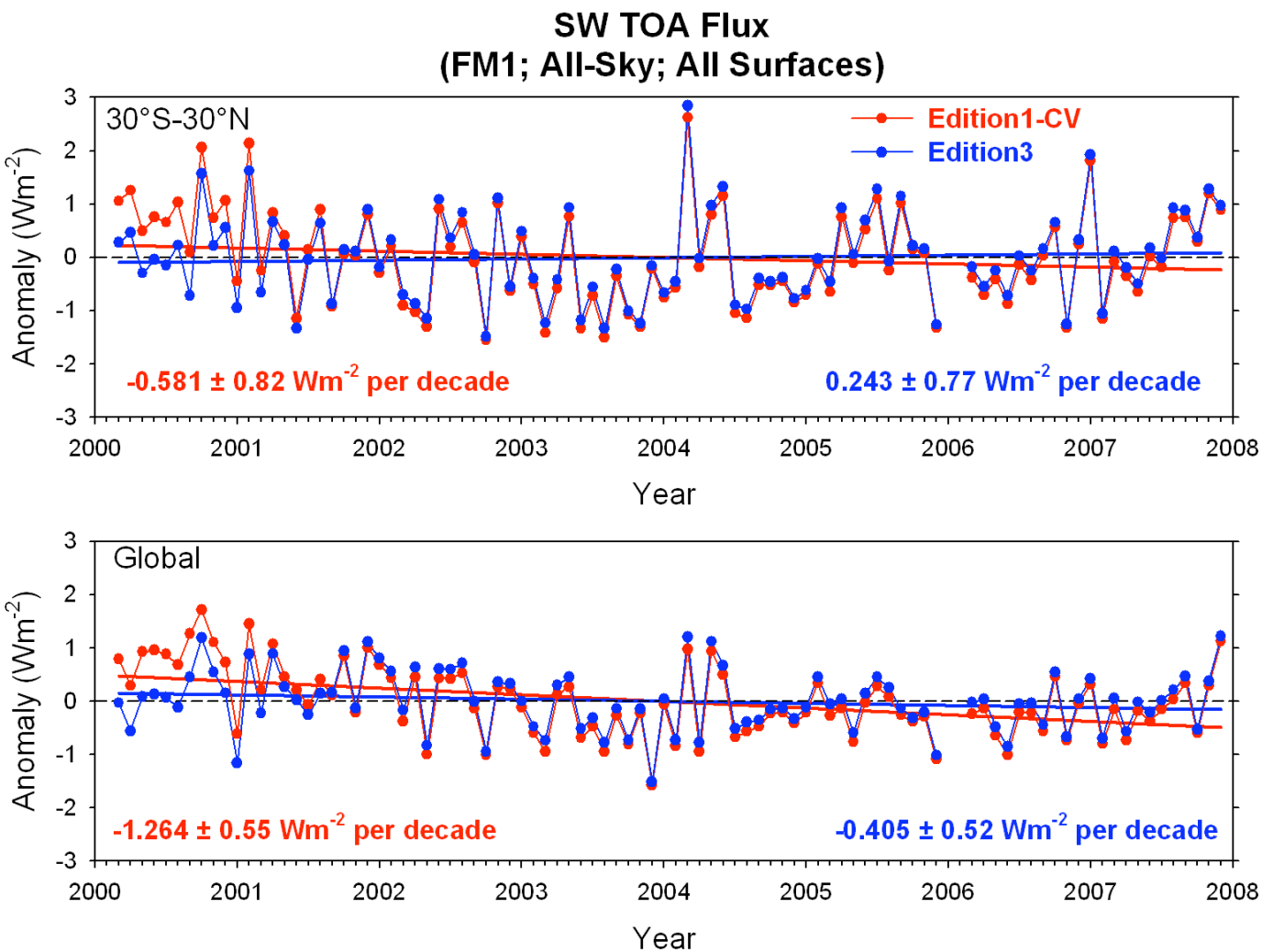
CERES Anom Minus SeaWiFS Anom: -0.106 ± 0.2 Wm^{-2} per decade

