Beta Maturity Science Review For NOAA-21 Surface Reflectance Algorithm

Presented by Yunyue Yu

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JPSS/GOES-R Beta Maturity Definition

JPSS/GOES-R Data Product Validation Maturity Stages – COMMON DEFINITIONS (Nominal Mission)

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.

BETA MATURITY REVIEW MATERIAL

Outline

- Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback
- Downstream Product Feedback
- Risks, Actions, and Mitigations
- Documentation (Science Maturity Check List)
- Conclusion
- Path Forward

NOAA-21 Surface Reflectance Cal/Val Team

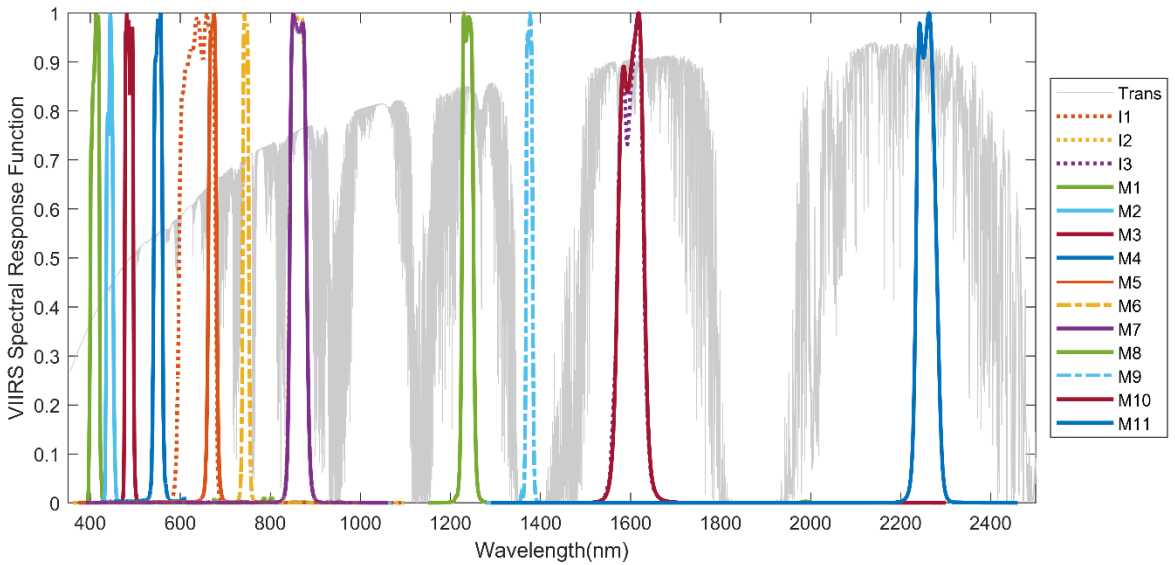
Algorithm Cal/Val Team Members

	Name	Organization	Major Task
Management & Science Team	Ivan Csiszar	NESDIS/STAR	Project lead
	Yunyue Yu	NESDIS/STAR	Surface Reflectance product lead
	Heshun Wang	UMD/CISESS	Surface Reflectance science team
	Eric Vermote et. al.	NASA GSFC	Surface Reflectance NASA science team
ASSIST Team	Priyanka Roy	GAMA-1	STAR ASSIST liaison
	Michaele Wilson	GAMA-1	STAR ASSIST liaison
	Brandon Laufer	GAMA-1	STAR ASSIST liaison
OSPO Team	Hanjun Ding	OSPO	OSPO PAL, transition to operations
	Yufeng Zhu	OSPO	OSPO PAL, transition to operations
Users	Xiwu(Jerry) Zhan et. al	STAR, UMD	STAR Surface Type team
	Corrine Cater et. al	UMD/CISESS	STAR VI team

Product Overview

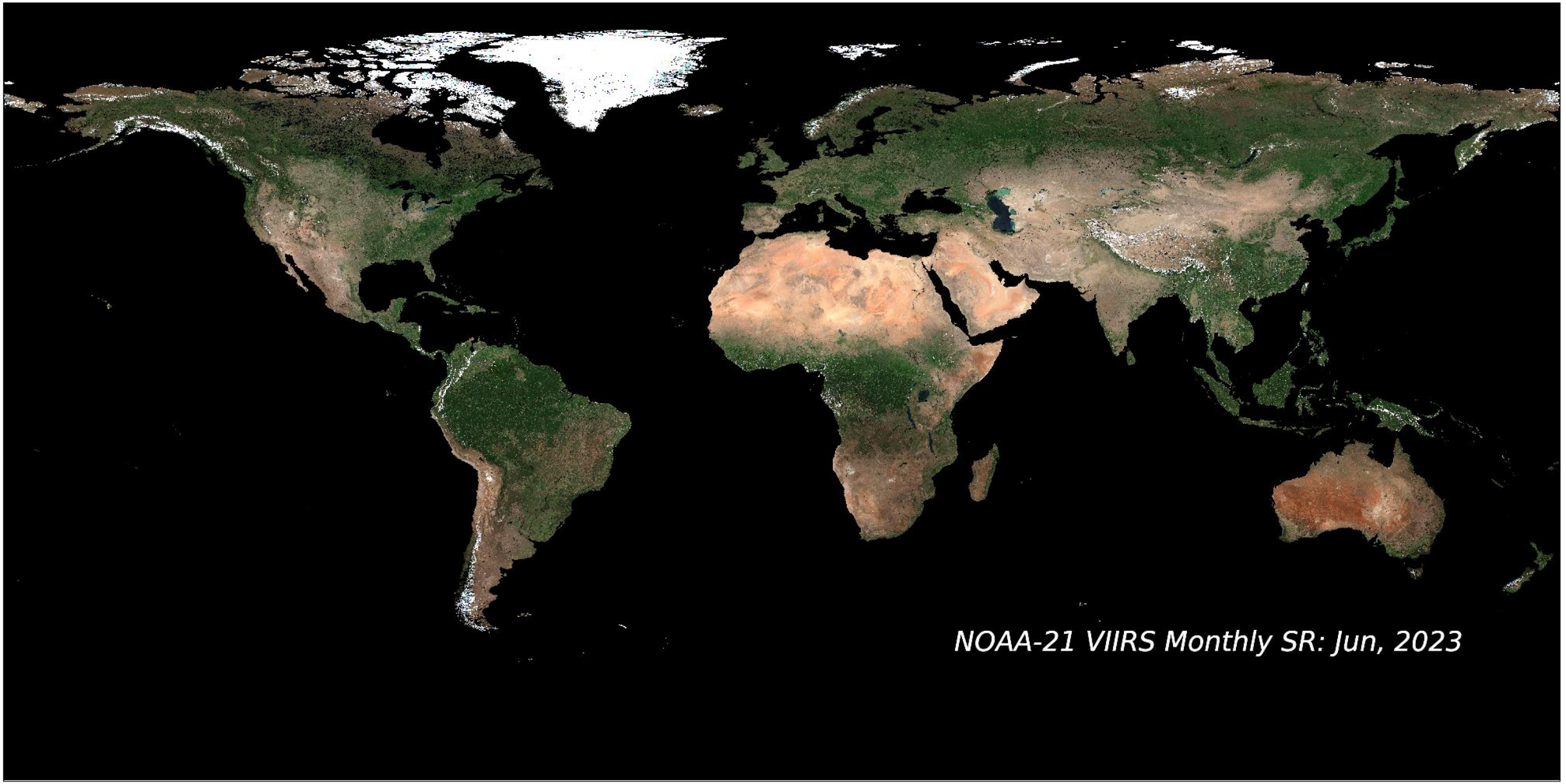
Surface reflectance (SR) is the most fundamental remotely sensed surface parameter, providing the primary input for most of the higher-level land products which rely on the solar reflective characters, including vegetation indices and leaf area index, land cover, and albedo. Therefore, the quality of SR product is critical to a bunch of downstream products.

- The VIIRS SR product is directly heritage from collection 5 MODIS and that it has been validated to stage 1 (Land PEATE adjusted version). The IDPS algorithm has been transitioned to NDE and MODIS algorithm refinements from Collection 6 have been integrated as well.
- The JPSS SR products provide directional surface reflectance values for VIIRS 12 bands centered at 0.412 µm, 0.445 µm, 0.488 µm, 0.555 µm, 0.645 µm, 0.672 µm, 0.865 µm (two different spatial resolutions), 1.24 µm, 1.61 µm (two different spatial resolutions), and 2.25 µm.
- The level 2 SR product are produced at 750m resolution for M bands and 375m for I Bands.



VIIRS Solar Reflective Bands Spectral Response Function

NOAA21 Monthly SR True Color Image



Product Overview/Requirements

- Product performance requirements from JPSS Data Product Specification (DPS)

Attribute	DPS	Requirement/Threshold	Performance
Geolocation	JERD-2441	The algorithm shall produce a surface reflectance product with a horizontal cell size of 0.80 km for radiometric and 0.40 km for imagery bands.	
Mapping uncertainty	JERD-2529	The algorithm shall produce a surface reflectance product with a mapping uncertainty, 3 Sigma, of the VIIRS SDR pixel geolocation uncertainty	
Valid range	JERD-2530	The algorithm shall produce a surface reflectance product with a measurement range of 0-1. (Note 1)	
Accuracy	JERD-2531	0.005+0.05ρ. (Note 2)	
Precision	JERD-2532	0.005+0.05ρ. (Note 2)	

Note 1: The actual retrieved range of Surface Reflectance is -0.1 to 1.6 .
Note 2: The symbol ρ denotes the retrieved surface reflectance. The APU metrics are applicable in conditions of low-to-moderate atmospheric turbidity (AOT (0.55µm) x m <1) where m is the air mass. The performance is degraded for the SR at wavelengths lower than 0.55µm by at least a factor 2. The SR errors may also be higher under partly cloudy and snow conditions.

