Beta Maturity Science Review For NOAA-21 Aerosol Optical Depth and Aerosol Particle Size

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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.

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.

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

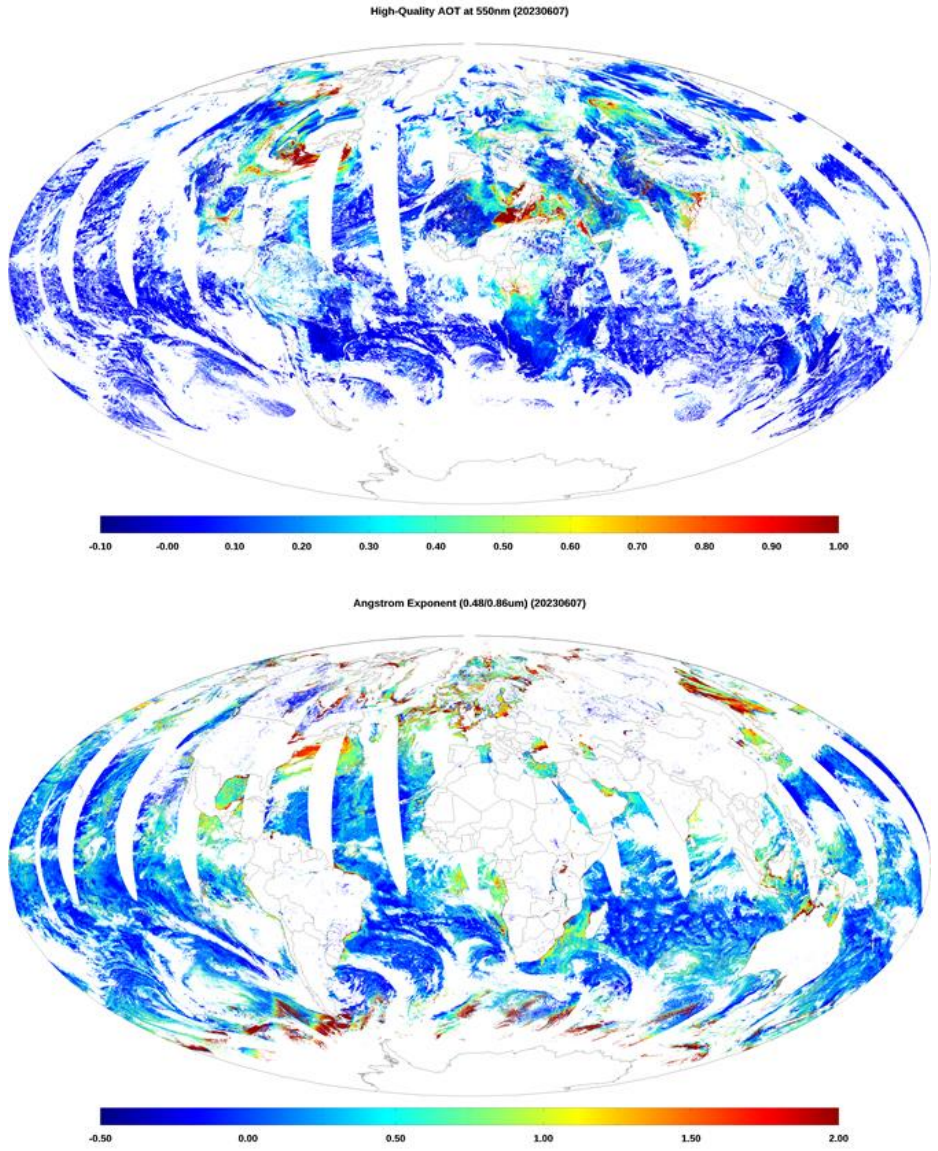
NOAA-21 Aerosol Cal/Val Team

Algorithm Cal/Val Team Members

Name	Organization	Major Task
Amy Huff	IM Systems Group	Aerosol Optical Depth and Aerosol Detection Product validation User outreach and training
Hai Zhang	IM Systems Group	Level 3 product generation and scientific analysis of reprocessed Aerosol Optical Depth product Surface PM2.5 algorithm development and scientific data analysis
Hongqing Liu	IM Systems Group	Aerosol Optical Depth algorithm development and update Development of regional and seasonal aerosol and land surface reflectance models Gridded, merged LEO-LEO VIIRS AOD product Evaluation of VIIRS AOD with ground and other satellite AOD SDR, AOD and ADP product reprocessing in the Cloud (AWS)
Istvan Laszlo	NESDIS/STAR	Co-Lead (AOD)
James Limbacher	IM Systems Group	Aerosol models Aerosol Detection Product algorithm work
Michael Cheeseman	IM Systems Group	Applications and assessment of VIIRS AOD and ADP for estimating PM2.5
Pubu Ciren	IM Systems Group	Aerosol detection algorithm work Aerosol detection product reprocessing on Cloud
Shobha Kondragunta	NESDIS/STAR	Col-Lead (ADP, AOD)
Zigang Wei	IM Systems Group	Level 3 product generation and scientific analysis of reprocessed Aerosol Optical Depth product
Vaishali Kapoor	NESDIS/OSPO/SPSD/SPB	OSPO PAL for AOD and ADP

Product Overview/Requirements (1/2)

- **Aerosol Optical Depth (AOD)**