CERES Variability (1σ) = 0.79 Wm^{-2}

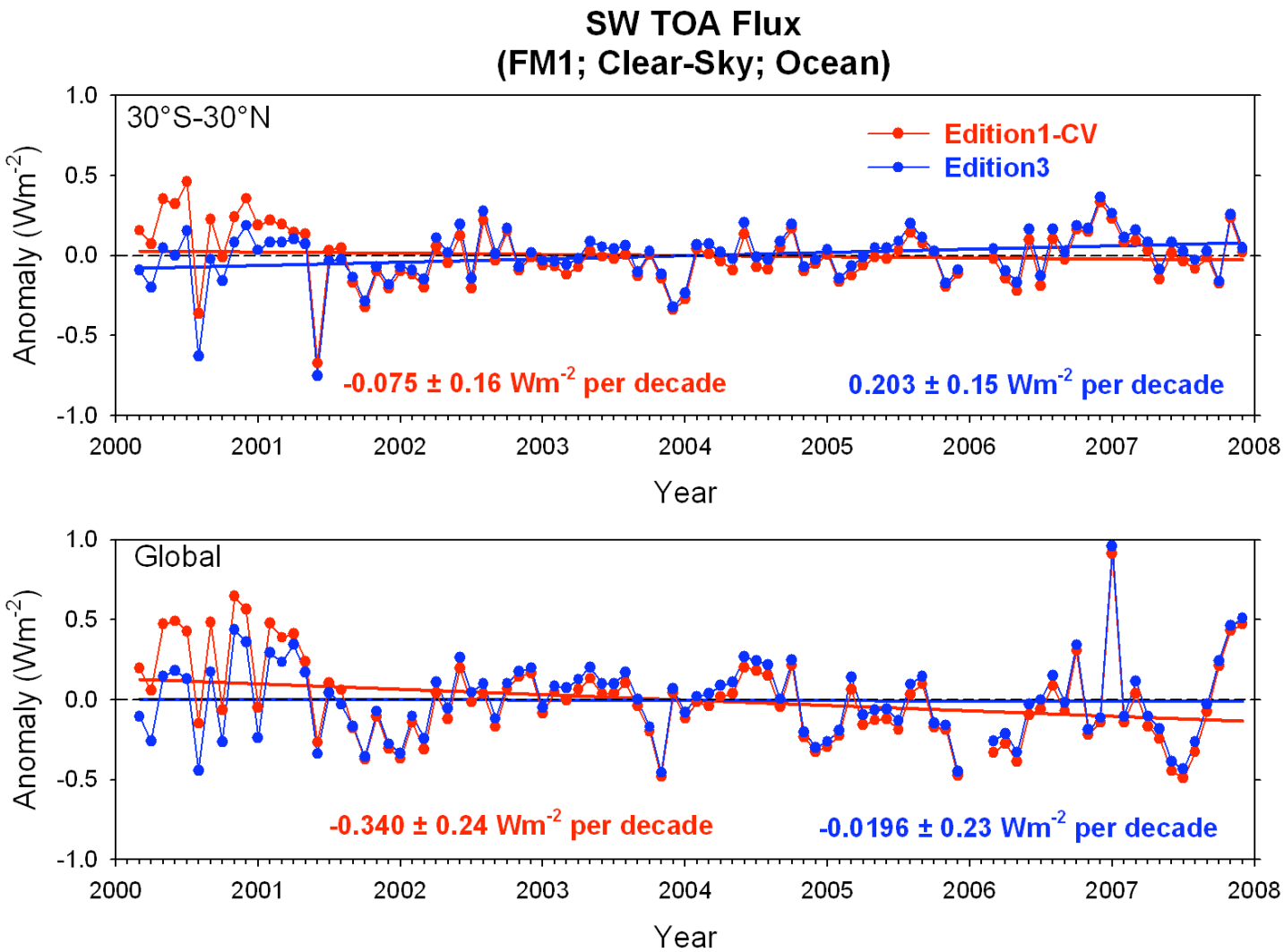
SeaWiFS Variability (1σ) = 0.76 Wm^{-2}

σ(CERES - SeaWiFS) = 0.21 Wm^{-2}

Edition3 Validation : SW TOA Flux



Edition3 Validation : SW TOA Flux



Part 2

SW Portion of Total Channel

or

Daytime LW Fluxes

LW Day Night Difference Trends

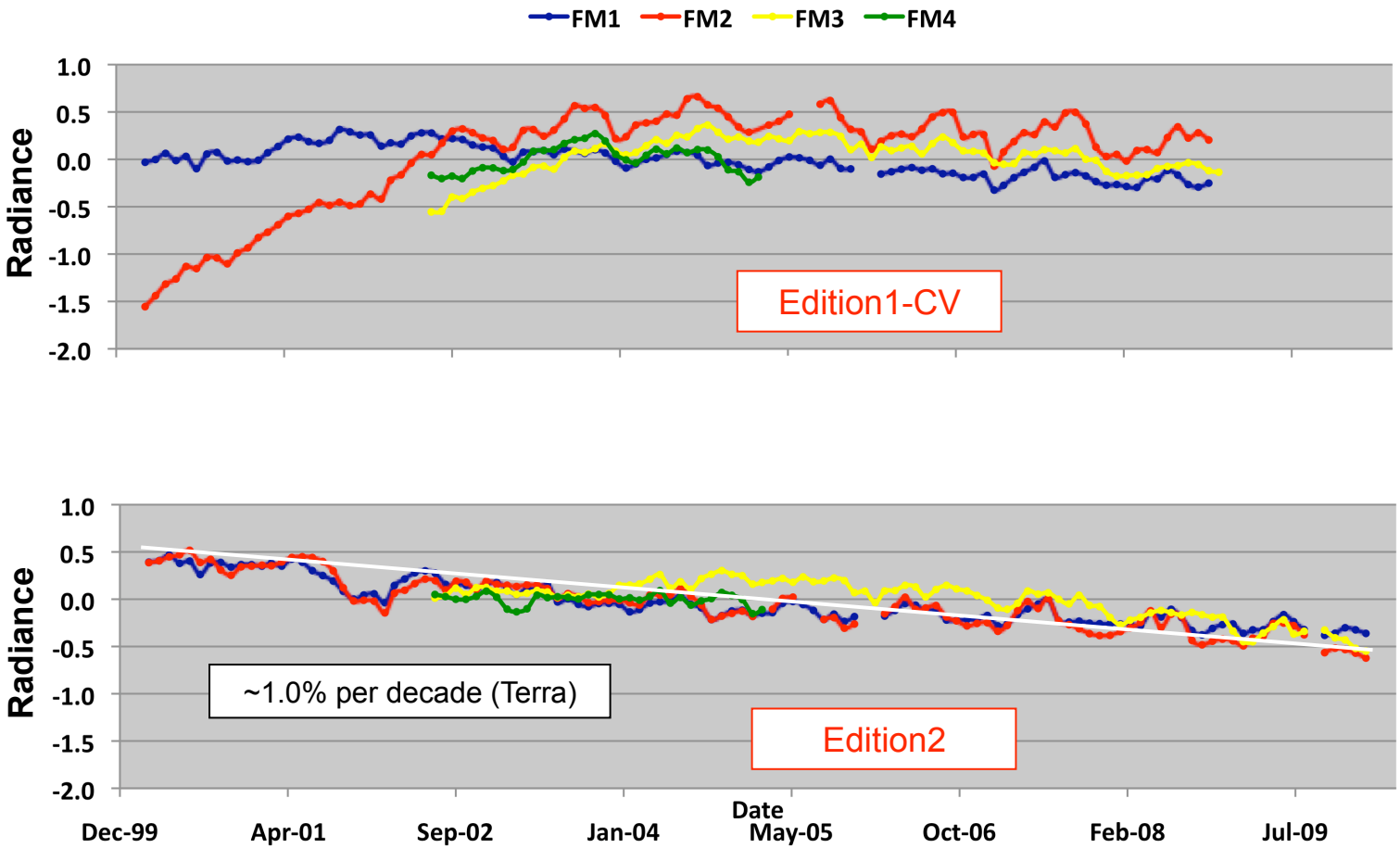
$$LW_{day} = Total - Shortwave$$

$$LW_{day} = LW/TOT + SW/TOT - Shortwave$$

$$LW_{night} = LW/Total$$

- Apply Total, WN and SW gains.
- Apply Optimal SW channel SRF's
- Select Total SRF from a "candidate" set of SRFs that constrains the OLR Daytime minus Nightime difference to the trend of the WN channel Daytime minus Nightime observations.
- WN channel Daytime minus Nightime difference is robust
  - Calibration stability over an orbital cycle
  - As a proxy for the broadband OLR Day Night difference trends
    - Verified by comparison to AIRs

