MODIS Reflective Solar Bands (RSB) Collection 6 Look Up Tables (LUT)

---Terra MODIS---

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- Introduction
  - Look Up Tables (LUT)
    - Calibration coefficients (m1)
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  - Algorithms and results
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  - Algorithms and results
  - EV reflectance comparison
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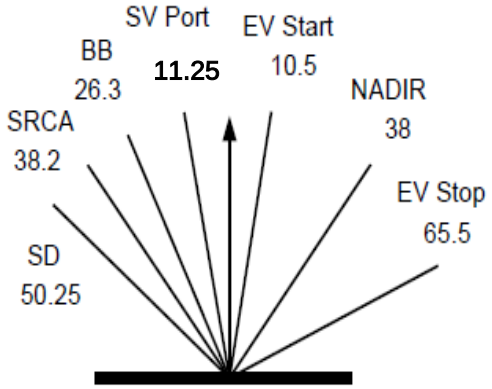
RSB m1 and RVS

- **EV Reflectance**

$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot d^2_{Earth\_Sun} \cdot dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst}) / RVS$$

- **LUT need to be updated for RSB**
  - m1: Inversely proportion to gain at the AOI of SD
  - RVS: Sensor Response versus Scan angle (normalized to SD view AOI to the scan mirror)
- **Calibration Source**
  - Lunar observation
  - SD/SDSM calibration
  - SRCA and EV mirror side (MS) ratios
  - Selected EV targets

MODIS scan mirror



Angle of Incidence (AOI)

RSB LUT History

- **m1 LUT Timeline**
  - Collection 2
    - Prelaunch calibration coefficients
  - Time-dependent m1 has been applied to MODIS RSB since Collection 3
  - Collection 3 – Collection 5
    - m1 generated using SD/SDSM calibration
  - Collection 6
    - m1 generated using SD/SDSM, lunar calibration and EV targets for Terra bands 1-4 and 8-9 and Aqua bands 8,9
    - m1 generated using SD/SDSM calibration for all other bands

RSB LUT History

- **RVS LUT Timeline**
  - Collection 2 – Collection 3
    - Prelaunch RVS
  - Time-dependent RVS has been applied to MODIS RSB since L1B Collection 4
  - Collection 4
    - Base on SD, lunar, and SRCA calibrations
    - Quadratic approximation for the AOI dependence of the RVS on-orbit variation
    - Applied to bands 3, 8 & 9
  - Collection 5
    - Based on SD and lunar calibration as well as SRCA and EV Mirror Side (MS) ratios for mirror side # 2 RVS
    - Linear and quadratic approximation for the AOI dependence for MS 1 and 2, respectively
    - Applied to all bands except SWIR (bands 5-7, 26) for both Terra and Aqua
  - Collection 6
    - Approach I based on calibrators for Terra bands 10-19 and Aqua 1-4 and 10-19
    - Approach II based on calibrators as well as desert sites for Terra bands 1-4, 8, 9 and Aqua bands 8, 9
    - No time-dependent RVS for SWIR bands

RSB LUT Summary

Terra

Version/Bands	Bands 1-4	Bands 5-7, 26	Bands 8-12	Bands 13-16	Bands 17-19
C4	m1/RVS^{pl}	m1/RVS^{pl}	m1/RVS***	m1/RVS^{pl}	m1/RVS^{pl}
C5	m1/RVS*	m1/RVS^{pl}	m1/RVS*	m1/RVS^{pl}	m1/RVS**
C6	m1^{EV}/RVS^{EV}	m1/RVS^{pl}	m1^{EV}/RVS^{EV} (B8,9) m1/RVS* (B10-12)	m1/RVS*	m1/RVS**

Aqua

Version/Bands	Bands 1-4	Bands 5-7, 26	Bands 8-12	Bands 13-16	Bands 17-19
C4	m1/RVS^{pl}	m1/RVS^{pl}	m1/RVS**	m1/RVS^{pl}	m1/RVS^{pl}
C5	m1/RVS**	m1/RVS^{pl}	m1/RVS**	m1/RVS^{pl}	m1/RVS**
C6	m1/RVS*	m1/RVS^{pl}	m1^{EV}/RVS^{EV} (B8,9) m1/RVS* (B10-12)	m1/RVS*	m1/RVS**

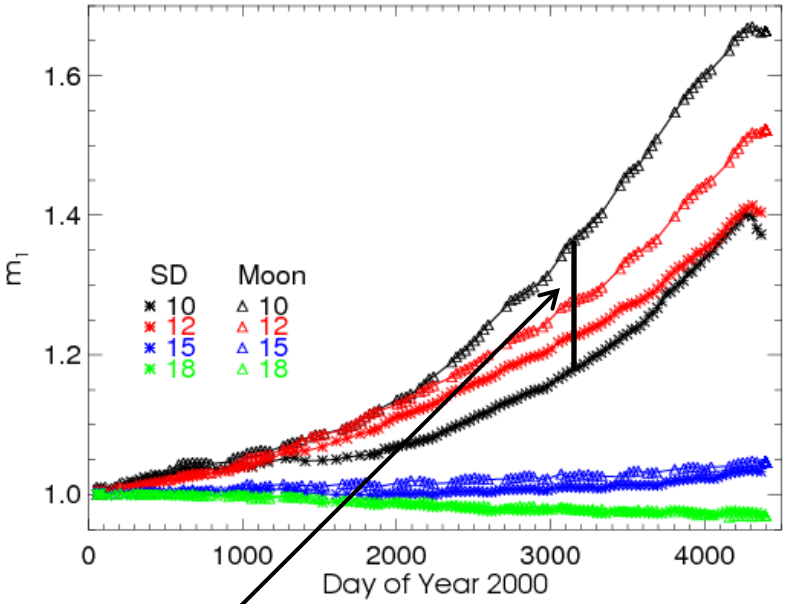
RVS ^{pl} : Pre-launch RVS
RVS* : Time-dependent RVS using SD and Moon for MS#1. MS#2 RVS derived using MS#1 as a reference and using EV and SRCA mirror side ratios.
RVS**: Time-dependent RVS using SD and Moon for both MS#2 (2-point RVS). On-orbit RVS applied since 08/10/2010 in C5 and for entire mission in C6.
RVS***: Time-dependent RVS using SD, SRCA and Moon for MS#1. MS#2 RVS derived using MS#1 as a reference
RVS^{EV}: Time-dependent RVS using the Moon and earth-scene measurements from pseudo-invariant desert targets at various AOI.
Additional correction for the SDSM D9 degradation has been applied to all bands except SWIR starting 01/01/2009.
Detector-dependent RVS applied for Bands 8-12 starting C6.

Approach I for C6 LUT

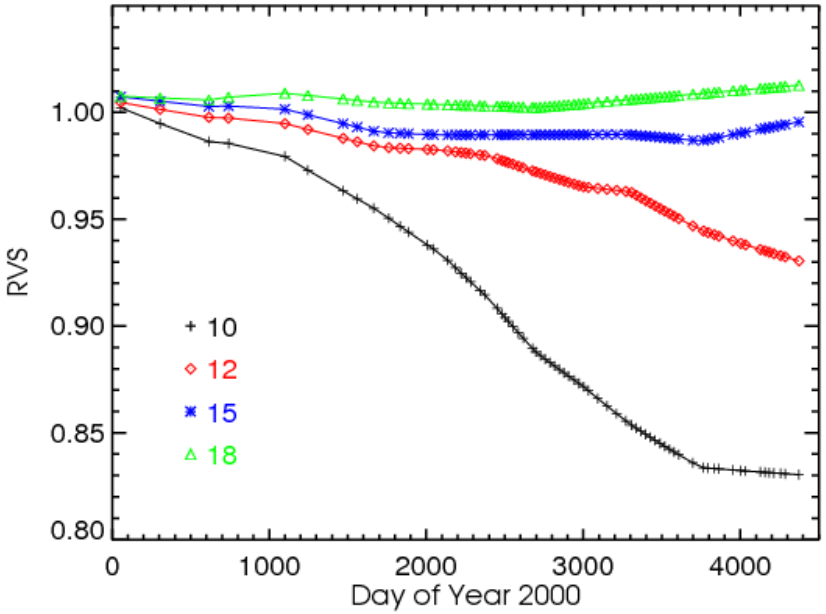
- m1 calibration coefficients generated from SD observations
- Mirror side 1 (MS1) RVS on-orbit variation is tracked using SD and lunar calibration coefficients with a linear approximation for its AOI dependence
- Mirror side 2 (MS2) RVS on-orbit variations calculated with MS1 as a reference and using mirror side ratios of sensor responses at multiple AOI (SD, Moon, EV, and SRCA) with a quadratic approximation for the AOI dependence.
- Applied to Terra bands 10-19 and Aqua bands 1-4 and 10-19
- No time-dependent RVS applied for SWIR bands
- Approach I is, in fact, the similar to C5 approach with the following improvements
  - RVS detector dependence for bands 10-12 for both instruments
  - Time-dependent RVS for bands 13-16
  - SD degradation at wavelength 936 nm measured by SDSM D9
  - Refit of the entire mission LUT

Terra MODIS RSB MS1 RVS

Band averaged m1 from SD and lunar calibration mirror side 1 of Terra MODIS bands 10,12,15 and 18



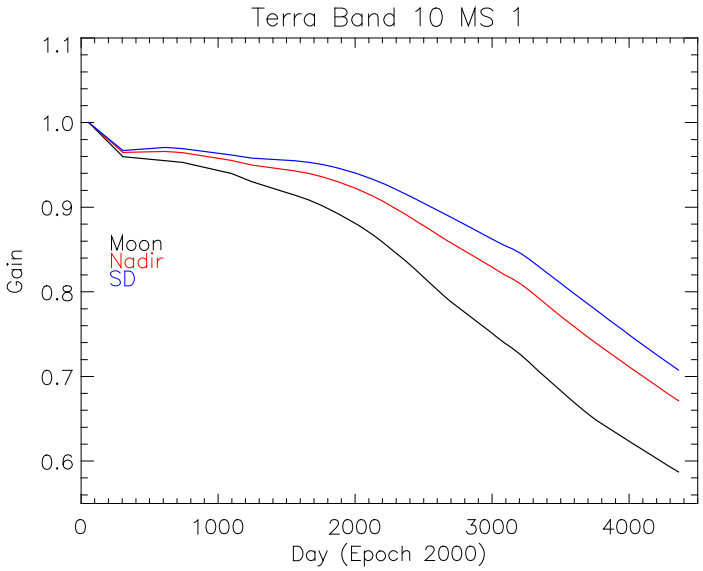
Band averaged RVS at the SV AOI for Terra bands 10,12,15 and 18 MS1.



