Suomi NPP VIIRS Reflective Solar Band (RSB) Calibration Stability Assessments

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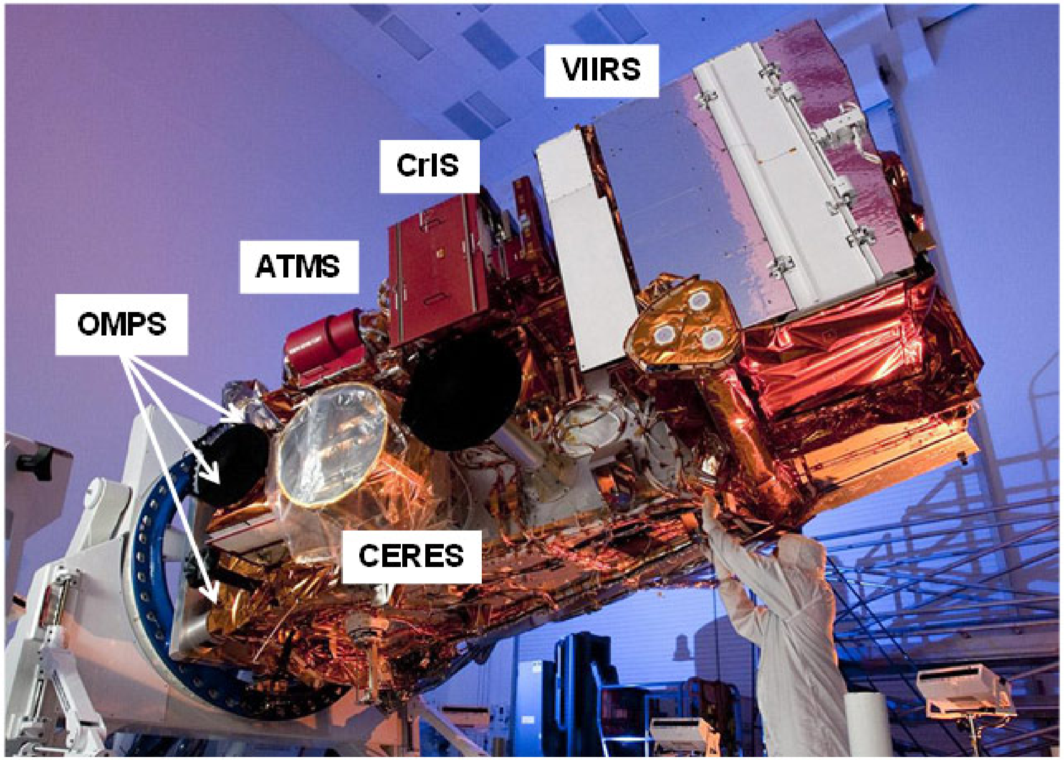
Outline

- Introduction
  - About S-NPP VIIRS
- RSB calibration
  - RSB F/H factors
  - Lunar F-factor
- Results
  - VIIRS Reflective Solar Band (RSB) Look-Up Tables (LUTs)
    - NOAA VIIRS SDR team RSBAutoCal vs. NASA VCST LUTs
  - Lunar F-factors
  - Solar Diffuser F-factor correction using lunar F-factors
  - Validation Example
- Summary

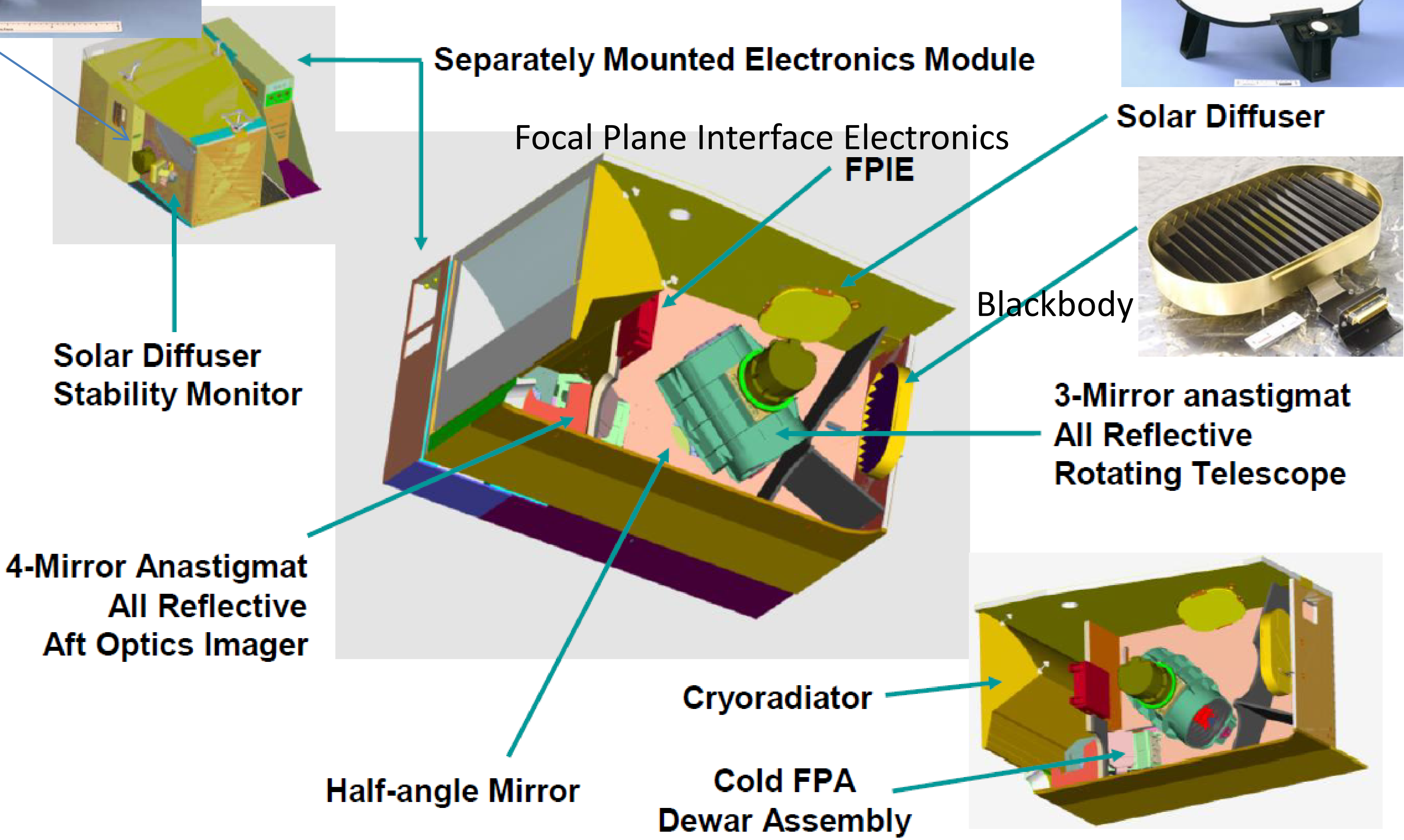
The Suomi National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS)

- Descriptions of S-NPP VIIRS
  - A whiskbroom scanning radiometer
  - Sun synchronous orbit
  - Field of view of 112.56^{o}
  - Nominal altitude of 829 km
  - A large scan coverage of 3060 km
  - Equator crossing local time of approximately 1:30 pm
  - 22 spectral bands covering a spectral range of 412nm to 12 μm.



From ICVS webpage
http://www.star.nesdis.noaa.gov/icvs/index.php

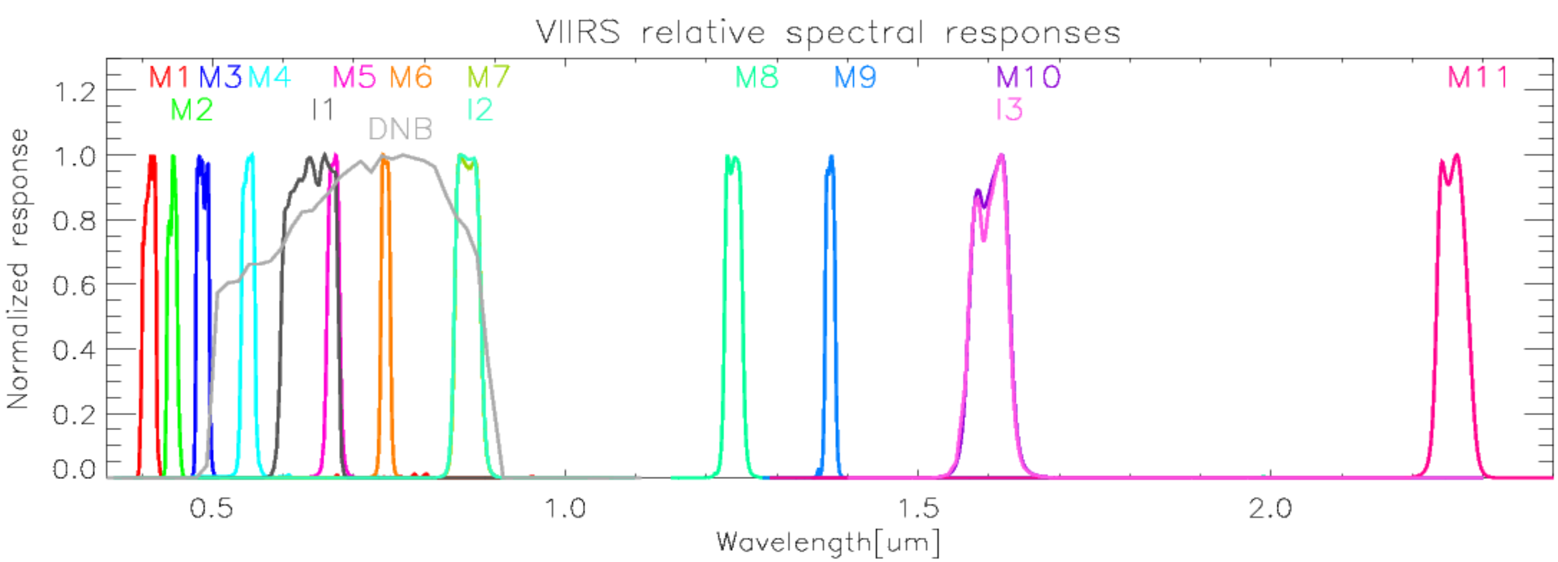
Introduction



From VIIRS Radiometric ATBD.

Introduction

- Spectral Responses of the VIIRS RSB
  - RSB cover a spectral range from 412nm to 2.25 μm.
  - There are 14 RSB with 3 image bands (I1-I3) and 11 moderate bands (M1-M11).
  - RSB band calibration is dependent on Solar Diffuser (SD) and Solar Diffuser Stability Monitor (SDSM) observations.
  - The required RSB calibration uncertainty is 2 percent.
    - Ocean Color group wants 0.2 percent level.



RSB Calibration: SD F-factor

- The RSB F-factor is just a ratio of computed sun radiance from SD over observed SD radiance from the VIIRS detectors.

