Post-launch Performance of VIIRS Sensor Onboard NOAA-21 (JPSS-2) Satellite

NOAA STAR VIIRS SDR Cal/Val Team

(with contributions from NASA/VCST, Aerospace Corp., and Univ. of Wisconsin)

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Global Science & Technology (GST)

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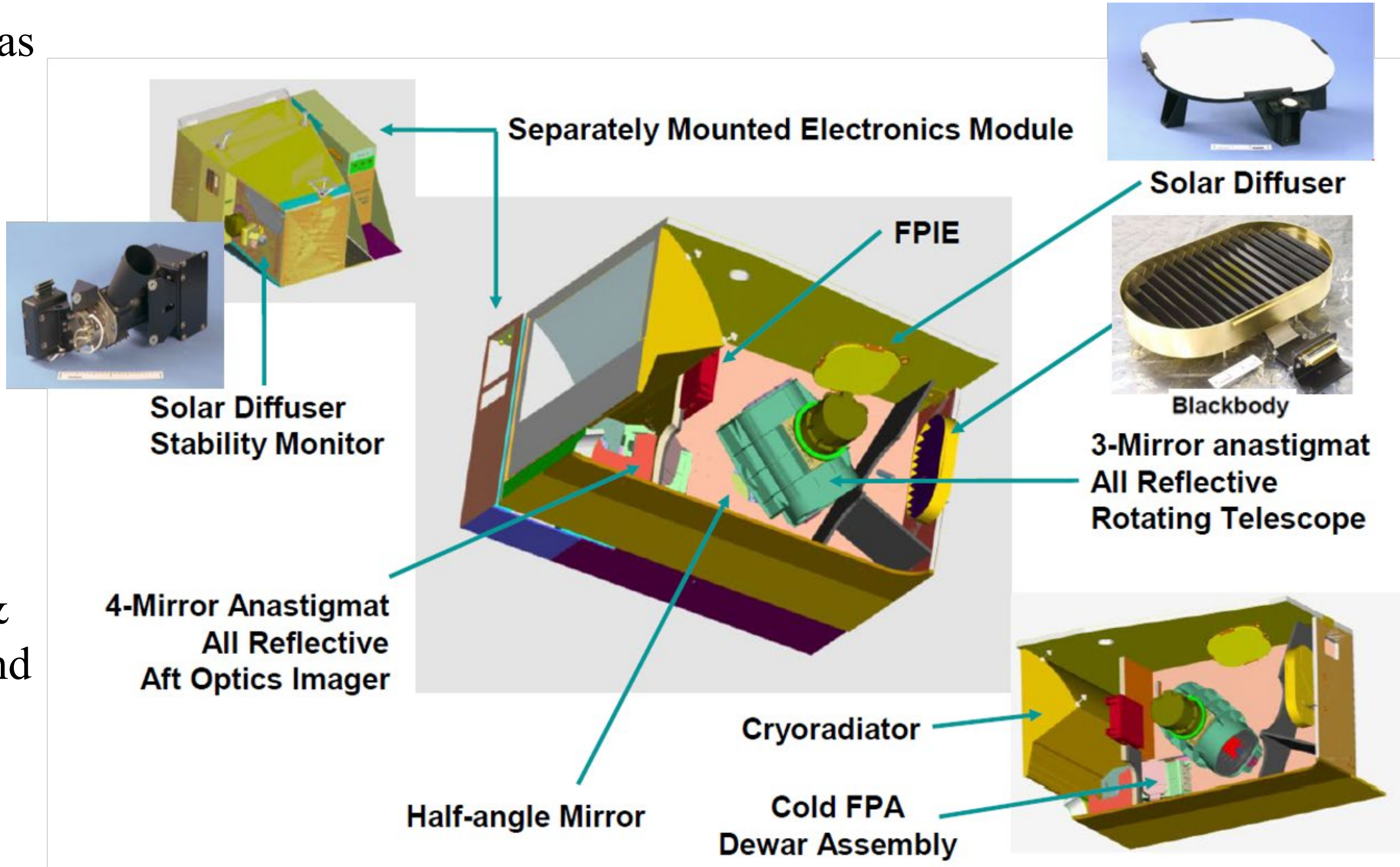
Outline

- Background: VIIRS instrument & Spectral Bands
- Post-launch Cal/Val Timeline & Major Tasks
- Performance of NOAA-21 VIIRS instrument:
  - Geolocation
  - Reflective Solar Bands (RSB)
  - Day/Night Band (DNB)
  - Thermal Emissive Bands (TEB)
- Summary & Path Forward

The VIIRS Instrument

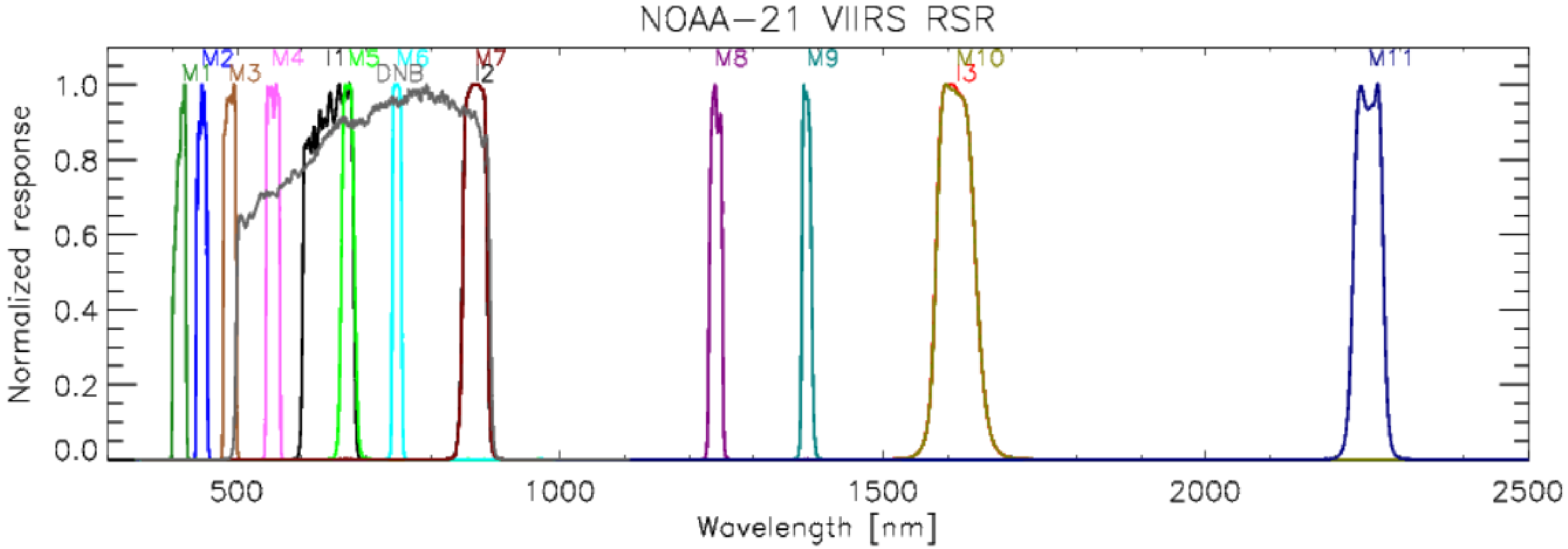
- JPSS-2 / NOAA-21 VIIRS instrument was successfully activated on 20 Nov 2022
- Cross-track scanning radiometer producing global imagery in 22 bands:
  - 14 Reflective Solar Bands (RSB)
  - 7 Thermal Emissive Bands (TEB)
  - Panchromatic Day-Night Band (DNB)
- VIIRS SDR data operationally used in a variety of environmental applications: monitoring hurricanes/typhoons, cloud & aerosol properties, ocean color, sea & land surface temperatures, active fires, and Earth's albedo
- Supports the production of ~ 26 Environmental data Records (EDRs)



Source: VIIRS Algorithm Theoretical Basis Document (ATBD)

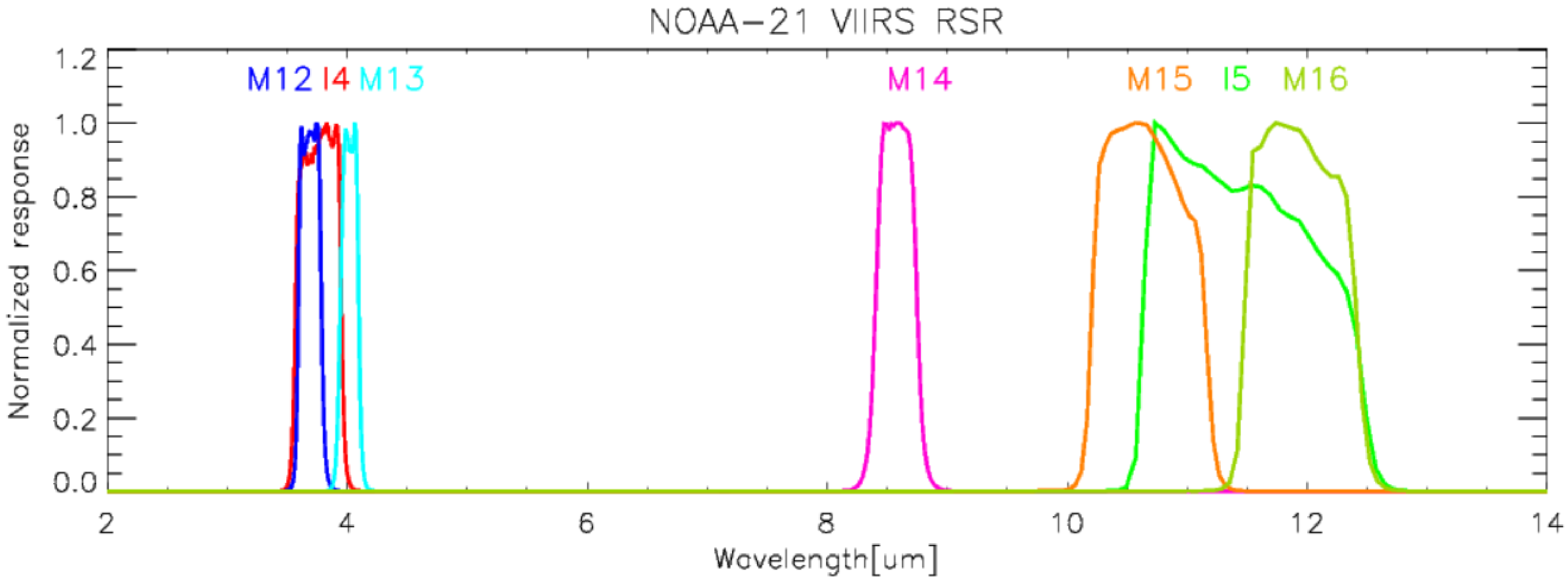
VIIRS Spectral Bands (RSB / DNB)

- There are 14 RSBs cover the spectral range from 0.412 µm to 2.25 µm:
  - 3 imagery resolution bands (I-bands): I1~I3; utilizing 32 detectors; 375-m nadir spatial resolution
  - 11 moderate resolution (M-bands): M1~M11; utilizing 16 detectors; 750-m nadir spatial resolution
  - Dual gain capability (M1-M5, M7)
- The primary source of the RSB radiometric calibration is an onboard sun-lit solar diffuser (SD) panel:
  - Illuminated once per orbit near the South Pole
  - Degradation regularly tracked by SD Stability Monitor (SDSM)
- The panchromatic DNB covers the spectral range from 0.5 µm to 0.9 µm; 750-m spatial resolution across swath



VIIRS Spectral Bands (TEB)

- There are 7 TEBs cover the spectral range from 3.7 µm to 12.0 µm:
  - 2 imagery resolution bands (I-bands): I4 & I5; utilizing 32 detectors; 375-m nadir spatial resolution
  - 5 moderate resolution (M-bands): M12~M16; utilizing 16 detectors; 750-m nadir spatial resolution
  - Band M13 has a dual gain capability
- The TEB radiometric calibration sources are onboard blackbody (BB) and space view (SV)



Post-launch Cal/Val Timeline

S/C Ka-Tx anomaly
(12/16/2022 ~ 2/2/0223)
Only ~ 15% science data availability

Launch day	Date	Flight Activity
L + 0	(11/10/2022)	JPSS-2 Launch
L + 10	(11/20/2022)	VIIRS Activation
L + 21	(12/1/2022)	DNB Straylight Test
L + 25	(12/5/2022)	Nadir Doors Open
L + 40	(12/20/2022)	Final Orbit
L + 90	(2/8/2023)	Cryoradiator Door Open
L + 92	(2/10/2023)	All Detectors Stable
L + 102	(2/20/2023)	DNB Calibration (new moon)
L + 105	(2/23/2023)	MMOG (3 days)
L + 112	(3/2/2023)	Lunar Calibration
L + 113	(3/3/2023)	TEB Detectors 82K → 80K
L + 116	(3/6/2023)	Yaw Maneuvers (2 days)
L + 120	(3/10/2023)	Pitch Maneuver ("backflip")
L + 122	(3/12/2023)	OBC BB WUCDs (3 + 2 days)
L + 127	(3/17/2023)	DNB Onboard Update
L + 131	(3/21/2023)	DNB Calibration (new moon)
L + 140	(3/30/2023)	
L + 266	(8/3/2023)	

