CERES/TRMM Instrument Post-Mortem

Returned to service February 24th, 2000

Kory J. Priestley

22nd CERES Science Team Meeting
Huntsville, AL
September 20, 2000

NASA Langley Research Center
Atmospheric SCIENCES

CERES/TRMM Anomaly History

- **3-distinct periods in the Anomaly Investigation**
  - Sample dependent bias on the science data
    - Began in mid-March
    - Magnitude of the bias was time dependent
    - Frequency content was time invariant
    - Spurious signal is removed on a packet-by-packet basis
  - Inter-parameter replacement/substitution
    - Began in early-April
    - Science and housekeeping values appeared in the wrong place in the data streams (75 housekeeping parameters and 3 science)
    - Originally interpreted as a change in the frequency content of the sample dependent bias
    - Erroneous temperatures being fed into thermal control logic caused large thermal perturbations in the detectors and loss of calibration
    - Correlated to the DAA sub-multiplexer patterned defined in the flight software
    - By making numerous modifications to the flight software this issue was stabilized by 6/01/00

CERES/TRMM Anomaly History cont'd

- Loss of all science and DAA Housekeeping parameters
  - Began suddenly on 6/14/00
  - Science data has never returned
  - Housekeeping data returns at low orbital temperatures (I.e. Minimum Beta angles)
  - Numerous software diagnostic patches have been developed by Jim Donaldson to develop a work-around, but the patient remains comatose.
    - Final emphasis has been to definitely identify the failing Interpoint converter as the source of all the anomalies.

CERES/TRMM Current Status

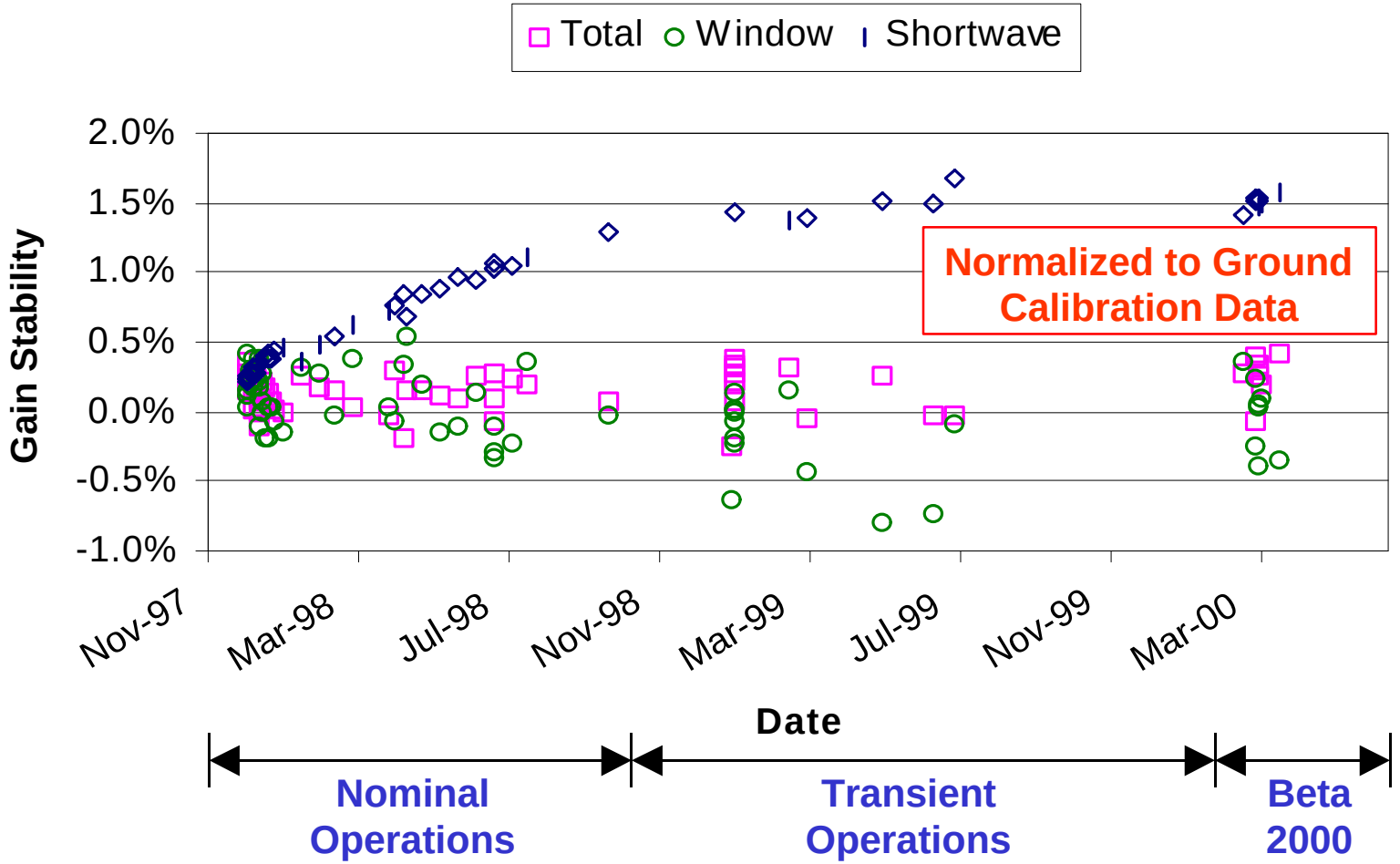
- **On 9/17/00 the TRMM spacecraft Flight Software autonomously removed powered from science instruments**
- **Cause appears to have been a FALSE reading indicating an extremely low state of charge on 8 of 22 battery cells.**
  - An *Interpoint Voltage Converter* has been identified as the culprit
  - An Interpoint Converter with possibly the same internal parts is what failed on the CERES/TRMM Instrument
- **Restoring Power to the CERES Instrument is quite risky**
  - A significant probability exists that the large in-rush current during power up will melt wire leads inside the converter.
  - This would cause a permanent loss of the DAA Science and housekeeping telemetry streams.
  - We are currently negotiating a strategy with the TRMM Mission Management to optimize our chances of being succesful
  - Even if we do successfully restore power, odds of obtaining additional science data from TRMM are very low.

Data Recovery Possibilities

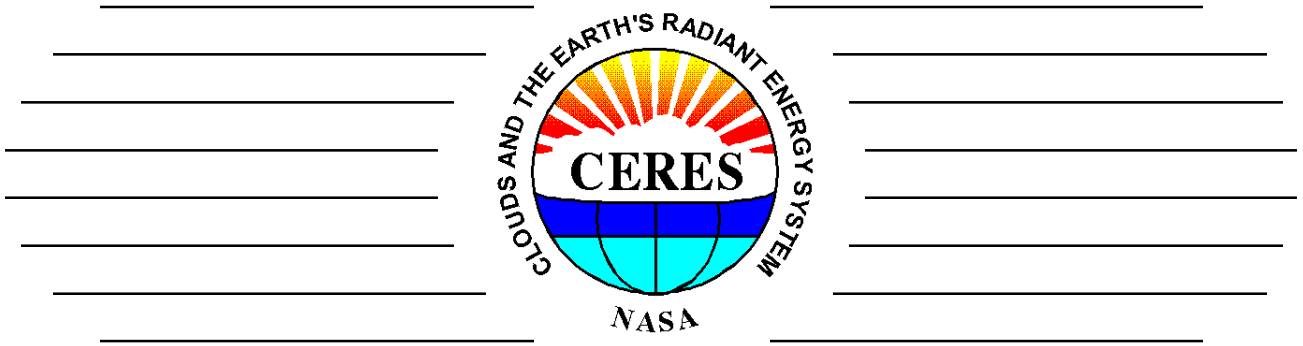
- **Instrument group is currently working on recovering all data through mid-April and after 6/1/00.**
  - Data from Mid-April to late May has unknown calibration due to large thermal transients.
- **Priority has been to recover SW data.**
  - An additional four weeks of SW data will significantly reduce any uncertainties in the comparison of TRMM/Terra SW radiance intercomparisons.
  - Initial efforts to recover SW look very encouraging
  - It's a very slow (somewhat manual) process
  - Recent focus of the instrument group has been trying to catch up on Terra validation efforts

TRMM/Proto Flight Model Lifetime Radiometric Stability

Determined with the Internal Calibration Module



CERES Instrument Cal/Val Report



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Robert Lee, Susan Thomas, Aiman Al-Hajjah, Robert Wilson,
D. K. Pandey, Jack Paden, Pete Spence, Dave Kratz, Lou Smith

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Terra/CERES Mission Status

Activation Timeline Summary

- **Succesful launch from Vandenberg, CA on December 18, 1999**
- **Operational Power applied December 21 (Scan head remained stowed)**
- **Full time A&E operations begun in early January**
  - **Instrument level functional testing**
  - **internal calibrations (Covers Closed)**
  - **simulated solar calibrations**
- **CERES Main and MAM covers opened on February 25, 2000**
- **Intense 30-day Validation phase begins**
  - **daily-bidaily-weekly internal/solar calibrations**
  - **daily intercalibrations with the TRMM instrument (still occuring)**
  - **3-day cycle of 2-days FAPS then 1-day RAPS**
- **Nominal operations begun April 1st with FM-1 in RAPS and FM-2 in FAPS**
- **May 1st instruments shift RAPS/FAPS duties (Begin 3-month Cycling)**

All major A&E activities completed except for Deep Space Maneuver….

