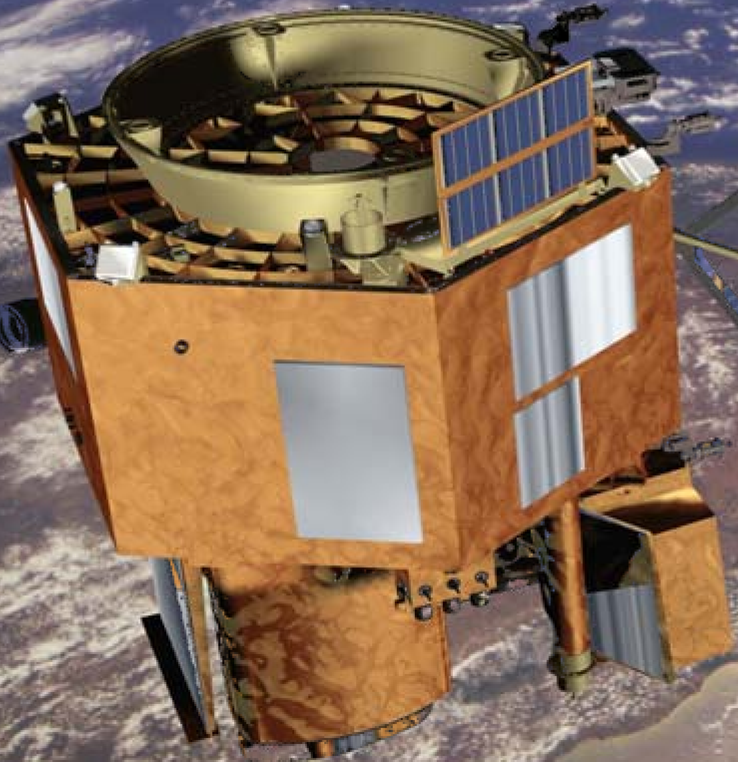
NASA / EOS Calibration Strategy



NASA/GSFC Calibration Science Team

Steve Ungar **Jack Xiong**
Kurt Thome **Jim Butler**
Lawrence Ong

CEOS/WGCV-30 Plenary
Sao Paulo – 27 May 2009

NASA / EOS Calibration Strategy

- Prelaunch
  - Calibrate and characterize (component and system level)
  - Characterize the calibration and characterization
  - Ensure conformity with, and comparison against, NMI laboratory standards
- Post-launch
  - Lamps
  - **Solar**
  - Lunar (astronomical)
  - Vicarious
  - “Special Targets” (limb scanning, active illumination)
  - Statistical (trending, 90° yaw)
  - Direct comparison against other satellites

CALIBRATION MEASUREMENTS STRATEGY
FOR PASSIVE OPTICAL (0.35-3.5 μm) SYSTEMS

OBSERVING SYSTEM CATEGORY

MS ≡ Multi-Spectral

WIS ≡ Wedge Imaging Spectrometer

GIS ≡ Grating Imaging Spectrometer

OBSERVING SYSTEM PARAMETERS

$F(\lambda)$ ≡ Spectral response function

R_N ≡ Radiometric response for detector N

S_o ≡ Dark response

$(x,y)_N$ ≡ Geometric response (detector pointing vectors)

MTF ≡ Modulation transfer function

CALIBRATION MEASUREMENTS STRATEGY

	PARAMETER														
	$F(\lambda)$			R_N			S_o			$(x, y)_N$			MTF		
	MS	WIS	GIS	MS	WIS	GIS	MS	WIS	GIS	MS	WIS	GIS	MS	WIS	GIS
COMPONENT TESTS AND ANALYSIS	●	○	—	○	○	○	○	○	○	—	—	—	○	○	○
SUBSYSTEM TESTS: TELESCOPE, GIS, WIS AND MS/PAN	○	●	○	○	○	○	○	○	○	●	●	○	○	○	○
INSTRUMENT LEVEL LABORATORY TESTS	○	○	●	●	●	●	○	○	○	○	○	●	●	●	●
ON-ORBIT MEASUREMENTS															
- SOLAR DIFFUSER	—	—	—	●	●	●	○	○	○	—	—	—	—	—	—
- CLOSED APERTURE COVER	—	—	—	—	—	—	●	●	●	—	—	—	—	—	—
- INTERNAL SOURCES	—	—	—	○	○	○	—	—	—	—	—	—	—	—	—
- LUNAR SCANS	—	—	—	○	○	○	○	○	○	—	—	—	○	○	○
- EARTH SCENES	—	○	○	○	○	○	—	—	—	○	○	○	○	○	○

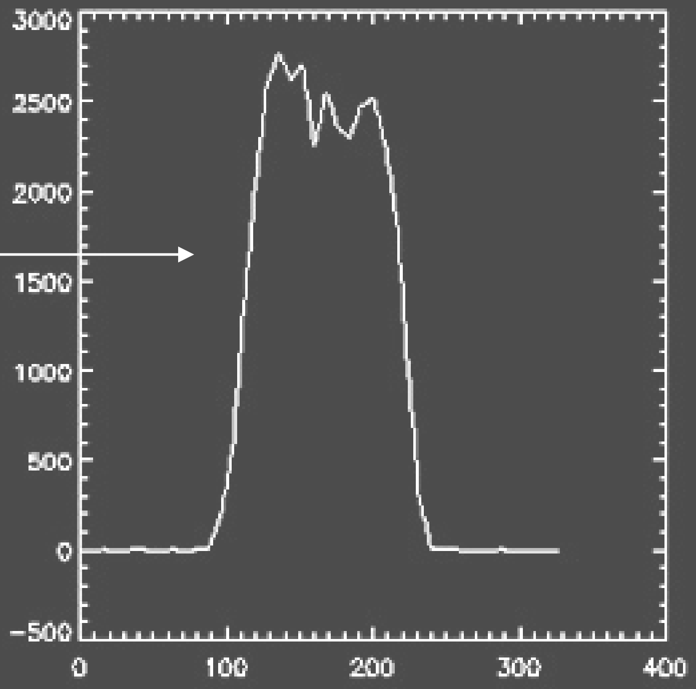
● PRIMARY MEASUREMENT ○ SECONDARY MEASUREMENT

CALIBRATION MEASUREMENTS STRATEGY

	PARAMETER														
	$F(\lambda)$			R_N			S_o			$(x, y)_N$			MTF		
	MS	WIS	GIS	MS	WIS	GIS	MS	WIS	GIS	MS	WIS	GIS	MS	WIS	GIS
COMPONENT TESTS AND ANALYSIS	●	○	—	○	○	○	○	○	○	—	—	—	●	○	○
SUBSYSTEM TESTS: TELESCOPE, GIS, WIS AND MS/PAN	○	●	○	○	○	○	○	○	○	●	●	○	○	○	○
INSTRUMENT LEVEL LABORATORY TESTS	○	○	●	●	●	●	○	○	○	○	○	●	●	●	●
ON-ORBIT MEASUREMENTS															
- SOLAR DIFFUSER	—	—	—	●	●	●	○	○	○	—	—	—	—	—	—
- CLOSED APERTURE COVER	—	—	—	—	—	—	●	●	●	—	—	—	—	—	—
- INTERNAL SOURCES	—	—	—	○	○	○	—	—	—	—	—	—	—	—	—
- LUNAR SCANS	—	—	—	○	○	○	○	○	○	—	—	—	○	○	○
- EARTH SCENES	—	○	○	○	○	○	—	—	—	○	○	○	○	○	○

● PRIMARY MEASUREMENT ○ SECONDARY MEASUREMENT

Image Quality (Edge Sharpness)



Lunar Image Expanded by a Factor of 8

Horizontal Slice Through Expanded Lunar Image Rise and Fall About 1 Pixel in Normal Image.

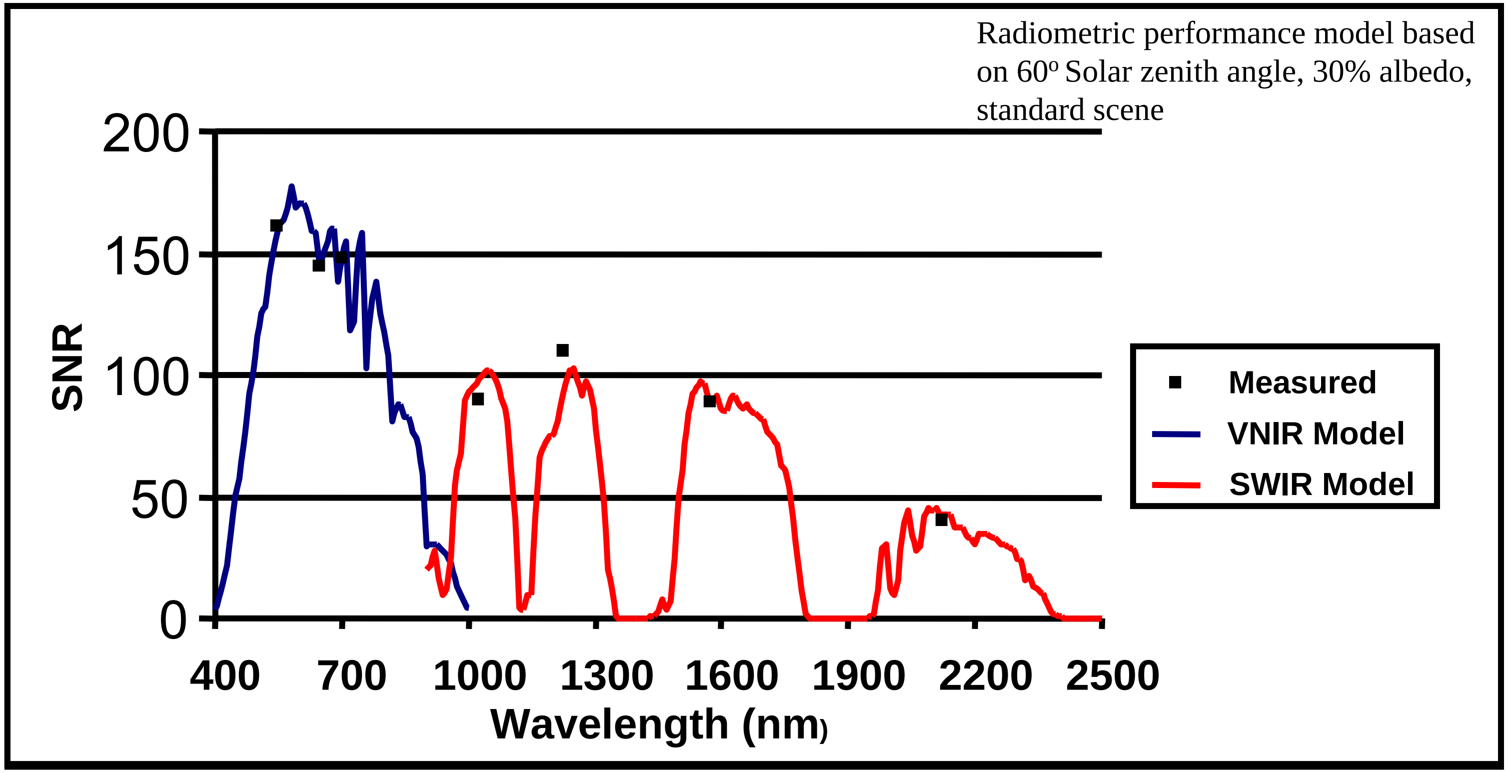
Focus : Lunar Edge

Hyperion Characteristics

Characteristic	Pre-launch Cal	On-orbit Cal
GSD (m)	29.88	30.38
Swath (km)	7.5	7.75
No. of Spectral Channels	220	200 (L1 data)
VNIR SNR (550-700nm)	144-161	140-190
SWIR SNR (~1225nm)	110	96
SWIR SNR (~2125nm)	40	38
VNIR X-trk Spec. Error	2.8nm@655nm	2.2nm
SWIR X-trk Spec. Error	0.6nm@1700nm	0.58
Spatial Co-Reg: VNIR	18% @ Pix #126	*
Spatial Co-Reg: SWIR	21% @ Pix #131	*
Abs. Radiometry(1Sigma)	<6%	3.40%
VNIR MTF @ 630nm	0.22-0.28	0.23-0.27
SWIR MTF @ 1650nm	0.25-0.27	0.28
VNIR Bandwidth (nm)	10.19-10.21	*
SWIR Bandwidth (nm)	10.08-10.09	*

*** Consistent with Pre-Launch Calibration or not measured**

Hyperion SNR



Hyperion Measured SNR						
550 nm	650 nm	700 nm	1025 nm	1225 nm	1575 nm	2125 nm
161	144	147	90	110	89	40