Dates in red imposed by moon phase

Ground Activity

- Begin Cal/Val Tasks: Onboard Calibrators & SDSM; Basic Functionality; DNB Straylight; Image Quality; VNIR Calibration; Orbit & Geolocation
- Begin VIIRS SDR Production
- VIIRS First Light Image for VNIR Data
- 1st Delivery of Updated LUTs: VNIR Cal., GEO
- VIIRS First Light Images for DNB/SWIR/TEB Data
- Beta Maturity
- Continue Cal/Val Tasks: SWIR and TEB Calibration; DNB Calibration; Inter-Satellite Comparisons
- 2nd Delivery of Updated LUTs: SWIR/DNB Cal.
- Provisional Maturity
- Validated Maturity

Post-launch Cal/Val Tasks

Task ID	Title
	Tasks Started after Instrument Activation
GEO-1	Initial Validation of Spacecraft Ephemeris and Attitude Data
GEO-2	Initial Validation of VIIRS Encoder Data, Scan Time, Scan Period, and Scan Rate Stability
FPF-2	Detector Operability and Noise Verification with Nadir Door Closed: RSB VNIR, DNB
FPF-6	DC-Restore Functionality and Performance Check
FPF-7	Calibrator Visual Inspection
PLT-X	DNB Straylight with Nadir Doors Closed (no sector rotation)
CSE-1	SD and SDSM Characterization
CSE-2	Onboard Calibrator Black Body (OBCBB) Temperature Uniformity
CSE-4	Temporal Analysis of SD Signal over Polar Region
CSE-5	Temporal Analysis of Solar Diffuser Stability Monitor (SDSM) Data
PTT-1	Operability, Noise, SNR Verification
PTT-6	Telemetry Trending Monitoring
PTT-10	RSBAutoCal Calibration Object Trending, Evaluation & LUT Updates
	Tasks Started after Nadir Doors Open
IMG-1	Crosstalk, Echo, and Ghost Investigation
IMG-2	Image Analysis (Striping, Glints and Other Artifacts)
RAD-7	SDR Comparison with S-NPP & N20 VIIRS
RAD-8	SDR Comparison with MODIS
GEO-3	Assess Reasonableness of First-Period SDR Geolocation
GEO-4 to 7	Analyze First-Period VIIRS GCP Residuals
GEO-9	Develop and Test Initial Geolocation LUT Updates
PTT-2	RDR Histogram Analysis

	Tasks Starting after Cryo-radiator Door Open
IMG-3	Moon Echo and Ghost Check
CSE-6	Yaw Maneuver Analysis
RAD-4	Response vs. Scan Angle (RVS)
RAD-9	RSB Radiance/Reflectance Validation – Radiometric Sites
RAD-11	In-Band Spectral Radiance Comparison with CrIS
RAD-14	Emissive Band Response Characterization (WUCD)
RAD-15	Moon in Space View Correction
RAD-18	Lunar Data Analysis - Roll Maneuver
RAD-19	Analysis of Pitch Maneuver Data
RAD-20	SDR Reprocessing and Updates
RAD-24a	Offline F/H Factor Analysis, Prediction and Validation Tool
RAD-24b	Offline TEB F-Factor Monitoring
PTT-4	DNB Offset and Gain Ratios Determination
PTT-7	Update Uploadable Tables ID5, ID33-35: DNB Offsets
WAV-4	DNB straylight assessment and correction LUT development
WAV-5	DNB radiometric/geolocation monitoring using point sources
WAV-6	VIIRS saturation monitoring

Successfully performed Post Launch Tests (PLTs) (green)

Long-term monitoring (LTM) PLTs (yellow)

GEO	Geolocation/Geometric Evaluation
FPF	Function Performance and Format Evaluation
CSE	Calibration System Evaluation
PTT	Performance and Telemetry Trending
IMG	Image Quality Evaluation
RAD	Radiometric Evaluation

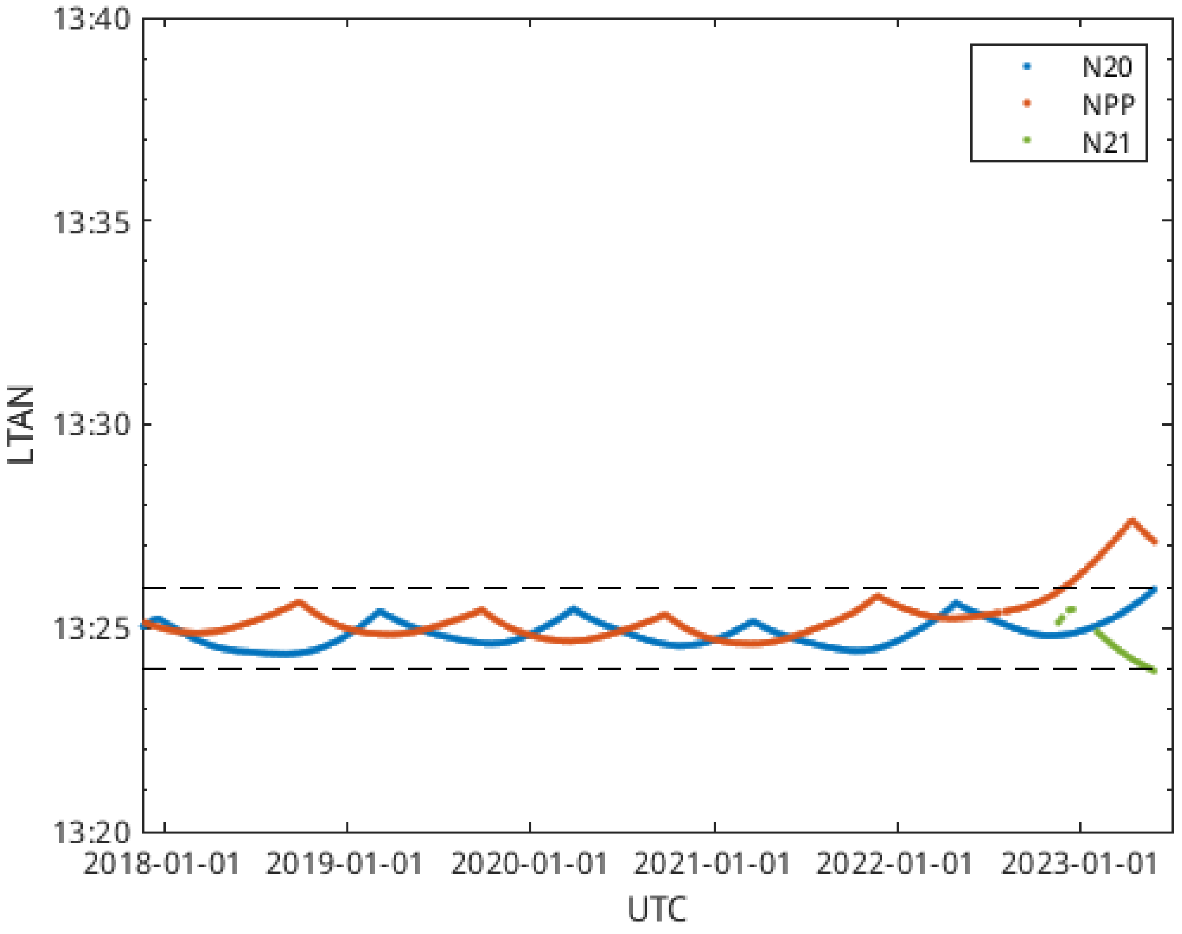
Geolocation Performance: Major Highlights

- Final sun-synchronous orbit on 20 Dec 2022:
  - Altitude ~ 829km
  - Local Time of Ascending Node (LTAN) ~ 13:25 UTC
  - Phasing ~ 20 min (NOAA-20 – NOAA-21 - S-NPP)

- Stable Telescope/HAM encoder scan parameters:
  - Average scan period ~ 1.789730 sec
  - Average Earth view (EV) scan time ~ 0.563798 sec
  - Consistent with pre-launch nominal values

- Post-launch optimization of mounting matrix (to improve geolocation accuracy) on 12 Jan 2023

- Known issue: occasional loss of synchronization (sync-loss) between Telescope & HAM:
  - A total of 9 events (~ 2 min/event)
  - Affected scans are flagged in SDR products
  - Erroneous data replaced with fill-values



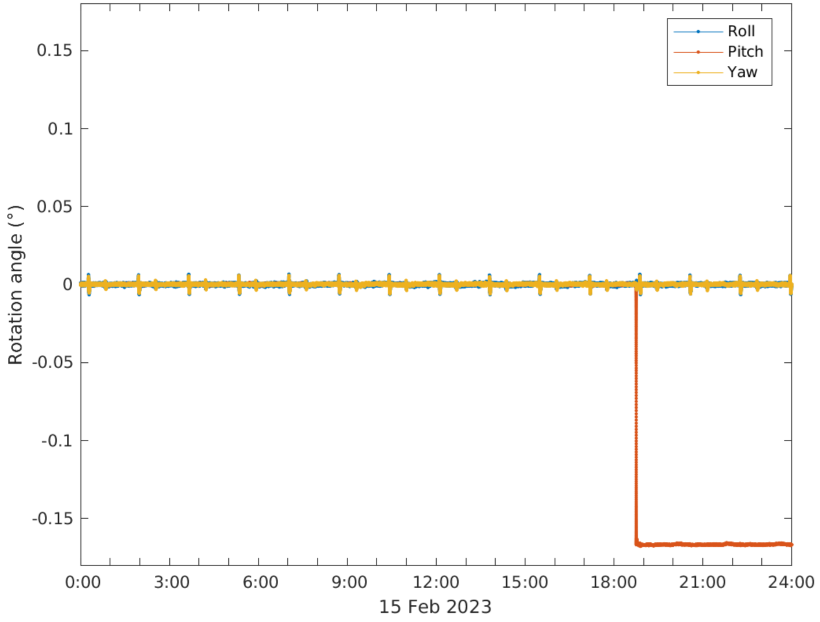
LTAN for the NOAA-21, NOAA-20 and Suomi NPP satellites

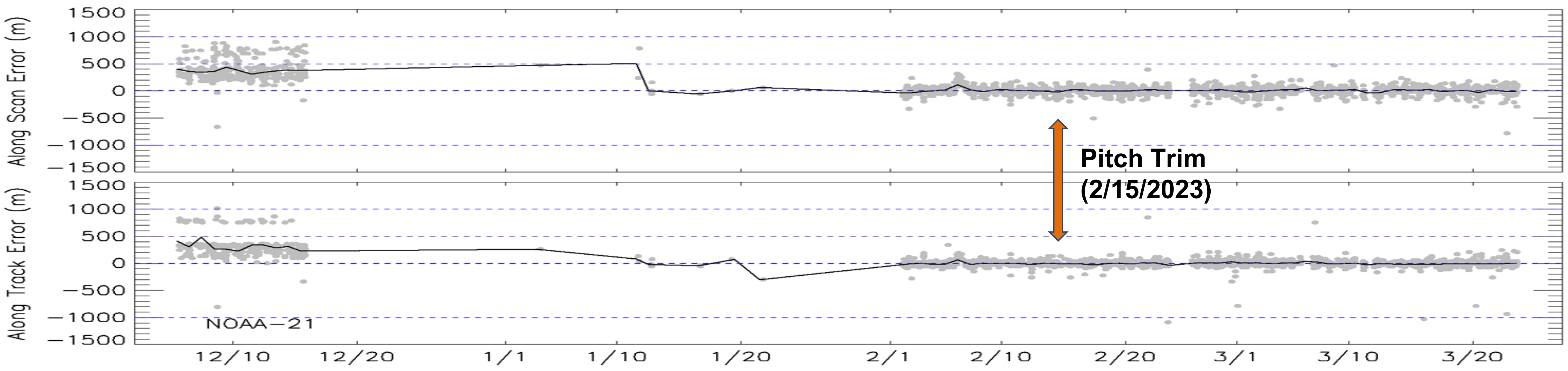
Geolocation Accuracy Monitoring

- All JPSS instruments (CrIS, OMPS, ATMS) rely on accuracy of VIIRS SDR geolocation products

- NOAA-21 VIIRS SDR geolocation errors remain mostly within 200 m (< 400 m required at the 3-sigma, 99.7%, level) after the post-launch mounting matrix update in January