Processing Environment and Algorithms

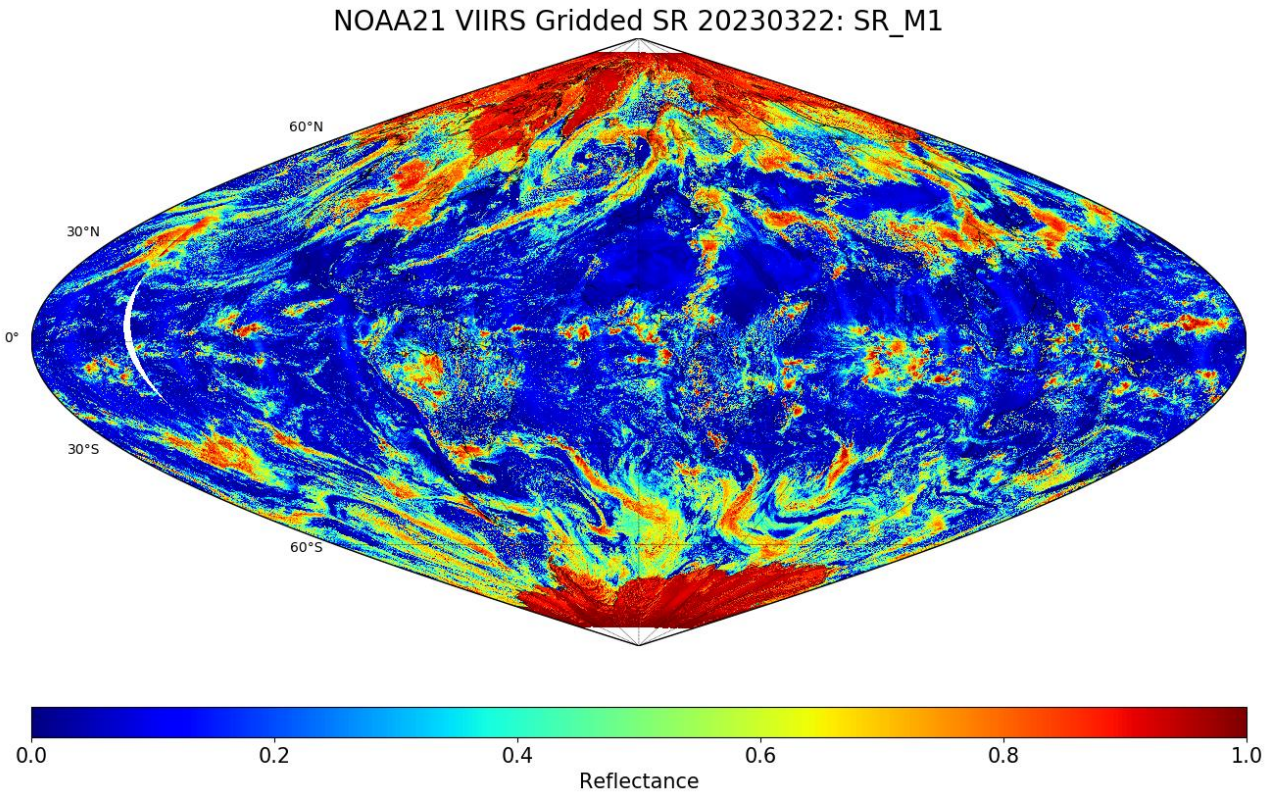
- Description of processing environment and algorithms used to achieve the maturity stage:
  - Algorithm version: v1r2
  - Version of LUTs used: v1.5.06.02_LP.
  - Version of PCTs used: SR v1r0
  - Effective date: Jan 6, 2022

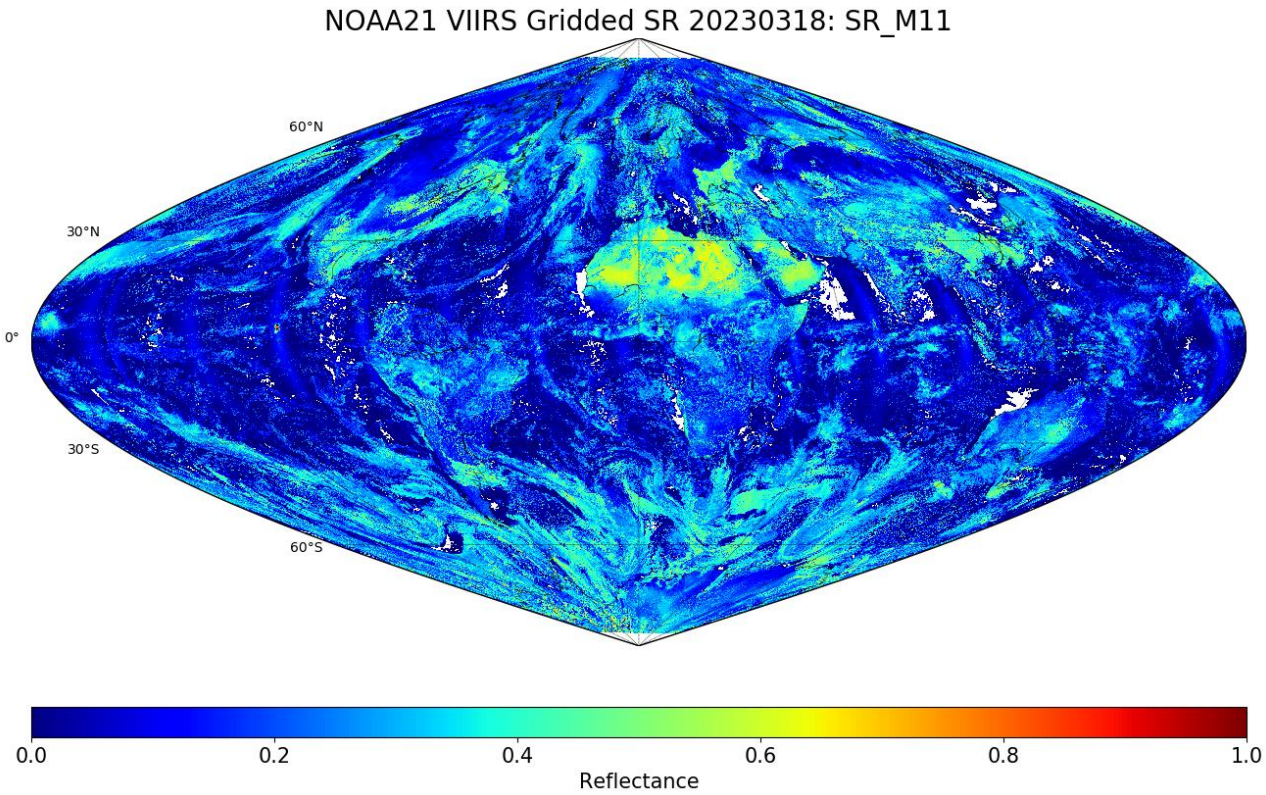
To be noted: the LUT used in beta review is same as the current operation used for SNPP and N20, the latest LUT has been delivered and tested in the CCAP package.

Evaluation of algorithm performance to specification requirements

- Algorithm performance evaluation
  - Product Visual Check
  - Validation data sets (type, periods, coverage)
  - Validation strategies / methods
  - Validation results
  - Long term monitoring readiness
- Inter-sensor comparison
  - Compare with S-NPP and NOAA-20

NOAA21 Single Band SR Visual Check



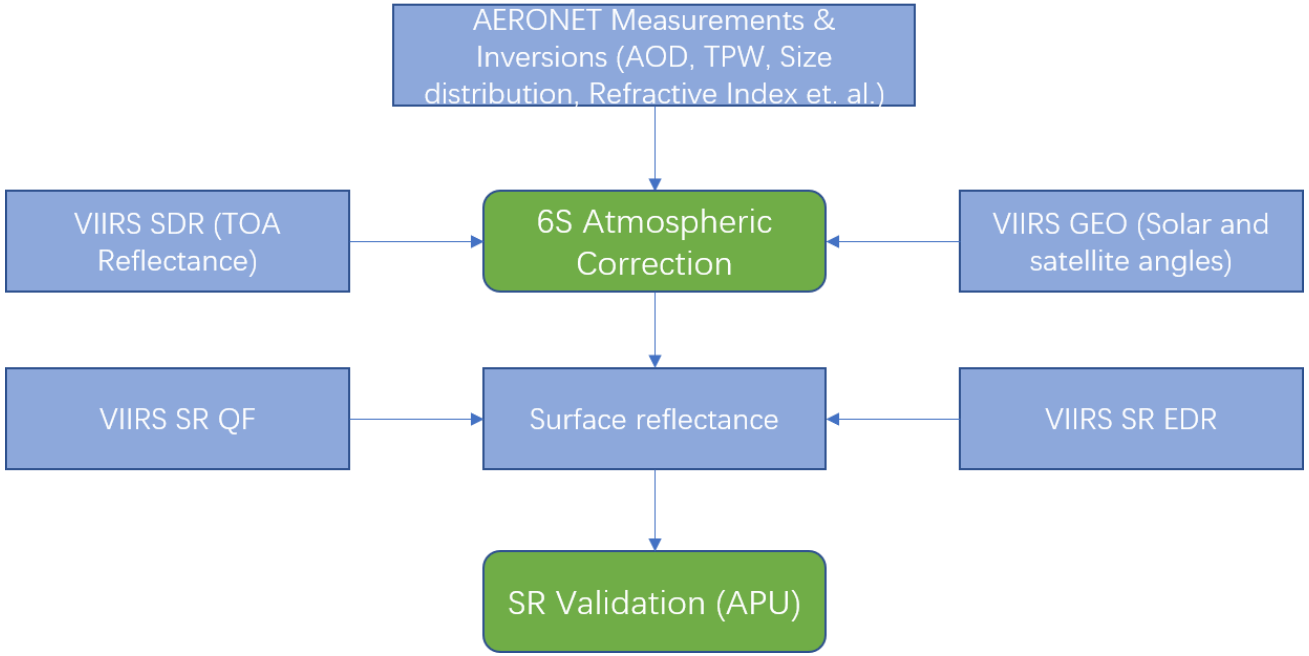


Visual check for the SR of each bands, *the overall global SR patten looks reasonable*.