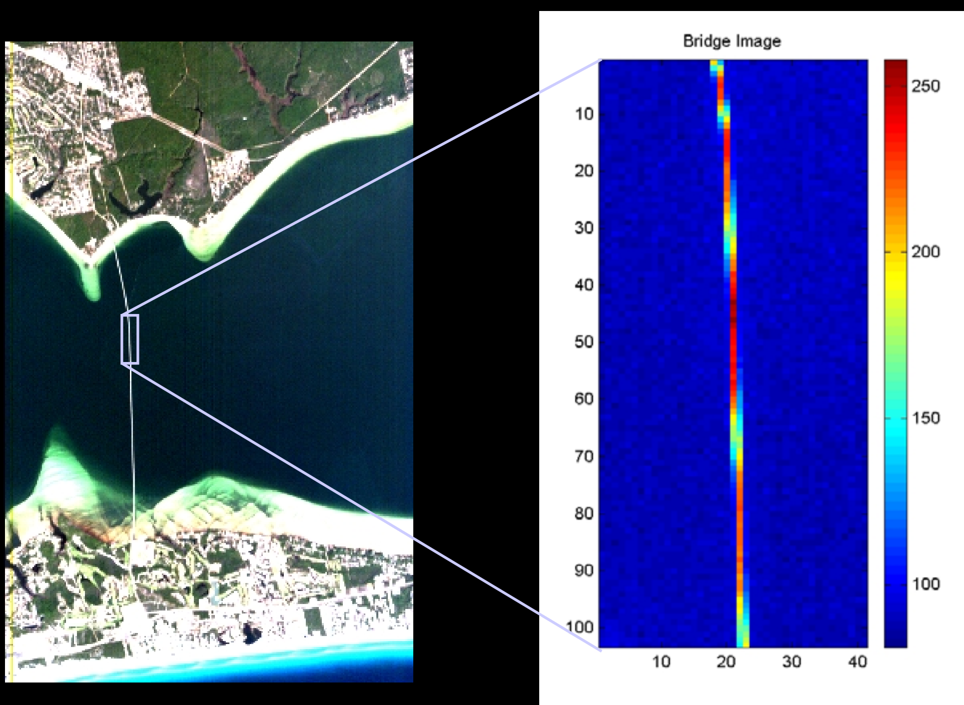
Post Launch MTF Approach

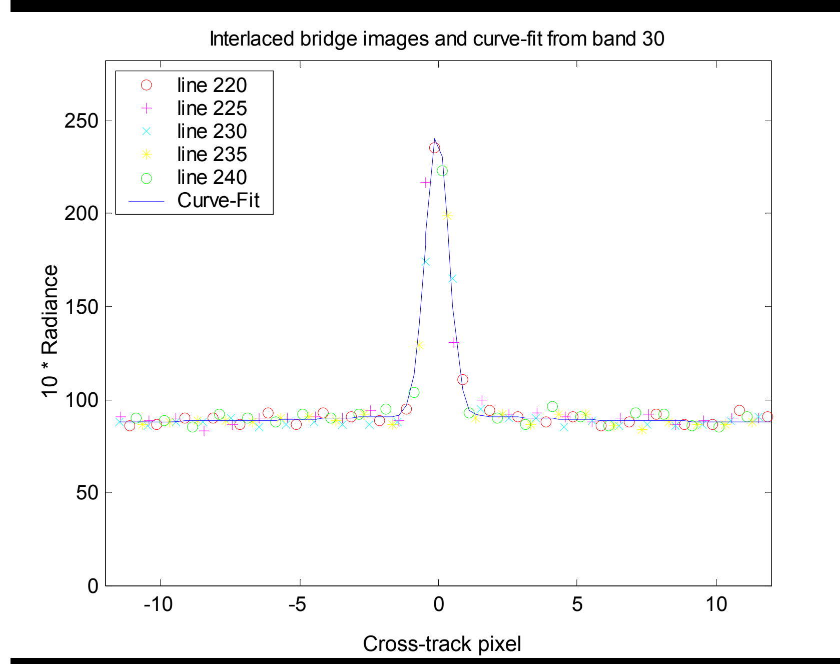
- Calculate cross-track and in-track MTF using a step response and impulse response example

- Results of on-orbit analysis give good agreement with the pre-launch laboratory measurements

Example: Cross-track MTF

– Scene is Port Eglin from Dec 24, 2000. Bridge is the Mid-bay bridge . Bridge width is 13.02 meters.
– Bridge angle to the S/C direction is small so every 5th line is used to develop the high resolution bridge image.
– MTF result at Nyquist is between 0.39 to 0.42 while the pre-flight measurement was 0.42.

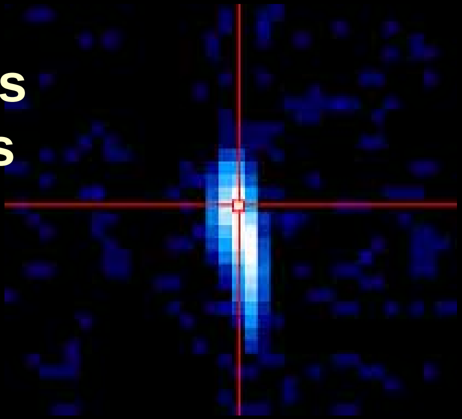




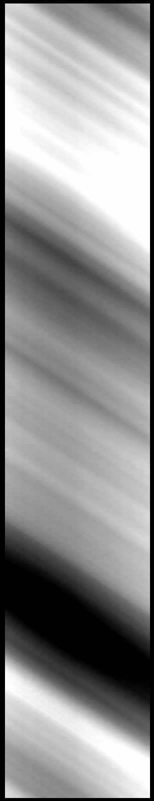
Special targets for characterization

Searchlights
-California

Planets
-Venus

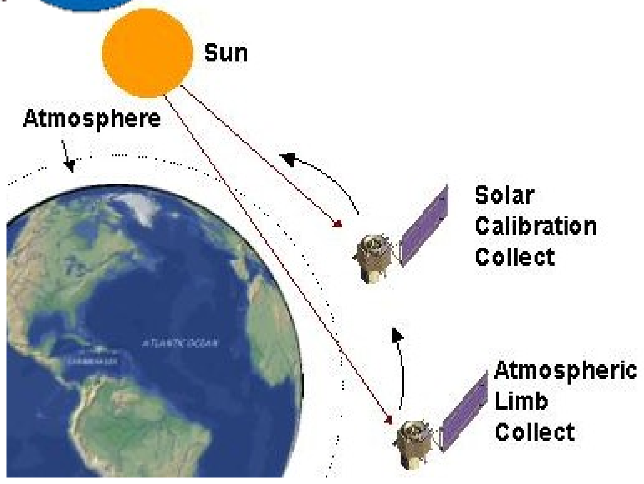


Gas Flares
-Moomba



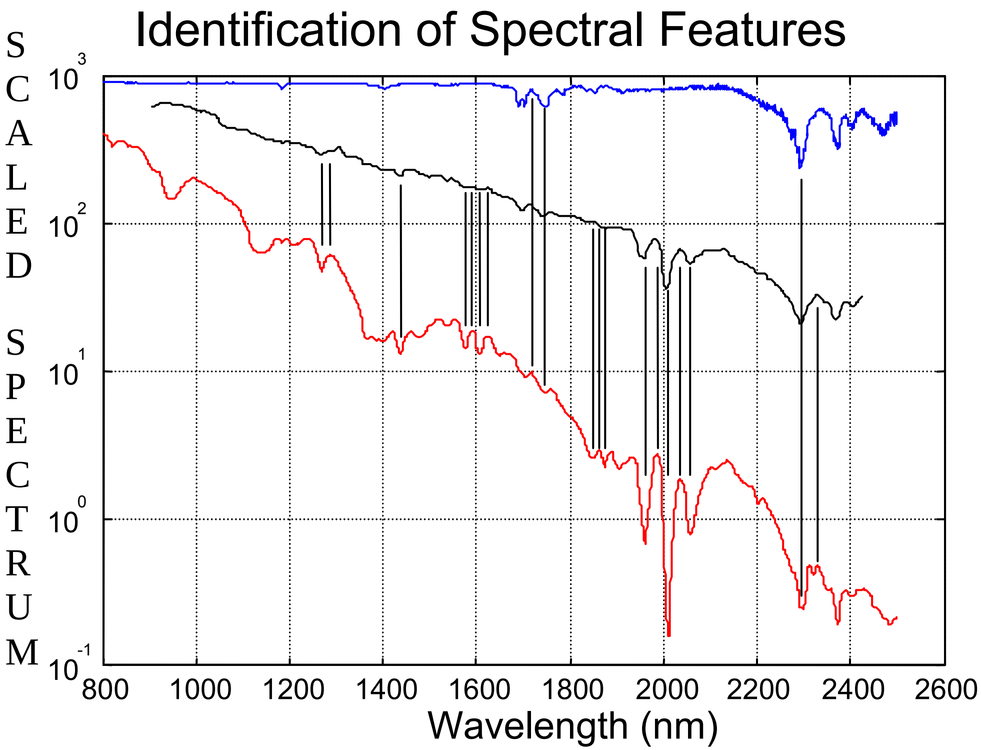
90 deg
Yaw

Spectral Calibration –SWIR



Process:

- Create Pseudo-Hyperion Spectra from reference: Modtran-3 for atmosphere, and Cary 5 & FTS measurements for diffuse reflectance of the cover
- Correlate Spectral Features: band number units of Hyperion max/min correlated with reference wavelength of max/min
- Calculate Band to Wavelength map: apply low order polynomial to fit the data over the entire SWIR regime



