

JPSS-4 VIIRS version 2 at-launch relative spectral response characterization

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ABSTRACT

The JPSS-4 VIIRS sensor, the last in a JPSS program that will eventually span some 25+ years of on-orbit data collection, has completed its pre-launch test program. The test program included measurements for characterizing the VIIRS relative spectral response (RSR) in support of the Sensor and Environmental Data Records that will be generated from JPSS-4 VIIRS on-orbit observations after launch. Subject matter experts of the Government Team's VIIRS DAWG have analyzed the VIIRS spectral measurements and produced the VIIRS spectral characterization, in the form of band averaged and supporting detector level RSR for each VIIRS band. The characterization is based upon the analysis of independent SpMA dual monochromator (all bands) and GSFC GLAMR laser system (reflectance bands only) spectral measurements. The SpMA and GLAMR measurements for reflectance bands (DNBLGS and DNBMGs, I1-I3, M1-M11) were combined to produce a "fused" RSR. For emissive bands (I4, I5, M12-M16), the SpMA measurements provide the entire characterization. The effort has led to the VIIRS Version 2 RSR product, the official at-launch RSR characterization for the JPSS-4 VIIRS mission, which is currently slated to be the next launch (expected Fall 2027) of the JPSS program. As expected, the JPSS-4 RSR are a close match to those of JPSS-3 and JPSS-2 (NOAA-21) VIIRS, while showing some spectral position and shape differences with SNPP and JPSS-1 (NOAA-20) VIIRS. An assessment on compliance with spectral performance metrics finds that VIIRS band-average RSR are compliant on nearly all metrics, with only a single minor exception. The Version 2 RSR will be available under EAR99 restrictions to the science community on the restricted access NASA Sharepoint.

Keywords: JPSS-4, VIIRS, RSR, Spectral, GLAMR, SDR

1. INTRODUCTION

The Joint Polar Satellite System-4 (JPSS-4) Visible Infrared Imaging Radiometer Suite (VIIRS) sensor^[1] is the fifth and final VIIRS in the series: F1 (SNPP) launched in 2011, JPSS-1 (NOAA-20) launched in 2017, JPSS-2 (NOAA-21) launched in 2022, and JPSS-3 in storage for a 2032 launch. VIIRS is a filter radiometer with 5 imager "I" bands at 375 m resolution and 16 moderate "M" bands at 750 m resolution (note: bands M16A and M16B are time delay integrated into a single M16 band) plus a multi-stage day-night band (DNB). VIIRS uses a rotating telescope assembly (RTA) to view an onboard solar illuminated diffuser panel and a high emissivity blackbody plus deep space to calibrate the reflectance solar band (RSB) and thermal emissive band (TEB) earth observations into radiances. The radiometric calibration relies in part on a high quality spectral characterization of the VIIRS bands to produce climate quality radiances for the earth-atmosphere observations.

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Table 1. JPSS-4 VIIRS specifications and measured spectral performance of the V2 band-average RSR. Red box indicates non-compliance with the specification.

Focal Plane Legend: - VisNIR; - S/MWIR; - LWIR

Band	Specified Center (nm)	Measured Center (nm)	Specified 50% Bandpass (nm)	Measured 50% Bandpass (nm)	Specified Lower 1% Limit (nm)	Measured Lower 1% Limit (nm)	Specified Upper 1% Limit (nm)	Measured Upper 1% Limit (nm)	Specified MIOOB (%)	Measured MIOOB (%)
I1	640 ±6	641.1	80 ±6	79.2	≥565	594.4	≤715	687.7	0.5	0.11
I2	865 ±8	867.8	39 ±5	38.5	≥802	835.8	≤928	897.8	0.7	0.19
I3	1610 ±14	1612.5	60 ±9	63.4	≥1509	1547.8	≤1709	1687.6	0.7	0.37
I4	3740 ±40	3754.0	380 ±30	379.7	≥3340	3485.1	≤4140	4031.5	0.5	0.17
I5	11450 ±125	11527.5	1900 ±100	1838.4	≥9900	10438.3	≤12900	12732.5	0.4	0.09
M1	412 ±2	410.2	20 ±2	21.3	≥376	397.3	≤444	423.7	1.0	0.13
M2	445 ±3	444.9	18 ±2	17.0	≥417	434.4	≤473	456.5	1.0	0.18
M3	488 ±4	488.2	20 ±3	20.1	≥455	475.9	≤521	501.2	0.7	0.16
M4	555 ±4	555.4	20 ±3	21.2	≥523	541.9	≤589	568.8	0.7	0.19
M5	672 ±5	671.3	20 ±3	20.7	≥638	651.3	≤706	693.6	0.7	0.44
M6	746 ±2	747.0	15 ±2	14.8	≥721	736.1	≤771	758.2	0.8	0.25
M7	865 ±8	868.1	39 ±5	38.5	≥801	836.0	≤929	898.0	0.7	0.23
M8	1240 ±5	1241.1	20 ±4	20.5	≥1205	1225.3	≤1275	1255.8	0.8	0.19
M9	1378 ±4	1381.9	15 ±3	15.1	≥1351	1368.9	≤1405	1398.0	1.0	0.34
M10	1610 ±14	1612.9	60 ±9	63.9	≥1509	1548.1	≤1709	1688.3	0.7	0.37
M11	2250 ±13	2252.9	50 ±6	47.9	≥2167	2207.8	≤2333	2295.6	1.0	0.28
M12	3700 ±32	3685.6	180 ±20	192.4	≥3410	3527.3	≤3990	3868.7	1.1	0.31
M13	4050 ±34	4024.7	155 ±20	155.0	≥3790	3870.3	≤4310	4179.2	1.3	0.35
M14	8550 ±70	8564.7	300 ±40	345.9	≥8050	8233.0	≤9050	8904.2	0.9	0.35
M15	10763 ±113	10666.5	1000 ±100	951.6	≥9700	10019.0	≤11740	11346.3	0.4	0.18
M16A	12013 ±88	11934.9	950 ±50	964.5	≥11060	11277.1	≤13050	12673.5	0.4	0.19
M16B	12013 ±88	11935.9	950 ±50	963.7	≥11060	11278.6	≤13050	12672.1	0.4	0.19
M16 ¹	12013 ±88	11935.4	950 ±50	964.1	≥11060	11277.8	≤13050	12672.9	0.4	0.19
DNBMGS ²	700 ±14	697.2	400 ±20	397.5	≥470	490.4	≤960	920.7	0.1	0.02
DNBLGS	700 ±14	692.6	400 ±20	396.9	≥470	484.5	≤960	923.3	0.1	0.10

¹M16 is an average of M16A and M16B.

²DNBMGS spectral characterization also represents DNBHGS. DNBHGS not measured due to its high gain.