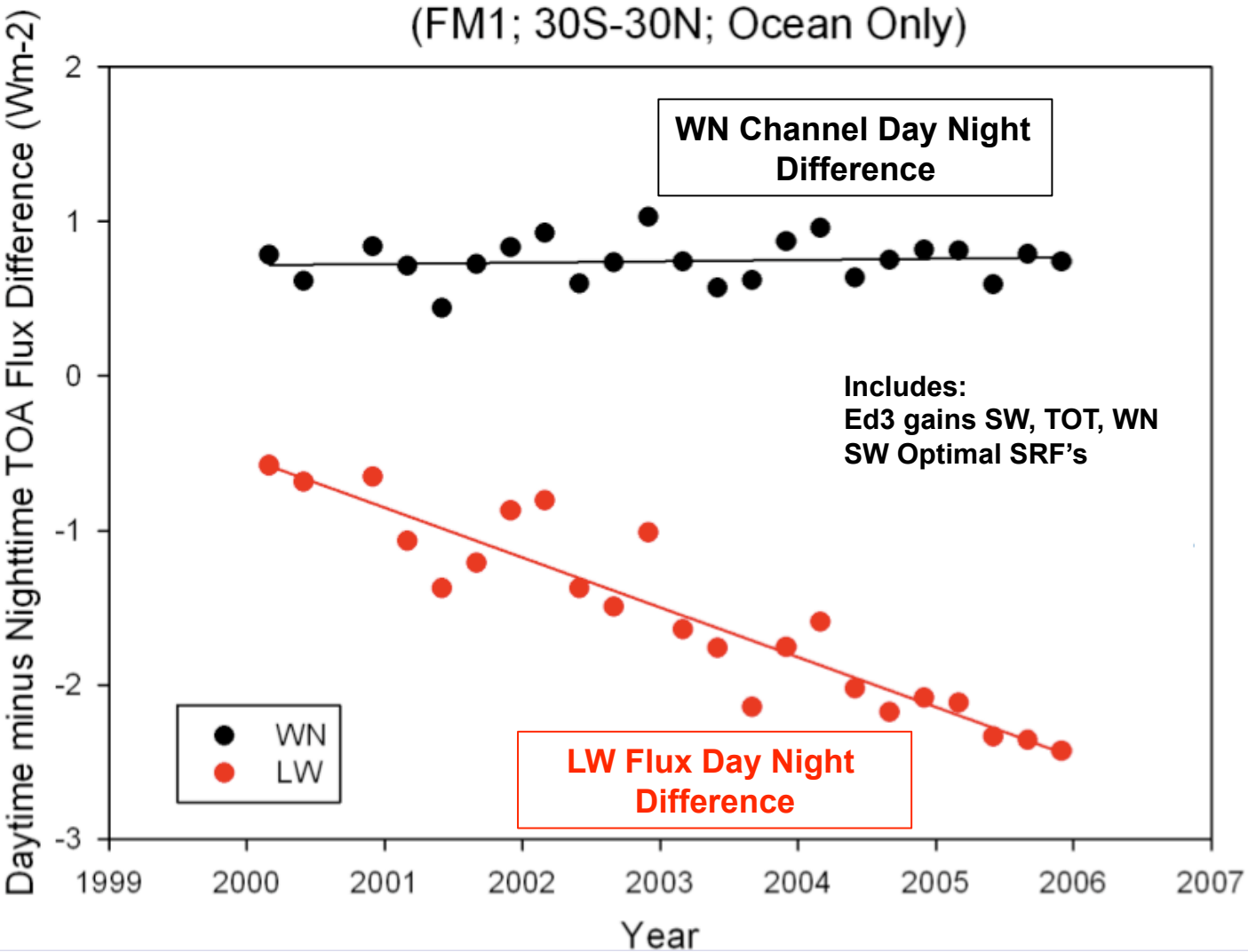
OLR Day Night Difference Trends : Tropical Mean



Data Set

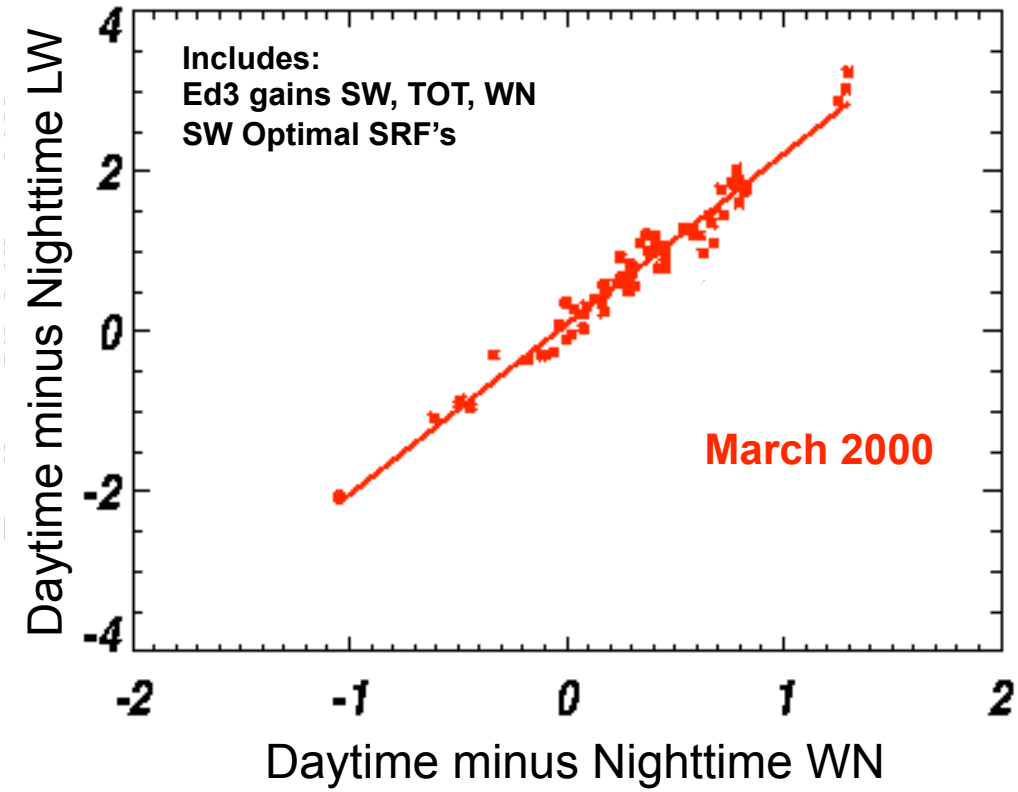
- LW Unfiltered Radiance
- Nadir
- 20N - 20S
- Tropical Ocean
- All-Sky

