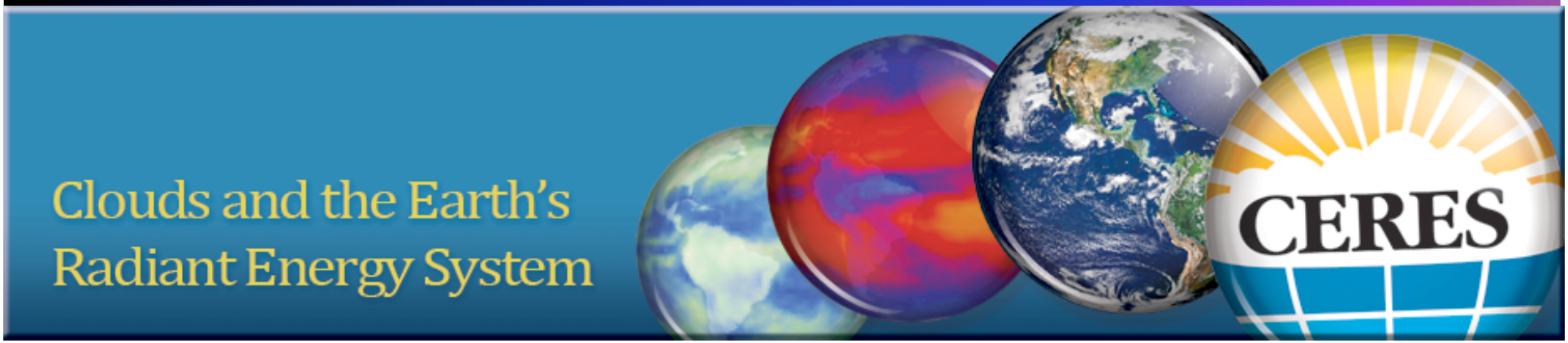


CERES FM1-FM6
Instrument Status Report

Kory Priestley
&
Instrument Working Group

CERES Science Team Meeting
Lawrence Livermore National Lab
October 4, 2011

Instrument Working Group Personnel

Clouds and the Earth's Radiant Energy System

Science

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

Data Management

- Denise Cooper -
- Dale Walikainen –
Chris Currey
Thomas Grepiotis
Nelson Hillyer
Jeremie Lande
Dianne Snyder
Richared Spivak
Mark Timcoe

Mission Operations

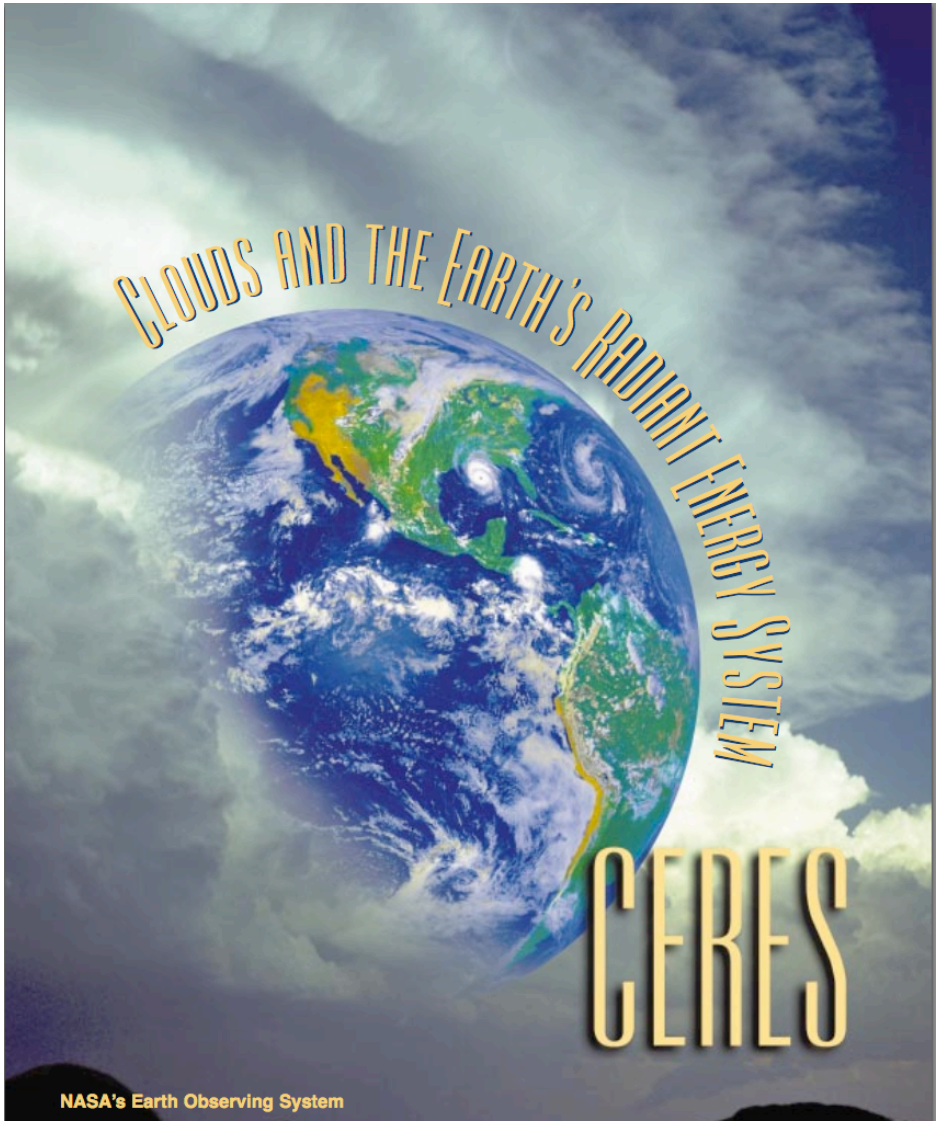
- Bill Vogler -
- James Bailey -
Christopher Brown
~ Jim Donaldson ~
John Butler
William Edmonds
Kelly Teague

S/C Integration & Test

- Roy Zalameda -
James Adams
Mike Tafazoli
Eugene Sutton
Bruce Wolff

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

Discussion Topics



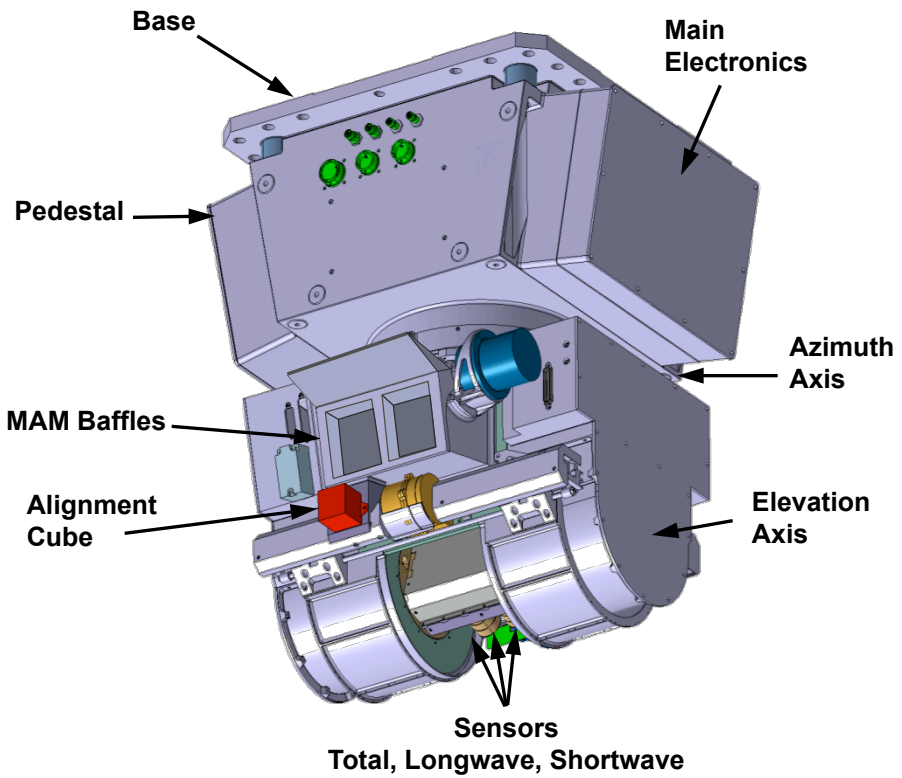
- **CERES Overview**
  - Measurement objectives
  - Instrument description
  - Flight history/future
- **Instrument Status**
  - EOS
  - FM-5 on NPP
  - FM-6 on JPSS-1
- **Radiometry**
  - Performance Requirements
- **Summary**

CERES Instrument

Clouds and the Earth's Radiant Energy System

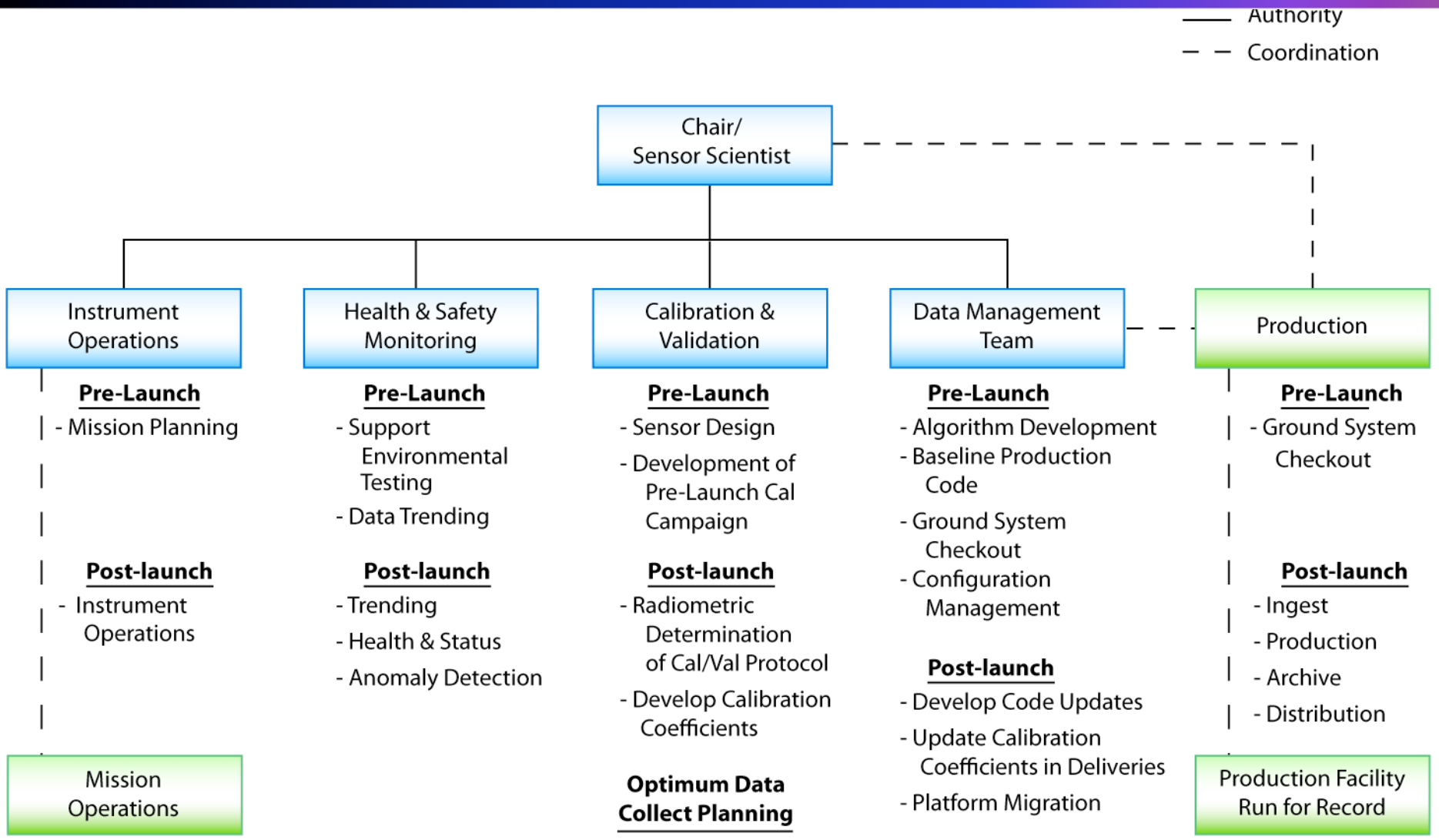
- **Designed, manufactured and tested by TRW, Redondo Beach, CA (currently Northrop Grumman Aerospace Systems)**
- **Contains three sensor assemblies with cassegrain optics and thermistor bolometer detectors**
- **Sensors measure thermal radiation in the near-visible through far-infrared spectral region**
- **Sensor channels are coaligned and mounted on a spindle that rotates about the elevation axis**
- **Hemispherical sampling obtained with an azimuthal axis drive system**

