Assessments of MODIS On-orbit Spatial and Spectral Characterization

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Acknowledgements

Raytheon MODIS Team members

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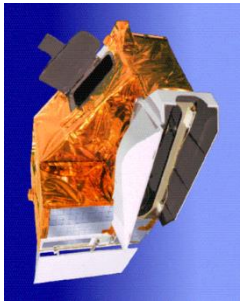
Outline

- **MODIS Instrument**
  - Spectral Bands and Focal Plane Assemblies (FPAs)
  - On-board Calibrators (OBCs)
  - Spectro-Radiometric Calibration Assembly (SRCA)
- **On-orbit Spatial and Spectral Characterization**
  - Activities and Methodologies
- **Spatial Performance**
  - Band-to-Band Registration (BBR)
  - Modulation Transfer Function (MTF)
- **Spectral Performance**
  - Center Wavelengths (CW) and Bandwidths (BW)
- **Summary**

Moderate Resolution Imaging Spectroradiometer (MODIS)

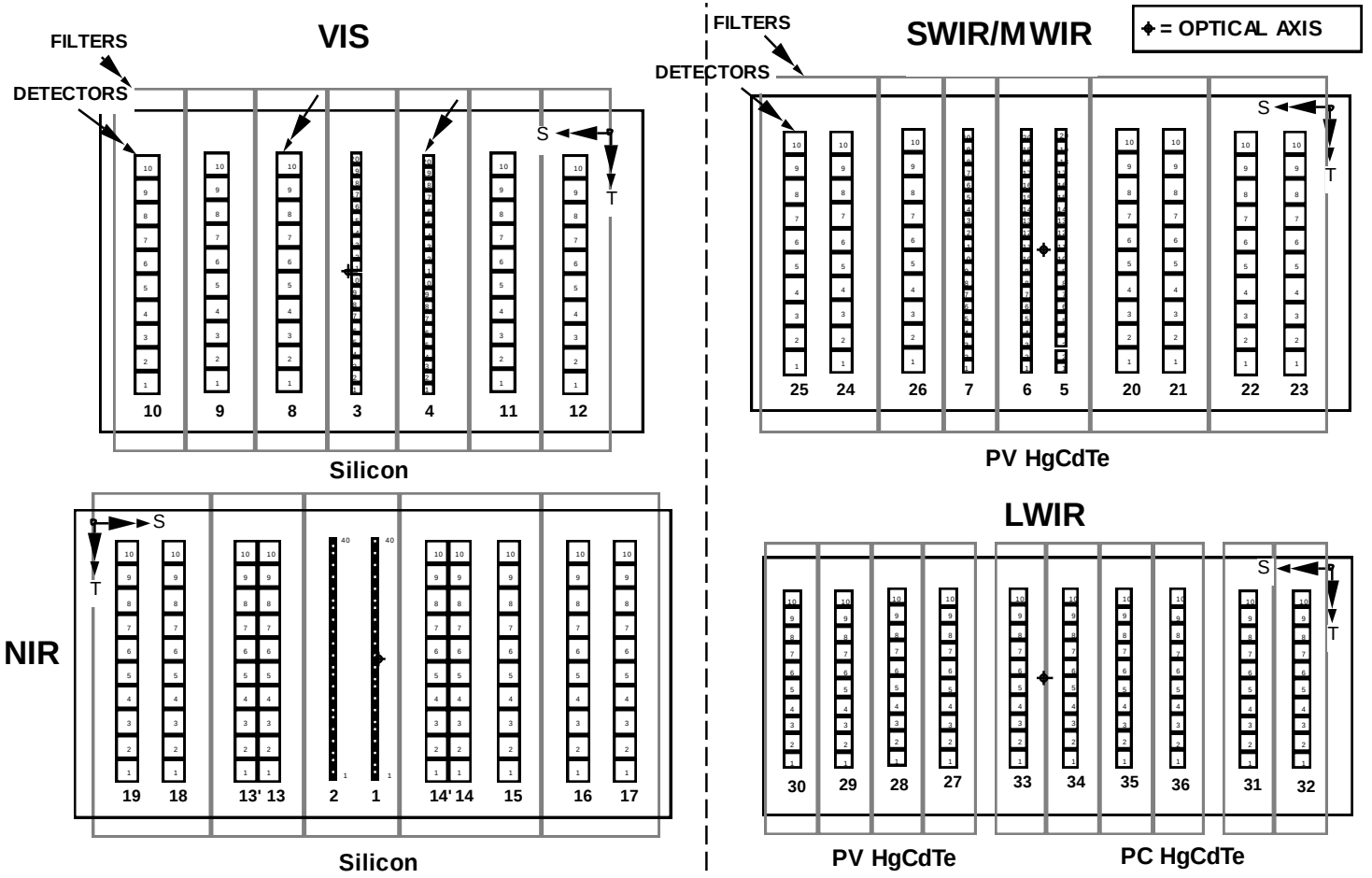
MODIS



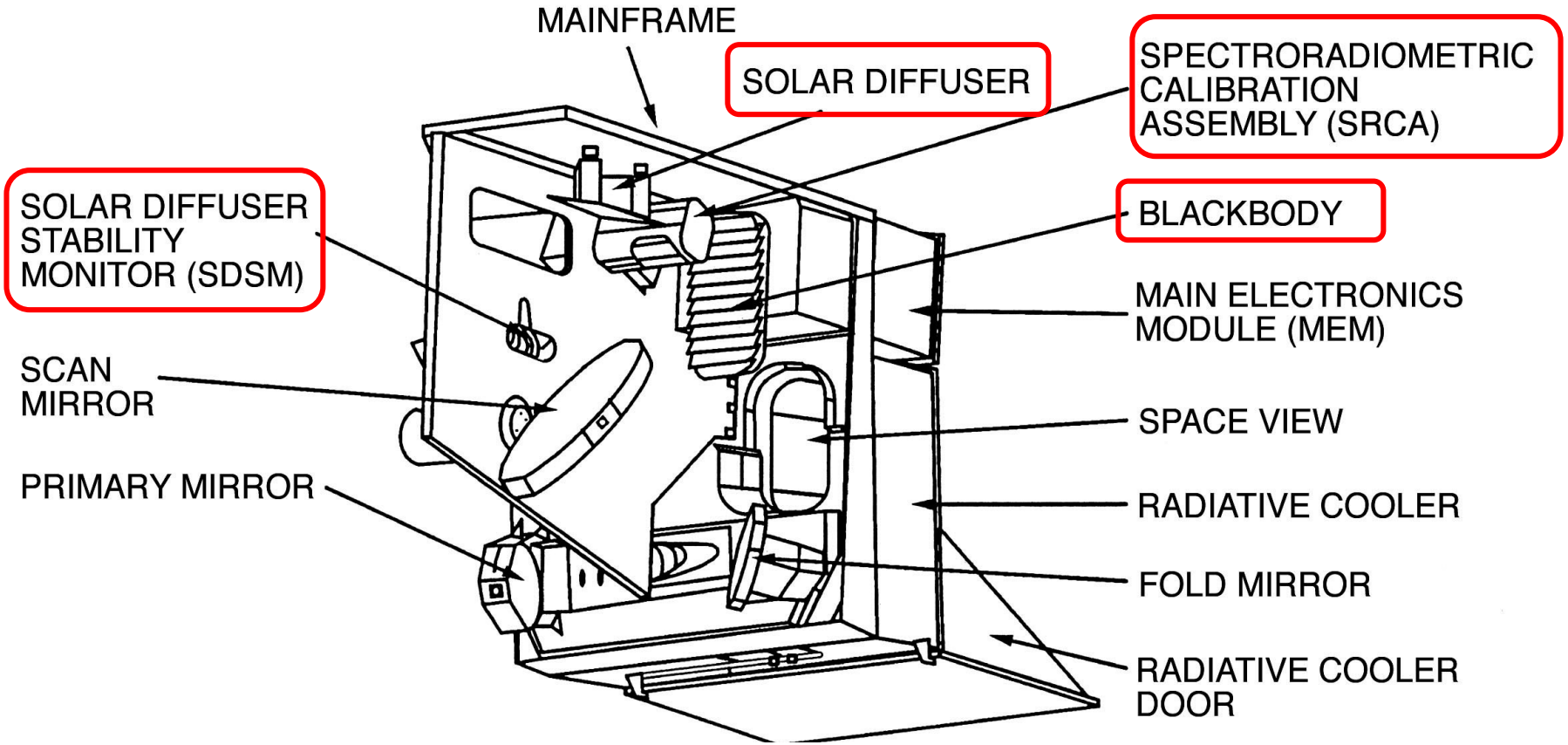
Terra since 1999

Aqua since 2002

36 spectral bands: 0.4 - 14.4 μm (VIS, NIR, SMIR, LWIR)
3 spatial resolutions (nadir): 250 m, 500 m, and 1000 m
4 focal plane assemblies (FPA) with a total of 490 detectors