Tropical Mean Day – Night Flux Difference



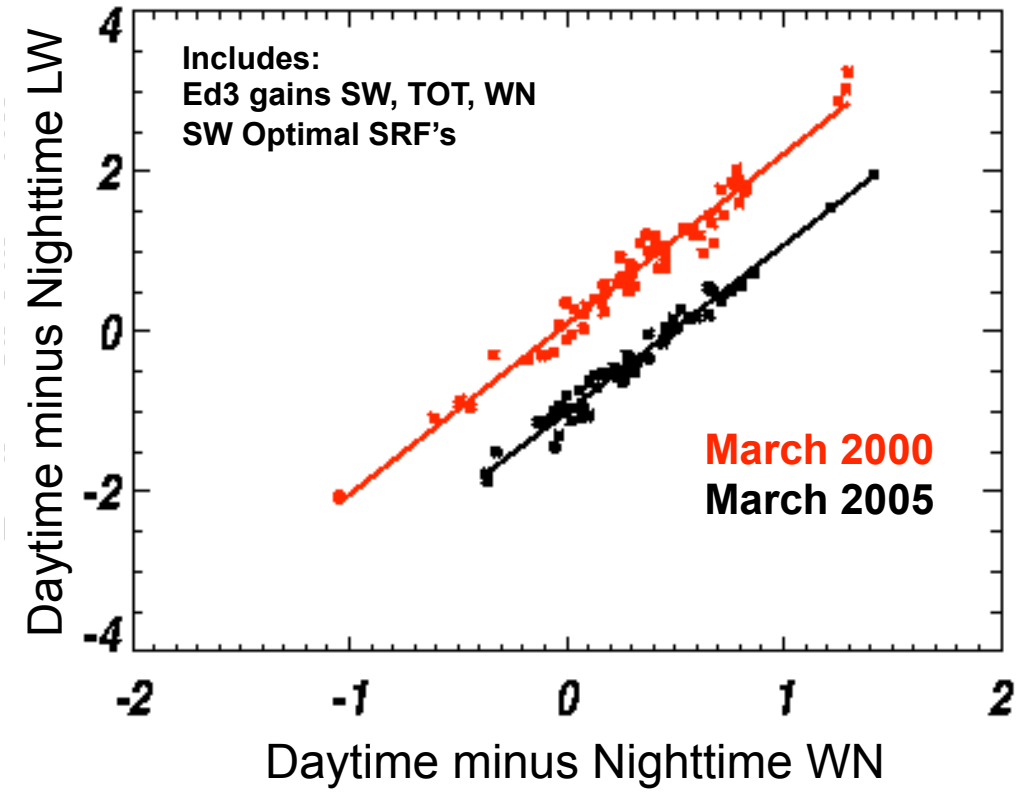
Establishing a Constraint for LW Fluxes

Zonal Averages of Unfiltered Radiances
All-Sky Ocean (30S – 30N), FM1



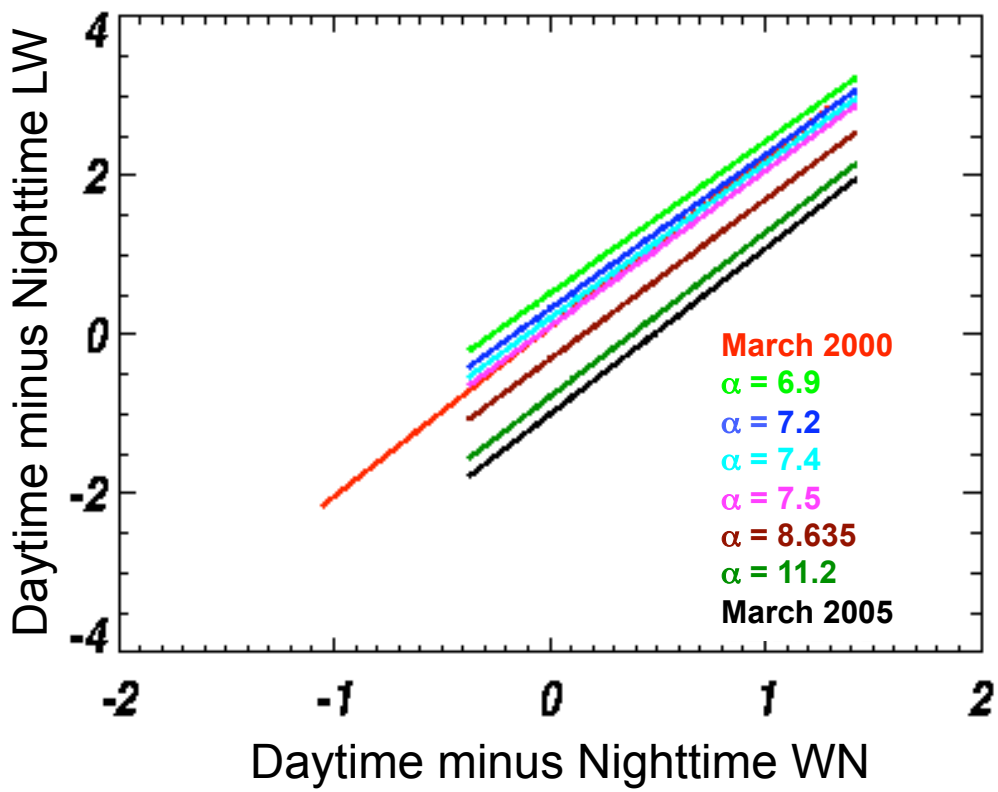
Establishing a Constraint for LW Fluxes

Zonal Averages of Unfiltered Radiances
All-Sky Ocean (30S – 30N), FM1

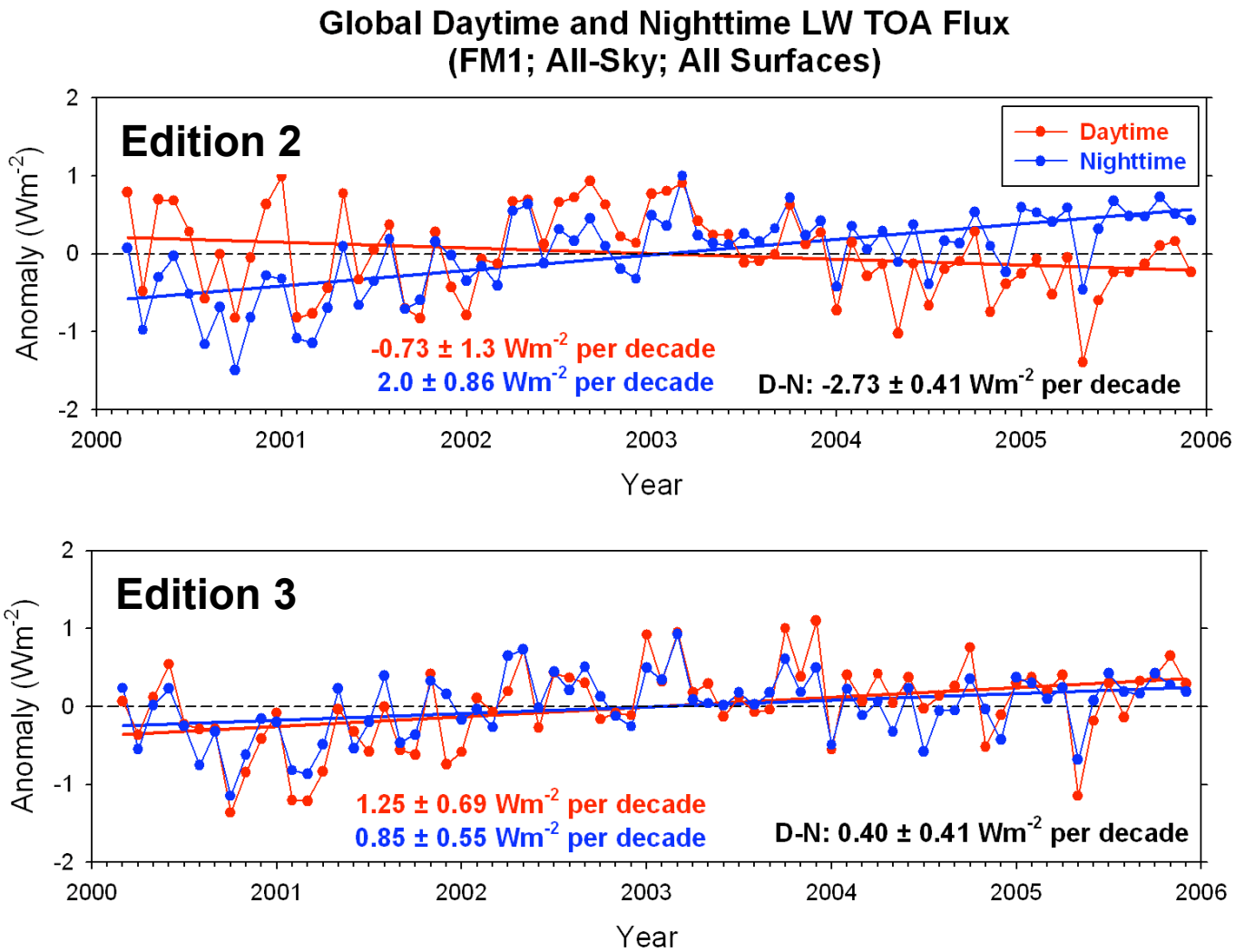


Determination of Optimal SRF for SW/TOT

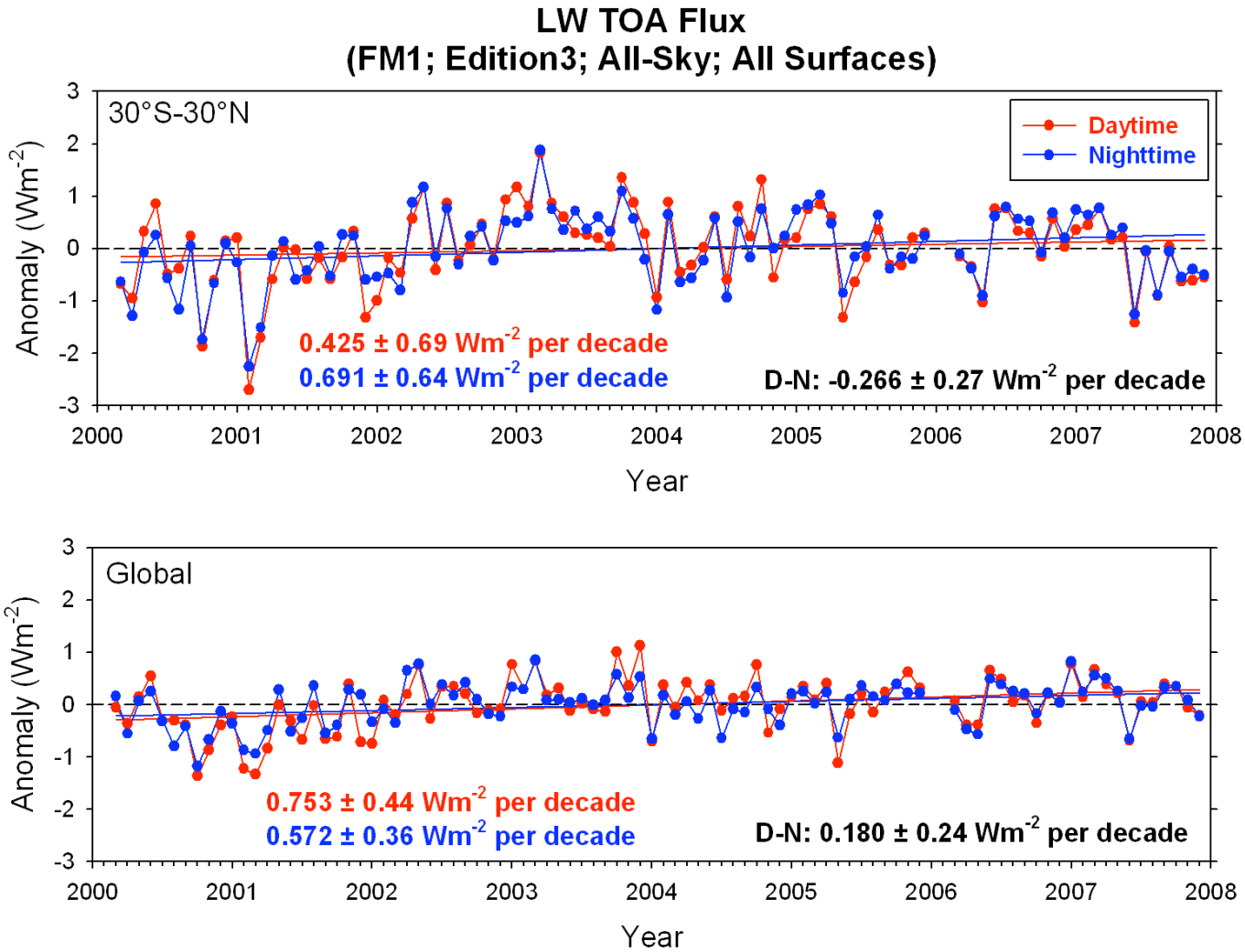
Zonal Averages of Unfiltered Radiances
All-Sky Ocean (30S – 30N), FM1



Edition 2 & 3 Day Night Comparison : LW TOA Flux