Orbits	705 km altitude, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (PM-1), sun-synchronous, near-polar; 350 km altitude, 35º inclination (TRMM)
Spectral Channels	Solar Reflected Radiation (Shortwave): 0.3 - 5.0 μm Window: 8 - 12 μm Total: 0.3 to > 100 μm
Swath Dimensions	Limb to limb
Angular Sampling	Cross-track scan and 360º azimuth biaxial scan
Spatial Resolution	20 km at nadir (10 km for TRMM)
Mass	45 kg
Duty Cycle	100%
Power	45 W
Data Rate	10 kbps
Size	60 x 60 x 70 cm (deployed)
Design Life	6 years



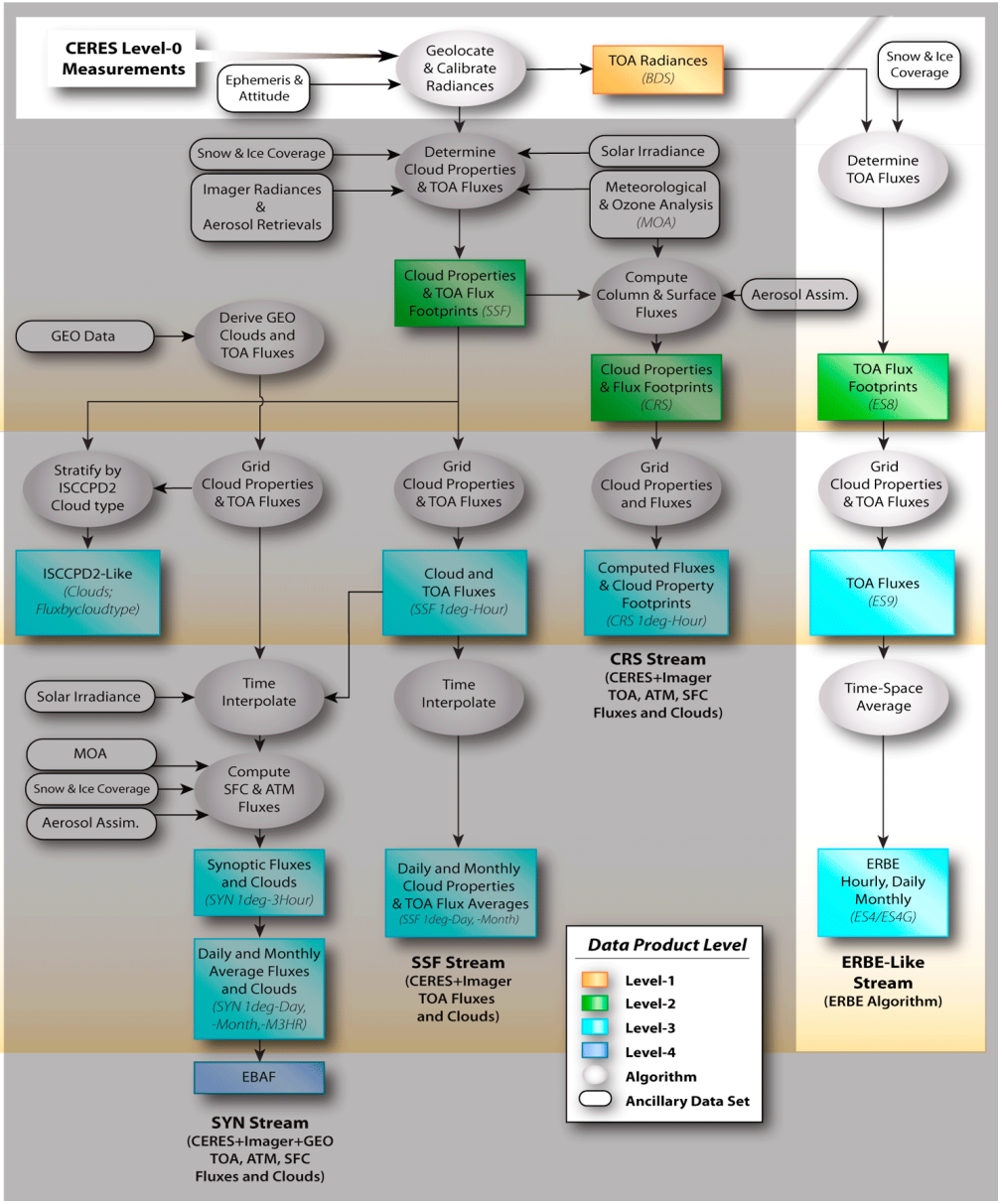
CERES
Instrument Working Group

Clouds and the Earth's Radiant Energy System



CERES Processing Stream

Clouds and the Earth's Radiant Energy System



Enabling Climate Data Record Continuity

Clouds and the Earth's Radiant Energy System

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	139 +
Aqua	FM3, FM4	5/02	6/02	111 +
NPP	*FM5*	*9/11*	-	-
JPSS - 1	*FM6*	*2016 (TBR)*	-	-
JPSS - 2	*ERBS*	*2021 (TBR)*	-	-

42 + Instrument Years of Data

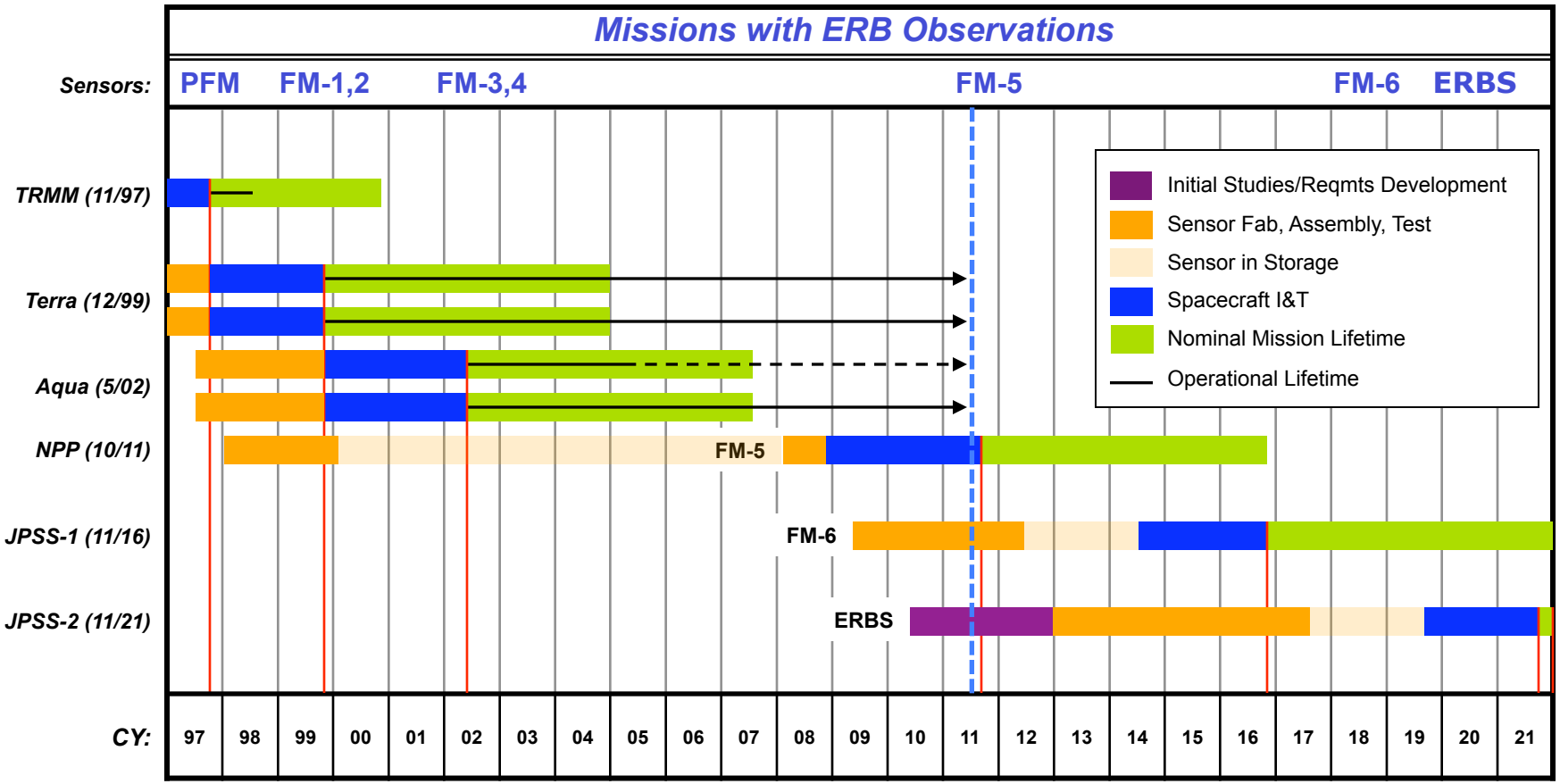
Agency Roles and Responsibilities

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

Enabling Climate Data Record Continuity

Clouds and the Earth's Radiant Energy System

CERES Flight Schedule



EOS Status

Terra/Aqua Instrument and ERBE-Like Availability

Clouds and the Earth's Radiant Energy System

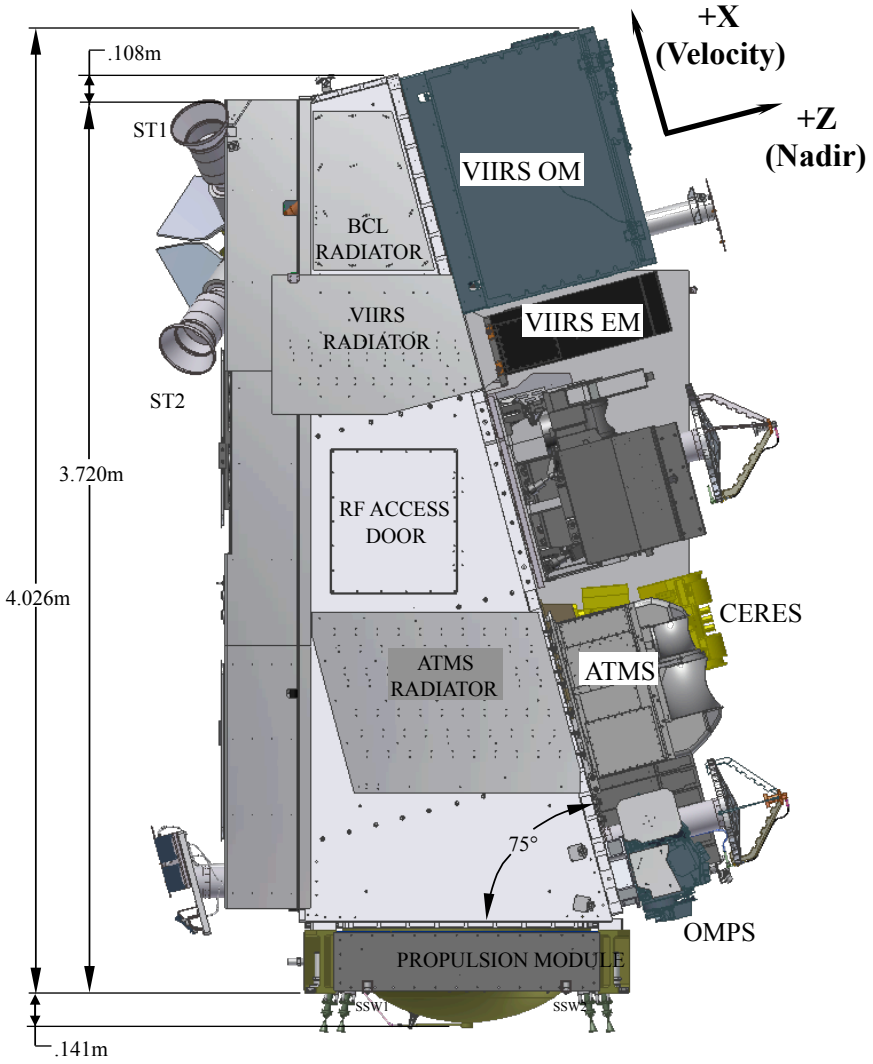
Spacecraft	Product	Version	Available	Months Processed
TRMM	BDS	Edition1	Yes	1/98 - 8/98 , 3/00
	ERBE-Like	Edition1	Yes	1/98 - 8/98 , 3/00
		Edition2	Yes	1/98 - 8/98 , 3/00
Terra	BDS	Edition1CV	Yes	2/00 - present
		Edition2	Yes	2/00 – 6/10
		Editon3	ASDC Testing	2/00 – 5/11
	ERBE-like	Edition1CV	Yes	3/00 - present
		Edition2	Yes	2/00 – 6/10
		Editon3	ASDC Testing	3/00 – 5/11
Aqua	BDS	Edition1CV	Yes	6/02 - present
		Edition2	Yes	6/02 – 6/10
		Editon3	ASDC Testing	2/00 – 5/11
	ERBE-like	Edition1CV	Yes	7/02 - present
		Edition2	Yes	7/02 – 6/10
		Editon3	ASDC Testing	7/02 – 5/11

Note: Red cells indicate datasets that are no longer in production.