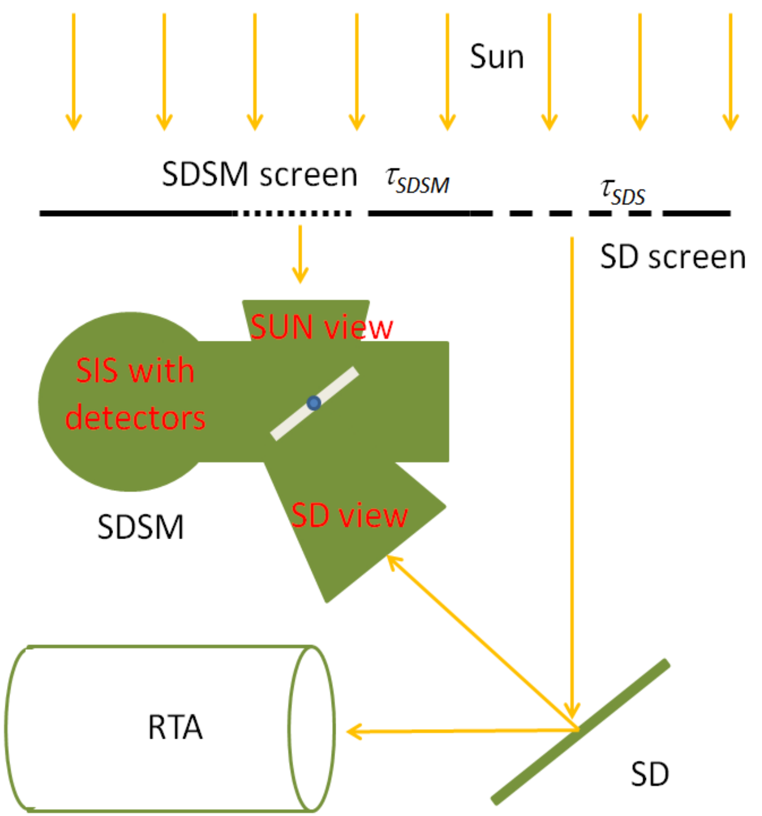
$$F = \frac{L_{Sun\_Model}}{L_{Sun\_Observation}} = \frac{Computed\_L_{Sun}}{Observed\_L_{Sun}}$$

$$F = \frac{\cos(\theta_{inc}) \cdot \left[E_{sun} \cdot \tau_{sds} \cdot BRDF(t)\right] \cdot RVS_{SD}}{c_0 + c_1 \cdot dn_{SD} + c_2 \cdot dn_{SD}^2}$$

dn_{SD} : offset corrected SD DN, RVS_{SD} : response versus scan function at the angle of SD, $C_{0,1,2}$: detectors and electronics temperature dependent calibration coefficients, θ_{inc}: solar incident angle to the SD screen, *Esun* :solar irradiance, τ_{sds} : screen transmittance function, *BRDF*: the BRDF function out of on-orbit yaw maneuvers, *H(t):* SD degradation over time

$$BRDF(t) = H_{Norm}(t) \cdot BRDF(t_0)$$

$$H_{Norm}(t) \propto \frac{SD\_response(t)}{SUN\_response(t)}$$



RSB Calibration: Lunar F-factor

- Lunar F-factor: as a Secondary calibration coefficient
- The lunar F-factor is calculated as a ratio between the theoretical lunar irradiance and observed lunar irradiance [2]

$$\mathrm{F(B,D)} = \frac{I_{GIRO}(B)}{Irrad(B,D)} = \frac{I_{GIRO}(B)}{L_{Avg}(B,D) \cdot \dfrac{\pi \cdot R_{moon}^2}{Dist_{Sat\_Moon}^2} \cdot \dfrac{1+\cos(\phi)}{2}}$$

$$L_{Avg} = \sum_{Pixel} L_{pix} / Number\_of\_effective\_pixels$$

I_{GIRO} : band dependent lunar irradiance value from the the Global Space-based Inter-Calibration System (GSICS) Implementation of RObotic lunar observatory (GIRO v1.0.0) model (at https://gsics.nesdis.noaa.gov/wiki/Development/LunarWorkArea), ϕ: moon phase angle, L_{Avg}: averaged radiance of the effective lunar pixels, R_{moon}: moon radius, $Dist_{Sat\_Moon}$: distance between satellite and moon

[2] Choi, T., Shao, X., Cao, C., Weng, F., Radiometric Stability Monitoring of the Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS) Reflective Solar Bands Using the Moon. Remote Sens. 2016, 8, 15.

Introduction

- Different version of RSB LUTs are available
- SD H & F-factor LUTs
  - Aerospace (Fast track & RSBAutoCal)
  - NASA VCST
  - NOAA Ocean Color group
  - NOAA VIIRS RSBAutoCal & ICVS
- Lunar F-factor LUTs
  - NASA VCST (ROLO, GIRO)
  - NOAA Ocean Color (ROLO)
  - NOAA VIIRS (GIRO, Miller Turner)
- Lunar Band Ratio (LBR)
  - NOAA VIIRS

Results: RSBAutoCal vs. NASA VCST LUTs

- Aerospace RSB LUTs
  - Bi-weekly fast-track LUTs were operational from the start of mission to November 2015.
  - RSBAutoCal LUTs currently operational since November 2015.
- The operational F-factors are monitored by Integrated Calibration/Validation System (ICVS) F-factors
  - ICVS web-page at http://www.star.nesdis.noaa.gov/icvs/status_NPP_VIIRS.php
- **NOAA VIIRS SDR team** produces a new set of VIIRS lifetime **RSBAutoCal LUTs** for reprocessing.
  - Applying current operational LUTs from IDPS [1].
  - very similar to NOAA ICVS LUTs.
- NOAA Ocean Color group produces their own RSB LUTs.
  - With their own screen transmission, BRF, and sweet spot Defs.
- **NASA VIIRS Calibration Support Team (VCST)** produces several different version of RSB LUTs.
  - NASA VCST provided latest RSB LUTs to validate.
  - Lunar correction, time dependent RSR corrections, Out-of-band H-factor correction and normalization, Screen transmission table updates, SWIR SD deg.

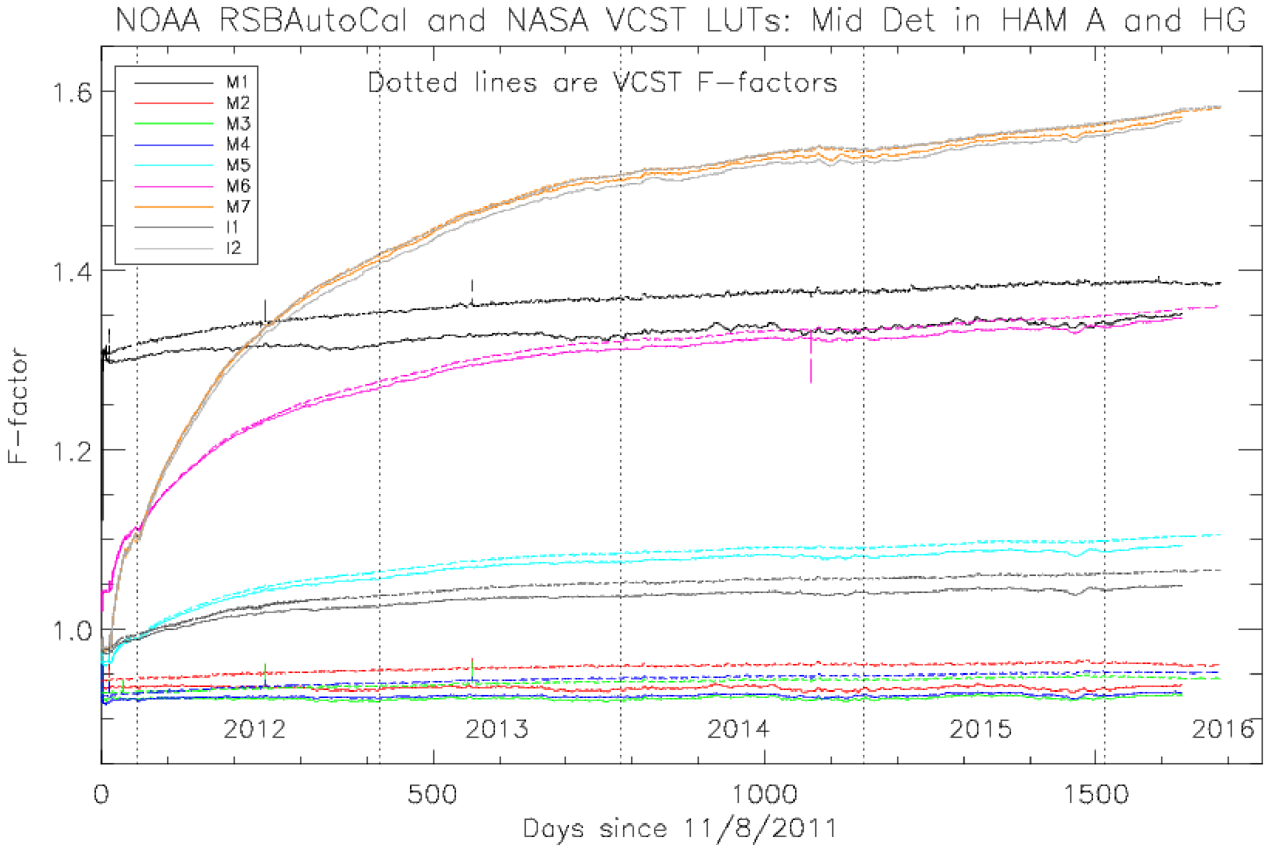
[1] Blonski & Cao, *Remote Sens.* **2015**, *7*(12), 16131-16149; doi:10.3390/rs71215823

Results: RSBAutoCal vs. NASA VCST LUTs

- NOAA VIIRS SDR team prepared a set of initial version of reprocessing LUTs.
  - Using RSBAutoCal from the start of S-NPP launch
  - 3236 RSBAutoCal LUTs are generated
    - Covering 11/8/2011 to 4/25/2016.
  - RSBAutoCal LUTs provide
    - RSB F/H factors
- NASA VCST H/F LUTs
  - VCST provided H(v25) and F(v20) LUTs.
    - 22,864 data points for F-factors (11/8/2011 ~ 5/22/2016)
    - 2,258 data points for H-factors (11/8/2011~5/16/2016)
  - F-factors include middle detectors, HAM side A, HG states for dual-gain bands.
    - The middle detectors are detector 8 for M bands and detector 16 for I bands starting from detector index 1.
  - F-factor comparisons are performed in
    - HAM side A, HG state, Middle detectors.