Edition3 Validation : LW TOA Flux



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

Funding not currently available

Design Change – Mirror Attenuator Mosaic

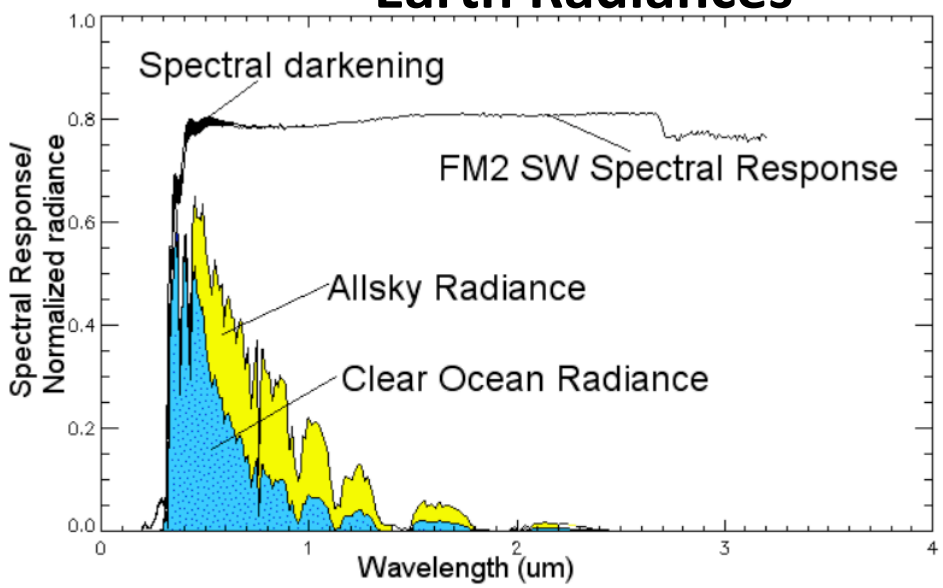
- **CERES utilizes a Mirror Attenuator Mosaic (MAM) to attenuate solar irradiance allowing the sun to serve as the primary radiometric source for quantifying radiometric stability of SW and SW portion of TOT channels**
  - Changes in the MAM's effective surface reflectance of 3 to 7 percent on the CERES/EOS 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***