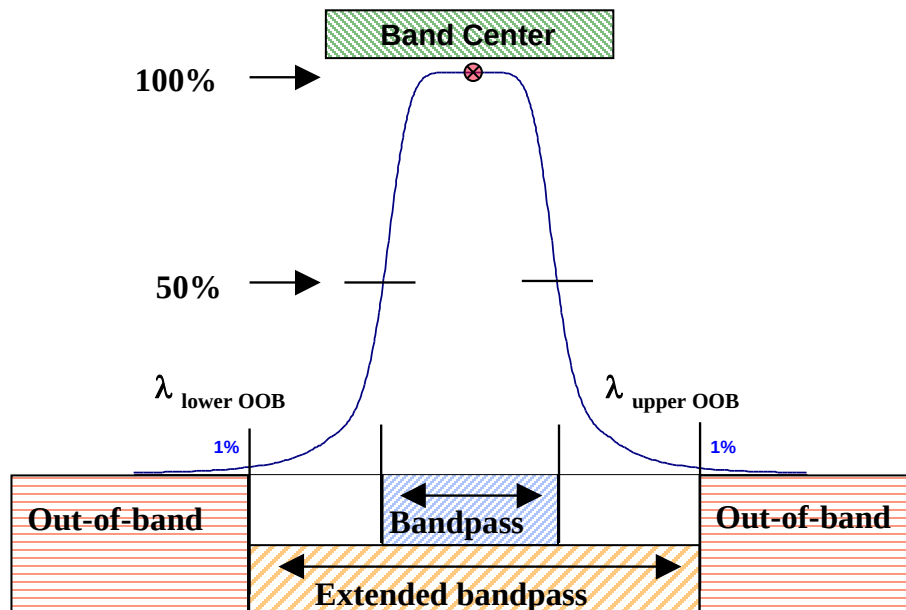


Figure 1. Graphical representation of VIIRS spectral performance specification metrics.

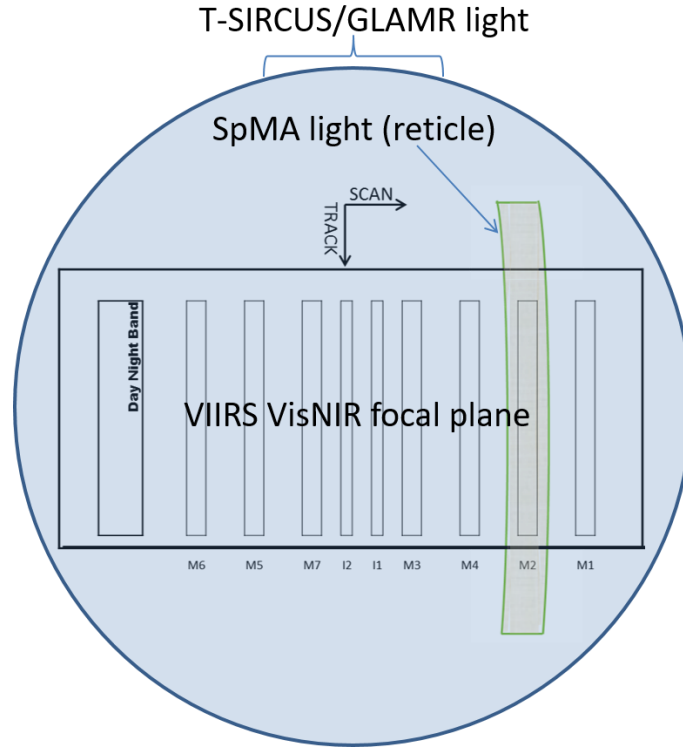


Figure 2. Illustration of focal plane illumination during SpMA (brown shading) and GLAMR (blue shading) spectral measurements. (Note: T-SIRCUS laser system used for SNPP and NOAA-20; GLAMR laser system used for NOAA-21, JPSS-3 and JPSS-4).

The JPSS-4 VIIRS pre-launch performance test program at the Raytheon El Segundo facility began late in 2021 and extended into early 2024 after a one year delay in the Thermal Vacuum Test Phase. The pre-launch performance characterization included, among other elements, spectral measurements of all VIIRS bands except the DNB high gain stage (HGS) which isn't included in the test program. Consistent with previous VIIRS builds the JPSS-4 VIIRS spectral measurements consisted of dual monochromator measurements using the Spectral Measurement Assembly (SpMA)^[2] for all bands except HGS plus complementary laser-based measurements by the Goddard Laser for Absolute Measurement of Radiance (GLAMR)^[3] for all RSB (M1-M11, I1-I3, DNBLGS and DNBMGs). For RSB, the SpMA and GLAMR measurements were analyzed independently and then merged or “fused” for the final RSR characterization. The analysis of the pre-launch spectral measurements has been completed yielding the Government Team's Version 2 (V2) “at-launch” relative spectral response (RSR) for JPSS-4 VIIRS. The at-launch RSR support the development of Look-Up Tables (LUTs) used by the VIIRS sensor data record (SDR) and environmental data record (EDR) algorithms as well as the NASA L1B algorithm. Spectral performance compliance of VIIRS is assessed on four metrics: Band Center, Bandpass (at 50% response level), Extended Bandpass (at 1% response level), and Maximum Integrated Out-of-Band (MIOOB) contribution (as a percent of the total RSR). The spectral metrics for the measured VIIRS bands are given in Table 1 with their definitions shown graphically in Figure 1.

2. MEASUREMENTS AND RSR ANALYSIS PROCEDURE

The JPSS-4 VIIRS measurements yielded similar high quality output to that of JPSS-3 VIIRS for the development of the RSRs. The SpMA and GLAMR spectral measurements and subsequent data analysis methodology for JPSS-4 VIIRS closely followed that of JPSS-3^[4] and NOAA-21^[5,6].

The SpMA and GLAMR-based spectral measurements of VIIRS are system measurements, i.e. full sensor optical path, bandpass filters, and detectors, and provide spectral coverage of the full in-band and out-of-band regions (see Figure 1). The SpMA measurements, known as “FP-15” (in-band) and “FP-16” (out-of-band), use monochromatic light with a slit over the source to constrain the illumination to a single VIIRS band (Figure 2) for identifying the in-band spectral response plus any out-of-band filter leaks in that band. Each VIIRS band (DNBLGS, DNBMGs, M1-M16A/B, I1-I5) was measured independently by the SpMA. The analysis process for each band is broadly described as follows:

1. Review and select FP-15 and FP-16 RSR measurements and relative spectral output (RSO) source characterization.
2. Average the VIIRS digital output and perform background subtraction for each wavelength.
3. Remove source spectral and temporal dependencies at each wavelength by dividing by the RSO characterization. Normalize the resulting FP-15 and FP-16 spectral responses to their respective peak response.
4. Insert the FP-15 RSR into the FP-16 RSR to create a full (in-band + out-of-band) RSR.
5. Determine and apply a threshold based on a band-average signal-to-noise (SNR) statistic to stratify data into high quality (light-driven) and low quality (noise-driven) response.
6. Average the high quality response over all detectors and assign a specified low response fill value (e.g. $1E-10$) to the low quality wavelengths.
7. The end result of this process is a band-average (over all detectors) RSR for each VIIRS band (except HGS) based upon the SpMA spectral measurements.