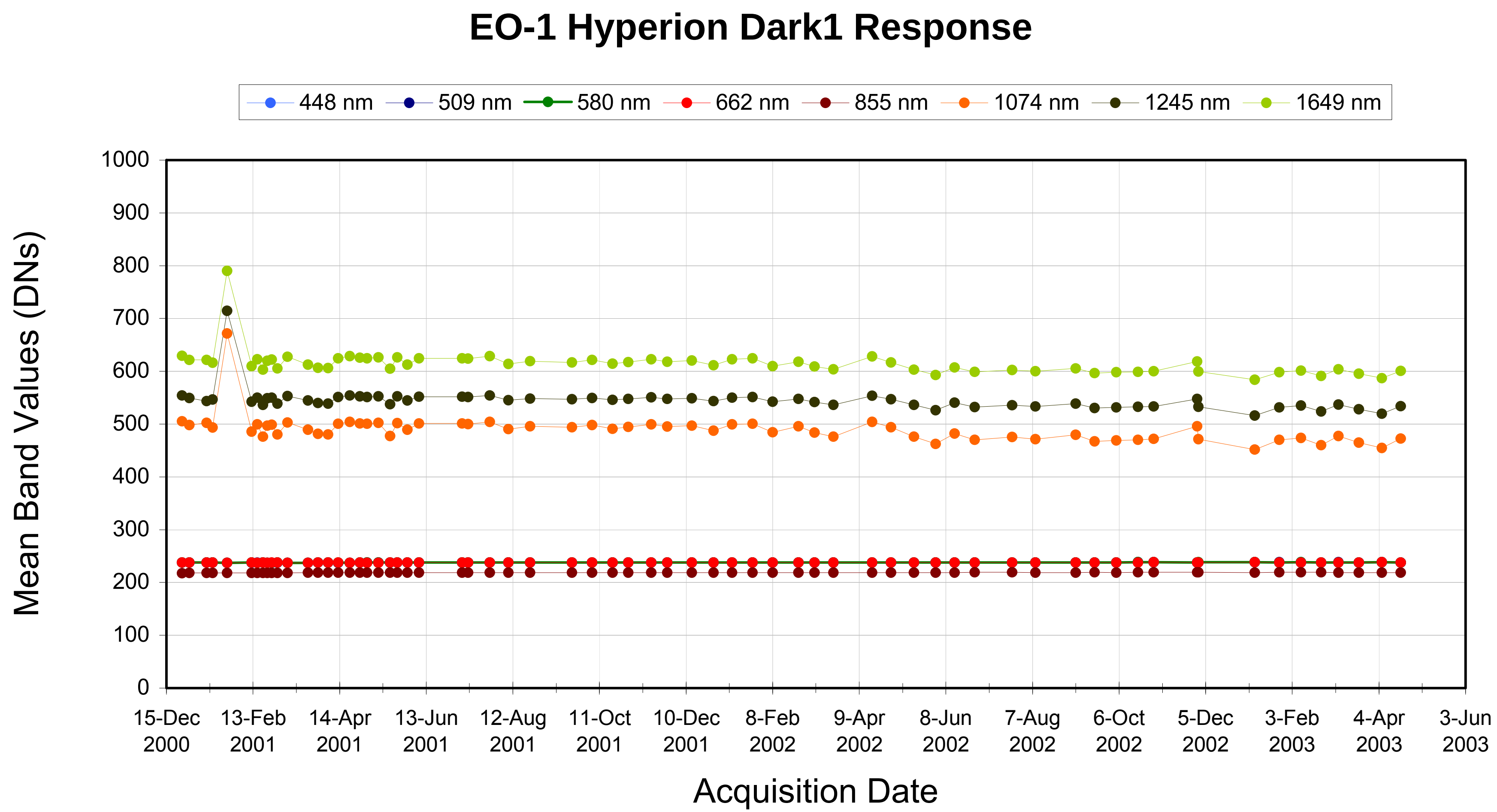
Hyperion Spectra – red

Atmospheric Reference – black

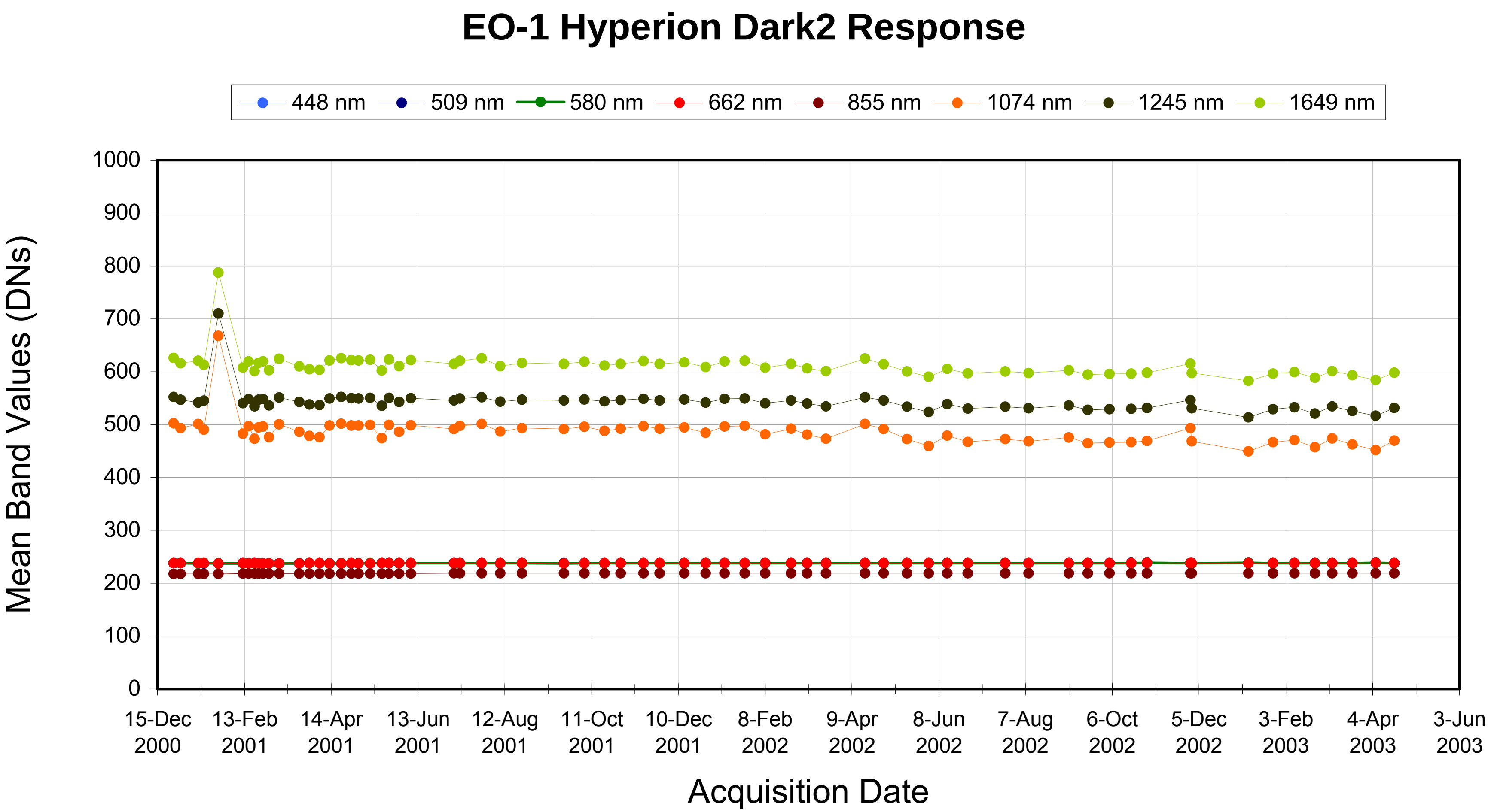
Diffuse Reflectance of cover – blue

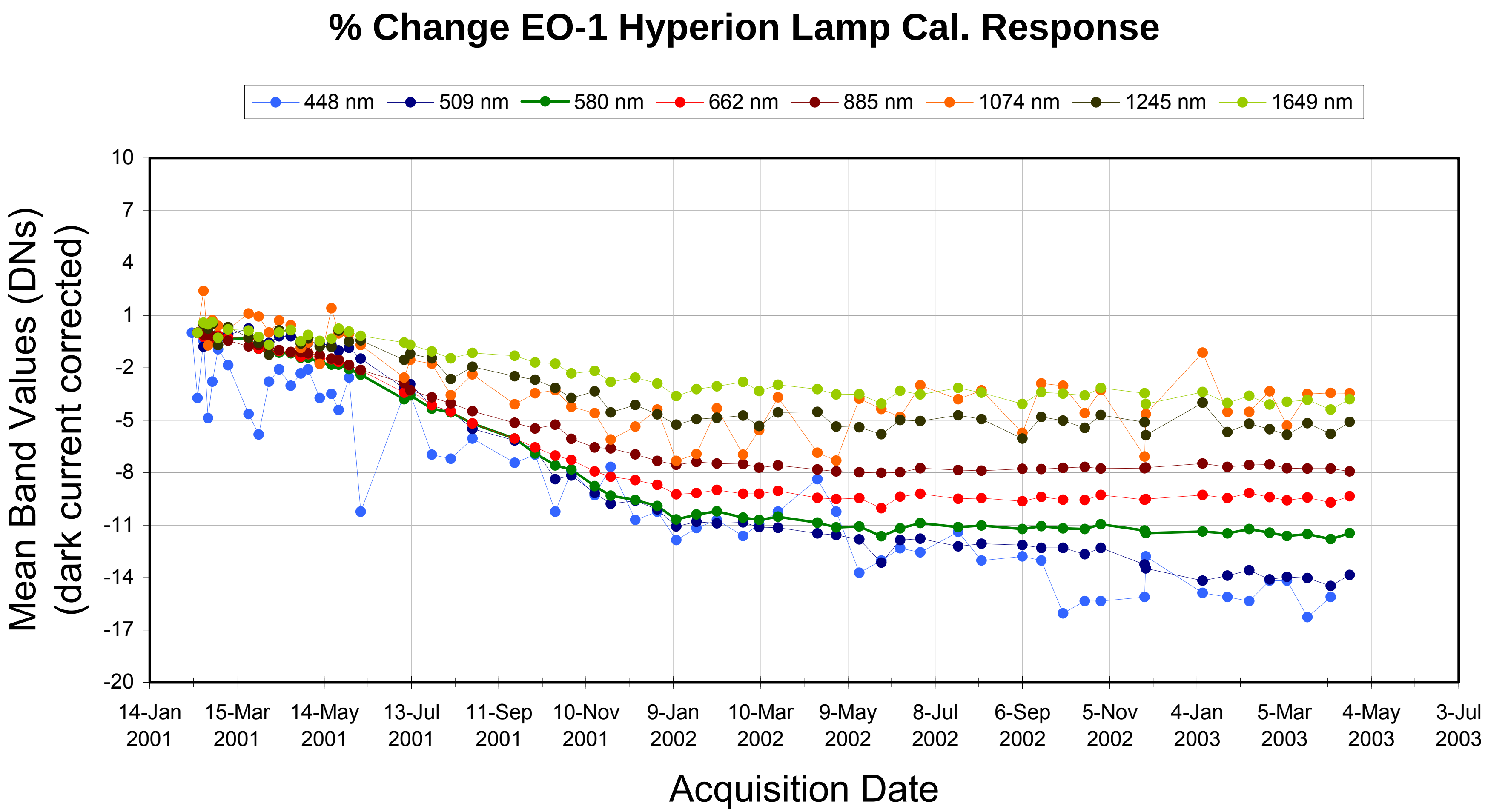
The EO-1 2002 Field Campaign

Salar de Arizaro - 11 Dec. 2002

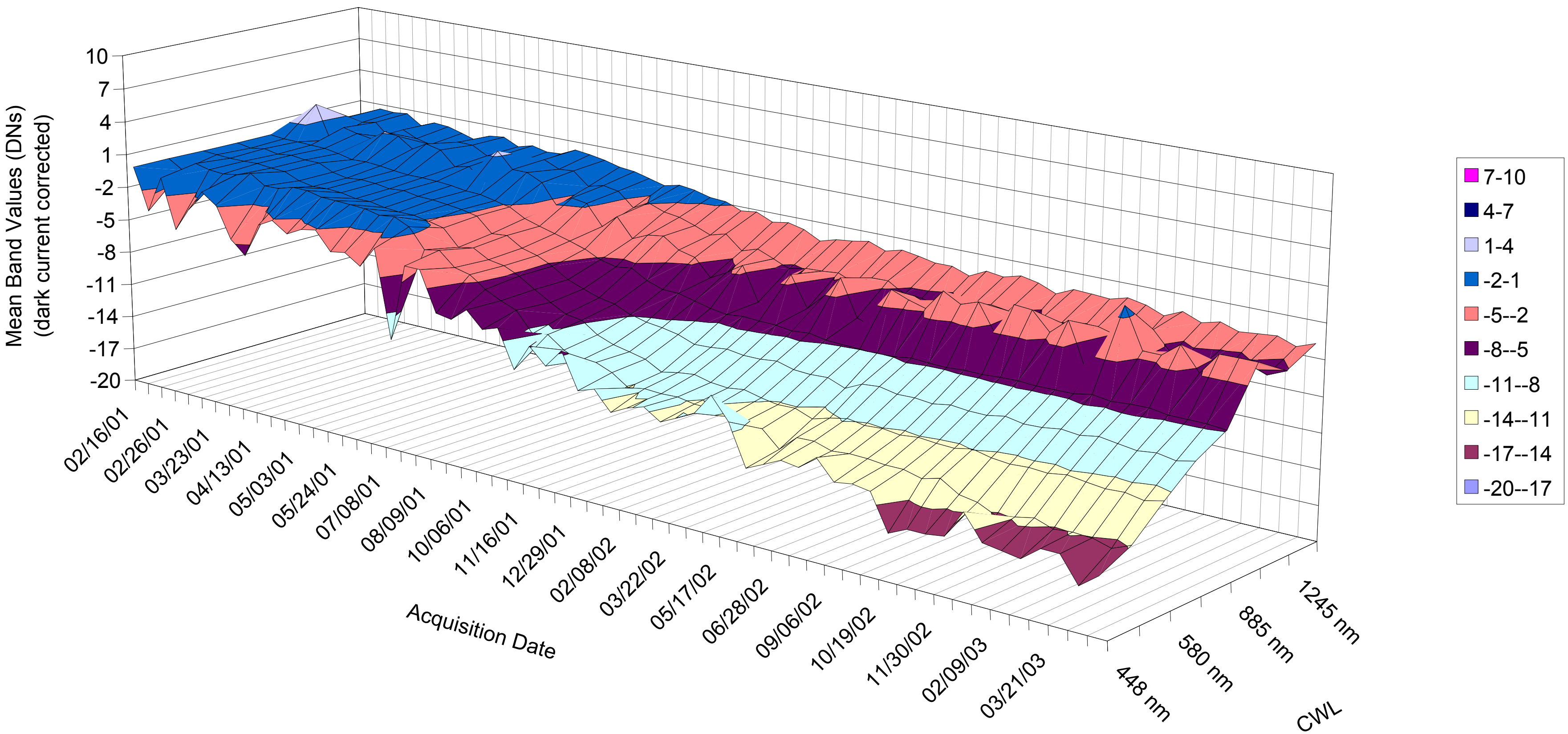


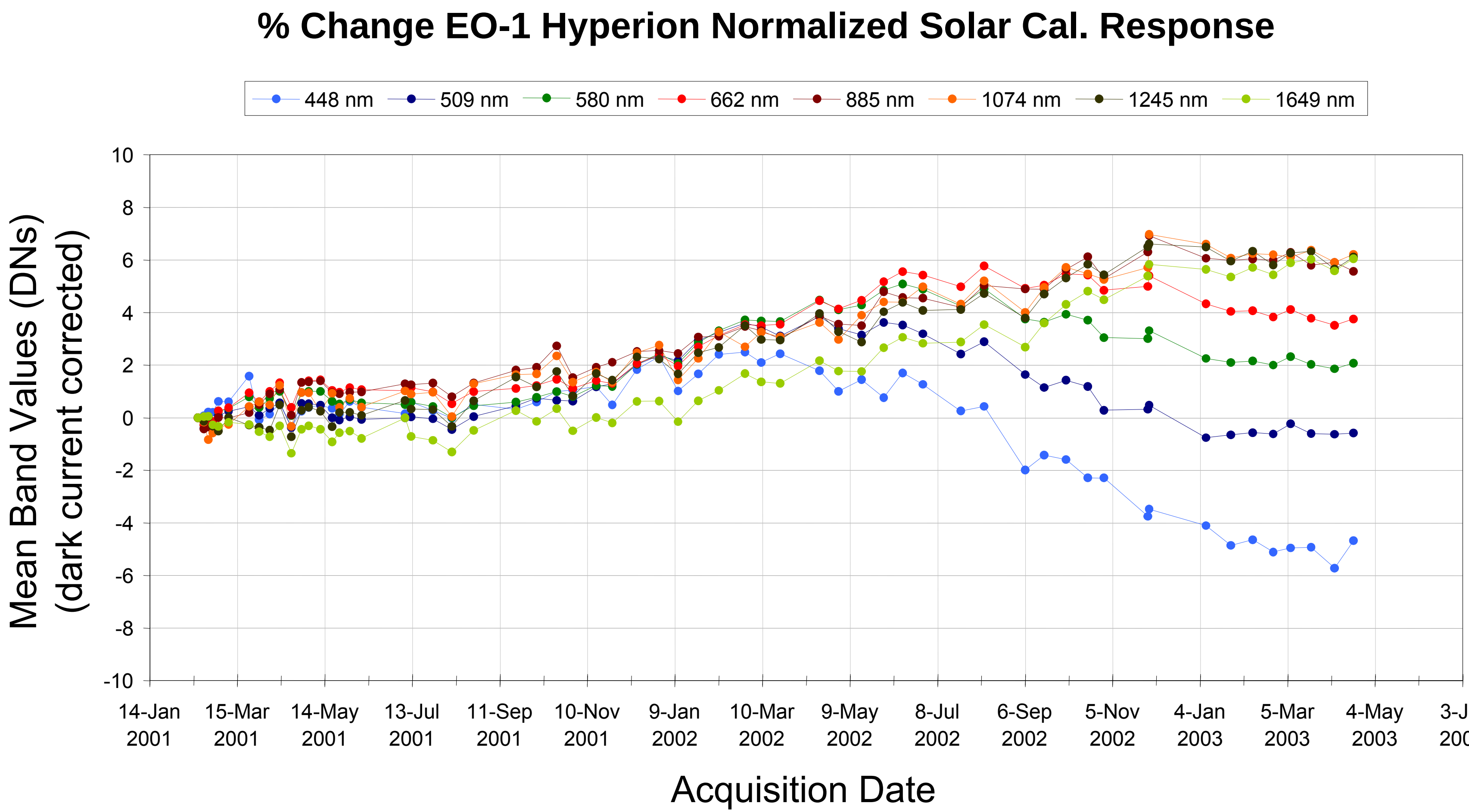
EO-1 Hyperion Dark1 Response
448 nm
509 nm
580 nm
662 nm
855 nm
1074 nm
1245 nm
1649 nm
Mean Band Values (DNs)
1000
900
800
700
600
500
400
300
200
100
0
15-Dec 2000
13-Feb 2001
14-Apr 2001
13-Jun 2001
12-Aug 2001
11-Oct 2001
10-Dec 2001
8-Feb 2002
9-Apr 2002
8-Jun 2002
7-Aug 2002
6-Oct 2002
5-Dec 2002
3-Feb 2003
4-Apr 2003
3-Jun 2003
Acquisition Date


EO-1 Hyperion Dark2 Response
448 nm
509 nm
580 nm
662 nm
855 nm
1074 nm
1245 nm
1649 nm
Mean Band Values (DNs)
1000
900
800
700
600
500
400
300
200
100
0
15-Dec 2000
13-Feb 2001
14-Apr 2001
13-Jun 2001
12-Aug 2001
11-Oct 2001
10-Dec 2001
8-Feb 2002
9-Apr 2002
8-Jun 2002