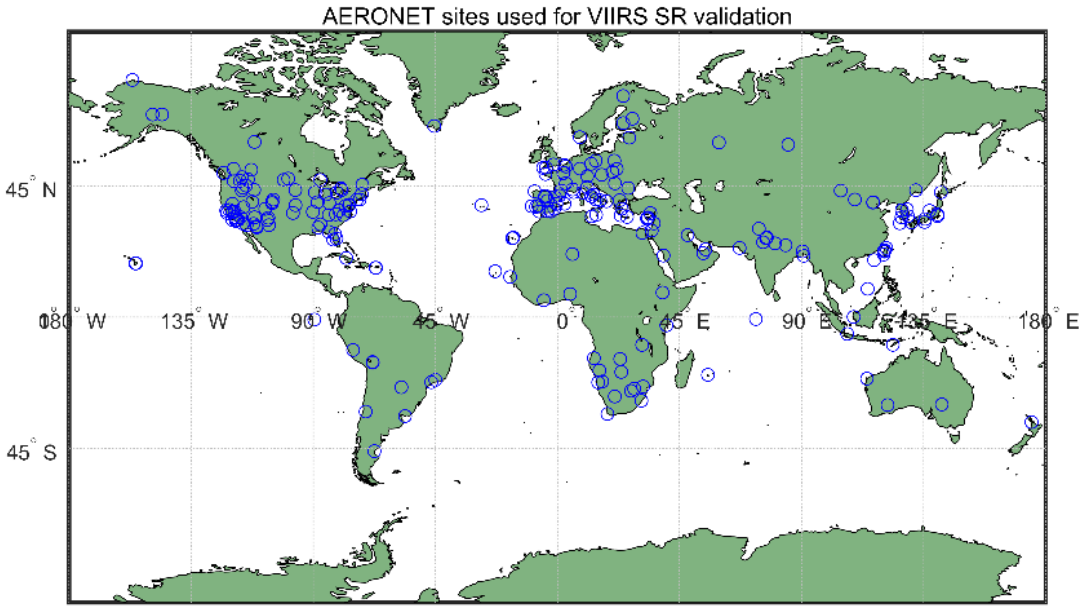
SR Validation datasets and methods

■ VIIRS SR validation at AERONET

- The matchup tool to select the valid AERONET measurements along with the inversions, then match with the VIIRS SDR and SR EDR subset (51*51 M band pixels).
- The validation tool first atmospherically correct VIIRS TOA reflectance using the AEROENT in-situ data, and then evaluate the VIIRS SR product.
- The AERONET sites are globally distributed as figure shows bellow.

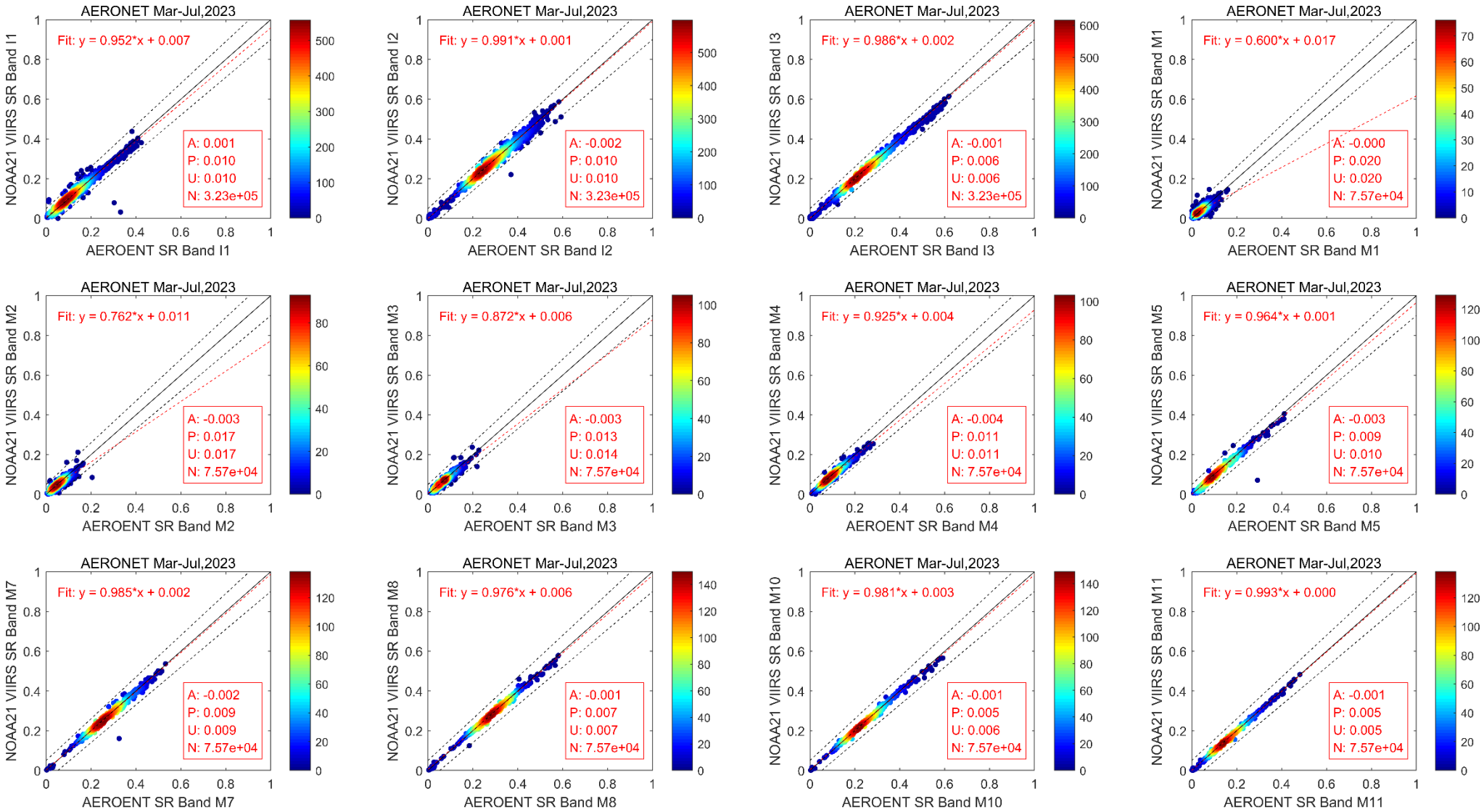


The AERONET SR validation method flowchart



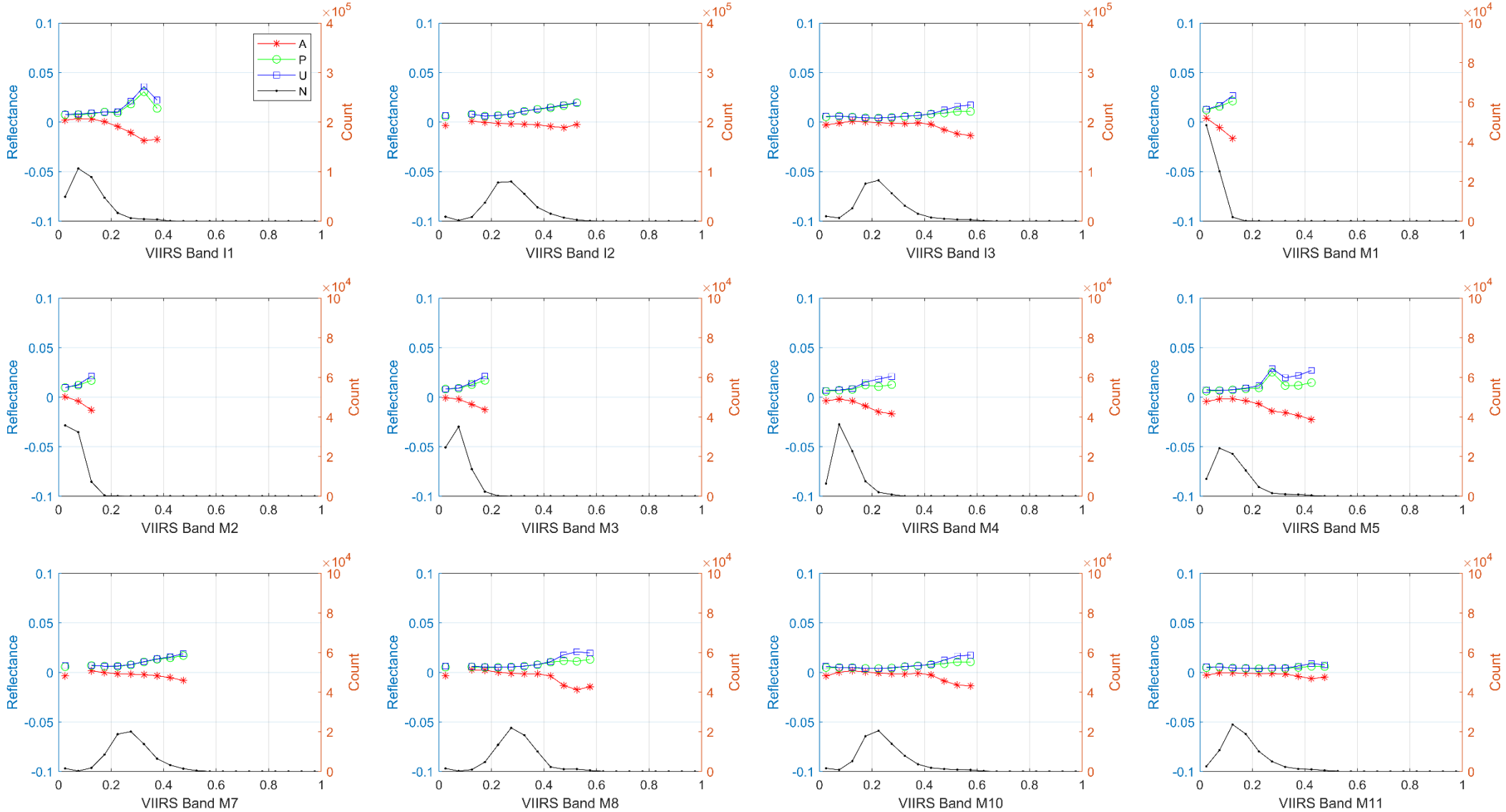
The location of AERONET sites used in the SR validation.