As opposed to use of a slit during FP-15/-16 measurements, the GLAMR-based spectral measurements use monochromatic light sent via fiber optic cable through an integrating sphere to illuminate the entire VIIRS focal plane (“flood” illumination) for each measured wavelength. Measuring with flood illumination yields an integrated response that includes in-band spectral response and out-of-band filter leaks plus any optical or electronic crosstalk that may be occurring on the focal plane in a “flight-like” measurement. For JPSS-4, the GLAMR lasers were tunable from about 360 nm out to about 2500 nm, providing spectral in-band + out-of-band coverage for RSB (DNBLGS, DNBMGs, M1-M11, I1-I3) to a maximum wavelength of 2500 nm. The analysis of GLAMR measurements is described as:

1. Average the VIIRS digital output and perform background subtraction for each wavelength.
2. Remove source dependence at each wavelength by dividing by the NIST-calibrated GLAMR monitor radiance. Normalize the resulting spectral response to its peak response.
3. Remove inconsistent/rogue response data in the GLAMR-based RSR. This removes out-of-family wavelengths and sweeps that have generally met baseline performance characteristics but remain out-of-family in their response.
4. Determine and apply a band-average SNR statistic threshold to the GLAMR-based RSR to distinguish high (light-driven) from low (noise-driven) quality response.
5. Average the high quality response over all detectors and remove all low quality response.
6. The end result of this process is a band-average (over all detectors) RSR for each VIIRS RSB to a maximum wavelength of 2500 nm based upon the GLAMR spectral measurements.

Two additional steps are required to fuse the GLAMR-based and SpMA-based measurements for RSB:

7. Merge high quality GLAMR-based RSR with SpMA-based RSR to form a fused RSR. The spectral gaps left by discarding the low quality response in the GLAMR-based RSR are filled with SpMA-based response. Any SpMA-based response outside the spectral boundaries of the GLAMR-based response is also added.

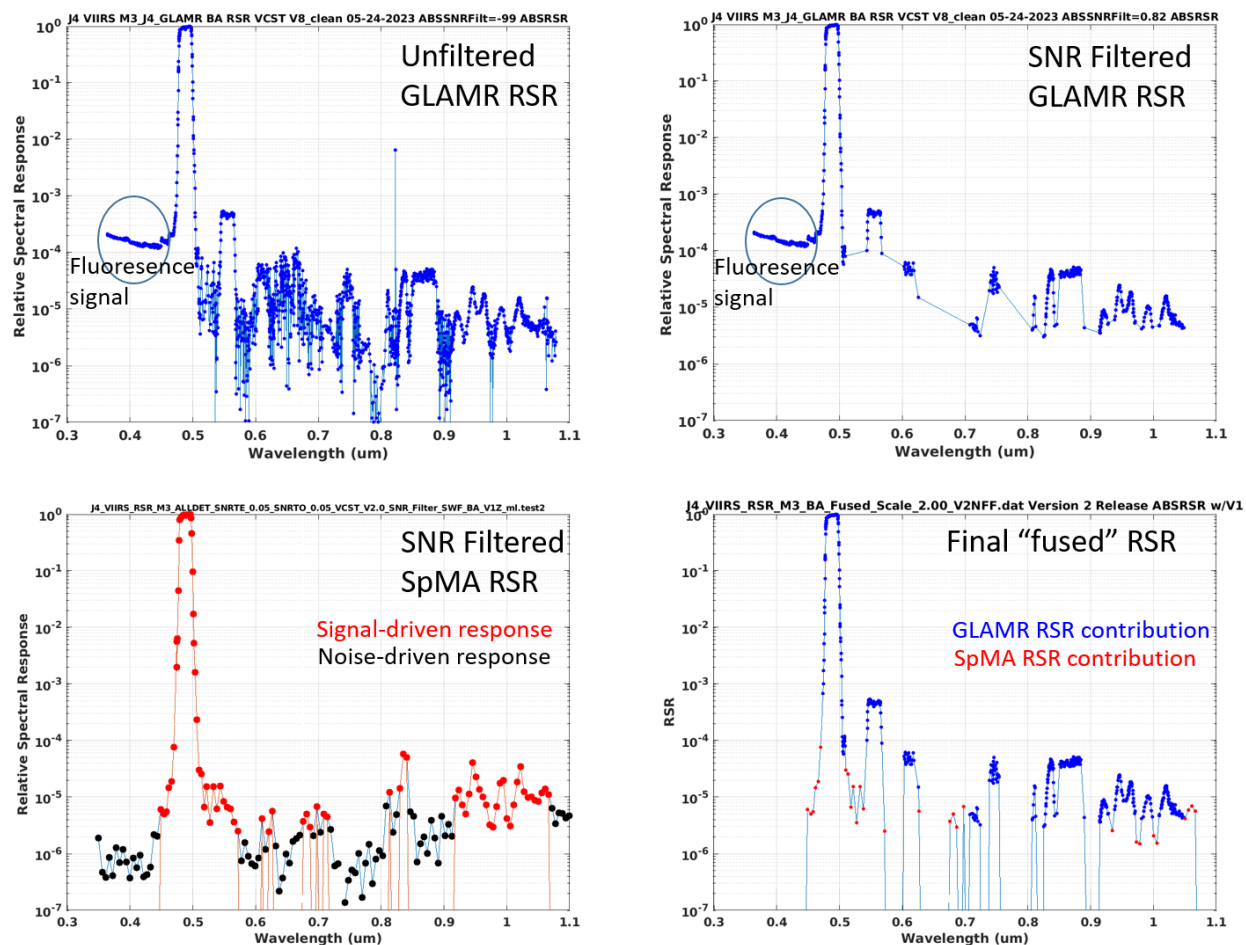


Figure 3. Band M3 processing example showing source-corrected but unfiltered GLAMR-based RSR (upper left), effect of signal-to-noise (SNR) filtering on GLAMR-based RSR (upper right), source corrected and SNR filtered SpMA-based RSR (lower left) and combined GLAMR-based and SpMA-based final RSR (lower right), including the removal of fluorescence-contaminated wavelengths from the GLAMR measurements.