7-Aug 2002
6-Oct 2002
5-Dec 2002
3-Feb 2003
4-Apr 2003
3-Jun 2003
Acquisition Date

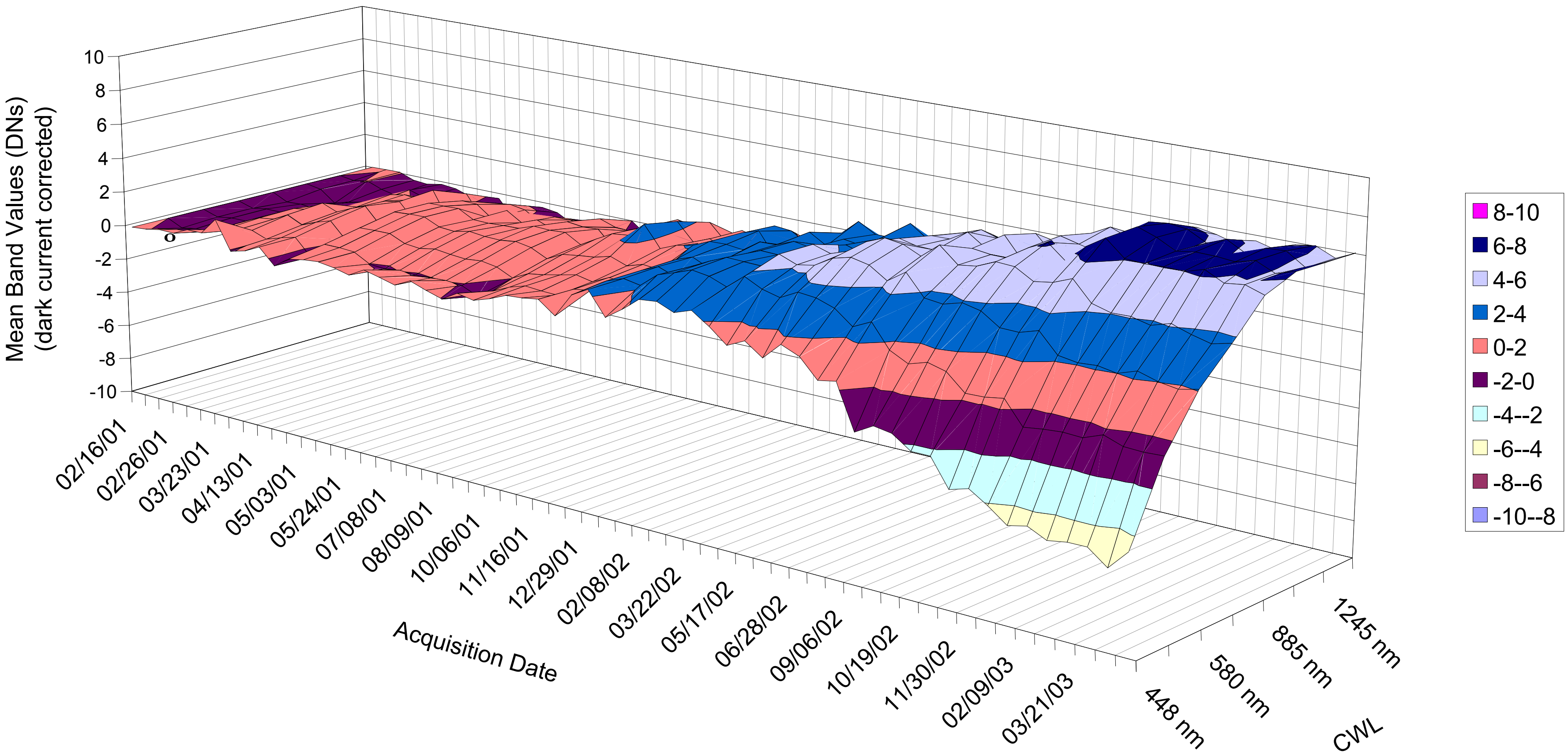

% Change EO-1 Hyperion Lamp Cal. Response
448 nm
509 nm
580 nm
662 nm
885 nm
1074 nm
1245 nm
1649 nm
Mean Band Values (DNs)
(dark current corrected)
10
7
4
1
-2
-5
-8
-11
-14
-17
-20
14-Jan 2001
15-Mar 2001
14-May 2001
13-Jul 2001
11-Sep 2001
10-Nov 2001
9-Jan 2002
10-Mar 2002
9-May 2002
8-Jul 2002
6-Sep 2002
5-Nov 2002
4-Jan 2003
5-Mar 2003
4-May 2003
3-Jul 2003
Acquisition Date

% Change EO-1 Hyperion Lamp Cal. Response

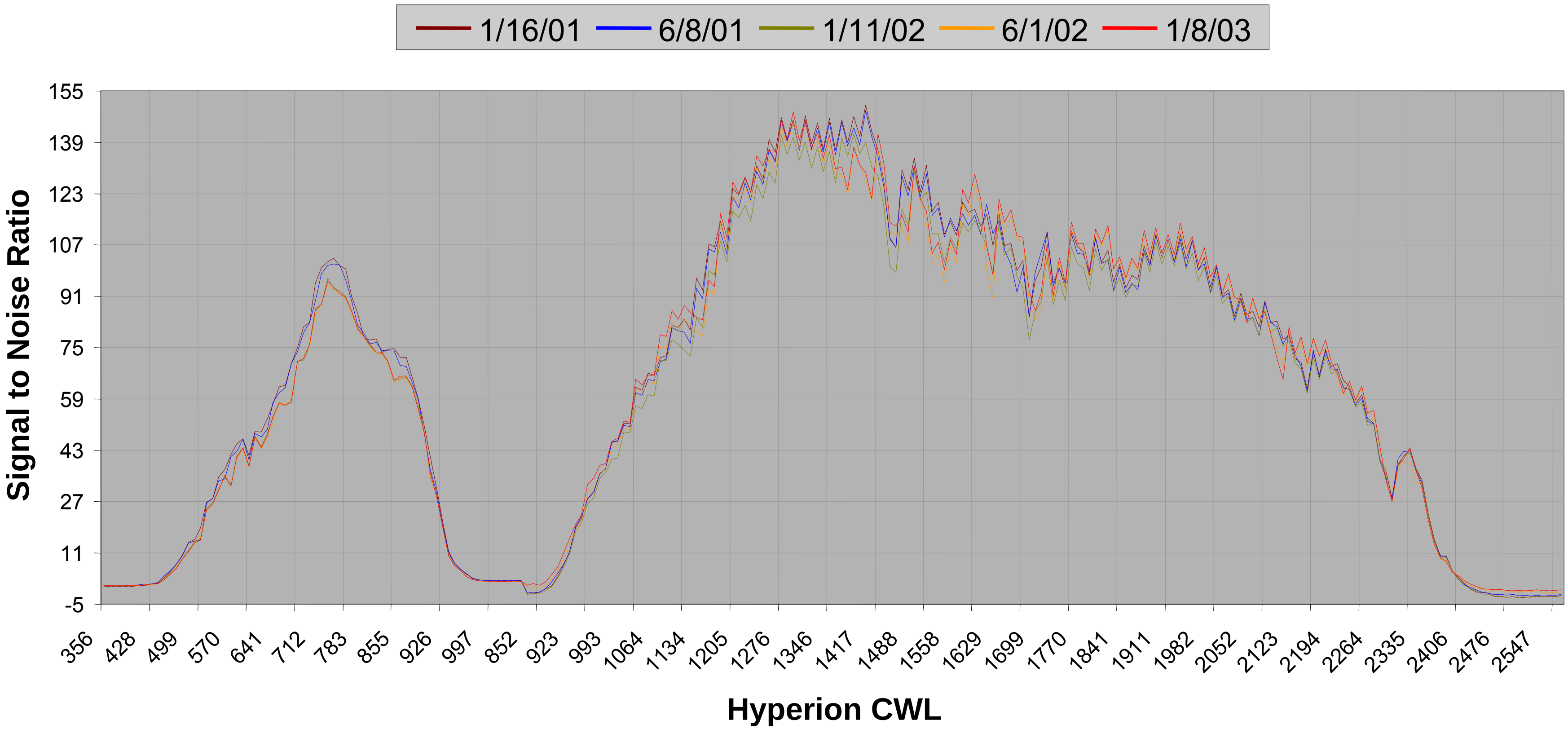



% Change EO-1 Hyperion Normalized Solar Cal. Response
448 nm
509 nm
580 nm
662 nm
885 nm
1074 nm
1245 nm
1649 nm
Mean Band Values (DNs)
(dark current corrected)
10
8
6
4
2
0
-2
-4
-6
-8
-10
14-Jan 2001
15-Mar 2001
14-May 2001
13-Jul 2001
11-Sep 2001
10-Nov 2001
9-Jan 2002
10-Mar 2002
9-May 2002
8-Jul 2002
6-Sep 2002
5-Nov 2002
4-Jan 2003
5-Mar 2003
4-May 2003
3-Jul 2003
Acquisition Date