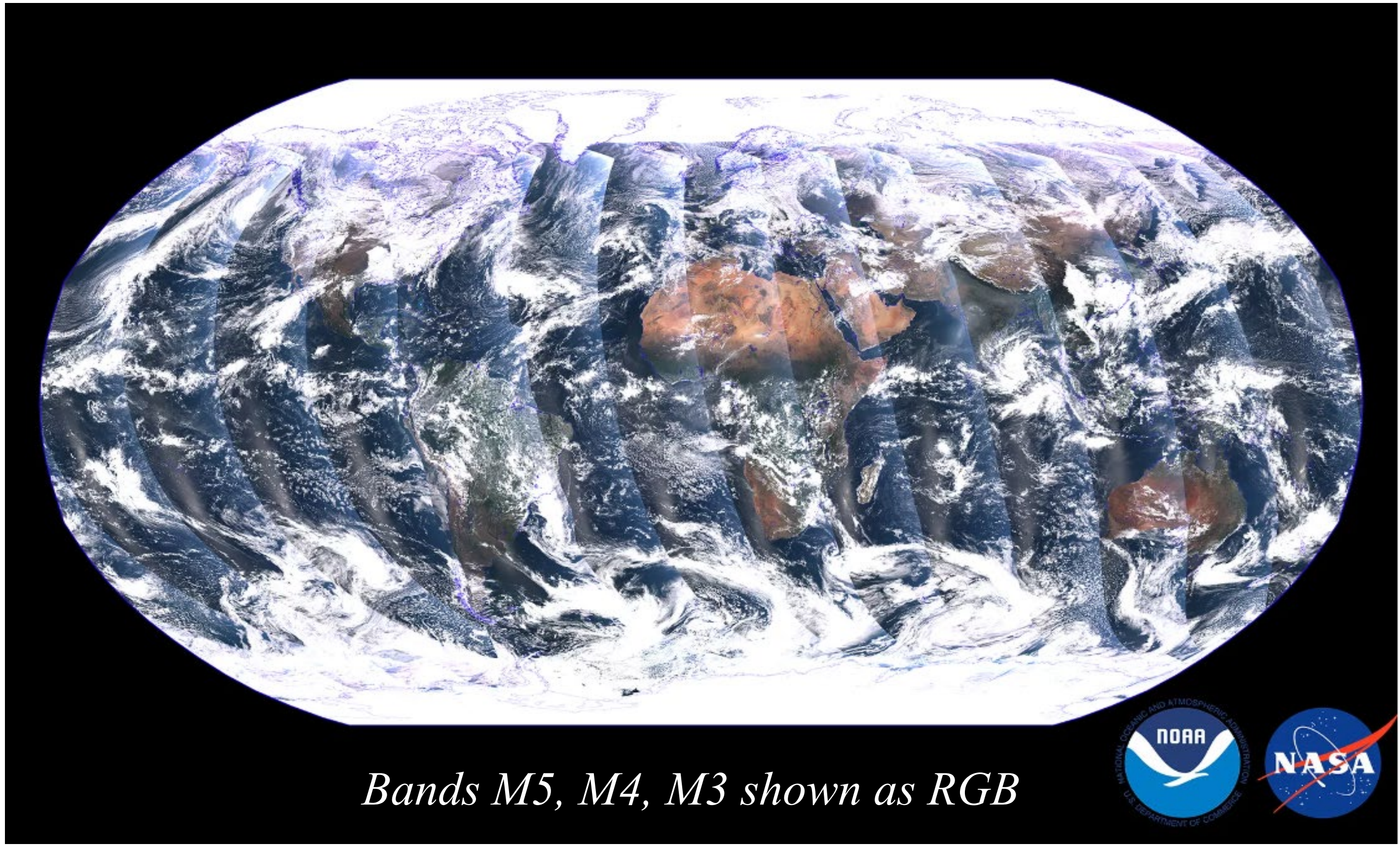
- A permanent pitch trim of -600 arcsec has been applied to the NOAA-21 spacecraft since Feb. 15, 2023 (to improve OMPS Limb sampling), it did not cause changes in the VIIRS geolocation accuracy





RSB Performance: Major Highlights

- VNIR (I1, I2, M1-M7) band data available since opening of nadir door on 5 Dec 2022
- VNIR calibration coefficients (F-Predict LUT) updated on 12 Jan 2023 by extrapolation of SD-derived values
- SWIR (I3, M8-M11) band data available after detector temperature cool-down to 82 K on 10 Feb 2023 (Subsequent CFPA temperature setpoint change to 80K on 3 Mar 2023)
- Lunar calibrations on: 3/2, 4/1, 5/1 of 2023
- Spacecraft yaw maneuvers (to quantify SD BRDF) during 6~7 Mar 2023
- Unexpected issue: faster than expected SWIR band gain degradation (mitigated through periodic F-Predict LUT updates)

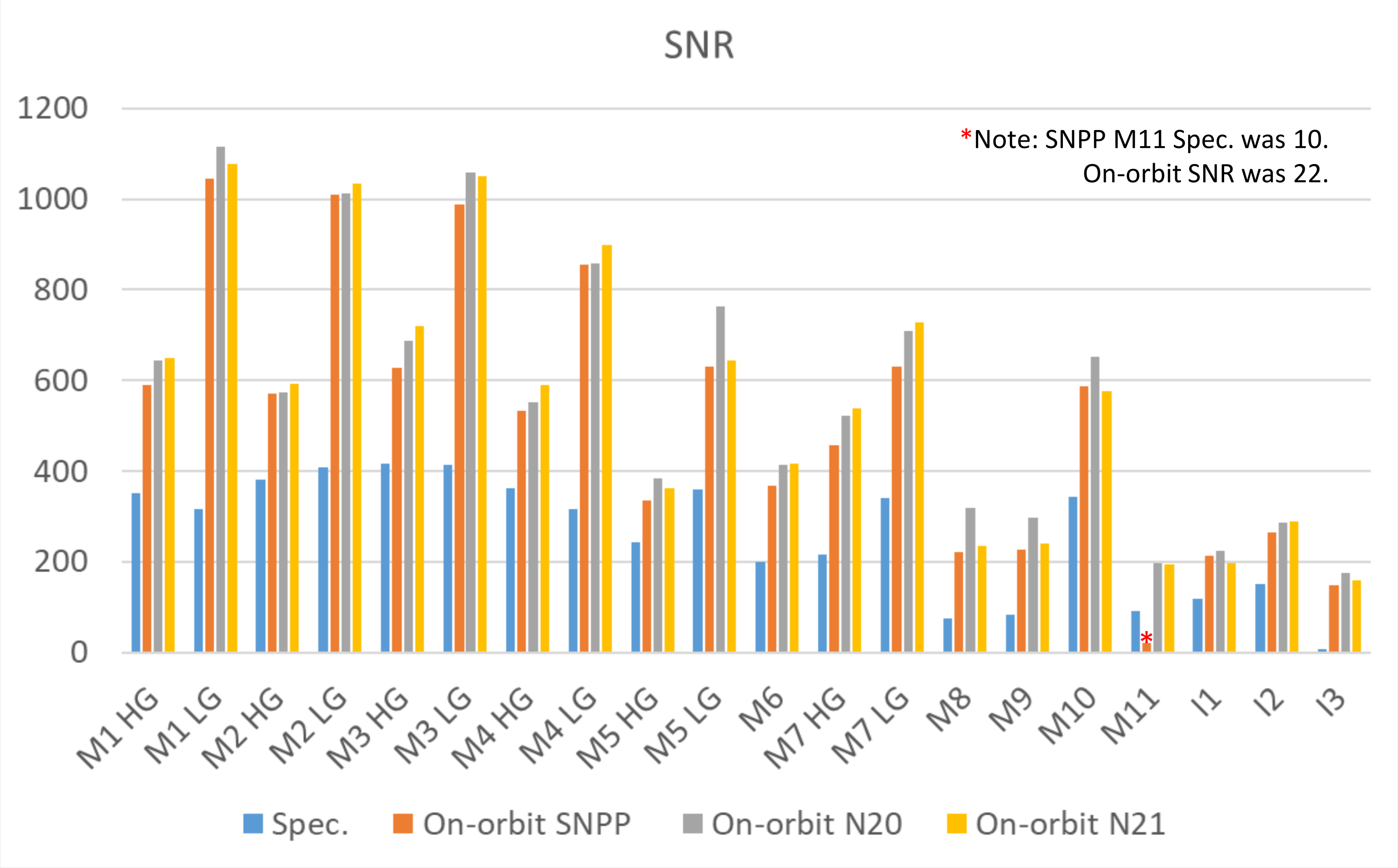


NOAA-21 VIIRS first light true color global image

(https://www.nesdis.noaa.gov/news/first-image-released-noaa-21-viirs-instrument)

RSB Signal-to-Noise Ratio (SNR)

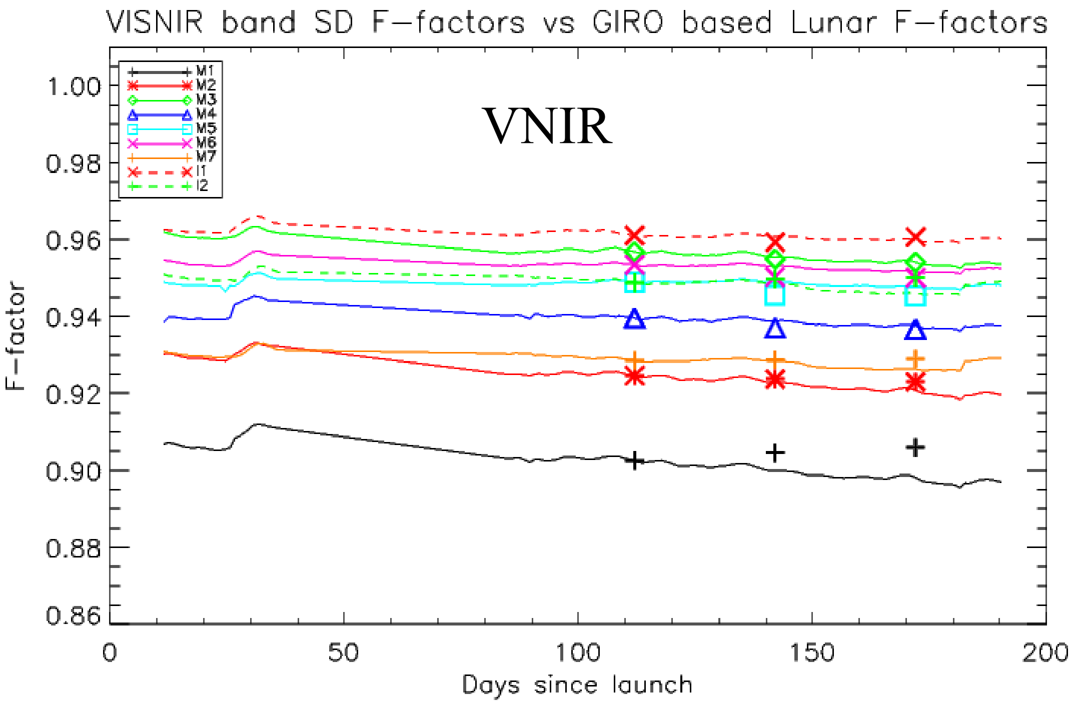
Band	L_{typ}	Spec.	SNR on-orbit
M1 HG	44.9	352	648
M1 LG	155	316	1076
M2 HG	40	380	591
M2 LG	146	409	1035
M3 HG	32	416	720
M3 LG	123	414	1049
M4 HG	21	362	589
M4 LG	90	315	898
M5 HG	10	242	362
M5 LG	68	360	645
M6	9.6	199	415
M7 HG	6.4	215	539
M7 LG	33.4	340	728
M8	5.4	74	234
M9	6	83	241
M10	7.3	342	577
M11	1	90	193
I1	22	119	198
I2	25	150	288
I3	7.3	6	158
L_{typ} unit: W/m^2-sr-µm			

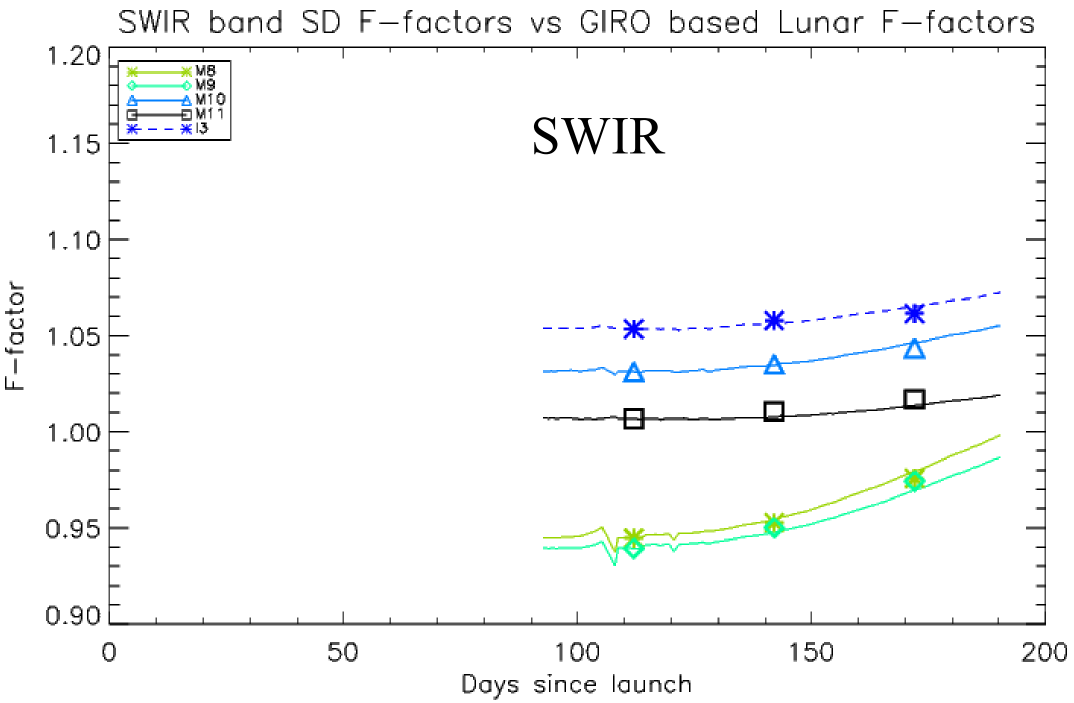


- RSB SNR is calculated from the Solar Diffuser observations on 3/26/2023
- SNR on-orbit of a given band is average over all detectors of the band
- The on-orbit SNR estimates meet the requirements for all RSBs