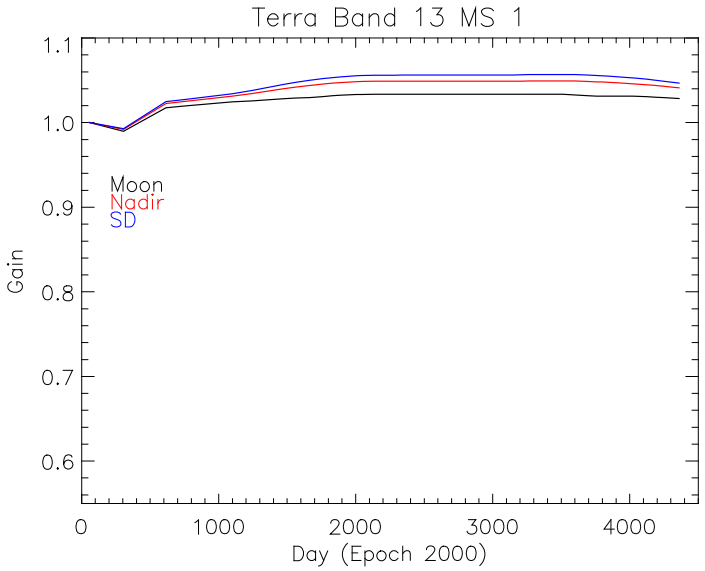
Difference between SD & lunar m1with time => RVS change
Shorter wavelengths show greater change

Terra MODIS RSB MS1 RVS

Band 10 RVS/m1 (gain) at different AOI



Band 13 RVS/m1 (gain) at different AOI



L1B derived from:

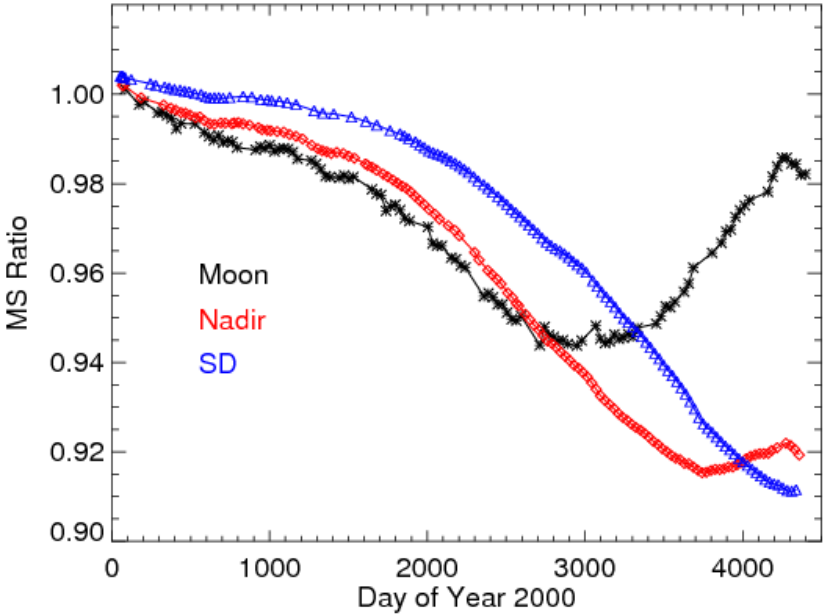
$$\rho_{EV} \cdot \cos(\theta_{EV}) = (m_1 / RVS) \cdot dn_{EV} \cdot d^2_{Earth\_Sun} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})$$

LUTs

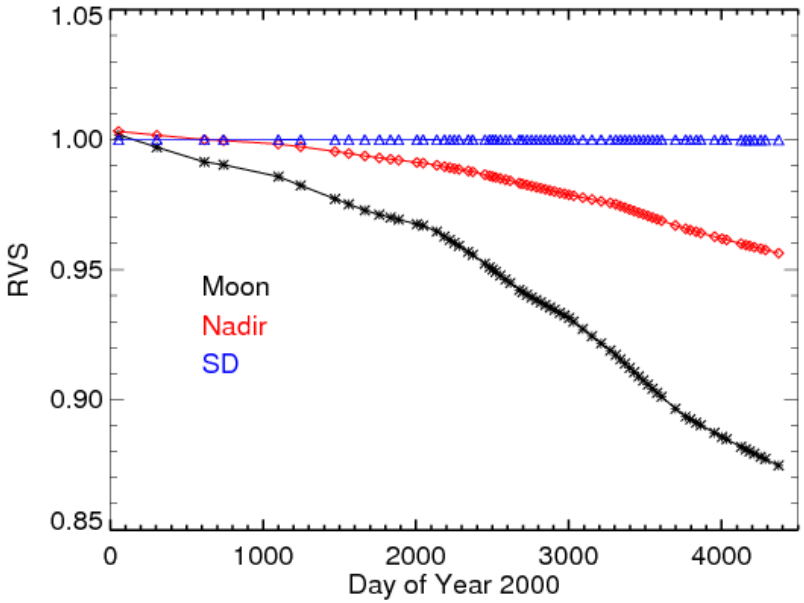
Constant with AOI

Terra MODIS RSB MS2 RVS

Band 10 mirror side differences

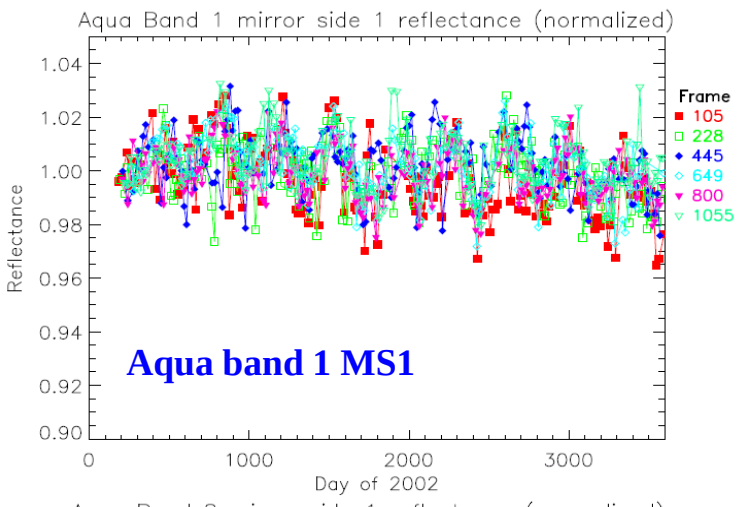


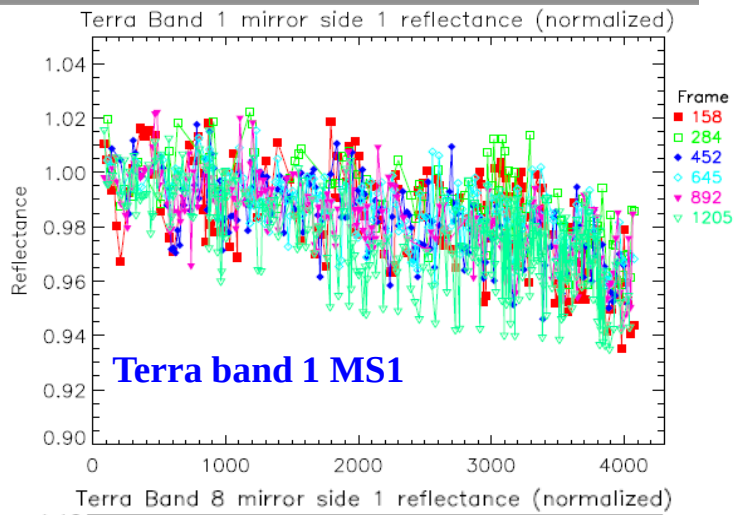
Terra Band 10 mirror side 2 RVS trending at different AOI