% Change EO-1 Hyperion Solar Cal. Response (normalized for solar distance)

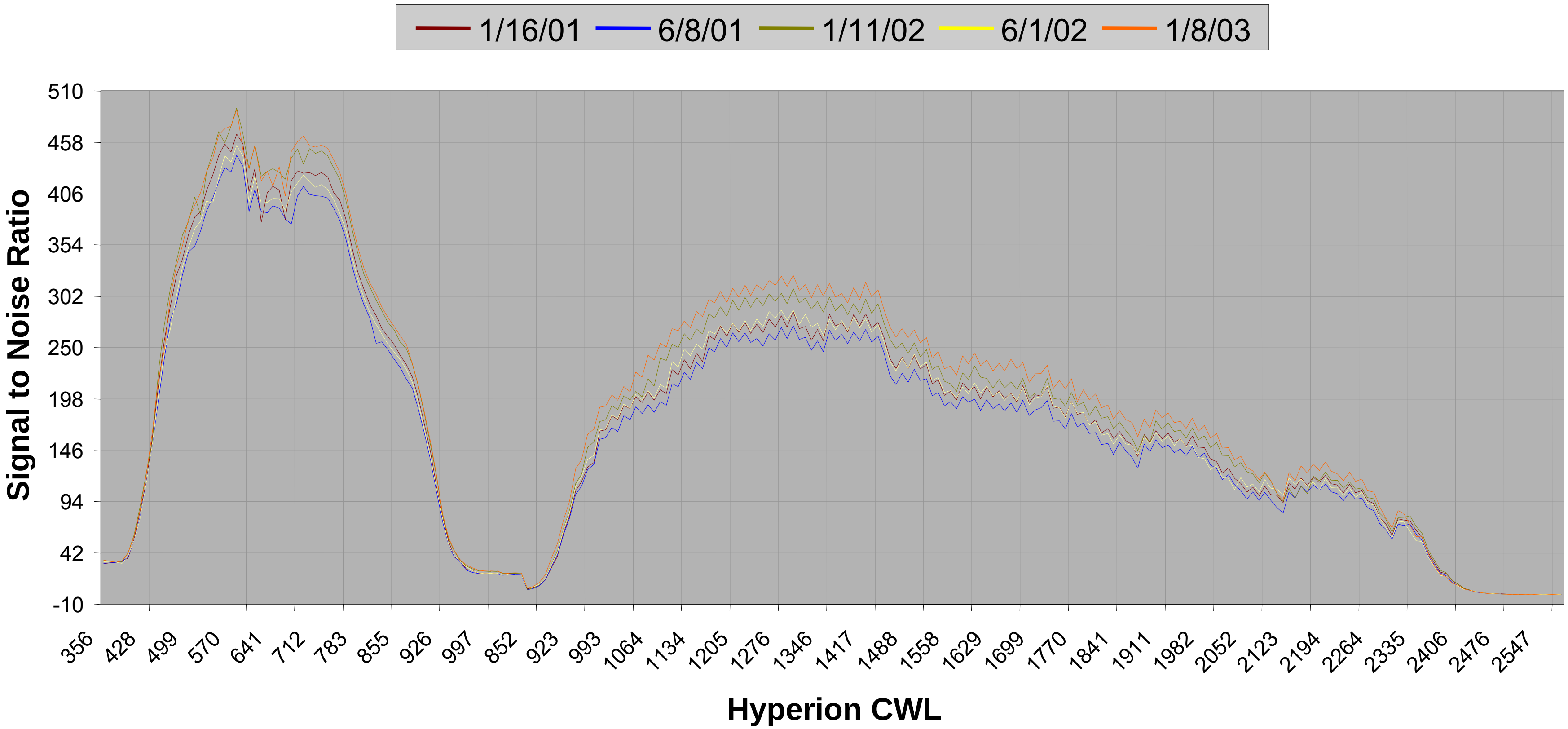


Hyperion Lamp Cal. Signal to Noise Ratio
(normalized solar mean / standard deviation)

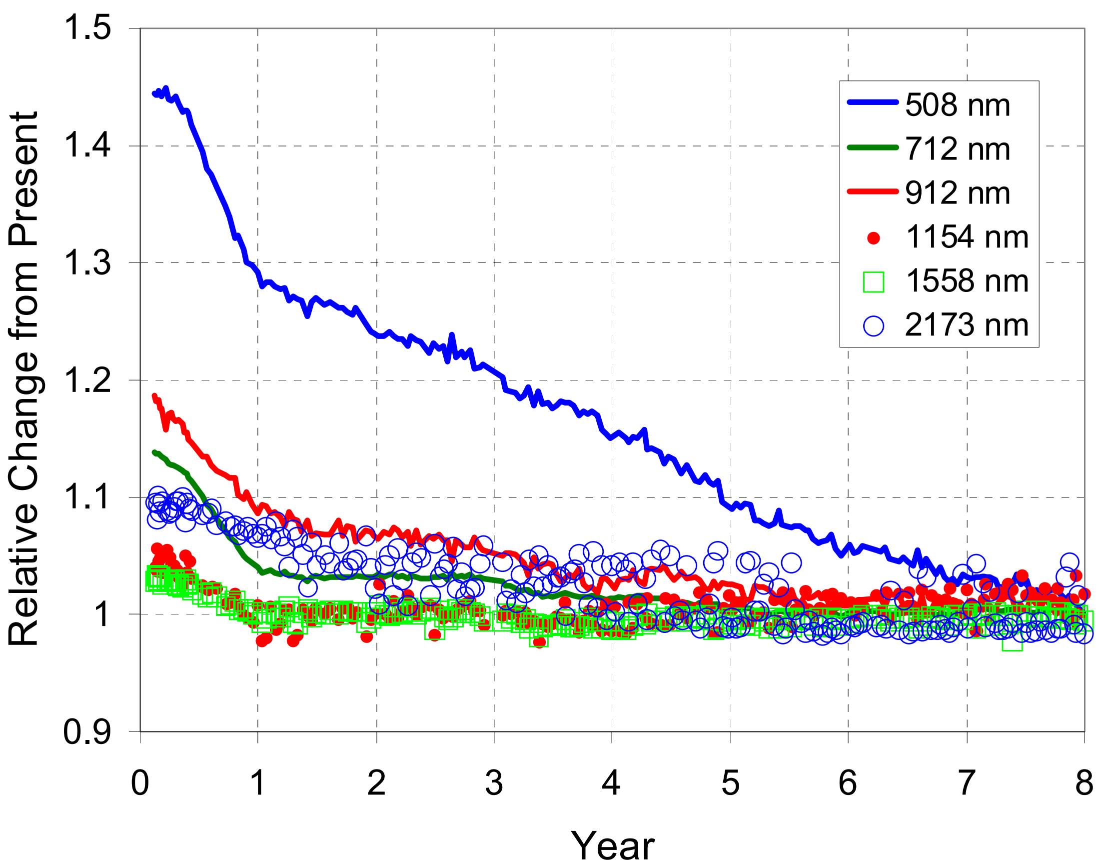


Hyperion Solar Cal. Signal to Noise Ratio

(normalized solar mean / standard deviation)

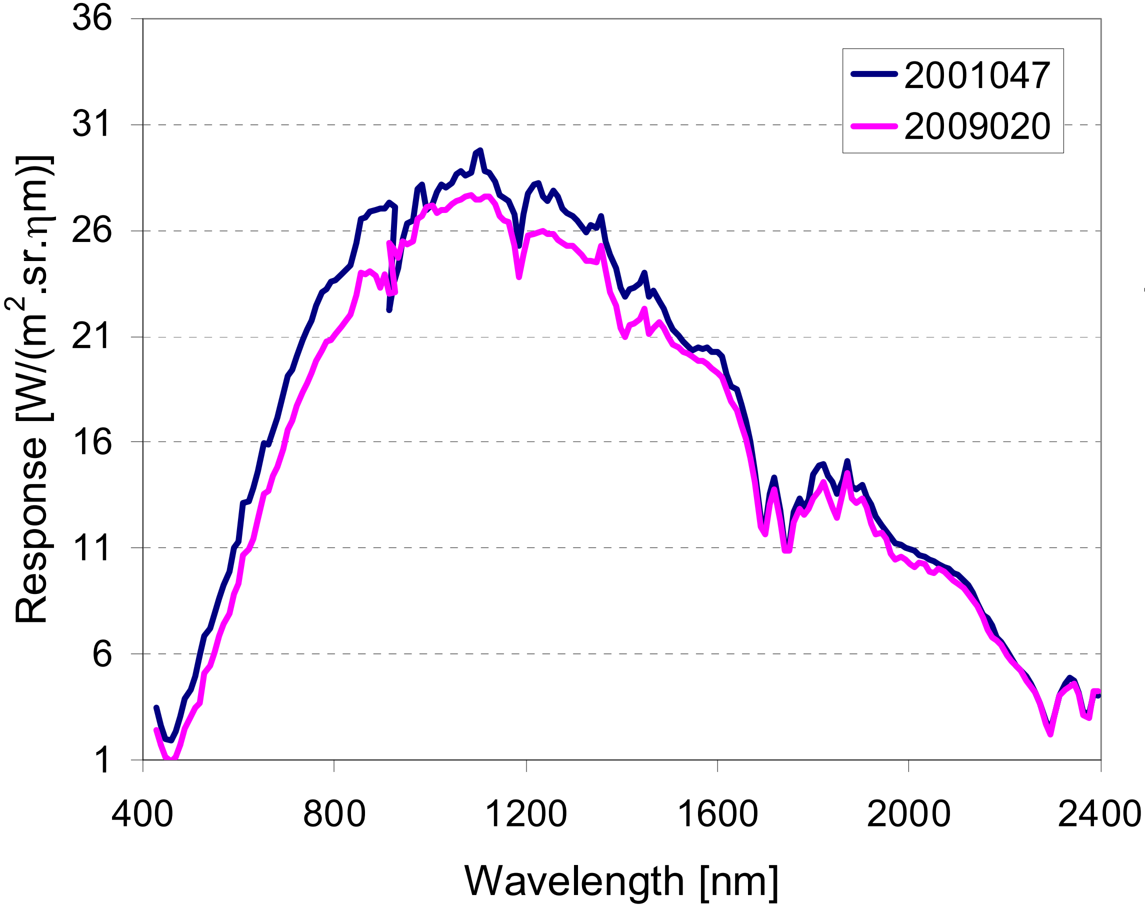


Hyperion Lamp Trends



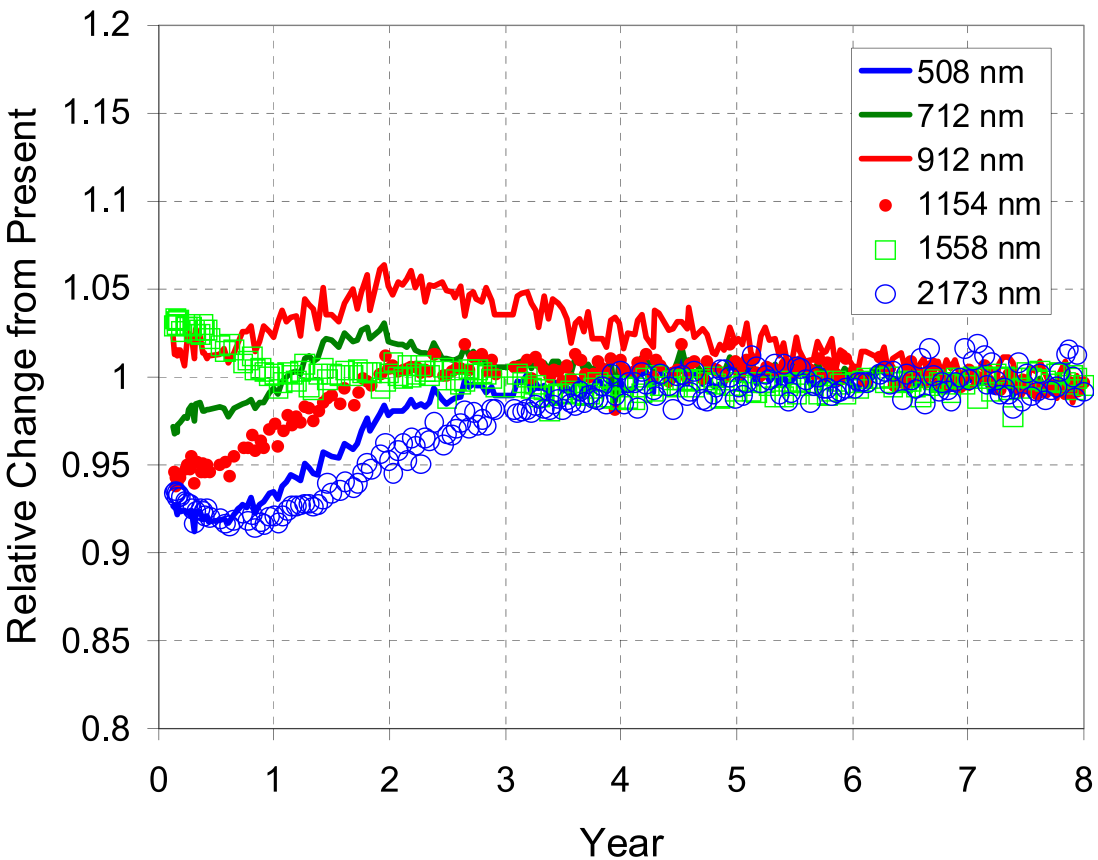
- There is a significant initial decrease in lamp output during the first year of operation.
- The lower wavelength channels (< 500 nm) exhibits the largest change.
- Changes in the SWIR channesl are less than 10%.
- For most bands the lamps appears to achieve some stability after year 4.