On-board Calibrators (OBC)

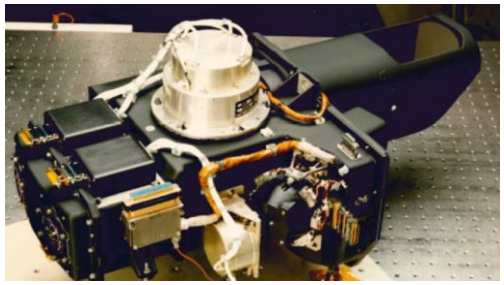


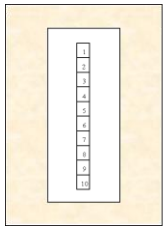
SD/SDSM for RSB radiometric calibration

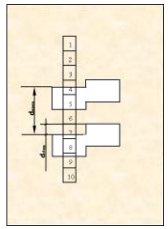
BB for TEB radiometric calibration

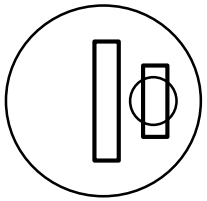
SRCA for spatial and spectral characterization

Spectro-Radiometric Calibration Assembly (SRCA)







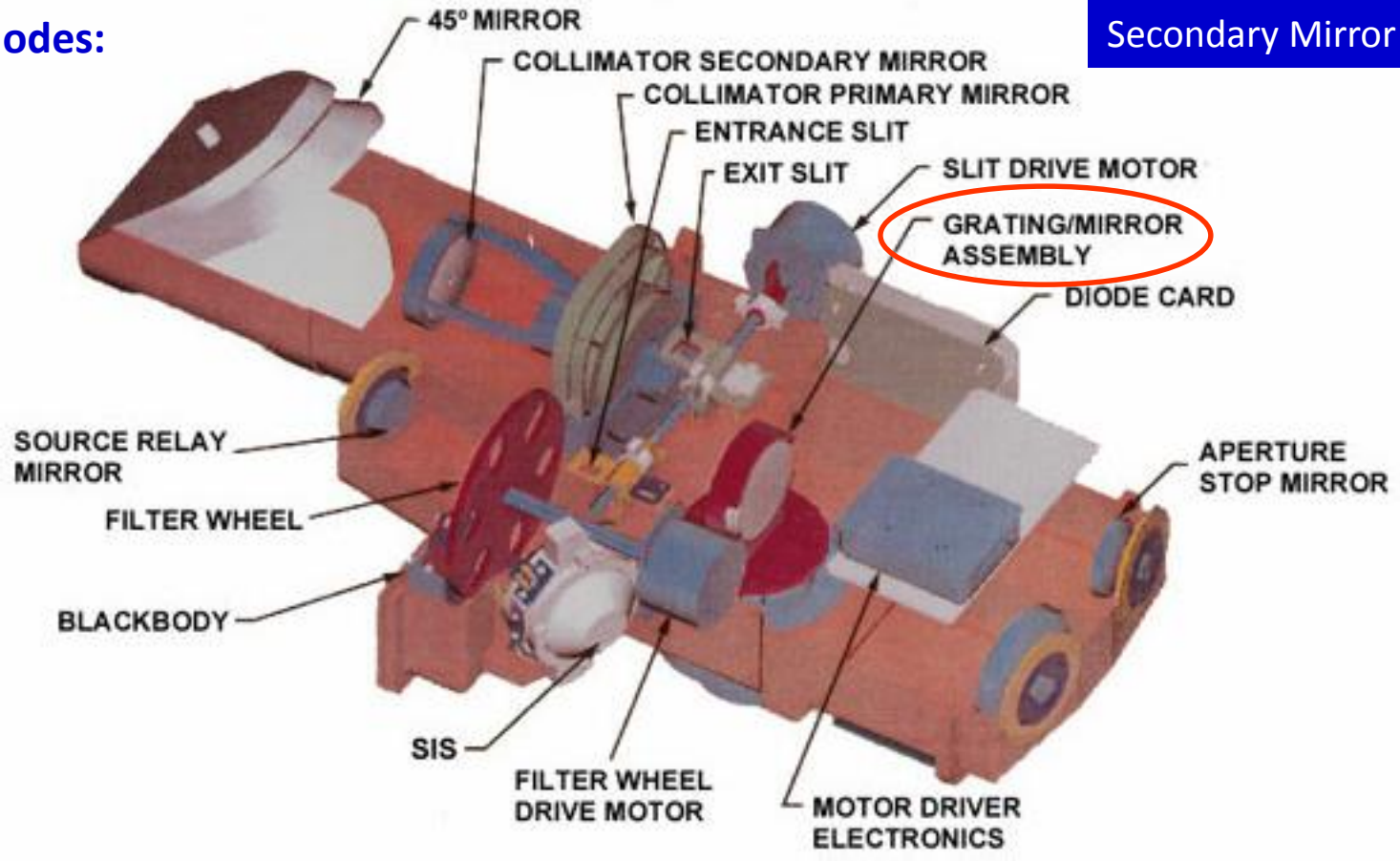


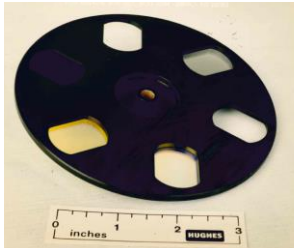
Didymium Filter Calibration SiPD

Reference SiPD at Secondary Mirror

3 Operational Modes:

- **Radiometric**
- **Spatial**
- **Spectral**





On-orbit Spatial and Spectral Characterization

Spatial (82/64)

Year	Terra	Aqua
2000	10	-
2001	6	-
2002	6	5
2003	6	6
2004	6	5
2005	3	4
2006	3	2
2007	4	4
2008	5	5
2009	4	4
2010	4	4
2011	5	5
2012	4	5
2013	4	4
2014	5	5
2015	4	4
2016	3	2

Spectral (58/44)

Year	Terra	Aqua
2000	6	-
2001	5	-
2002	4	3
2003	4	4
2004	4	4
2005	3	2
2006	2	2
2007	3	1
2008	3	3
2009	3	3
2010	3	3
2011	4	4
2012	3	3
2013	3	3
2014	4	4
2015	3	3
2016	1	2

Lamp Usage

Terra

- Launch: Lamps 1-3, 5 in operation (4, 6 in reserve)
- Nov. 2004 – L4 replaced L2
- Feb. 2006 – Lamp 3 taken out of service

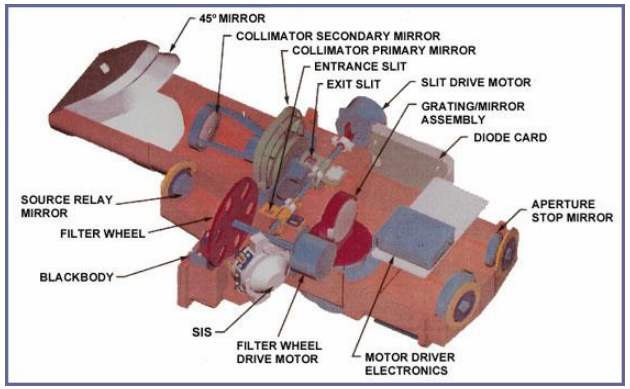
Aqua

- Launch: Lamps 1-3, 5 in operation (4, 6 in reserve)
- April 2003 – L4 replaced L2
- June 2005 – Lamp 3 taken out of service
- July 2016 – Lamp 4 taken out of service