  - Unitless measure of extinction of radiation by particles suspended in air (aerosol). Depends on the amount and microphysical and chemical properties of particles.
- **Aerosol Particle Size (APS)**
  - Measure of the size distribution in terms of an effective radius.
  - Reported as the unitless Ångström Exponent (AE).
    - Small/large AE represents large/small particles.
    - Derived from AOD.
  - Only over water.



Product Overview/Requirements (2/2)

Attribute	AOD		APS	
Applicable Conditions	Clear sky, daytime only, zenith angles ≤80^{o}			
Geographical Coverage	Global			
Vertical Coverage	Total column			
Vertical Cell Size	Total column			
Horizontal Cell Size	0.75 km at nadir, 1.6 km at edge of scan			
Mapping Uncertainty, 3σ	4 km			
Measurement Range	-0.05 to +5		-1 to +3	
Measurement	*Accuracy*	*Precision*	*Accuracy*	*Precision*
Over Ocean	0.08 (AOD< 0.3) 0.15 (AOD≥ 0.3)	0.15 (AOD≤ 0.3) 0.35 (AOD≥ 0.3)	0.3	0.6
Over Land	0.06 (AOD< 0.1); 0.05 (0.1≤AOD≤0.8) 0.20 (AOD>0.8)	0.15 (AOD< 0.1) 0.25 (0.1≤AOD≤0.8) 0.45 (AOD>0.8)	n/a	n/a
Refresh Rate	90 minutes (~100 minutes)			

Source: JPSS L1RD supplement, JERD, JPSS-REQ-1002/470-00032, Revision 2.11, February 7, 2019

Processing Environment and Algorithms

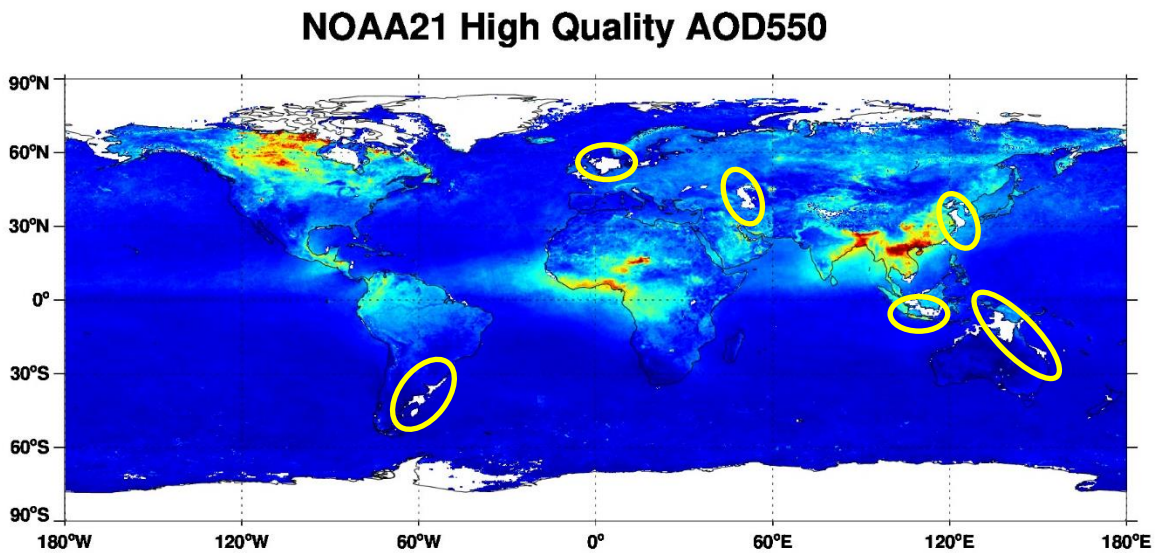
	Description	Effective Date
Algorithm version	Version 1.4	November 16, 2021
Version of LUTs atmosphere sunglint	NOAA-21 VIIRS atmosphere LUT Version 1.0 NOAA-21 VIIRS sunglint LUT Version 1.0	September 30, 2020
Version of PCTs gas absorption dark land bright land	Gas absorption coefficients Version 2.1 Dark land spectral reflectance relationship version 2.1 Bright land spectral reflectance relationship version 1.0	May 26, 2021