FM-5 on NPP
Status

CERES Compatibility with NPP Spacecraft

Clouds and the Earth's Radiant Energy System



Observatory Information

- Launch Readiness October, 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 FM-5 on NPP

- FM-5 is a NASA sensor manufactured by TRW (Currently Northrop Grumman), and provided to NPP by NASA and NOAA.
- Final instrument integration and test conducted from January to November, 2008.
- Observatory Level TVAC testing completed in April, 2011
- The Earth Radiation Budget Climate Analysis and Research System (ERB CARS) at LaRC is responsible for CERES instrument operation, data processing, and science analysis.
- ERB CARS is an element of the NPP Science Data Segment, and receives NPP data from the Land Product Evaluation and Test Element (PEATE) at GSFC.

Radiometric Performance Requirements

CERES is defined as a class 'B' Mission
5-year design Lifetime

Spectral Region	Solar		Terrestrial		Atmospheric Window
Wavelengths	0.3 – 5.0 microns		5 – 200 microns		8-12 microns
Scene Levels	<100 wm^2/sr	>100 wm^2/sr	<100 wm^2/sr	>100 wm^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		0.07 %/yr	
FM5 Accuracy Capability		1.7 %		0.7 %	
FM5 Stability Capability		0.32 %/yr		0.12 %/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**
- **FM5 Capability is significantly less than Requirement**

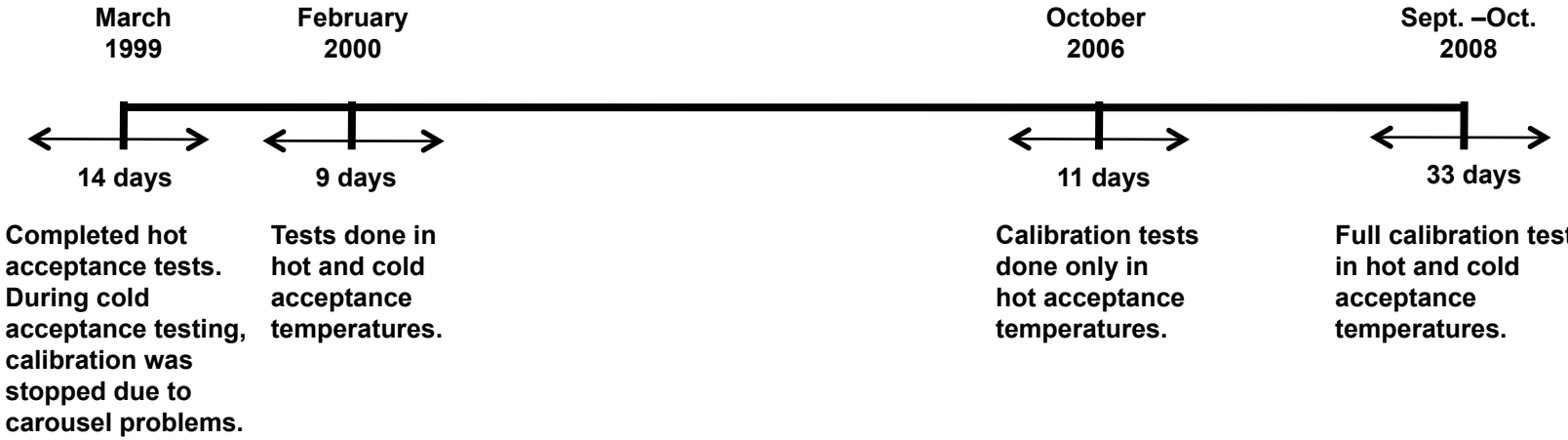
CERES FM5 Hardware Status & Near-Term Activities

- **Fabrication, Assembly and Test Program is complete**
  - Ground Calibration was most extensive to date in the CERES Program
- **System Acceptance Review 10/30 at NGST**
- **Shipped to BATC on 11/2/09**
- **Mechanical/Electrical Integration to NPP spacecraft completed 11/11/08**
- **Observatory Pre-environmental Test Readiness Review 9/20-21/10**
- **Spacecraft Environmental Campaign 11/10-4/11**
- **Operational Readiness Review 6/20-24/11**
- **Satellite Pre-Ship Review 8/2/11**
- **Mission Readiness Review (L-75) 9/6/11**
- **LaRC Science Operational Readiness Review 9/16/11**
- **Flight Readiness Review (L-4) 10/21/11**
- ***Launch Readiness Review (L-1) 10/24/11***
- ***NPP 'Official' Launch Readiness Date is currently - October 25, 2011***
- ***Operations Handover Review - January 2012***
- ***Mission Transfer Review – April 2012***

CERES FM-5 Pre-Launch Calibration

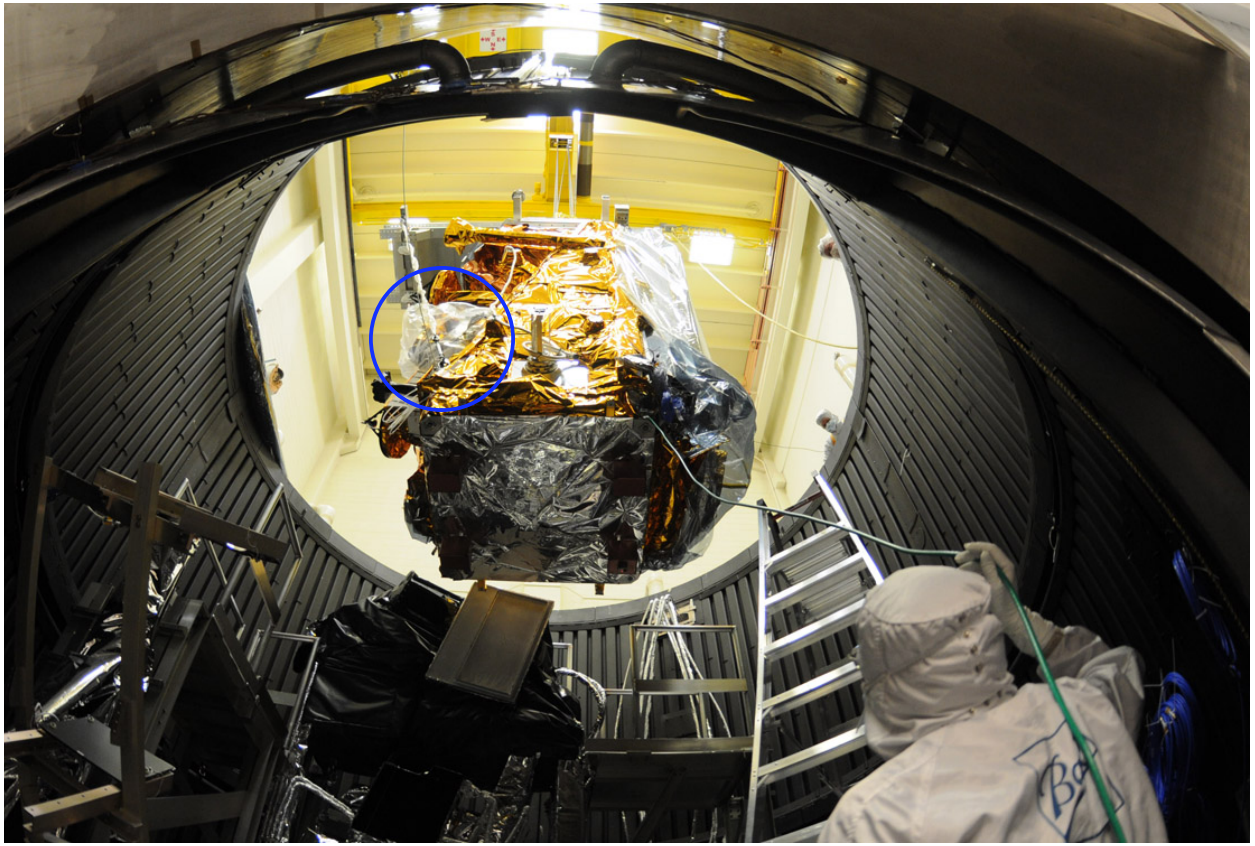
Pre-launch Calibrations were performed with TRW's Radiometric Calibration Facility (RCF).

Four separate pre-launch calibration campaigns have been performed on the CERES FM5 instrument since it was fabricated.



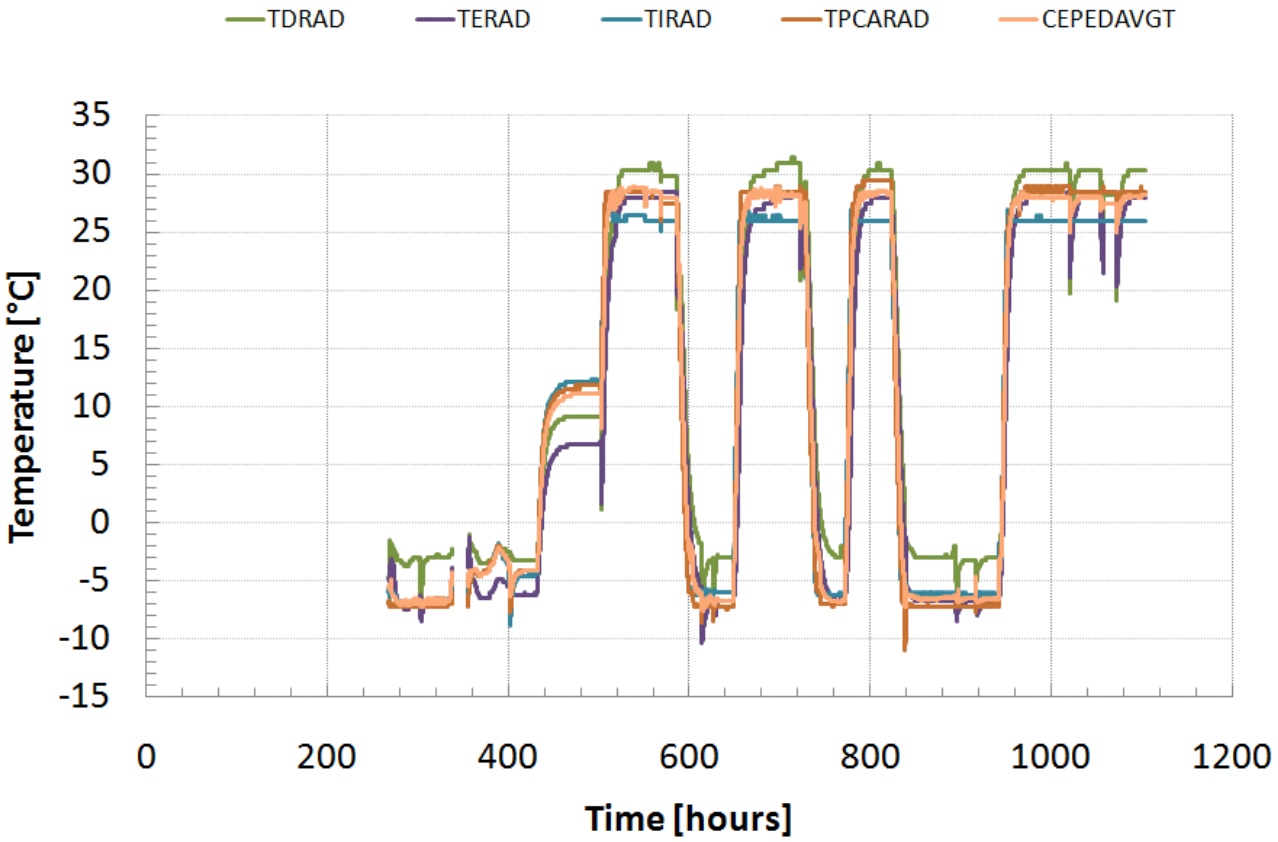
Observatory TVAC Testing Complete

Clouds and the Earth's Radiant Energy System



NPP Thermal Vacuum Summary

- **CERES successfully completed Observatory level thermal vacuum testing**
  - All plateau temperature goals were achieved
  - Cold & Hot balance thermal predicts within 1 & 5.5 deg. C respectively
  - All calibrations within +- 0.25% of instrument level testing (within expectations)
  - All functional testing, including cover operations were nominal