SR Evaluation at AERONET (scattering plot)



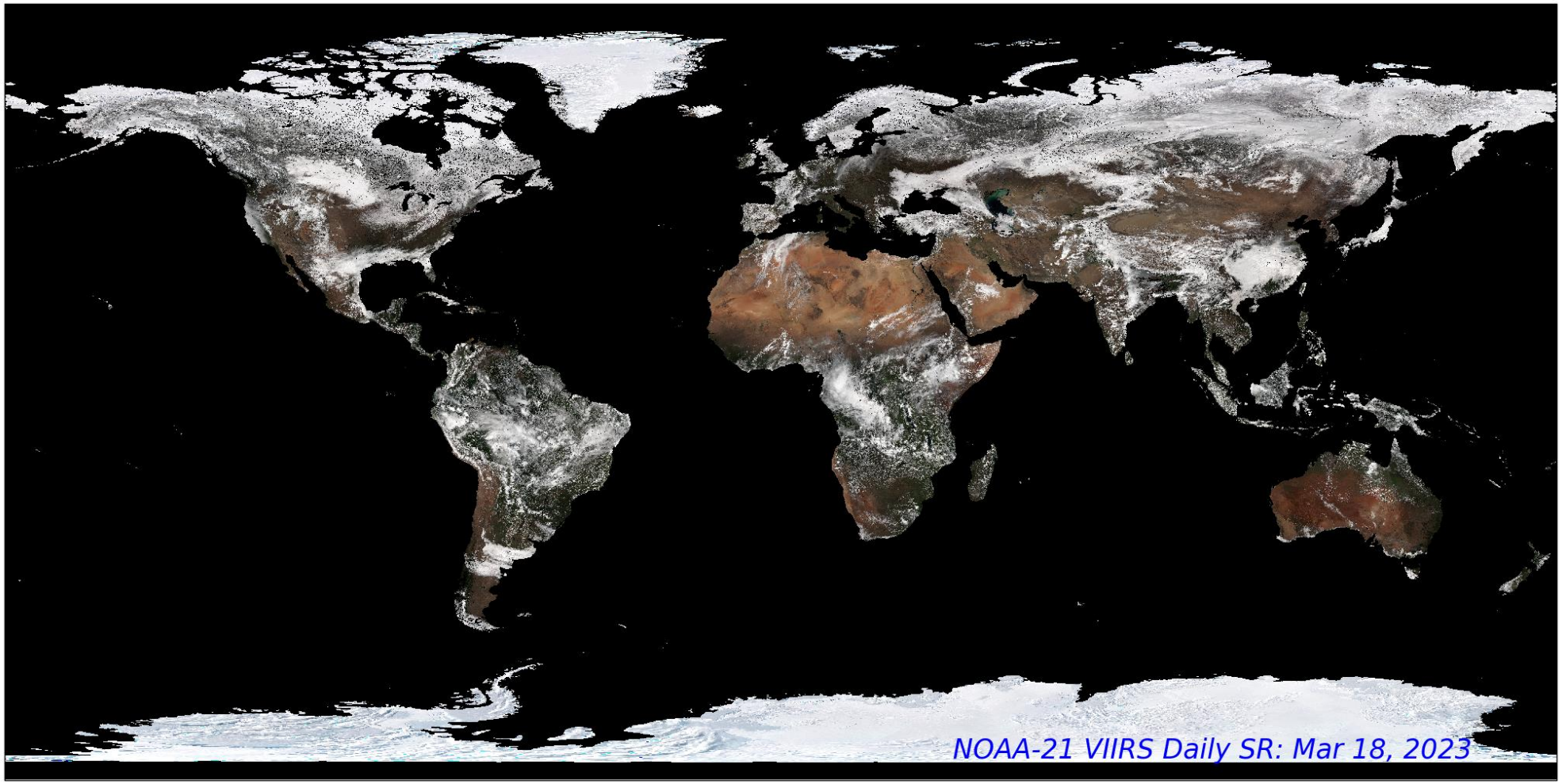
For the good quality data (clear sky, no cloud shadow or cirrus, no heavy AOD), most data are within the requirements (the dash line)
The shorter wavelength bands (M1-M3) a little bit worse, but still meet the requirement (two times of the other channels)

SR Evaluation at AERONET (Stratified SR plot)



The stratified the plot shows the SR APU performance for each SR bins, along with the data population. The results indicated the product are within the requirement.

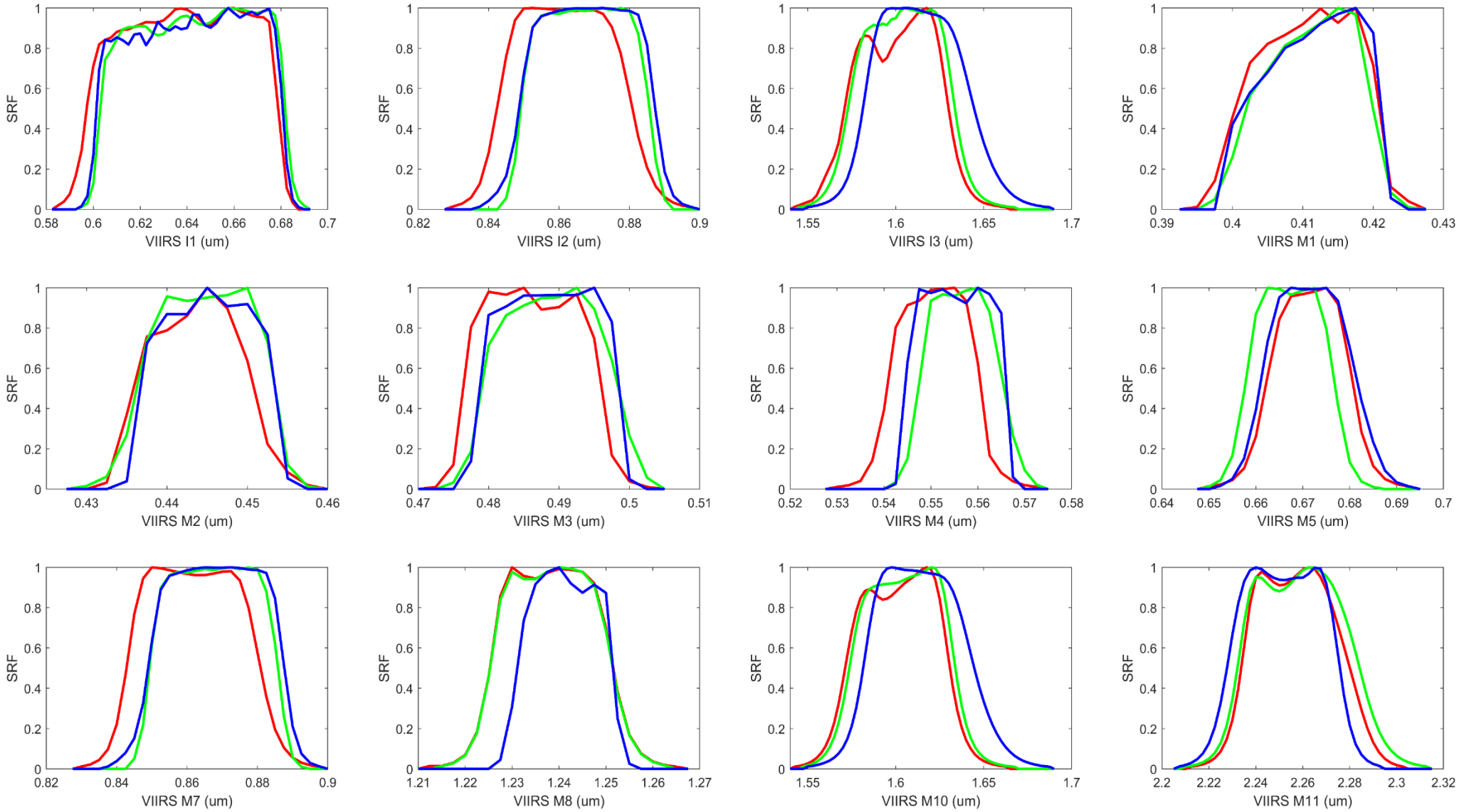
NOAA21 SR Long Term Monitoring Readness



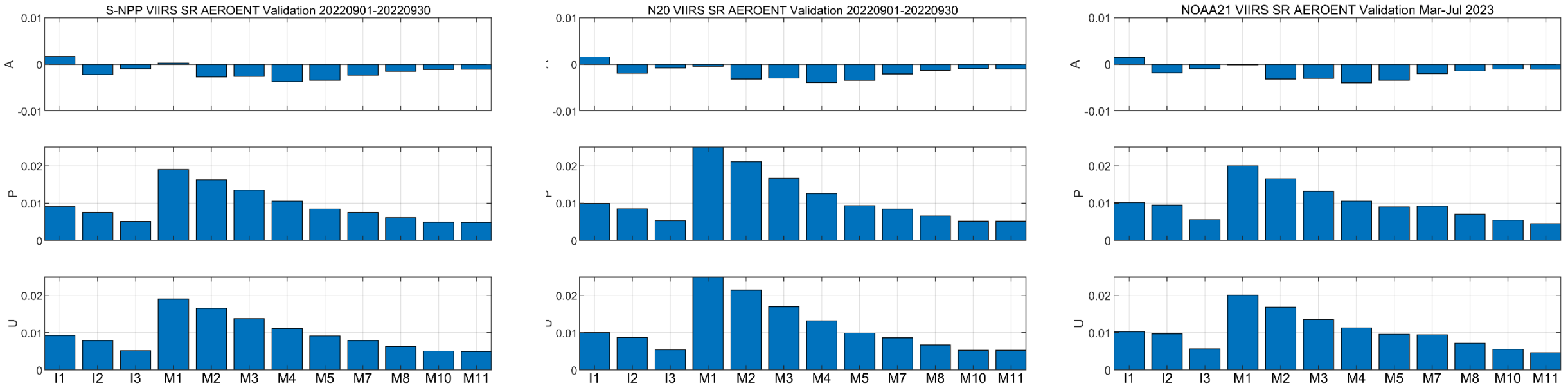
Global daily gridded true color images are routinely generated and posted on the website for monitoring, a weekly AERONET routine validation will performed later as SNPP and NOAA20 are doin.
https://www.star.nesdis.noaa.gov/smcd/emb/land/animation.php?product=SR&variable=SR-Land&sat=JPSS2

Spectral Response Function Comparison (NPP/N20 vs N21)

VIIRS SR bands spectral Response Function for SNPP (red), NOAA-20 (green), NOAA-21 (blue)



Inter-Comparison between SNPP, NOAA20 and NOAA21



- The NOAA21 SR validation at AERONET shows comparable performance with SNPP and NOAA20
- The short wavelength (M1-M3) band with larger uncertainty due to the intrinsic issue.
- Other bands with good performance

- Directional SR inter-comparison between different satellite/sensor are challenging due to angle sensitive.
- A BRDF corrected SR inter-comparison in under going, some preliminary results are included in the backup slides.

Evaluation of the effect of required algorithm inputs

- Required Algorithm Inputs
  - Primary Sensor Data
    - *VIIRS I1, I2, I3, M1,2,3,4,5,7,8,10,11 band, and Geolocation data.*
  - Ancillary Data
    - *GFS (surface pressure, total column ozone, total precipitable water)*
  - Upstream algorithms
    - *Enterprise Cloud Mask, Cloud Height, Aerosol Optical Thickness*
  - LUTs / PCTs
    - *LUT explanation & the new LUT Test*
- Evaluation of the effect of required algorithm inputs
  - VIIRS SDR performance monitoring through ICVS and Beta review results
  - VIIRS AOD beta review

Algorithm inputs: Primary Sensor Data

Reflective Solar Band (RSB) Noise / Signal to Noise Ratio (SNR)

- The on-orbit SNR estimation met the Spec. for all RSBs.