Hyperion Lamp Spectra



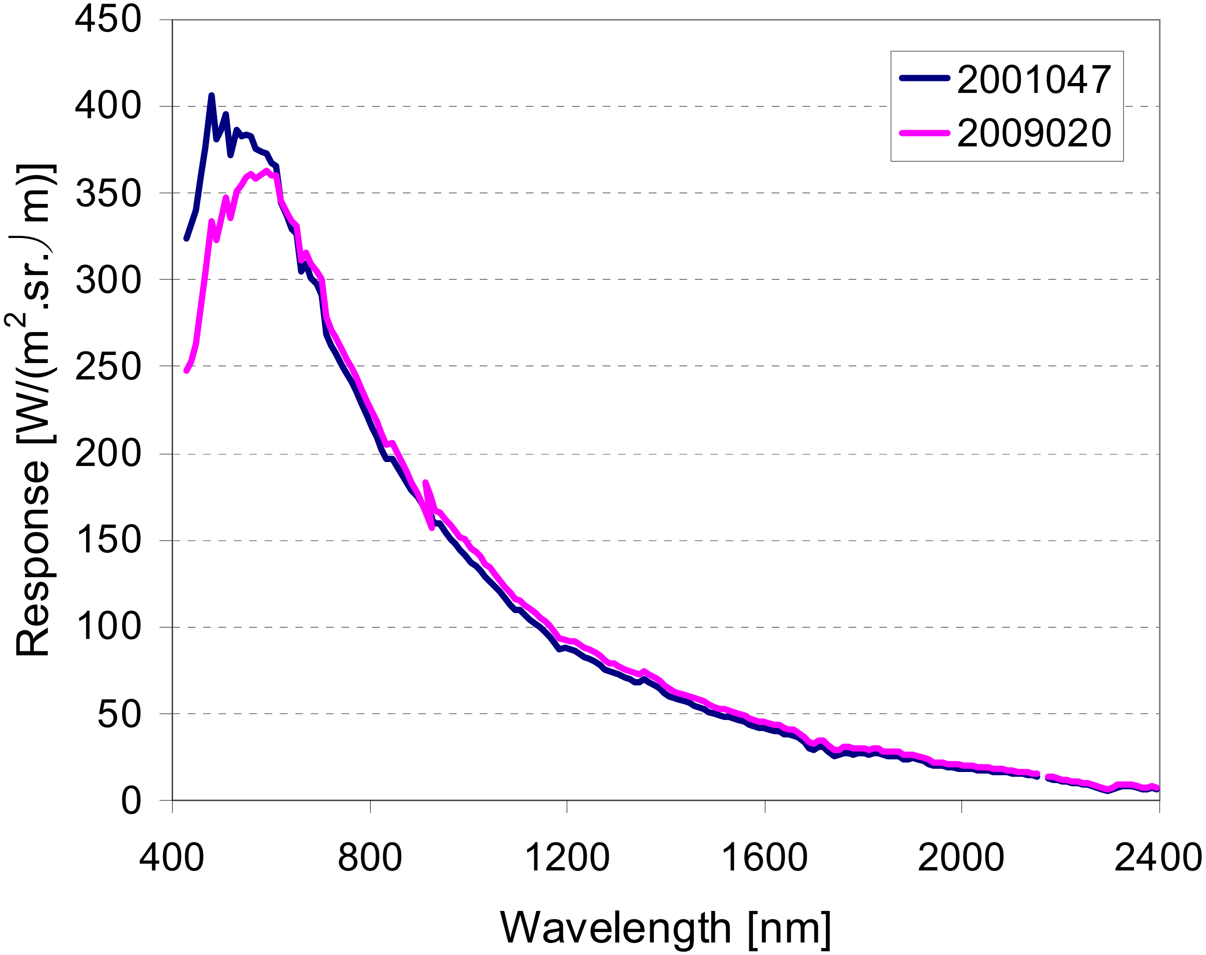
Lamps intensity shows some degradation over the entire spectral range over the 8 years of operation

Hyperion Solar Trends



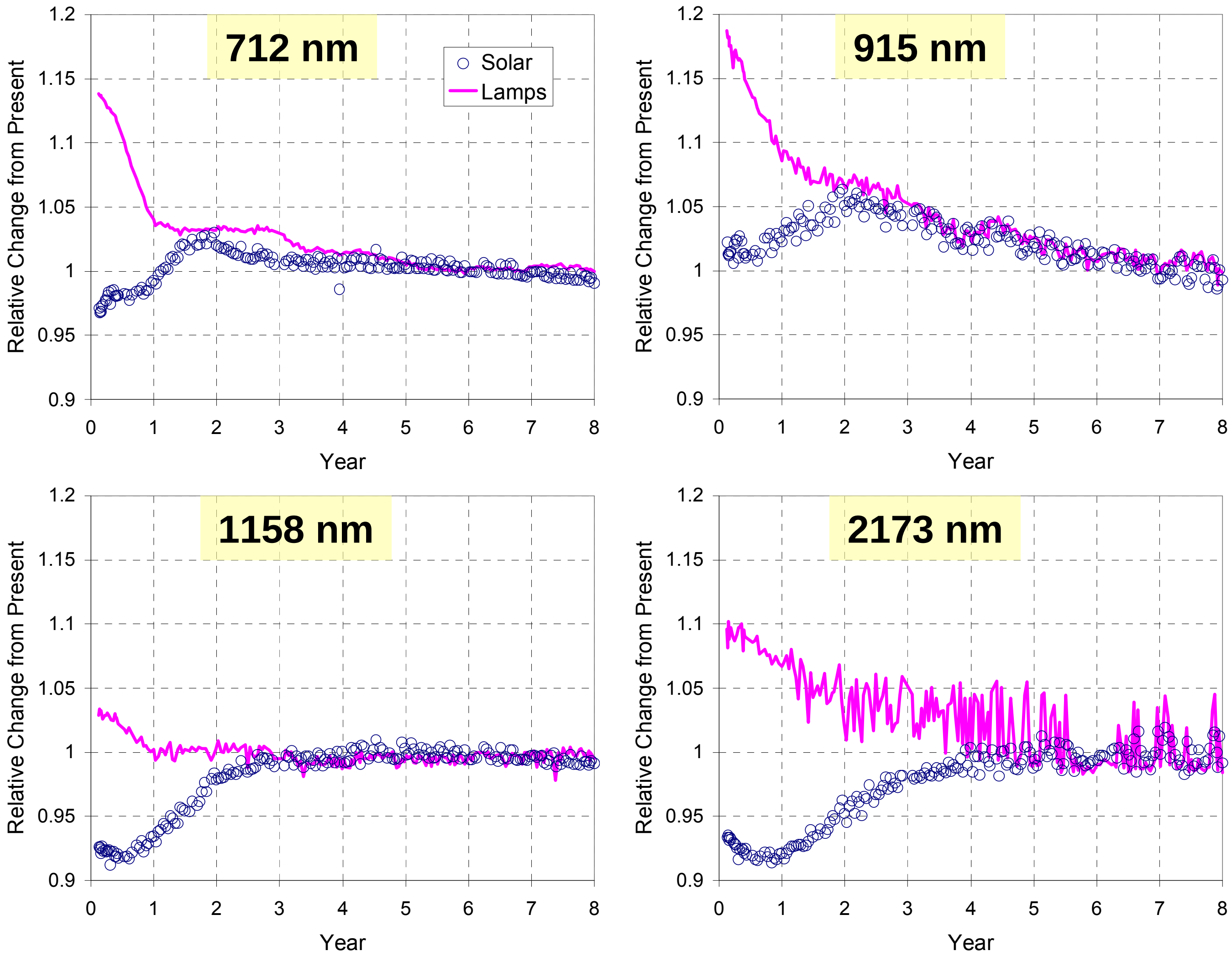
- Changes in the solar panel on orbit are most pronounced during the first 3 years
- Most of the variations are within +/1 5% except for the longer wavelengths.
- For most bands the lamps appears to achieve some stability after year 4.

Solar Panel Spectra



Spectra of the solar panel show large degradation in the shorter wavelengths

Comparing Lamp & Solar Trends



Although inconsistent during early mission life, the solar and Lamp trends agree well after 4 years in orbit

Typical Lunation (aka Lunar Cycle)

EO-1 Lunar Cal/Val

USGS Robotic Lunar Observatory

ROLO Model

$$I_k = \Omega_p \sum_{i=1}^{N_p} L_{i,k}$$

$$A_k = \frac{\pi \cdot I_k}{\Omega_M E_k}$$

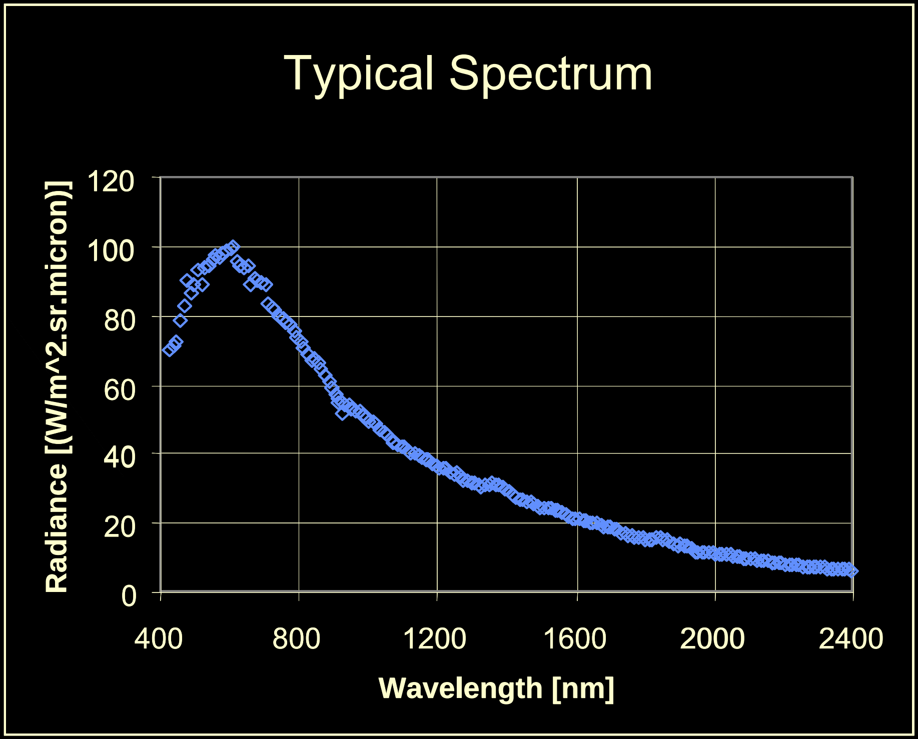
1 total lunation takes ~29.5 days

EO-1 views the moon monthly

(EO-1 ALI Pan band)

Full Moon

(EO-1 Hyperion)