Spatial and Spectral Characterization Methodologies

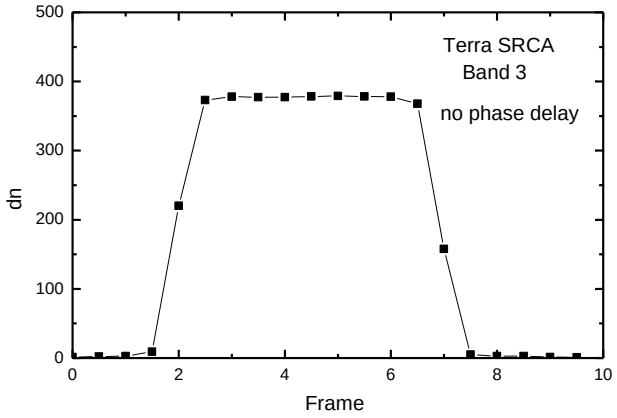
$$\bar{x}(b,d) = \frac{\sum_{x=0}^{N_x} dn(b,d,x) \cdot x}{\sum_{x=0}^{N_x} dn(b,d,x)}$$

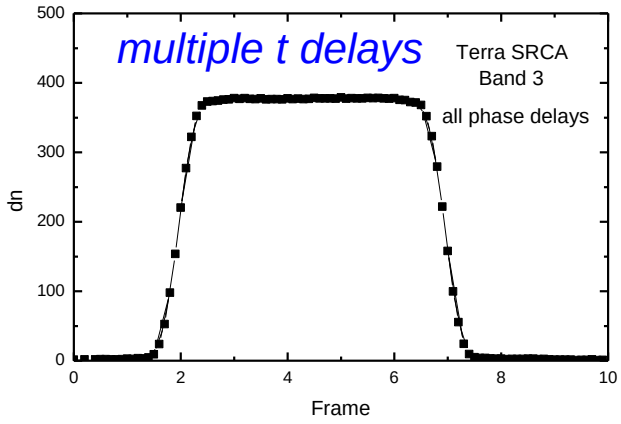
Spatial



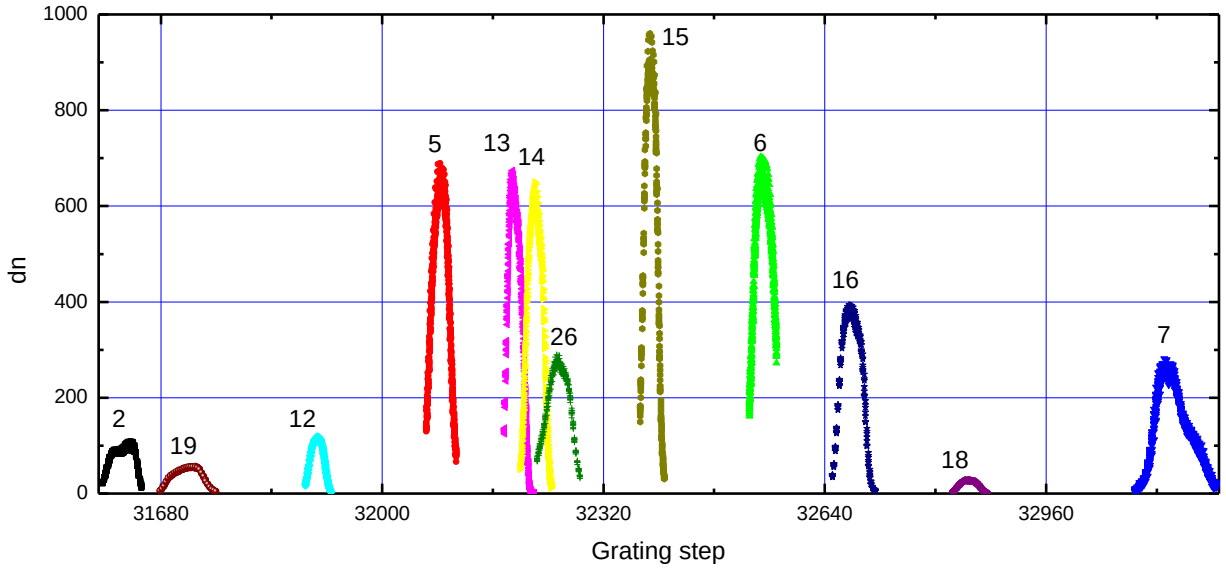
Spectral

$$\lambda_C = \frac{2A}{m} \cdot \sin(\theta_C + \theta_{off}) \cdot \cos\beta$$





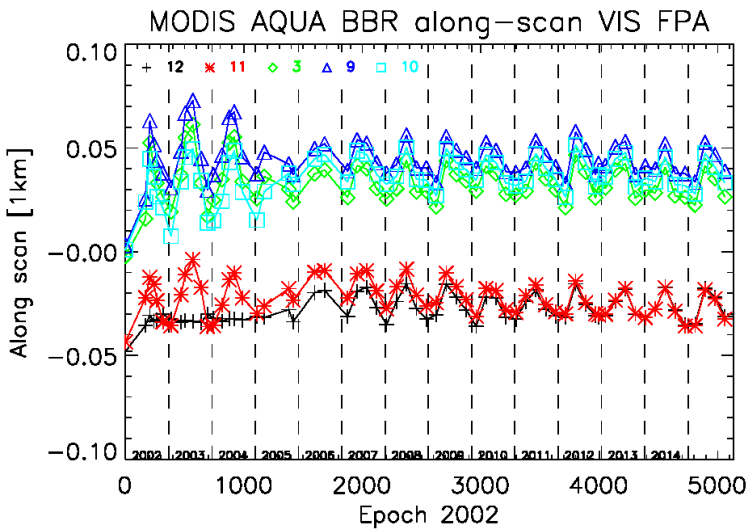
Frame -> x