Funding not Currently Available

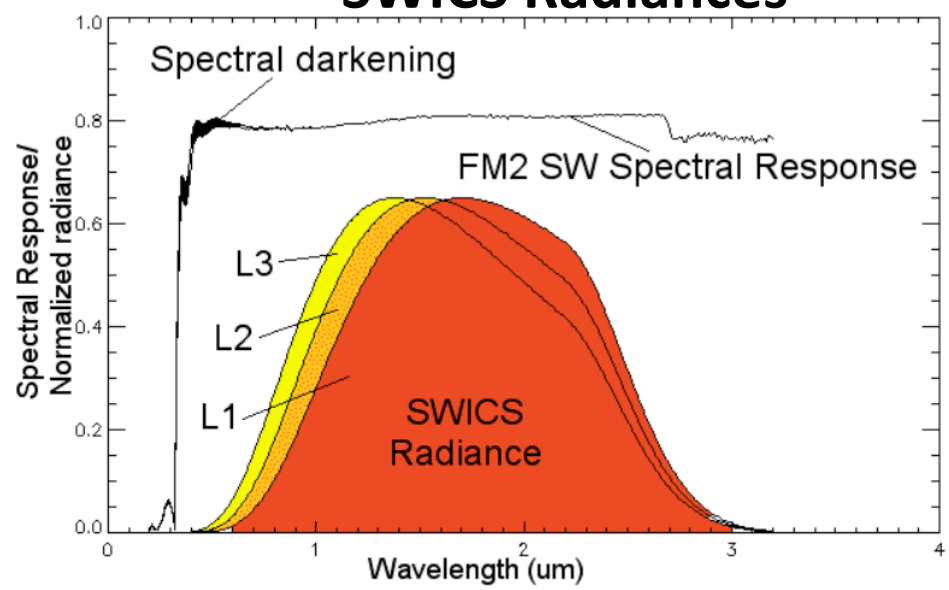
Legacy SWICS Calibration Source Spectral Content

- 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



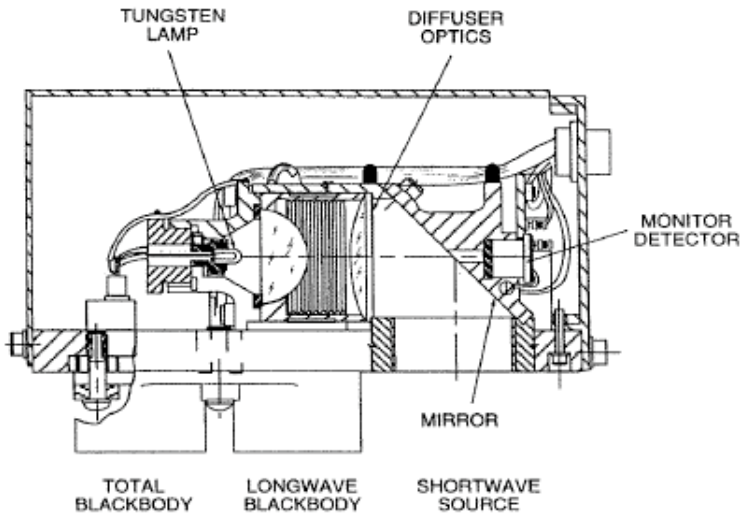
EOS Results

- 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)

Legacy CERES SW Onboard Calibration Sources

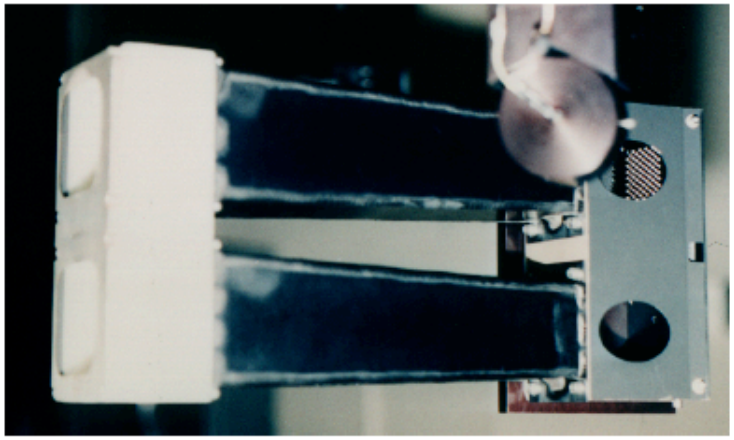
Shortwave Internal Calibration Source (SWICS)

- 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

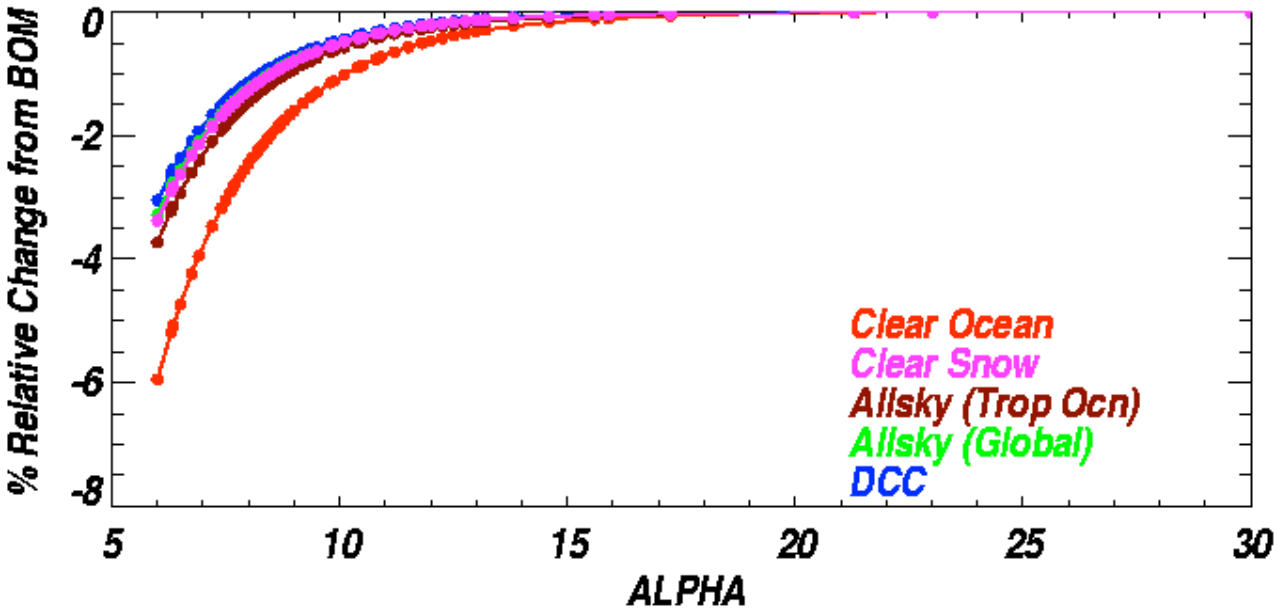


Mirror Attenuator Mosaic (MAM)