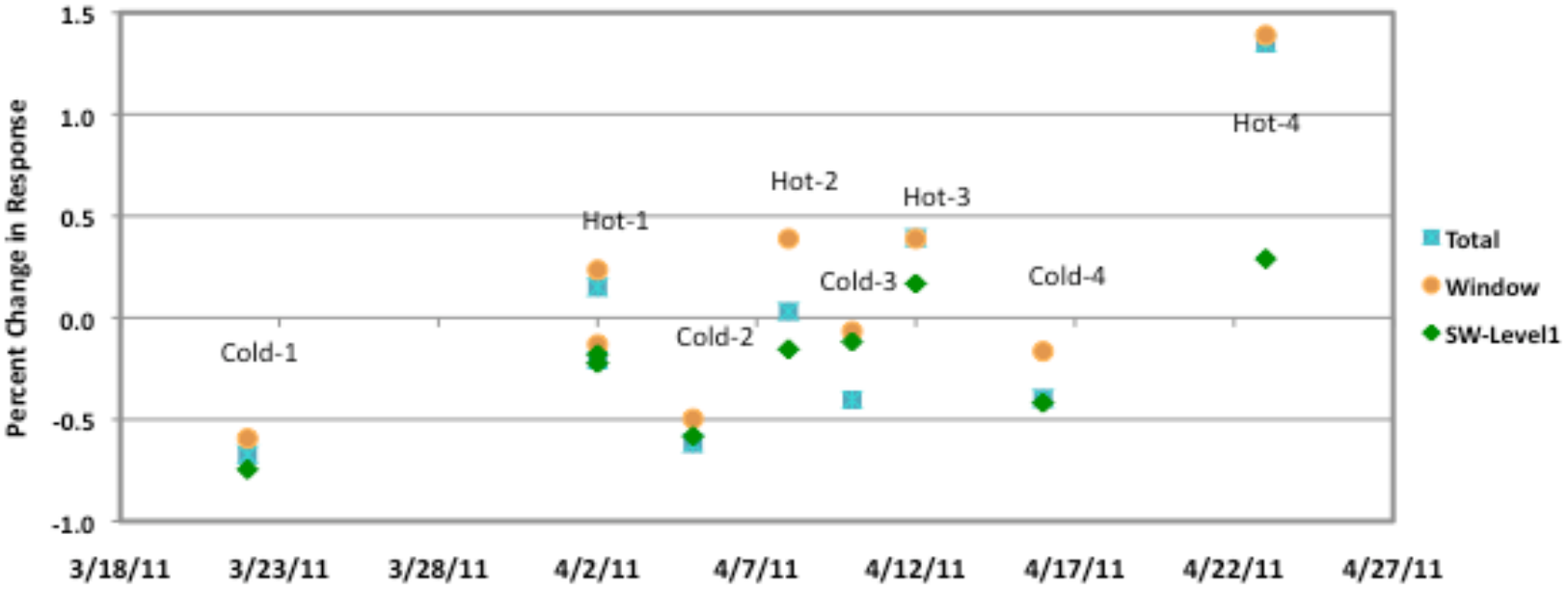
CERES goal temperatures over the duration of the test

Calibration Results from TVAC Testing

- **Calibrations performed at each thermal plateau using On-board sources**
- **Detector Gains varied -0.8 to +1.4 percent in comparison with instrument level tests.**
- **Apparent large deviations are due to test environment and lack of external reference.**
  - Approximate 2-week settling time for detectors in vacuum environment, eliminate 1st
  - Final Hot Plateau results skewed due to cooling reference source, eliminate last.
  - Thermal Plateaus at Qual levels, significantly different from Flight, increased variability

Correcting for environment demonstrates traceability at +- 0.25% level

CERES FM-5 Observatory TVAC Internal Calibration Test Results



CERES Integrated Mission Timeline

- **L+11 Days**
  - **Operational Power Applied to CERES instrument**
  - **Commence Functional Checkout**
  - ***Begin routine science data processing***
- **L+12 Days**
  - **First internal Calibration executed**
- **L+17 Days**
  - **Regular internal Calibrations begin**
- **L+43 Days**
  - **Intensive Cal Val period initiates**
  - **Main & Solar Diffuser Cover's open**
  - ***Science Operations Commence (SOC)***
  - **Daily internal calibrations initiated**
  - **Bi-Weekly Solar calibrations initiated**
- **SOC+6 Months**
  - **Intensive Cal Val period complete**
  - **Spacecraft Calibration Maneuvers Complete**
  - **Commencement of Long Term Radiometric Validation Activities**

Aqua/Terra and NPP Intercomparison Opportunities

- **Primary comparison - Aqua and NPP:**
  - Ascending 1330 orbits, inclination angles differ by about 0.5°
    - Simultaneous (within 6.6s)
      - Groundtrack difference for lat < 0.25 deg; lon < 2 deg
      - Each opportunity lasting 1 minute
    - Matched sites (within 0.25deg)
      - Time differential < 5 min.
      - Groundtrack difference for lat < 0.25 deg.; lon < 0.25 deg
      - Varying duration of each opportunity from 1 to 5 minutes

- **Secondary comparison - Terra and NPP:**
  - Descending 0930 and Ascending 1330 orbits
    - Matched sites (within 0.25deg)
      - Time differential < 5 min.
      - Groundtrack difference for lat < 1.0 deg.; lon < 1.0 deg
      - Duration of each opportunity ~20 seconds

Instrument and ERBE-Like Data Product Release Strategy

At_Launch - Static Algorithms and Pre-Launch coefficients - baseline product used during intensive Cal Val Period (Launch to SOC+8 Months)

Edition1_CV - Static Algorithms and coefficients - baseline product used in cal/val protocol (SOC+7.5 Months, continuous over mission)

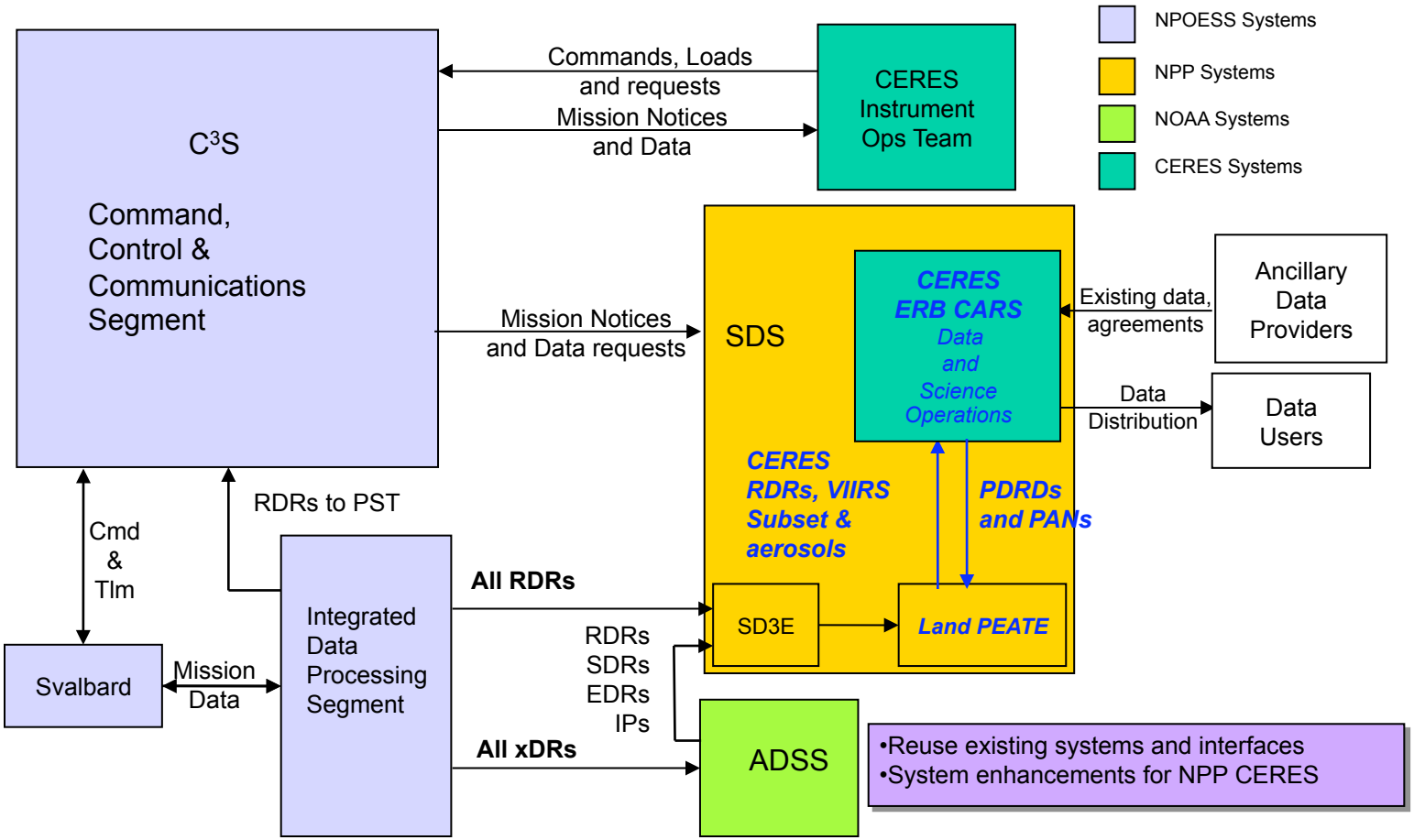
Edition2 - Utilizes temporally varying coefficients to correct for traceable radiometric drift. All spectral changes are broadband and 'gray'. (L+1 yrs to ~5 yrs)

Edition3 - Will incorporate temporally varying spectral artifacts in the SW measurements. A complete re-analysis of Ground Calibration with additional component characterization measurements. (L+5 yrs)

Edition2 products lag Edition1_CV by a minimum of 6 months

NPP CERES Operational Data Flow

Clouds and the Earth's Radiant Energy System



FM-6 on JPSS-1
Status

CERES FM6 Status & Near-Term Activities

- **Project received ~$5M for FM6 in CY08**
- **Allowed for enhanced study phase only, start 11/08**
- **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**
  - **All major subassemblies delivered to NG, currently in sensor I&T**
  - ***Radiometric Calibration Facility Upgrades Complete – January 2012***
  - ***Pre-Environemental Readiness Review - February 2012***
  - ***Ground Calibration Campaign – Spring 2012***
  - ***Delivery to storage – Summer/Fall 2012***
  - ***Launch Date of Oct. 2016 (TBR)***

Radiometric Performance Requirements

CERES is defined as a class 'B' Mission

5-year design Lifetime

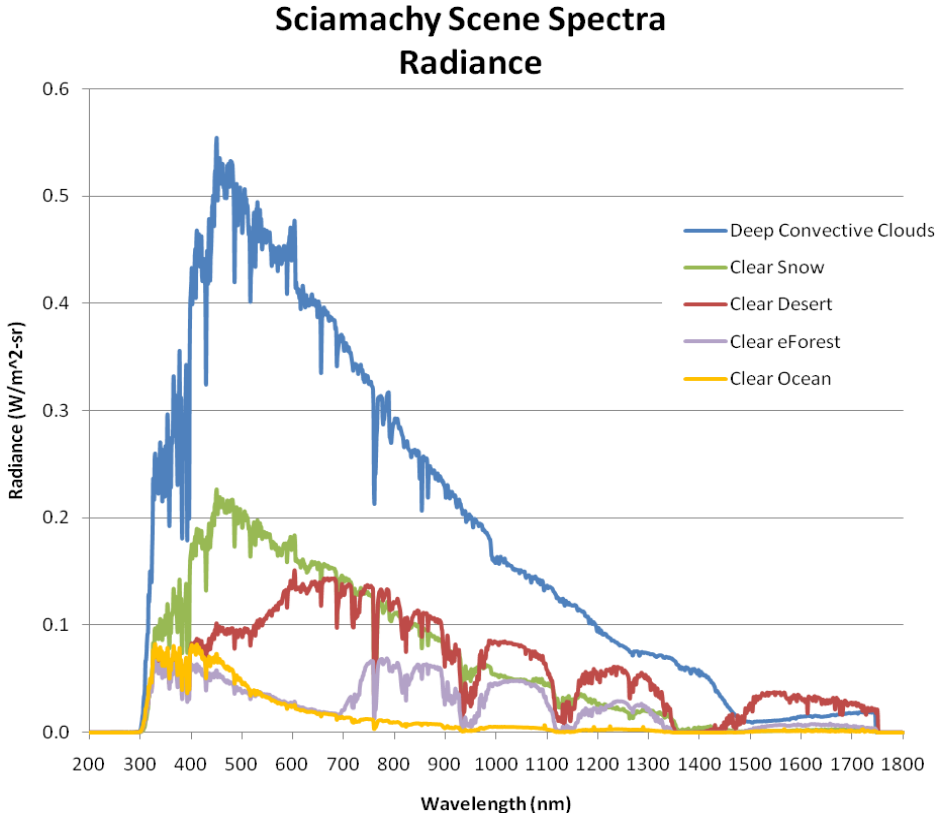
Spectral Region	Solar		Terrestrial		Atmospheric Window
Wavelengths	0.3 – 5.0 microns		5 – 200 microns		8-12 microns
Scene Levels	<100 wm^2/sr	>100 wm^2/sr	<100 wm^2/sr	>100 wm^2/sr	All Levels
Accuracy Requirements	0.8 w/m^2-sr	1.0 %	0.8 w/m^2-sr	0.5 %	0.3 w/m^2-sr
SOW Stability Requirements		0.14 %/yr		0.07 %/yr	
FM5 Accuracy Capability		1.7 %		0.7 %	
FM5 Stability Capability		0.32 %/yr		0.12 %/yr	
Climate Stability Goals		< 0.6 w/m^2/dec < 0.03 %/yr		< 0.2 w/m^2/dec < 0.02%/yr	