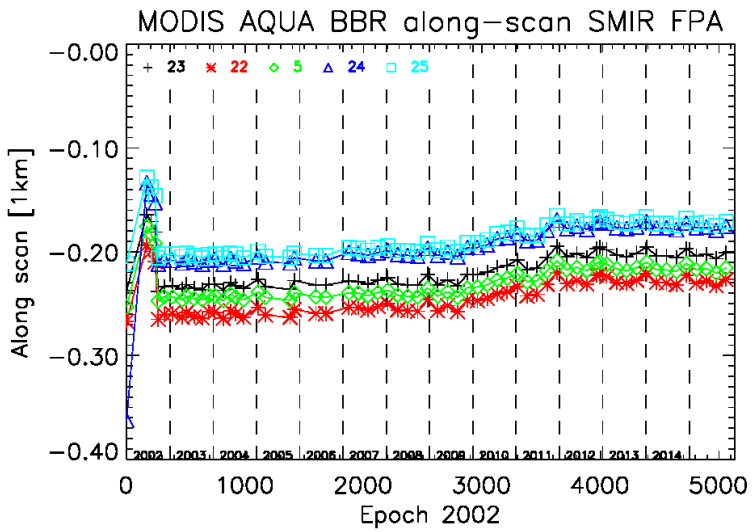


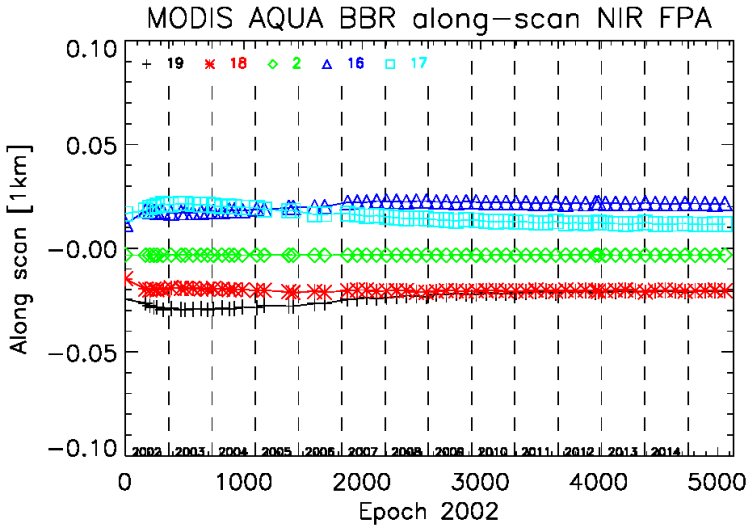
Grating step -> θ -> λ

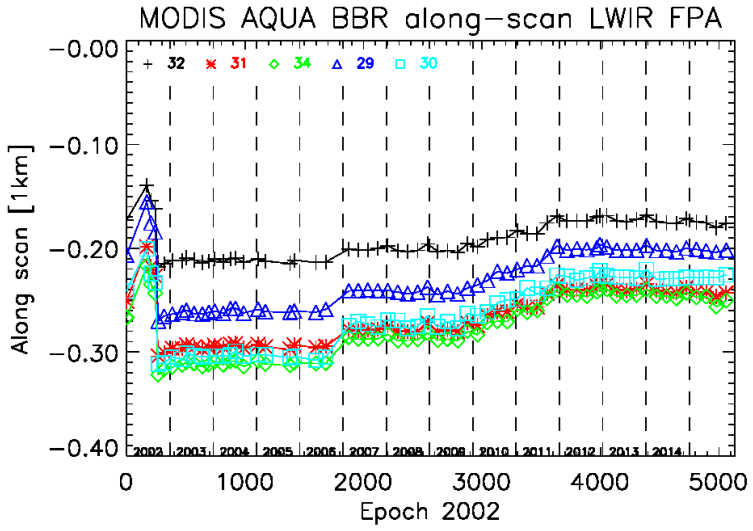
λ calibration performed with didymium filter

Spatial Performance (Aqua along-scan BBR)



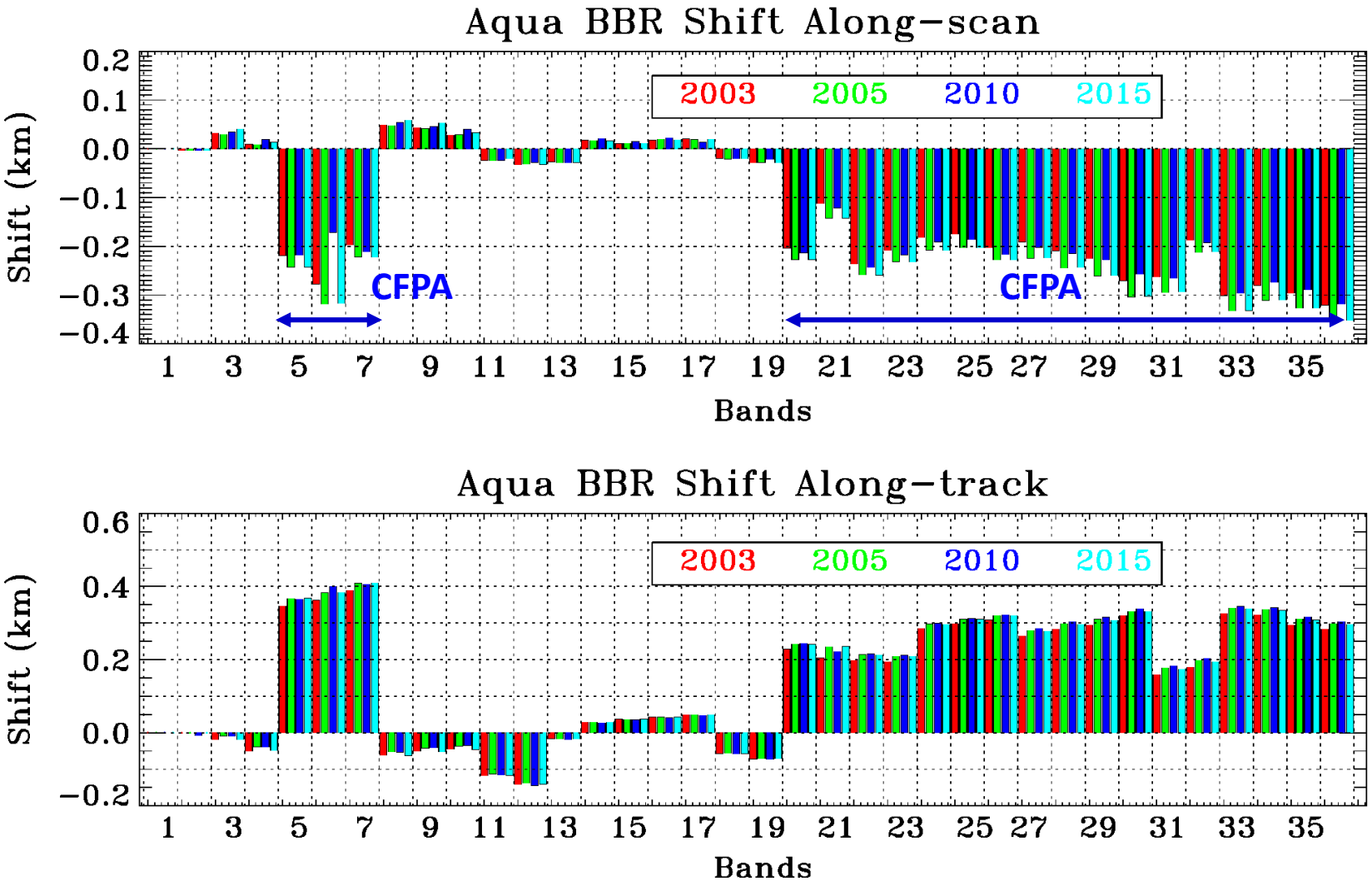




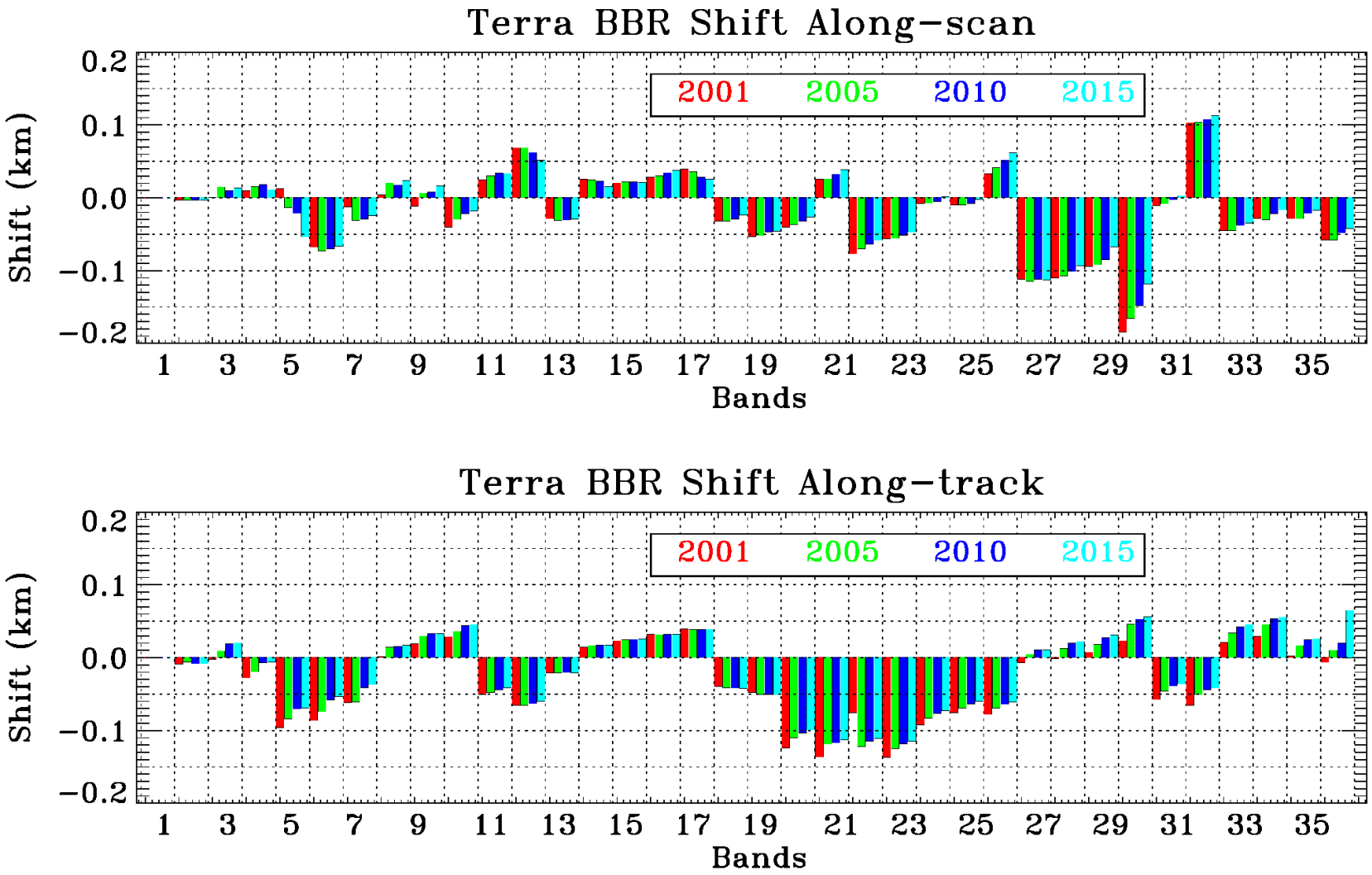


Aqua BBR: a known issue since pre-launch; shift between warm and cold FPA

Spatial Performance (Aqua yearly BBR)



