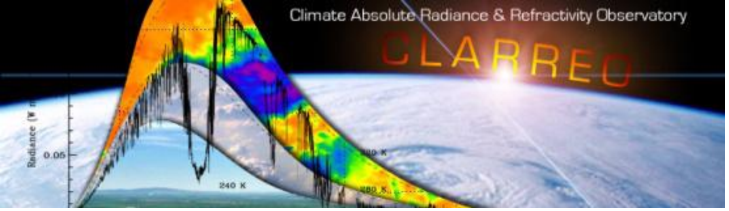

Science Definition Support for the CLARREO RS Instrument and Measurements: Proposed Activities and Progress

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CLARREO Science Team Meeting
The Pyle Center at the University of Wisconsin-Madison, WI, October 12-14, 2011

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- NASA/GSFC
  - Aisheng Wu (intercalibration)
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  - Constantine Lukashin (polarization)

Outline

- Introduction
- Proposed Activities
- Progress
- Future Work

Focus on Reflected Solar (RS) Instrument

Introduction

- **CLARREO Mission**
  - Addresses the need to observe climate change and to determine the accuracy of its projections
    - Enables highly accurate and SI traceable decadal change observations
    - Provides reference intercalibration of temporally and spatially coincident measurements from other on-orbit sensors
- **CLARREO SDT Objective**
  - Supports science definition activities and planning for the mission
    - Refines and prioritizes scientific goals and the measurement requirements and accuracies
    - Defines geophysical products and data sets to be provided by the mission
    - Provides guidance for mission cal/val plan, algorithm development, data processing system, and the use of CLARREO data for testing and improving climate projections

Proposed Activities

- **Liaisons with the Broad Science Community**
  - Provide guidance on instrument design, measurement requirements, calibration approaches, and L1 algorithm development, all while incorporating "lessons learned" from previous sensors
  - Participate in the science and user community conferences
  - Engage agency and interagency missions and projects
  - Support CEOS, GSICS, and CGMS activities

- **Intercalibration (IC) Assessment**
  - Identify candidate sensors and CEOS-endorsed reference sites for CLARREO IC study
  - Evaluate reflective solar (RS) IC methodologies

Proposed Activities

- **Traceable Uncertainty Analysis**
  - Provide guidance and recommendations for the development of CLARREO RS instrument calibration and validation plan
  - Perform detailed SI-traceable measurement uncertainty analysis for the proposed CLARREO RS instrument
  - Design and develop an uncertainty analysis tool (utility) that can be adapted to comprehensively identify and quantify CLARREO RS instrument uncertainties

Progress made in a number of areas

Progress

- **Liaisons with the Broad Science Community**
  - Conferences and Workshops
  - Technical reviews and presentations
- **Intercalibration Assessment**
- **Traceable Uncertainty Analysis**

Liaisons with the Broad Science Community

- **Conferences and Workshops:**
  - IGARSS, SPIE, and CALCON
  - GSICS RWG, COES/IVOS, and GSICS Executive Panel Meeting
- **Papers and presentations:**
  - Xiong, Chiang, McIntire, Schwaller, and Butler, "Post-Launch Calibration Support for VIIRS onboard the NASA NPP Spacecraft," *Proceedings of IGARSS, 2011*
  - Cao, Deluccia, and Xiong, VIIRS Performance (pre-launch) and SDR presentation at *IGARSS* NPP Data User Workshop, 2011
  - Wu, Angal, and Xiong, "Using MODIS to calibrate NOAA series AVHRR reflective solar channels," *Proceedings of SPIE* Vol. 8153, 2011
  - Xiong, Geng, Angal, Sun, and Barnes, "Using the Moon to Track MODIS Reflective Solar Bands Calibration Stability," *Proceedings of SPIE* Vol. 8176, 2011
  - Doelling, Morstad, Bhatt, Scarino, Xiong, and Wu, "MODIS Visible Sensor Radiometric Performance with Multiple Approaches over Various Targets," CALCON 2011
  - Xiong, Butler, and Sun, "Assessment of MODIS Reflective Solar Calibration Uncertainty," CALCON 2011
  - Xiong and Salomonson, "MODIS On-orbit Performance and Lessons Learned," CALCON 2011

Liaisons with the Broad Science Community

- GSICS Research Working Group Meeting (March 2011)
  - Meeting held March 22-25 at Daejeon, Korea
  - Different calibration inter-comparison methodologies and applications
    - » Terra and Aqua MODIS calibration and performance presented and compared
    - » Aqua MODIS selected as the reference sensor for reflective solar intercalibration

- CEOS IVOS (April 2011)
  - Meeting held April 13-15 at the CNES, Toulouse, France
  - Different calibration inter-comparison methodologies and applications
    - » MODIS pre-launch and on-orbit calibration activities presented

Liaisons with the Broad Science Community

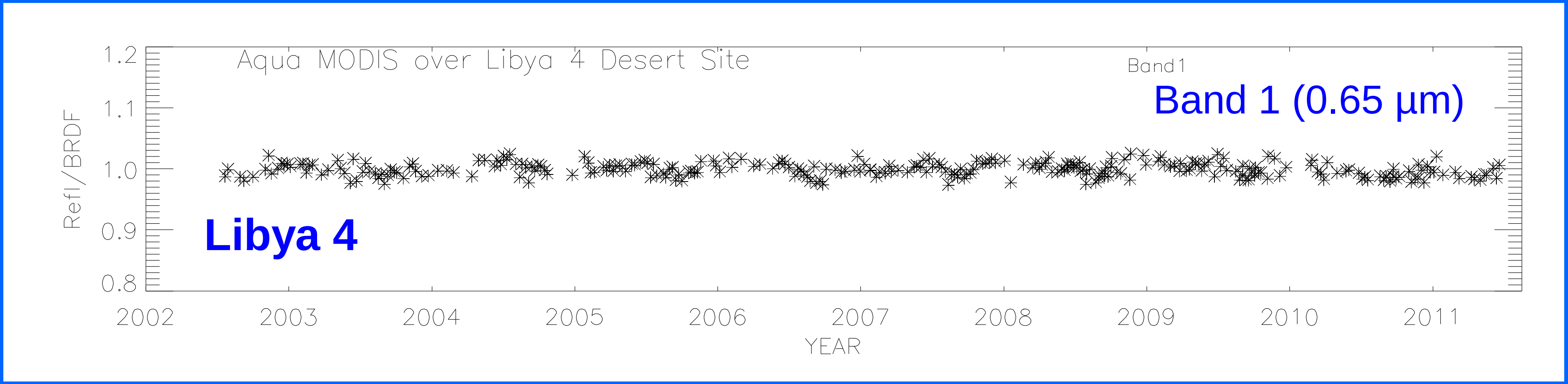
- GSICS Executive Panel Meeting (June 2011)
  - Meeting held June 6-8 at the WMO, Geneva, Switzerland
  - Panel was informed that the CLARREO program is currently in an extended pre-Phase A formulation period
    - » Panel reaffirmed the benefit of a mission such as CLARREO to provide necessary traceability of space-based climate observations and to improve instrument inter-calibration
    - » Following action item was generated:
      - » ***Action EP-10.05:*** *WMO to communicate to NASA its support to the CLARREO project and express in particular the views of GSICS that a mission such as CLARREO would bring a unique benefit in providing absolute traceability and improved instrument inter-calibration, and therefore increase the values of a number of other, either research or operational, environmental missions; WMO to express furthermore the expectation that the CLARREO mission be reconsidered for implementation in the coming years.*
      - » **Status:** GSFC is in communication with the WMO in finalizing a draft letter of support for CLARREO with a GSFC goal of completion by the end of this month.
    - » Patrice Henry of CNES noted that some of the advanced features of CLARREO (e.g. phase change blackbody) were extremely valuable and could be considered to improve the traceability of other future reference missions, such as the IASI follow-on on MetOp-B and C
      - » CNES requested that NASA keep them informed on the development of these advanced on-board calibration approaches