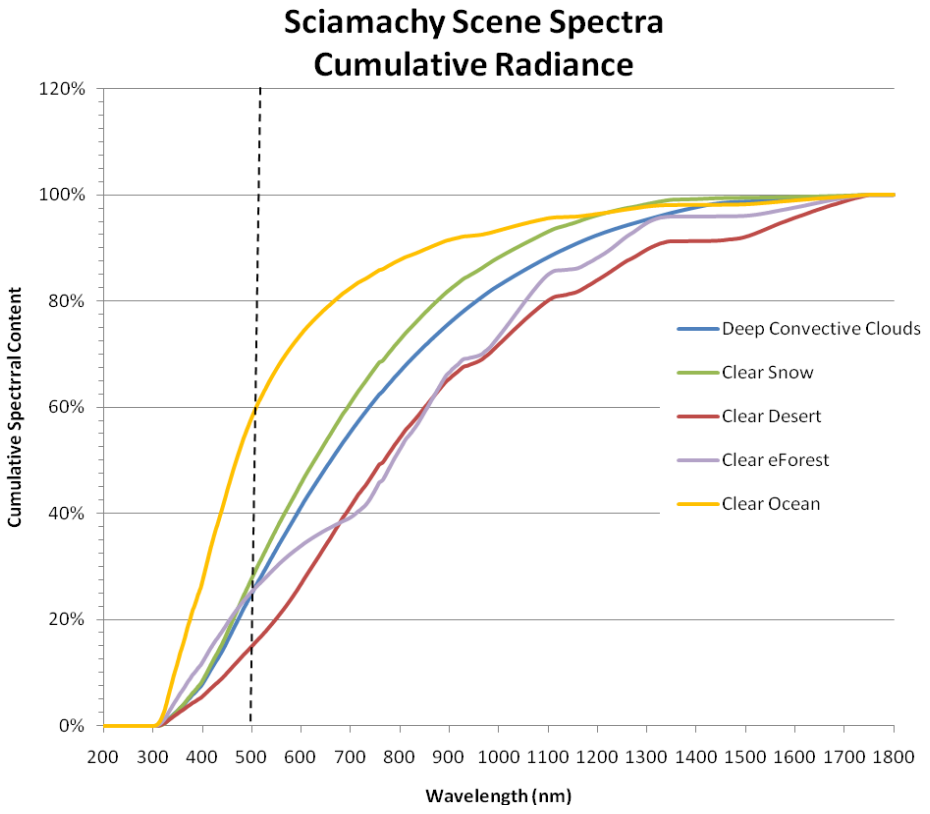
Current efforts are focused on improving traceability within the reflected solar bands (Short-Wave and Total channels) by enhancing the ground calibration in the short-wave region for FM-6.

Reference Reflected Solar Scene Spectra

Clouds and the Earth's Radiant Energy System

Historically, the contribution of short wavelength radiance in reflected solar spectra has been underappreciated in the CERES calibration program





The globally averaged All Sky composite scene contains as much as 30% of its reflected solar radiance below 500nm

CERES Ground Calibration

Radiometric Calibration Facility

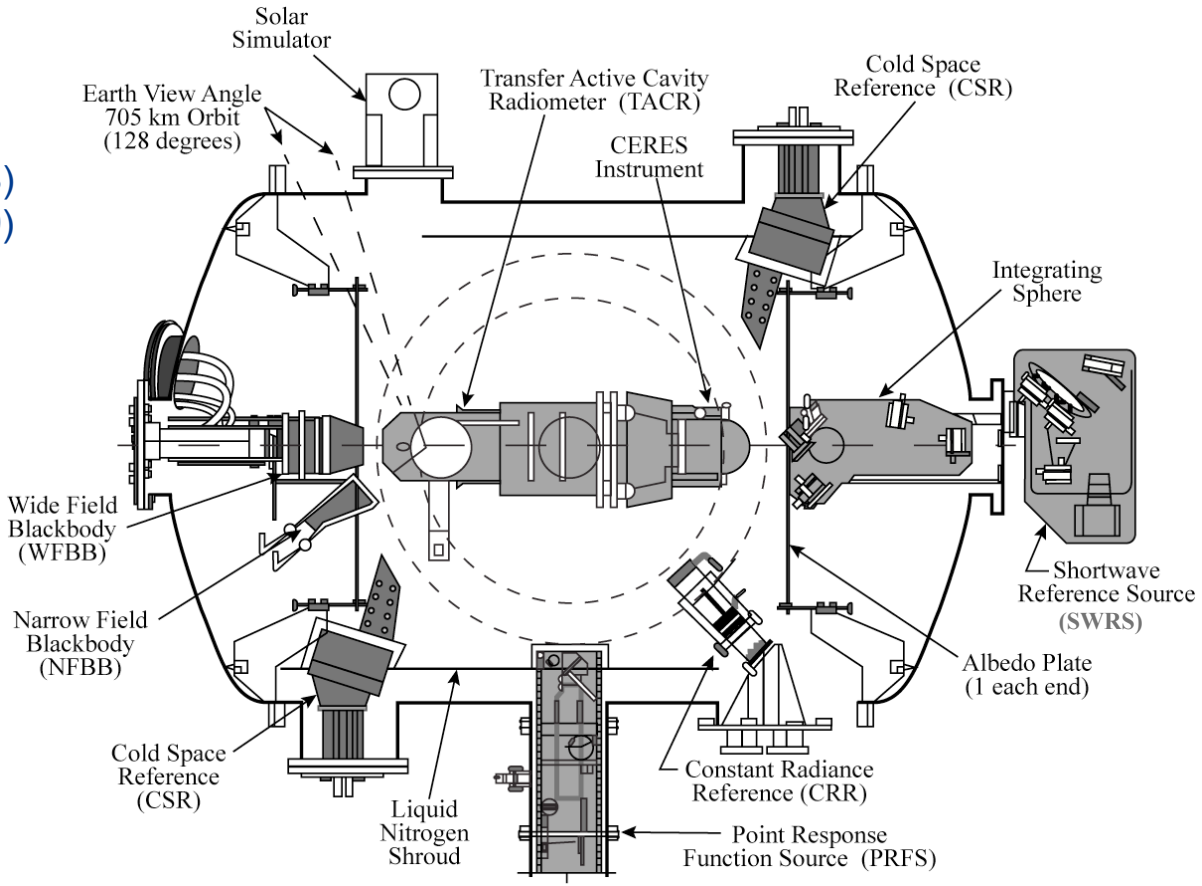
- Heritage ERBE calibration facility
- Revamped for CERES in 90's

Thermal IR Bands

- Narrow Field of View Blackbody (NFBB) is primary standard (emissivity >0.9999)
- 12.5 cm Wide Field of View Blackbody (WFBB)
- Cold Space Reference (CSR) blackbodies

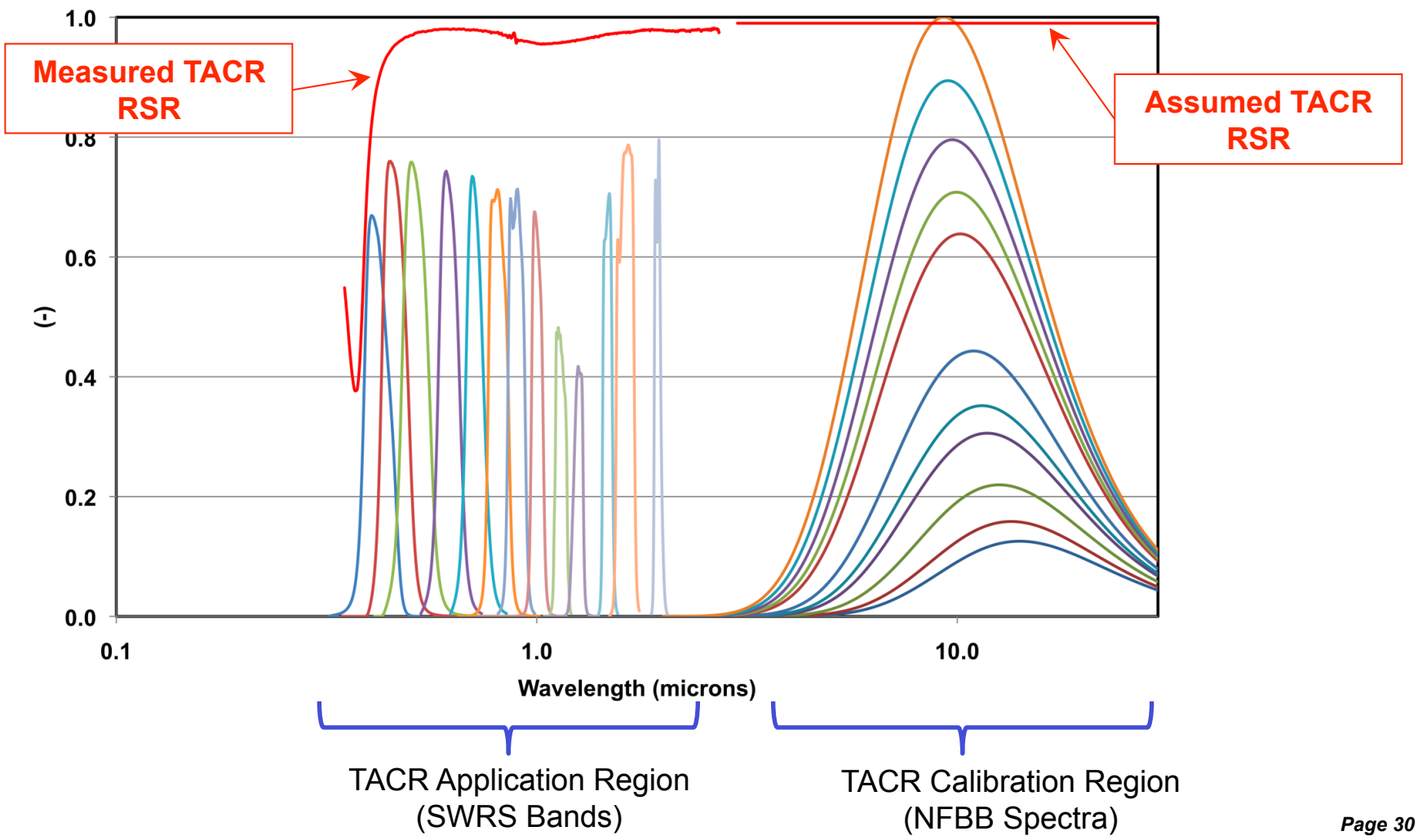
Reflected Solar Bands

- SW reference source (SWRS) with minimum LW variations and spectral characterization capability
  - 13 discrete bands between 420 and 1960 nm
  - 5 cm integrating sphere with associated optics
- Cryogenically cooled Transfer Active Cavity Radiometer (TACR)



CERES Traceability

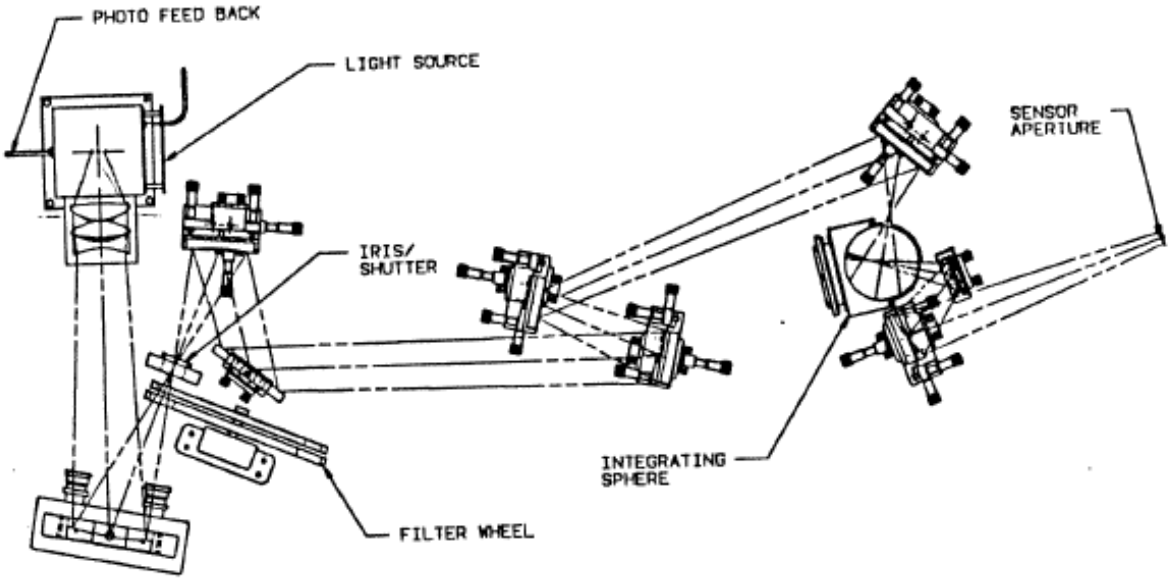
- NFBB is used for long-wave calibration at temperatures between 205 K to 318K
- Short-wave calibration is achieved by transfer of NFBB standard to SWRS via TACR



RCF Shortwave Reference Source (SWRS)