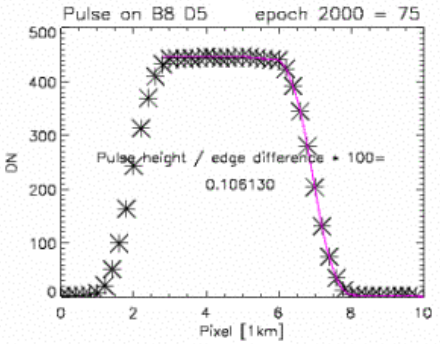
Spatial Performance (Terra yearly BBR)

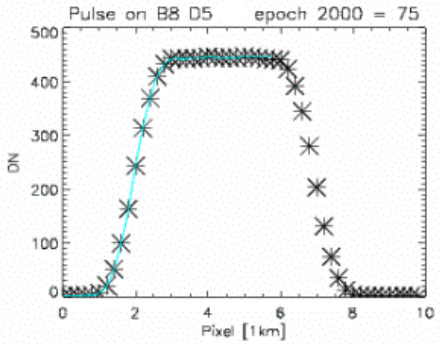


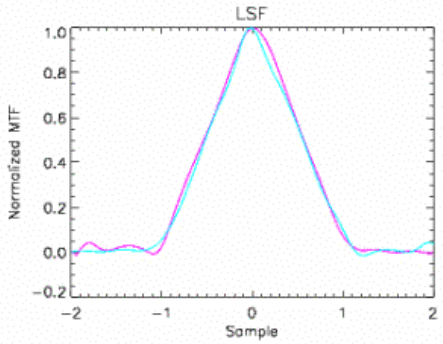
Terra BBR: within spec (±0.1 km) for all band pairs (except for along scan B30 and B32)

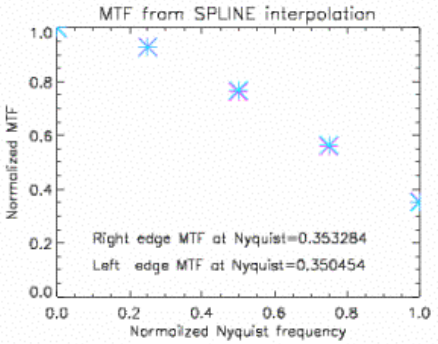
Spatial Performance (Terra along-scan MTF)

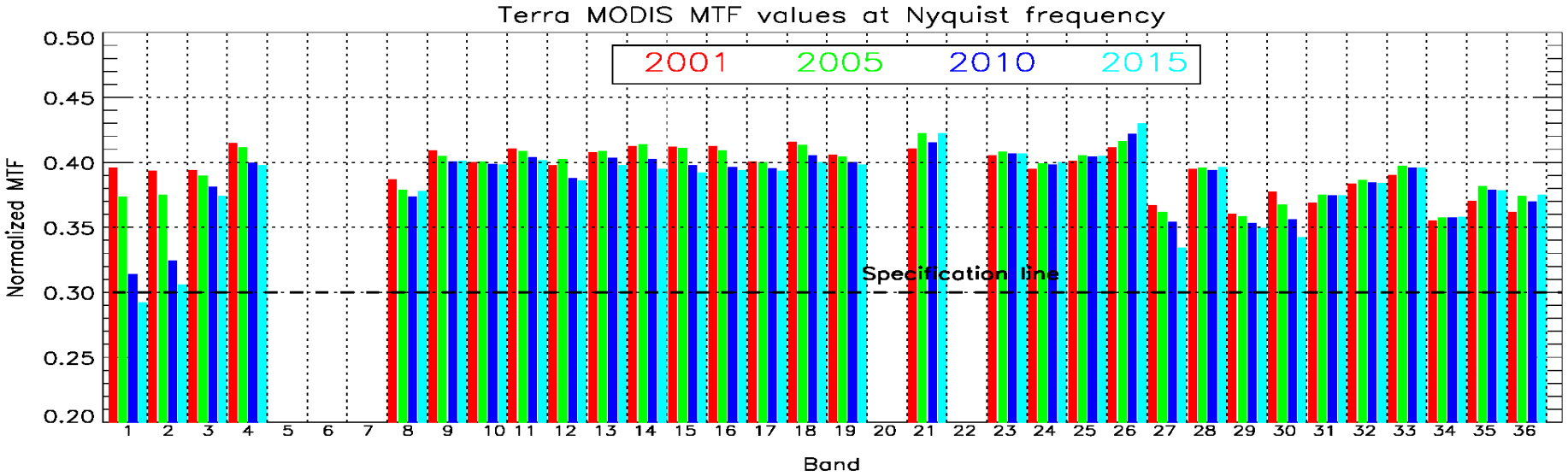
ERF => LSF => MTF









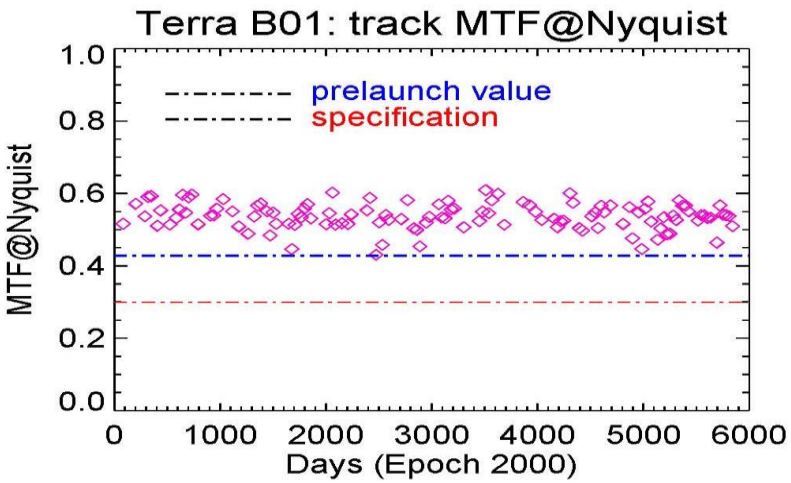


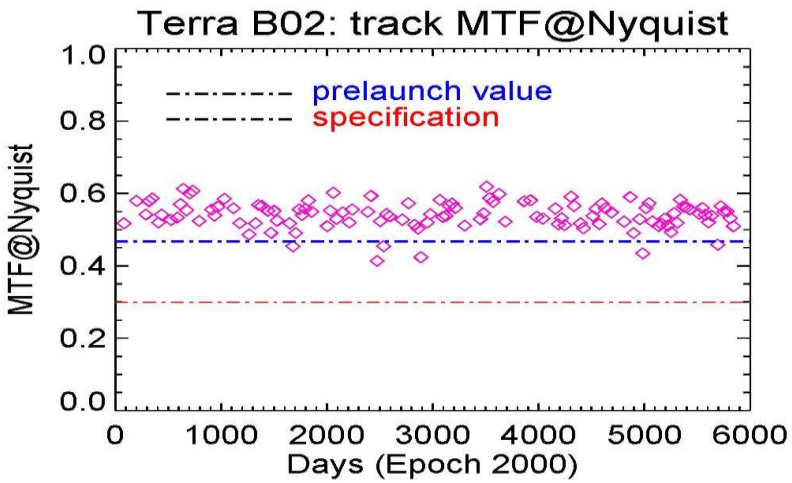
MTF performance meets design requirements except for a few bands in Aqua