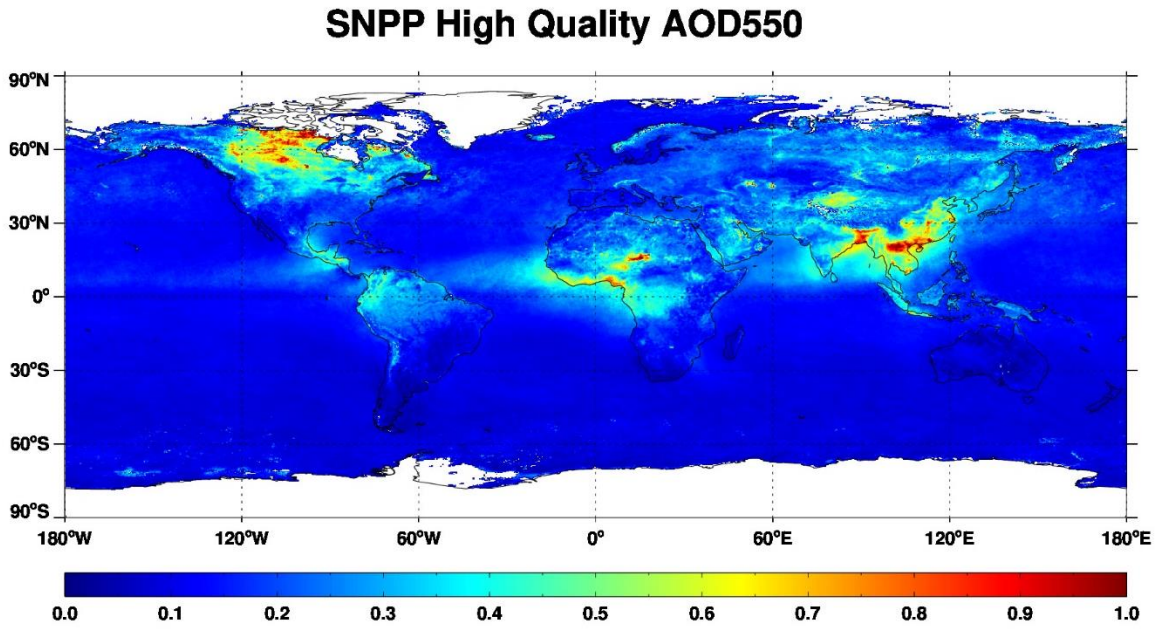
Evaluation of algorithm performance to specification requirements