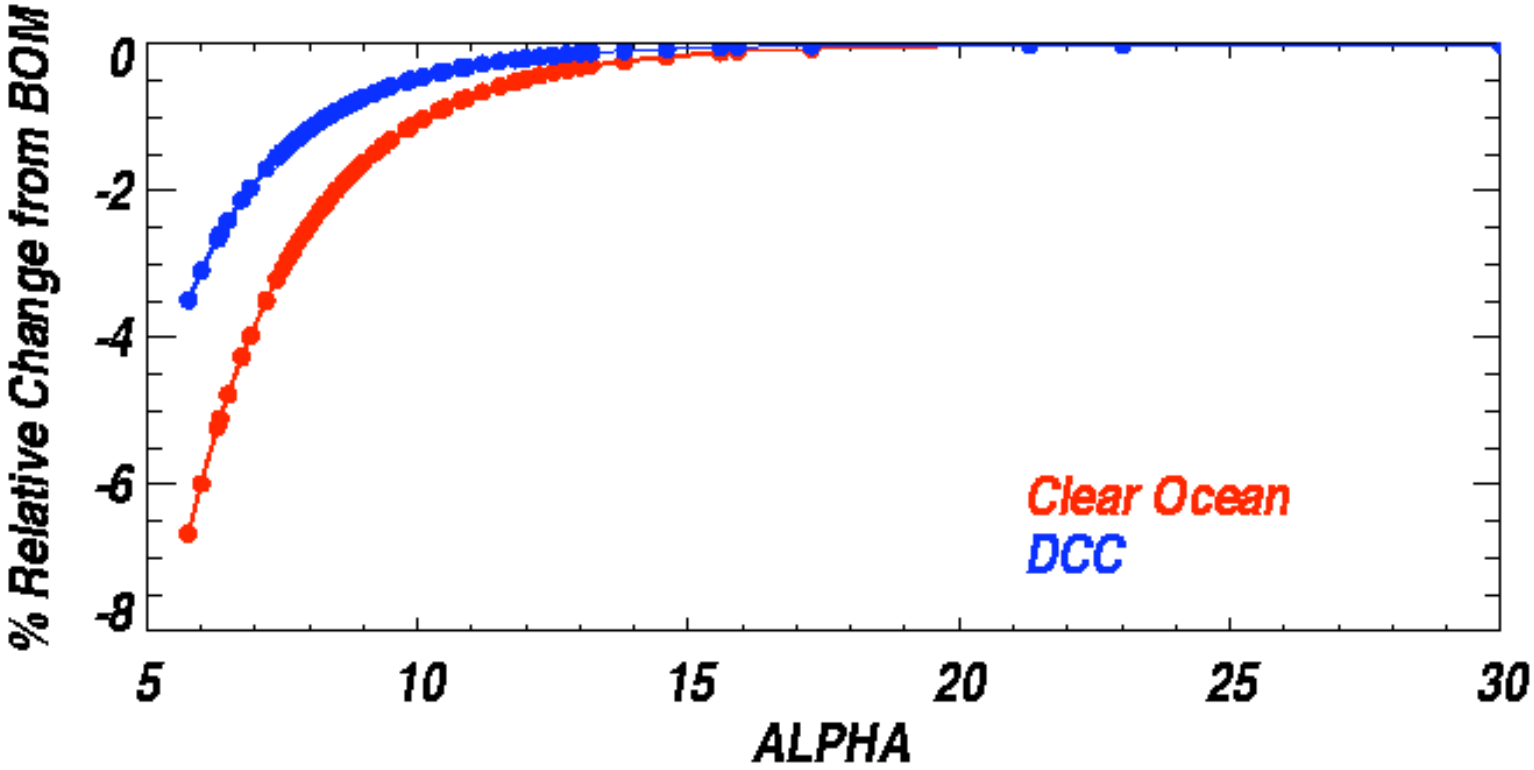
- Solar Diffuser plate attenuates direct solar view (~5800 K Spectrum)
- Nickel substrate with Aluminum coated spherical divots
- ***No independent reference detector***
- Provides a relative calibration of the Shortwave and Total channel
- Designed to provide a long-term on-orbit SW calibration source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



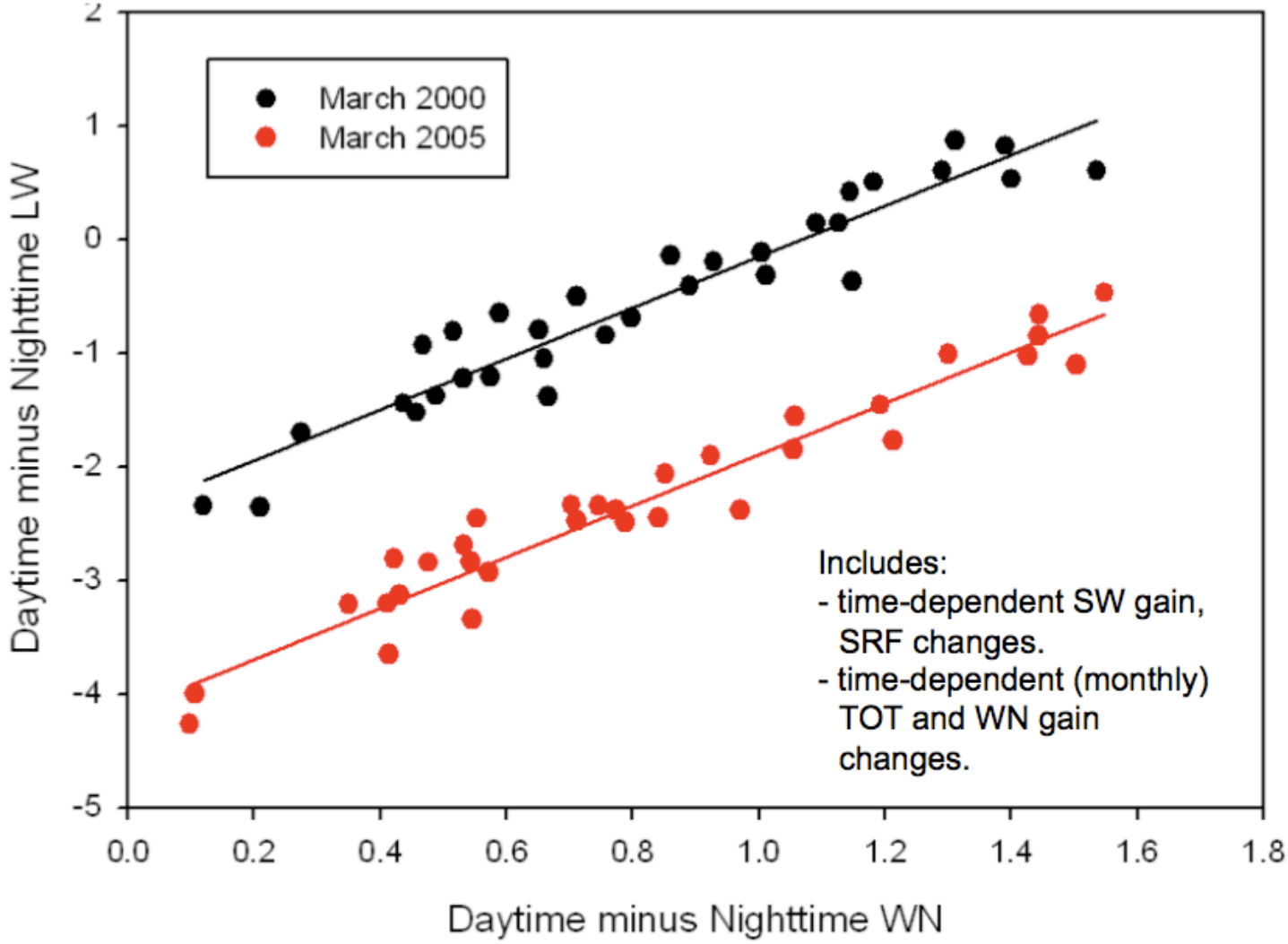
Approximate Relationship between Spectral Darkening Parameter and SW Radiance Changes since BOM (Aqua)