The SWRS consists of a stabilized Halogen lamp fed into the RCF via optical train

- 8 mirrors, 1 triplet lens set,13 filters in a filter wheel, an iris aperture, a vacuum window and an integrating sphere

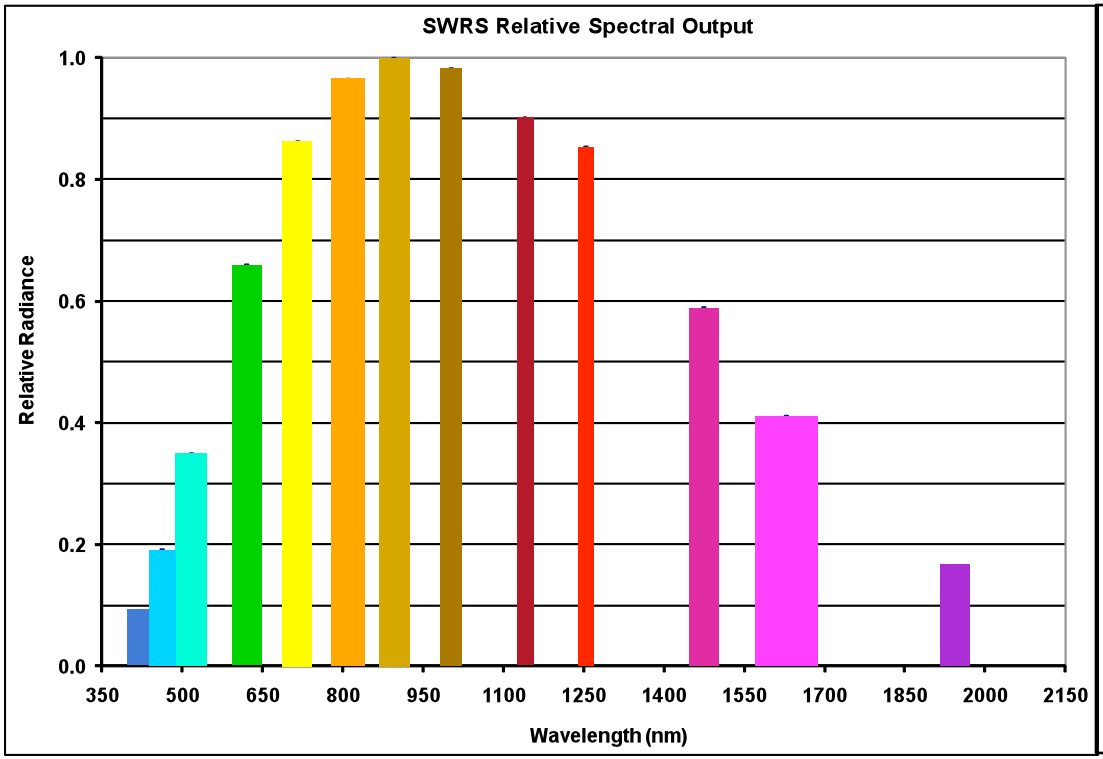


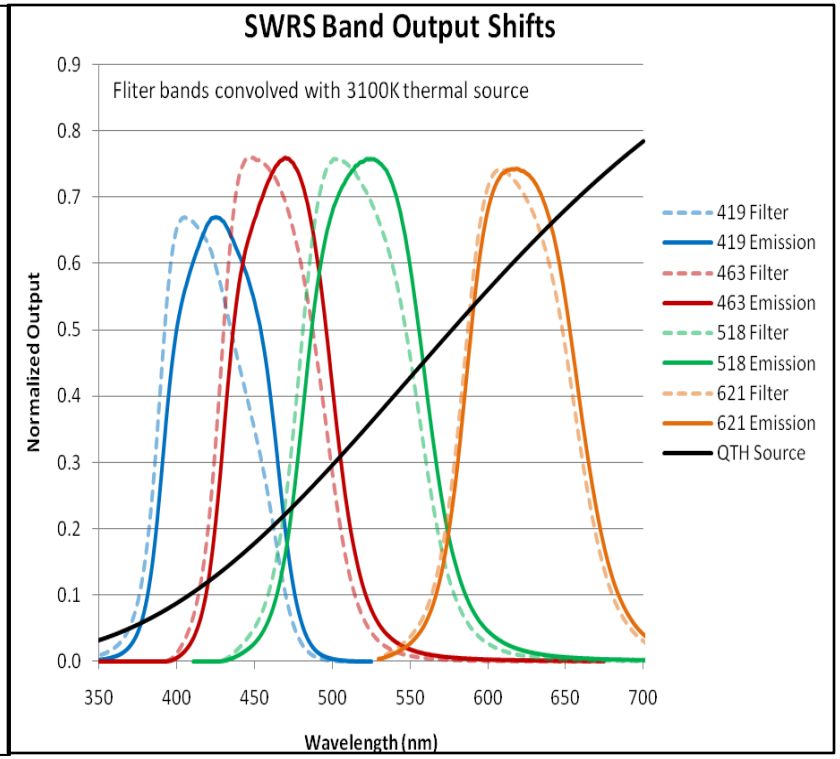
- 250-watt QTH lamp source @ ~3100K
- Precision power supply with <0.4% rms radiance ripple
- Photofeedback system using a thermally-stabilized silicon photodiode

PARAMETER	VALUE
Filters used for CERES Calibration (center wavelengths in μm)	0.42, 0.46, 0.51, 0.62, 0.71, 0.81, 0.90, 1.00, 1.15, 1.25, 1.35, 1.63, 1.94
Broadband Radiance Range ($W/m^2/sr$)	13 to 2500
Exit Port Angular Subtense (degrees): cross-scan; in-scan	3.5; 7.8
Radiance Uniformity (peak to valley): aperture; field angle	± 0.5%; ± 1.5%
Radiance Fluctuation (0.01 sec. to hours)	< ± 0.1% (1-sigma)
Thermal Stability and Uniformity (Kelvin)	± 0.5
Sphere Operating Temperature (Kelvin)	< 85

Existing SWRS Limitations

- Intra-band knowledge assumes spectral shapes of filters and source only and does not include the optical train spectral profile
- Characterization of legacy SWRS throughput has demonstrated marked change in filter bands (Helmlinger 2010) – Most probable cause is degradation of silver coated mirrors
- Spectral content in the UV-blue region is limited, which impacts calibration for this region
- No filter bands below 420nm, where there is known reflected solar radiation collected by the CERES sensor

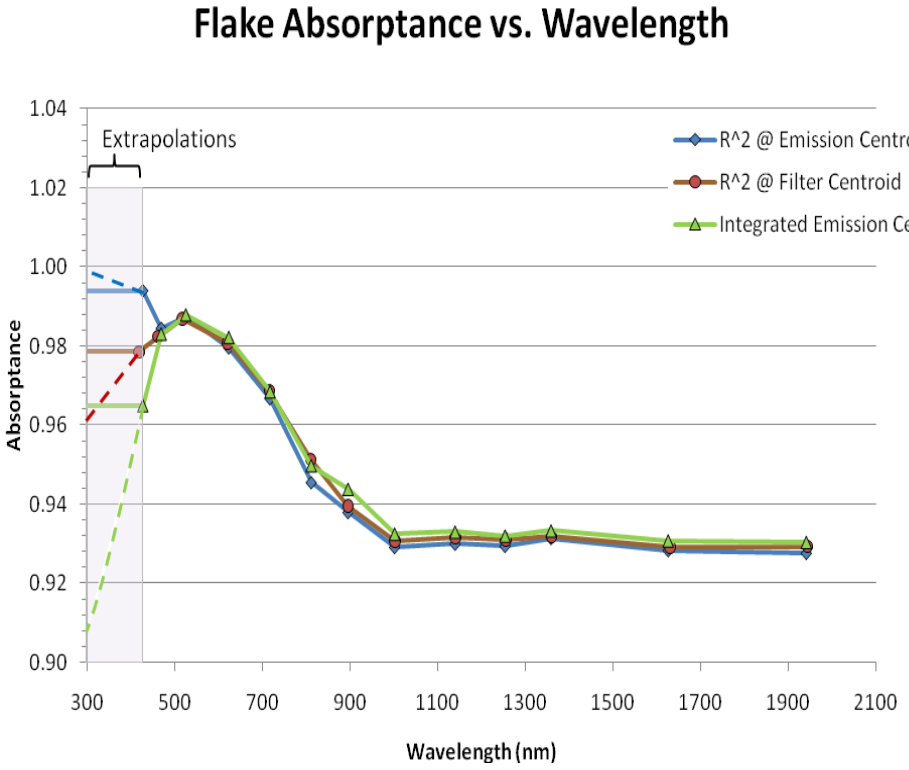


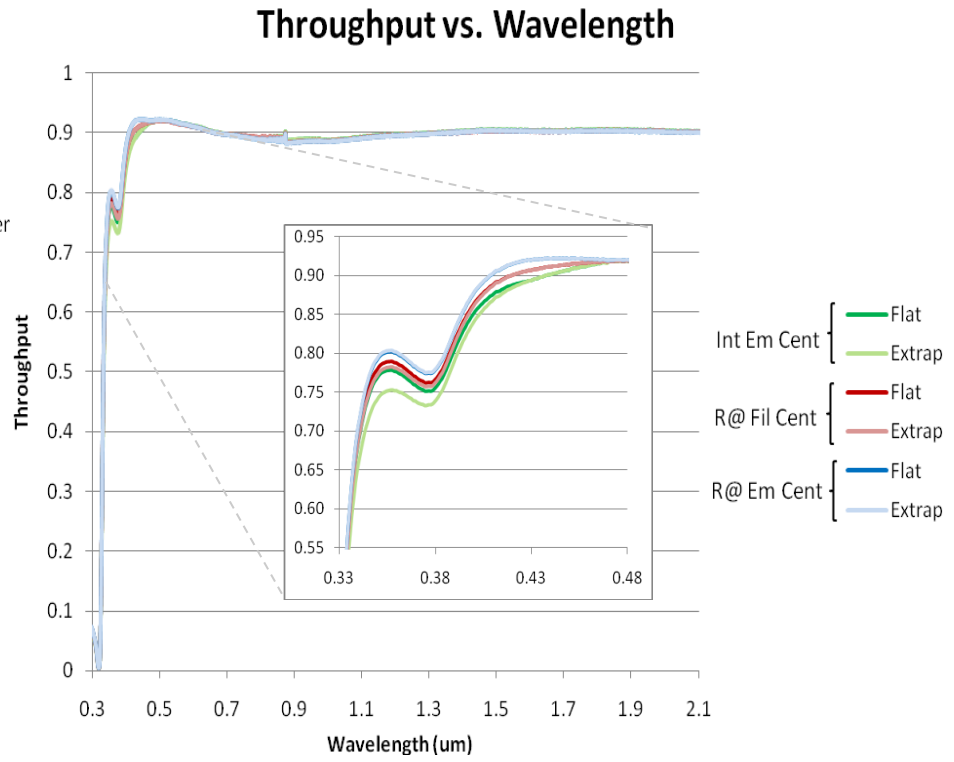


Response Functions & Extrapolation Issue

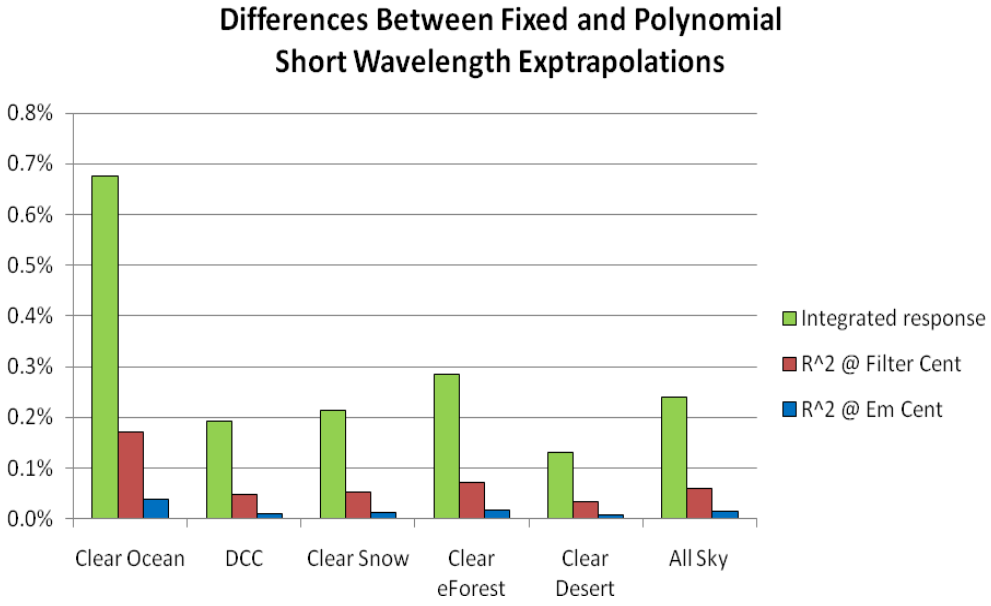
Uncertainty in short wavelength bands coupled with extrapolation of flake absorptance at sensor limits, yields variability in expected response of the CERES sensor.