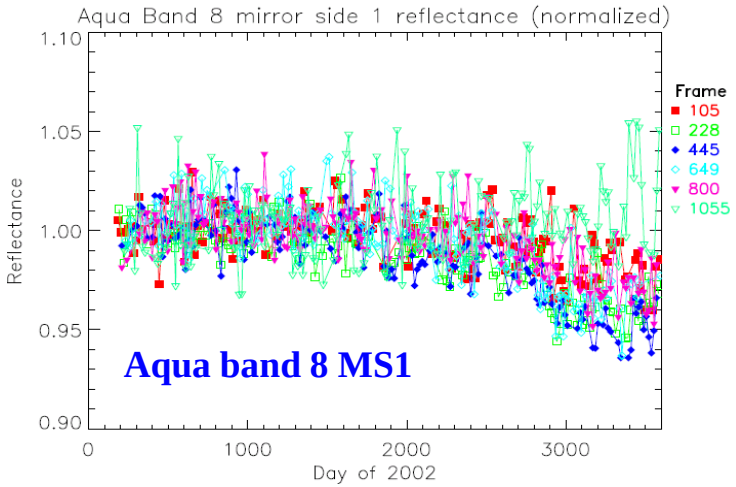


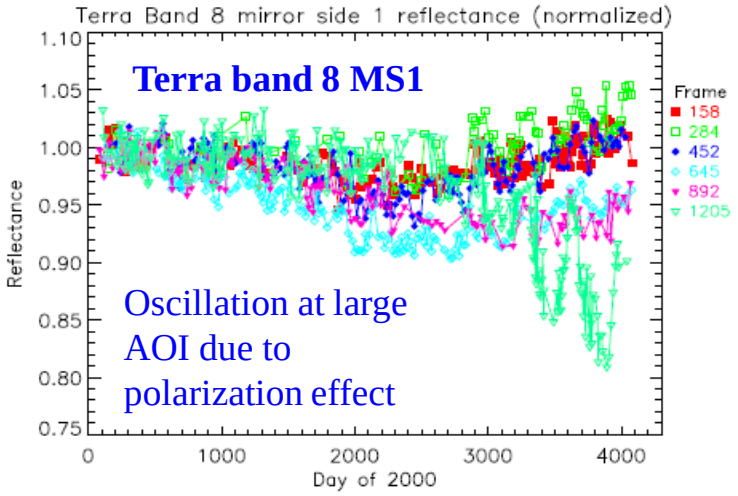
- MS ratio changes with AOI & time
- Smaller AOI show largest change in RVS

EV Reflectance Using App. I LUT









- Assumption: EV reflectance trending (L1B) over selected desert sites expected to show minimal drift over time
- Drifts observed in Terra bands 8, 9 & 1-4 indicate Approach I not sufficiently capturing on-orbit changes in m1 and RVS

Approach II for C6 LUT

- m1 and RVS are generated using the lunar calibration, SD calibration (absolute calibration at beginning of the mission), and sensor EV responses trending at multiple AOIs
- Desert Sites
  - *Sites: Mauritania 1, Mali 1, Algeria 1, Algeria 3, Niger 1,* ***Libya 1****,* ***Libya 2****,* ***Libya 4****, Egypt 1, Sudan 1, Yemen Desert 1, Arabia 2*
  - *Detail information for these sites:* *http://calval.cr.usgs.gov/sites_catalog_map.php*
  - *Earth-Sun distance, Cosine, and BRDF corrections*
- Applied to Terra bands 1-4 and 8-9 and Aqua bands 8-9
- Detector dependency is applied to bands 8-9 RVS for both instruments

Approach II Algorithms

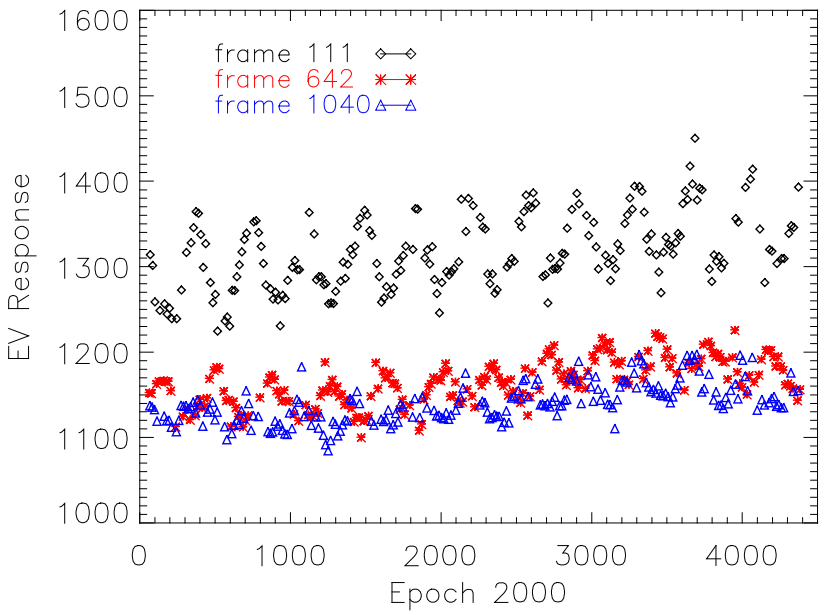
- **Lunar view response and Earth view responses at selected AOIs**
  - Terra Frames: 17 (lunar), 38, 111, 146, 225, 325, 450, 583, 642, 745, 890, 1040, 1134, 1329
  - Aqua Frames are slightly different from those of Terra
  - For each AOI, the instrument response is fitted to smoothly connected analytical functions
- **Detector-averaged m1 and RVS on-orbit variation**
  - The fitted smooth functions are normalized to the time when the nadir door was first opened
  - For any time t, the RVS on-orbit variation for a given band and mirror side is determined by fitting the values of the functions of the band and mirror side to fourth-order polynomial (Terra bands 8, 9, 3 & 4) /quadratic form (Terra bands 1-2)
  - Constraint fitting to pass through the on-board lunar measurement for all Approach II bands except Bands 1 and 2
  - The inverse of the fitted polynomial at AOI of the SD is the detector-averaged m1 on-orbit variation
  - The polynomial normalized by the m1 above is the detector-averaged RVS on-orbit variation
- **Detector-averaged RVS**

$$m1(B,M,t) = m1(B,M,t_0)m1^{oo}(B,M,t)$$

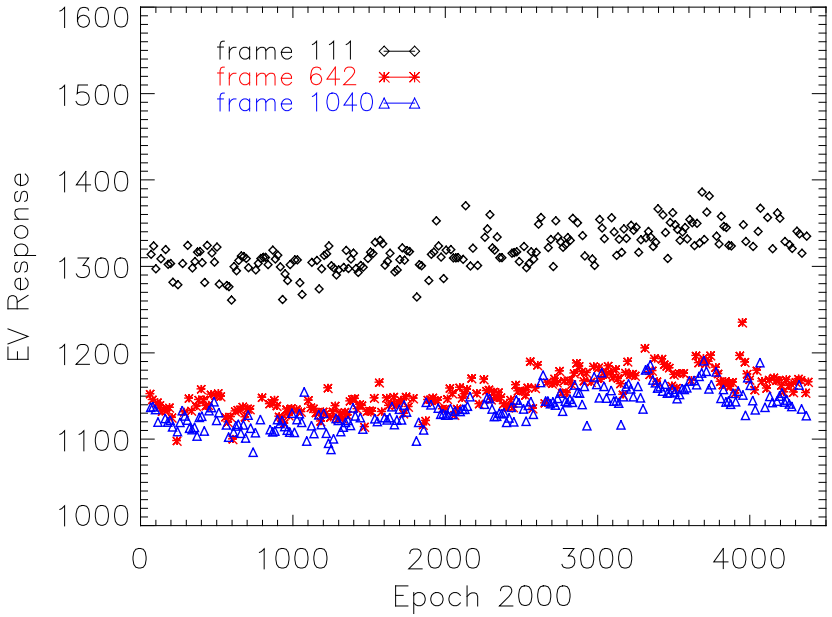
$$RVS(B,M,\theta,t) = RVS^{pl}(B,M,\theta)RVS^{oo}(B,M,\theta,t)$$

- **Detector dependent m1 and RVS**
  - Both m1 and RVS detector differences are the same as those derived in approach I
  - RVS is fitted to a quartic to all Approach II bands except Terra bands 1 & 2 (quadratic)

BRDF Correction



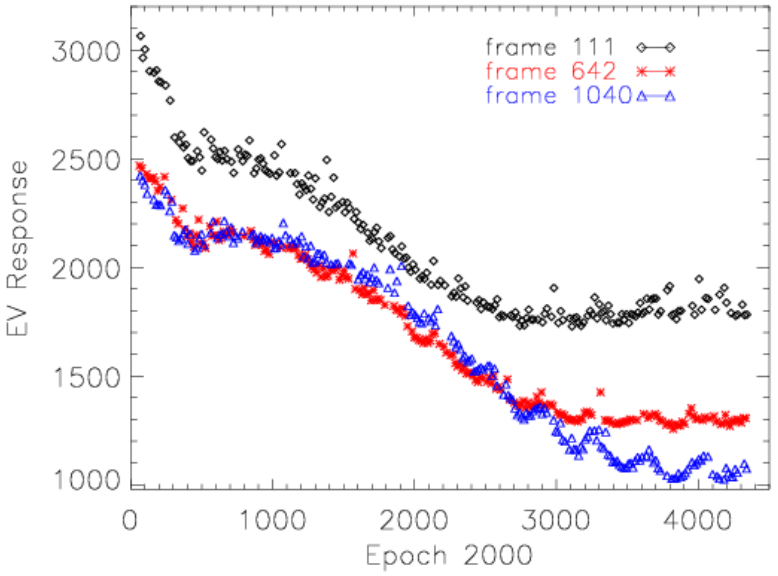
EV response for Terra MODIS band 1 mirror side 1 before BRDF correction



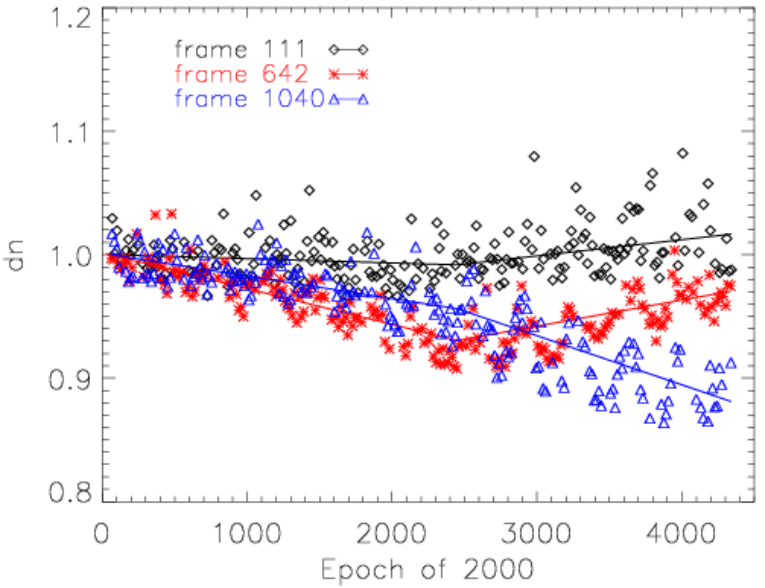
EV response for Terra MODIS band 1 mirror side 1 after BRDF correction

A semi-empirical BRDF model developed by Roujean et al is used to perform the BRDF correction.