Lunar Calibration

- VIIRS lunar calibration conducted at least four times each year, often with a spacecraft roll maneuver
- Independent verification/correction of the SD reflectance degradation estimates
- Also, allows to evaluate spatial resolution, band-to-band registration and calibration biases



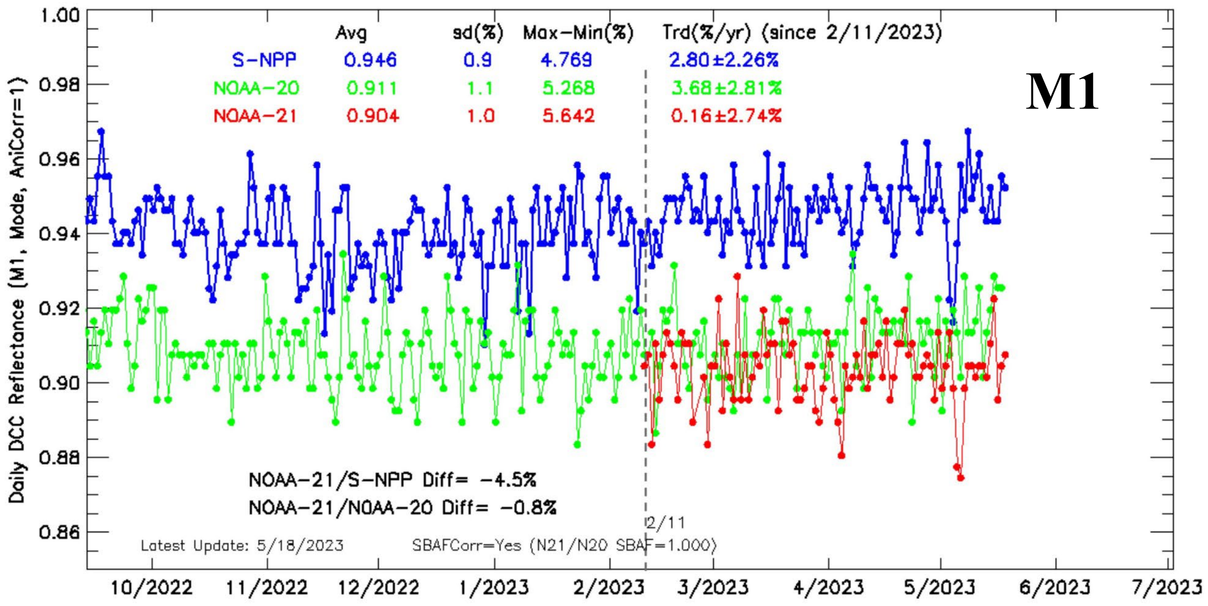


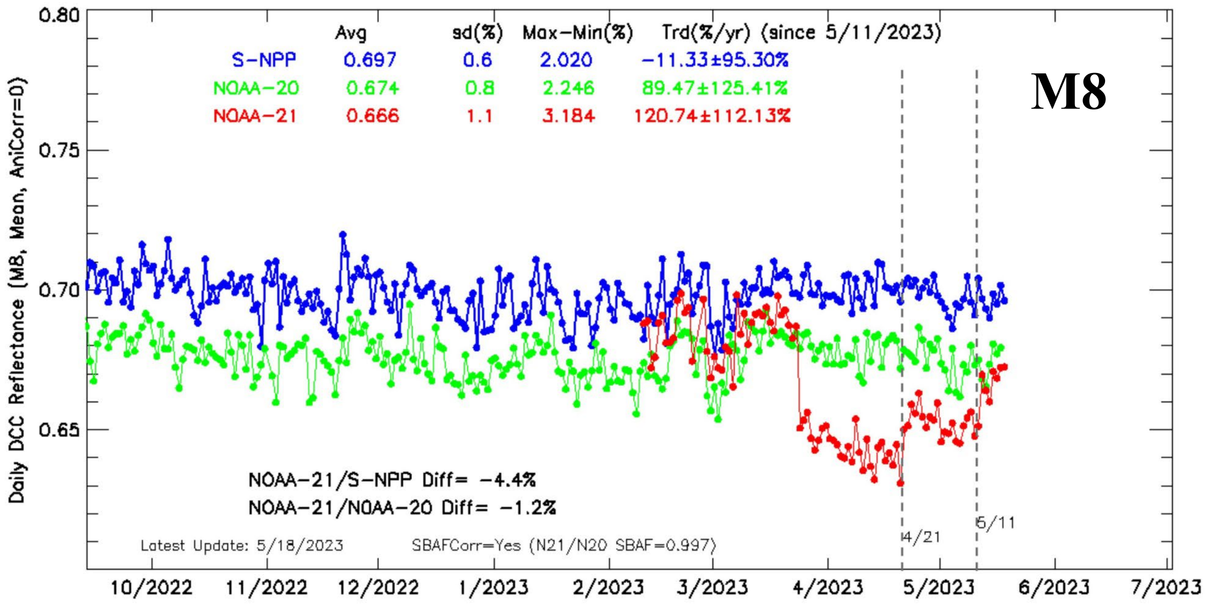
GIRO based lunar F-factors (symbols) vs. SD F-factors (lines)

RSB Comparisons over DCC

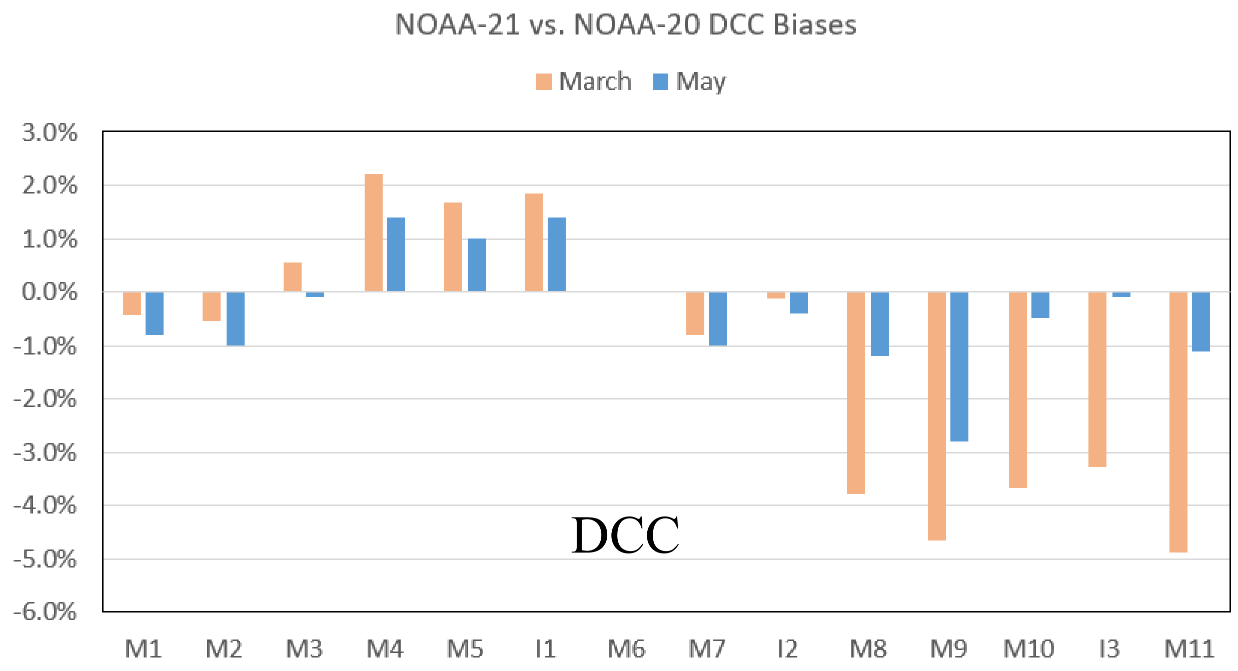
- The VNIR bands are in good agreement with NOAA-20:
  - Biases are with ±1.5%
  - Post-launch calibration F-Predict LUT update on 12 Jan 2023

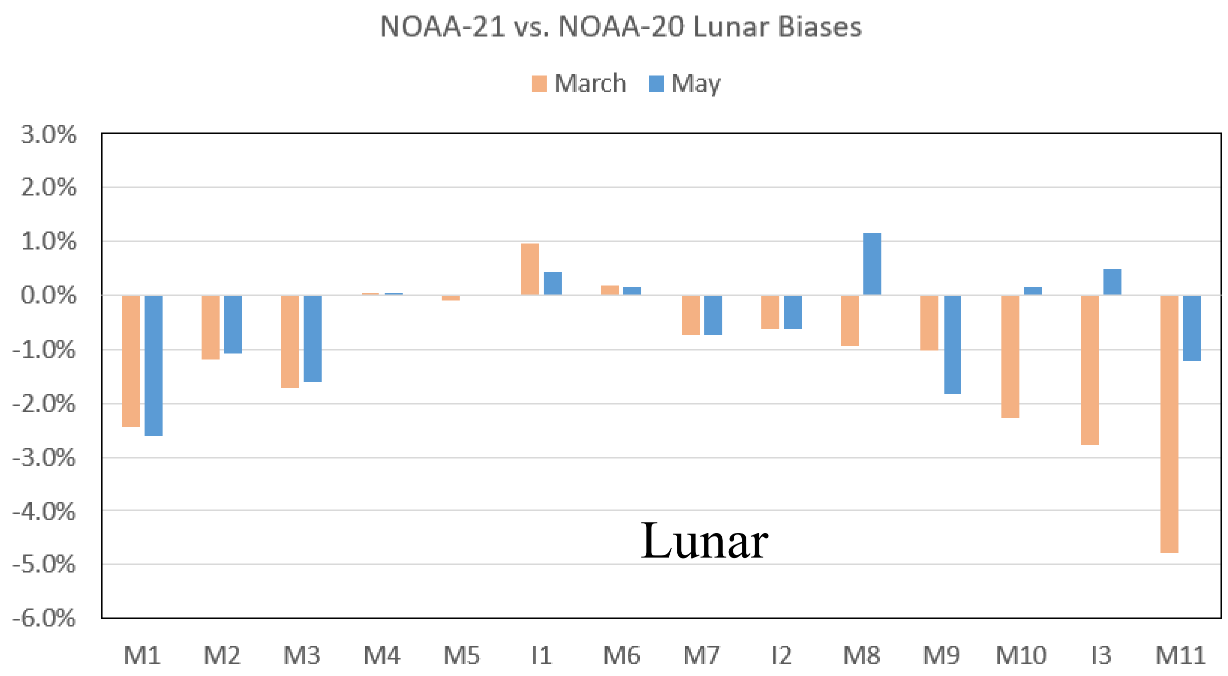
- The SWIR bands continue to get into closer agreement with NOAA-20 after calibration updates:
  - Biases are -1.5% or less, except for M9 (~ -3%)
  - Post-launch calibration F-Predict LUT updates: 23 Mar 2023, 21 Apr 2023, and 11 May 2023





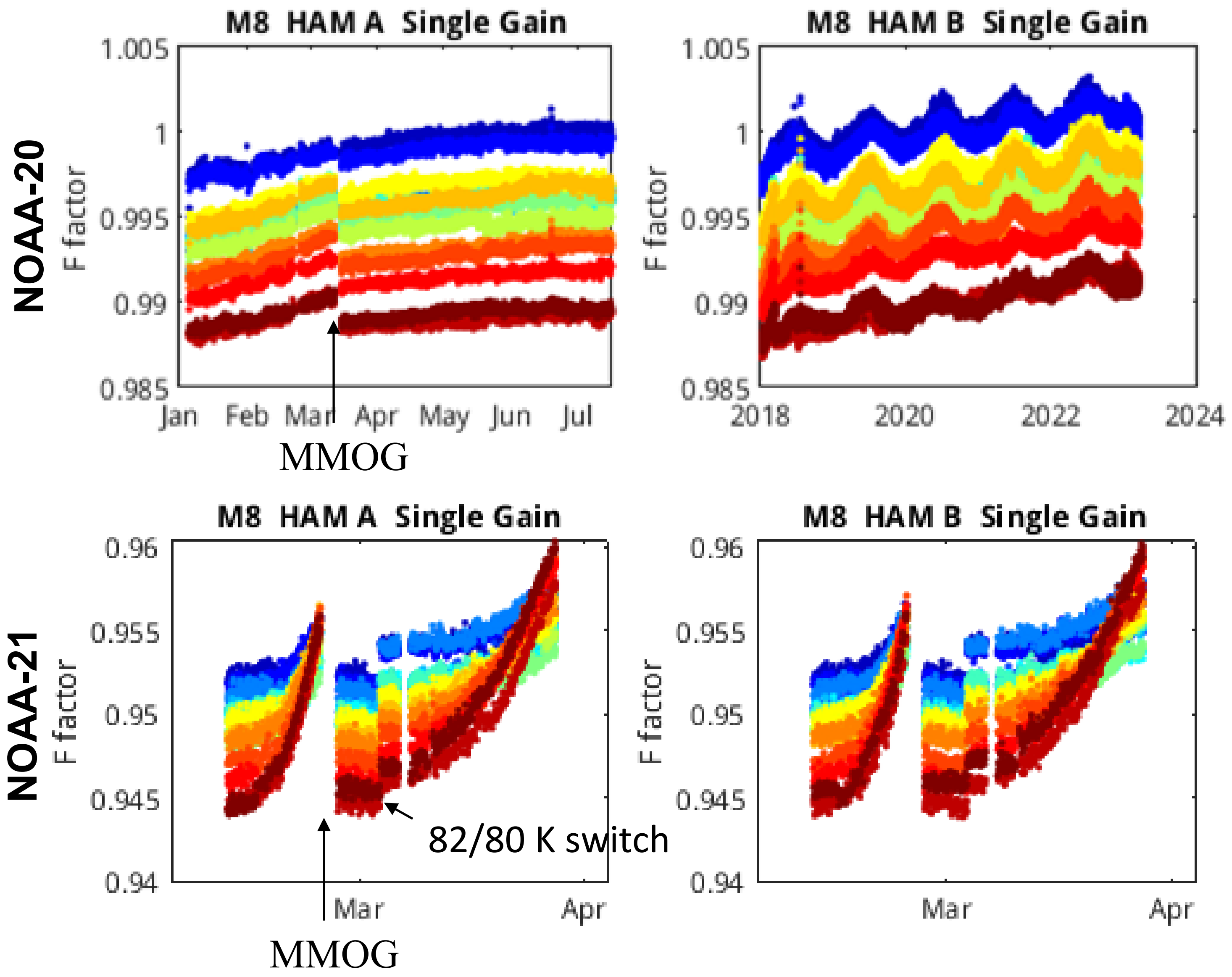
RSB Bias Comparisons





- The estimated biases are improved with time after calibration updates, especially for SWIR (I3, M8-M11) bands
- The preliminary lunar biases are generally in good agreement with DCC values:
  - Larger biases observed in some of the VNIR bands need further investigation