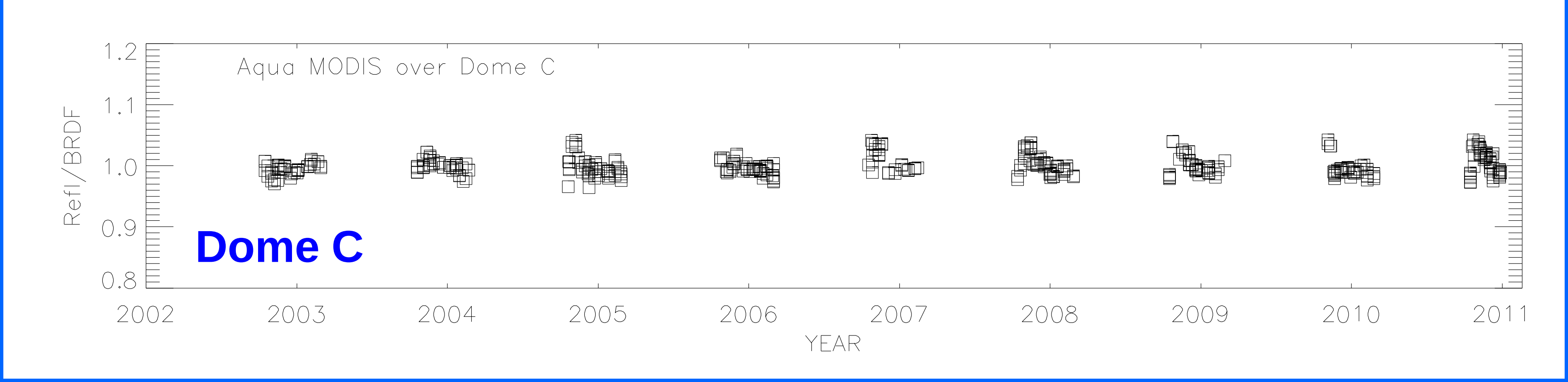
Progress

- **Liaisons with the Broad Science Community**
- **Intercalibration Assessment**
  - Candidate sensors: AVHRR, MODIS, and VIIRS
  - Reference sites: Libya 4 and Dome C
    - *http://calval.cr.usgs.gov/sites_catalog_ceos_sites.php*
  - IC methodologies: SNO, reference sensor, DCC, and model simulation
  - Spatial, spectral, and polarization impact
  - Lunar Calibration
    - Applied to spectral bands with saturated pixels
- **Traceable Uncertainty Analysis**

Reference Sites

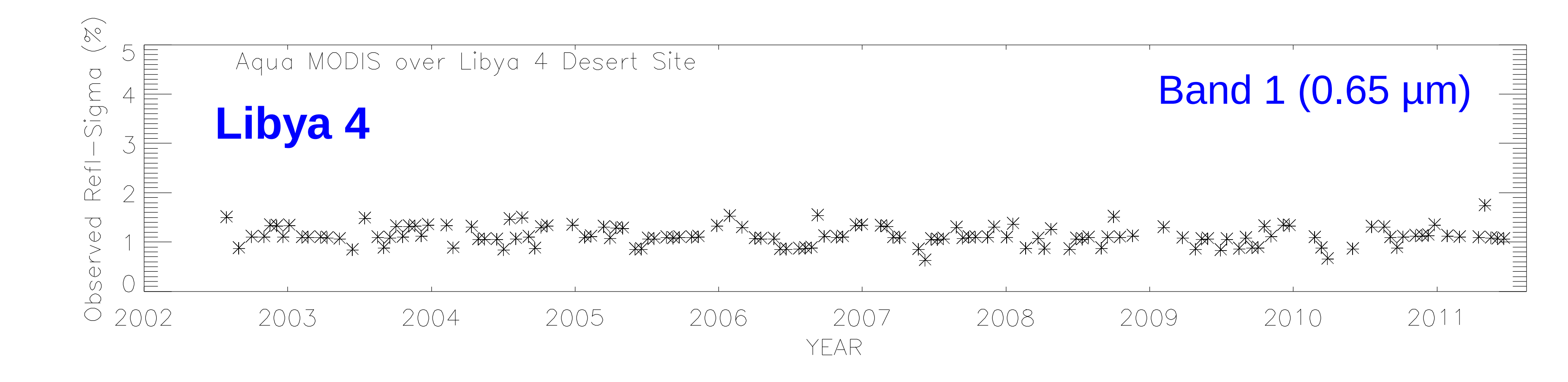
Stability Characterization – Long-term reflectance trend for MODIS band 1 at 0.65 μm, normalized to BRDF models over selected test sites, such as Libya 4 (desert) and Dome C (snow)