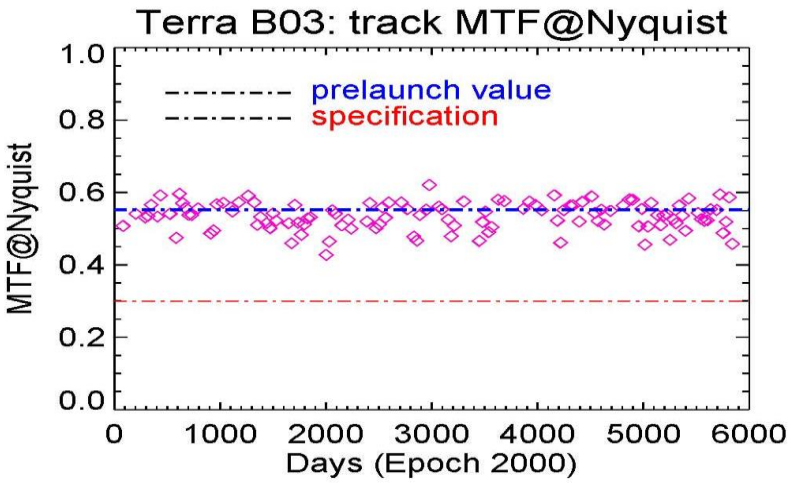
Limitation of SRCA: along-track MTF

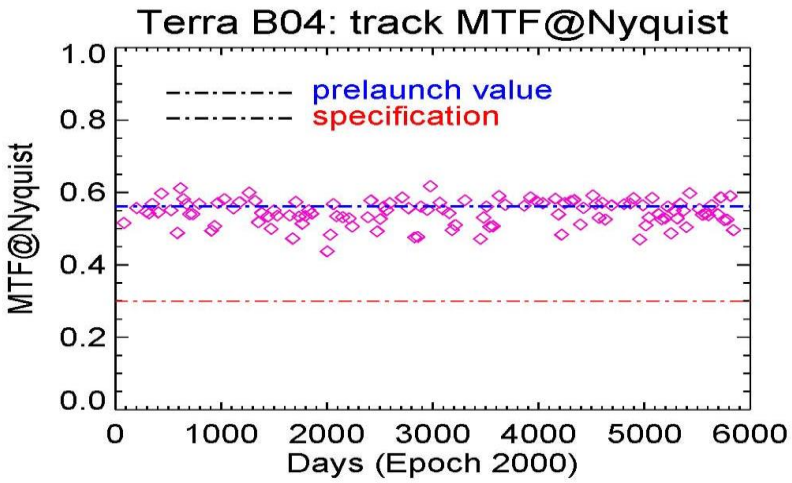
Data quality impact on MTF (e.g. SWIR crosstalk)

Spatial Performance (Terra along-track MTF; Moon)









Similar results (stable along-track MTF) for Aqua MODIS

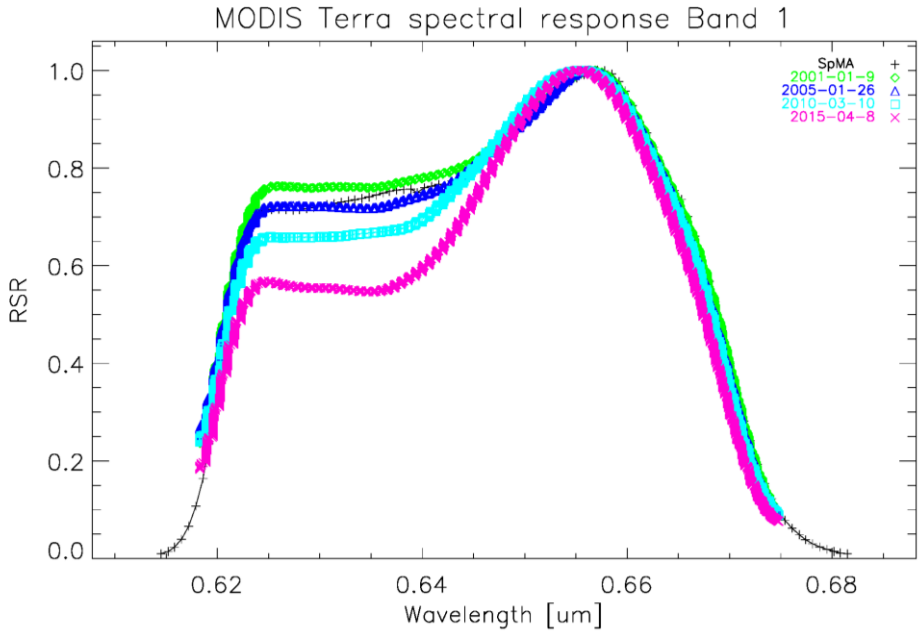
Methodologies developed for MODIS also applied to VIIRS

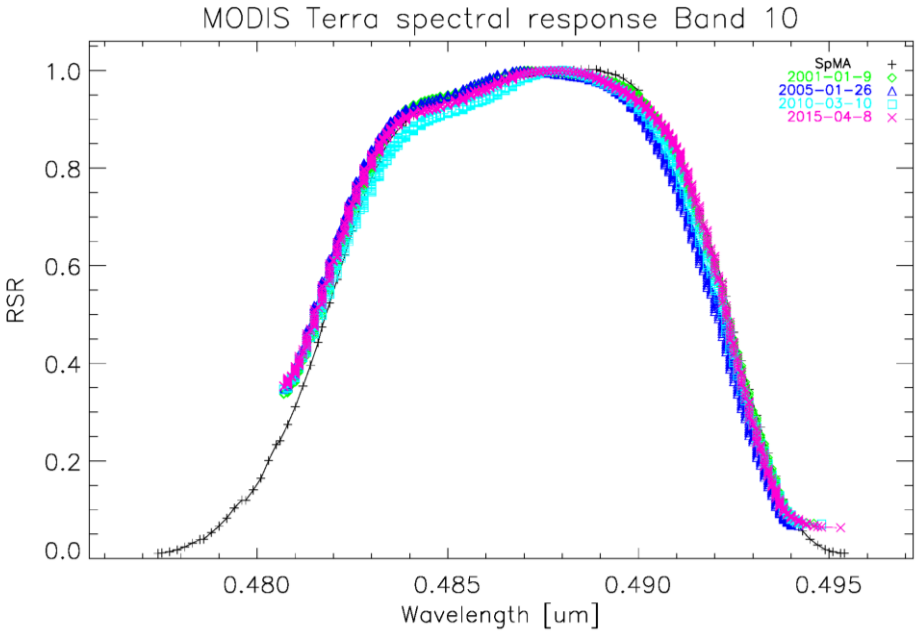
Limitation of lunar approach: TEB saturate when viewing the Moon

Spectral Performance (on-orbit RSR from SRCA)

Pre-launch from SpMA used as the reference

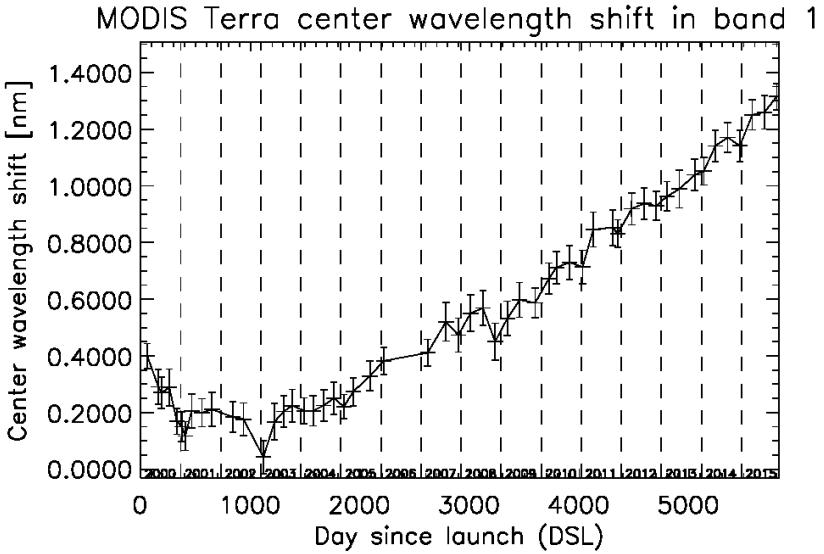
On orbit SRCA measurements (Terra) made in 2001, 2005, 2010, 2015