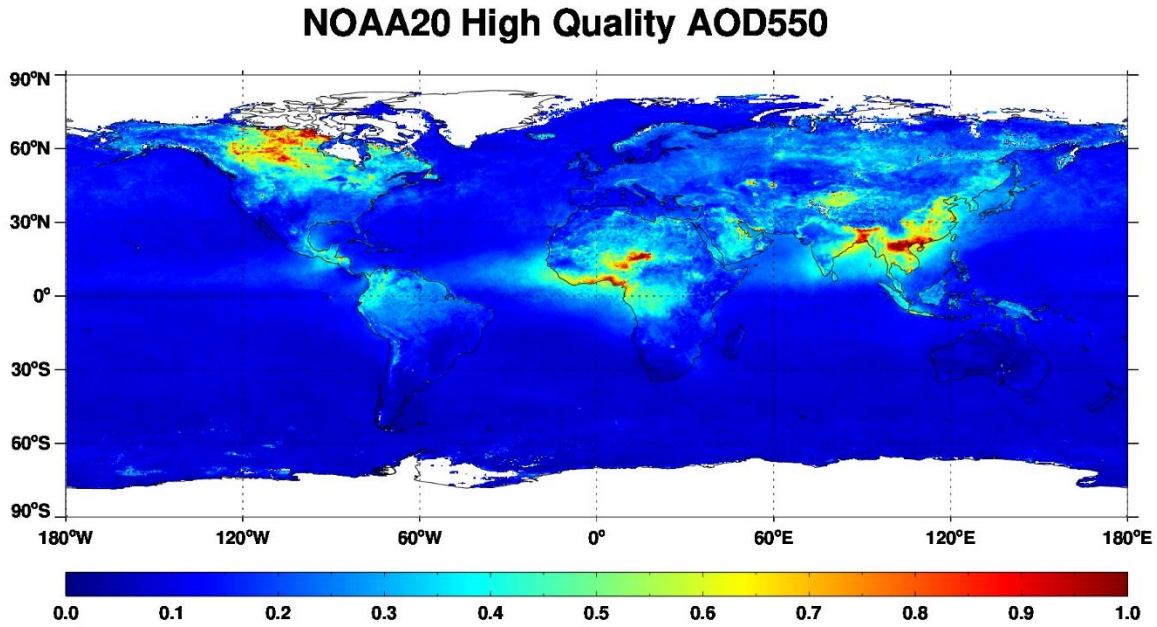
- **Findings/Issues from NOAA-20 Validated Maturity Review**
  - LUTs, PCTs specific for J2 should be prepared using J2 RSR
  - Too few high-quality AOD retrievals available. This “forces” the surface reflectance algorithm to use AOD climatology.
- **Improvements since NOAA-20 Validated Maturity Review**
  - LUTs and PCTs are calculated with NOAA-21 RSR
  - Updated the algorithm to use the dark-land retrieval over bright pixels when the ancillary bright land spectral reflectance ratio is not available (increases number of retrievals)
  - Used LBLRTM, instead of 6S, to compute transmittance of ozone and water vapor in NOAA-21 bands (leads to somewhat more H2O absorption in band M11)
  - Used detailed land/water mask for data quality control (degrades retrievals over shallow inland water and shallow ocean)
  - Updated thresholds in internal tests of sea ice and heavy aerosol over water (used in both NOAA-20 and NOAA-21 algorithms)

- **Data sets**
  - S-NPP, NOAA-20 and NOAA-21 VIIRS AOD and APS data
  - Period: 2/10/2023 – 6/10/2023 (4 months)
  - Coverage: global and over selected (AERONET) sites
- **Validation strategies / methods**
  - Use VIIRS AOD/APS retrievals gridded at 0.25° resolution
  - Visual examination of averaged global distributions
  - Examine the difference between NOAA21 and NOAA20, and those between NOAA-21 and S-NPP retrievals at common grids
  - Examine time series of global averages
  - Compare Probability Plots
  - *Notes:*
    - *Differences are expected (due to differences in SDRs and times of observations, etc.)*
    - *More analyses of AOD than APS are presented; APS is derived from AOD*

Global Mean High-Quality AOD550 (2/10/2023 – 6/10/2023)