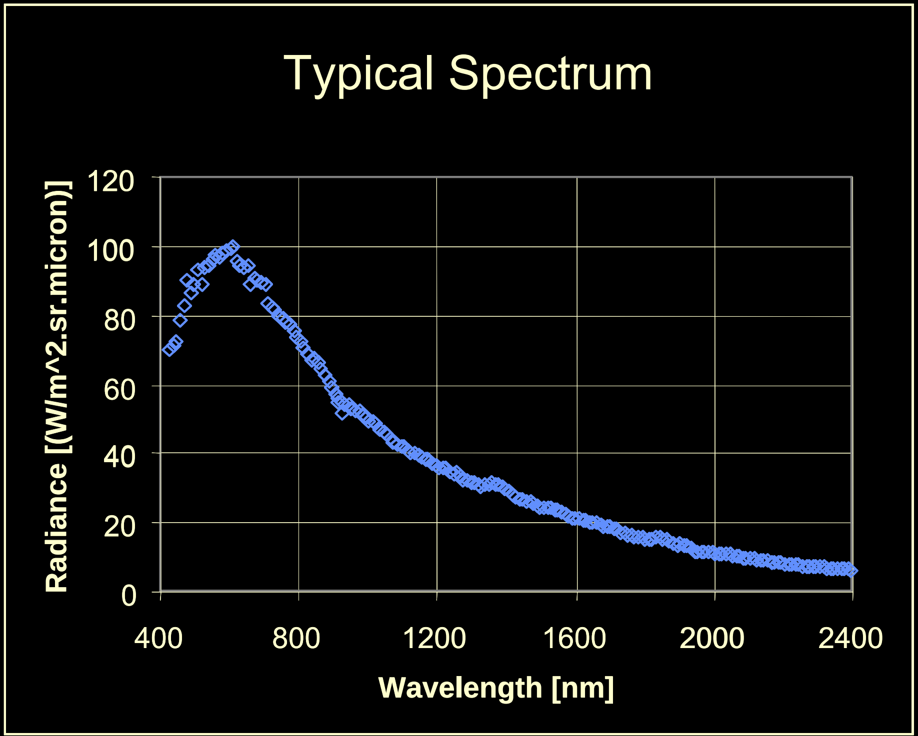
Cumulative Spectral Radiance

EO-1 views the moon monthly

(EO-1 ALI Pan band)

Full Moon

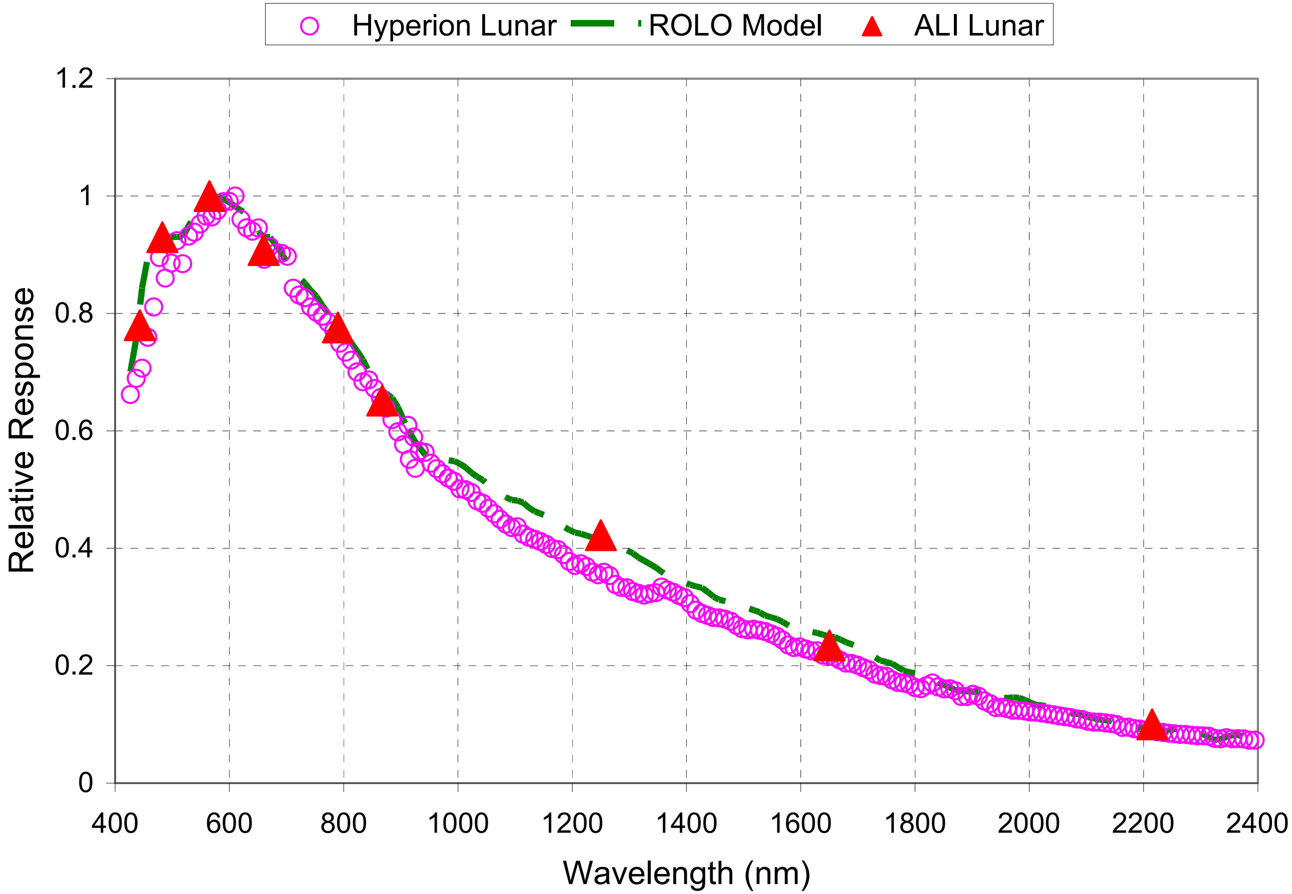
(EO-1 Hyperion)



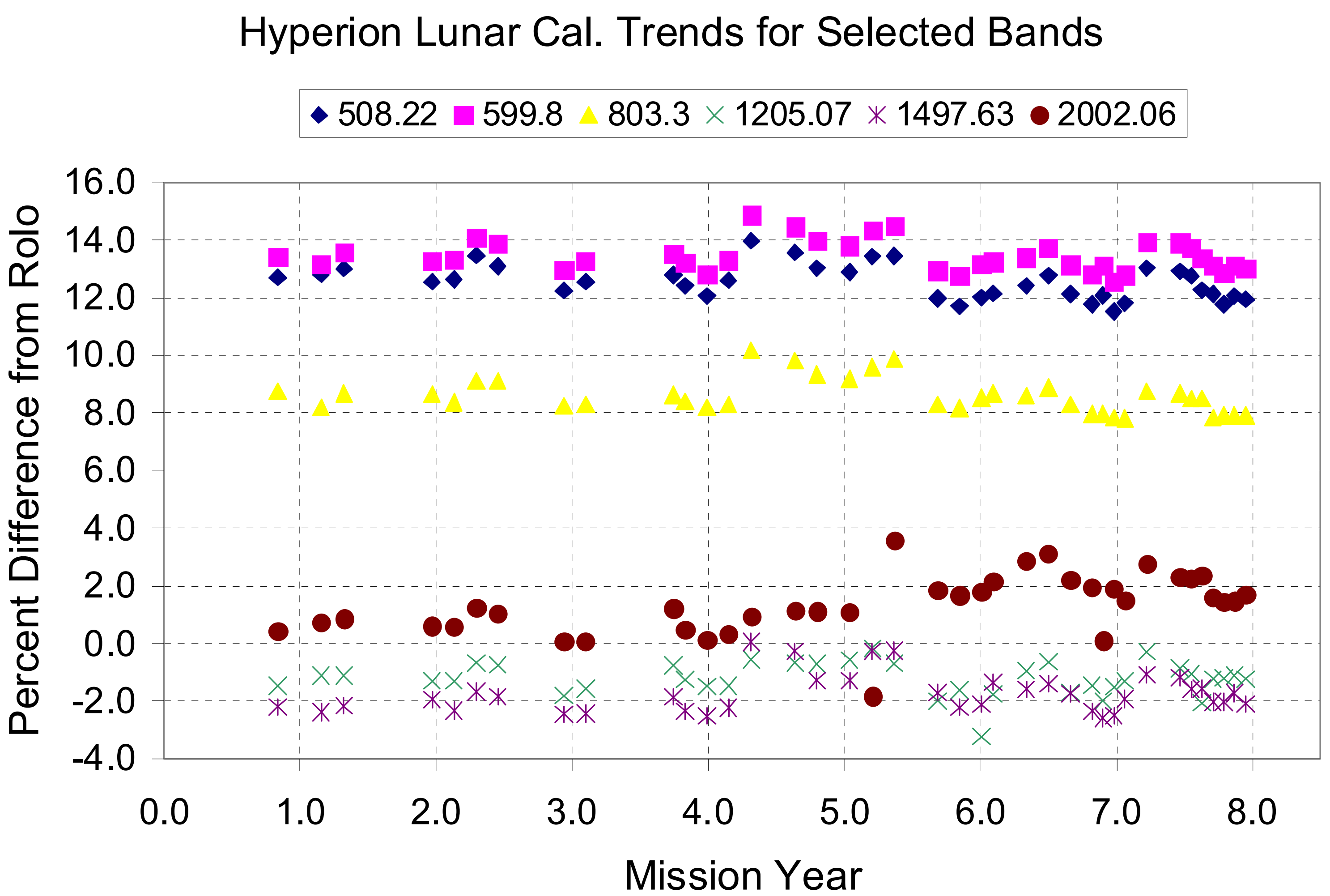
Cumulative Spectral Radiance

Hyperion Lunar Spectra

The pitch rate across the moon is the same as that used for earth imaging. This results in a 8X oversampling of the moon.



Lunar Calibration Results

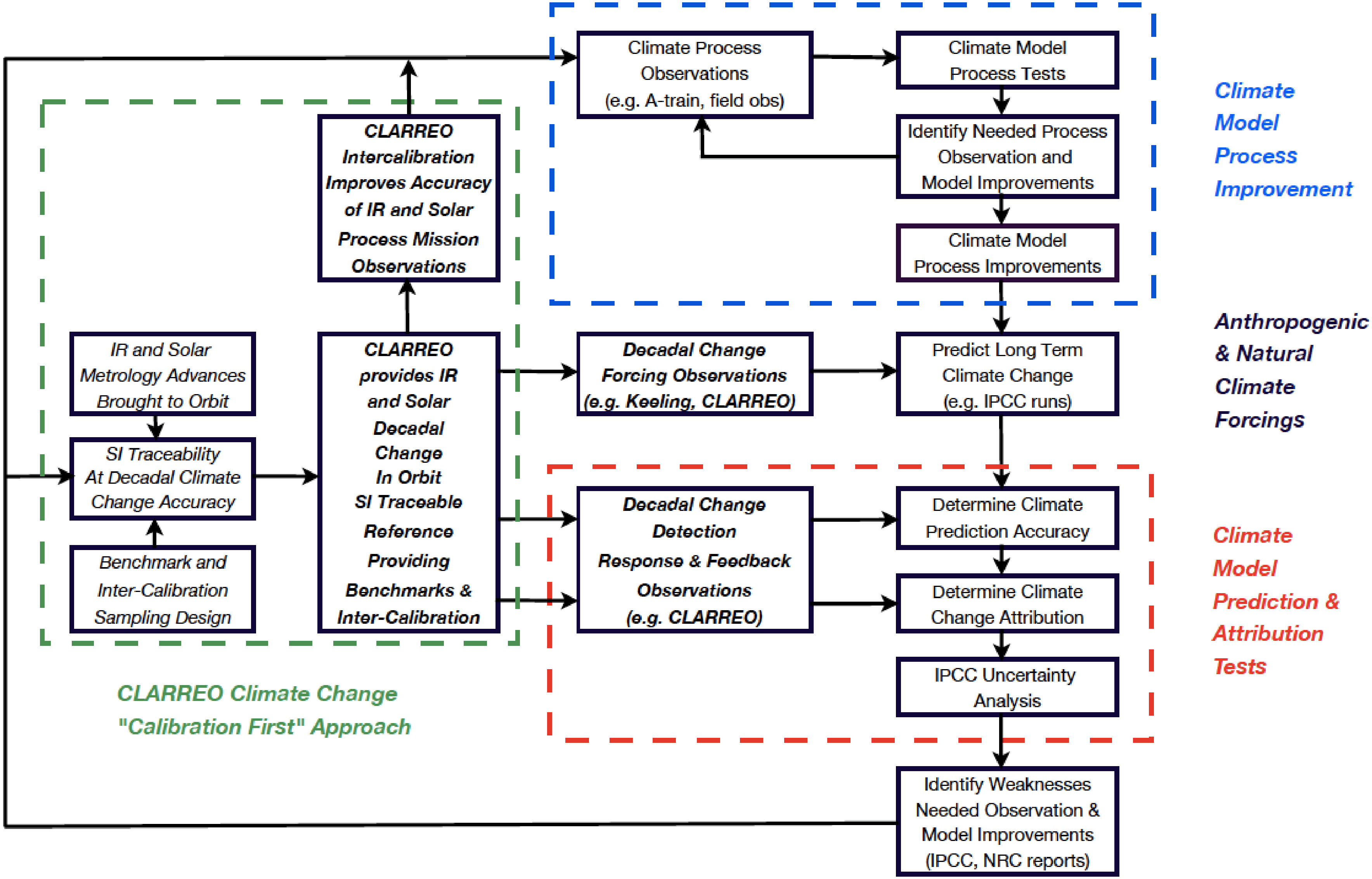


CLARREO

- Provides S.I. traceable absolute accuracy in infrared and solar reflected spectra
  - Observe decadal climate change
  - Verify climate predictions.
- Anchors research and operational sensors at climate change accuracy providing the first “NIST in Orbit”.
- Provides first full IR spectra by including the far infrared
  - Half of the Earth’s emitted radiation
  - Bulk of the earths water vapor greenhouse effect
- Provides first full solar reflected spectra from the Earth at climate change accuracy.