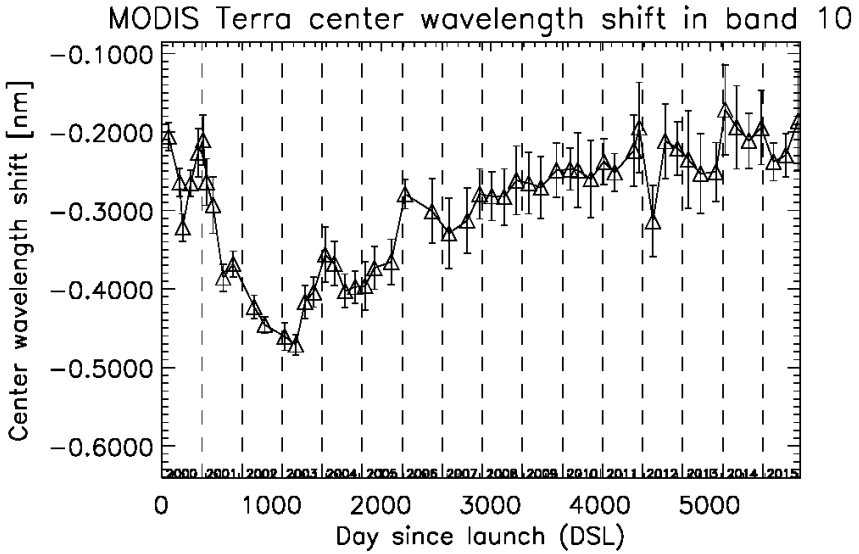


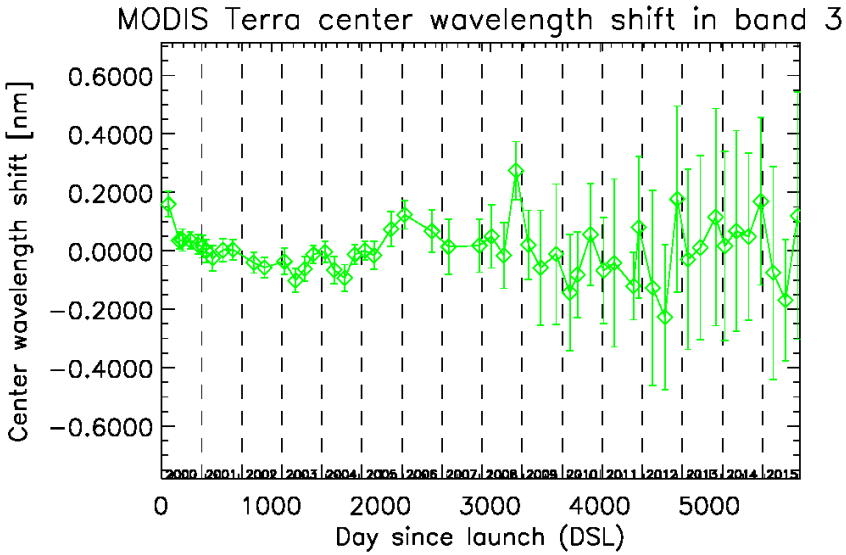


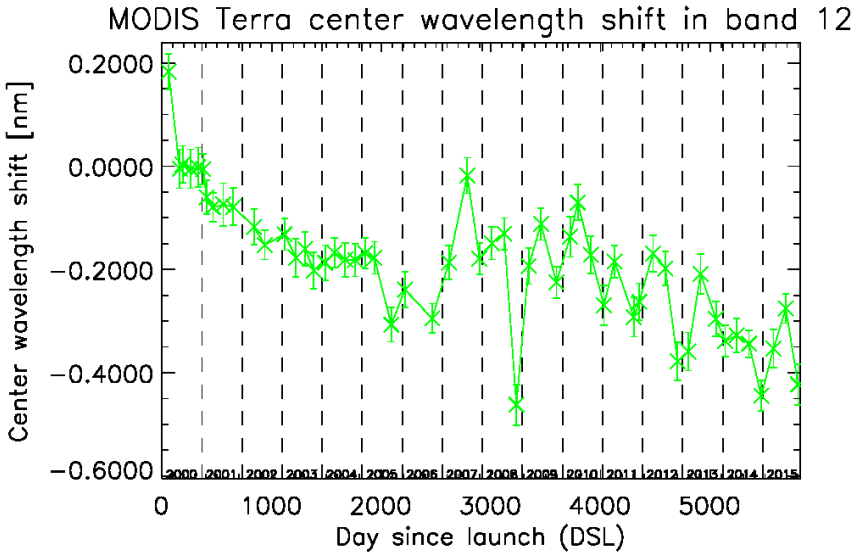
Center Wavelengths (CW) and Bandwidths (BW)

Spectral Performance (Terra changes in CW)