Time Dependency Fitting

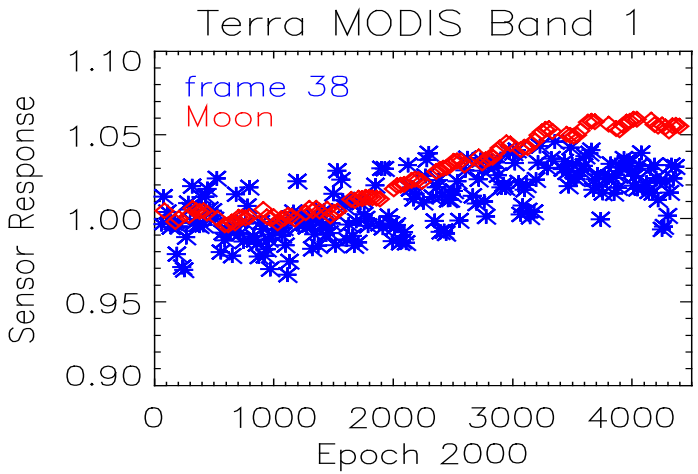


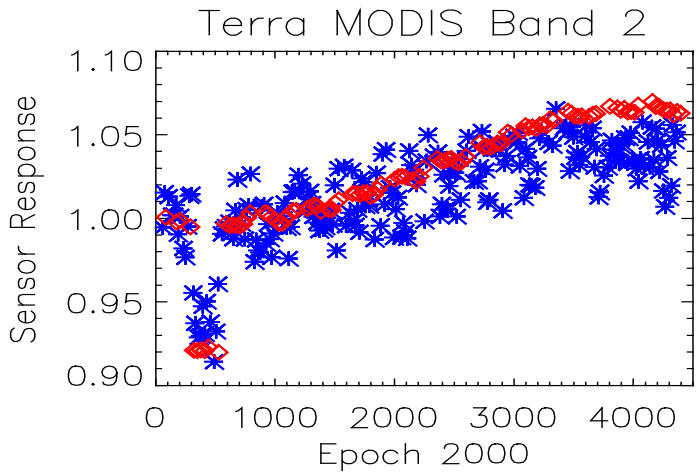
EV response for Terra MODIS band 8 mirror side 1 after BRDF correction

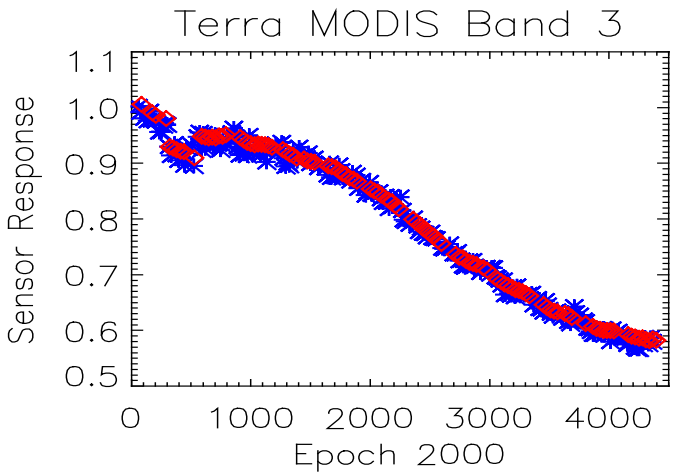


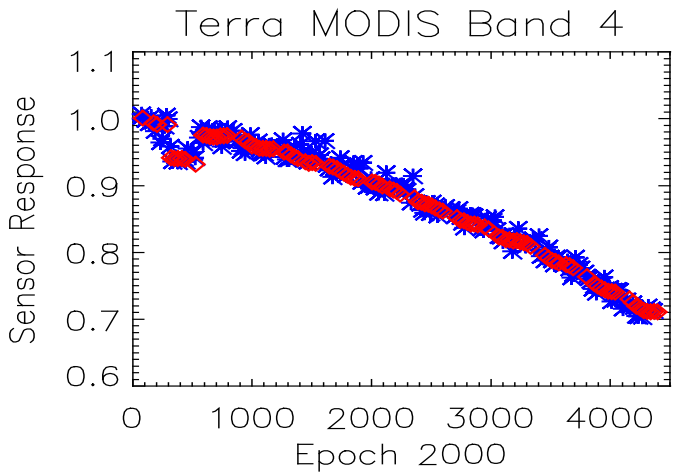
EV response divided by App. I m1/RVS and normalized at time of nadir door opening

Lunar and EV Response Trending

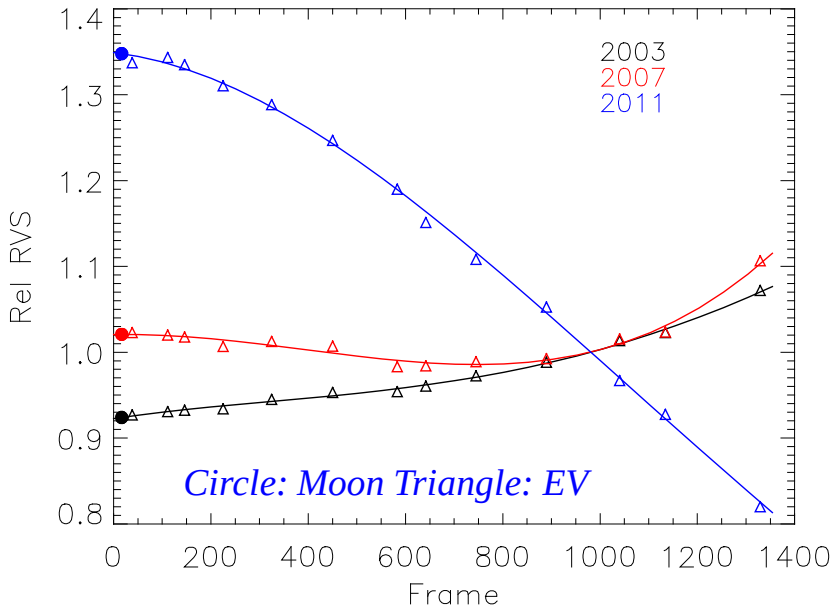




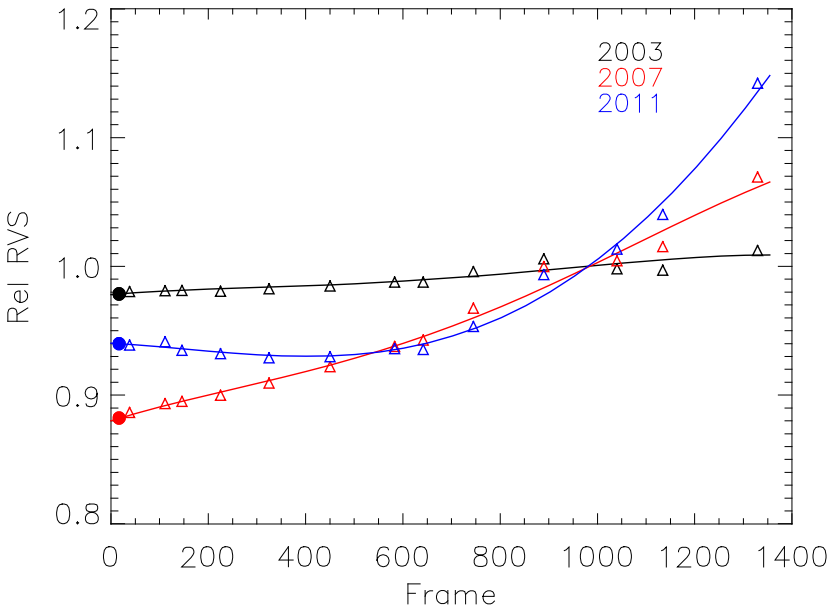




AOI Fitting



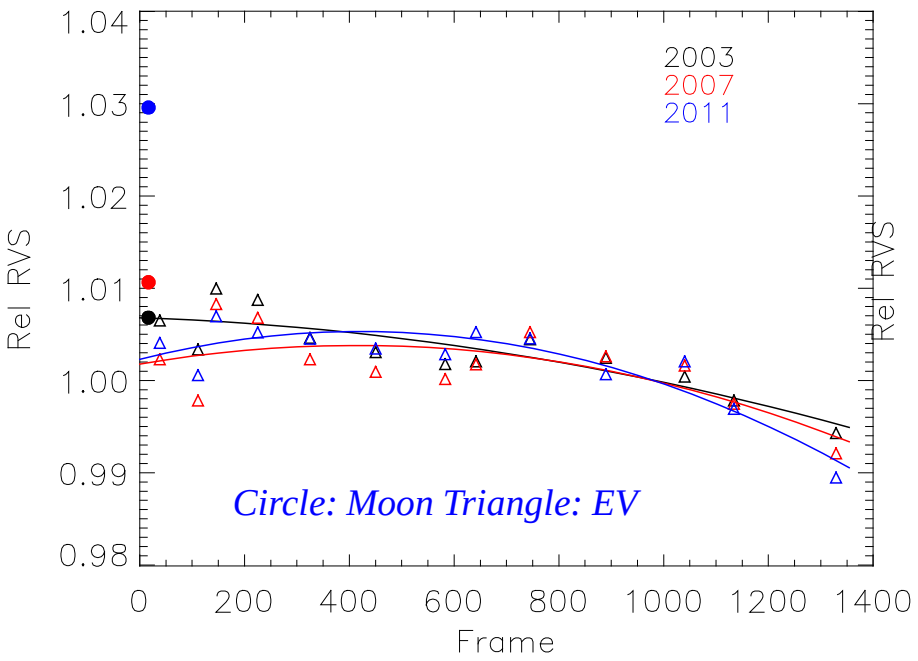
RVS on-orbit variation for Terra MODIS Band 8 Mirror Side 1