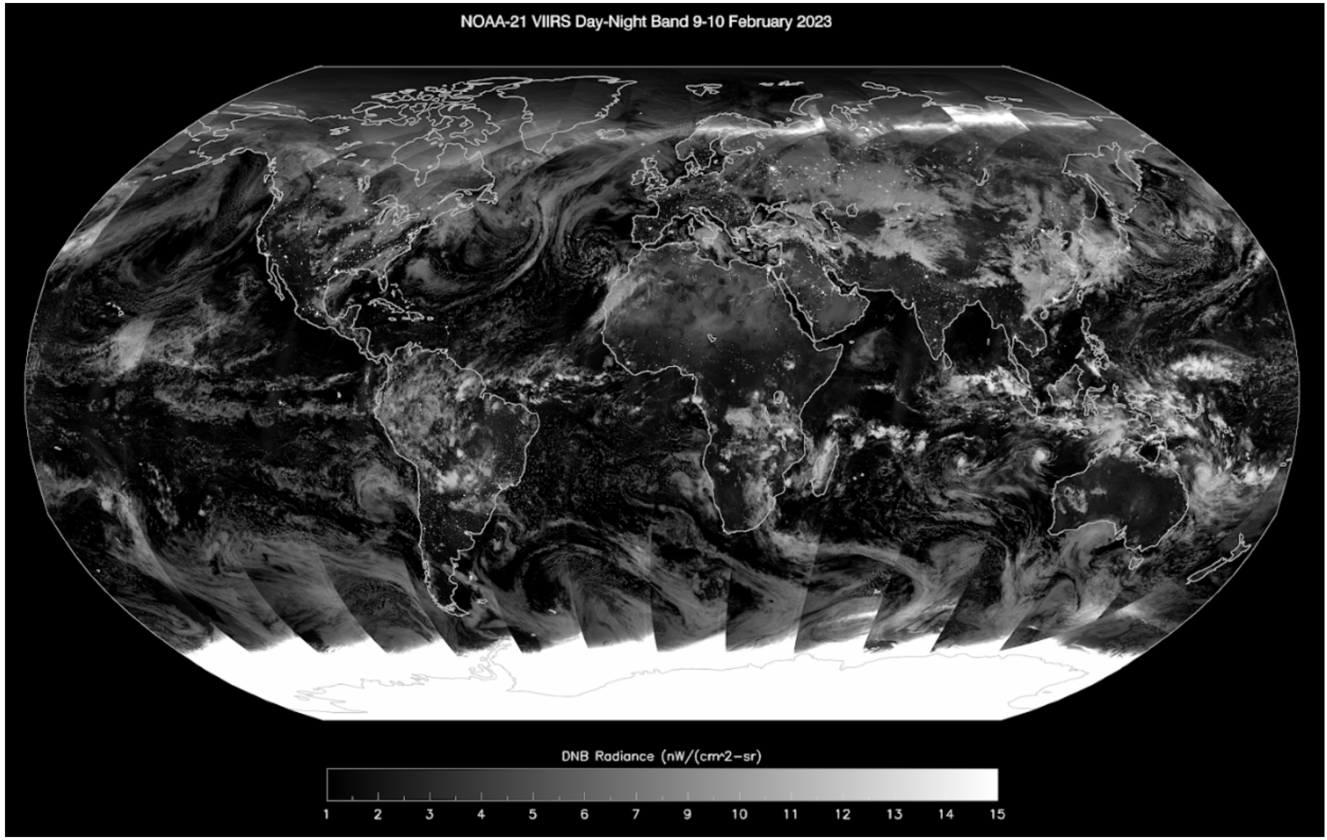
Unexpected Issue: SWIR Band “Degradation”



- The NOAA-20 increase (radiometric response degradation) for M8 before MMOG was very small: only about 0.1-0.2%
  - After MMOG, the changes include annual oscillations of about 0.2% and a slow increase over the years due to omitting solar diffuser degradation for the SWIR bands
- For NOAA-21, the increases for are much larger:
  - Upto ~ 15% by 5/31 (~ 3% / month)
  - Band dependent (largest for M8)
  - Detector dependent (largest for D#16)
  - Noticeable similarities to the trends before MMOG
- The radiometric calibration coefficients are being updated periodically

DNB Performance: Major Highlights

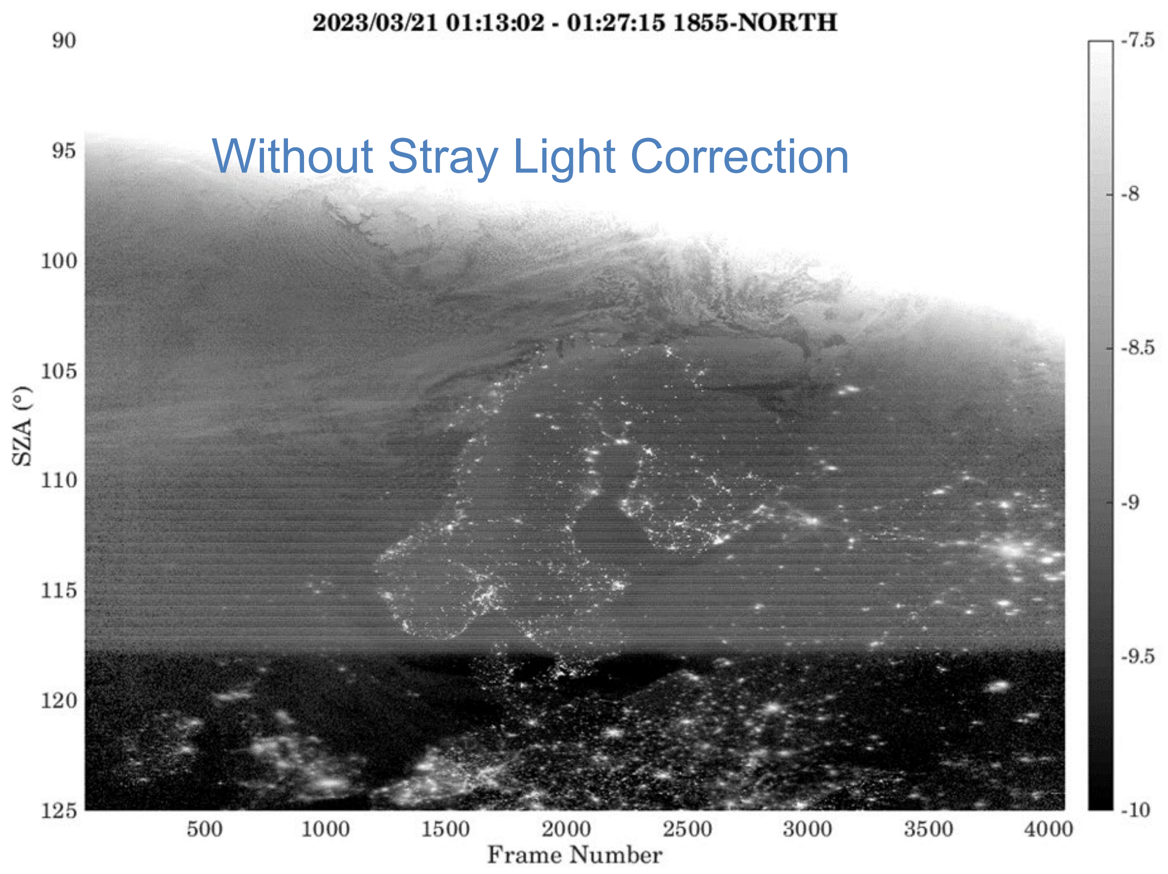
- DNB Focal Plane temperature stabilized on 9 Feb 2023 ~ 14:00 UTC
- New moon day DNB calibrations: 2/20, 3/21, 4/20, and 5/19:
  - Stray light correction, DN0, and Gain Ratios LUTs implemented in operations on since 3/30 with monthly updates afterwards
- Low gain stage (LGS) LUT was updated in IDPS on 3/23
- DNB onboard offset derived using pitch-maneuver (backflip) from 3/10. Uploaded to spacecraft on 3/17