Predominant impact is in the blue-visible region, where there are no filter bands



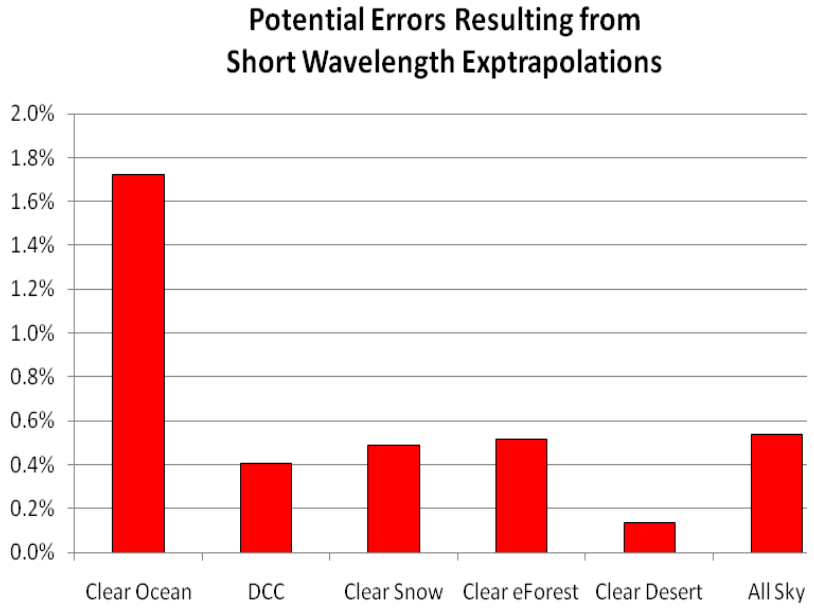


Limitations in Traceability



The issue is that this region is unknown and there is no choice but to extrapolate.

Taking the largest difference yields a potential, worst case systematic error of > 0.5% for All Sky



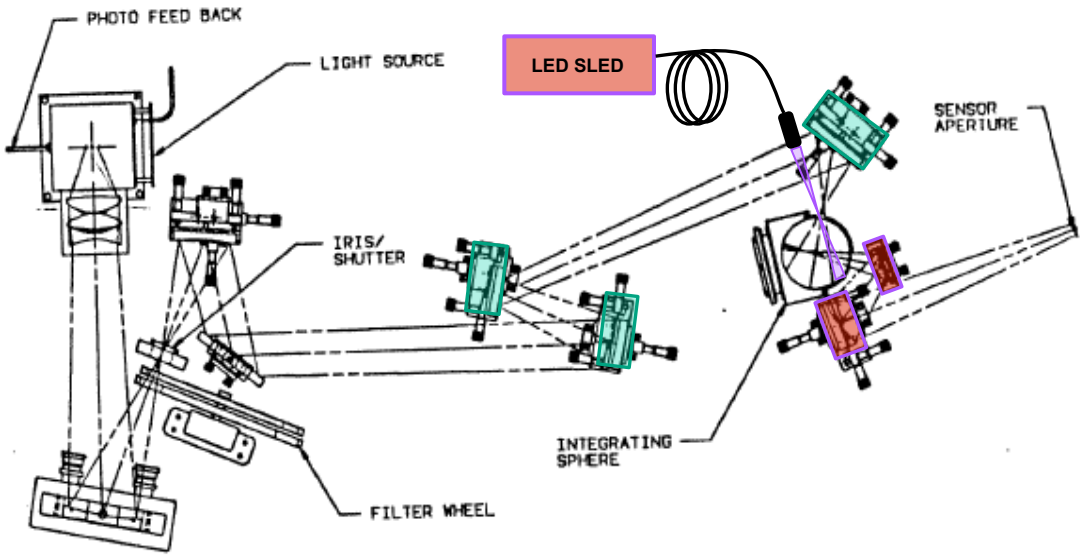
Improvement in traceability requires calibration in the UV-blue region

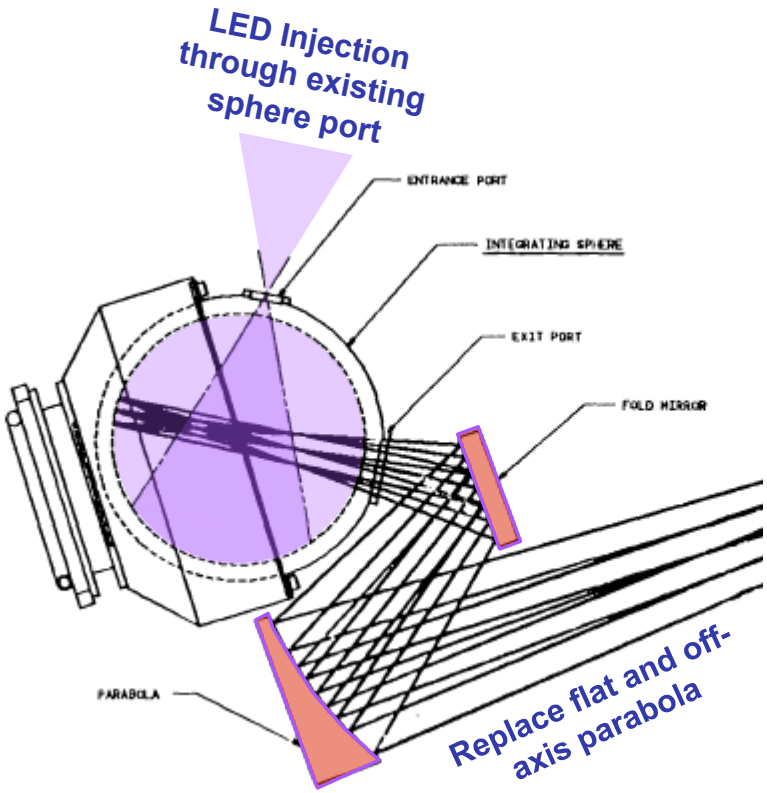
- Brighter, stable sources in the UV-blue
- More throughput to TACR in the UV-blue

FM 6 Ground Calibration Improvements

SWRS Improvements

- **Improve SWRS optics**
  - NASA has contracted mirror replacement – enhanced aluminum coatings on mirrors following sphere
  - Option to replace additional mirrors in SWRS optical train to improve throughput
- **Supplement SWRS for increased radiance at the shorter wavelengths**
  - NASA has contracted LED augmentation to existing SWRS
  - Discrete LED sources at 365nm, 385nm and 405nm
  - Option for additional LED coverage up to 970nm
  - Option for future coupling of coherent sources

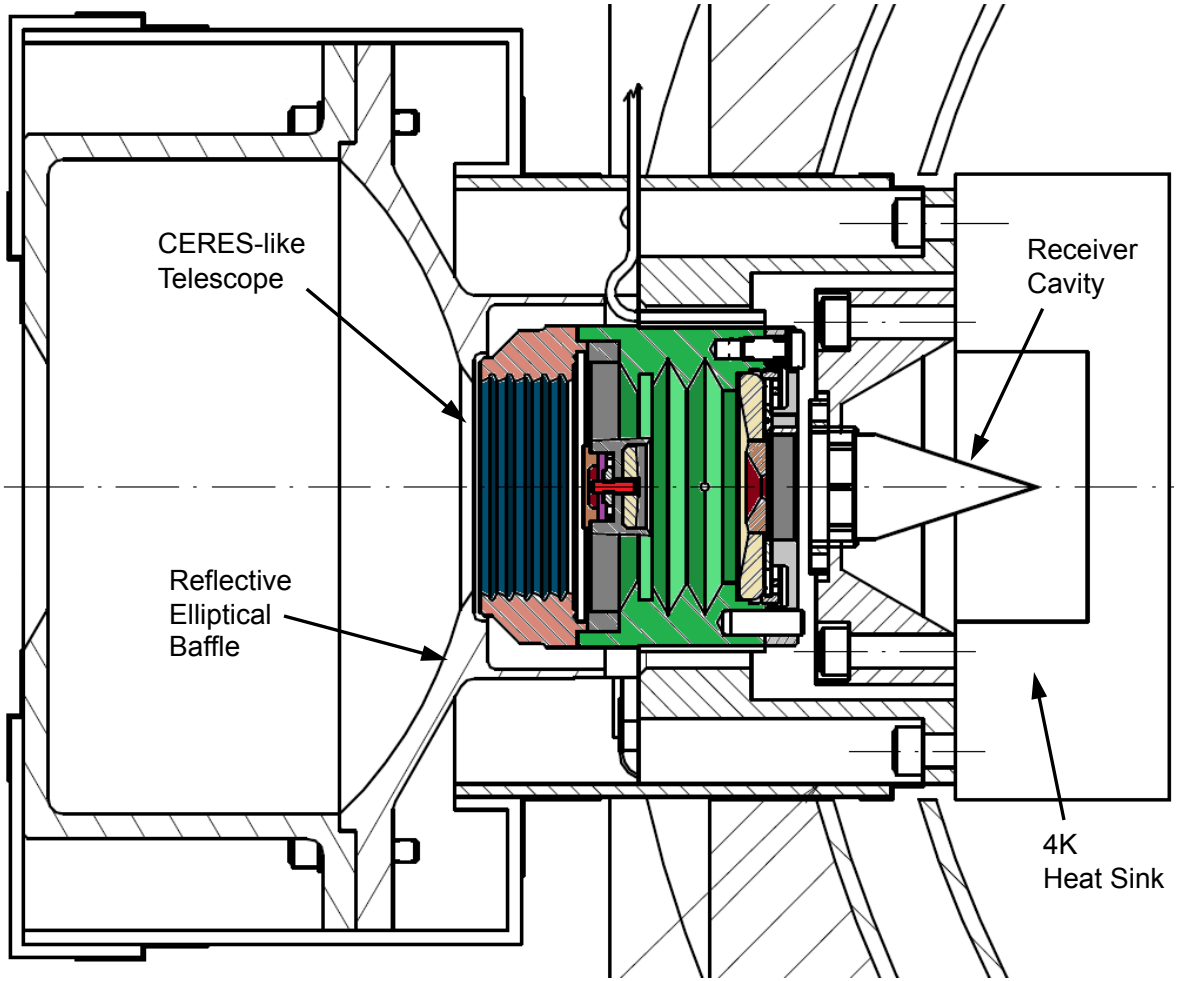




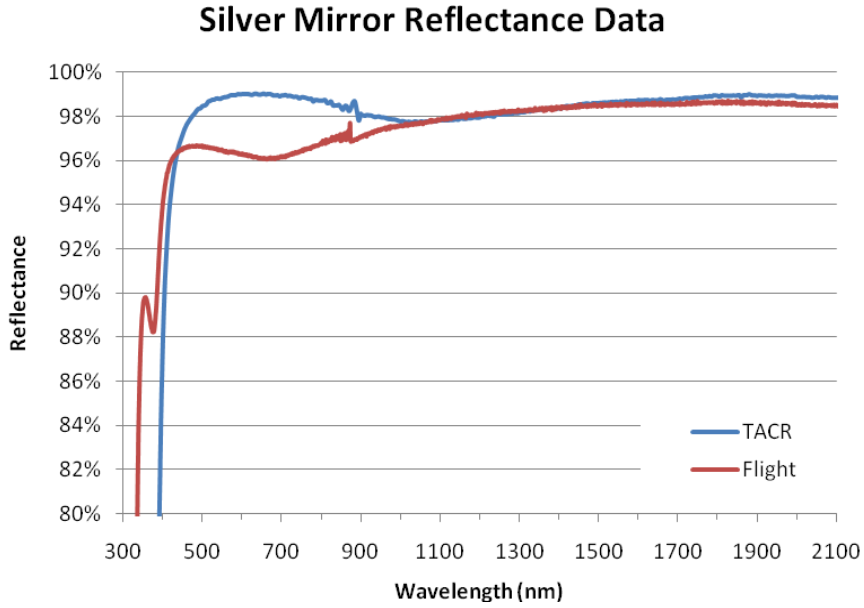
RCF Transfer Active Cavity Radiometer

TACR

- **Cryogenic receiver cavity**
  - Black copper cone, thermally sunk to a liquid He dewar
  - Absorptance >0.999 from visible to IR
- **TACR telescope**
  - CERES-like fore optics
  - Telescope housing and baffle are optically identical to flight configuration
  - Nickel mirrors with flight optical prescription
- **Elliptical reflective baffle**
  - Replaces sensor forward baffle
  - Provides radiance heat rejection
  - Increases thermal stability