CERES Instrument Cal/Val Report

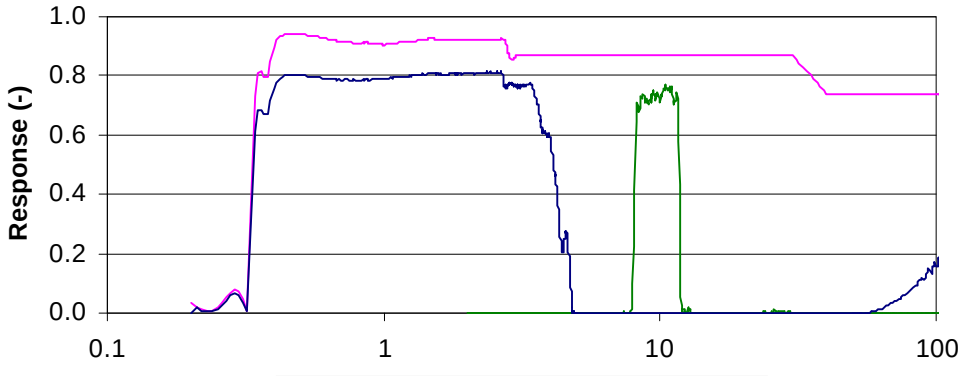
Summary of what is / isn't included in 'Edition 1' Data Products

- **Edition-1 Spectral Response Functions same as Beta**
  - Revisions will not be made until a full understanding of the Edition-1 products is obtained
- **Ground Derived Scan Dependent Offsets**
  - Terra Calibration Attitude Maneuver scheduled for either November or January????
- **Revised 2nd Time Constant Coefficients**
  - based upon in-flight measurements
- **Revised 2nd Time Constant Algorithm**
  - Minor error in the original derivation (2nd order effect on a 2nd order correction)

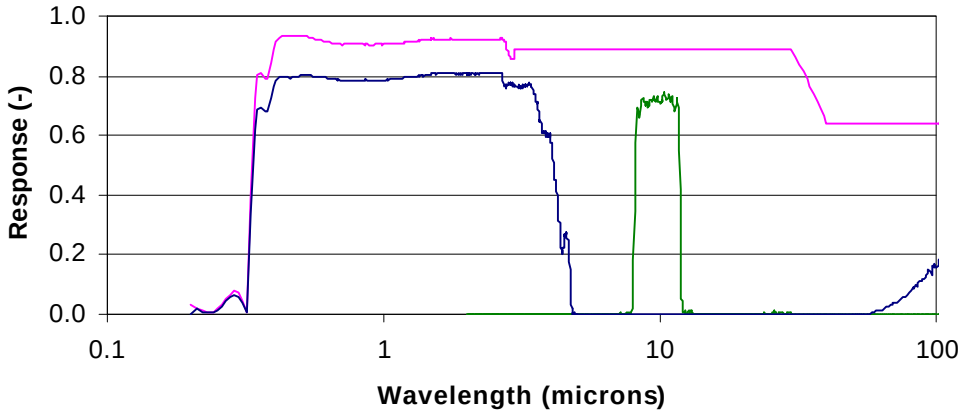
All analyses presented are based upon 'Beta' version of data products, spot checks performed on 'Edition-1' products to verify changes

CERES Flight Models 1 & 2
Edition-1 Spectral Response Functions

Flight Model 1



Flight Model 2



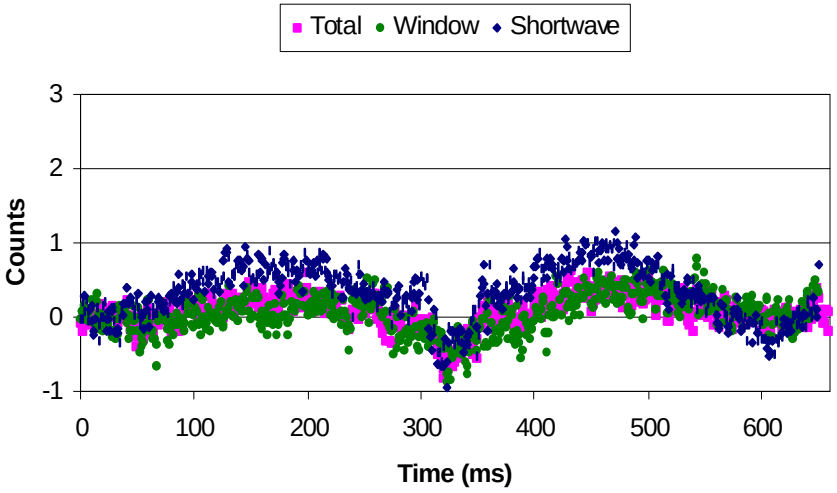
These Pre-Flight Spectral Response Functions are used in the 'Edition-1' Erbe-like data products

CERES Terra Scan Dependent Offsets

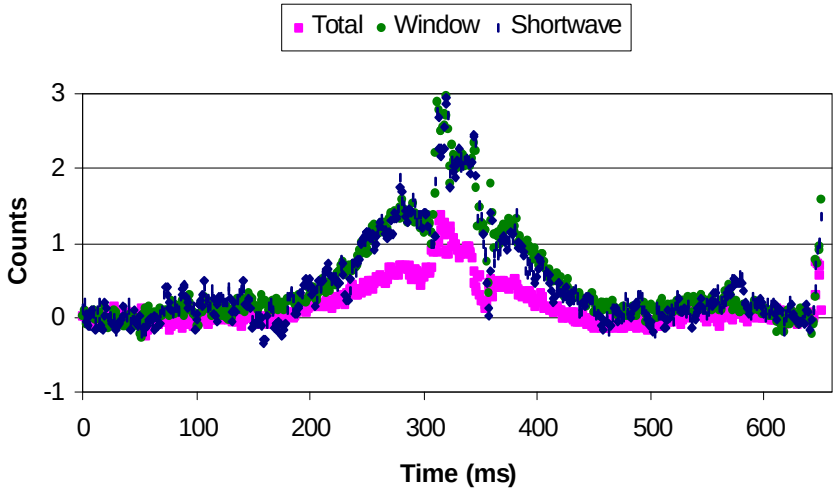
Ground Derived Values

(Fixed Azimuth Plane Scan mode)

Flight Model 1



Flight Model 2



SW : 1 count ~0.50 W/m^2 TOA Flux

LW $_{NIGHT}$: 1 count ~0.55 W/m^2 TOA Flux

LW $_{DAY}$: 1 count ~1.05 W/m^2 TOA Flux

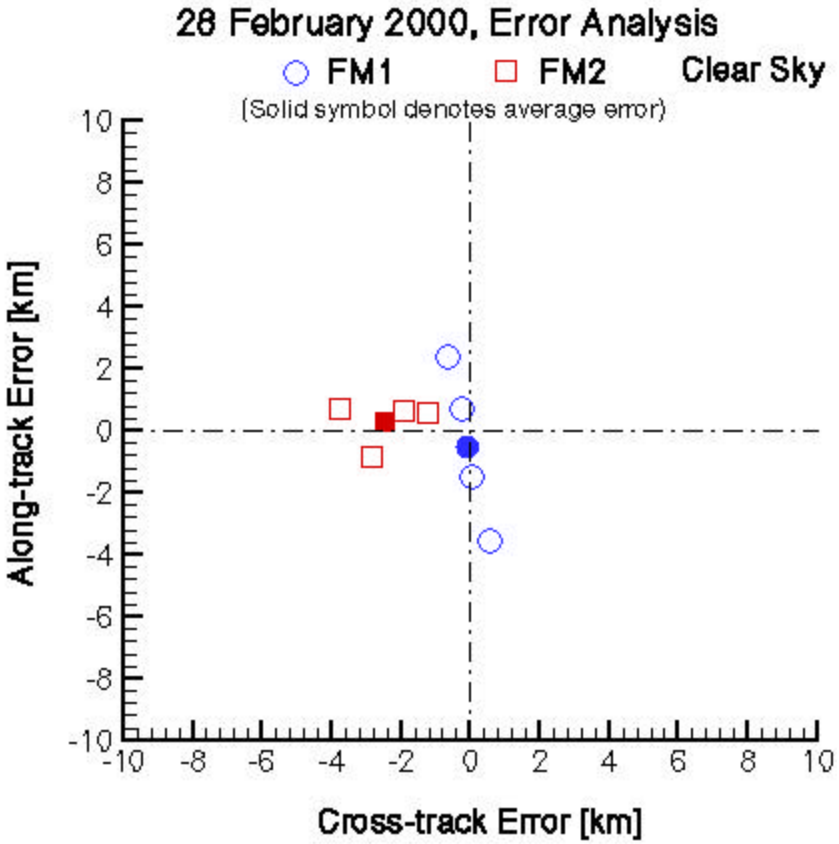
For all CERES 'Edition-1' data products the scan dependent offsets are assigned ground-determined values.