Geolocation Accuracy

- Initial optimization of the mounting matrix reduced the geolocation errors from around 400 m to less than 200 m

Radiometric Bias Evaluation

- NOAA-21 vs. NOAA-20 VIIRS VIS/NIR Comparison at SNO using Aqua MODIS as Reference: Radiometric bias of NOAA-21 VIIRS VIS/NIR (M1-M5, M7, I1, I2) channels are within 2% bias relative to NOAA-20

Issue need pay attention

- NOAA-21 VIIRS short-wavelength infrared (SWIR) band gain changes are faster than expected. Close monitoring of these changes for all SWIR bands and updating the radiometric calibration coefficients are carried out to address this issue.
- Dual-gain anomaly flagging as “poor quality” disabled for NOAA-21 VIIRS, current EDR products not affected since users were advised to ignore this flag

From NOAA-21 VIIRS SDR Beta Review (02/23/2023)

Algorithm inputs: AOD & Cloud Mask/Heigh

AOD Product (From AOD team)

- Based on the analysis of about three months of VIIRS AOD from the three satellites we also find the quality of the high-quality NOAA-21 AOD over land to be similar to those from NOAA-20 and S-NPP. The global averages of biases relative to AERONET are -0.022, -0.026 and -0.025 for NOAA-21, NOAA-20 and S-NPP, respectively. All three products somewhat underestimate the AOD relative to AERONET. Regional and seasonal differences can be smaller or larger than these.

Cloud Product (Cloud mask & Cloud Height)

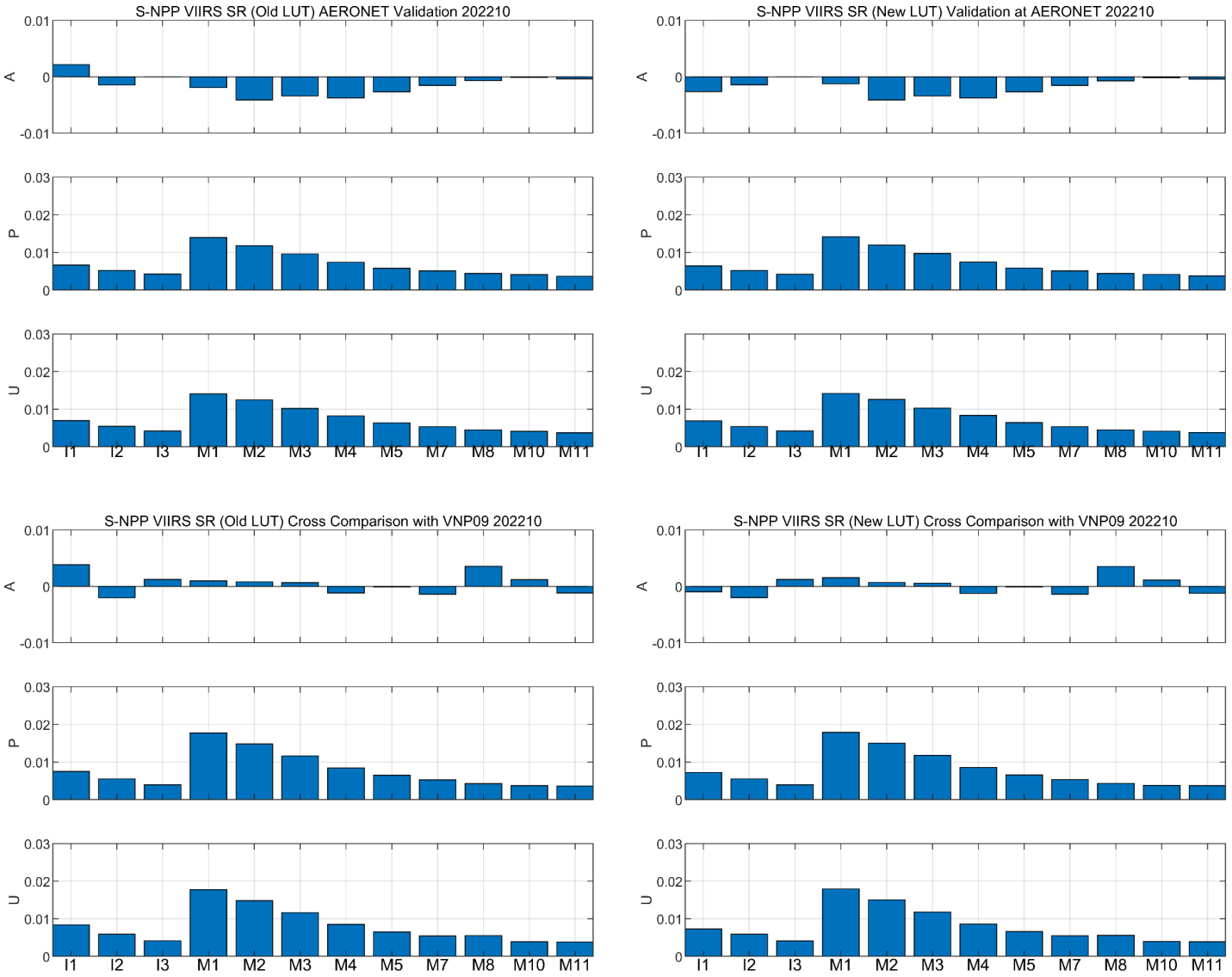
- VIIRS SR use cloud confidence levels, land water type, cirrus test, sun glint and snow/ice from VIIRS enterprise cloud mask EDR and the cloud shadow from Cloud Height EDR as the main data source for the quality flags.
- By comparing with SNPP and NOAA20 related flags, NOAA-21 with good consistency and similar patten.

Enterprise Surface Reflectance LUTs

File name	Dimension	Description
VIIRS-SR-IP-AC-INT_v1.5.06.02_LP	9+12*11	Binary lookup table containing a variety of ancillary information including the range of retrieved surface reflectance, aerosol optical depth, GFS fields, aerosol model limits, Rayleigh optical depth coefficients, and transmittance coefficients for ozone, water vapor and other gasses
VIIRS-SR-ScatAngDims-LUT_v1.5.06.02_LP	NSOLZA*NSENZA	Binary lookup table containing the location of the maximum scattering angle corresponding to 105 different pairs of solar and sensor zenith angles
VIIRS-SR-IncScatAngles-LUT_v1.5.06.02_LP	1	Binary lookup table containing the scattering angle increment
reflect	NMOD*NAOT*NBND*NANG	4-D Binary lookup table of reflectance.
trans	NMOD*NAOT*NBND*NSOLZA	4-D Binary lookup table of transmittances.
albedo	NMOD*NAOT*NBND	3-D Binary lookup table of albedos.
aot	NAOT	Binary lookup table of 20 aerosol optical thicknesses
szen	NSENZA	Binary lookup table of 20 viewing zenith angles
vzen	NSOLZA	Binary lookup table of 21 solar zenith angles

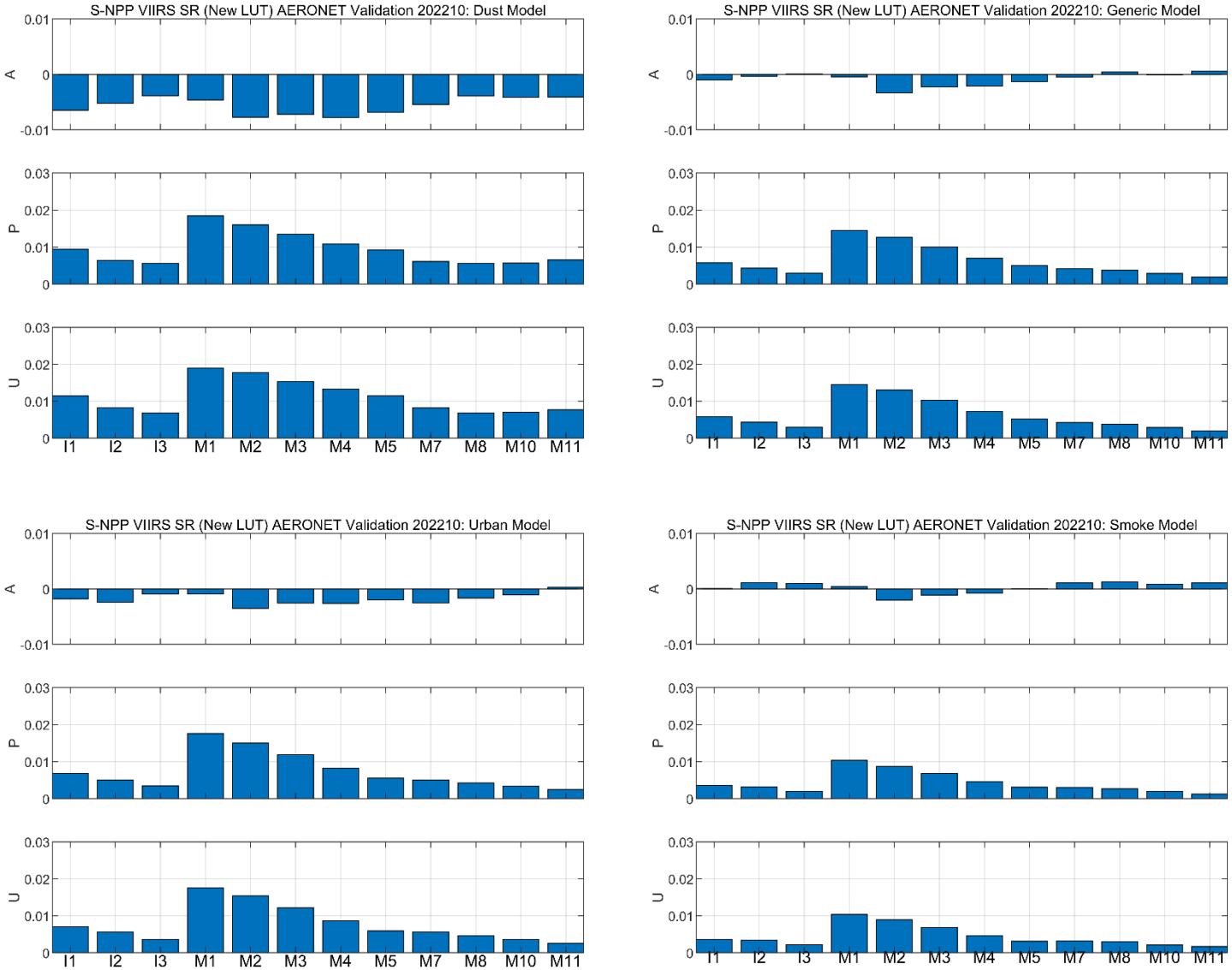
NMOD (4), NAOT (20), NBND (10), NSOLZA (21), NSENZA (20), NANG (5527)

The LUT Evaluation and Test



- An existing issue for SNPP and NOAA20 is the bias in I1 band, which is due to the approximation in LUT, as the top left figure shows, the I1 band shows slight positive bias compared with other bands.
- The new LUT for both SNPP, NOAA20 and NOAA21 have a consistent agreement with AERONET based SR.
- The new LUT for SNPP have better agreement with NASA VNP09 product, particularly for I1 band.