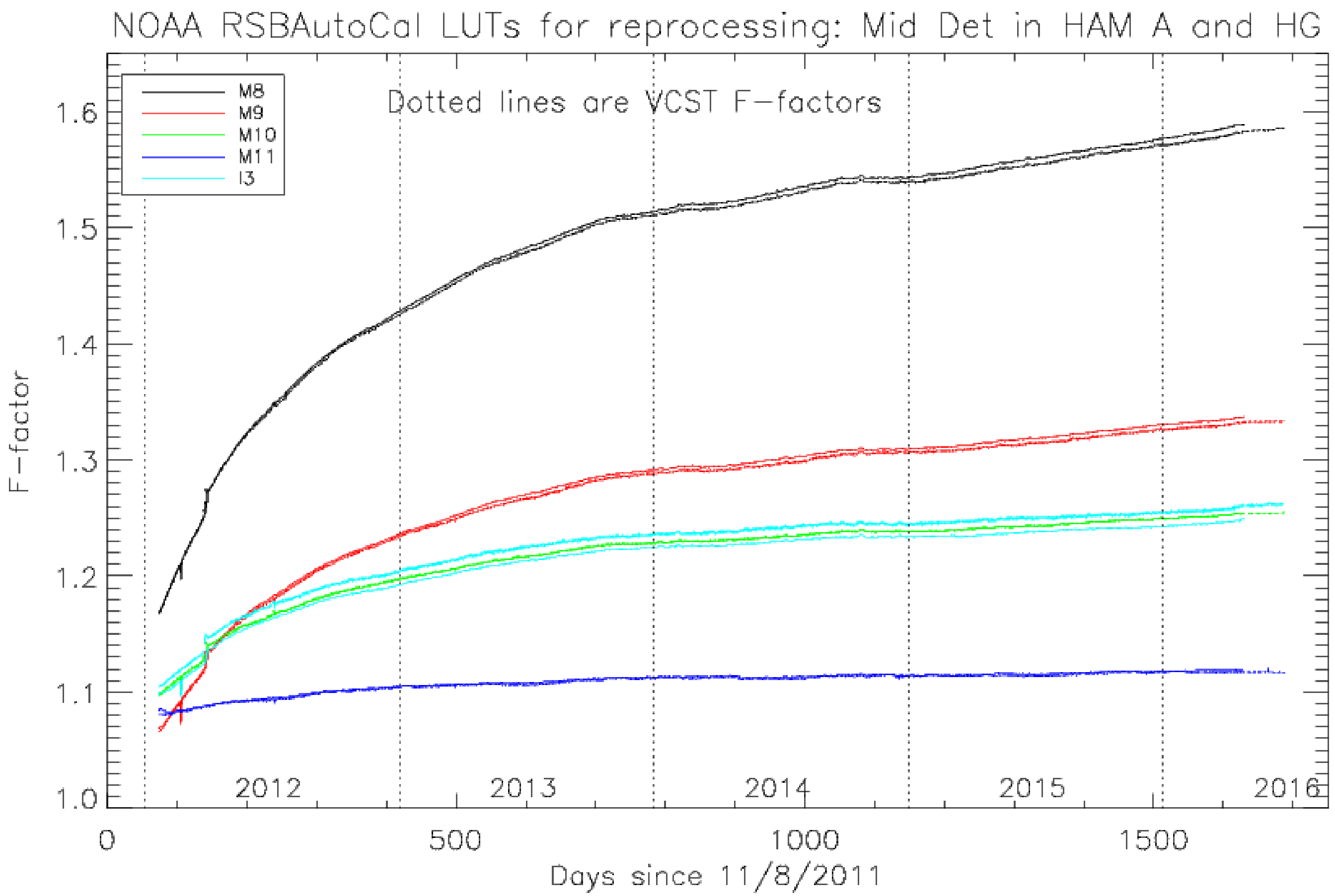
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal vs. VCST F-factors in VIS and NIR bands
  - M1 (412nm) F-factors show ~3% differences.
  - M5 (672nm) 1%, I2/M7 (867nm) 0.4% → getting smaller.
  - VCST F-factors are larger than RSBAutoCal LUTs.



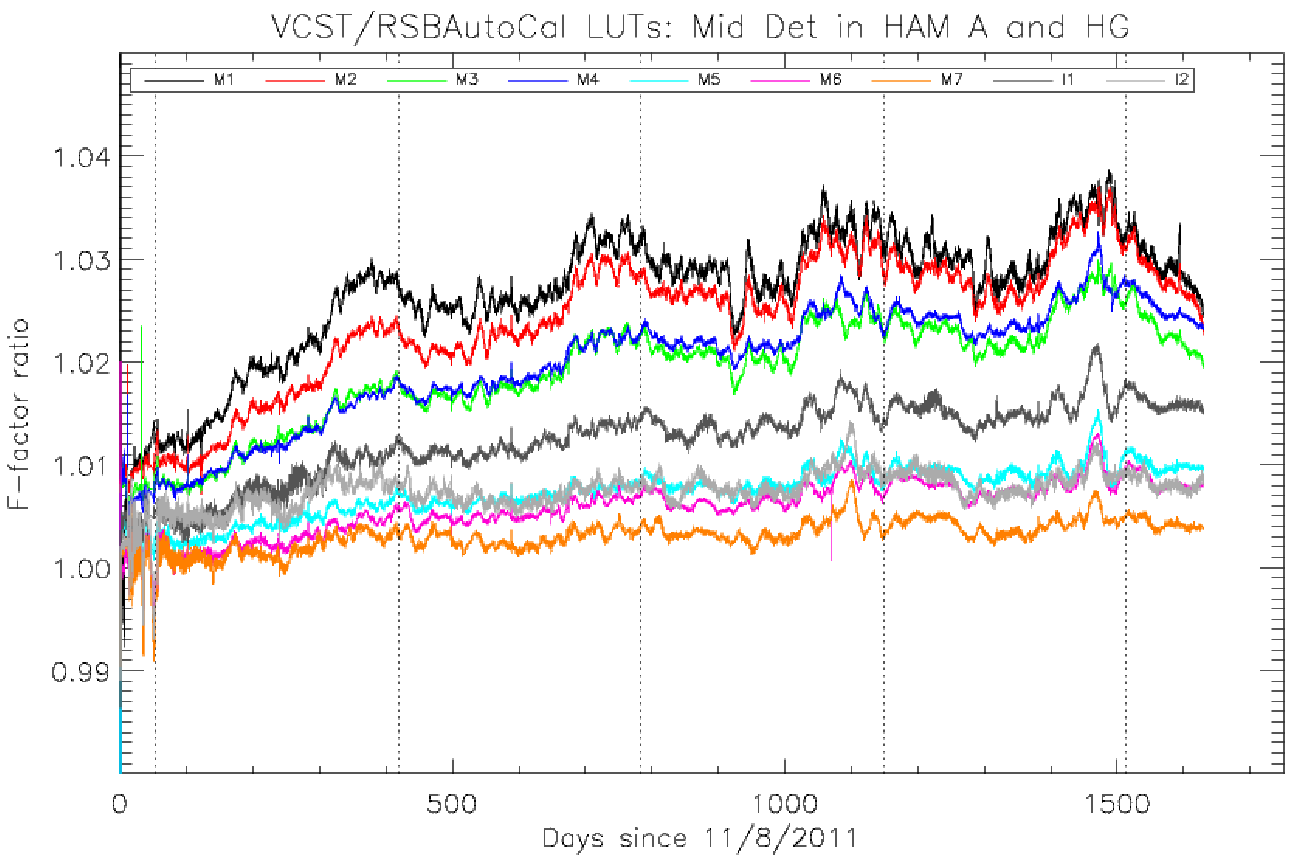
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal vs. VCST F-factors in SWIR bands
  - I3 and M10 differences are large (>0.5%) with NASA VCST LUTs.
  - VCST LUTs are below RSBAutoCal LUTs.



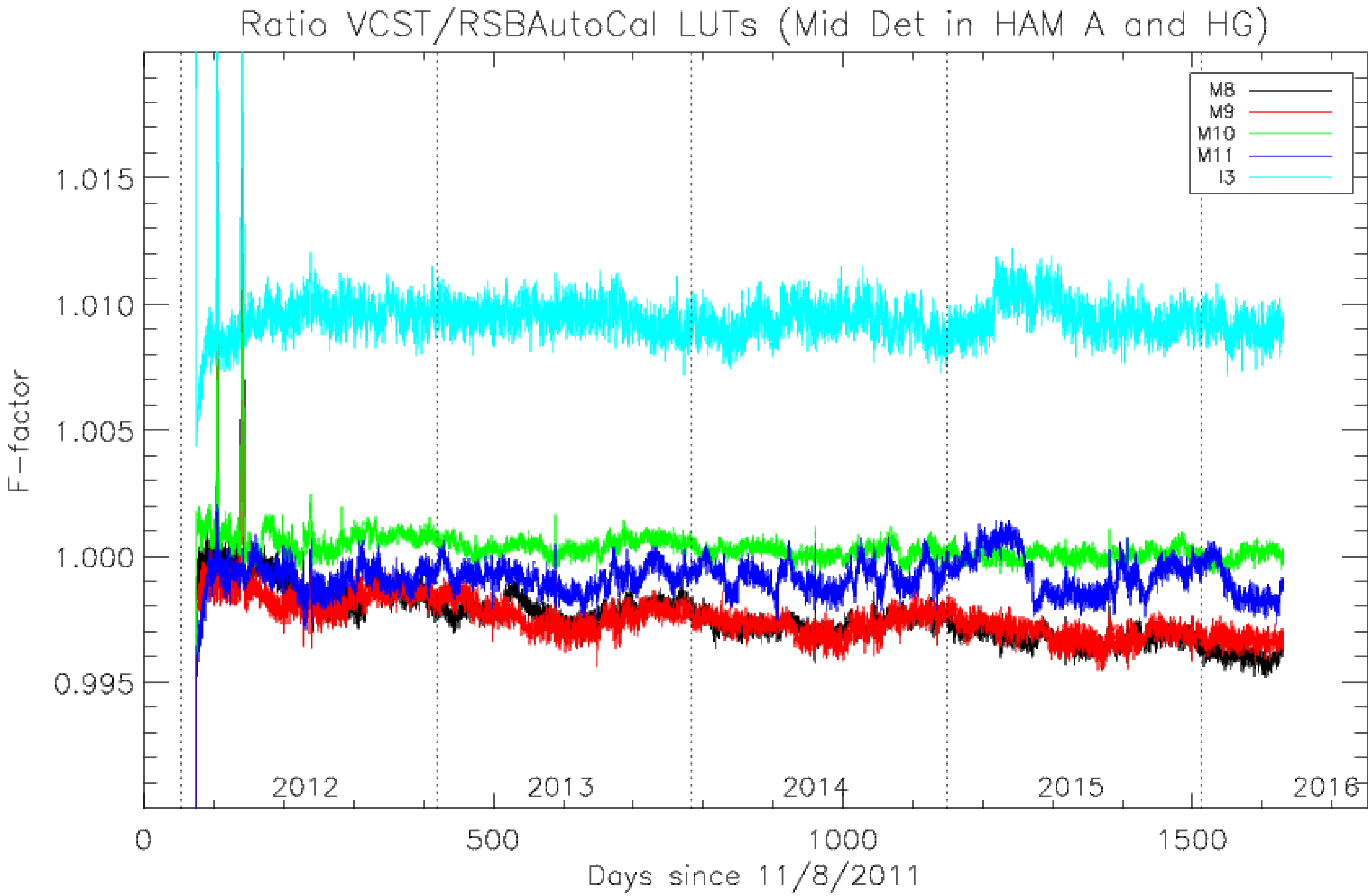
Results: RSBAutoCal vs. NASA VCST LUTs

- F-factor ratio plot in VIS and NIR bands
  - There are initial offsets and long-term drifts.
  - The differences are larger in short wavelength bands and getting smaller in longer wavelengths.