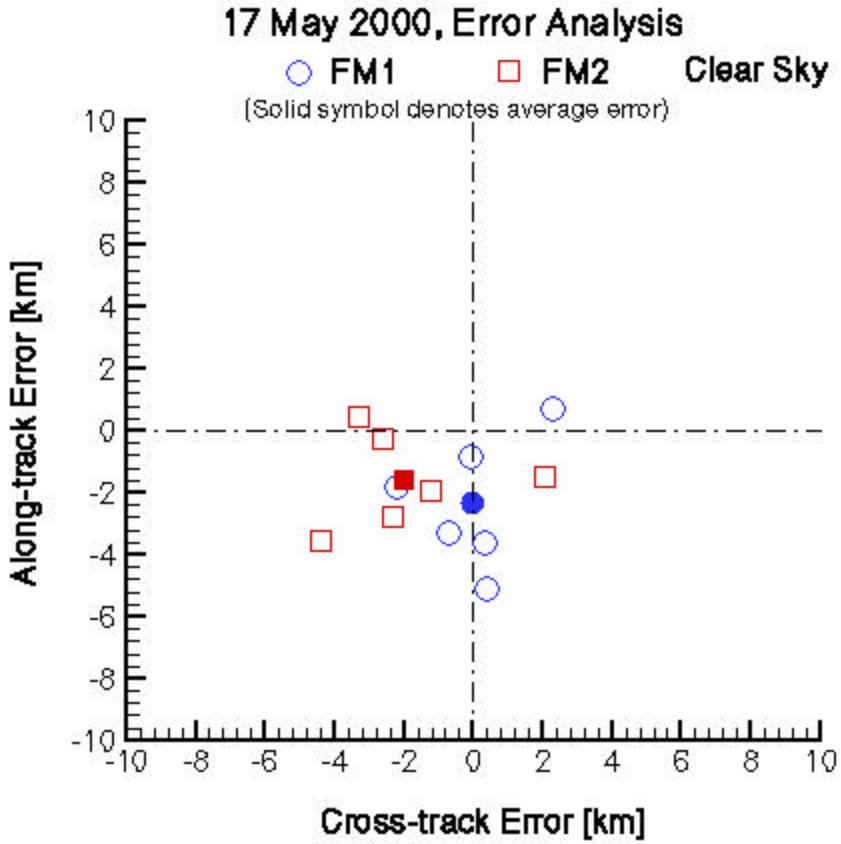
Navigation Accuracy
Automated Coastline Detection

Status

- Automated system uses the Total channel to detect coastlines
- Analysis completed for February 28 and May 17, 2000
- <2km mean navigational errors for both instruments in both along-track and cross-track directions
- Additional days need to be analyzed to improve statistics/monitor performance

CERES Terra Navigation Accuracy
Coastline Detection





Terra Validation Effort / Executive Summary

- **Ground to Flight calibration stability is better than 0.3% for TOT and SW channels**
- **The WN channel calibrations both shifted ~0.5-percent, but in opposite directions.**
  - FM-2 WN radiances > FM-1 WN radiances by ~0.9%
  - Insufficient settling time allowed during ground cal's
- **Unfiltering algorithms more robust for Terra SW compared to TRMM.**
- **FM-1 and FM-2 unfiltered Radiance biases are independent of scene ID and SZA**
- **SW radiances are consistent at the 0.2% level for FM-1 and FM-2**
- **FM-1 day and nighttime LW radiances are high by ~0.6%**
  - Caused by LW/TOT spectral response being too low
- **FM-1 daytime Longwave radiances are too low by ~1.0%**
  - Caused by the SW/TOT spectral response being too high
- **Any errors in the FM-2 SW or SW/TOT are les than 0.3%**
- **Day-Night Difference for the FM-1 WN channel is too large by about 0.1-0.2%.**

This is a status list for Edition 1, and a To Do list for Edition 2

Instrument group recommends archiving the Edition 1 Data Products

CERES Instrument Radiometric Validation Activities

		Product	Spatial Scale	Temporal Scale	Metric	Spectral Band
On-Board	Internal BB	Filtered Radiance	N/A	N/A	Absolute Stability	TOT, WN
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	DCC 3-channel	Unfiltered Radiance	>100 Km	Monthly	Inter-Channel consistency, stability	TOT, SW
	TIme Space Averaging	Fluxes	Global	Monthly	Inter-Instrument Agreement	LW, SW