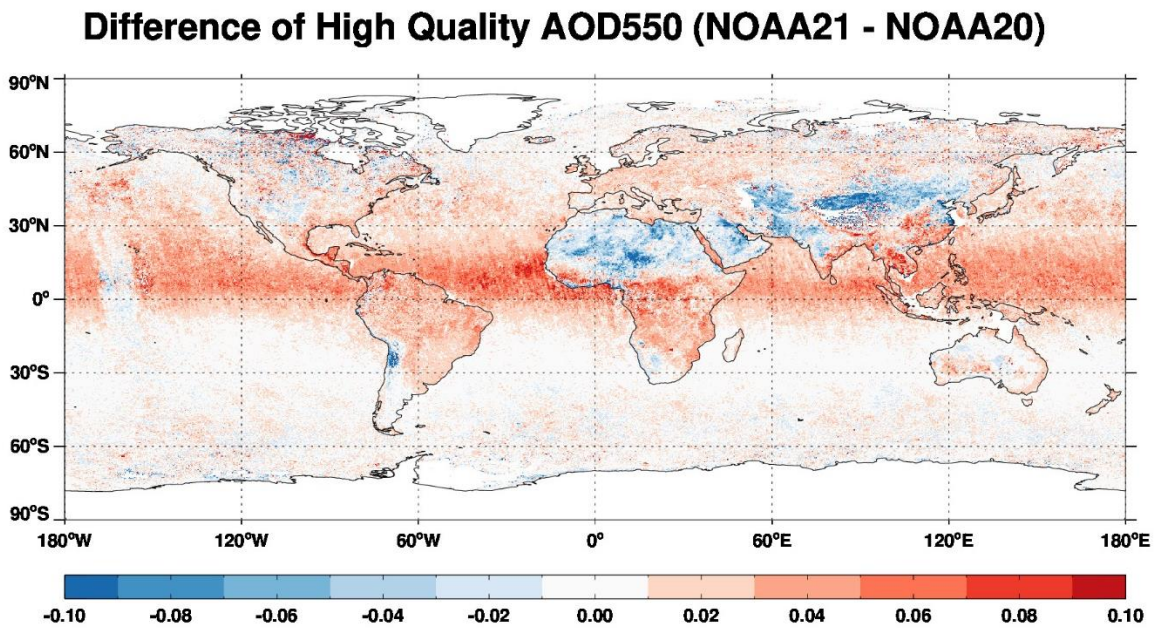


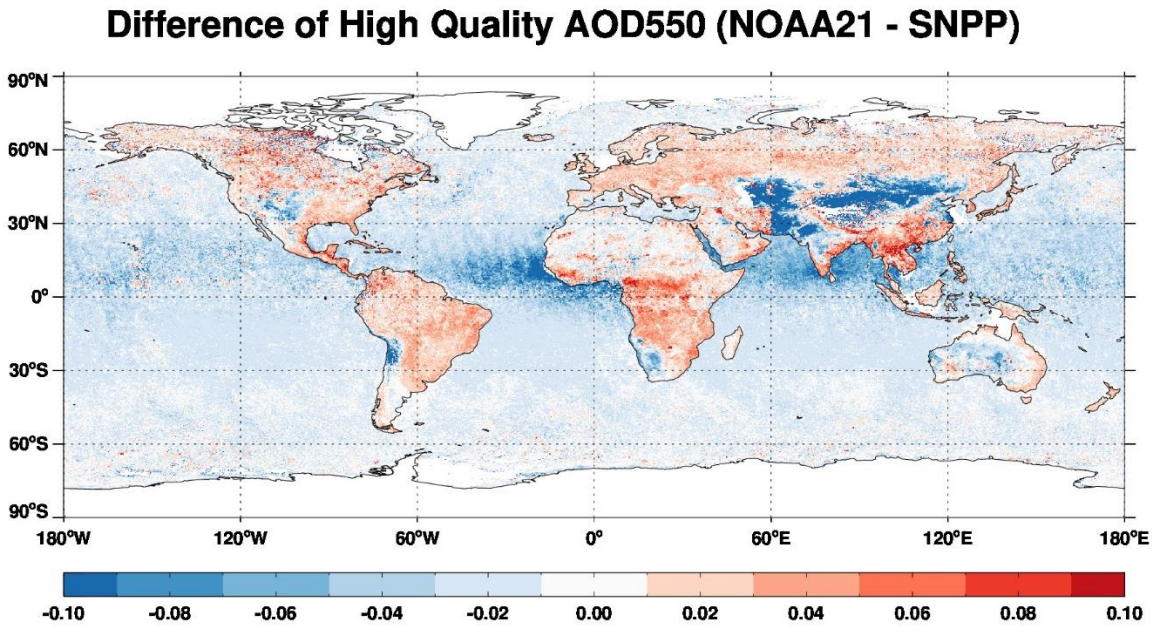


Maps of mean of gridded, high-quality AOD from three satellites from period 2/10 – 6/10, 2023.

- NOAA-21, NOAA-20 and S-NPP AOD have visually very similar spatial patterns.
- Exceptions are the marked areas in the N21 plot which show no high-quality N21 AOD due to use of the detailed land/water mask.