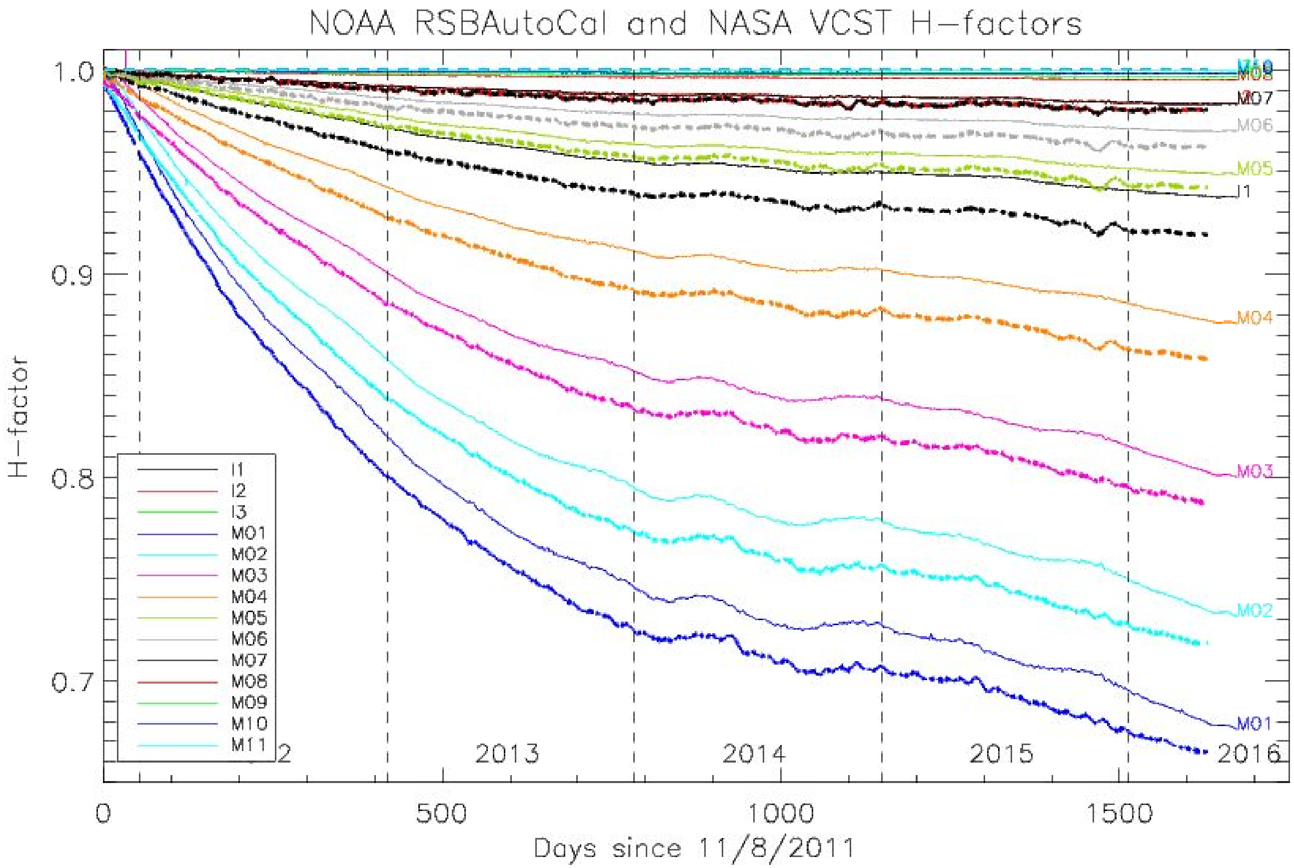
Results: RSBAutoCal vs. NASA VCST LUTs

- F-factor ratio plot in SWIR bands
  - H-factor (SD degradation) free bands show long-term drifts.



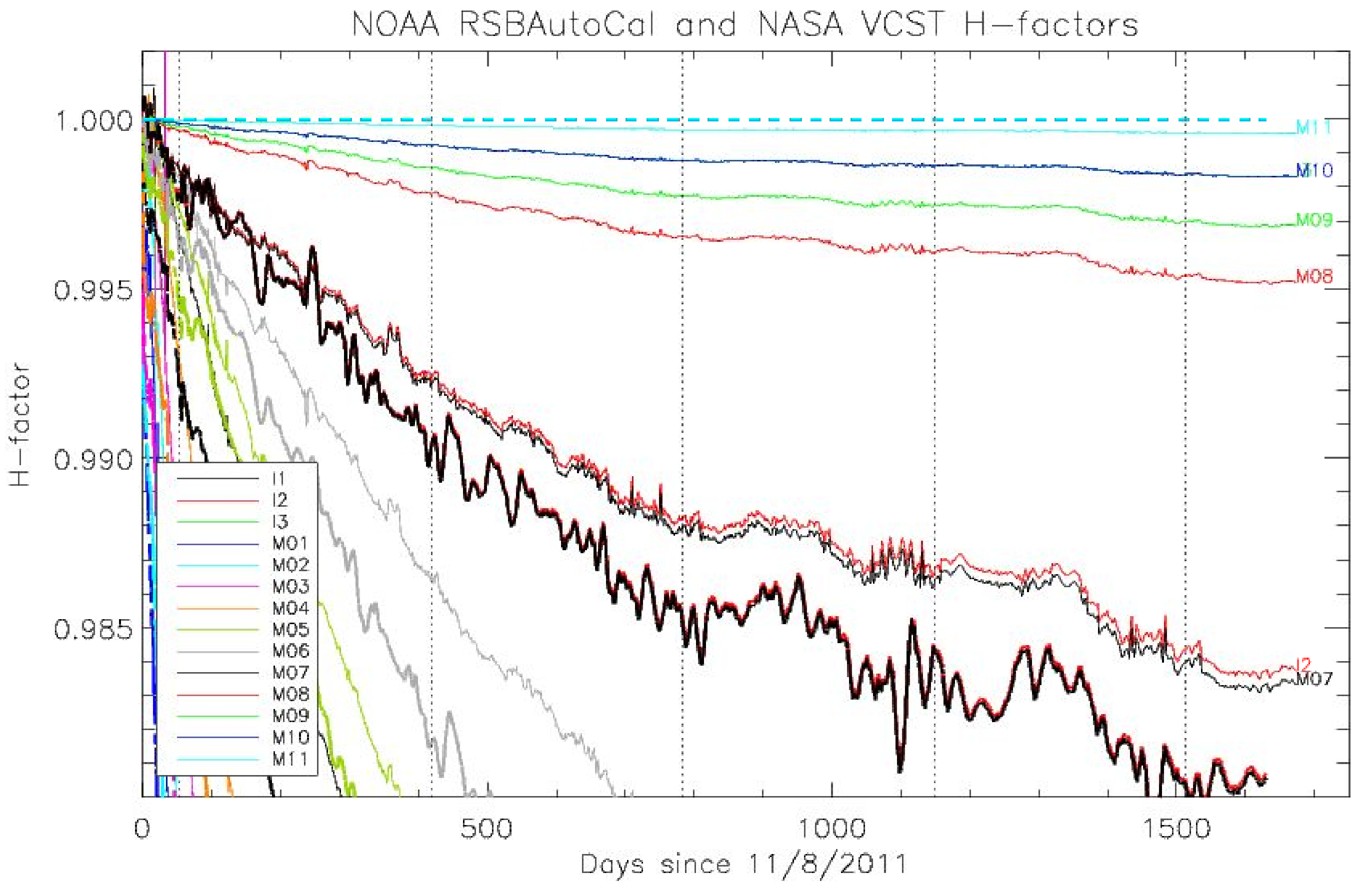
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal (dotted line) vs. VCST H-factor over plot
  - VCST H-factors are larger than RSBAutoCal.
  - The differences seem to be dependent on wavelengths.
  - There are initial sate differences.