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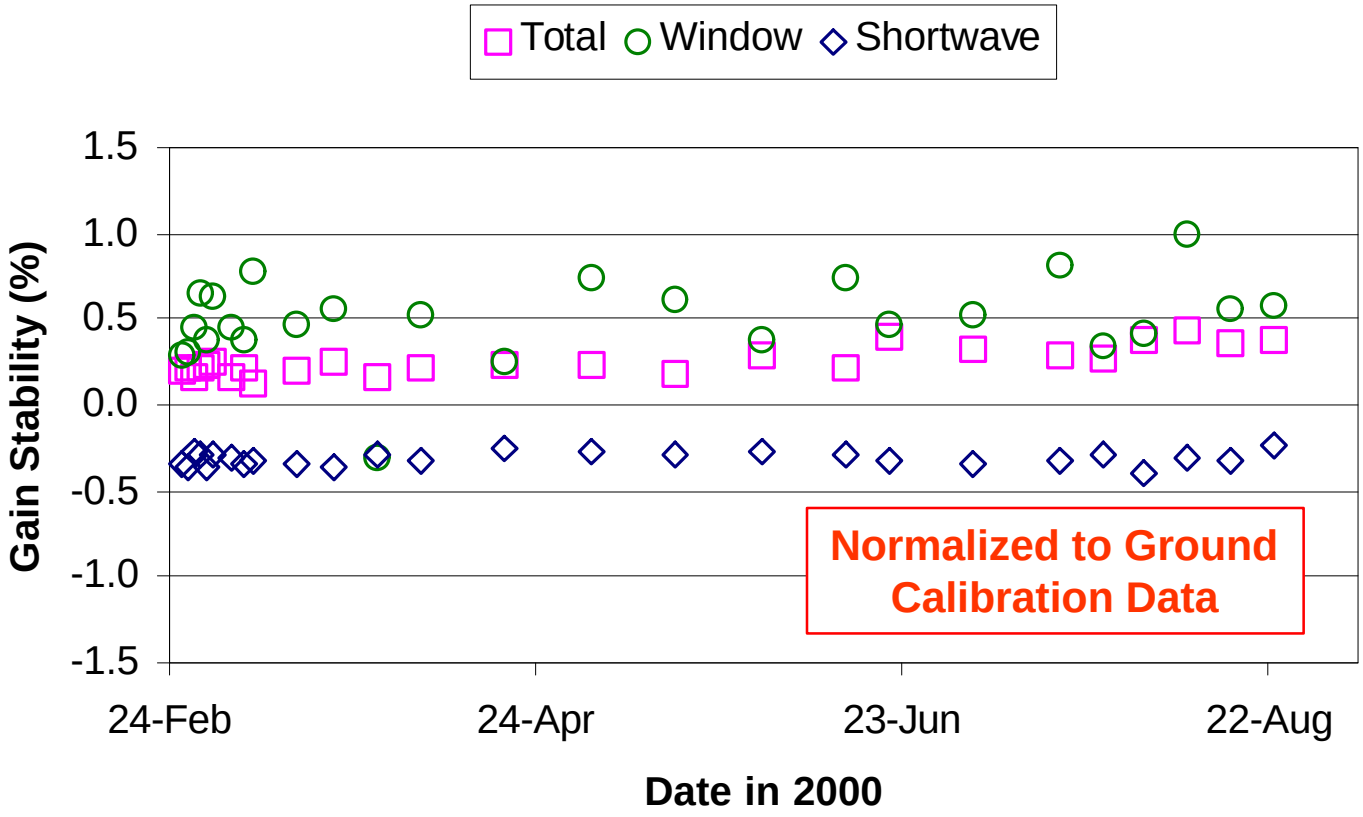
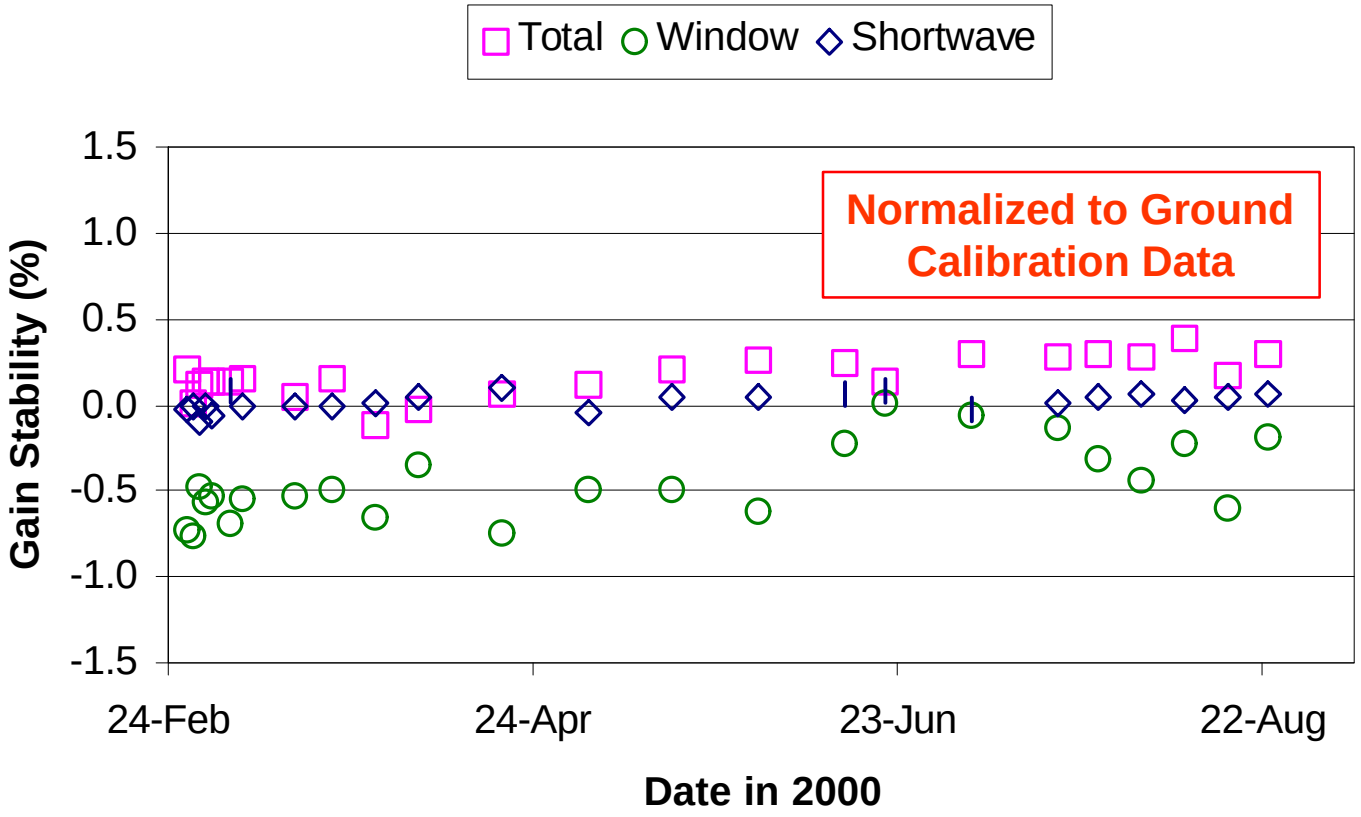
Terra/Flight Model 1
Lifetime Radiometric Stability
Determined with the Internal Calibration Module

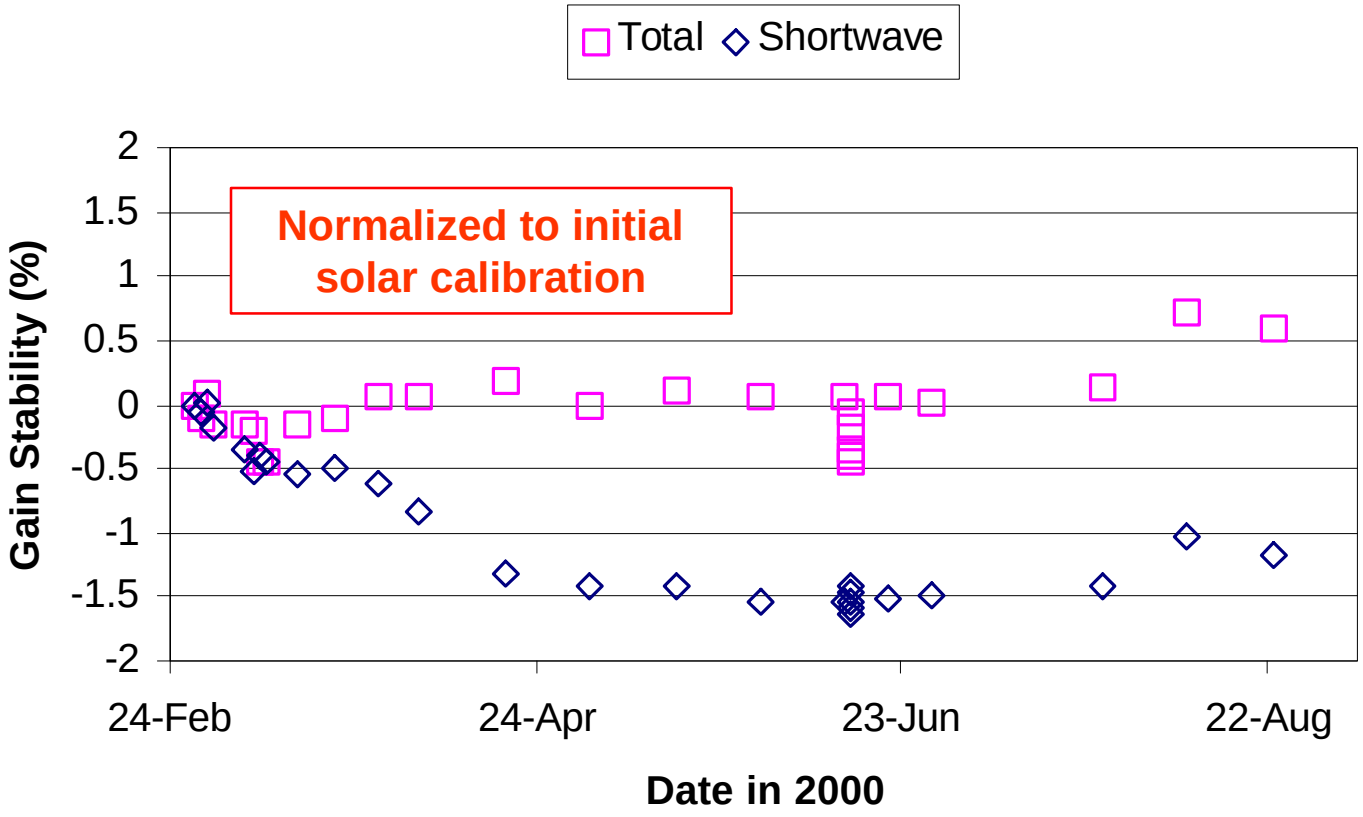


Terra/Flight Model 2
Lifetime Radiometric Stability
Determined with the Internal Calibration Module