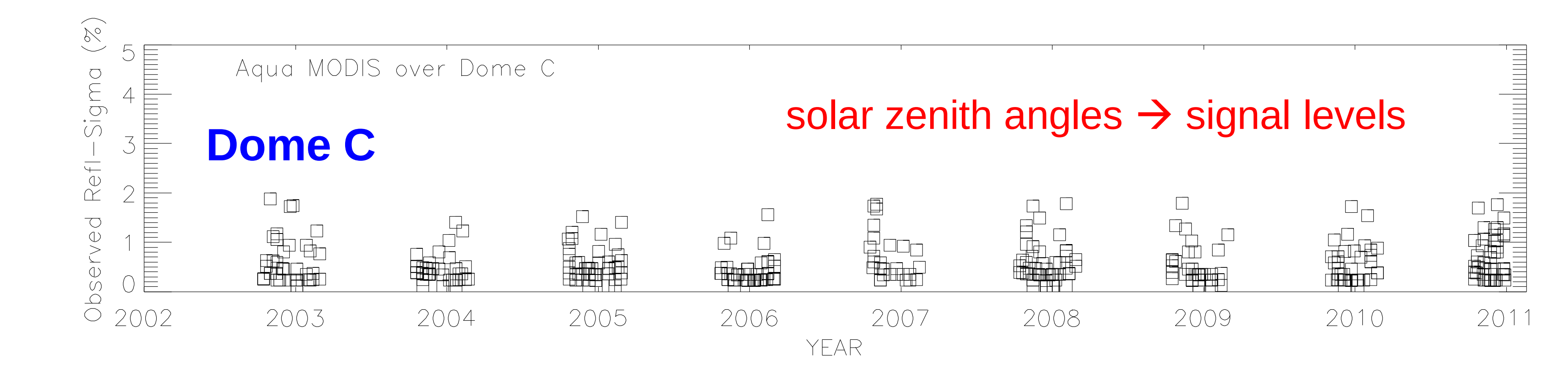




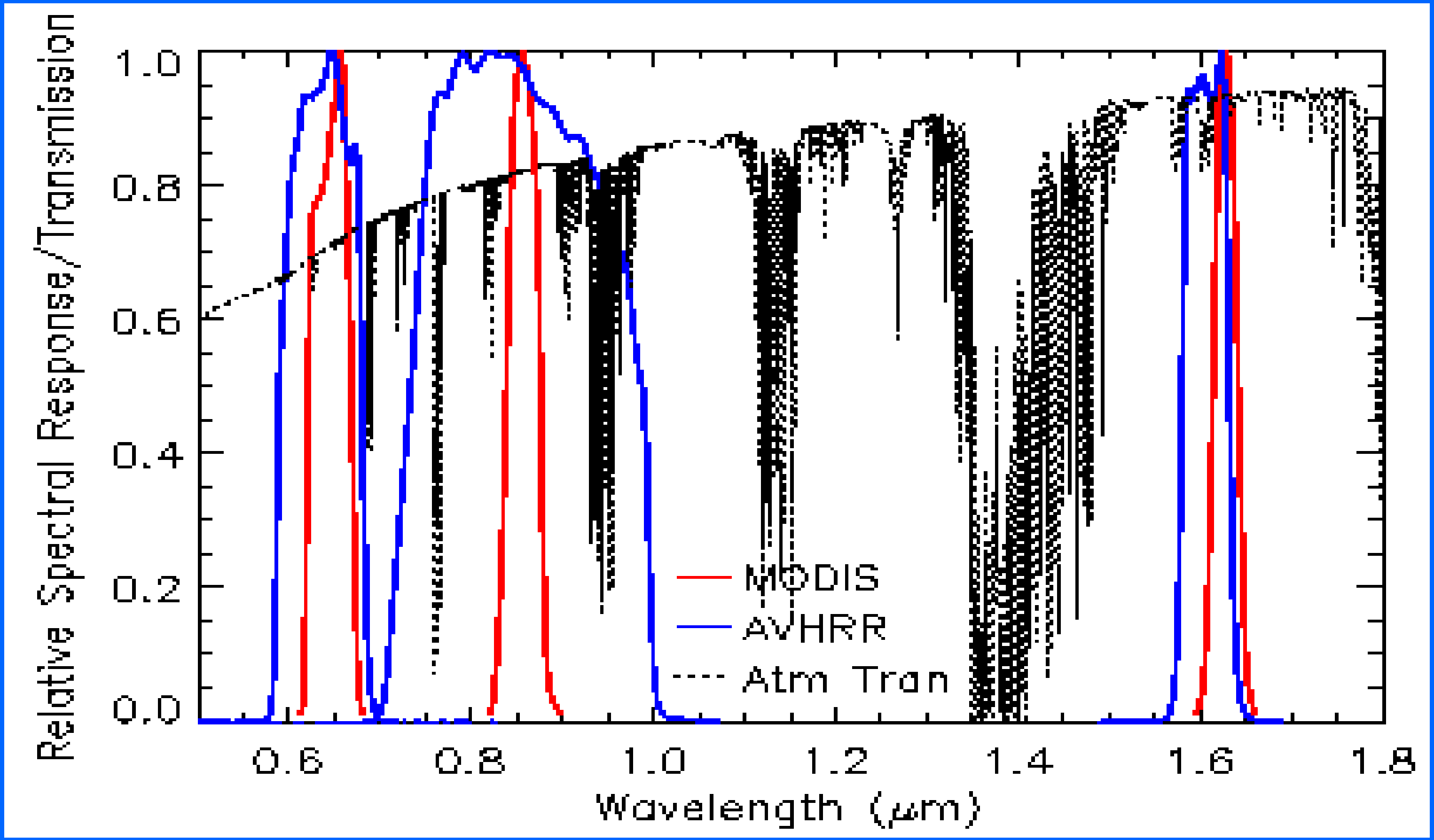
Reference Sites

Uniformity Characterization - standard deviations of reflectance are within 2.0% for Libya 4 and Dome C sites (over a 20x20 km^2 area, MODIS band 1 at 0.65 μm)