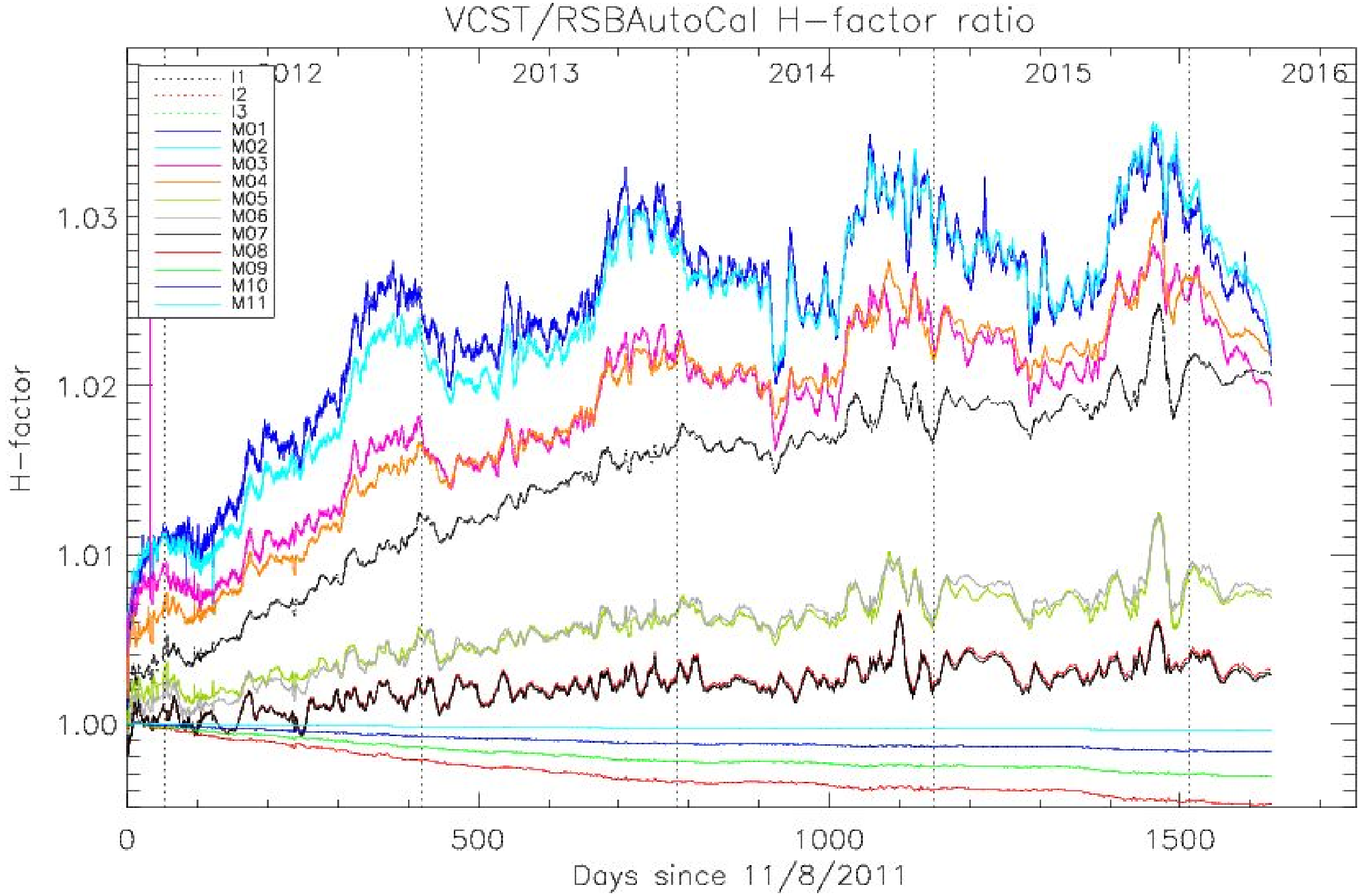
Results: RSBAutoCal vs. NASA VCST LUTs

- RSBAutoCal vs. VCST H-factor over plot
  - Thick lines are RSBAutoCal and narrow lines are VCST H-factors.
  - RSBAutoCal H-factors are set to be 1 in M8~M11, I3.
  - VCST has corrected for SD degradation.



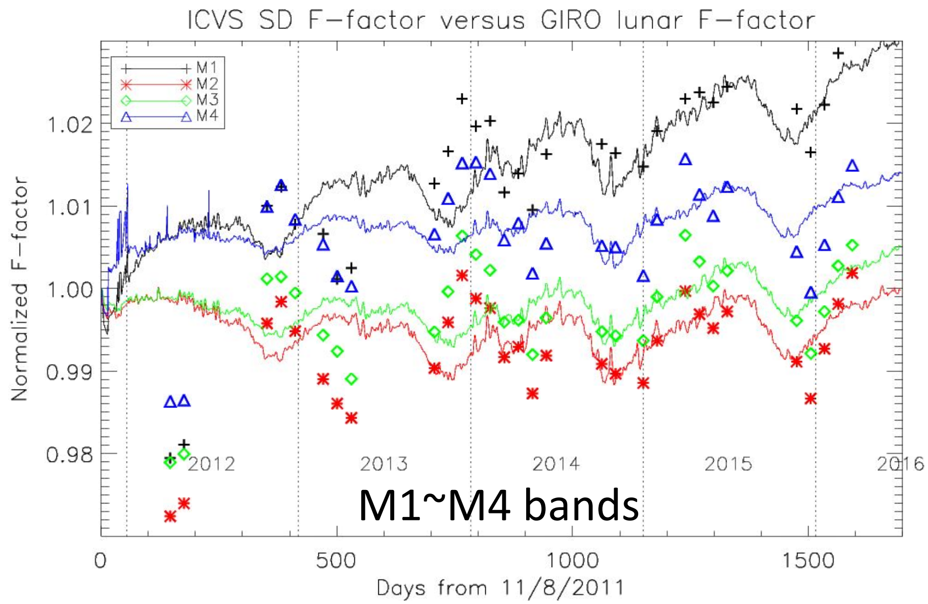
Results: RSBAutoCal vs. NASA VCST LUTs

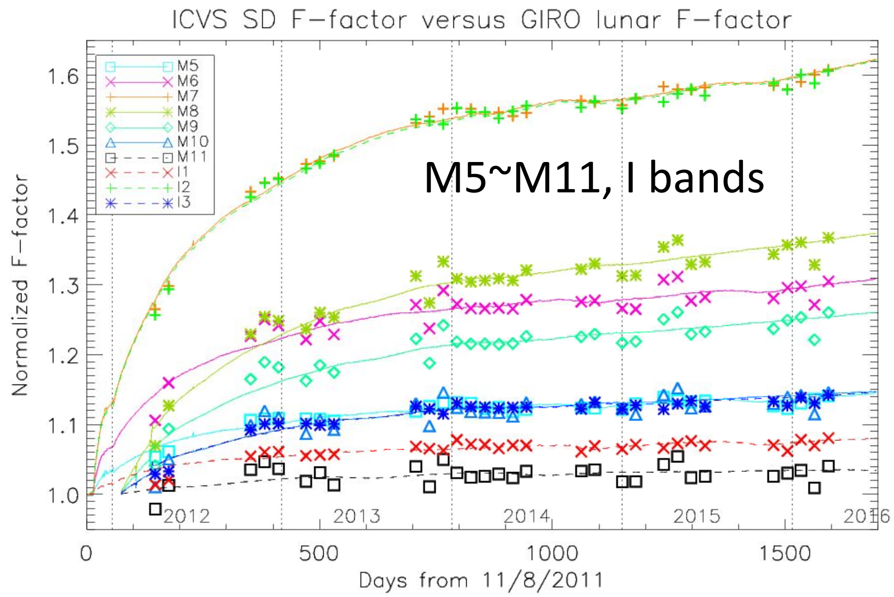
- H-factor ratio plot
  - H-factor differences are very similar to the F-factor differences.
  - F-factor differences are caused by the H-factors.



Results: Lunar F-factor comparisons

- The two F-factors need to be normalized (or scaled) properly because of the different solar irradiance models.
- The SD F-factors (solid lines) are normalized for better comparison and visualization in the figures.
- The best fitting scaling factors are calculated and applied for lunar F-factors (symbols).
- Lunar and SD F-factors are showing similar annual trends in starting from end of 2014 to current time.
- The first two lunar points are below the SD F-factors.
  - Potential errors in SD F-factors.





Results: Lunar F-factor comparisons

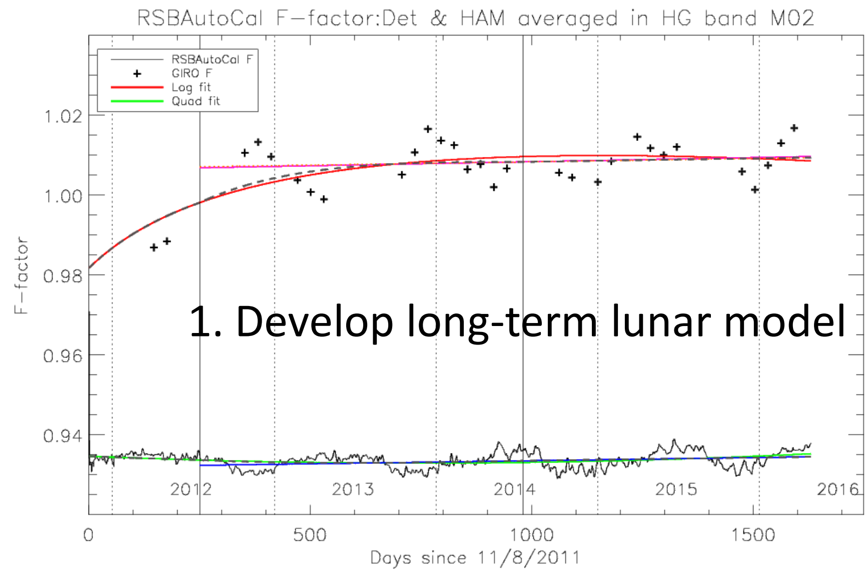
- The one-sigma root mean square(RMS) of the differences between SD and lunar F-factors are also shown in Table 1.
  - The SD F-factors are interpolated at the lunar collection time.
  - The short wavelength bands (M1~M4) are well within one percent level.
  - Other bands also show agreements less than 2 percent level.

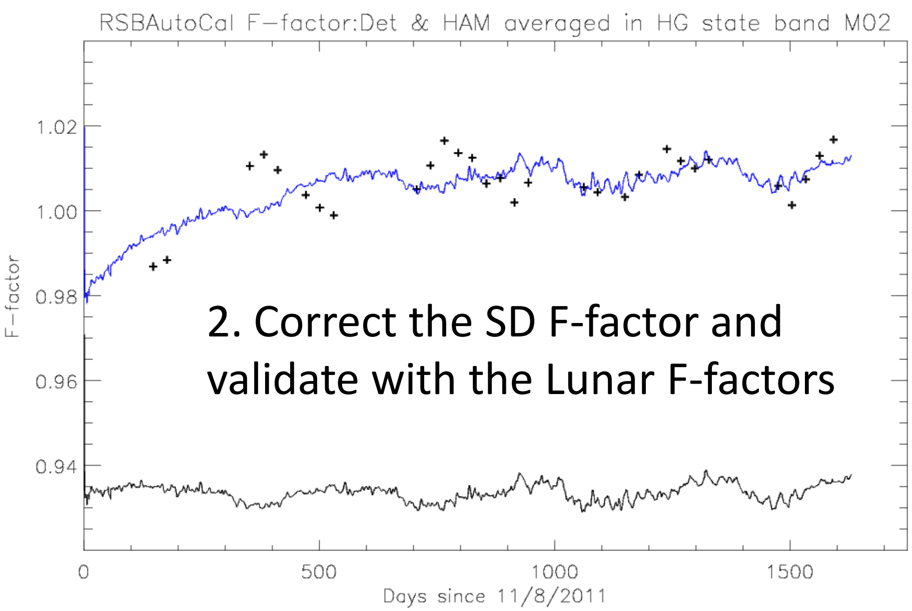
Table 1. One-sigma RMS of the percentage differences between the SD and lunar F-factors.