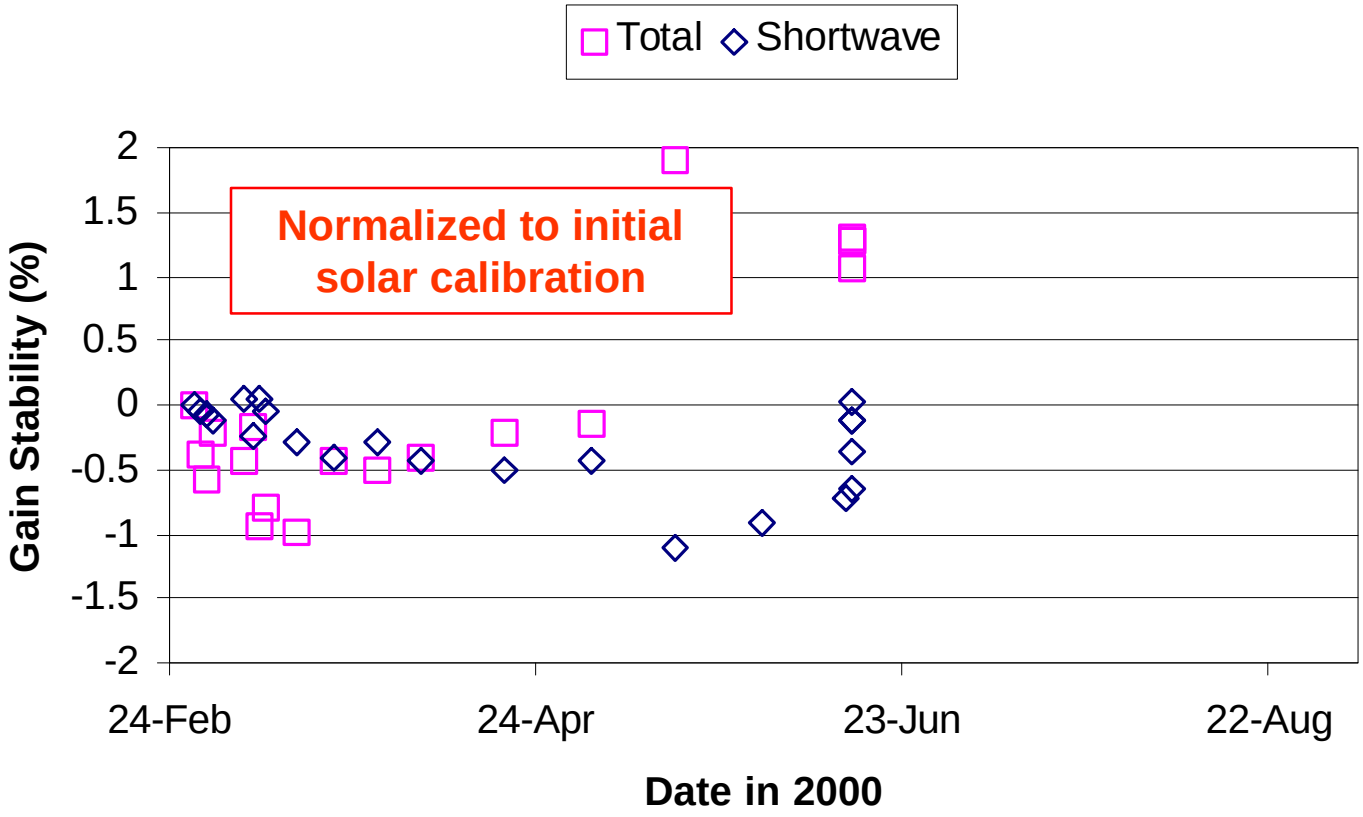
Terra/Flight Model 1
On-orbit Shortwave Radiometric Stability

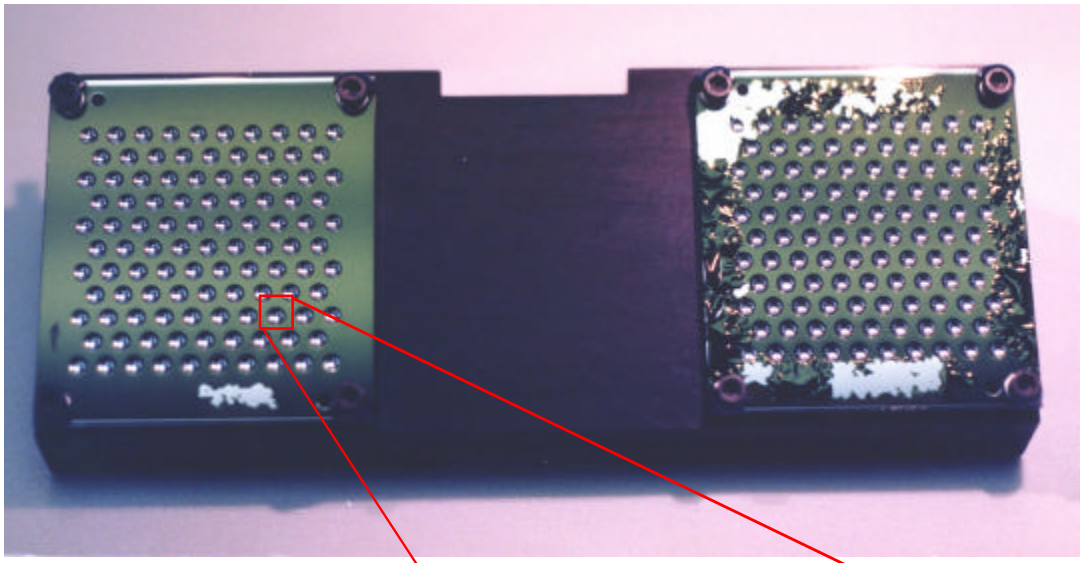
Solar Calibrations Performed with the Mirror Attenuator Mosaic



Terra/Flight Model 2
On-orbit Shortwave Radiometric Stability

Solar Calibrations Performed with the Mirror Attenuator Mosaic





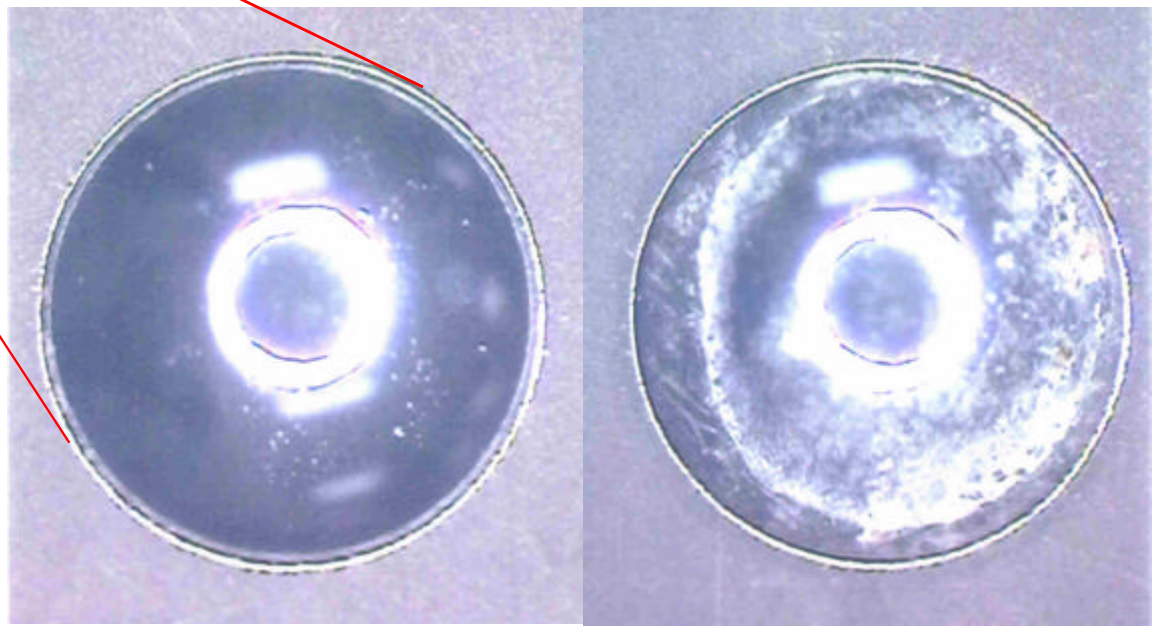
FM-1 MAM's had a 'dull matte finish with varying degrees of blistering'.

Deemed acceptable after passing accelerated life-test.

FM-2 MAM's from later production run.