Impact due to Sensor Relative Spectral Response



Studies also carried out using hyperspectral observations

Document the impact due to RSR differences and spectral resolution

Impact due to Polarization

$$\rho_{EV}\cos(\theta_{EV}) \propto m_1 \cdot dn$$

+

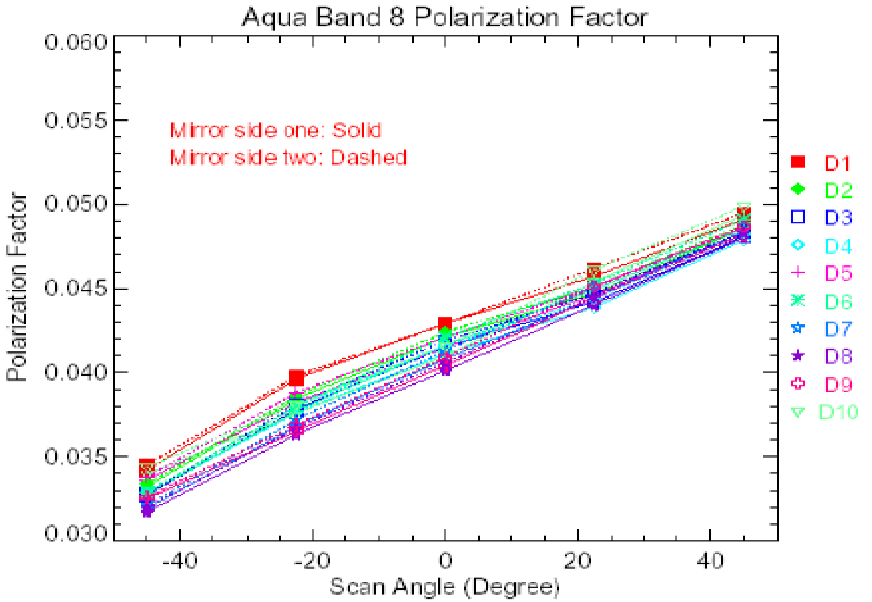
Polarization

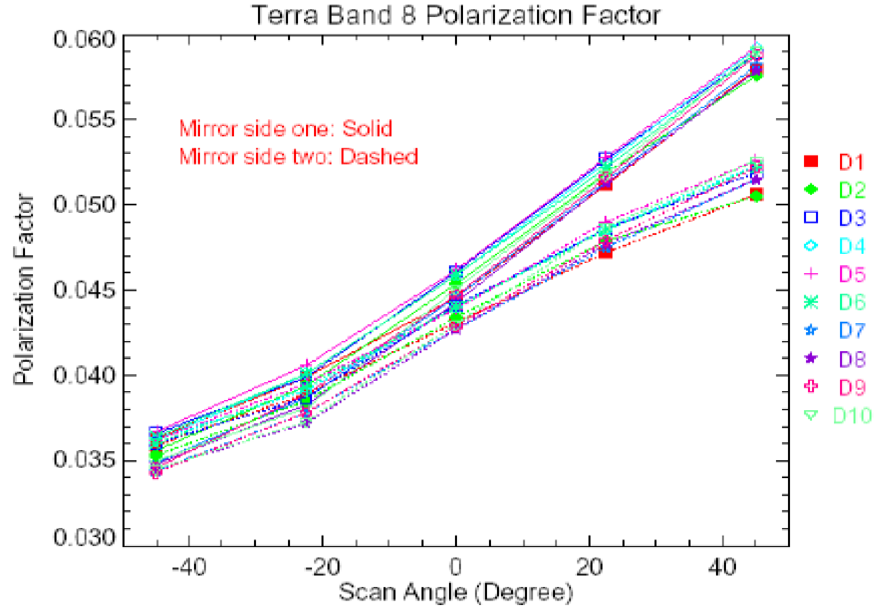
$$[\rho_{EV}\cos(\theta_{EV})]_C = \rho_{EV}\cos(\theta_{EV})\{1 + f \cdot \alpha \cos[2(\mu + \delta)]\}$$

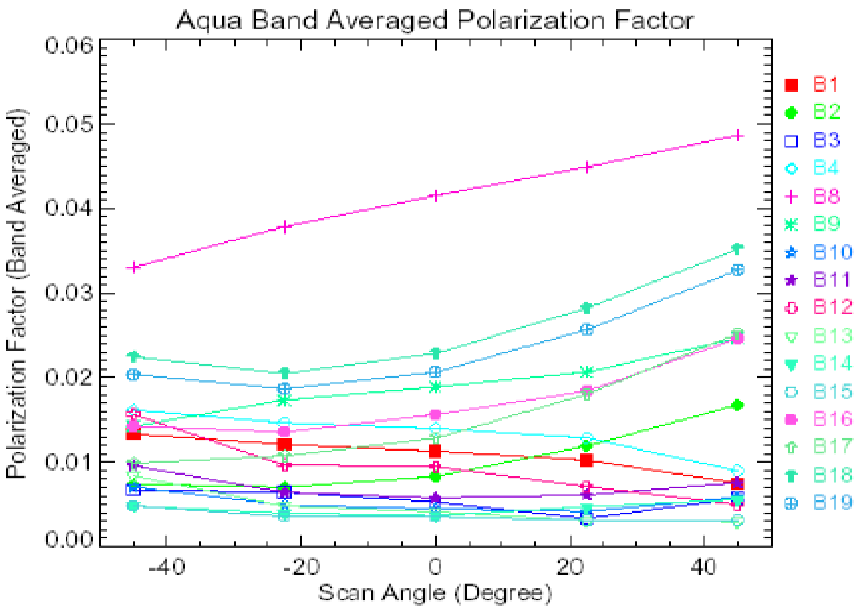
- m_1 and dn are sensor calibration coefficient and detector response in digital number
- α and δ are sensor polarization factor and phase angle
- f and μ are degree of polarization and polarization direction of the incident light
- α and δ are characterized prelaunch but may need to be updated on-orbit
- f and μ are scene dependent and can be measured or simulated for typical scenes

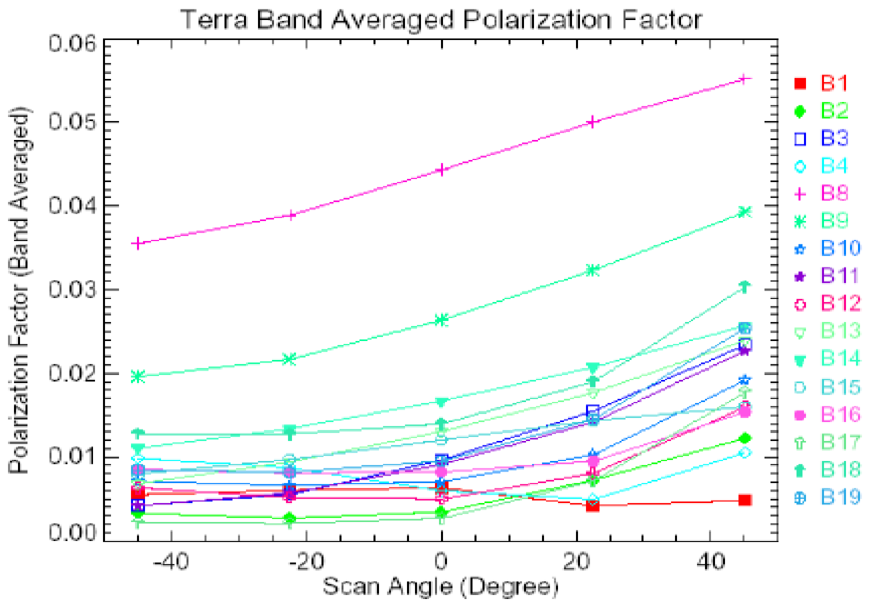
Instrument and model parameters studied
Approaches developed
Resource needed to implement