Approximate Relationship between Spectral Darkening Parameter and SW Radiance Changes since BOM



FM1 Zonal Averagse (16S – 16N) for Ocean



Establishing a common CERES Radiometric Scale

- CERES measurements span 12 years (1998-2009) and are taken by 5 different instruments.
  - TRMM-PFM : January – August 1998, March 2000
  - Terra – FM1& FM2: March 2000 – Present
  - Aqua – FM3 & FM4: July 2002 - Present
- The same radiometric scale at the Beginning of Mission
  - March 2000 for Terra and July 2002 for Aqua
- FM1 is selected to be the climate instrument:
  - Produces the longest, continuous data set
  - Longest in crosstrack mode of operation
  - Shows the smallest spectral changes for the mission
  - Shows the best consistency for the 3-channels comparison
  - Shows the smallest day-night difference
  - Has been used to compare with AQUA since 2002

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….

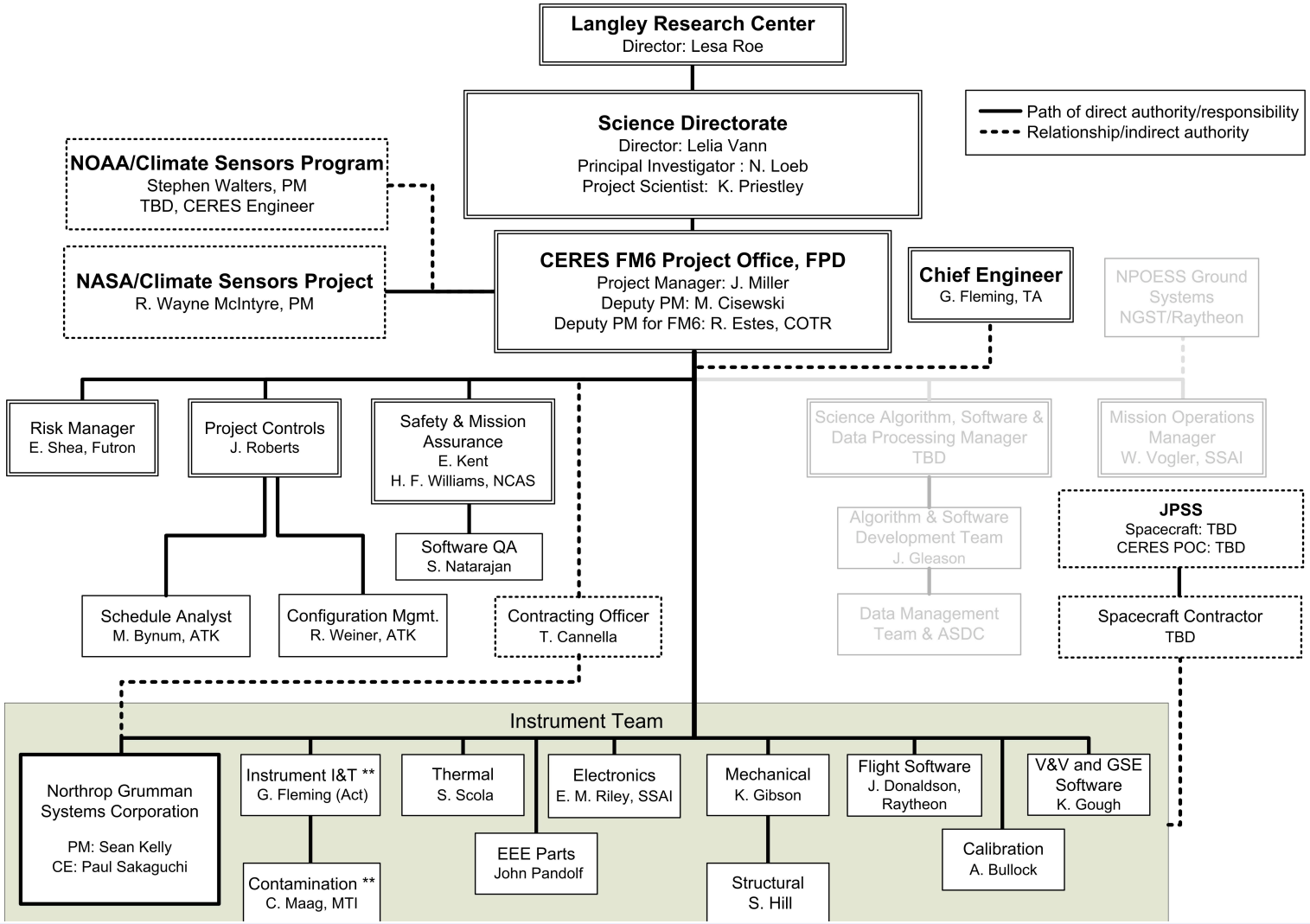
Path to ERB CDR Continuity

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

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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.

LW Day Night Difference Trends

- Apply Total, WN an
- With SW spectral da
  optimal SRFs,
  that eliminates

(BOM).

Use of WN channel day-night difference as a stability metric has been independently verified by AIRs

AIRs study mitigates the concern we had regarding broadband day night changes which would not be observed by our 8-12 micron window channel

ected SW
ate" set of SRFs
g of Mission

Strategy for Characterizing Spectral Degradation (Direct Nadir Radiance Comparison)

Need overall strategy slide

SW constrained by ClrOcn, verified with All-sky
then SW/TOT constrained by Day/Night Difference WN channel AIRs confirms this.

Edition3 Studies

♣ Spectral response degradation in SW channel
- determine time-dependent “optimal” SRFs from Direct Compare approach
- incorporate temporally varying SRFs in the SW measurements (implemented in spectral unfiltering algorithm)

♣ Divergence between daytime and nighttime OLR records with time

In-Flight Gain Analysis for Edition3

Ground to Flight change in sensor responsivity :

Lead : Susan Thomas

	Total	Window	Shortwave
FM1	-0.13%	0.40%	-0.50%
FM2	-0.21%	1.61%	-0.01%
FM3	0.04%	0.25%	8.00%
FM4	-0.62%	0.37%	-1.96%