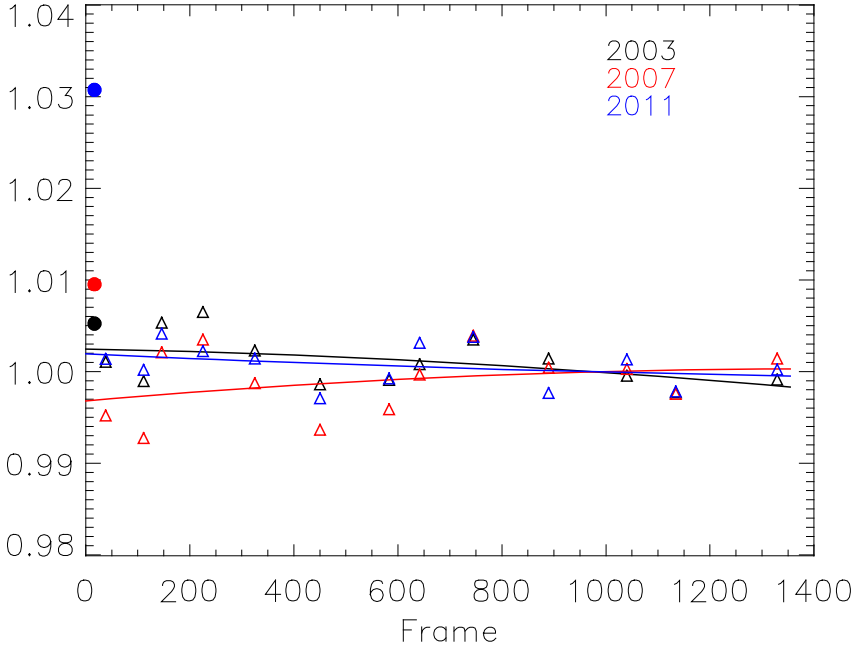
RVS on-orbit variation for Terra MODIS Band 3 Mirror Side 1

A quartic polynomial is applied to fit the response trending at each selected time for the AOI dependence

AOI Fitting



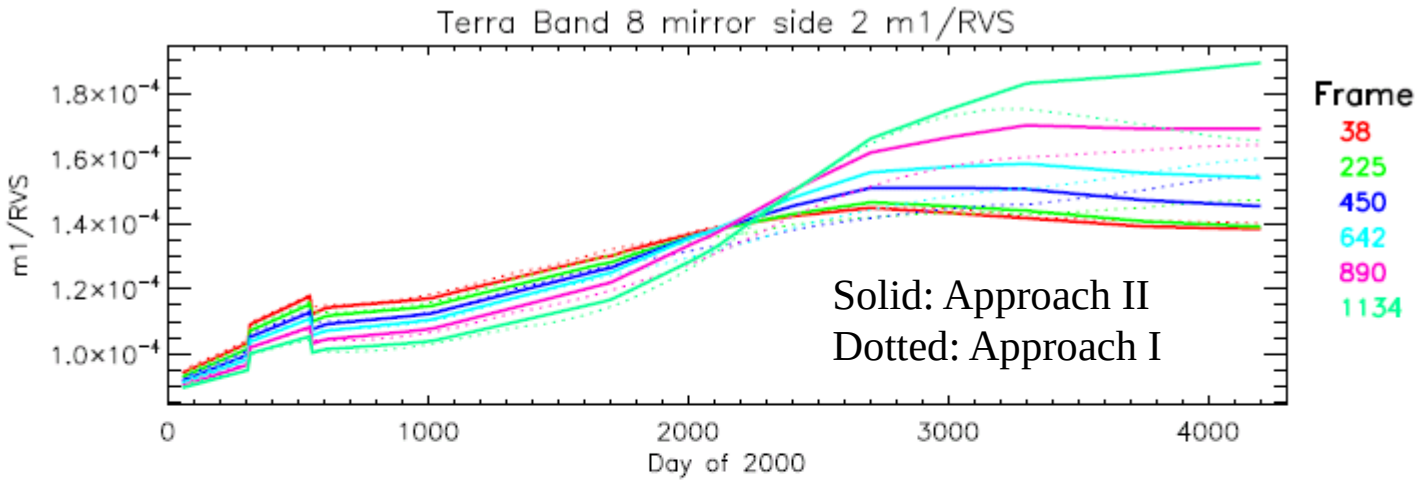
Relative RVS for Terra MODIS Band 1 Mirror Side 1

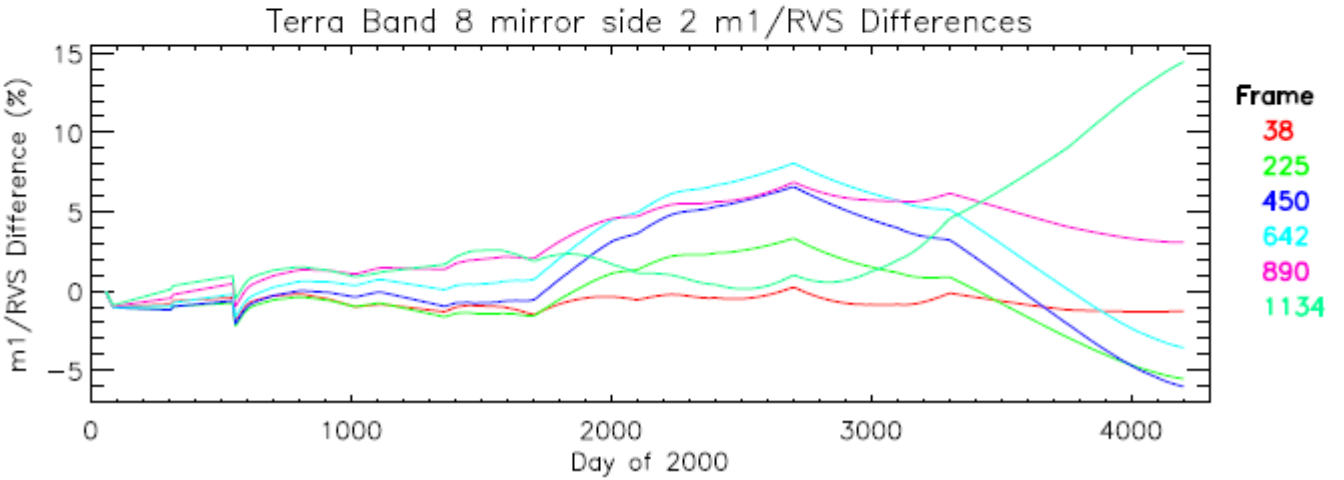


Relative RVS for Terra MODIS Band 2 Mirror Side 1

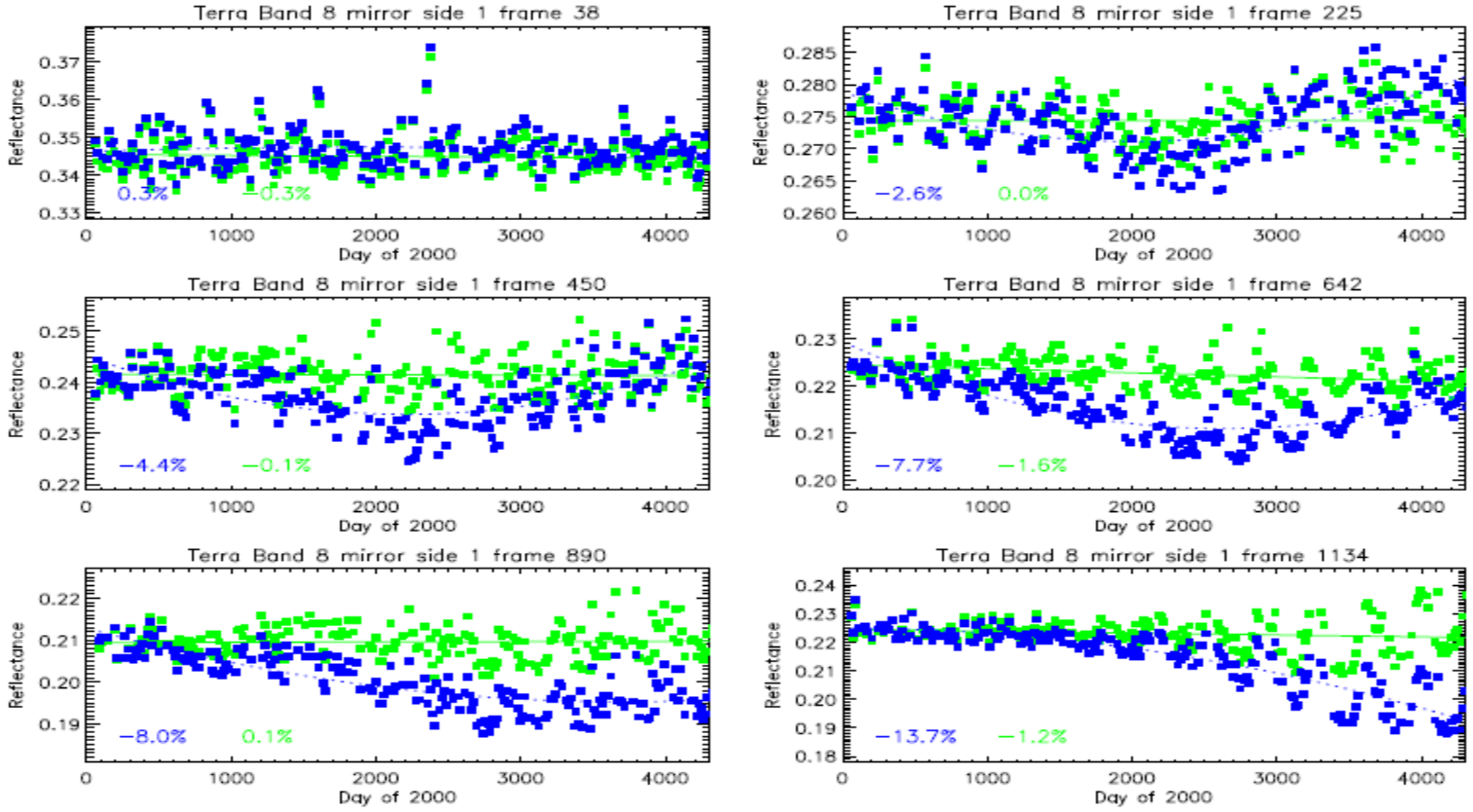
A quadratic form is applied to fit the response trending at each selected time for the AOI dependence