MODIS Polarization Factor









Impact due to Polarization

- **Polarization impact**
  - **Angle of incidence (AOI) dependent**
  - **Scene dependent**
  - **Spectral wavelength dependent**
  - **Geo-location depended**
  - **Mirror side dependent**
  - **Detector dependent**

  - **Impact on radiometry and imagery**

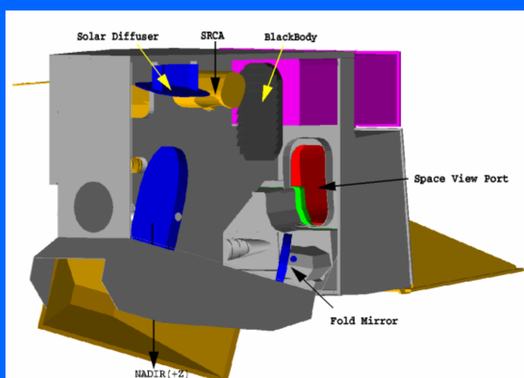
Knowledge of sensor polarization sensitivity

↓

Instrument Design and Calibration Uncertainty

Lunar Calibration

$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$



$$m_1 = \frac{f(view\_geometry)}{< dn^*_{Moon} >}$$

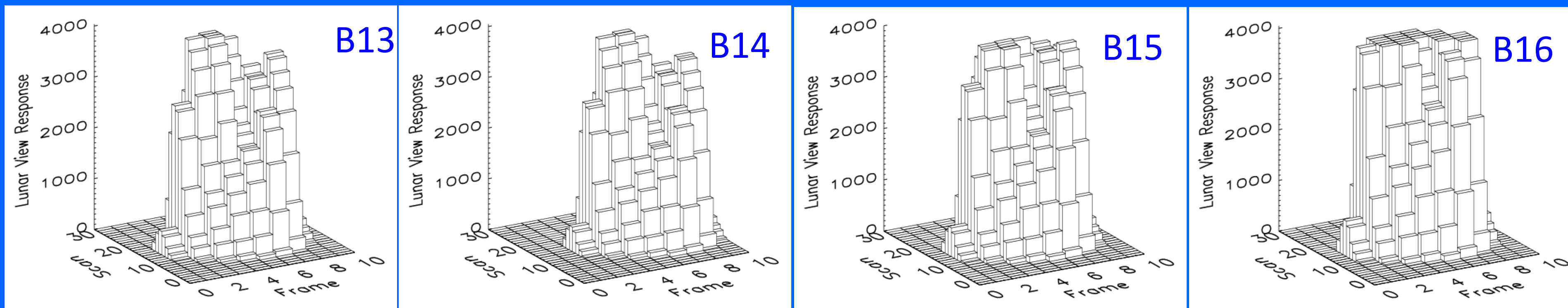
Geometric Factors

$$f = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{over-sampling}}{d^2_{Sun-Moon} \cdot d^2_{Modis-Moon}}$$

Δ_{SD}: SD degradation factor;
Γ_{SD}: SD screen vignetting function
d: Earth-Sun distance
dn*: Corrected digital number
dc: Digital count of SDSM

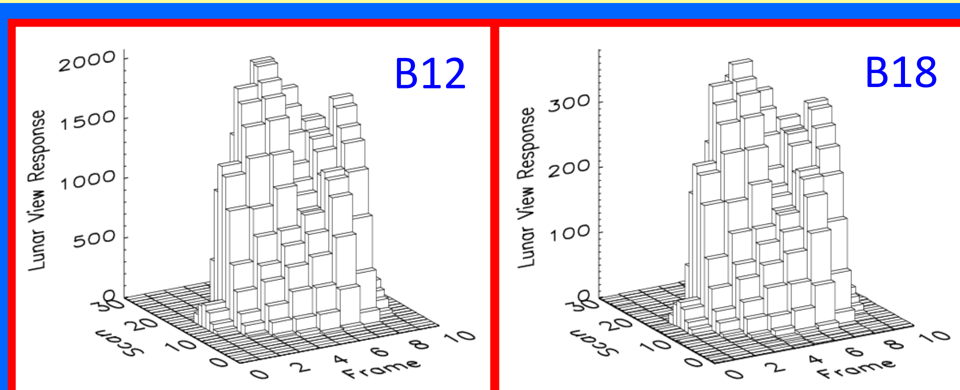
Lunar Calibration

MODIS bands 13-16 (0.67-0.87 μm) saturate when viewing the Moon



MODIS is a 12-bit instrument

Use non-saturated pixels in bands 13-16
Normalize to matched pixels in non-saturated bands



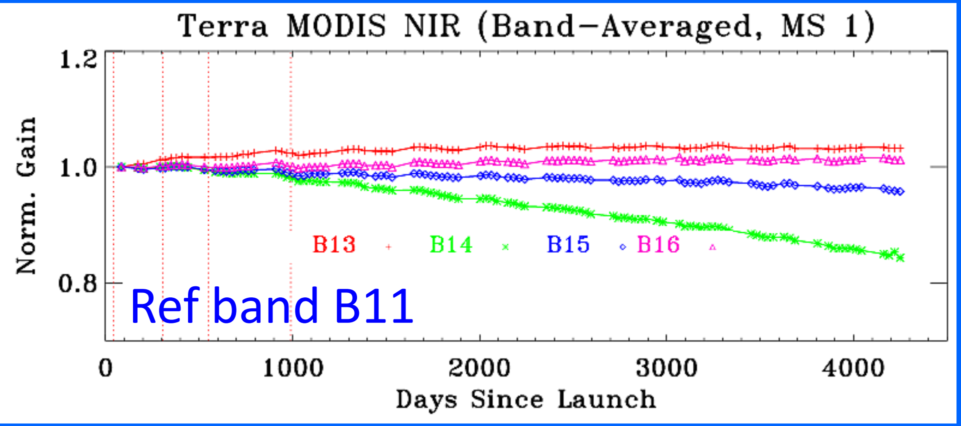
Lunar Calibration

Relative Approach

1. Sum non-saturated pixels for each detector for saturation bands (13-16)
2. Sum matched pixels for the same detector in a reference band (e.g. 18)
3. Compute the ratio for each detector, average all detectors for each band
4. Normalize to ROLO and reference band (detector) response