CERES

Mirror
Attenuator
Mosaic



Acceptable Coating

Blistered/Crazed Coating

Internal/Solar Calibrations
Key Results

- **Ground to Flight Calibration Stability**
  - Determined with Internal Calibration Module
    - TOT: 0.2, and 0.1% for FM1 and FM2
    - WN: 0.5 and –0.5% for FM1 and FM2
    - SW: -0.3 and <0.1% for FM1 and FM2
- **On-Orbit Calibration Stability**
  - Internal Calibration Module
    - demonstrates no detectable drifts
  - Solar Calibrations
    - suggests large drift in FM-1 SW channel
    - **But**, questionable build history on the FM-1 MAM's

CERES Instrument Radiometric Validation Activities

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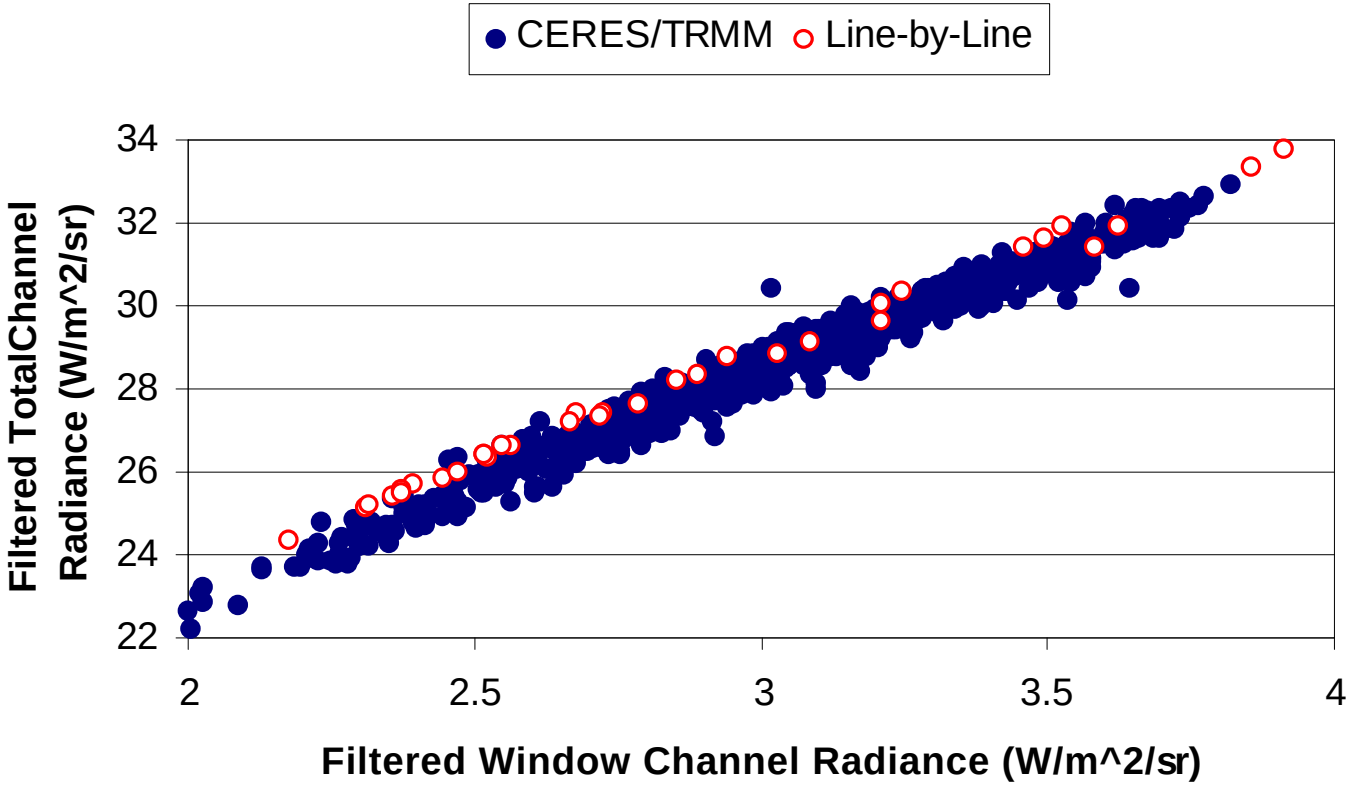
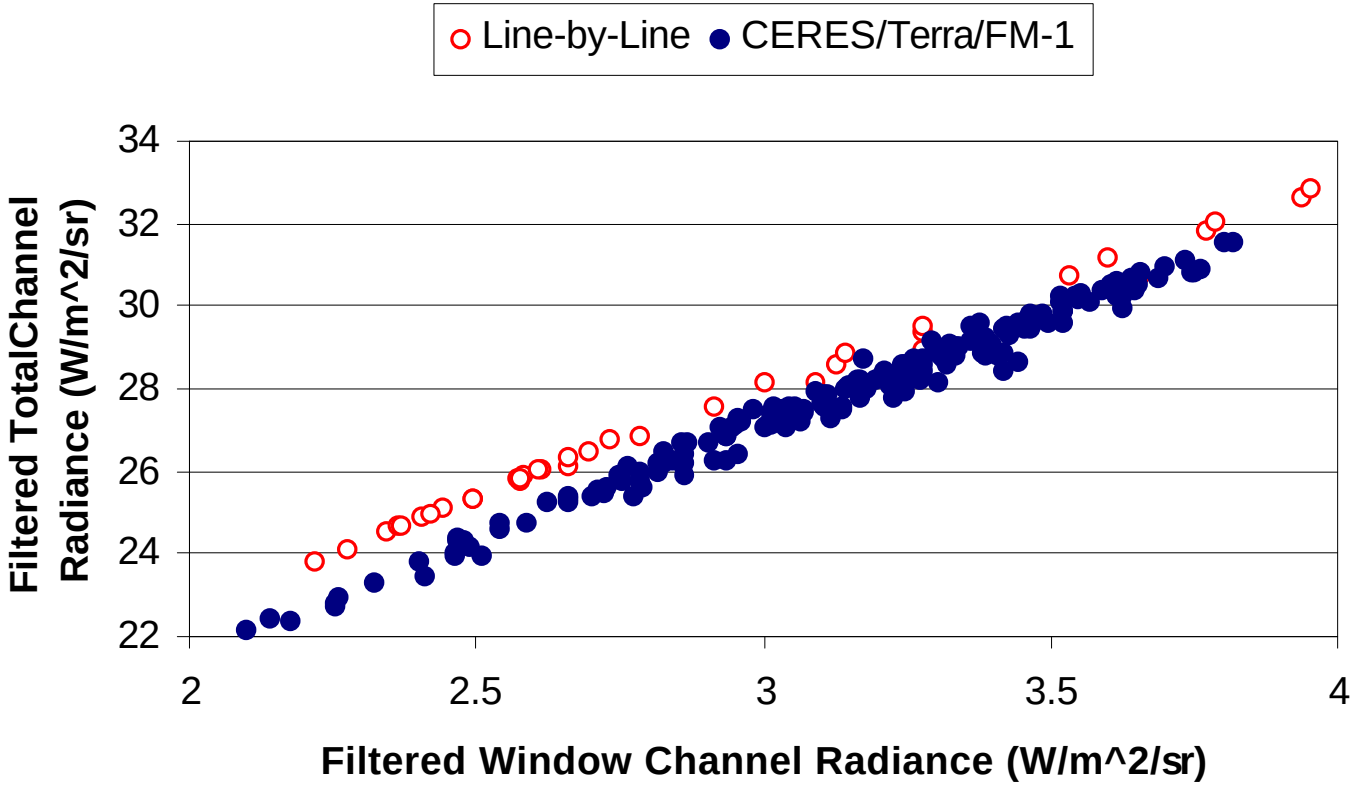
Line by Line Radiative Transfer Code Comparison