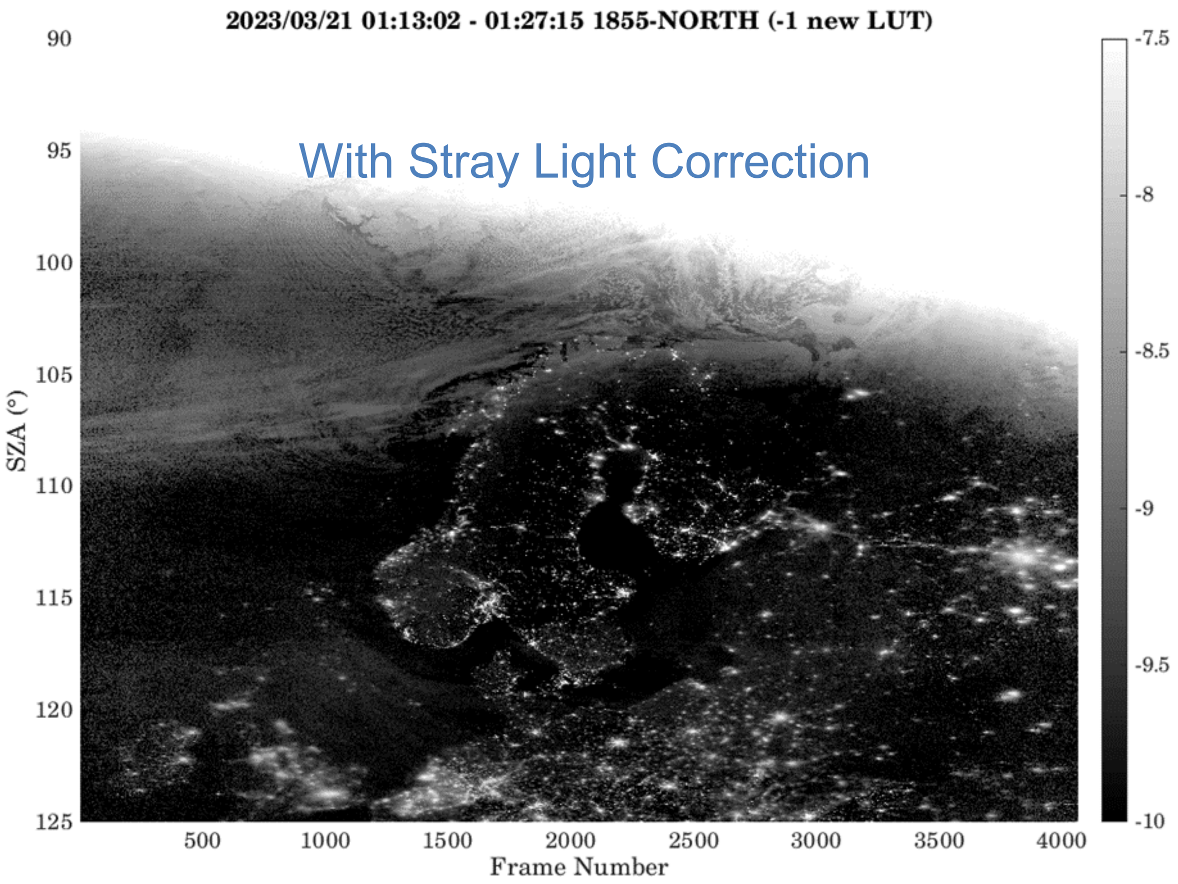


DNB First light image 9-10 Feb. 2023

DNB Stray Light Correction

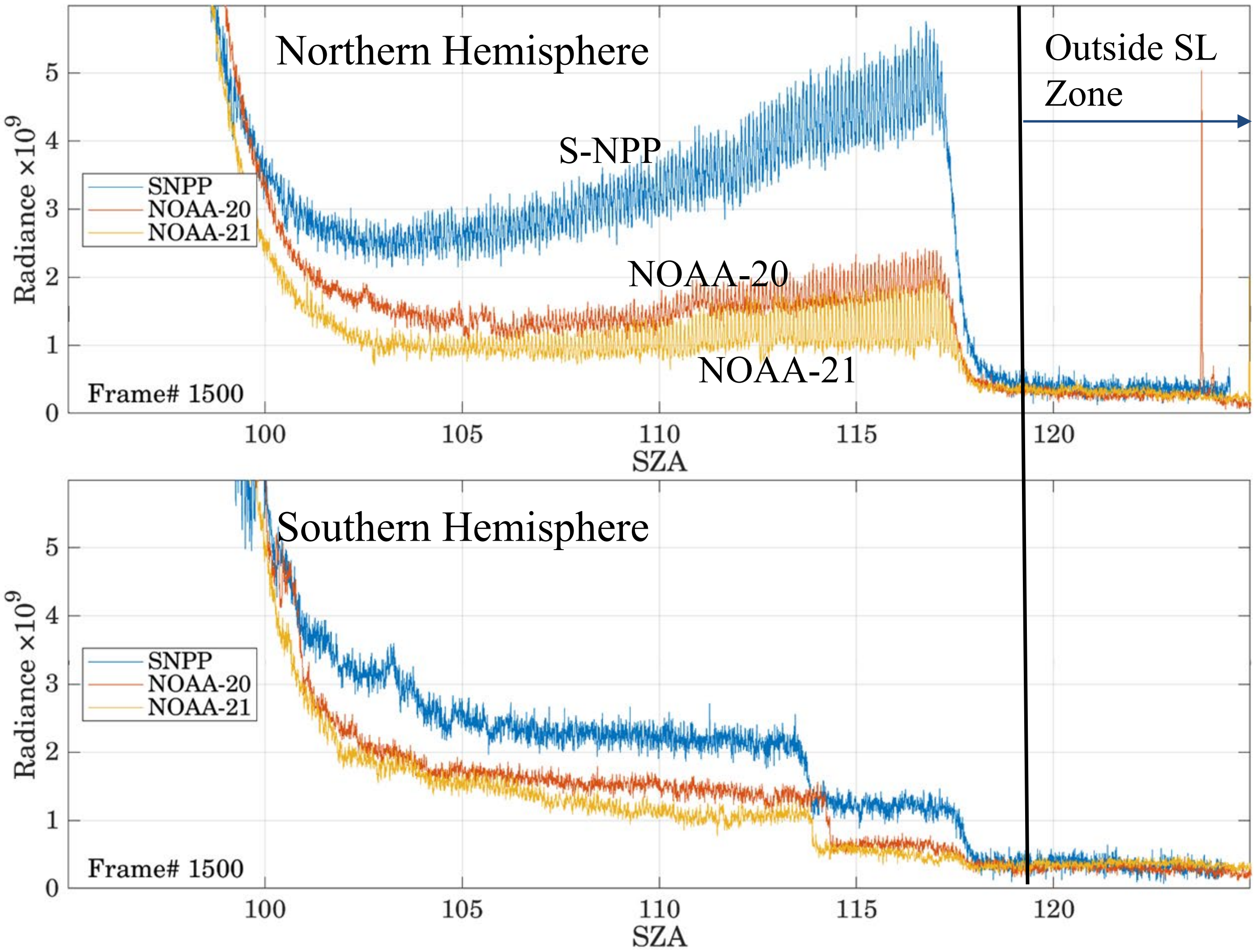
Northern Hemisphere





- DNB stray light observed over both the Northern and Southern Hemispheres
- Developed stray light correction tables from 3/21 new moon day data; Effective in IDPS after 3/30 00:10 UTC
- Twelve monthly DNB stray light correction LUTs will be developed using the following new moon day data

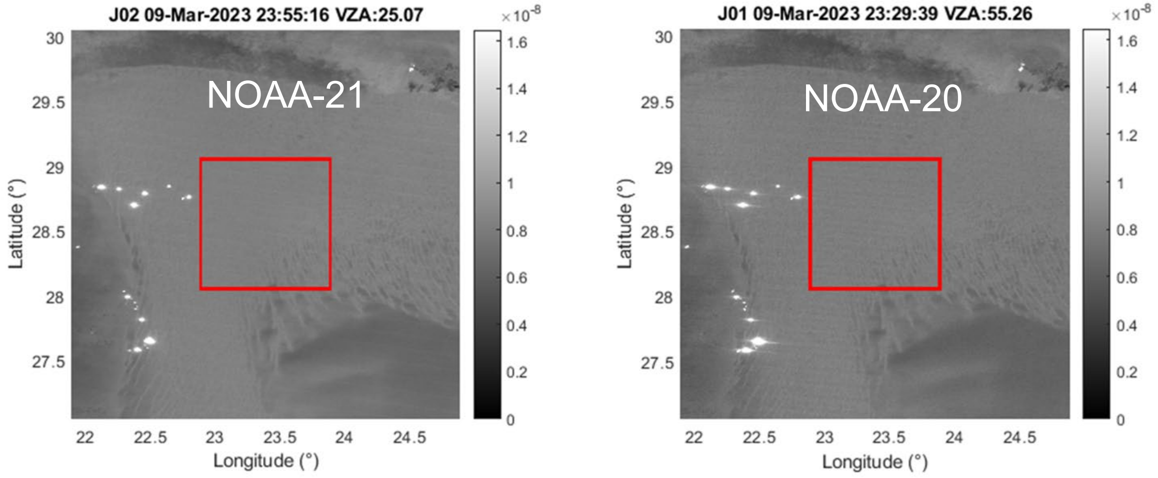
DNB Stray Light Comparisons

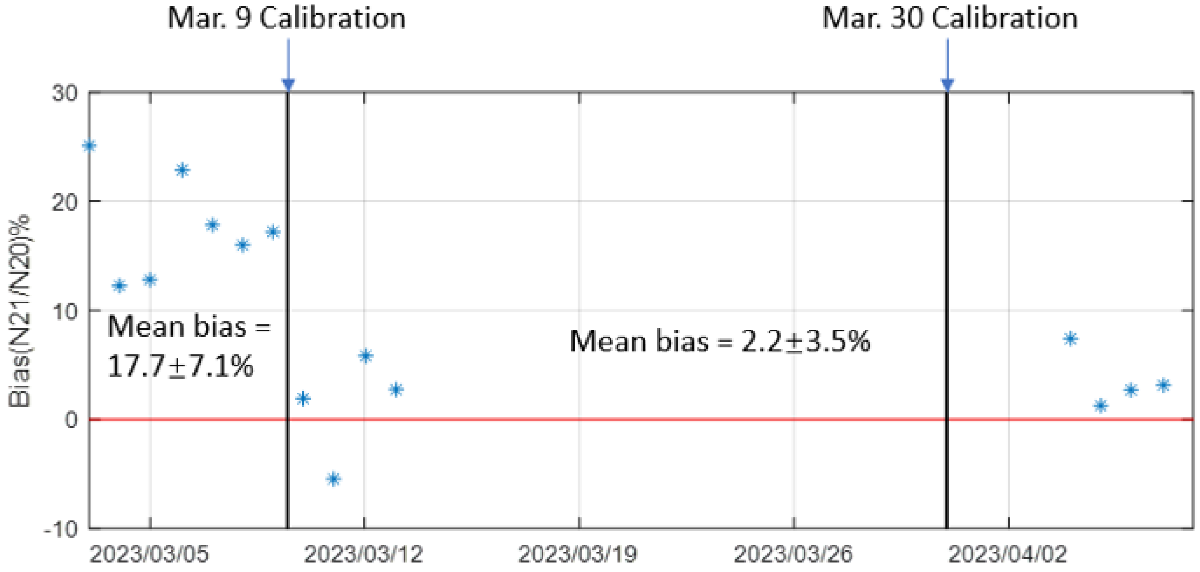


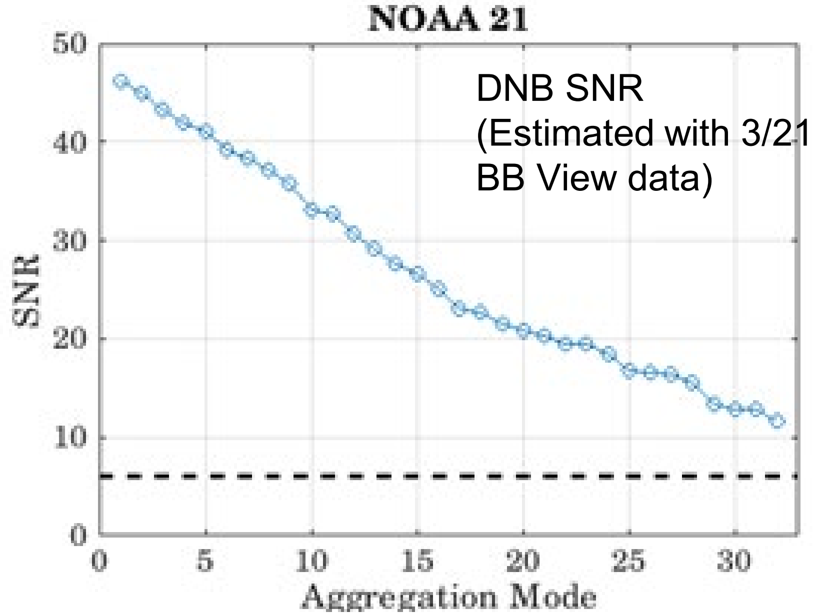
- NOAA-21 DNB stray light is significantly lower than SNPP and NOAA-20
- After the post launch calibration, NOAA-21 DNB stray light over both hemispheres were reduced by ~40 to 60% (depending on the along scan zone) in comparison to NOAA-20

DNB Radiometric Comparison

DNB Radiometric Bias Assessment
(over Libya-4 Desert under Moon Light)



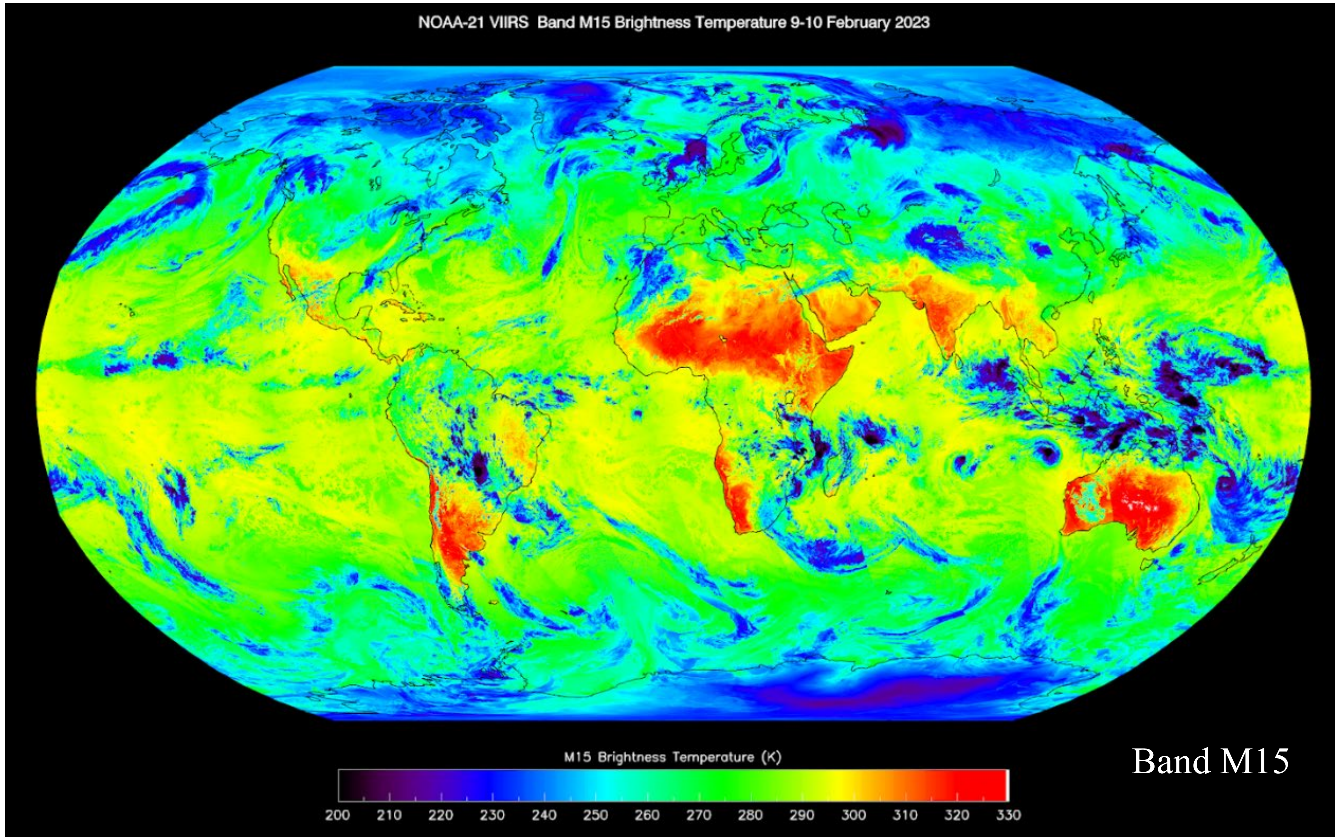




- NOAA-20 leads NOAA-21 by ~ 20-min
- Account for lunar phase difference with lunar irradiance model, lunar zenith angle and SRF difference
- Calibration updates reduced observed bias