$$R = \frac{\sum_{scan,frames}^{sat} dn^*}{\sum_{scan,frames}^{ref} dn^*}$$

$$m_{1\_Sat} = (1/R) \cdot m_{1\_ref} \cdot \frac{f_{sat}}{f_{ref}}$$

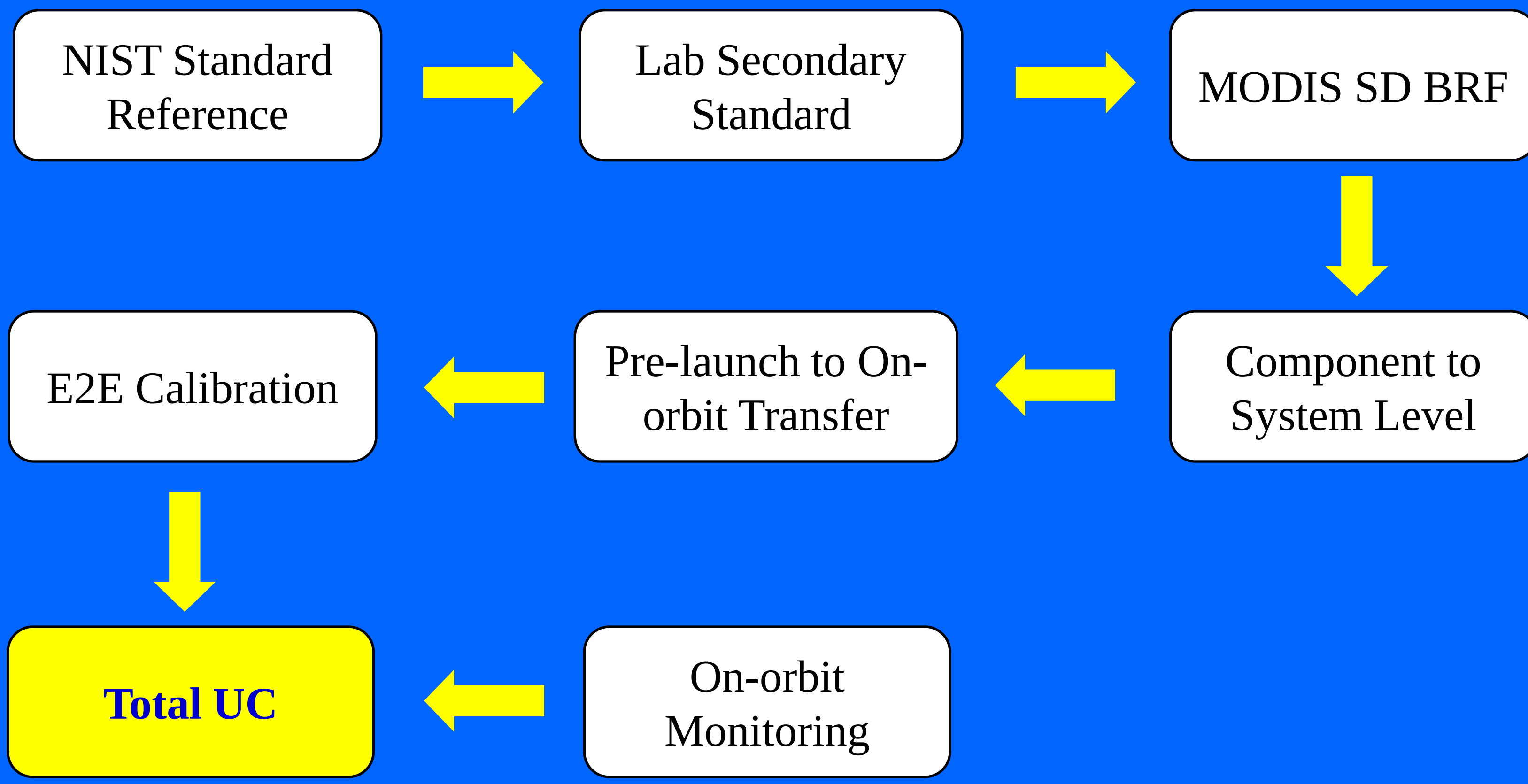


Progress

- **Liaisons with the Broad Science Community**
- **Intercalibration Assessment**
- **Traceable Uncertainty Analysis**
  - To date, work has largely focused on pre-launch, radiometric performance
  - Plan is to use MODIS as a validation “reference” for all uncertainty analyses performed on CLARREO RSB instrument hardware concepts
  - Excel spreadsheet with internal automatic update effectively used for NPP VIIRS (solar diffuser based reflectance calibration)
    - Can be easily adapted to CLARREO uncertainty analysis

MODIS RS Calibration Chain

MODIS Reflective Solar Calibration Flow (Pre-launch to On-orbit)