8. “Shoulder” response observed on the short wavelength side of the in-band region in the Step 7 result may be due to fluorescence in the GLAMR Spherical Integrating Sphere (SIS). Fluorescence has been identified previously in PTFE-coated spheres^[7] and in the GLAMR SIS during separate testing by the GLAMR Team^[8]. The suspected fluorescence-driven response is most prevalent in bands M1 – M4 and was removed and replaced with SpMA-based response to form the final band-average fused RSR.

As an example, the processing steps of the GLAMR and SpMA measurements for band M3 are summarized in the four panels of Figure 3. The processing example shows the source-corrected but unfiltered GLAMR-based RSR (upper left), the effect of signal-to-noise (SNR) filtering on GLAMR-based RSR to identify high quality (light-driven) response (upper right), source corrected and SNR filtered SpMA-based RSR separating high and low quality response (lower left) and combined GLAMR-based and SpMA-based final RSR, including removal of the fluorescence driven response (lower right).

Table 2. SpMA and T-SIRCUS/GLAMR measurement characteristics. (Note: T-SIRCUS laser system used for SNPP and NOAA-20; GLAMR laser system used for NOAA-21, JPSS-3 and JPSS-4).

<u>SpMA Spectral Measurements</u>	<u>T-SIRCUS/GLAMR Spectral Measurements</u>
1. All bands, all detectors, system level	1. Reflectance bands, all detectors, system level
2. Bulb/Ceramic source, slit illumination, TVAC	2. Laser source, flood illumination, ambient
3. Source output drift >0.1%/hr at 400nm	3. Absolute source radiance known to within 0.5%
4. Offline source monitoring/characterization	4. Continuous realtime source monitoring
5. Polarized source output	5. Unpolarized source output
6. Measurement noise floor $\sim 1\text{E-}06$	6. Measurement noise floor $\sim 1\text{E-}04$
7. >30% source non-uniformity in track direction	7. <10% source non-uniformity in track direction
8. Source output has spectral wavelength “smile”	8. No source spectral smile
9. Contiguous spectral measurements	9. “Picket fence” spectral measurements

3. VERSION 2 RSR RESULTS AND DISCUSSION

As with the earlier VIIRS builds, the JPSS-4 VIIRS V2 RSR release consists of band-averaged (over all detectors) fused GLAMR and SpMA-based RSR for Visible-Near Infrared (VisNIR) and Shortwave Infrared (SWIR) bands (M1-M11, I1-I3, DNB LGS and MGS), plus band-averaged SpMA-based RSR for Midwave Infrared (MWIR) and Longwave Infrared (LWIR) bands (M12-M16A/B, I4, I5). For spectral regions where SpMA-based and GLAMR-based high quality measurements overlap, the GLAMR-based measurements are selected for the V2 RSR. This strategy was followed for multiple reasons as presented in Table 2. Those include the real-time NIST-traceable absolute calibration accuracy of the GLAMR source (items 3 and 4), the unpolarized nature of GLAMR light (item 5), and the highly uniform and non-dispersive nature of the GLAMR light on the VIIRS focal plane (items 7 and 8). A noteworthy disadvantage of GLAMR-based measurements is that the GLAMR SIS used in the test setup contributes fluorescence to the light entering the VIIRS aperture. This is identifiable as a response “shoulder” in the GLAMR-based measurements. Wavelengths containing significant fluorescence were removed from the GLAMR-based measurements as portrayed in Figure 3.

For the VisNIR and SWIR bands, GLAMR measurements provide the entire characterization for the in-band region and for portions of the out-of-band region while SpMA measurements fill in spectral gaps where GLAMR measurement quality was low, i.e. noise-driven response (Figure 4). For example, in band M1 GLAMR measurements dominate the response characterization around the M1 in-band region down to a response level of about 10^{-4} as well as much of the out-of-band response region from $0.7\text{ }\mu\text{m}$ to about $1.1\text{ }\mu\text{m}$. SpMA measurements generally provide much of the response characterization at lower response levels including a filter leak from 0.55 to near $0.70\text{ }\mu\text{m}$ that GLAMR was partially able to resolve. This is typical of all VisNIR bands and all SWIR bands with the exception of an out-of-band filter leak in the $3.5 - 4.0\text{ }\mu\text{m}$ region that was beyond the $2.5\text{ }\mu\text{m}$ limit of the GLAMR spectral coverage. GLAMR lasers don’t cover MWIR or LWIR wavelengths and thus the spectral characterization for those bands is taken from SpMA measurements.

VIIRS out-of-band response includes optical filter leaks, electronic and optical crosstalk. Response that appears at the spectral position of another band on the same focal plane is often an electronic crosstalk response. For example, in Figure 4 band M1 shows an out-of-band response in the $.43 - .46\text{ }\mu\text{m}$ region. The spectral position (and shape) of this out-of-band response matches that of band M2 (see blue bars along the top of each panel, representing bandpass of each band on the respective focal plane). M1 also shows out-of-band electronic crosstalk response at the spectral positions of M6 and M7 as well as other out-of-band response likely associated with filter leaks, e.g. $0.46 - 0.65\text{ }\mu\text{m}$ region, $0.78 - 0.83\text{ }\mu\text{m}$ region, $0.89 - 1.08\text{ }\mu\text{m}$ region. The band M2 plot