Terra V6 m1 and RVS LUTs





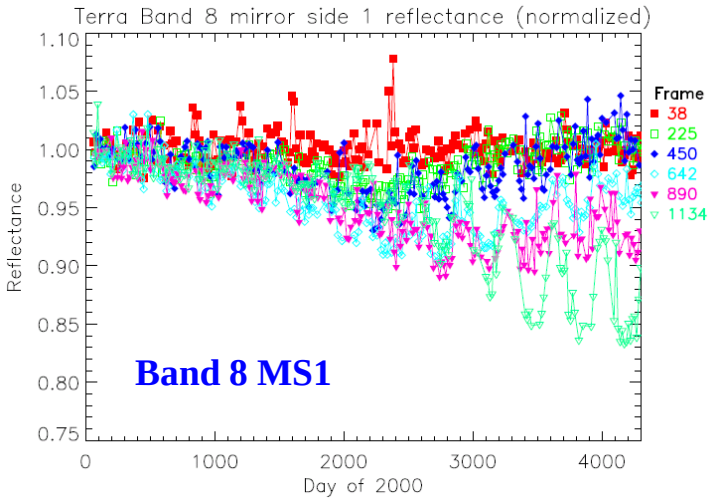
Terra EV Reflectance

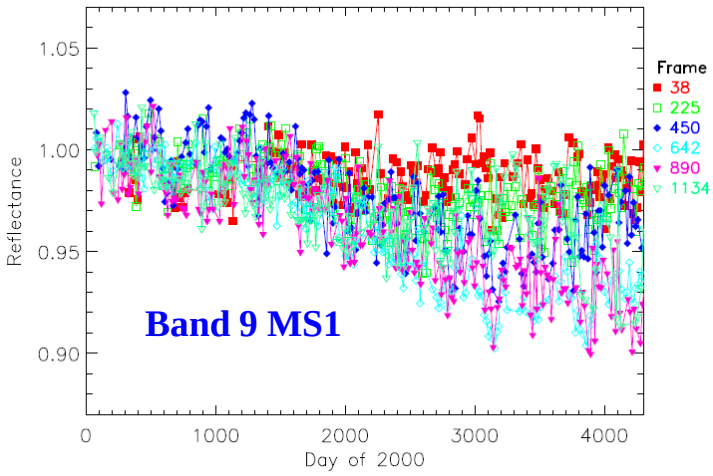


Green: LUTs with EV correction; Blue: LUTs without EV correction

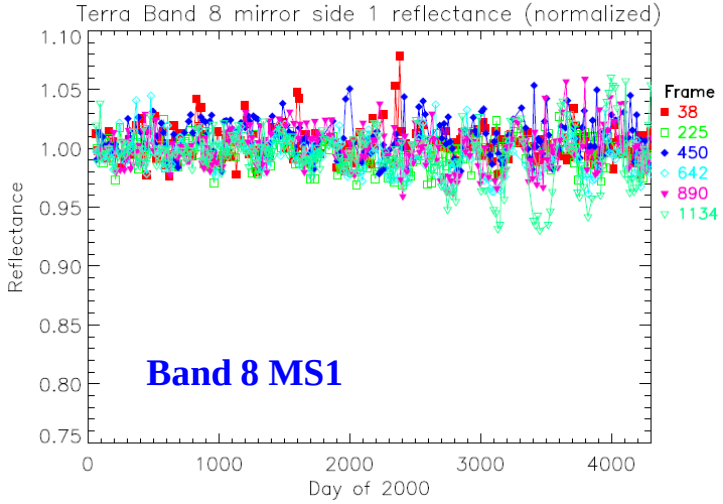
Terra EV Reflectance

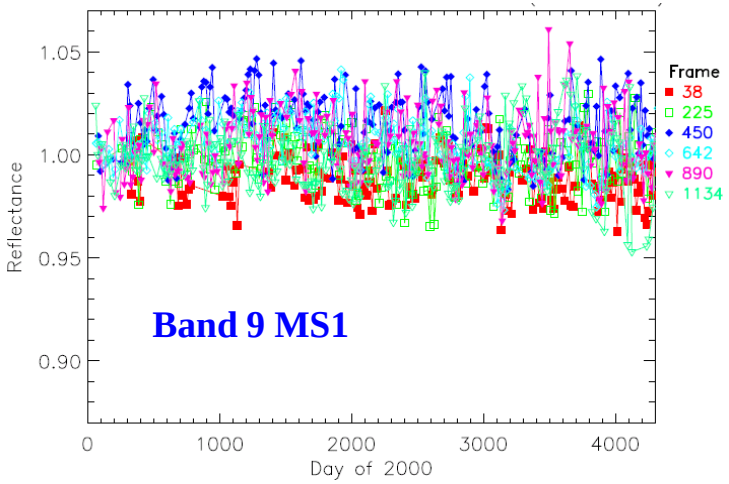
Approach I





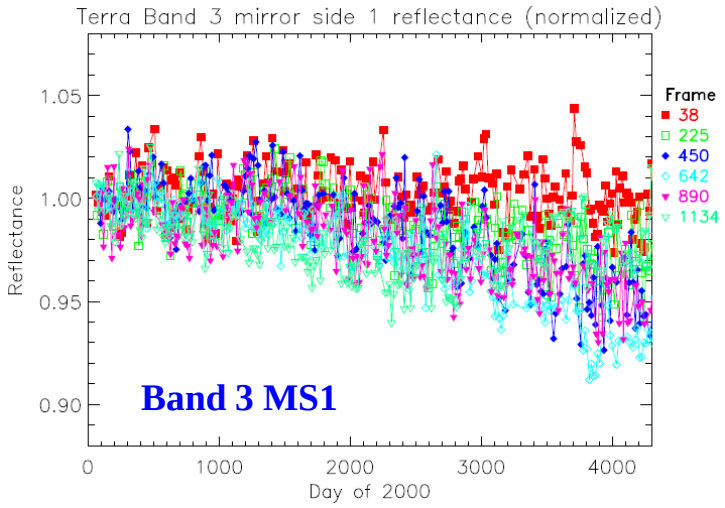
Approach II

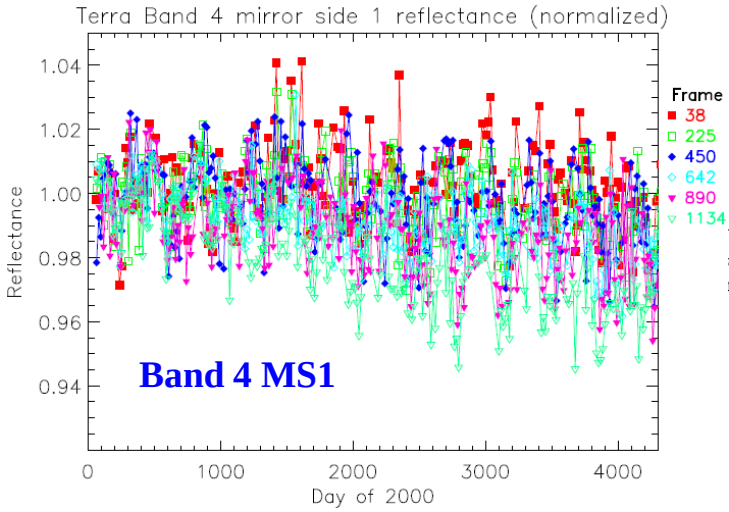




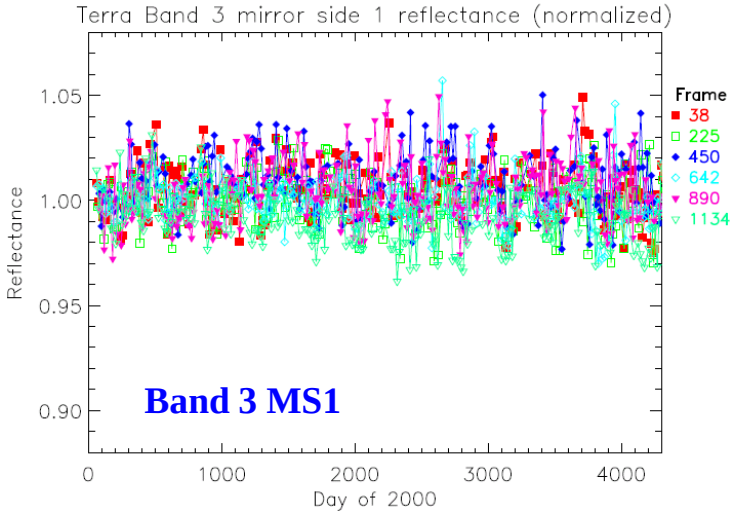
Terra EV Reflectance

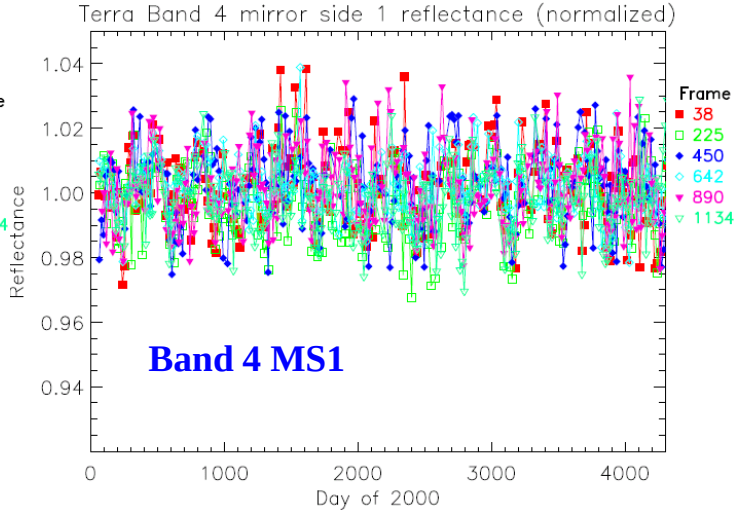
Approach I





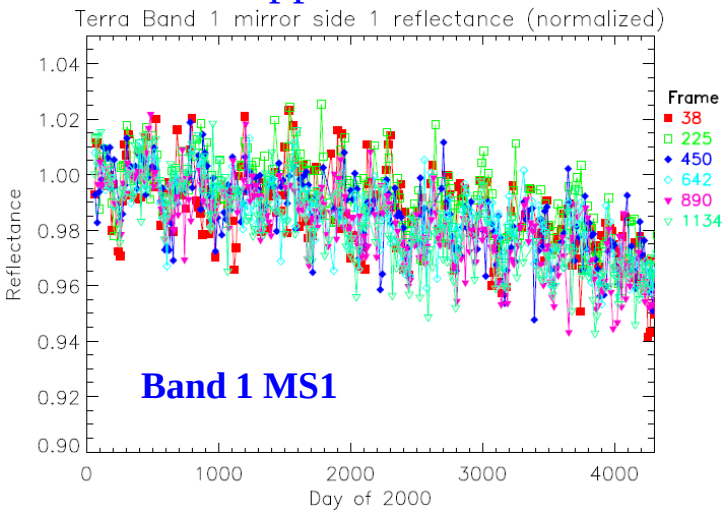
Approach II

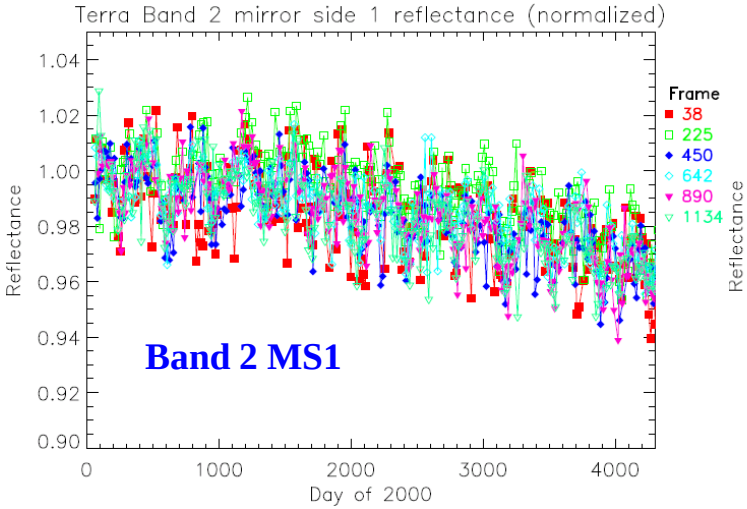




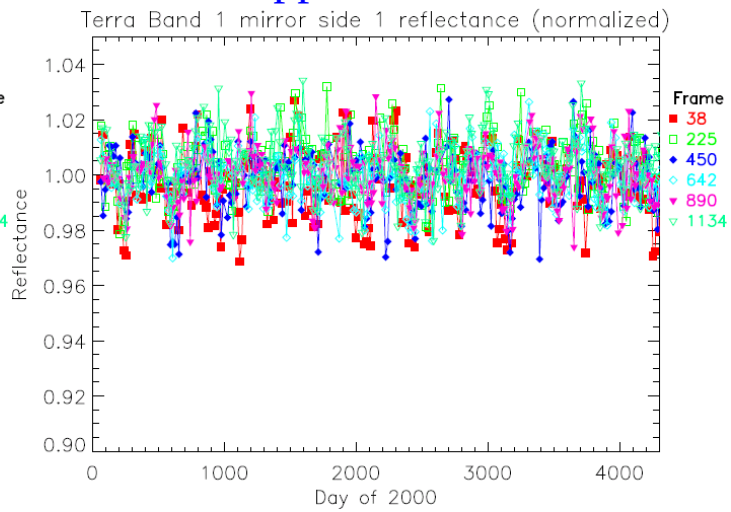
Terra EV Reflectance

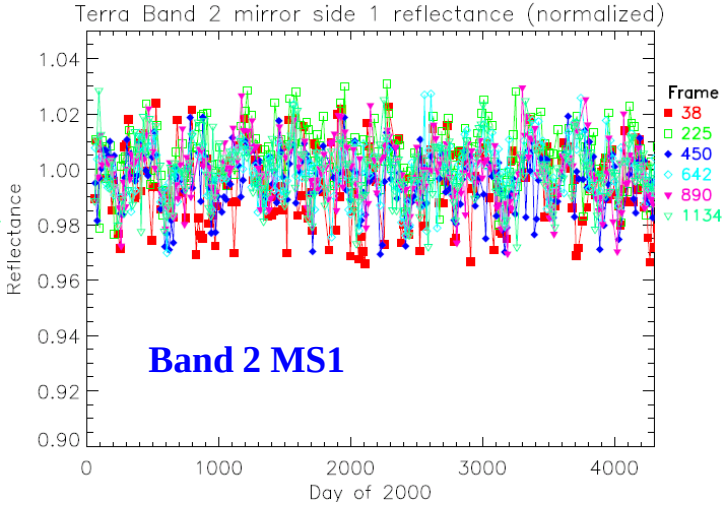
Approach I





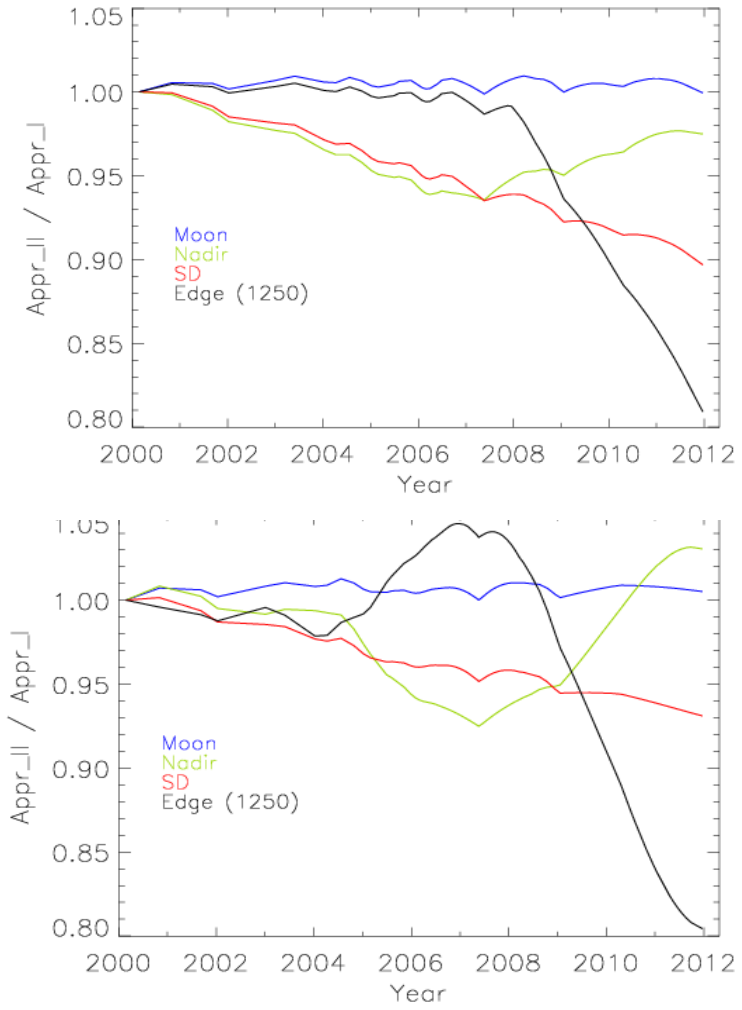
Approach II



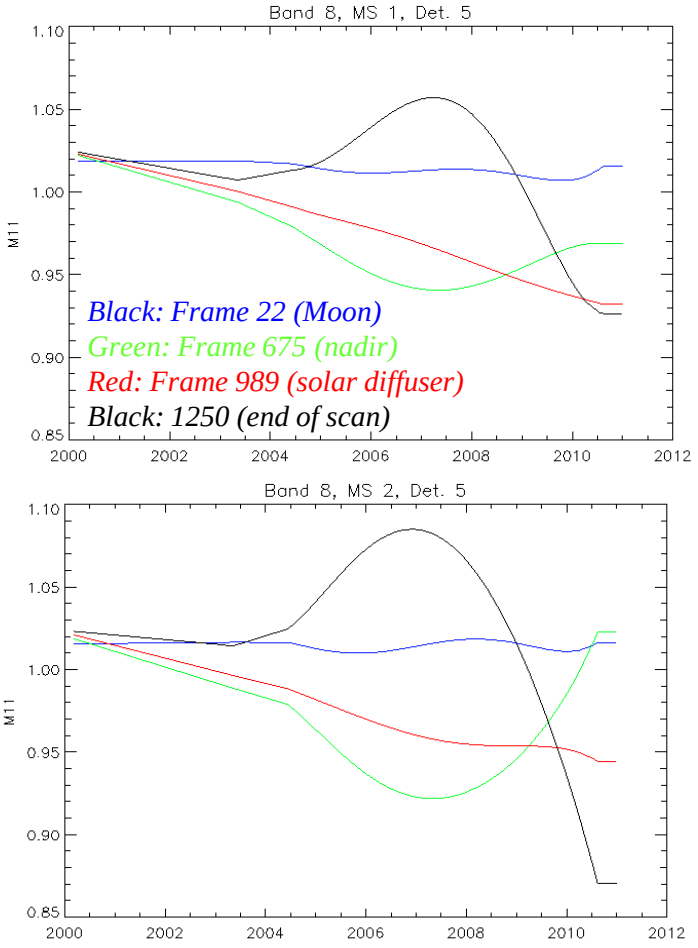


Approach II and OBPG Correction Comparison

Approach I and II difference



OBPG Correction to Approach I



OBPG results provided by Gerhard Meister

Summary and Challenges

- **Two approaches are developed to generate MODIS C6 RSB m1 and RVS LUT**