Investigate the SR performance of Dust Aerosol Model



- In the validation dataset, the dust model are one of four aerosol models, and when perform the SR validation for each type, the dust model with obvious negative bias compared with AERONET SR.
- A mitigation algorithm has been proposed and tested for the SR uncertainty for the pixels classified as dust model.

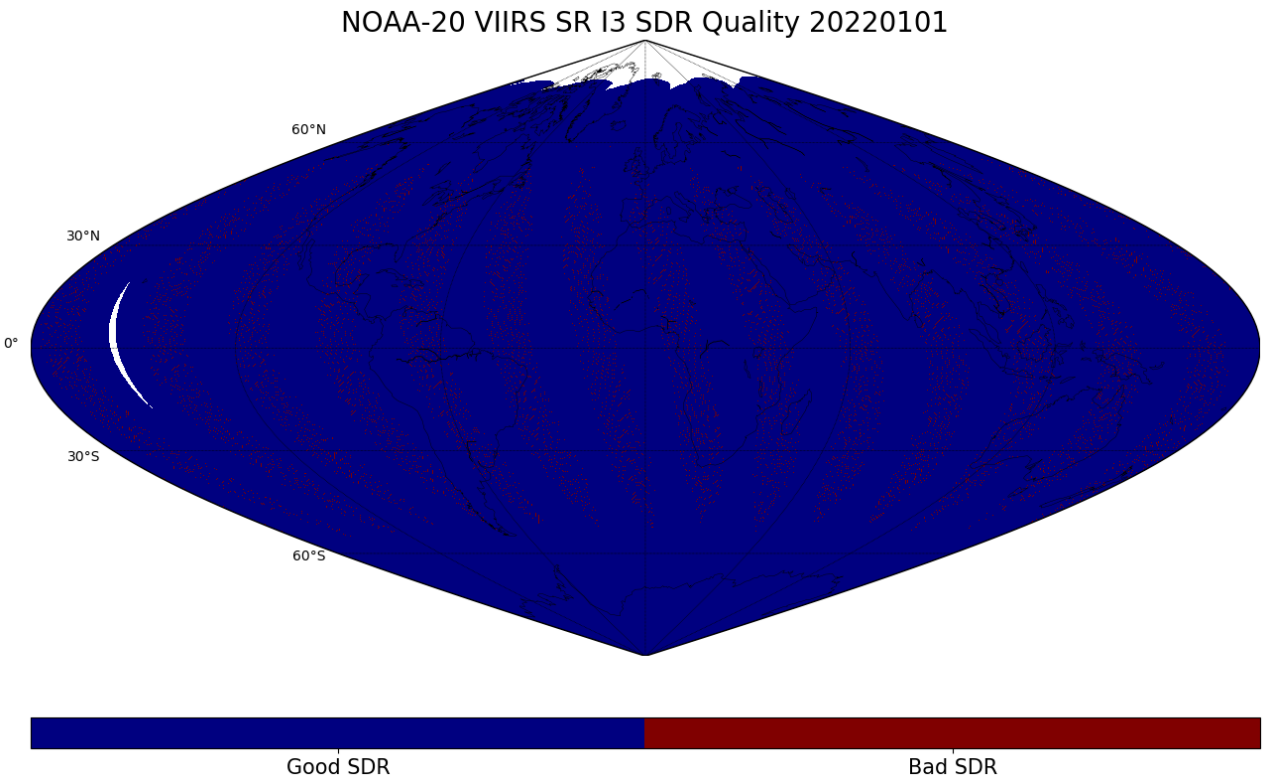
Quality flag analysis/validation

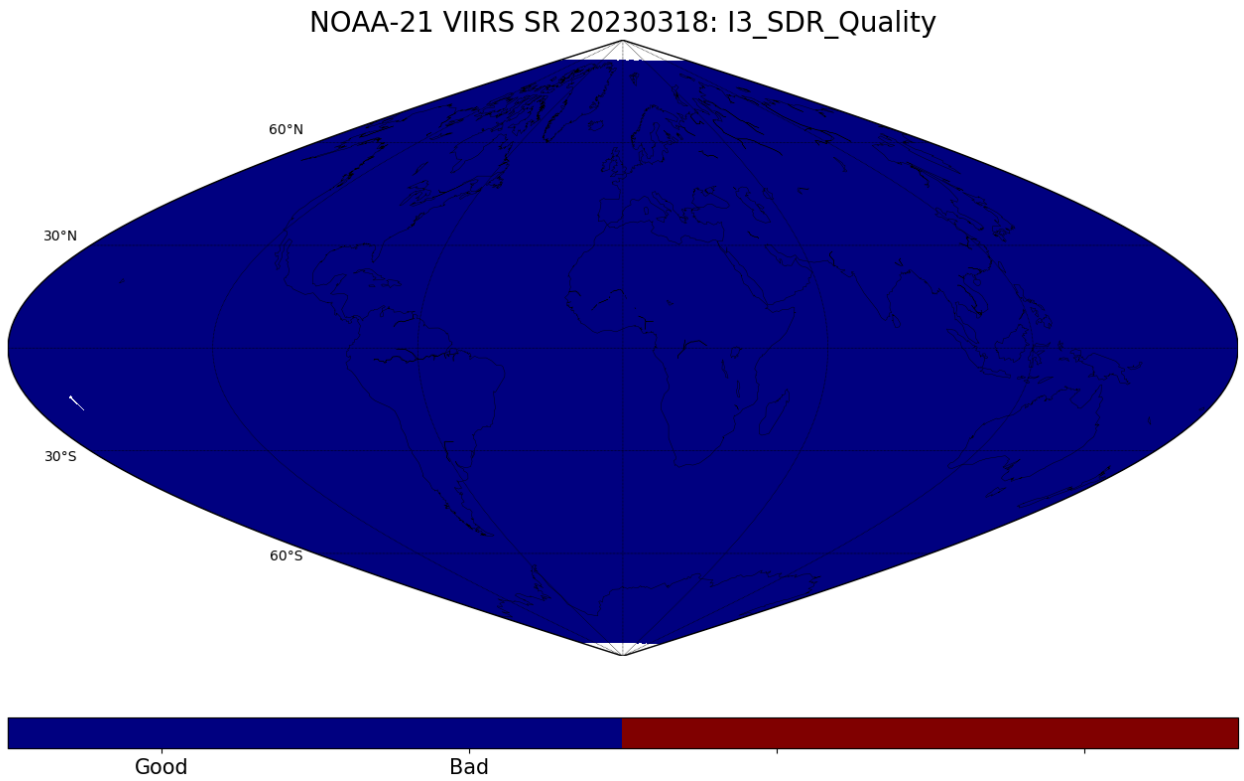
- Defined Quality Flags
  - Variable
  - Description
  - Value
- Quality flag analysis/validation
  - Test / example / ground truth data sets
  - Analysis / validation results
  - Analysis / validation plan

SR Quality flag

	Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
QF1	Cloud Mask Quality		Cloud Detection Confidence		Day/Night Flag	Low Sun Flag	unused	unused
QF2	Land/Water Mask			Cloud Shadow	Heavy Aerosol	Snow/Ice Flag	Reflective Cirrus test	Emissive Cirrus test
QF3	Bad M1 SDR	Bad M2 SDR	Bad M3 SDR	Bad M4 SDR	Bad M5 SDR	Bad M7 SDR	Bad M8 SDR	Bad M10 SDR
QF4	Bad M11 SDR	Bad I1 SDR	Bad I2 SDR	Bad I3 SDR	AOT Quality	Missing AOT	Invalid Aer Model	Missing TPW
QF5	Missing Column O3	Missing Surf Pres.	Quality of M1 Retr.	Quality of M2 Retr.	Quality of M3 Retr.	Quality of M4 Retr.	Quality of M5 Retr.	Quality of M7 Retr.
QF6	Quality of M8 Retr.	Quality of M10 Retr.	Quality of M11 Retr.	Quality of I1 Retr.	Quality of I2 Retr.	Quality of I3 Retr.	unused	unused
QF7	Snow Present	Cloud Adjacency	AOD Quantity Flag		Thin Cirrus	unused	unused	unused

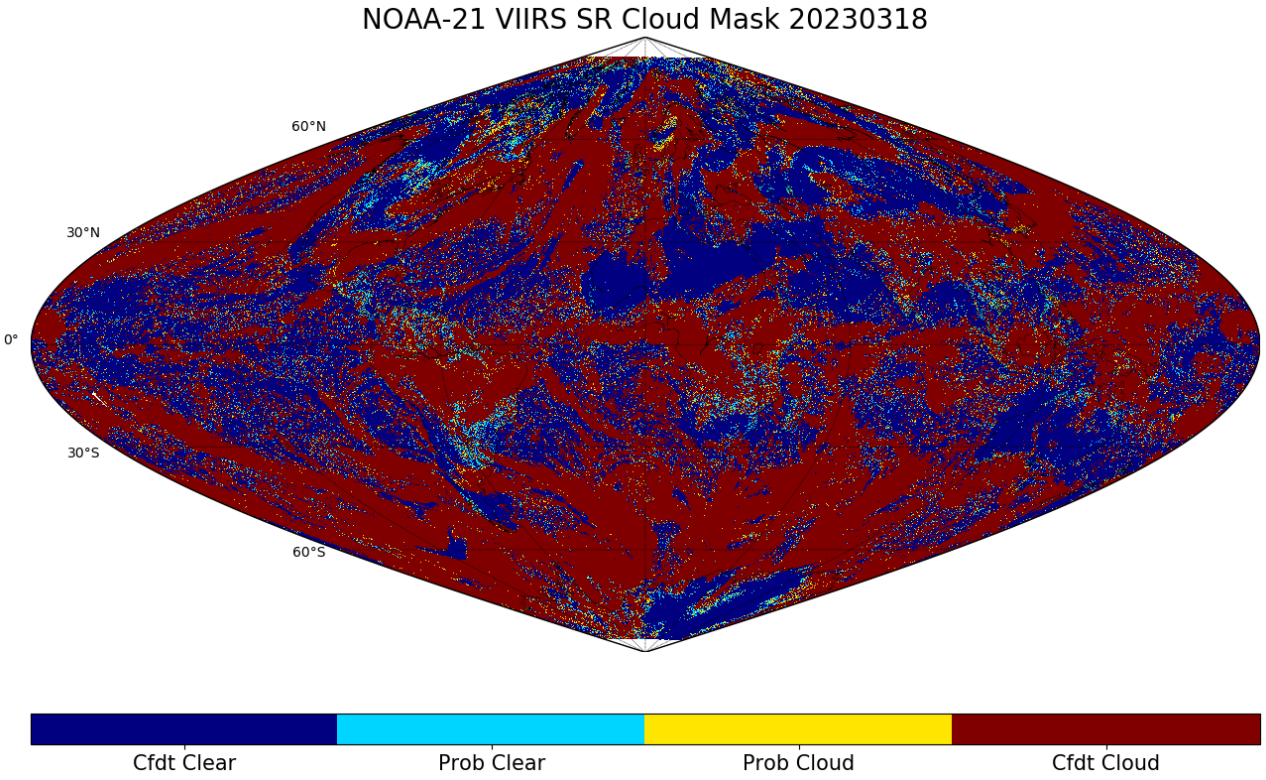
NOAA21 QF (I3 band quality)