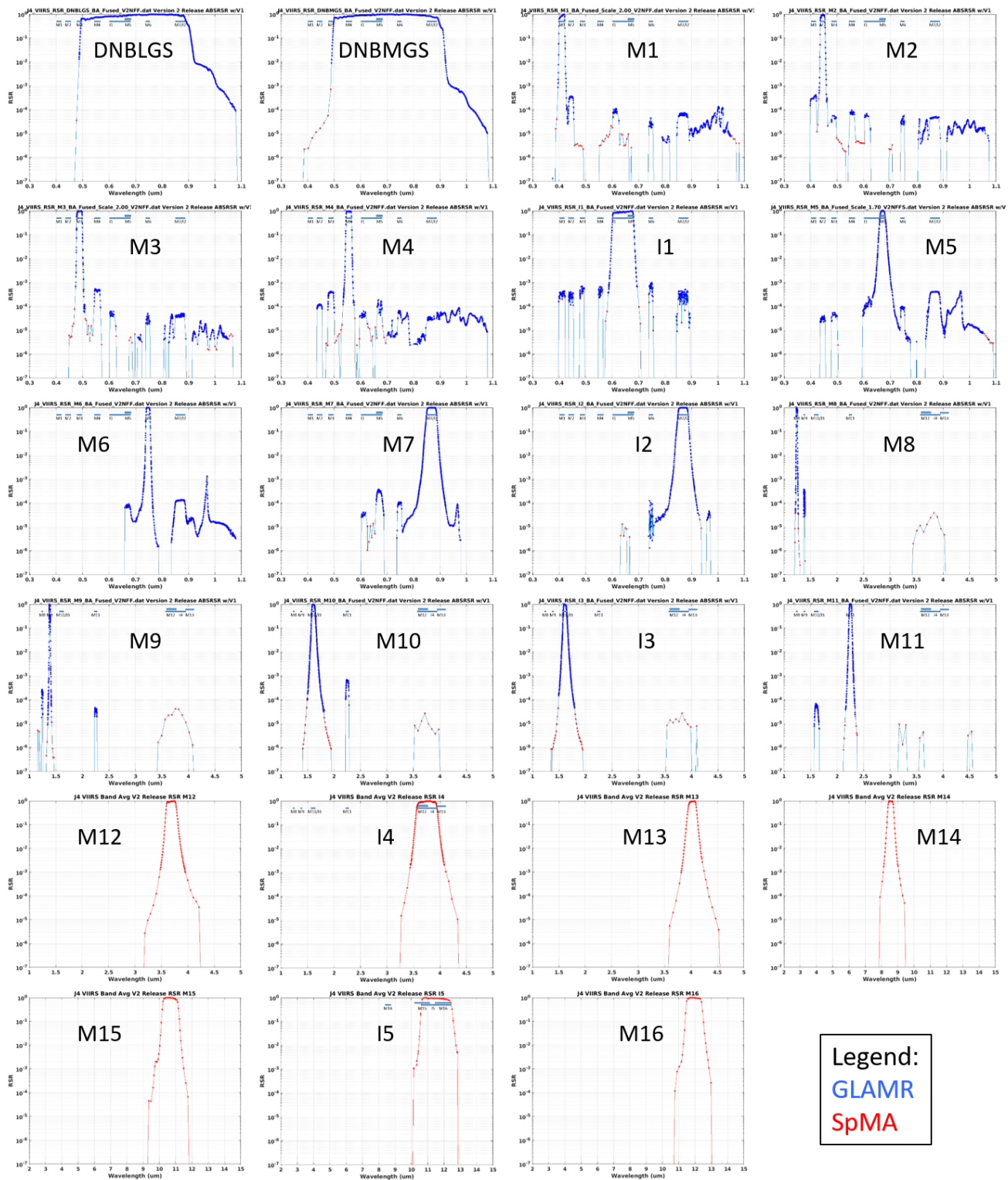


Figure 4. JPSS-4 VIIRS V2 band-average RSR. Data separated into GLAMR-based (blue) and SpMA-based (red) contributions. For RSB (DNB, I1-I3, M1-M11), GLAMR-based response exclusively dominates the in-band high response zone and much of the out-of-band response zone while SpMA-based response supplements in low response zones. For TEB (I4, I5, M12-M16) only SpMA-based measurements were collected and thus the characterization is entirely provided by the SpMA.

in Figure 4 shows out-of-band electronic crosstalk response at the spectral positions of bands M1, M3, M4, M6, and M7 and filter leaks in other regions of the out-of-band, most notably the 0.80 – 0.85 and 0.92 – 1.08 μm regions. Other VisNIR and SWIR bands show similar behavior. While filter leaks contribute positively to the integrated on-orbit earth scene signal, electronic crosstalk can be either a positive or negative domain response, i.e. either contribute towards or detract from the signal; however, for the purpose of Figure 4, negative electronic crosstalk is plotted as a positive value using an absolute value function. The official JPSS-4 VIIRS V2 RSR release files appropriately show negative electronic crosstalk response as a negative value.

A comparison of JPSS-4 and JPSS-3 VIIRS V2 RSR (Figure 5) shows generally close agreement between the sensors, not surprising since the design of the bandpass filters is the same for both sensors. In the in-band region (top half) only minor differences in shape are seen (e.g. DNBLGS, DNBMGs, M1, M9, M13, M15, M16A/B, I5). These differences result typically from minor performance differences in the optics of the JPSS-4 and JPSS-3 VIIRS sensors. In the out-of-band spectral region (bottom half), most response features in JPSS-4 are found in JPSS-3, typically down to the measurement objective of the 10^{-4} response level and lower. A few exceptions exist:

- 1) DNBLGS and DNBMGs show an extensive response shoulder from 900 – 1100 nm in JPSS-4, perhaps due to bandpass filter performance.
- 2) Additional electronic crosstalk response features from 400 – 600 nm were captured for I1, likely due to an improvement in GLAMR measured data quality for JPSS-4.
- 3) A response feature was found between 600 – 620 nm in M1 – M5, and M7, possibly related to electronic crosstalk from I1 into those bands.
- 4) A decrease in the 3500-4000 nm response was seen in JPSS-4 for M8 – M11, and I3.
- 5) Band I5 out-of-band response is captured only down to 10^{-3} response due to a higher noise floor in the measurements; however, no out-of-band features are observed above 10^{-3} response.

As indicated in Table 1, the integrated out-of-band response of these features doesn't exceed that allowed in VIIRS spectral metric specifications. Also, while not presented in Figure 5, VIIRS "M16" observations are spectrally represented by a linear average of M16A and M16B RSR, which are a close match to one another. The downlinked on-orbit VIIRS M16 observations are a time delay integrated signal of the M16A and M16B observations.

As with previous VIIRS builds, the pre-launch laboratory spectral measurements of band M9 are biased by atmospheric water vapor present in the ambient measurement path. This water vapor attenuates the source signal at absorbing wavelengths, depressing the signal at the VIIRS detector. As with JPSS-3^[4] and previous builds, a forward model (LBLRTM^[9]) using real time atmospheric temperature and humidity measurements as input was used to estimate the transmittance at each wavelength and correct the water vapor influence. Attempts to use the model transmittance to correct the signal at all wavelengths resulted in over-correcting the water vapor influence at strong absorption wavelengths; however, the narrow spectral nature of the GLAMR source used for M9 measurements allowed the collection of M9 response between the water vapor absorption lines. Wavelengths where the model transmittance exceeded 0.99 in the high response zone (response > 0.4), and 0.98 in the low response zone (response < 0.4) were corrected by the model and used to construct the M9 RSR. The resulting JPSS-4 in-band RSR profile (top half in Figure 5) is smooth and largely devoid of any water vapor influence and agrees closely with that of JPSS-3 M9 RSR. As was also the case for JPSS-2 and JPSS-3, CO₂ attenuation of the source signal occurs when measuring band M13 in the low response (< 1%) wing on the long wavelength side of M13; this signal attenuation was corrected by interpolating the M13 response over the low response range of 4200 – 4400 nm, removing the large majority of the CO₂ influence. As is evident in the lower half of Figure 5, the JPSS-4 M13 RSR is smooth in the long wavelength wing and closely agrees with that of JPSS-3.