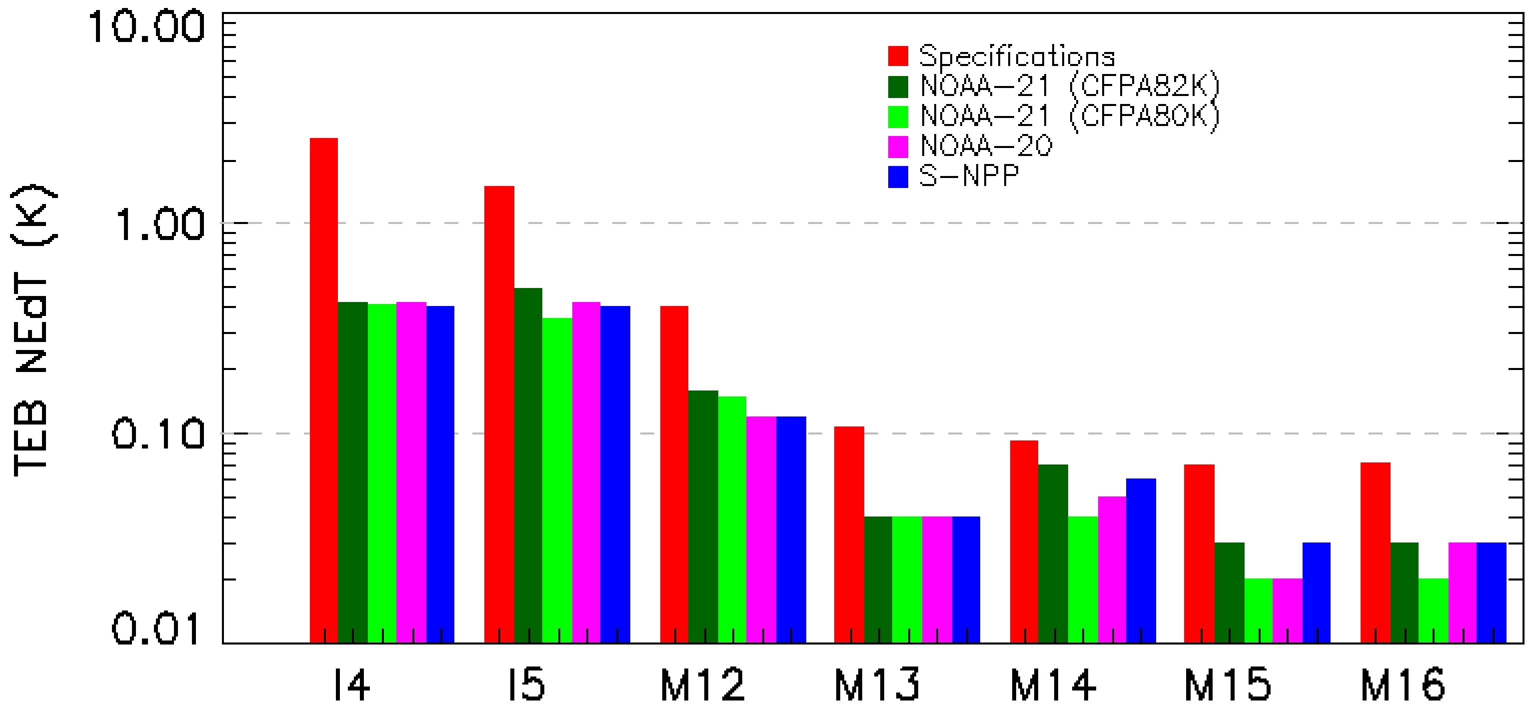
TEB Performance: Major Highlights

- Cryo-radiator door opened on 8 Feb 2023
- Cold Focal Plane Temperatures (CFPA) temperatures have stabilized to 82 K on late 10 Feb 2023
- Mid-mission outgassing (MMOG) was performed 23~26 Feb 2023 (mitigate contamination in Dewar)
- CFPA setpoint temperatures was switched to 80 K on 3 Mar 2023. A new TEB 80 K Delta-C LUT was developed, and implemented in operations on 30 Mar 2023
- Two blackbody warm-up/cool-down (WUCD) events were performed during Mar 10-13 and 16-18, respectively



First light Brightness Temperature image on 9-10 Feb. 2023

TEB Noise (NEdT)



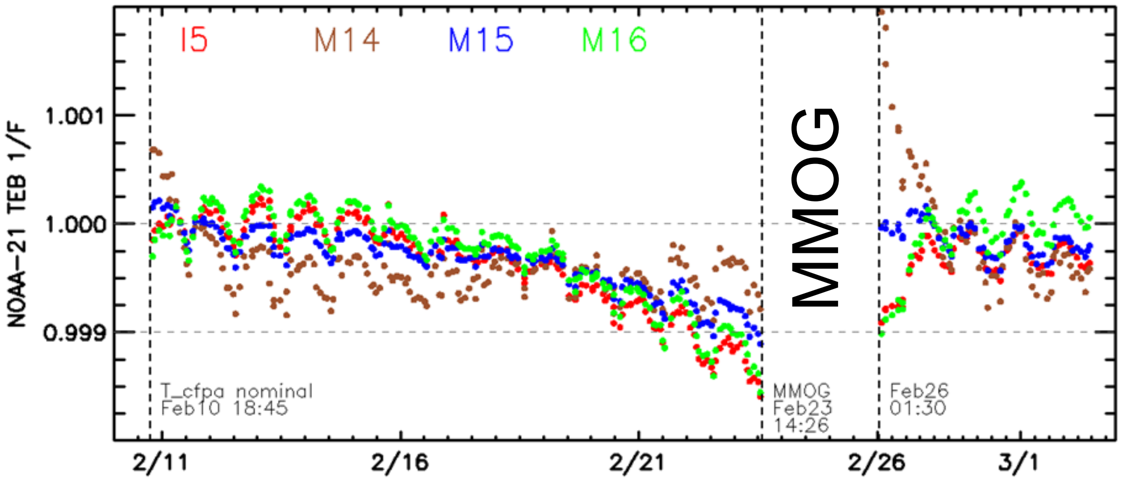
- NOAA-21 VIIRS TEB NEdTs are comparable to NOAA-20 / S-NPP:
  - All well within requirement specifications
  - LWIR NEdTs were further reduced after the CFPA setpoint temperature switched to 80K

TEB Gains

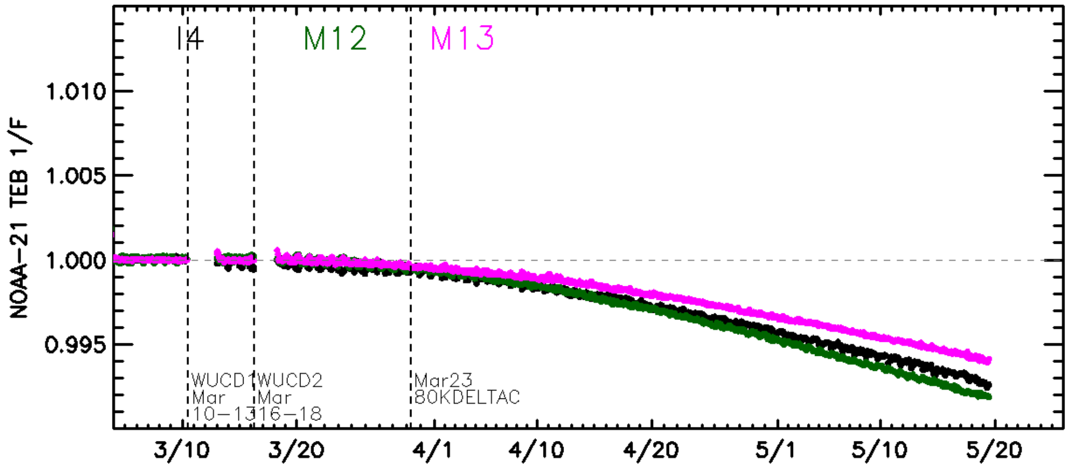
- NOAA-21 TEB calibration has been generally stable during nominal operations

- The MMOG (Feb 2023) successfully removed potential ice contamination:
  - Small degradations observed early in the mission (up to 0.15%).
  - After the MMOG, TEB gains returned to the similar levels as the beginning of the mission.

- The TEB MWIR (I4, M12-M13) gains have been continuously degrading since mid- March:
  - Band averaged degradations: ~ 0.8% for I4/M12; ~ 0.6% for M13
  - No significant effect on data quality since TEBs are calibrated on scan-by-scan basis



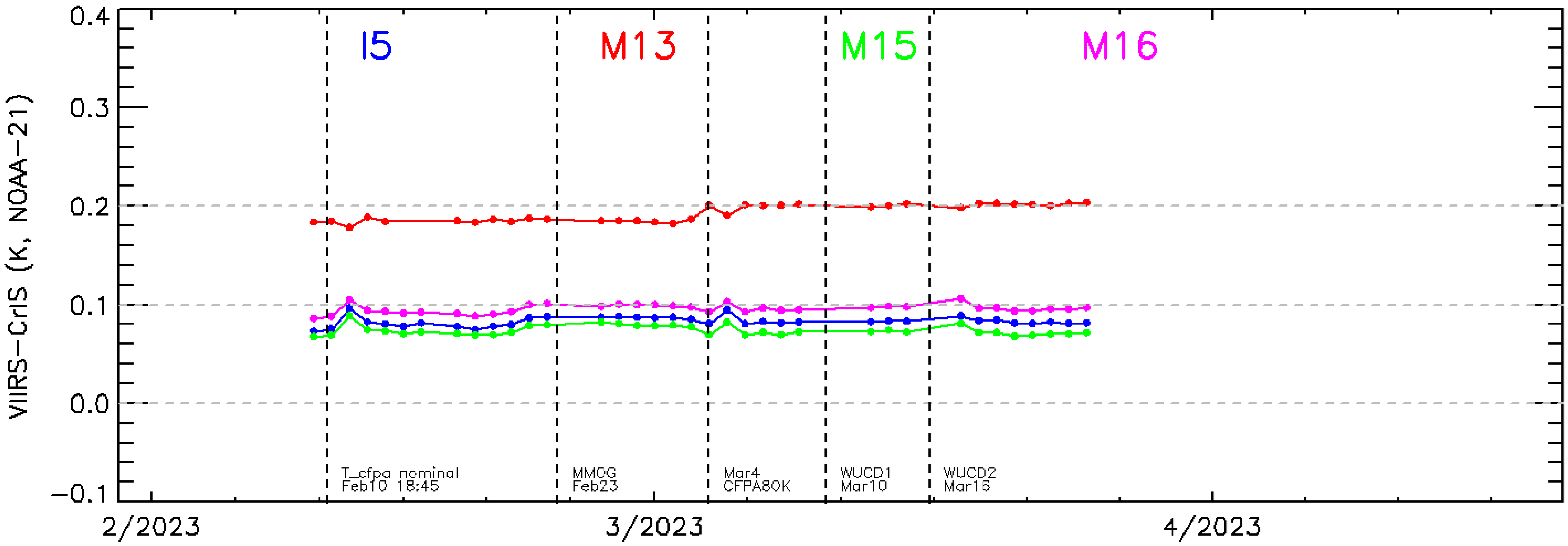
Normalized LWIR Gains



Normalized MWIR Gains

TEB Comparisons with CrIS Observations

- I5 and M15-M16 agree well with CrIS during nominal operations
  - Biases are within ~0.1 K, comparable to NOAA-20 and S-NPP
- M13 brightness temperature bias ~ 0.22 K
  - Slightly larger than that of NOAA-20 and S-NPP
  - NOAA-21 M13 is not fully covered by CrIS spectra, different from NOAA-20 and S-NPP



Summary & Path Forward

- Latest evaluations of NOAA-21 VIIRS post-launch SDR performance show:
  - Radiometric biases and image data quality are comparable to NOAA-20 & S-NPP VIIRS instruments
  - SNRs & NEdTs are consistent with pre-launch measurements and comply with requirements
  - RSB SWIR band degradation is faster than expected (closely monitored & mitigated through period calibration updates)
  - DNB image quality greatly improved after implementation of stray light LUTs on 3/30
  - TEB performance is stable (MWIR band degradations are closely monitored)
  - Geolocation performance is excellent (< 200m; sub-pixel)

- Path forward:
  - Monitor radiometric biases; prepare & submit LUT updates to implement improved calibration and error correction coefficients in the operational ground processing system
  - Continue developing & delivering monthly DNB stray light correction LUTs
  - Continue analyzing lunar calibration data to independently characterize SD degradation
  - Monitor & quantify geolocation accuracy
  - Achieve SDR product validated maturity – August of 2023

Backup Slides

Product Validation Maturity Stages

1. **Beta**
   - Product is minimally validated, and may still contain significant identified and unidentified errors.
   - Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
   - Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

2. **Provisional**
   - Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
   - Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
   - Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
   - Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