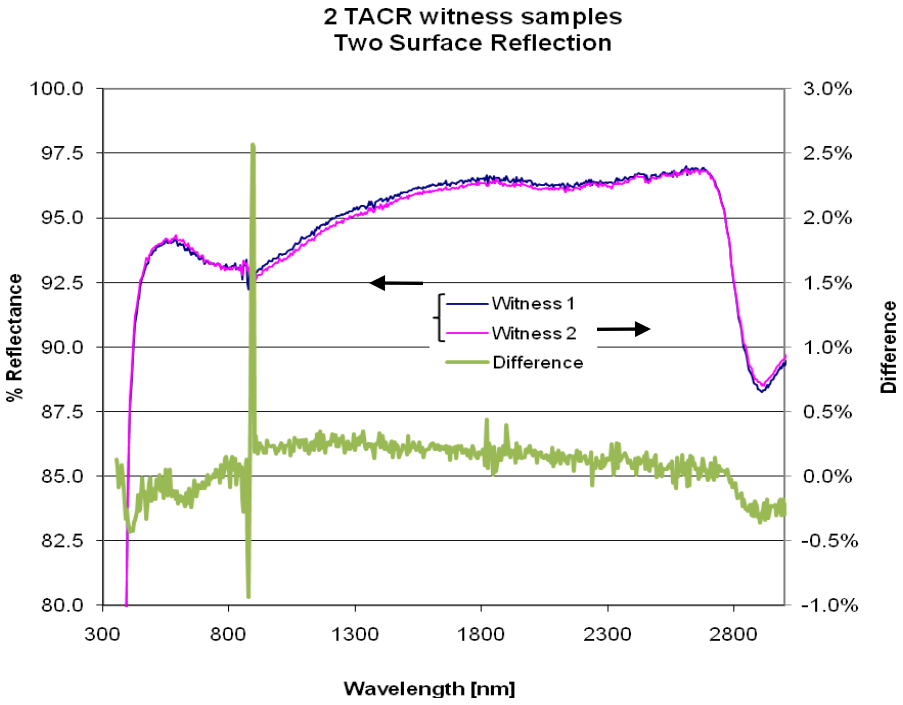


Existing TACR Limitations



- TACR mirror coating run did not meet reflectance specifications near 350nm, and is not identical to the sensor mirrors, which met spec
- Acceptance of TACR mirrors was based on accepted understanding of reflected solar content in the UV-blue spectrum in the early 90's, which was assumed to introduce minimal systematic error

- TACR mirror reflectance determined from witness sample measurements – no direct characterization was made
- IR response of TACR telescope assumed to be 99.0% based on composite data from FTS and manufacturer test reports

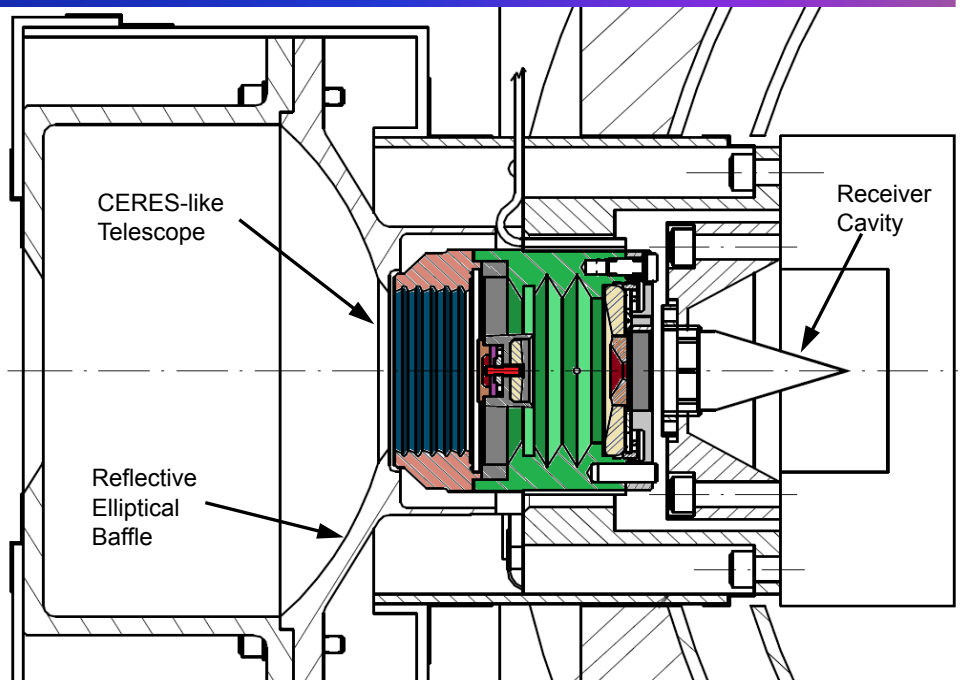


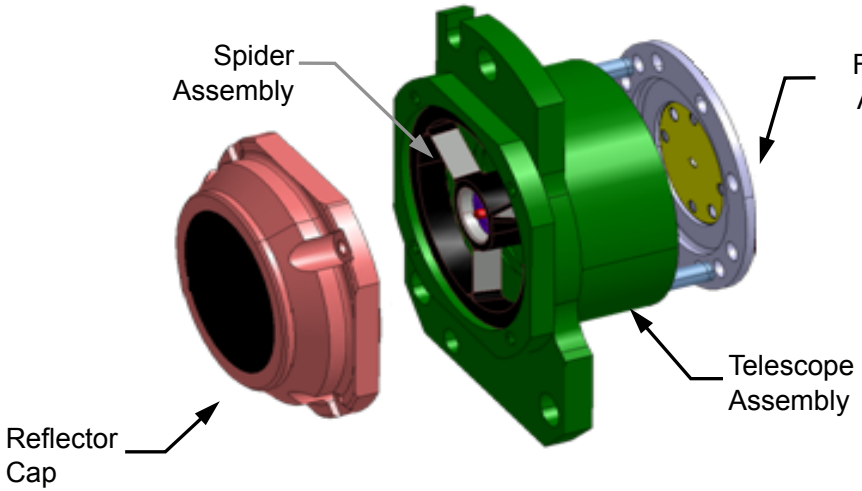
FM 6 Ground Calibration Improvements

TACR Improvements

- **Install new CERES-like front end with aluminum telescope mirrors**
  - Replacing silvered mirrors with aluminum mirrors
  - Telescope geometry and optical prescription remains identical to flight
  - Ambient and cryogenic reflectance measurements from 0.3 to 100 μm on witness samples
  - Telescope throughput measurements from 0.3 to 100 μm
  - Baseline gain, out-of-field contribution and linearity tests to be run in calibration chamber

- **Remove and characterize legacy TACR telescope**
  - Determine total throughput to better than 0.15% from 0.3 to 100 μm
  - Compare with heritage reflectance measurements



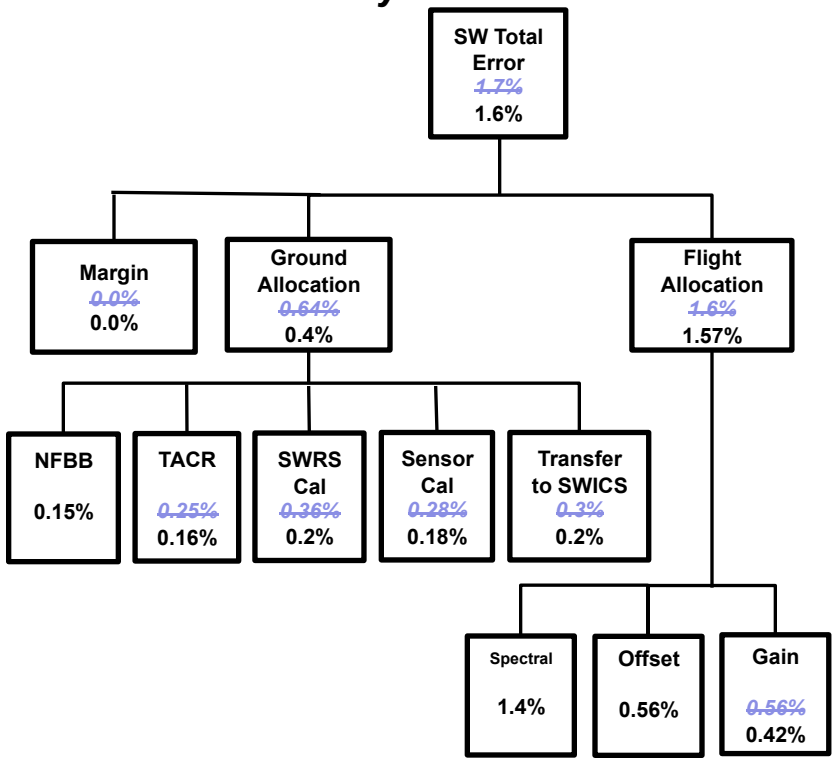


Traceability Improvements

- SW Ground Calibration error allocation is 0.6%
  - The proposed improvements will provide capability of 0.4% ground accuracy or better through
    - TACR spectral reflectance
    - SWRS Calibration
    - Sensor Calibration
    - Transfer to SWICS
  - Spectral response uncertainty below 500nm can be reduced from 3% to less than 0.25%
    - Additional sources to measure SW spectral response
    - Larger throughput to TACR receiver cone – improved signal-to-noise performance in SW bands
    - Bypassing optical filters improves spectral stability in SW bands

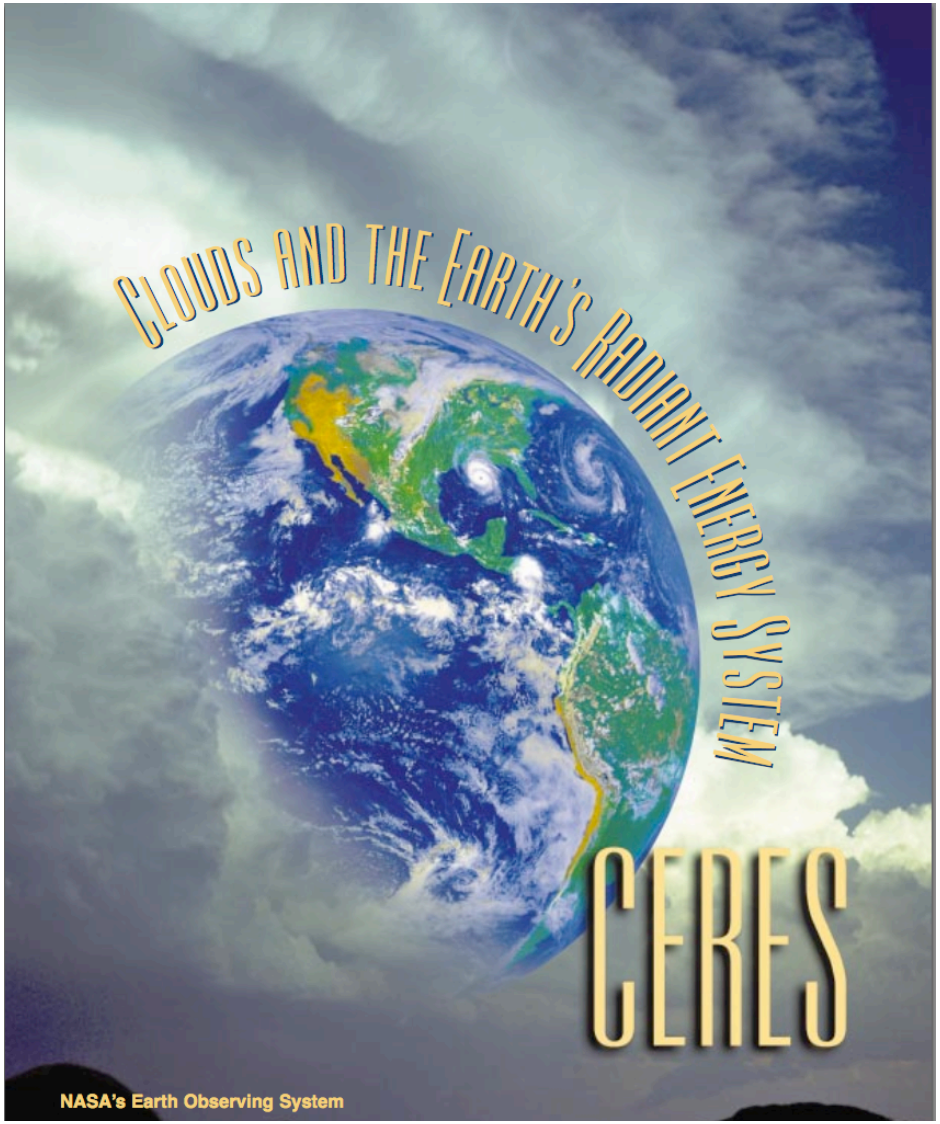
FM-6

Short-wave Channel Error Allocation
Global All-Sky Scenes



- SW Flight Calibration error allocation is 1.6%
  - With improvements in the SWICS photodiode in-flight SW calibration error is reduced
  - Predicted reduction in error to 1.5% accuracy
- Expected improvement in traceability – better than 1.6% total accuracy for SW for FM6
- Legacy traceability improvements to be assessed following existing TACR telescope removal and re-characterization

Summary



- **CERES Team is fully prepared**
  - Heritage Team members
  - 6th CERES sensor to fly (FM-5)
- **Radiometry**
  - Most highly characterized CERES instruments to date.
  - Significant concern as budgets did not allow known design weaknesses to be addressed in cal subsystems
- **Cal/Val Implementation**
  - Protocol is mature and proven