Figure 5. JPSS-4 VIIRS V2 RSR highlighting in-band (top section) and out-of-band region (lower section) for all bands measured during the pre-launch test program. Very close spectral agreement is seen between the JPSS-4 (red shaded) and JPSS-3 RSR (blue) for the in-band region (top section) with only minor differences in shape in a few bands. Out-of-band response is also very similar in JPSS-4 and JPSS-3 with some exceptions, e.g. a decrease in the 3500-4000 nm feature in bands M8, M9, M10, I3, and M11.

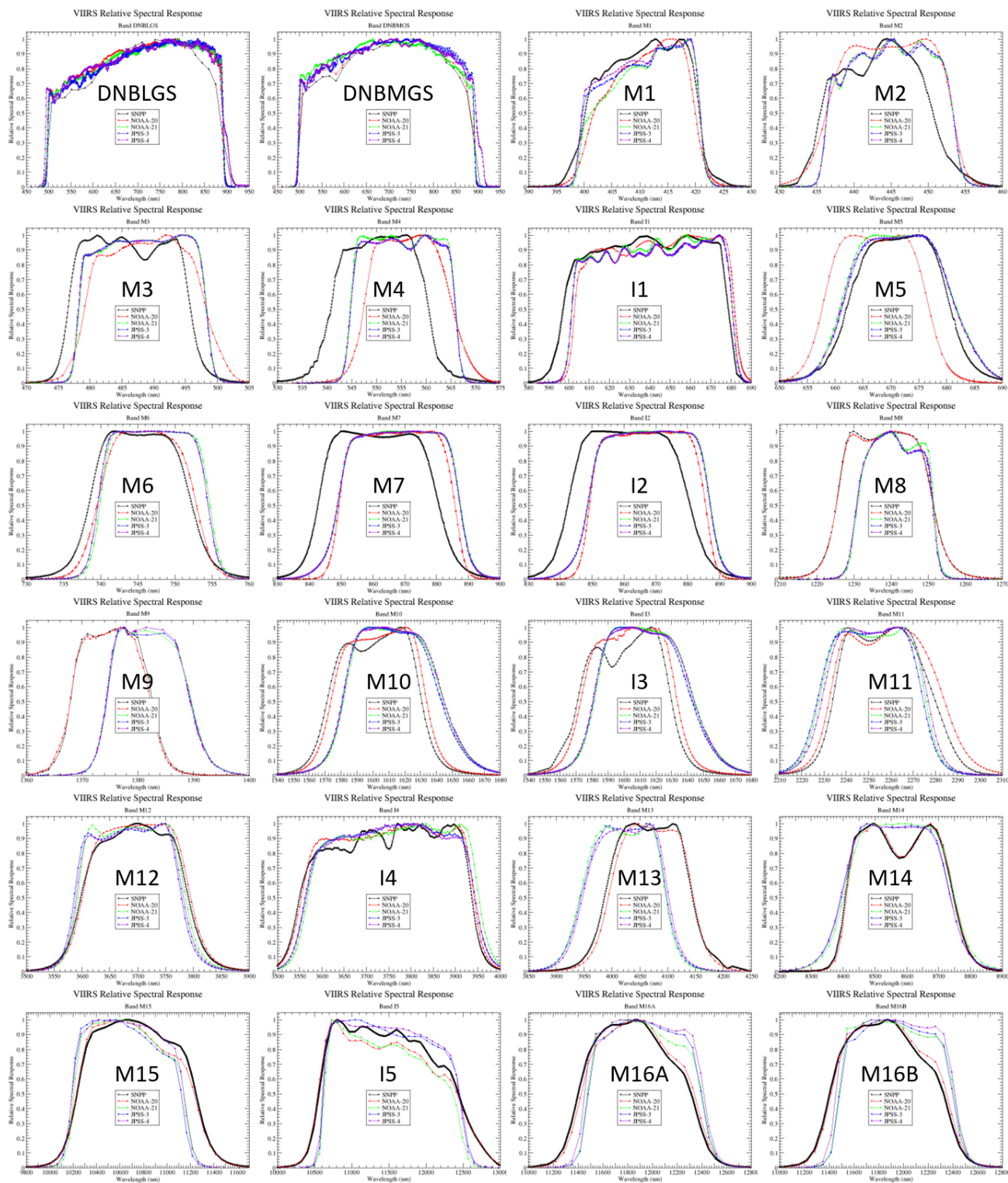


Figure 6. In-band RSR for all 5 VIIRS builds (SNPP, NOAA-20, NOAA-21, JPSS-3, JPSS-4) demonstrating how VIIRS spectral bandpass, shape, and position have changed over the course of the JPSS program. Large changes are due to changes in the optical design (filters, dichroics) of the sensor from build to build. Significant optical design changes occurred in VIIRS builds for NOAA-20 (JPSS-1) and NOAA-21 (JPSS-2); however, since NOAA-21 the optical hardware has been largely unchanged.