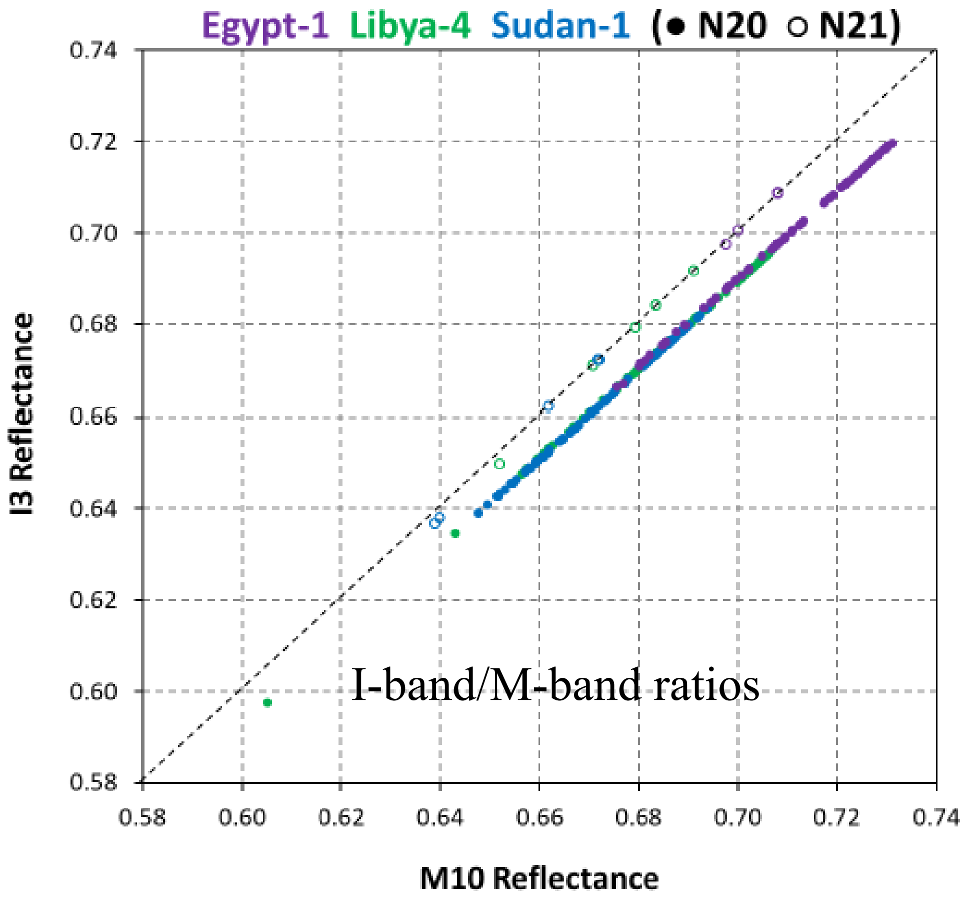
3. **Validated**
   - Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
   - Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
   - Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
   - Product is ready for operational use based on documented validation findings and user feedback.
   - Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

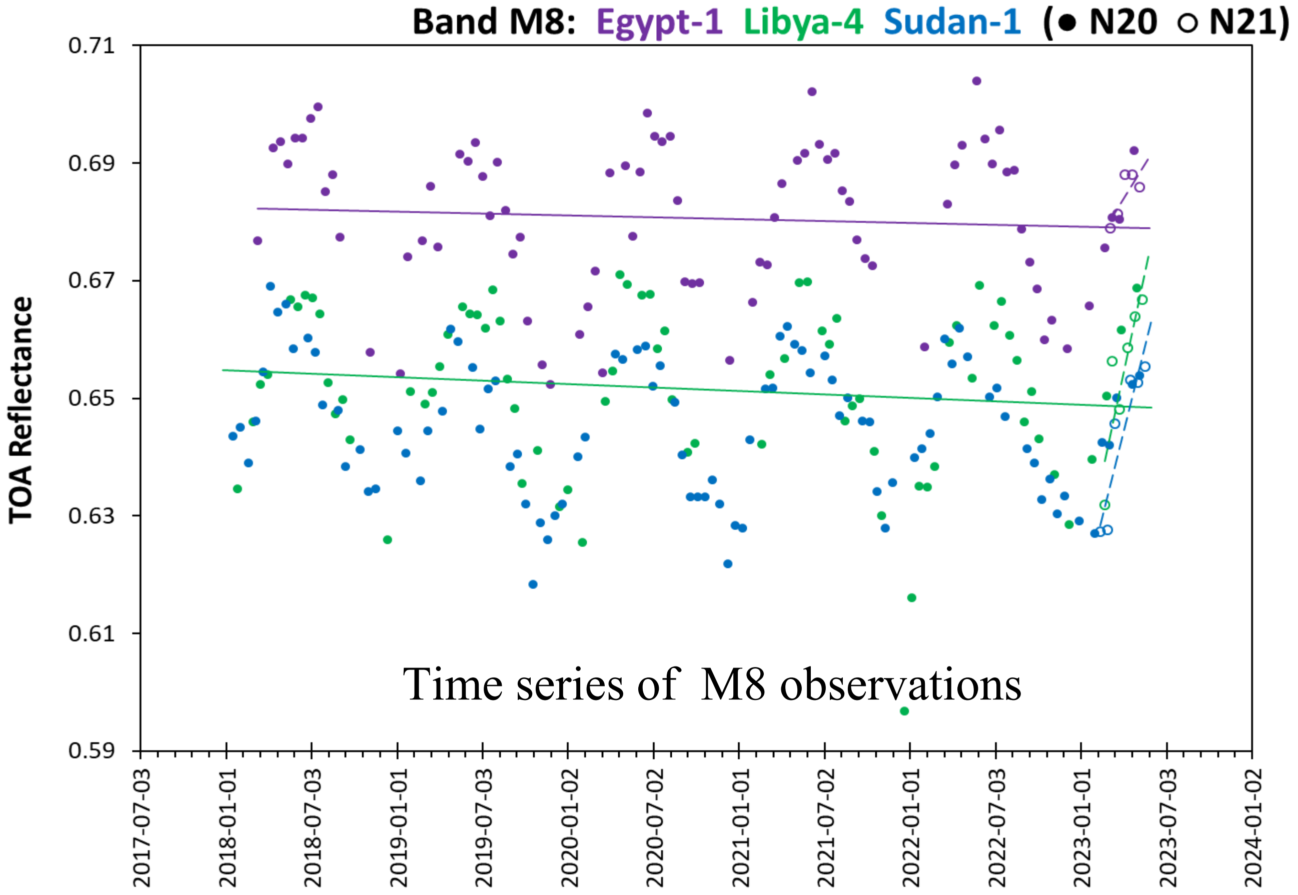
VIIRS SDR Requirements

Band		Center Wavelength (nm)	Maximum FOV @ Nadir (km)	Maximum FOV @ Edge-of-Scan (km)	Ltyp or Ttyp (spec)	Specification SNR (RSB & DNB) NEDT (TEB)	Accuracy Specification
RSB	**M1**	412	0.8	1.6	155, 44.9 (LG, HG)	316, 352 (LG,HG)	2%
	M2	445	0.8	1.6	146, 40 (LG, HG)	409, 380 (LG,HG)	2%
	M3	488	0.8	1.6	123, 32 (LG, HG)	414, 416 (LG,HG)	2%
	M4	555	0.8	1.6	90, 21 (LG, HG)	315, 362 (LG,HG)	2%
	M5	672	0.8	1.6	68, 10 (LG, HG)	360, 242 (LG,HG)	2%
	M6	746	0.8	1.6	9.6	199	2%
	M7	865	0.8	1.6	33.4, 6.4(LG, HG)	340, 215 (LG,HG)	2%
	M8	1240	0.8	1.6	5.4	74	2%
	M9	1378	0.8	1.6	6	83	2%
	M10	1610	0.8	1.6	7.3	342	2%
	M11	2250	0.8	1.6	1.0	90	2%
	I1	640	0.4	0.8	22	119	2%
	I2	865	0.4	0.8	25	150	2%
	I3	1610	0.4	0.8	7.3	6	2%
TEB	**M12**	3700	0.8	1.6	270	0.396	0.7% (0.13 K)
	M13	4050	0.8	1.6	380, 300 (LG, HG)	0.107, 0.423 (LG, HG)	0.7% (0.13 K)
	M14	8550	0.8	1.6	270	0.091	0.6% (0.26 K)
	M15	10763	0.8	1.6	300	0.07	0.4% (0.22 K)
	M16	12013	0.8	1.6	300	0.072	0.4% (0.24 K)
	I4	3740	0.4	0.8	270	2.5	5% (0.97 K)
	I5	11450	0.4	0.8	210	1.5	2.5% (1.5 K)
DNB	**DNB**	700	0.8	0.8	$3x10^{-9}$ (w/cm^2-sr)) (HG)	6	5%, 10%,30% (LG,MG,HG)

RSB Comparisons over Saharan PICS

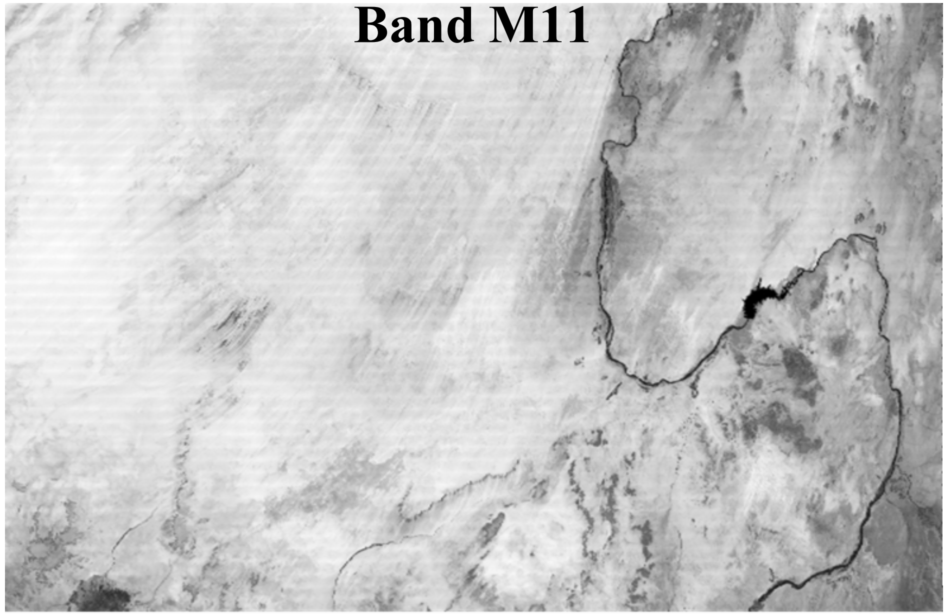
- The PICS data from March and April 2023 were reprocessed using the latest F- PREDICTED LUT
- The updated SWIR bias corrections maintain the good I3/M10 agreement observed with the pre launch calibration
- Slightly larger differences visible for data from February 2023 when the detectors were still at 82 K and the constant F factor LUT was applied



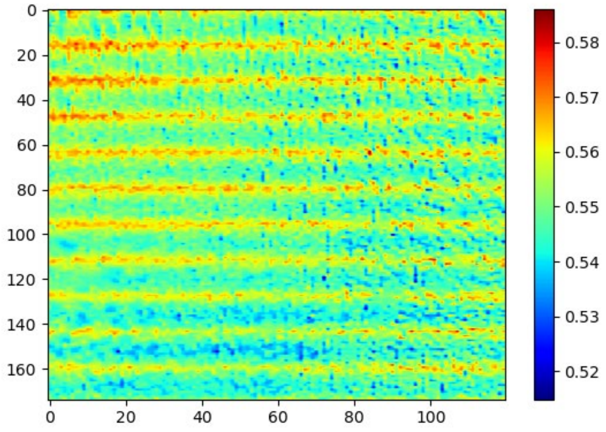


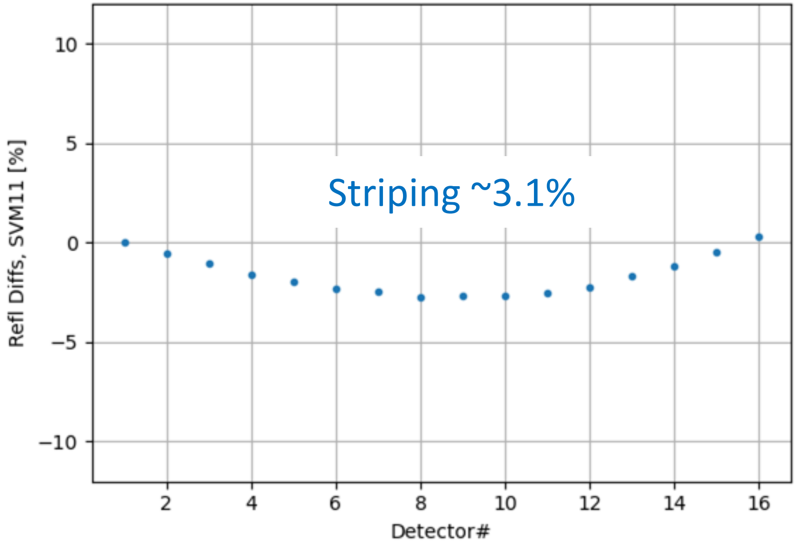
Striping Reduction in Saharan Image

Band M11



Pre-launch Calibration





Post-launch Calibration