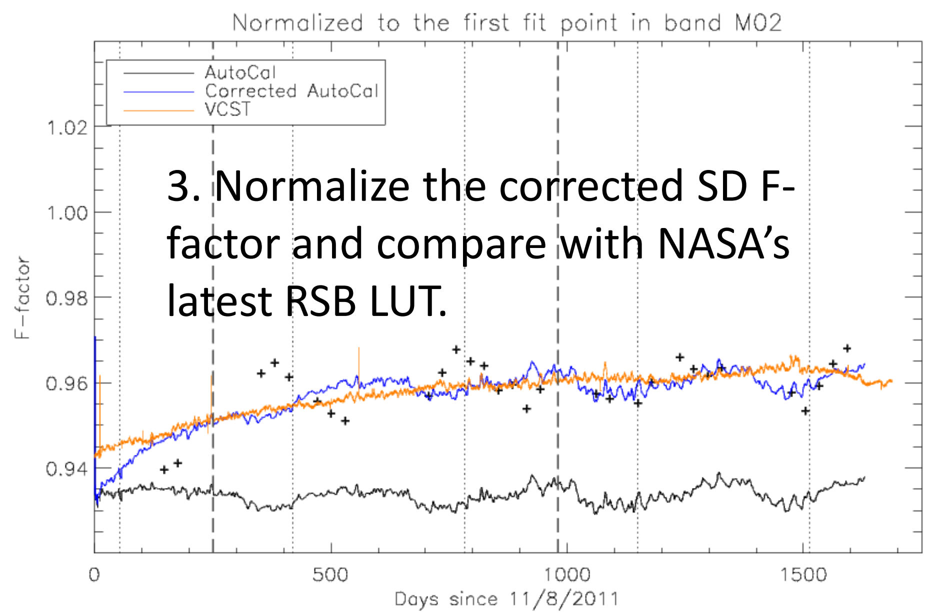
Band	RMS	Band	RMS
M1	0.90	M8	1.70
M2	0.83	M9	1.59
M3	0.71	M10	1.46
M4	0.73	M11	1.33
M5	0.70	I1	0.75
M6	1.66	I2	0.90
M7	0.87	M3	0.73

Results: SD F-factor Correction

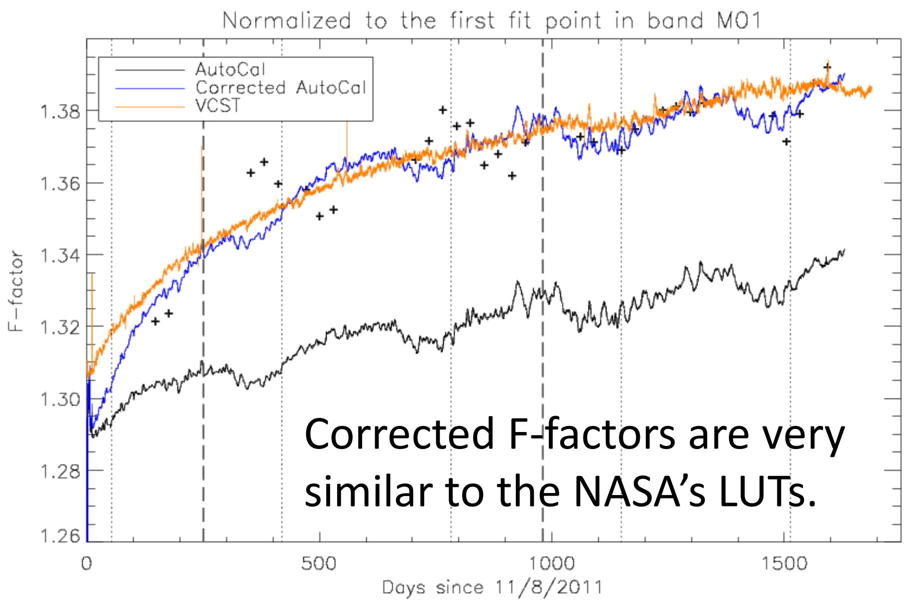
- SD F-factor correction to Lunar F-factor
  - Lunar F-factors are fitted.
    $Y = a \cdot log(x-b) + c \cdot x + d$
  - SD F-factors are fitted to a quadratic polynomial.



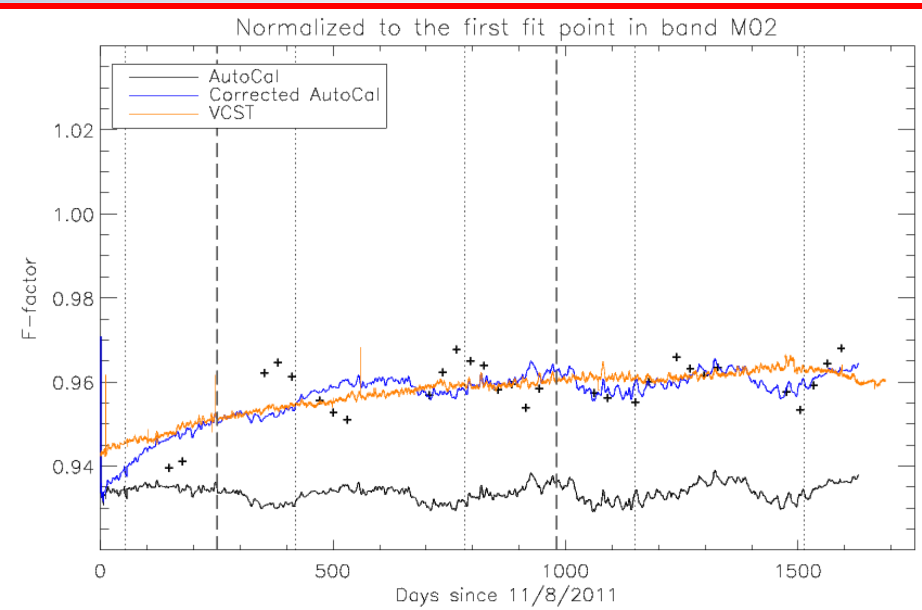


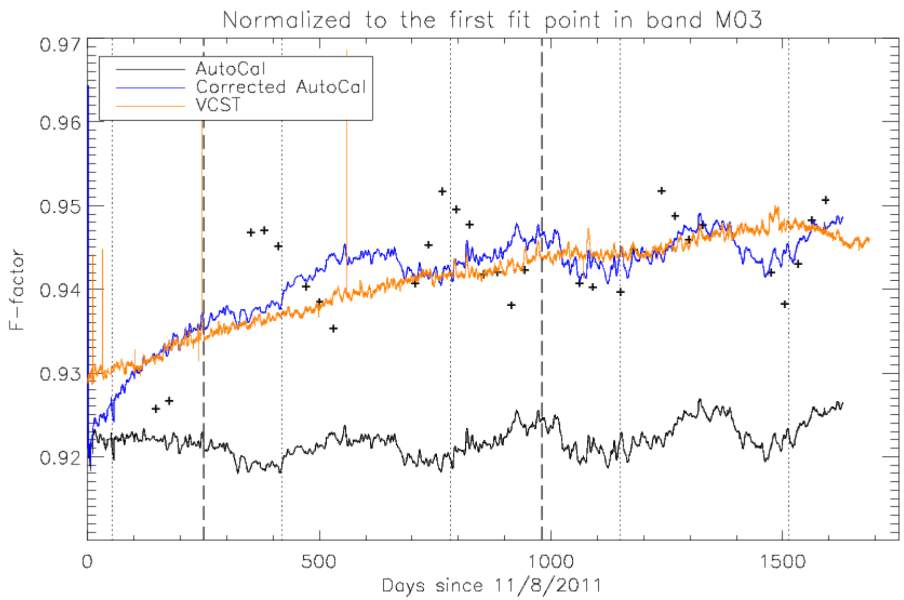


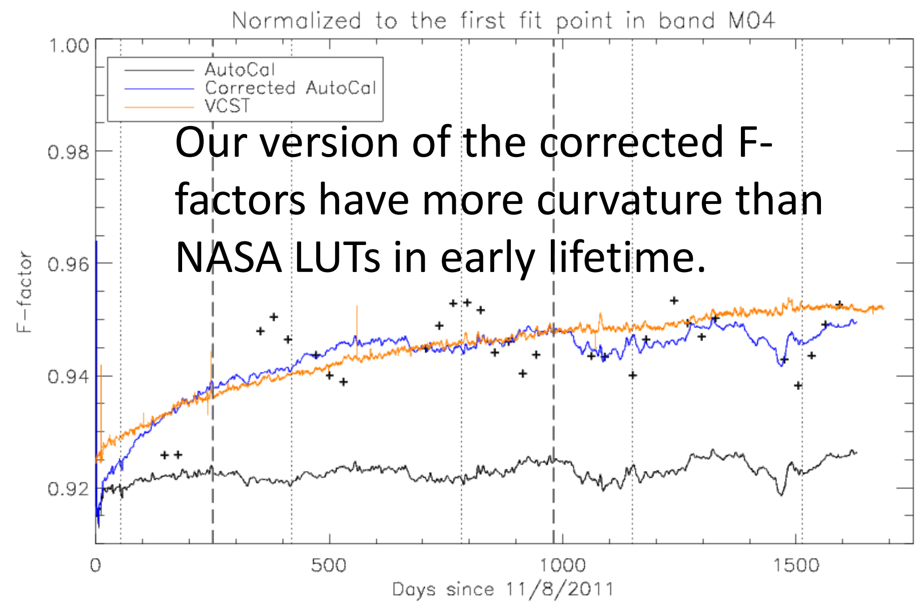
Results: SD F-factor Correction



Corrected F-factors are very similar to the NASA's LUTs.



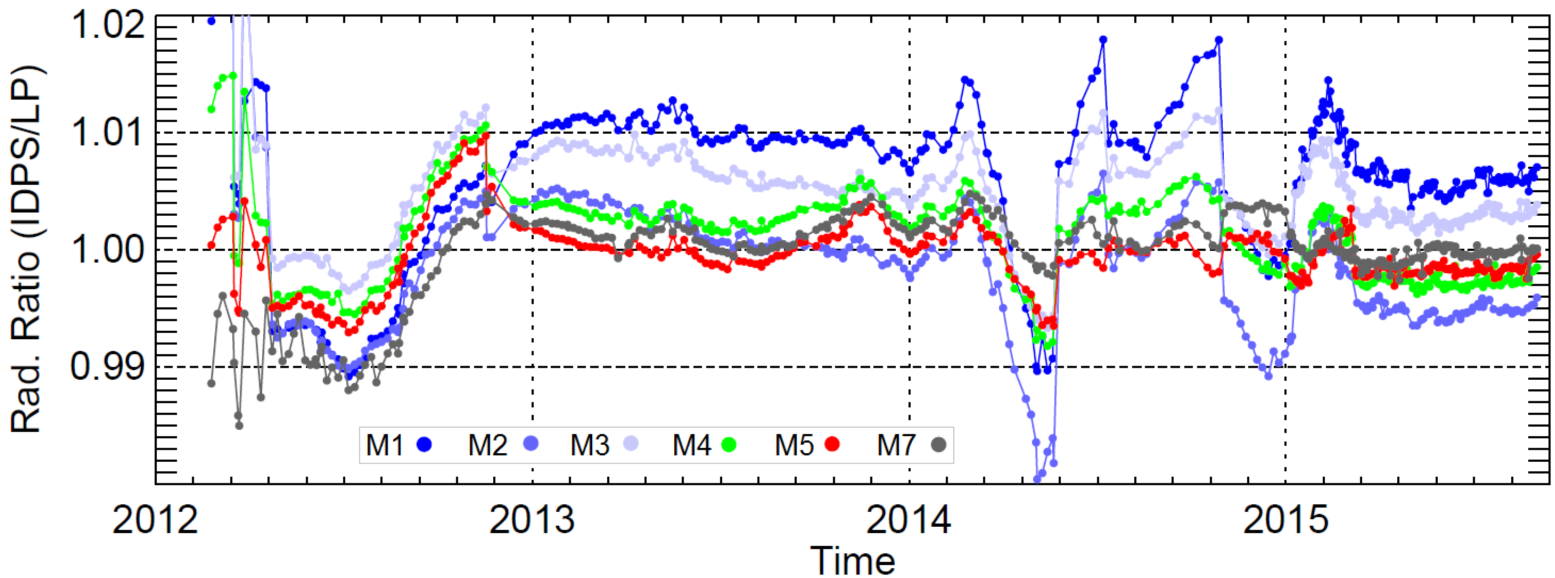




Our version of the corrected F-factors have more curvature than NASA LUTs in early lifetime.