- **Approach I based on SD and lunar observations, and SRCA and EV response mirror side ratios with a linear approximation for the AOI dependence of the RVS for MS 1**
  - Aqua bands 1-4 and 10-19
  - Terra bands 10-19 and 26
- **Approach II is based on lunar observations and EV response trending at selected AOI in addition to the SD measurements for absolute calibration at the start of the mission**
  - Aqua bands 8-9
  - Terra bands 1-4 and 8-9
- **Improvements compared to C5**
  - Detector dependent RVS for bands 8-12
  - Time-dependent RVS applied to bands 13-16
  - Long-term drifts observed in Aqua bands 8-9 and Terra bands 1-4 and 8-9 significantly reduced
- **Challenges**
  - Polarization
  - Low instrument response in SD calibration, especially for short wavelength bands
  - Large noise in EV response
  - Ageing instruments: Terra 12 years, Aqua 9.5 years
  - Recent observed gain rapid changes in Aqua short-wavelength bands and Terra NIR bands

Backup

C6 Approach I Formula

- **RVS is characterized by prelaunch measurement and on-orbit variation**

$$RVS(B,D,M,\theta,t) = RVS^{pl}(B,M,\theta)RVS^{oo}(B,D,M,\theta,t)$$

  - *B, D, M, θ and t represent band, detector, mirror side, AOI and time*