CLARREO and Climate Models

The Role of CLARREO in Testing and Improving Climate Models, Climate Change Detection, and Attribution



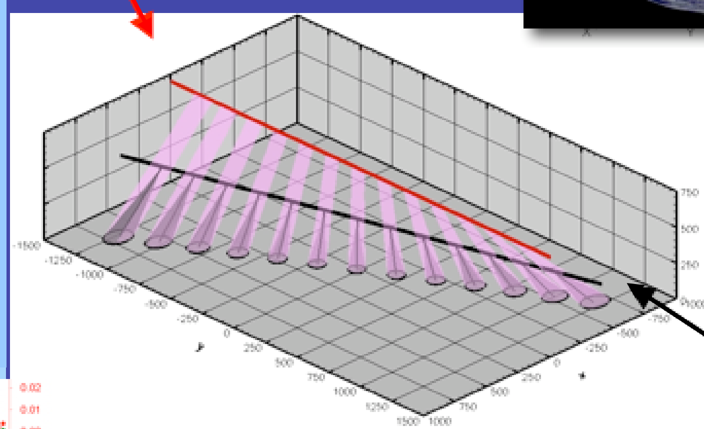
Intercalibration role

- CLARREO Mission Objectives require that climate variables remotely sensed from space using reflected solar radiation be at accuracies sufficient for detection of decadal change.
  - Accuracy requirements for decadal change taken from previous reports
  - A potential method to achieve climate accuracy is for CLARREO to calibrate other sensors.

Climate Change

- **There are several key intercalibration studies**
  - Does spectral response of filters change enough over time to alias climate change (e.g. MODIS, VIIRS)?
  - Can CLARREO detect and correct spectral response changes of other sensors?
  - Can CLARREO achieve sufficient space-time-angle sampling for intercalibration of other sensors?

Aqua MODIS, CERES 705km orbit



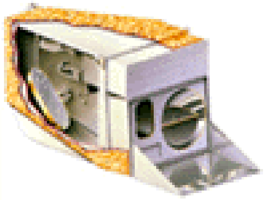
CLARREO 600km orbit

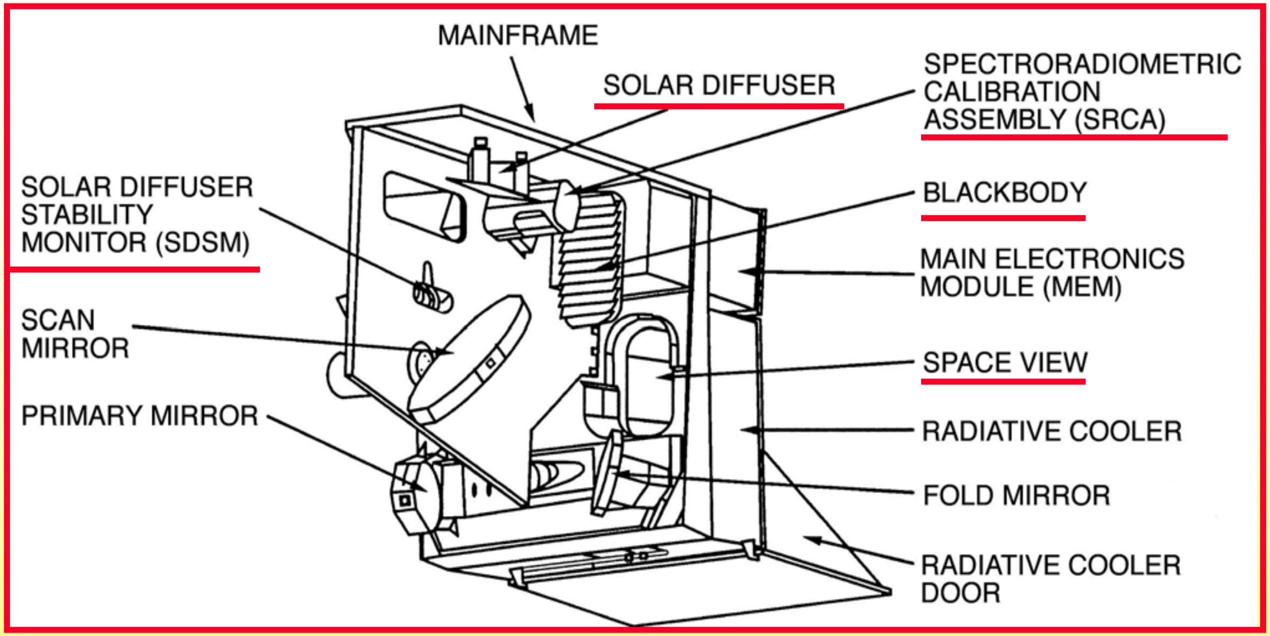
Cloud Feedback Observations

CLARREO Calibrates CERES/VIIRS

- **Three approaches**
  - Climate OSSE using CLARREO simulator in climate model for decadal change
  - Simulate MODIS and VIIRS using Schiamachy in orbit spaceborne spectrometer (< 1nm $\Delta\lambda$; 30 by 60km fov)
  - Simulate CLARREO using MODIS surface/aerosol/cloud properties + radiative transfer theory (< 1nm $\Delta\lambda$; 1km fov)

MODIS Instrument





Terra launch: 12/18/1999

Aqua launch: 05/04/2002

- 20 Reflective solar bands (RSB): 0.41-2.2μm
- 16 Thermal emissive bands (TEB): 3.7-14.4μm
- 3 spatial resolutions at nadir: 250m, 500m and 1000m
- 4 Focal Plane Assemblies (FPA): VIS, NIR, SMIR, LWIR
- 5 On-Board Calibrators: SD, SDSM, SRCA, BB, and SV port

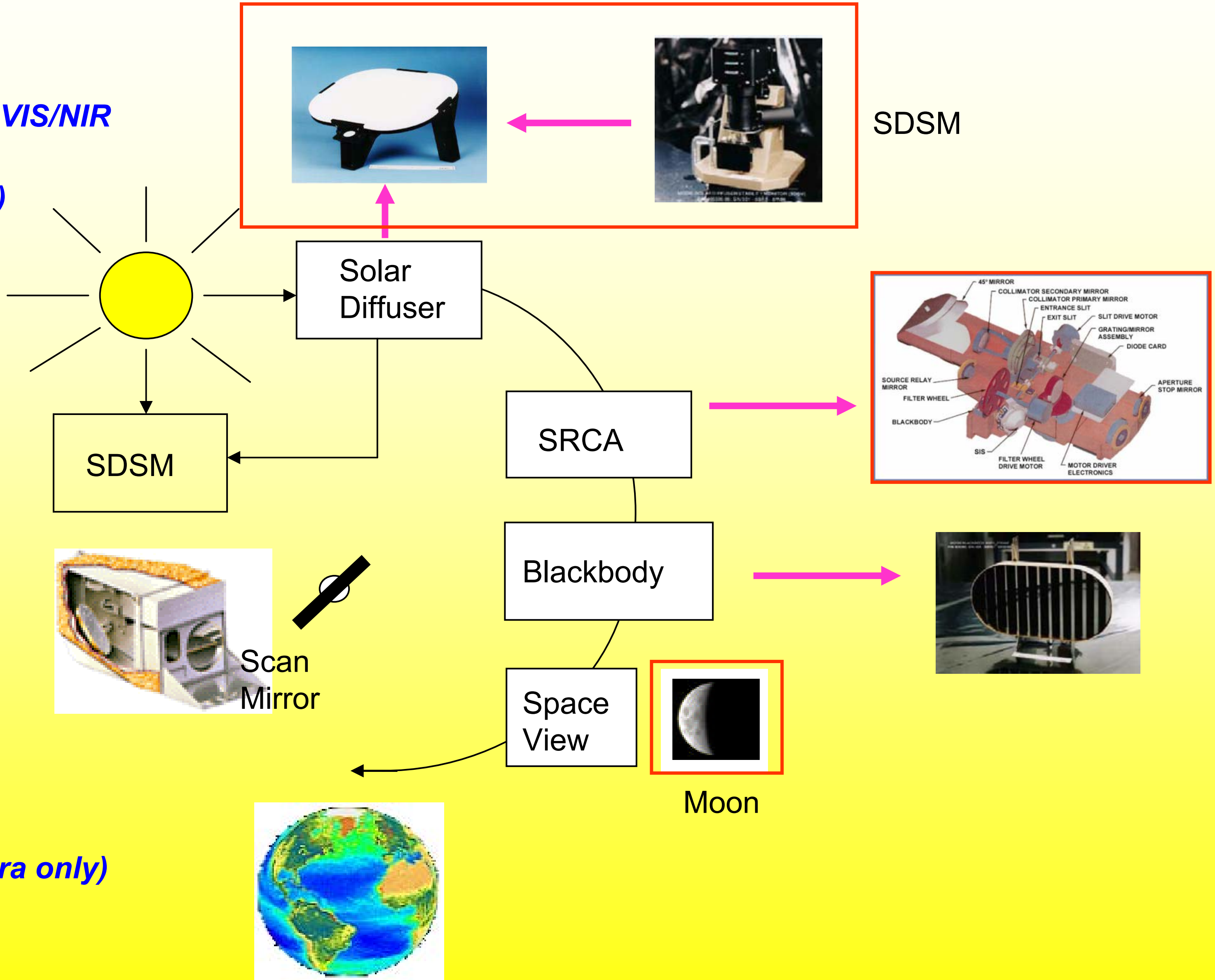
- Two MODIS (Terra and Aqua): Complementary morning and afternoon observations
- A broad range of applications: land, oceans, and atmosphere

MODIS Pre-launch Calibration

- Radiometric
  - VIS/NIR/SWIR calibration source: SIS-100 (NIST traceable) at multiple radiance levels (lamp configurations)
  - MW/LWIR calibration source: Blackbody Calibration Source (BCS)
  - Calibration parameters: gain, nonlinearity, SNR, dynamic range, gain dependence on the instrument temperatures
  - Three instrument temperatures for thermal vacuum test and three focal plane temperatures for the cold focal plane assemblies
  - Primary and redundant electronics
  - Solar diffuser BRDF calibration (NIST traceable)
  - On-board BB emissivity characterization (from BCS)
- Others System Level Calibration and Characterization
  - Spectral: relative spectral response (RSR)
  - Spatial: pointing, band-to-band registration (BBR), MTF, IFOV
  - Response versus scan angle (RVS)
  - Polarization sensitivity

MODIS On-orbit Calibration

Quarterly BB for IR
Bi-weekly SD/SDSM for VIS/NIR
Regular SRCA 3 modes
(spat, spec, radiometric)



Spacecraft maneuvers:
Yaw, roll, and pitch (Terra only)
Lunar observations

MODIS Calibration Inter-comparison Activities
by MODIS Characterization Support Team (MCST)

- Moon (reference to ROLO model; VIS/NIR spectral bands)
  - Terra MODIS/Aqua MODIS
  - MODIS/SeaWiFS
- SNO
  - Terra and Aqua MODIS /AVHRR
  - Aqua MODIS/AIRS (on the same platform)
  - Terra MODIS/Landsat (near SNO)
- Ground Targets
  - Dome C
  - Desert Sites
- Additional Calibration/Validation Work by MODIS Calibration/Validation Scientists

GEOSS looking forward

- Key GEOSS information system attributes:
  - Interoperability
  - Trusted sources
  - Data policy – affordable and timely data
- Key GEO implementations for interoperability and trusted sources
  - Standards (IEEE supported registry and interoperability forum)
  - Best Practices (IEEE supported registry and editorial board)
  - Data Quality Task (Data calibration and validation (IEEE and CEOS)
  - Other