Validation Example

- Radiance ratio of VIIRS data generated from IDPS and NASA Land SIPS is obtained for bands M1 through M7 near MOBY site.
- The ratio trends suggest the calibration differences among two products.
- All bands suggest agreement to within ±1% except M1 that shows almost ±2% difference mainly in 2014.
- It is to be noted that SIPS data are reprocessed data whereas IDPS is near real time data.



Summary (1/2)

- RSBAutoCal vs. NASA VCST LUTs
  - Reprocessing LUTs are compared between
    - RSBAutoCal and NASA VCST.
  - There are some initial state differences with long-term drifts up to 3% in band M1 (1% initial and 2% long-term drift).
    - Because of the normalization of H factors.
    - The differences are band wavelength dependent.
  - The F-factor differences are directly caused by the H-factor differences.
  - NASA VCST has corrected for SD degradation in SWIR bands.
    - In the H-factor free bands (M8~M11 and I3).

Summary (2/2)

- The SD and lunar F-factors suggested potential differences.
  - Up to 3 % in band M1 and M2.
  - The SD F-factors can be scaled to match lunar F-factors.
  - The corrected F-factors needs to be validated by other evidences.
    - Deep convection clouds (DCC), pseudo-invariant calibration sites, or sensor cross calibration using simultaneous nadir observations (SNOs).
    - Before applying to operational production and reprocessing.
- The long-term lunar corrections models are developed and applied.
  - Producing very similar results to NASA VCST's LUTs.
- NOAA VIIRS team will continue to monitor on-orbit calibration coefficients and vicarious observations.
  - Among different agencies (NASA, NOAA, and Aerospace)
  - And different working groups (**Ocean Color**, and NASA VCST)

Acknowledgements

- Authors thank to EUMETSAT sharing the GIRO version 1.0.0 with NOAA VIIRS team.
  - Global Space-based Inter-Calibration System (GSICS) Implementation of RObotic lunar observatory (GIRO v1.0.0) model
  - https://gsics.nesdis.noaa.gov/wiki/Development/LunarWorkArea

- Backup slides

Backup Slides

- Reflective Solar Band (RSB) F-factor Calculation
  - F: RSB Calibration coefficient.
  - H: SD degradation factor.

$$L_{EV} = \frac{F \cdot (c_0 + c_1 \cdot dn_{EV} + c_2 \cdot dn_{EV}^2)}{RVS_{EV}}$$

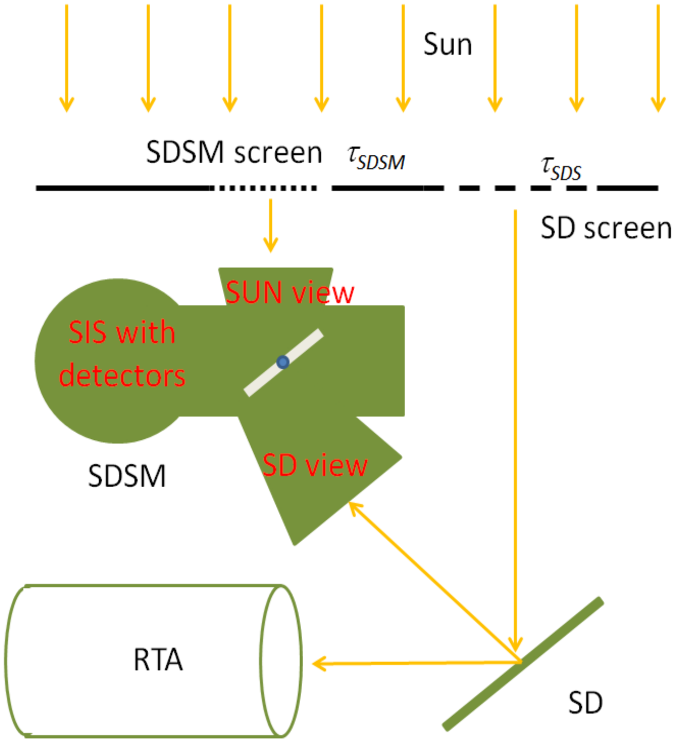
$$F = \frac{L_{Sun\_Model}}{L_{Sun\_Observation}} = \frac{Computed\_L_{Sun}}{Observed\_L_{Sun}}$$

$$F = \frac{\cos(\theta_{inc}) \cdot \left[E_{sun} \cdot \tau_{sds} \cdot BRDF(t)\right] \cdot RVS_{SD}}{c_0 + c_1 \cdot dn_{SD} + c_2 \cdot dn_{SD}^2}$$

$$BRDF(t) = H_{Norm}(t) \cdot BRDF(t_0)$$

$$H_{Norm}(t) = \frac{H(t)}{H(t_0)}$$

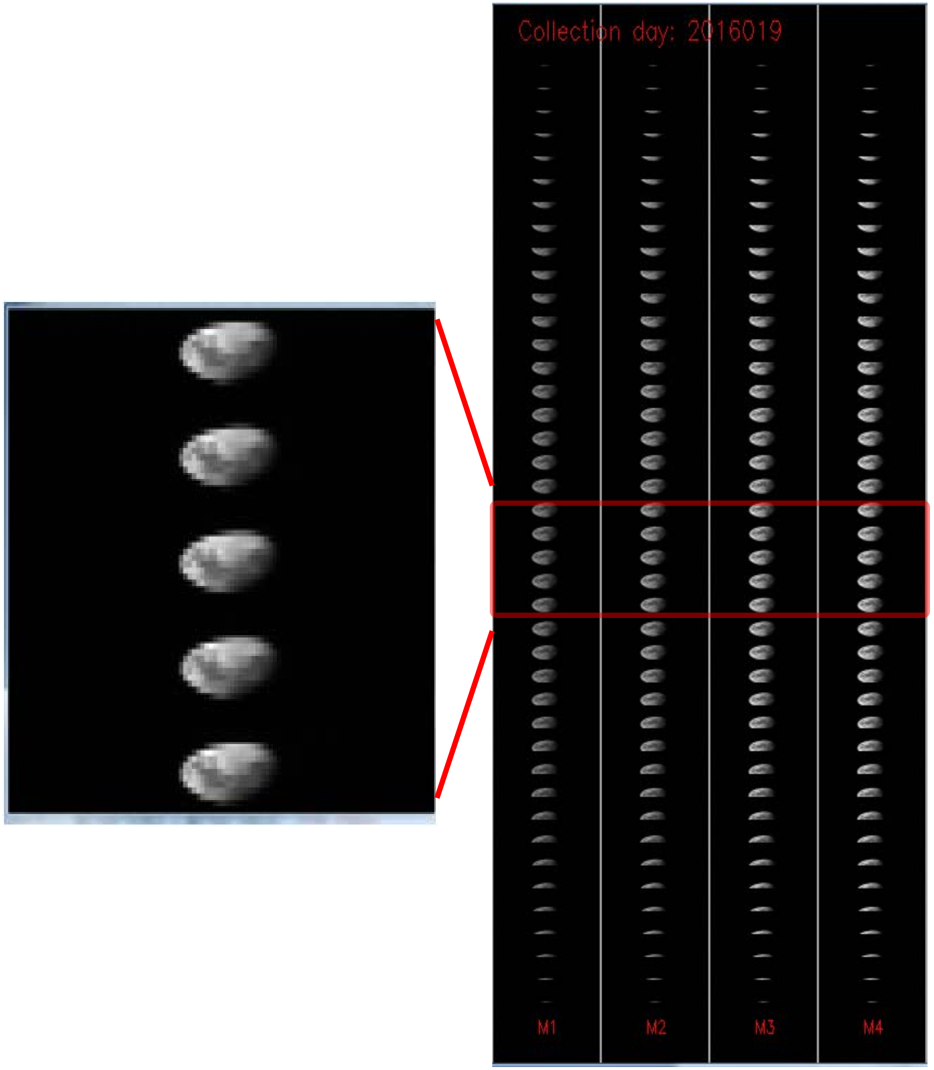
$$H(t) = \frac{dc_{SD} \cdot \tau_{SDSM}}{dc_{SUN} \cdot BRDF(t_0) \cdot \tau_{SDS} \cdot \cos(\theta_{inc}) \cdot \Omega_{SDSM}}$$



dn: VIIRS bias removed response
dc: SDSM bias removed response

Backup Slides

- Lunar F-factor Calculation from the Scheduled Lunar Collections
  - Moon observation made through the Space View (SV)
  - During the sector rotation, the VIIRS observations are set to be fixed High Gain (HG) mode.
  - Spacecraft roll maneuvers are required.
  - To avoid the complex oversampling factor calculation,
  - Center 5 scans with full moon in the entire scan are used.