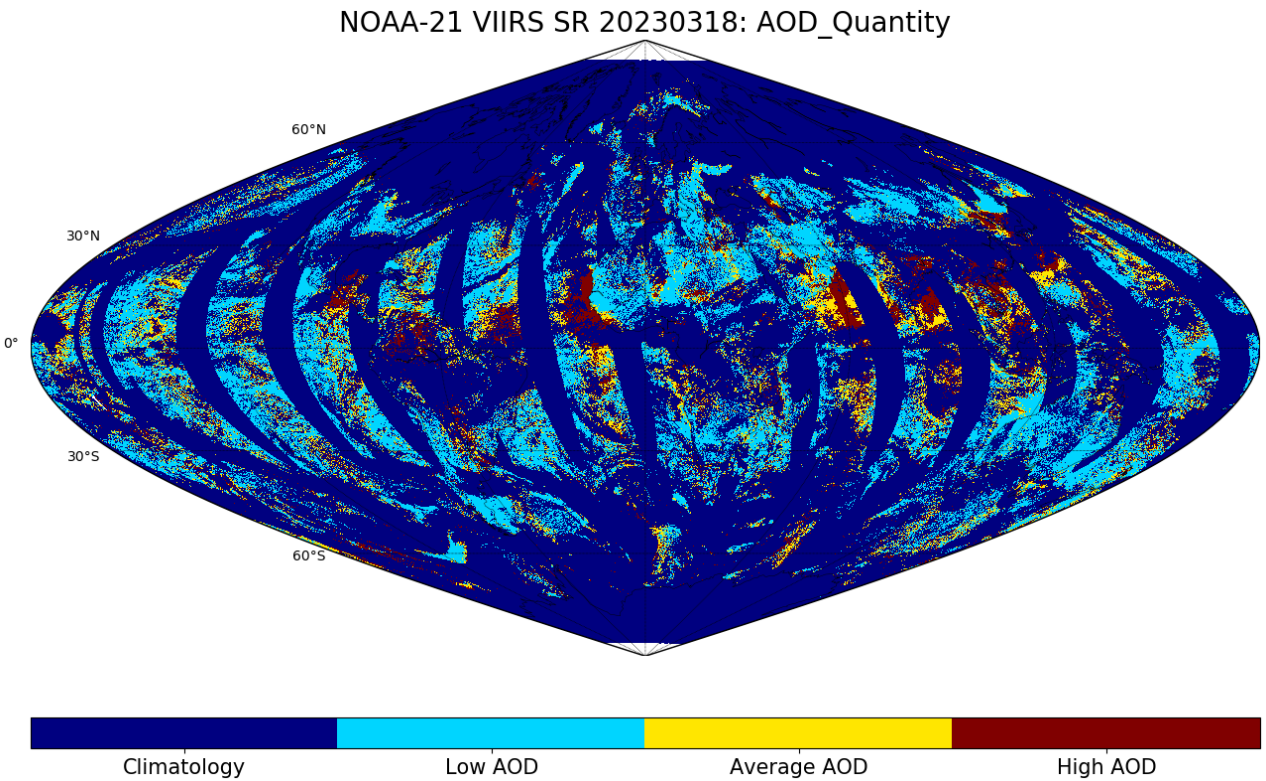




QF check for the I3 SDR quality, NOAA20 with the saturation issue for scan line (#29), while N21 does not have this issue.

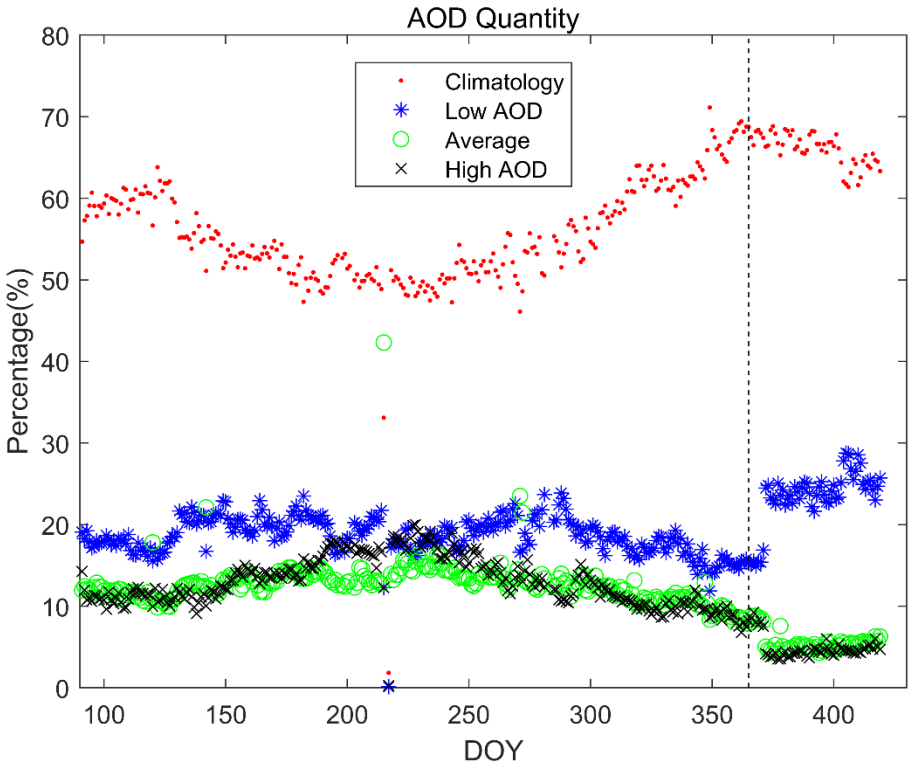
NOAA21 QF (Cloud Mask & AOD Quantity)

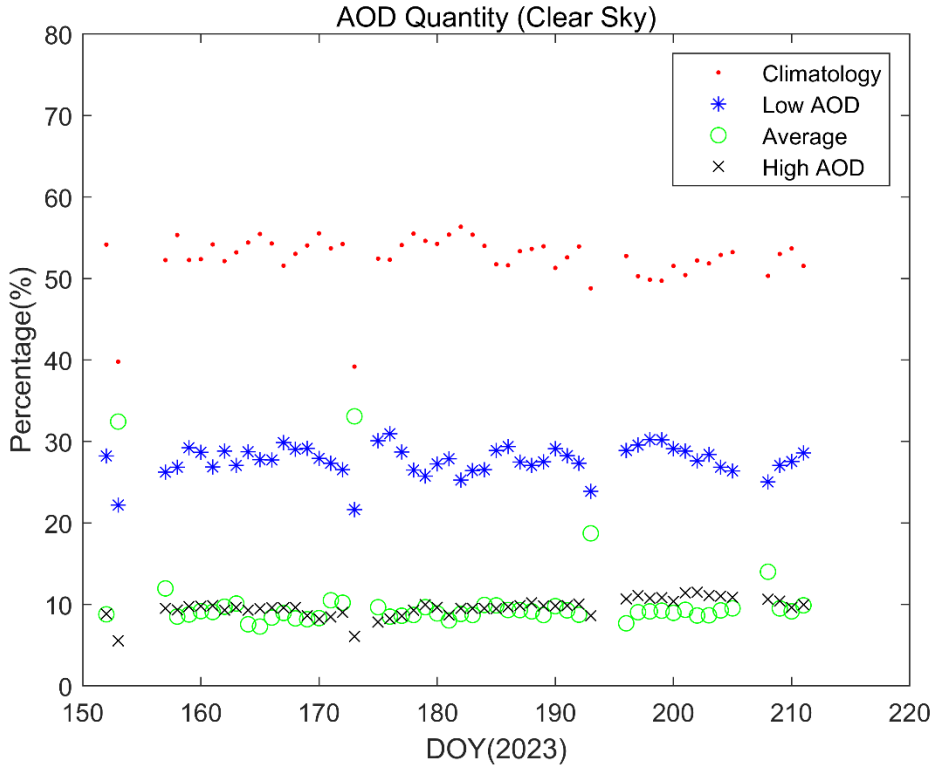




Two most frequently used QFs: the cloud mask and AOD quantity check, after the latest update (v1r2) the low AOD Flag increase while High AOD percentage reduce.

NOAA21 AOD Quantity Time series





- One of update from v1r1 to v1r2 is the AOD quantity flag, v1r2 use new criteria to stratify the AOD quantity
- The statistics based on all clear sky land surface grid between 60N – 60S
- Current version (v1r2) start from January, 2022 (dash line in left figure), Average and high AOD percentage drop by 3 percent, while low AOD percentage increase.
- the NOAA-21 AOD Quantity (right figure) has similar percentage as NOAA20 (Left Figure).

Error Budget

Compare analysis/validation results against requirements, present as a table. Error budget limitations should be explained. Describe prospects for overcoming error budget limitations with future improvements of the algorithm, test data, and error analysis methodology.

Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Accuracy	JERD -2531	0.005+0.05ρ	NA	<±0.003 <±0.006 for M1-4	<±0.003 <±0.006 for M1-4	<±0.003 <±0.006 for M1-4	Yes	
Precision	JERD -2532	0.005+0.05ρ	NA	<0.01 <0.02 for M1-4	<0.01 <0.02 for M1-4	<0.01 <0.02 for M1-4	Yes	For the good quality data

The symbol ρ denotes the retrieved surface reflectance. The APU metrics are applicable in conditions of low-to-moderate atmospheric turbidity (AOT (0.55µm) x m <1) where m is the air mass. The performance is degraded for the SR at wavelengths lower than 0.55µm by at least a factor 2. The SR errors may also be higher under partly cloudy and snow conditions.