  - *pl: prelaunch; oo: on-orbit.*

- **RVS on-orbit variation at AOI of the SV**

$$RVS^{oo}(B,D,M,\theta_{SV},t) = \frac{m_1^{moon}(B,D,M,t_0)m_1(B,D,M,t)}{m_1^{moon}(B,D,M,t)m_1(B,D,M,t_0)}$$

- **Mirror side one RVS on-orbit variation – a linear function of AOI**

$$RVS^{oo}(B,D,1,\theta,t) = 1 + \frac{\theta-\theta_{SD}}{\theta_{SV}-\theta_{SD}}\left[RVS^{oo}(B,D,1,\theta_{SV},t)-1\right]$$

- **Mirror side two RVS**

$$RVS(B,D,2,\theta,t) = \frac{dn(B,D,2,\theta,t)}{dn(B,D,1,\theta,t)}\frac{m_1(B,D,1,t)}{m_1(B,D,2,t)}RVS(B,D,1,\theta,t)$$

  - *Instrument response mirror side ratio is obtained from SD, lunar, SRCA, and EV observations*

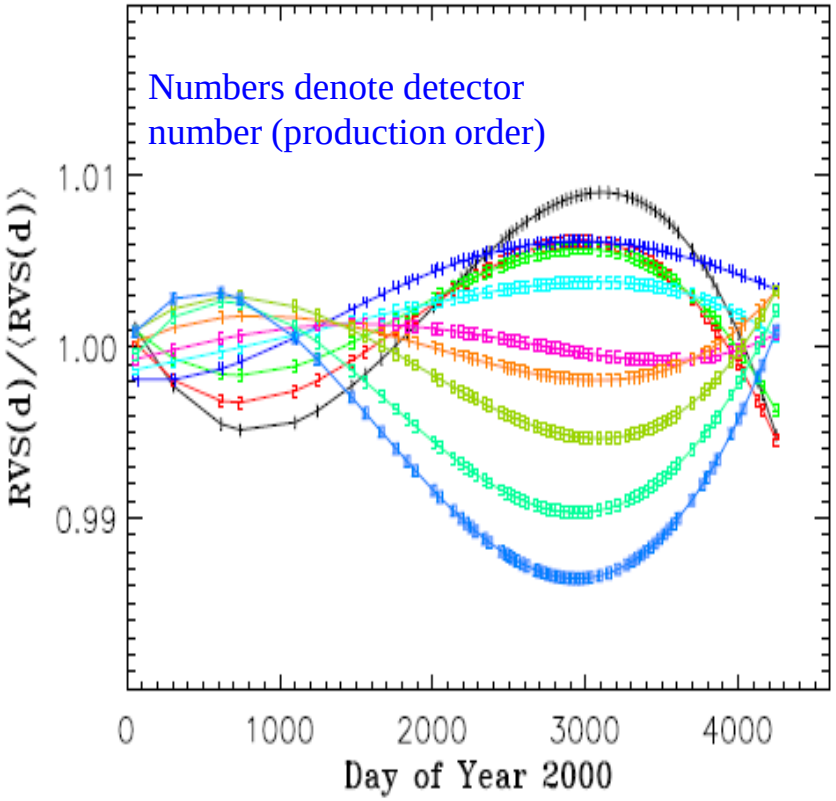
- **The calculated RVS is fitted to a quadratic form of the frame, and the fitted coefficients form a time dependent Look-Up Table (LUT) for MODIS RSB RVS**

$$RVS^{L1B}(F,t) = c_0(t) + c_1(t)F + c_2(t)F^2$$

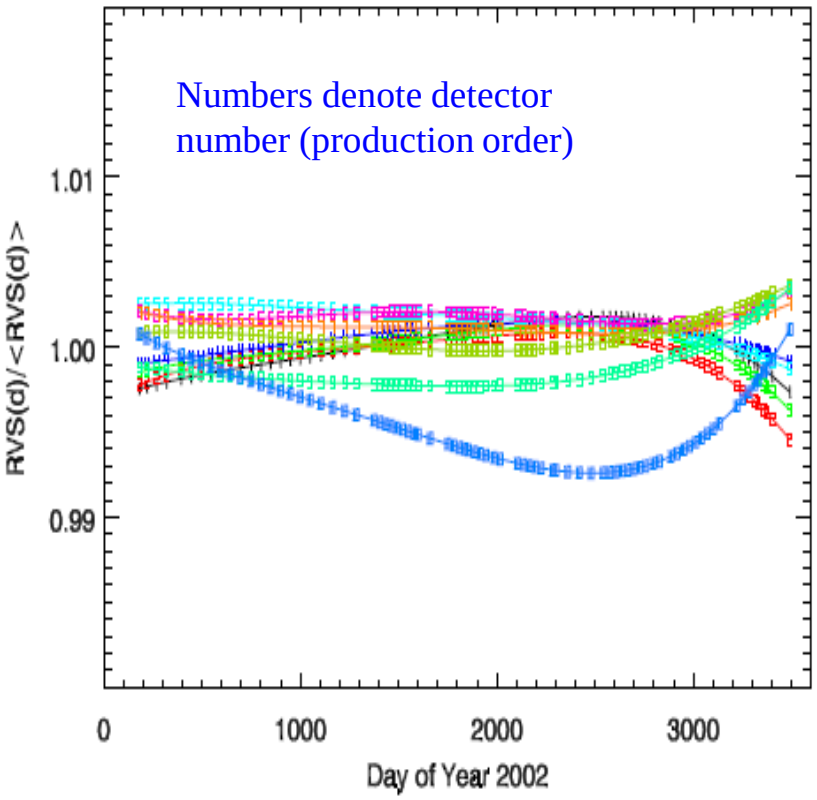
  - *F: Frame, which is related to AOI by*

$$\theta = 55F/1353 + 10.5$$

RVS Detector Difference



RVS detector difference for Terra band 8 MS1.



RVS detector difference for Aqua band 8 MS1.

EV Reflectance Detector Difference