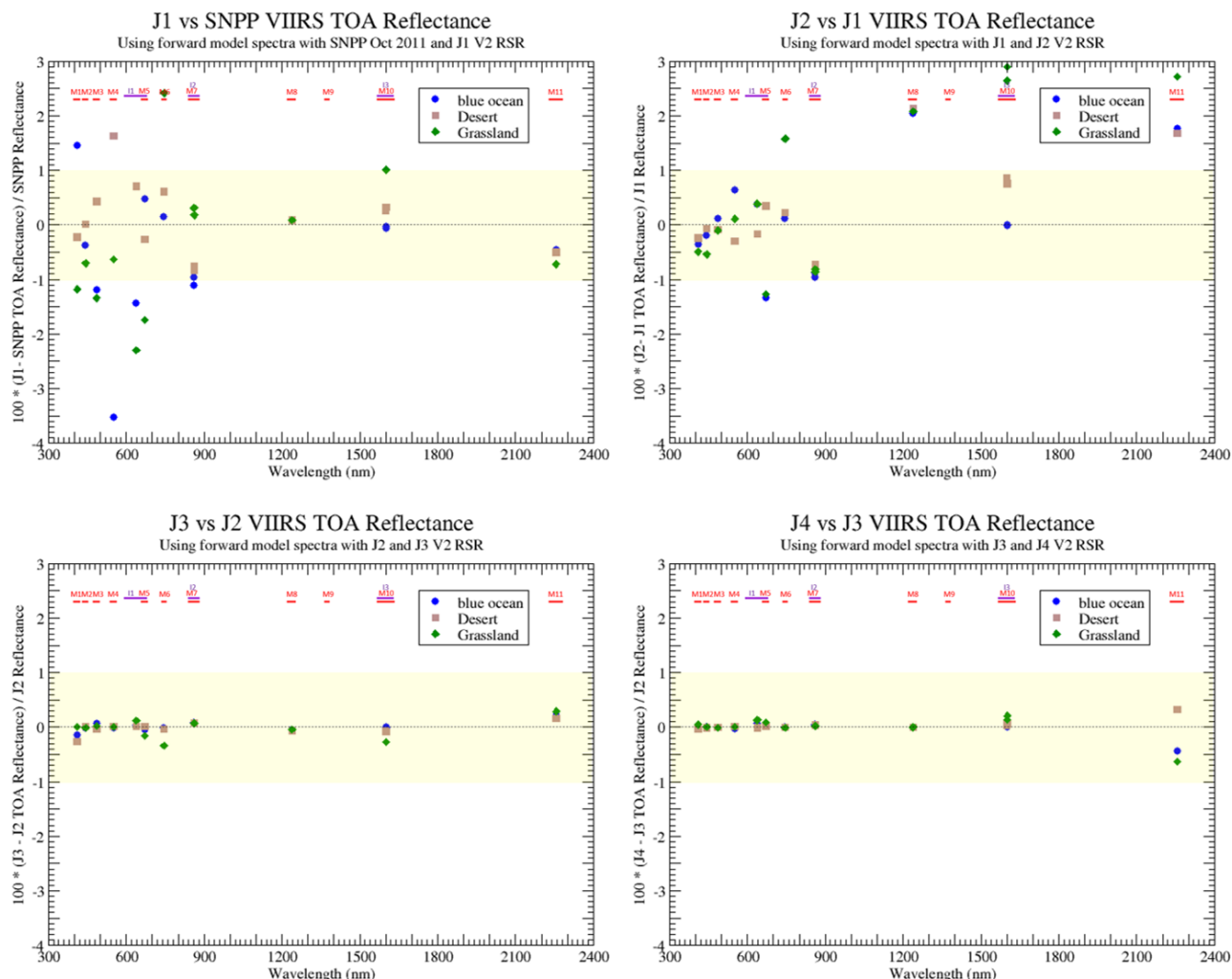


Figure 7. Top-of-atmosphere simulated reflectance for the reflectance solar bands of each VIIRS sensor compared to the previous sensor, showing the impact of spectral changes from sensor to sensor. Largest changes occur comparing JPSS-1 (NOAA-20) to SNPP (upper left) and JPSS-2 (NOAA-21) to JPSS-1 (upper right) when changes to the VisNIR (JPSS-1 and JPSS-2) and SWIR (JPSS-2 only) focal planes were made. JPSS-3 and JPSS-4 used the same focal plane designs as JPSS-2 and thus the spectral impact on TOA reflectance for those sensors is very small.

A view of the VIIRS in-band spectral characterization across all builds (SNPP, NOAA-20, NOAA-21, JPSS-3, JPSS-4) is presented in Figure 6. Differences between SNPP and NOAA-20 are most apparent for VisNIR bands. A new VisNIR focal plane design was obtained for NOAA-20 due to the presence of large angle scatter causing crosstalk in the SNPP VisNIR focal plane. Larger differences exist between NOAA-20 and NOAA-21/JPSS-3/JPSS-4 due to a redesign of all focal planes for NOAA-21 (that design also used for JPSS-3 and JPSS-4). This resulted in spectral position changes for several bands, most notably M9 and M13, as well as shape changes in most bands. Beginning with NOAA-21, VIIRS spectral characterization remained very stable. Importantly, the changes that have occurred over the program lifetime have been largely all within compliance on the VIIRS spectral metrics with some minor exceptions that were resolved through waivers. In addition, in

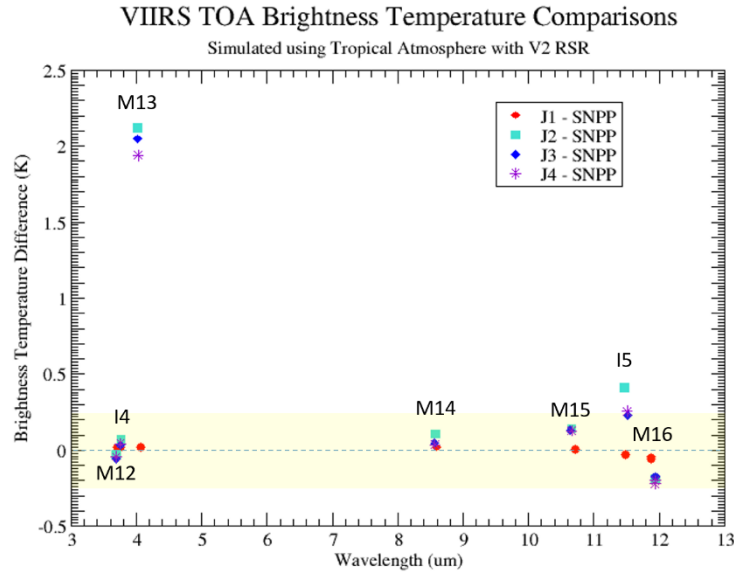


Figure 8. Top-of-atmosphere simulated brightness temperature for thermal emissive bands of each sensor compared to that of SNPP, showing the impact of spectral changes from sensor to sensor. Most bands changed by no more than ± 0.25 K (yellow highlighted region) for any of the sensors with the exception of M13 whose spectral position moved away from a CO₂ absorption region when a new focal plane design was acquired for JPSS-2 (also used in JPSS-3 and JPSS-4).

the out-of-band portion of the VIIRS response (not shown), non-compliances on out-of-band light in SNPP were resolved with the focal plane redesign for NOAA-20. NOAA-21, JPSS-3 and JPSS-4 have all been largely compliant on all spectral metrics after the focal plane redesign for NOAA-21 with the exception of a consistent small non-compliance in M14 bandpass (see Table 1).

To evaluate the impact of these spectral differences on on-orbit observations, top-of-atmosphere (TOA) reflectances (for RSB) and brightness temperatures (for TEB) were simulated using forward model spectra for blue ocean, desert, grassland, and a tropical atmosphere. The simulated RSB reflectances of each sensor were compared to simulations using the “at-launch” RSR for the previous sensor, i.e. NOAA-20 (JPSS-1) to SNPP, NOAA-21 (JPSS-2) to NOAA-20, etc. The four panels of Figure 7 show that the largest RSB changes are found comparing NOAA-20 to SNPP and less so comparing NOAA-21 to NOAA-20. This is because new VisNIR focal plane designs were acquired for both NOAA-20 and NOAA-21, with the NOAA-21 focal plane design also used in JPSS-3 and JPSS-4 which show very small changes. Figure 8 shows a similar comparison of simulated brightness temperatures using a tropical atmosphere for TEB, with the exception that each sensor is compared to the SNPP sensor. In large part, TEB brightness temperature differences are small across the 5 VIIRS builds with the exception of band M13, whose spectral position moved further away from CO₂ absorption when the NOAA-21 S/MWIR focal was redesigned for NOAA-21 resulting in an approximate 2 K increase for NOAA-21, JPSS-3, and JPSS-4. Importantly RSR changes in each sensor are captured by the RSR characterization and thus appropriately included in the SDR calibration of each sensor.