CERES/TRMM
Nighttime Deep Convective Cloud Data
Edition 2



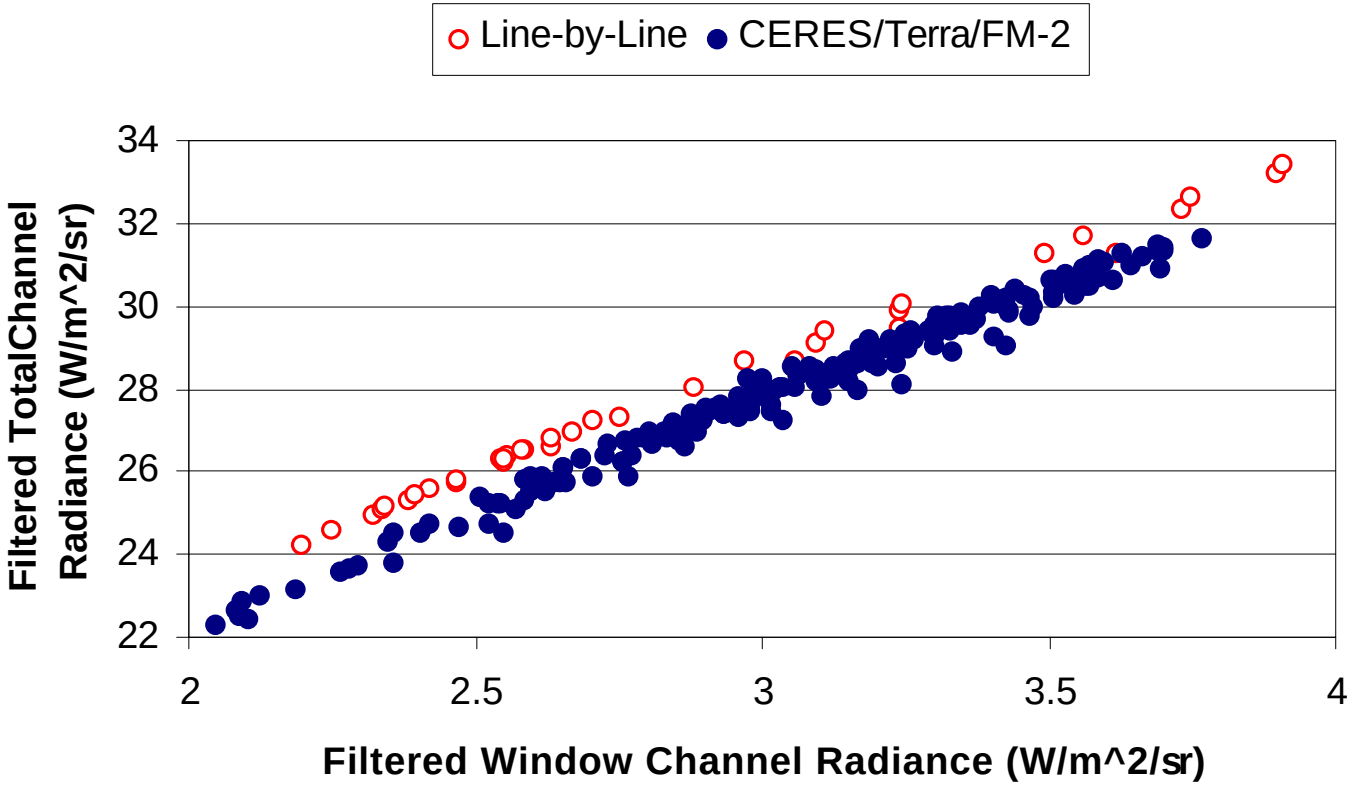
Line by Line Radiative Transfer Code Comparison

CERES/Terra FM-1
Nighttime Deep Convective Cloud Data
Beta Data

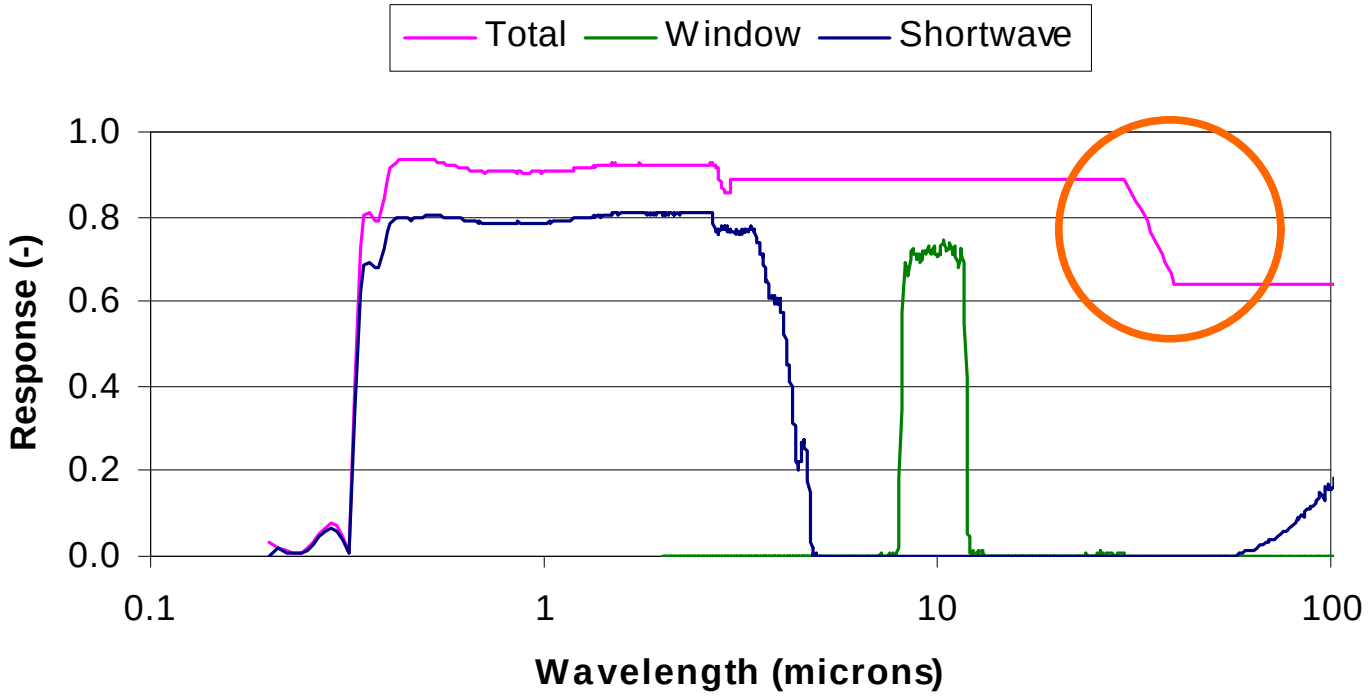


Line by Line Radiative Transfer Code Comparison

CERES/Terra FM-2
Nighttime Deep Convective Cloud Data
Beta Data



CERES Flight Model 2
Edition-1 Spectral Response Function



Deep Convective Cloud have a larger proportion of energy beyond 30 microns where the Spectral Response Function is less certain

Line-by-Line Theoretical Comparison Key Results

- **PFM measurements agree quite well with theory (<0.5%)**
  - PFM data is already of Edition 2 quality
- **Agreement between theory and the Terra Instruments is at the ~3-4% level**
  - Will study the inter-relationship between the fall-off of the spectral response function beyond 30 microns and possible bias errors.
  - Deep Convective Clouds are an extreme case where the impact of bias errors is maximized due to the low radiance values.

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CERES Deep Convective Albedo, March 2000

We have calculated the isotropic albedo, or reflectance, R, for Tropical Deep Convective Clouds as defined by

$$R = \frac{\pi I}{E_o d^{-2} \cos\theta_o}$$

The goal is to intercompare the three CERES instruments.

DATASET

Scene Type: Independent Deep Convective Cloud systems

Cloud Size: Greater than 20 Km in ground track direction

Cloud Temperature: Less than 215 K (Dispersion <0.1)

Data Product: CERES PFM, FM1 and FM2 (March 2000)

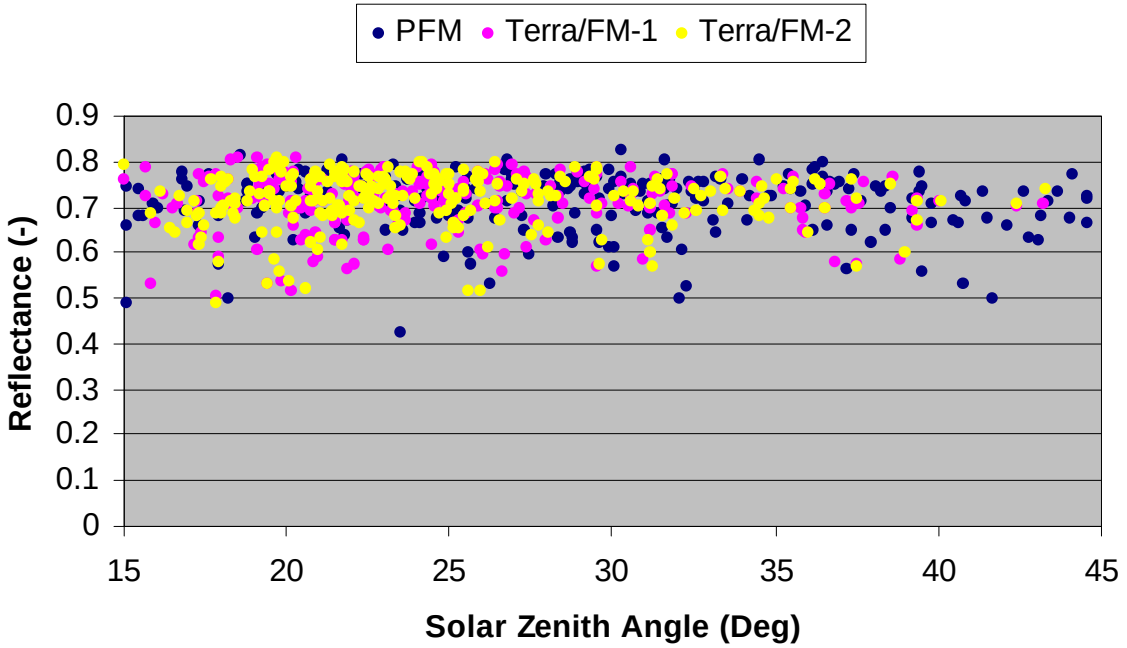
View Zenith: Nadir footprints only

Solar Zenith: 15 to 45-degrees **(Limited by Terra Orbit)**

Latitude: 20 N to 20 S

CERES Deep Convective Albedo

Results of estimating reflectance over the solar zenith range of ~15-45 degrees.