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Veronica Lance	NOAA	Coastal Watch	NOAA Coast Watch Central (the central processing team housed in STAR) is generating true color images using the VIIRS Land Surface Reflectance product
Jerry Zhan	NOAA/UMD	Surface type	We have been able to process the NetCDF files of your NDE surface reflectance product for developing the VIIRS Annual Global Surface Type Map.

Downstream Product Feedback

Name	Organization	Application	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts
Corrinne Cater	UMD/CISESS	VI	we did not see any issues that might have been caused by problems with SR. the NOAA-21 SR is fit for the purpose of generating VI and GVF
Zhangyan Jiang	IMSG	GVF	

VIIRS bands I1, I2, and M3 Surface Reflectance are used to generate Top Of Canopy (TOC) Normalized difference vegetation index (NDVI) and TOC Enhanced vegetation index (EVI), and then product Green Vegetation Fraction (GVF) using EVI.

Risks, Actions, and Mitigations

- Provide updates for the status of the risks/actions identified during the previous maturity review(s); add new ones as needed

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Dust aerosol model	The misclassified dust aerosol model might have larger uncertainty	Increased SR uncertainty	A mitigation algorithm is under development to reduce the uncertainty for the misclassified dust aerosol.

Documentations

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	Yes
Algorithm Theoretical Basis Document (ATBD)	Yes
Algorithm Calibration/Validation Plan	Yes
(External/Internal) Users Manual	Yes
System Maintenance Manual (for ESPC products)	Yes
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	Yes for NPP, N20/N21 under preparation
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	Yes

Check List - Beta Maturity

Beta Maturity End State	Assessment
Product is minimally validated, and may still contain significant identified and unidentified errors	Validated over globally distributed AERONET sites, the data covers from March to July, 2023. No significant issue found, close monitoring will be performed for the SWIR band
Information/data from validation efforts can only be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose	NOAA-21 VIIRS SR data have met the beta maturity requirements and can be used to make initial qualitative or limited quantitative assessments for downstream products.
Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists	No documentation of product performance available yet. Will document once anomalies detected.

Conclusion

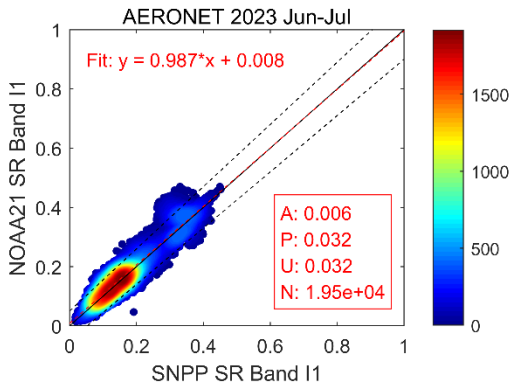
- Cal/Val results summary:
  - Team recommends algorithm beta maturity
    - The SR value and QFs are performed as expected, no obvious issue is found.
    - The AERONET validation shows the SR with good quality could meet the requirements.
    - Good consistence with SNPP, NOAA20 product.
    - Latest LUT have not been incorporated into current data, so similar issue (I1 band slight bias) were found as NPP and N20, the update LUT has been tested and included in the CCAP delivery.
    - According to the SDR team, there is a degradation issue found in the band M8, M10 and M11, close monitoring has been carried out and calibration coefficients are update frequently.
    - Users and downstream products have not found significant issues for NOAA21 SR.

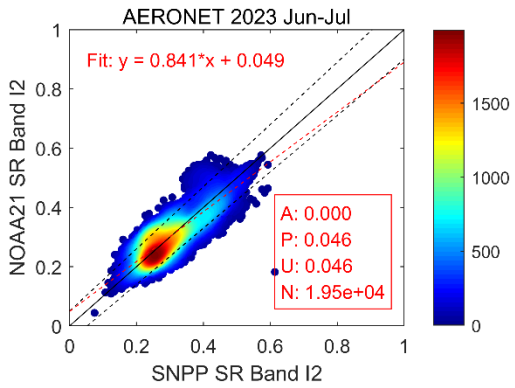
Path Forward

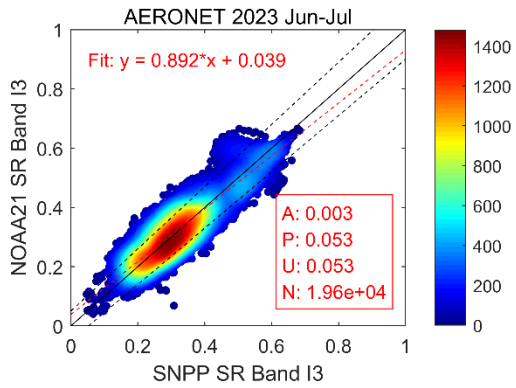
- Lessons learned for NOAA-21 Cal/Val
  - Independent in-situ measurements are limited. SDR data uncertainty or inconsistency could not be detected by AERONET validation.
- Planned improvements
  - Update the LUT to the latest version which has been tested in the CCAP package.
  - Mitigation algorithm used for data classified as the dust aerosol model.
- Future Cal/Val activities / milestones
  - Inter-comparison with NASA VJ209 product (once available)
  - Inconsistency between JPSS satellites analysis and impact evaluation.
  - Long term validation at AERONET
  - Develop routine validation tool and post the results on the website
  - Further collaboration with the vegetation team to evaluate the performance

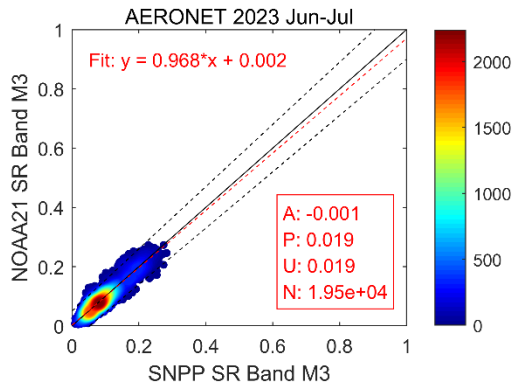
Backup Slides For Reference

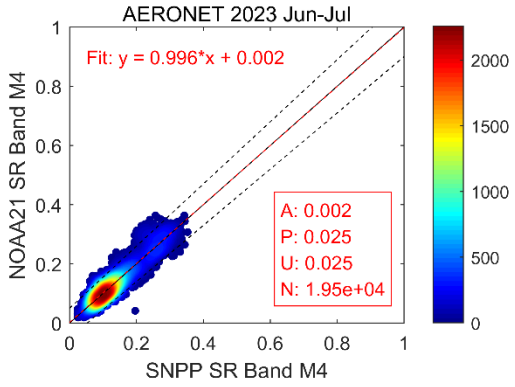
BRDF Corrected SR Intercomparison (NPP vs N21)

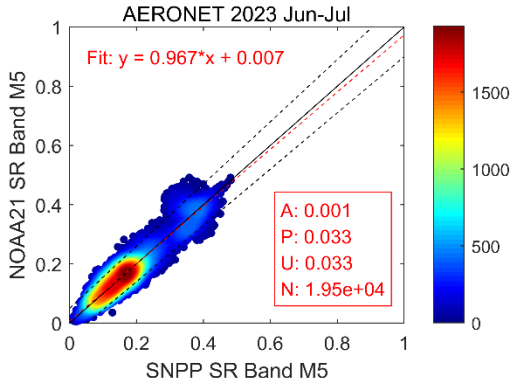


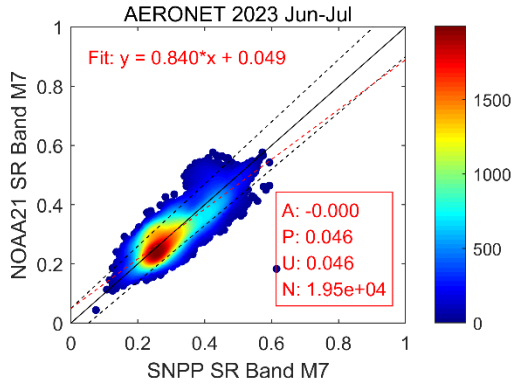


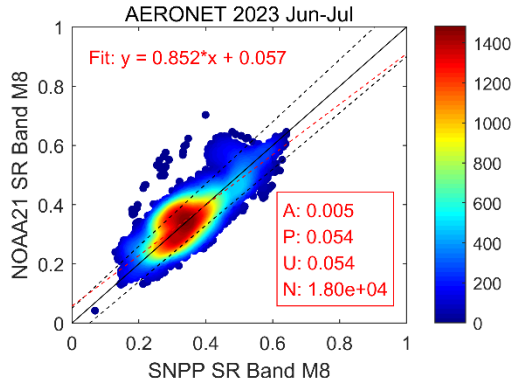


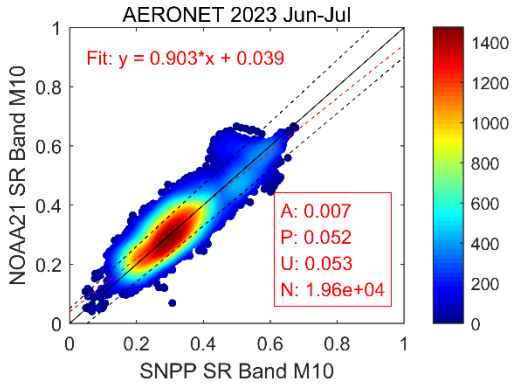


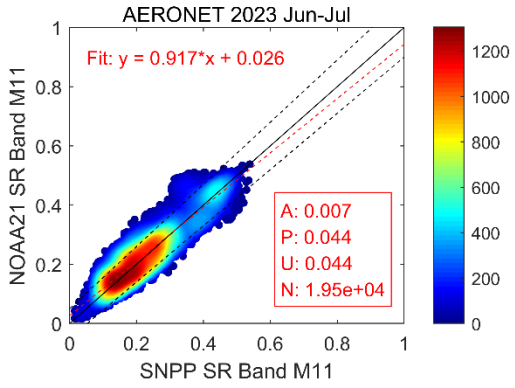












- A BRDF Corrected SR are under development to perform the inter-comparison between SNPP, N20 and N21.
- The preliminary results are shown in this and following slides.

BRDF Corrected SR Intercomparison (N20 vs N21)