Xiong et al, CALCON 2011

MODIS/VIIRS-like Instrument

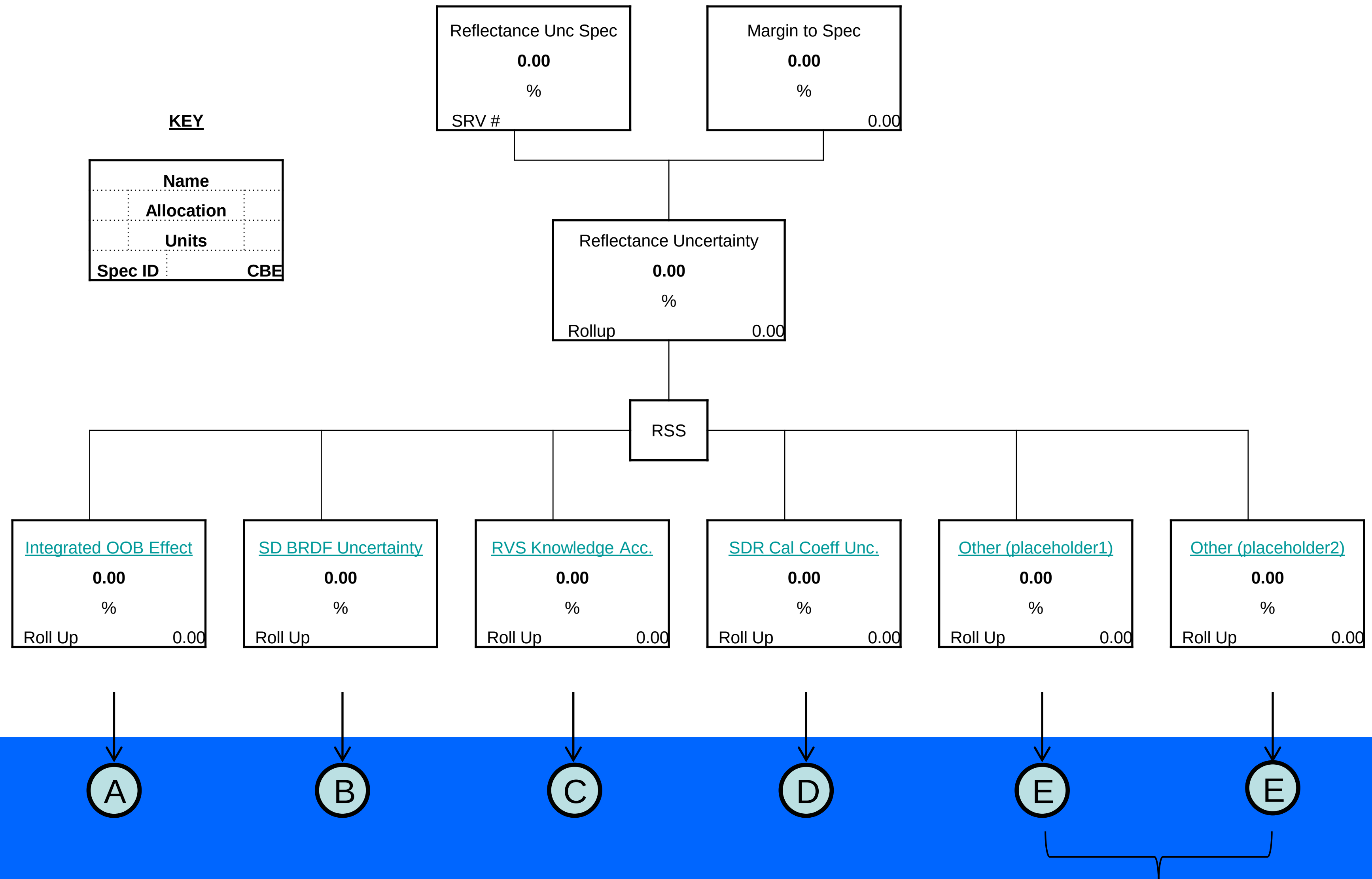
MODIS Calibration UC

	MODIS Band 1 Cal Uncertainty	%
1	NIST reference:	0.50
2	SBRS scattering goniometer:	0.70
3	NIST BRF scale to MODIS SD reference:	0.50
4	MODIS SD characterization:	0.50
5	SD spatial non-uniformities:	0.35
6	Interpolation angular / spectrally:	0.10
7	Pre-launch to on-orbit SD BRF change:	0.50
8	SD screen (0.5% with screen in place):	0.00
9	SDSM screen impact:	0.50
10	Earthshine/Straylight:	0.60
11	SD degradation:	0.30
12	SD observations:	0.06
13	EV observations:	0.53
14	Instrument temperature:	0.04
15	Temperature correction:	0.06
16	Response versus scan angle:	0.32
17	Total	1.65

Future "MODIS-like" Calibration UC

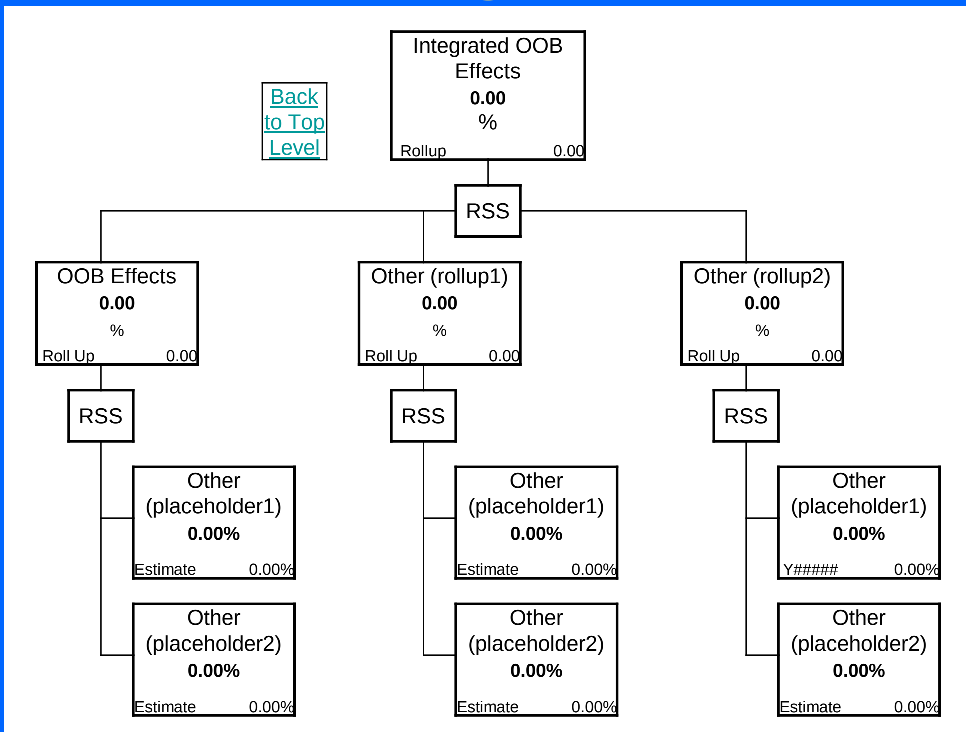
	Cal Uncertainty using SD/SDSM	%
1	NIST reference:	0.20
2	Goniometer:	0.10
3	NIST BRF scale to SD reference:	0.00
4	SD characterization:	0.10
5	SD spatial non-uniformities:	0.10
6	Interpolation angular / spectrally:	0.00
7	Pre-launch to on-orbit SD BRF change:	0.05
8	SD screen	0.00
9	SDSM screen impact:	0.10
10	Earthshine/Straylight:	0.00
11	SD degradation:	0.10
12	SD observations:	0.06
13	EV observations:	0.25
14	Instrument temperature:	0.04
15	Temperature correction:	0.06
16	Response versus scan angle:	0.00
17	Total	0.40