	PFM (M-A-M-J)	FM1 (M-A-M-J)	FM2 (M-A-M-J)
% Reflectance (Std. Error)	71.16 (.41)	71.31 (.39)	71.50 (.37)

Mean Values agree to within 0.5%

3-Channel Deep Convection Results

Assess the agreement between our best estimates of the unfiltering of the SW channel and the SW portion of the Total Channel.

With this method we cannot distinguish between errors in the spectral response function and relative errors in the spectral unfiltering method.

DATASET

Scene Type: **Deep convective clouds**

Cloud Size: **Greater than 80 Km in ground track direction**

Cloud Temperature: **Less than 215K**

Data Product: **Terra FM-1 and FM-2 'Beta' ES-8 files**

View Zenith: **Nadir footprints only**

Solar Zenith: **Less than 80-degrees (TRMM), 15 - 45 degrees (Terra)**

Latitude: **20 N to 20 S**

3-Channel Intercomparison

Methodology

- **Regress Filtered Window against Unfiltered Total (i.e. LW) radiances at night.**
- **Predict daytime LW with two methods…**

$$LW_{day} = Total_{day} - SW_{day} \qquad LW_{day} = C_1 * WN_{day} + C_2$$

- **Difference these two estimates and plot as a function of Filtered SW, I_f^{sw}.**

$$\Delta LW_{day} = (Total_{day} - SW_{day}) - (C_1 * WN_{day} + C_2)$$

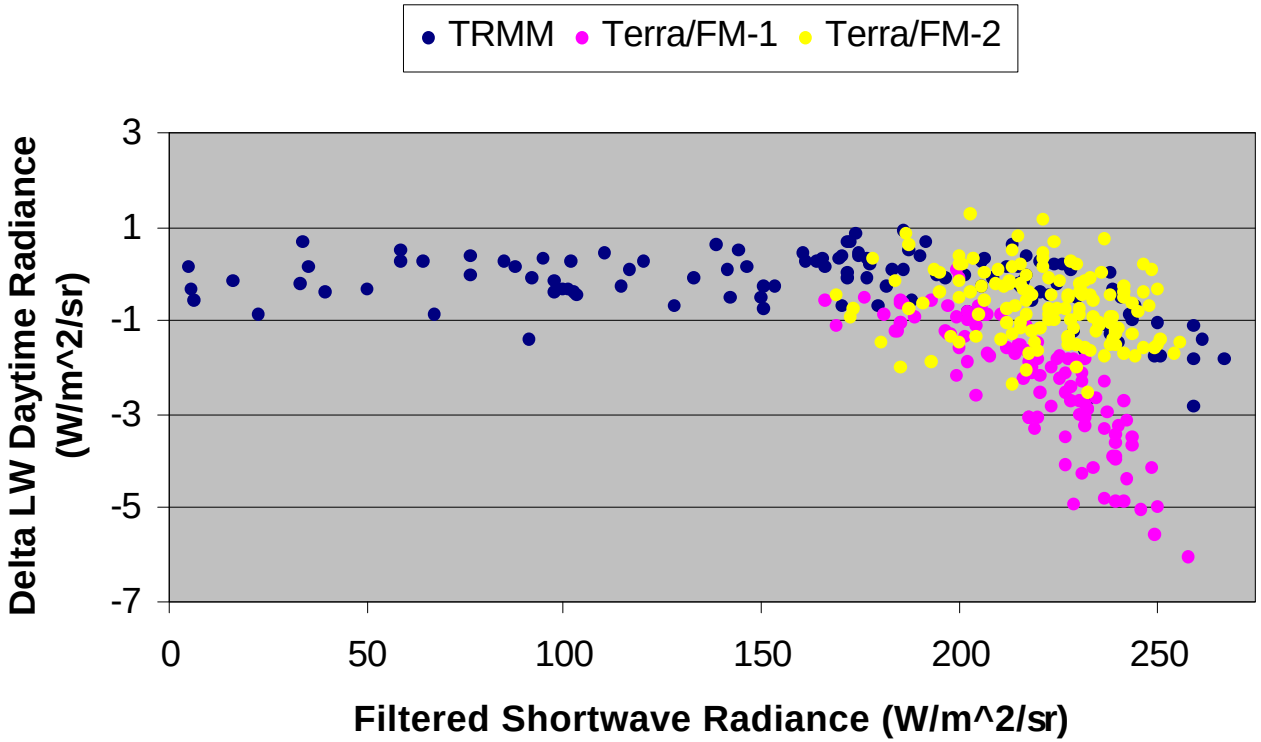
- **Any error in the unfiltering process (either due to errors in S_λ, or in detemining the unfiltering coefficients) may be represented by**

$$error = -\frac{\left(\frac{d\Delta}{dI_f^{sw}}\right)}{\hat{a}^{lw/tot}\left(\frac{\hat{a}^{sw}}{\hat{a}^{sw/tot}}\right)} * 100$$

- **where the a's are spectral unfiltering coefficients for the longwave channel (lw), shortwave channel (sw) and the shortwave portion of the total channel (sw/tot) for DCC.**

3-Channel Deep Convection Results

March - June 2000



From March – June the FM-1 and FM-2 instruments display inconsistencies between the SW and SW/TOT channels at the 1.1 and 0.3-percent levels

DCC Albedo / 3-Channel Intercomparison Key Results

- **DCC Albedo**
  - The SW channels from PFM, FM-1, and FM-2 agree to within 0.5%
- **3-Channel Intercomparison**
  - FM-1
    - SW and SW/TOT channel inconsistency at the 1.1% level
      - Fewer number of DCC's found during the daytime suggests unusually large Day-Night difference for the FM-1 WN channel
  - FM-2
    - SW and SW/TOT channels inconsistent at the 0.3% level
      - Not statistically significant

DCC Albedo result suggests the FM-1 Inconsistency is in the SW/TOT

CERES Instrument Radiometric Validation Activities

		Product	Spatial Scale	Temporal Scale	Metric	Spectral Band
On-Board	Internal BB	Filtered Radiance	N/A	N/A	Absolute Stability	TOT, WN
	Internal Lamp	Filtered Radiance	N/A	N/A	Absolute Stability	SW
	Solar	Filtered Radiance	N/A	N/A	Relative Stability	TOT, SW
Vicarious	Theoretical Line-by-Line	Filtered Radiance	> 20 Km	Instantaneous	Inter-Channel Theoretical Agreement	TOT, WN
	Theoretical Unfiltering Algorithm Validation	N/A	N/A	N/A	N/A	TOT, SW, WN
	Inter-satellite (Direct Comparison)	Unfiltered Radiance	1-deg Grid	1 per crossing	Inter-Instrument Agreement, Stability	TOT, SW, WN
	Tropical Matched Pixels (Direct Comparison)	Unfiltered Radiance	Pixel to Pixel	Daily	Inter-Instrument Agreement	TOT, SW, WN
	Tropical Mean (Geographical Average)	Unfiltered Radiance	20N – 20S	Monthly	Inter-Channel Agreement, Stability	TOT, WN
	DCC Albedo	Unfiltered Radiance	>40 Km	Monthly	Inter-Instrument agreement, Stability	SW
	DCC 3-channel	Unfiltered Radiance	>100 Km	Monthly	Inter-Channel consistency, stability	TOT, SW
	TIme Space Averaging	Fluxes	Global	Monthly	Inter-Instrument Agreement	LW, SW

Terra Validation Effort / Executive Summary

- **Ground to Flight calibration stability is better than 0.3% for TOT and SW channels**
- **The WN channel calibrations both shifted ~0.5-percent, but in opposite directions.**
  - FM-2 WN radiances > FM-1 WN radiances by ~0.9%
  - Insufficient settling time allowed during ground cal's
- **Unfiltering algorithms more robust for Terra SW compared to TRMM.**
- **FM-1 and FM-2 unfiltered Radiance biases are independent of scene ID and SZA**
- **SW radiances are consistent at the 0.2% level for FM-1 and FM-2**
- **FM-1 day and nighttime LW radiances are high by ~0.6%**
  - Caused by LW/TOT spectral response being too low
- **FM-1 daytime Longwave radiances are too low by ~1.0%**
  - Caused by the SW/TOT spectral response being too high
- **Any errors in the FM-2 SW or SW/TOT are les than 0.3%**
- **Day-Night Difference for the FM-1 WN channel is too large by about 0.1-0.2%.**

Instrument group recommends archiving the Edition 1 Data Products