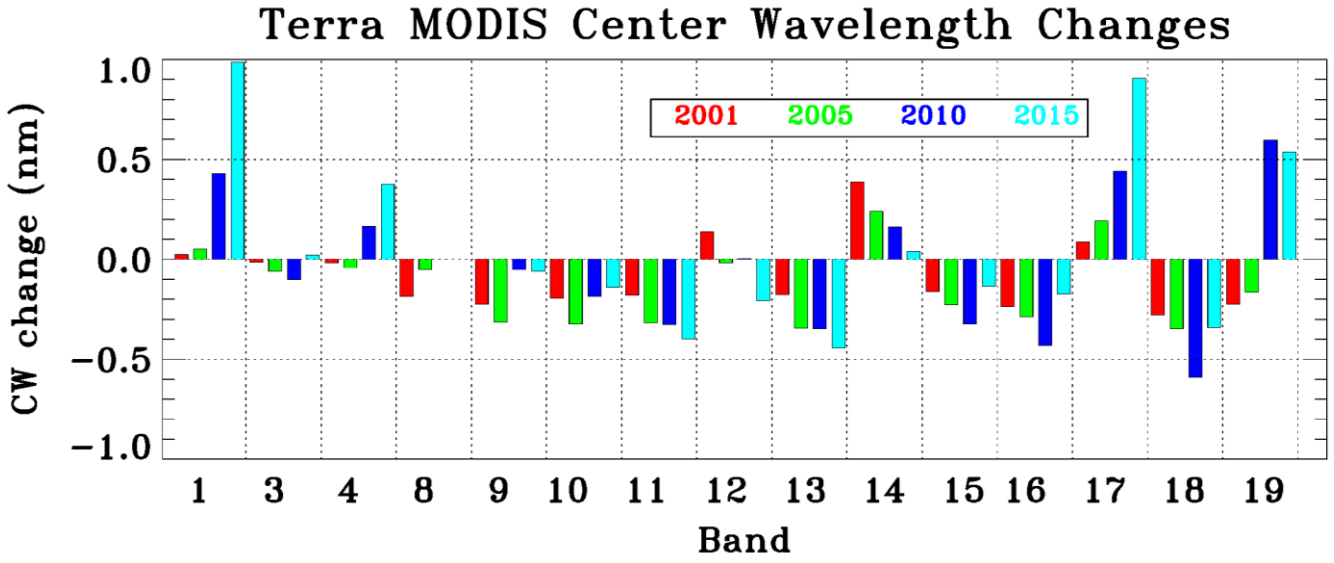


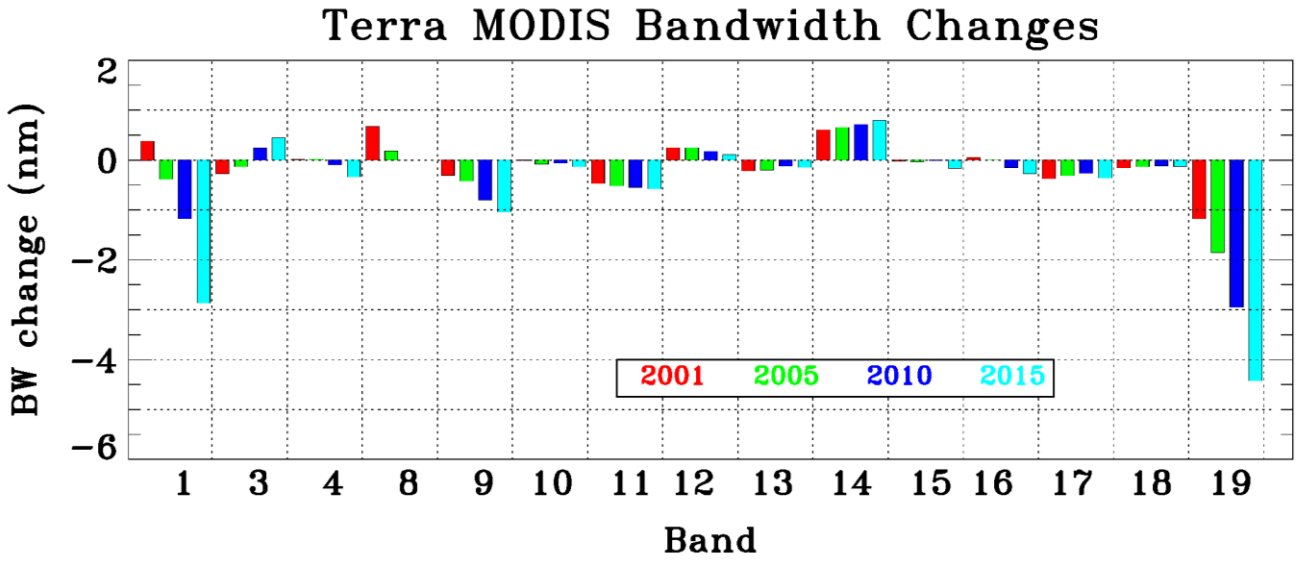






Spectral Performance (Terra CW and BW)

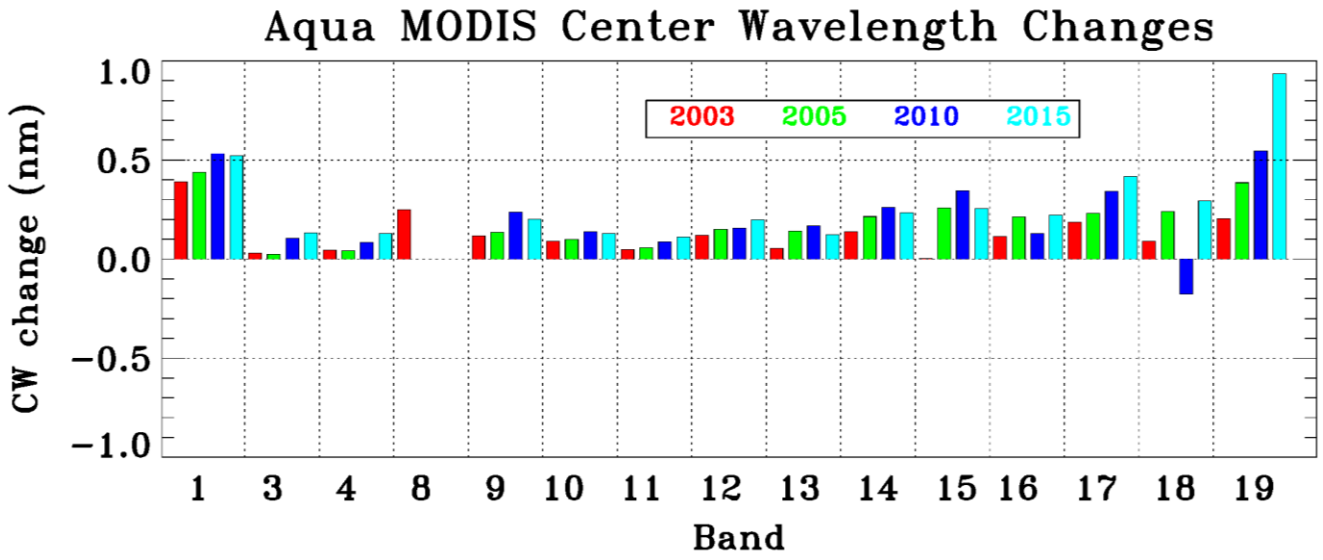


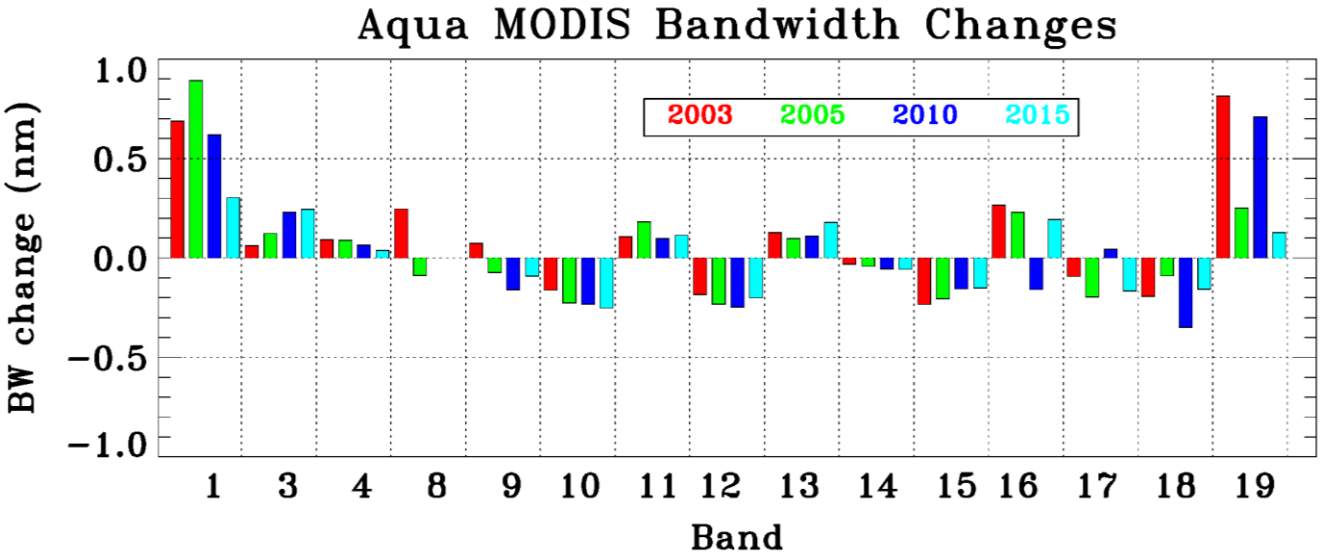


Changes in CW and are within 0.5 nm and 1.0 nm, respectively, for most VIS/NIR bands

Relatively large changes seen for bands with broad bandwidths (e.g. band 1 and 19)

Spectral Performance (Aqua CW and BW)





Changes in CW and are within 0.5 nm and 1.0 nm, respectively, for most VIS/NIR bands

Relatively large changes seen for bands with broad bandwidths (e.g. band 1 and 19)

Summary

- Terra and Aqua MODIS SRCA continue to operate and function (as good as expected)
  - Adjustments made to operation configuration due to loss of internal lamps
  - Sufficient margin in the expected lifetime for the remaining lamps
- Overall spatial and spectral performance remains stable
  - Terra BBR: within spec (±0.1 km) for all band pairs except for B30 and B32 in scan direction)
  - Aqua BBR: a known issue since pre-launch (same on-orbit)
  - MTF performance meets design requirements except for a few bands (Aqua)
  - Changes in CW and BW are within 0.5 nm and 1.0 nm, respectively, for most VIS/NIR bands (large for bands with broad bandwidths)
- Approaches developed using MODIS lunar observations (validated with SRCA) successfully applied to VIIRS
- Challenging issues and lessons

Challenging Issues and Lessons

- Use of SRAC data to improve sensor radiometric calibration
  - Radiometric mode (changes of internal calibration source): very useful for relative calibration
  - Use of on-board spectral and spatial performance parameters: justification/validation; uncertainty; …
- Lamp degradation
  - Different operation configurations - impact on radiometric stability monitoring
  - Impact of SNR for spectral calibration
- Lessons and benefits from MODIS SRCA design and operation
  - Radiometric calibration transfer (can be improved)
  - Sensor anomaly diagnosis and resolution
  - Development and validation of different calibration and characterization approaches