VIIRS RS UC Analysis → CLARREO

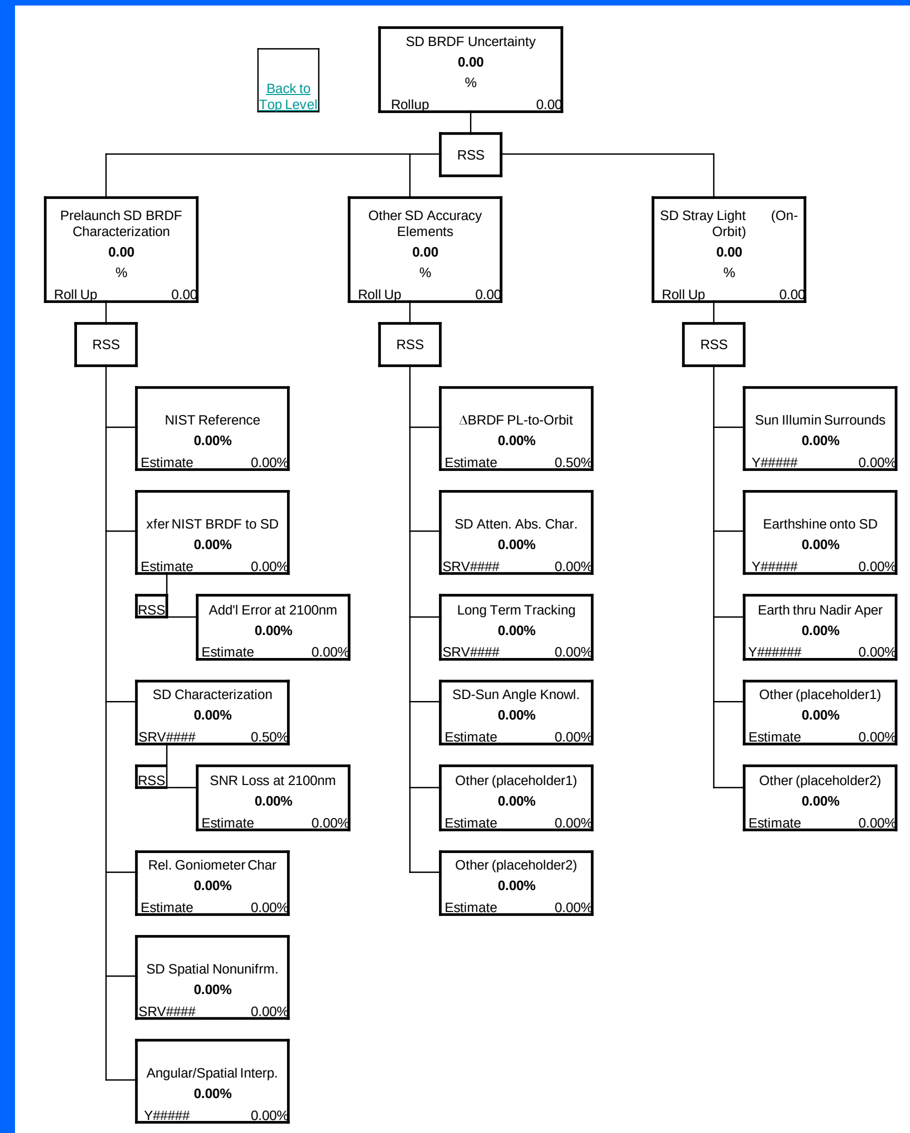


Other contributors can be configured based on instrument calibration and characterization approaches.

A



B



Similar approach for C D E

Future Work

- **Continue making progress for the proposed activities in support of CLARREO Science Definition study**
  - Collaboration with other team members
  - Development of an UC analysis tool (utility)
  - More effort on documentation, especially peer-reviewed journal articles
    - An IEEE TGRS special issue on "Inter-calibration of Satellite Instruments"

IEEE TGRS special issues on “Inter-calibration of Satellite Instruments”

CALL FOR PAPERS

IEEE Transactions on Geoscience and Remote Sensing

Special Issue on “Inter-Calibration of Satellite Instruments”

The ability to detect and quantify changes in the Earth’s environment using remote sensing is dependent upon sensors providing accurate and consistent measurements over time. A critical step in providing these measurements is establishing confidence and consistency between data from different sensors and putting them onto a common radiometric scale. However, ensuring that this process can be relied upon long term and that there is physical meaning to the information requires traceability to internationally agreed, stable, reference standards ideally tied to the international system of units (SI). This requires robust on-going calibration, validation, stability monitoring, and quality assurance, all of which need to be underpinned and evidenced by comparisons involving a reference standard or sensor and a methodology with defined uncertainty (in an absolute or temporal sense). This process can be used to provide calibrations to other sensors (i.e. Inter-calibration).

Inter-calibration and comparisons between sensors have become a central pillar in calibration and validation strategies of national and international organizations. The Global Space-based Inter-Calibration System (GSICS) is an international collaborative effort initiated by World Meteorological Organization (WMO) and the Coordination Group for Meteorological Satellites (CGMS) to monitor and harmonize data quality from operational weather and environmental satellites. The Infrared Visible Optical Sensors (IVOS) sub-group of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) extends this vision to include all Earth observation sensors and satellite operating agencies. Inter-calibration techniques provide a practical means of correcting biases between sensors and bridging any potential data gaps between non-contiguous sensors in a critical time-series and the inter-calibration reference serves as a transfer standard. It is expected that promotion of the use of robust inter-calibration techniques will lead to improved consistency between satellite instruments, reduce overall costs, and facilitate accurate monitoring of planetary changes.

List of topics

Contributions for this special issue are welcome from the research community. This special journal issue will focus on how inter-calibration and comparison between sensors can provide an effective and convenient means of verifying post-launch sensor performance and correcting the differences. The guest editors invite submissions that explore topics including, but not limited to, pseudo-invariant calibration sites, instrumented sites, simultaneous nadir observations and other ray-matching comparisons, lunar and stellar observations, deep convective clouds, liquid water clouds, Rayleigh scattering and Sun glint. The inter-calibration results should focus on rigorous quantification of bias and associated sources of uncertainty from different sensors, crucial for long-term studies of the Earth. The goal of this special journal issue is to capture the state-of-the-art methodologies and results from inter-calibration of satellite instruments, including full end-to-end uncertainty analysis. Accordingly, it will become a reference anthology for the remote sensing community.

Paper submission deadline: 31 January 2012

Submission guidelines

Normal page charges, peer-review, and editorial process will apply. Prospective authors should follow the regular guidelines of TGRS, and should submit their manuscripts electronically to *http://mc.manuscriptcentral.com/tgrs*. Please indicate during your submission that the paper is intended for this Special Issue. Inquiries with respect to the special issue should be directed to the Guest Editors.

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Backup Slides

Proposed Timeline and Deliverables (year-1)

- Identify candidate instrument design and pre-launch calibration and characterization approaches for the CLARREO RS instrument.
- Identify, for each candidate instrument hardware design, the complete suite of subsystem level characterization measurements required as part of acceptance testing; quantify, with respect to radiometric and spectral performance, the complete measurement uncertainties for these subsystem characterization approaches.
- Identify and examine candidate sensors and CEOS-endorsed reference sites for CLARREO IC study.
- Compare and evaluate different IC methodologies, and identify key uncertainty contributors to each approach.
- Present results of the above studies at CLARREO Science Team Meetings, Technical Meetings, and refereed publications.