4. RSR UNCERTAINTY

The uncertainties associated with JPSS-4 VIIRS V2 RSR will not depart markedly from that of previous JPSS VIIRS builds. Evaluations of NOAA-20 and NOAA-21 measurements show typical GLAMR wavelength uncertainties of about 0.1 nm (well within VIIRS band dependent wavelength uncertainty requirements of 1.0 nm or more) and response uncertainties at or below .001 response (at or below .0001 for VisNIR M bands)^[6,10] based largely on measurement data quality and estimated GLAMR radiance uncertainty. This translates to a

relative uncertainty of about 0.1% or less for the in-band region of the RSR and about 10% in the lower response out-of-band region. Recent evaluations by the GLAMR Team of VIIRS band-integrated response uncertainty suggest response uncertainty of < 0.5% for VisNIR bands, and < 1.0% for SWIR bands². Additionally, Raytheon has independently determined that SpMA-based spectral measurements meet the wavelength uncertainty requirement for all bands. There is not a spectral metric requirement for response and as such Raytheon does not make an evaluation of response uncertainty. These evaluations all suggest that VIIRS RSR are an excellent representation of the true VIIRS RSR performance.

5. SUMMARY

This paper introduces the JPSS-4 VIIRS Version 2 “at-launch” RSR as retrieved by subject matter experts of the Government Team’s VIIRS DAWG. The characterization uses monochromator-based SpMA spectral measurements of all bands plus complementary laser-based GLAMR spectral measurements for all RSB (out to 2500 nm) from the JPSS-4 VIIRS pre-launch test program. The analysis captures a high quality characterization of the high response in-band region plus response features typically down to 10^{-4} and lower (band I5 exception) caused by optical filter leaks or electronic/optical crosstalk in the out-of-band region. The JPSS-4 VIIRS spectral characterization is very similar to that of JPSS-3 (and NOAA-21), not surprising since both sensors used bandpass filters of the same design. Modest in-band spectral shape differences between JPSS-3 and JPSS-4 exist in the LGS and MGS stages of the DNB plus M1, M9, M13, M15, M16A, M16B, and I5 (likely due to minor performance differences in the optics), while modest out-of-band response differences (likely electronic crosstalk changes) occur in bands I1, M1-M5, M7 and M8 – M11 and I3. In all cases the differences do not cause non-compliance of VIIRS spectral metrics and importantly are all well characterized for inclusion in the VIIRS SDR and L1B calibrations. JPSS-4 VIIRS RSR are compliant on nearly all VIIRS spectral performance metrics with the exception of a minor non-compliance in band M14 which has occurred in all previous VIIRS builds and is allowed through waivers accepted by the Government Team.

After completion of supporting materials and documentation, the JPSS-4 VIIRS V2 release package will be made available under EAR99 restrictions to the user community on the password-protected NASA Sharepoint repository.

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7. REFERENCES

- [1] Murphy, R. P., P. E. Ardanuy, F. De Luccia, J. E. Clement, and C. Schueler, “The visible infrared imaging radiometer suite”, in *Earth Science Satellite Remote Sensing*, Vol. 1, pp. 199-223, Springer-Verlag: New York, USA (2006).
- [2] Xiong, X., N. Che, and W. Barnes, "Terra MODIS On-Orbit Spectral Characterization and Performance", *IEEE Trans. Geosci. Remote Sens.* 44 (8), pp. 2198-2206, (2006).

² Brendan McAndrew, e-mail message to author, May 20, 2024 (cited with permission)

- [3] Barsi, J.A.; Donley, E.; Goldman, M.; Kampe, T.; Markham, B.L.; McAndrew, B.; McCorkel, J.; Morland, E.; Pedelty, J.A.; Pharr, J.; et al. Prelaunch Spectral Characterization of the Operational Land Imager-2. *Remote Sens.* 2024, 16, 981; <https://doi.org/10.3390/rs16060981>.
- [4] Moeller, C., T. Swarting, D. Moyer, and J. Barsi "The JPSS-3 VIIRS version 2 at-launch relative spectral response characterization", *Proc. SPIE* 12685, Earth Observing Systems XXVIII, 126851F (4 October 2023); <https://doi.org/10.1117/12.2677674>.
- [5] Swarting, T., C. Moeller, D. Moyer, J. McIntire, H. Oudrari, and X. Xiong, "JPSS-2 VIIRS Version 1 spectral characterization and performance assessment", *Proc. SPIE* Vol. 11127, 111270C, doi:10.1117/12.2530097, (2019).
- [6] Moeller, C., T. Swarting, J. McCorkel, D. Moyer, and J. McIntire "The JPSS-2 VIIRS version 2 at-launch relative spectral response characterization", *Proc. SPIE* 11127, 111270D, doi:10.1117/12.2530022, (2019).
- [7] Ping-Shine Shaw and Zhigang Li, "On the fluorescence from integrating spheres," *Appl. Opt.* **47**, 3962-3967 (2008).
- [8] Julia A. Barsi, Joel T. McCorkel, Brendan McAndrew, Timothy Shuman, Andrei Sushkov, Michael Rodriguez, Nicholas Reed, "Spectral and radiometric performance of the Goddard laser for absolute measurement of radiance," *Proc. SPIE* 12685, Earth Observing Systems XXVIII, 126850A (4 October 2023); <https://doi.org/10.1117/12.2678195>.
- [9] Clough, S. A., M. W. Shephard, E. J. Mlawer, J. S. Delamere, M. J. Iacono, K. Cady-Pereira, S. Boukabara, and P. D. Brown, "Atmospheric radiative transfer modeling: a summary of the AER codes", *Short Communication: J. Quant. Spectrosc. Radiat. Transfer*, 91, 233-244, (2005).
- [10] Moeller, C., T. Swarting, J. McIntire, D. Moyer, and J. Zheng "JPSS-1 VIIRS version 2 at-launch relative spectral response characterization and performance", *Proc. SPIE* 9972, Earth Observing Systems XXI, 997203 (September 19, 2016); doi: 10.1117/12.2238050, (2016).