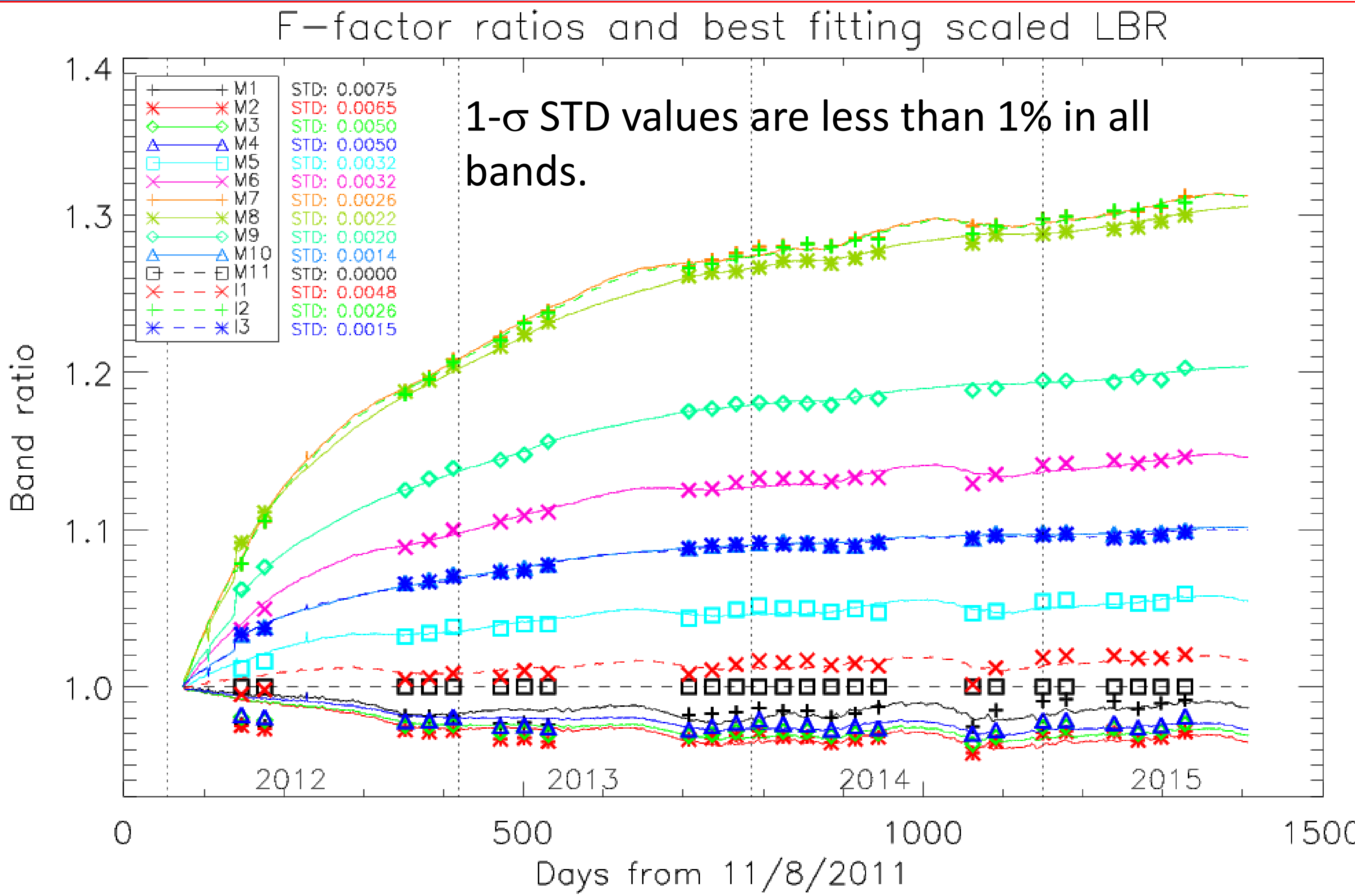
Backup Slides

- Lunar Band Ratio (LBR)
  - Lunar data processing
    - Lunar area is properly trimmed.
    - Based on all the valid bias corrected lunar pixels.
    - Bias is calculated from the background value.
  - LBR is now calculated using M11 as a reference band

$$\mathrm{LBR(B)} = \frac{\sum dn_{Pixel}(B)}{\sum dn_{Pixel}(Band\ M11)}$$

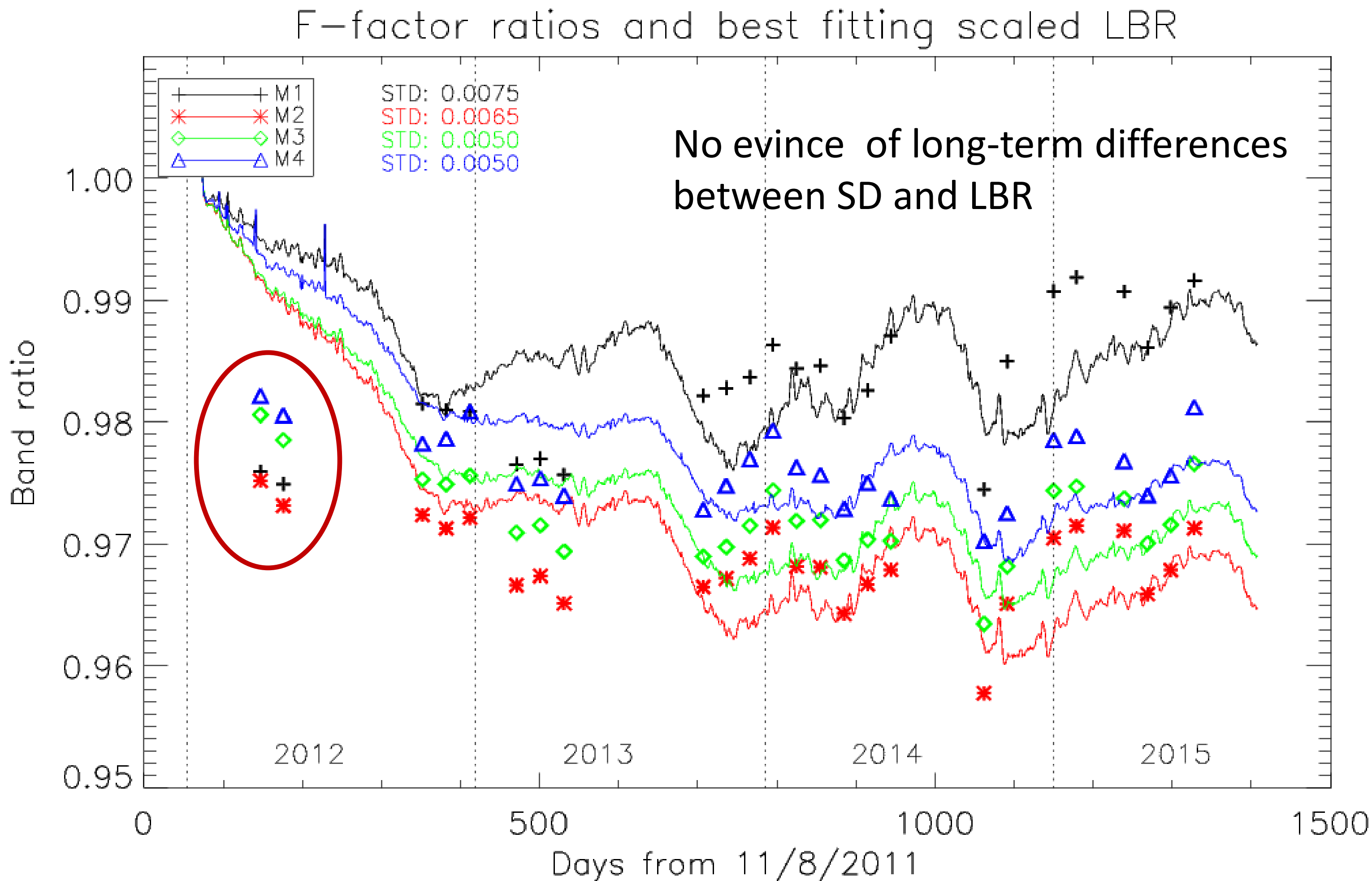
- LBR is compared to the SD F-factor ratios
  - Using M11 as a reference band.

Backup Slides

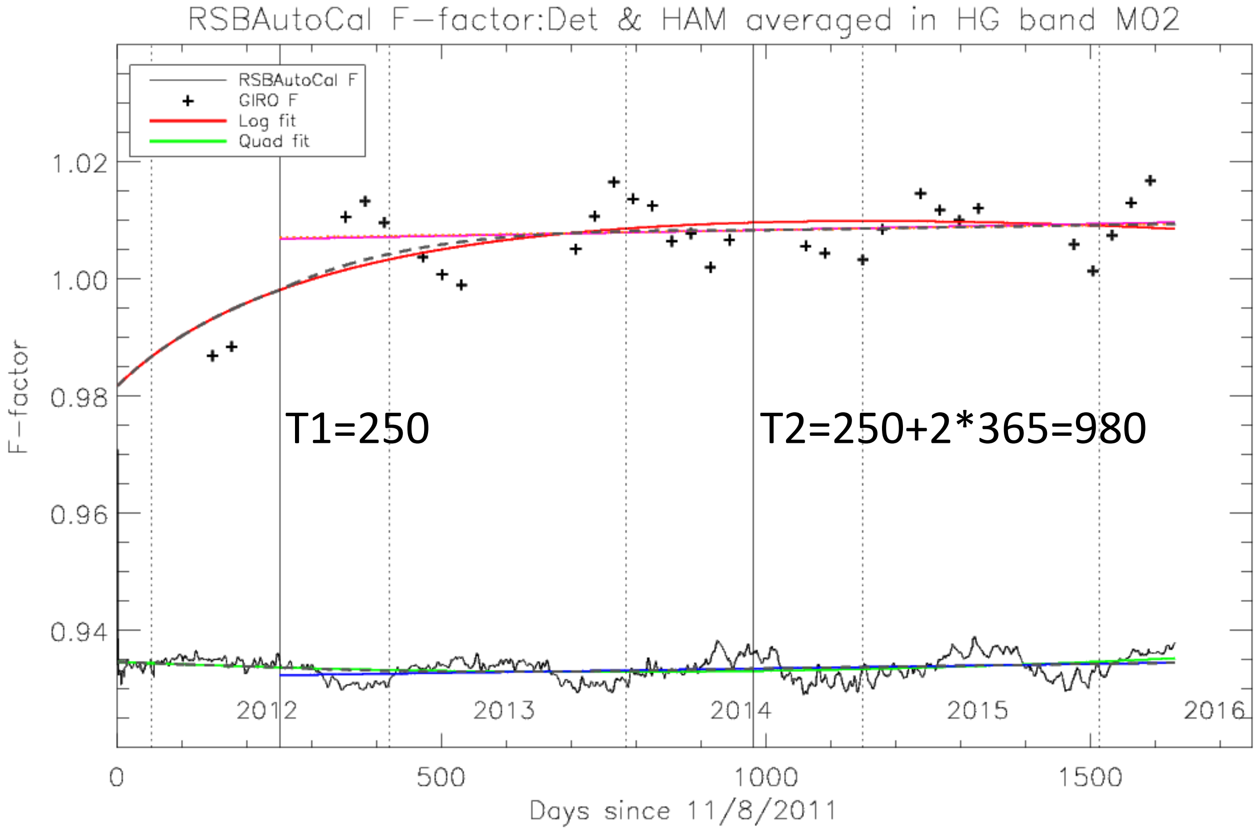


Backup Slides

- Zoomed in for M1~M4
  - LBR and F-factor ratios are very consistent except the first two points.



- SD F-factor correction to Lunar F-factor
  - SD F-factor linear fit to blue solid line.
  - Linear transition between t1 and t2 with Quad fit and linear fit.
  - Linear lunar F-factor is calculated after t1.
  - Constant ratio was found from SD to lunar F-factor after t1.



Comparing Reprocessed IDPS Data with Land SIPS

- Previous slide suggests that 2014 exhibits the largest discrepancies between IDPS and NASA Land SIPS data.
- Few IDPS data over desert for 2014 were reprocessed using calibration coefficients generated at STAR.
- Radiance ratio trends between the reprocessed IDPS and Land SIPS data indicates much smaller differences between the two products.
- Blue bands (M1-M3) agrees mostly to within 0.5% and M4 through M8 agree to within 0.3%.