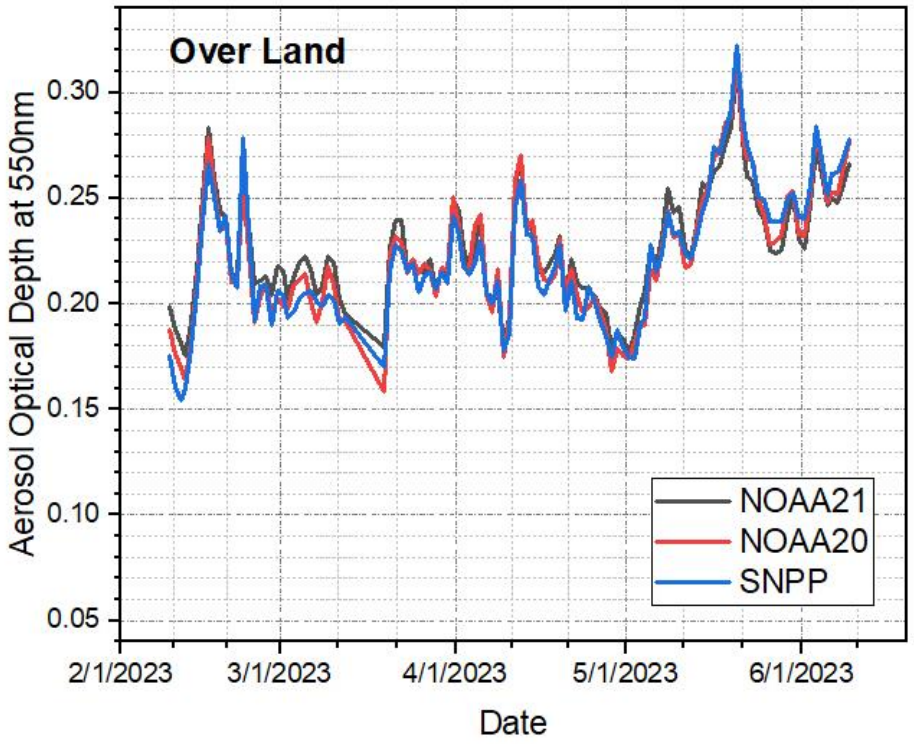
Difference of Global High-Quality AOD550 (2/10/2023 – 6/10/2023)

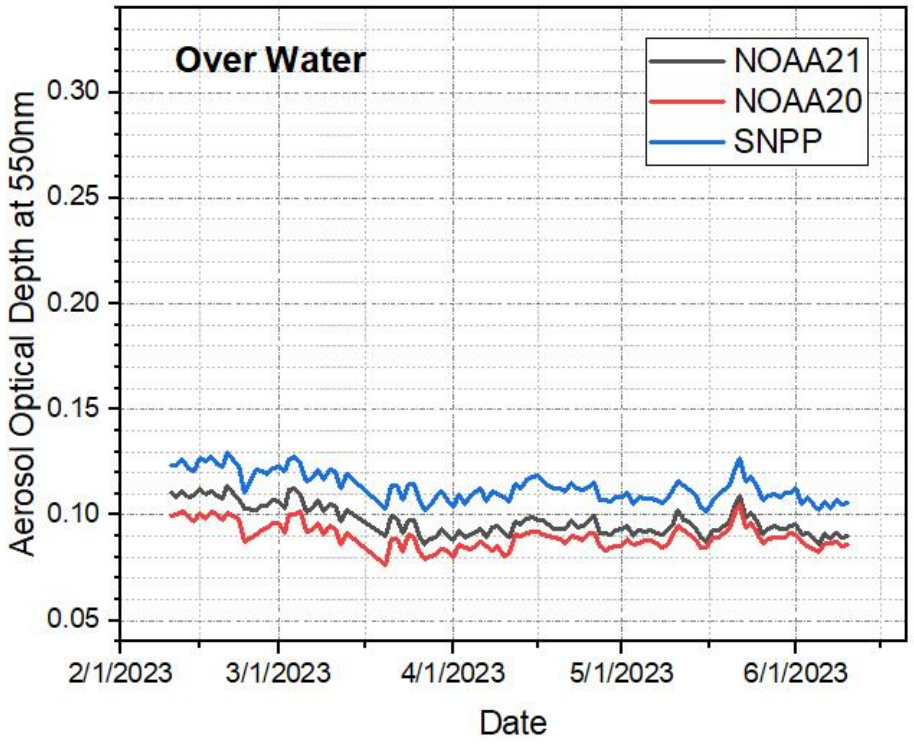




- Compared to NOAA-20 (left panel)
  - NOAA21 AOD tends to be higher over tropical Northern Hemisphere oceans
  - NOAA21 AOD tends to be lower over bright land surface
- Compared to S-NPP (right panel)
  - NOAA21 AOD tends to be lower over water
  - NOAA21 AOD tends to be higher over land in general except over arid regions

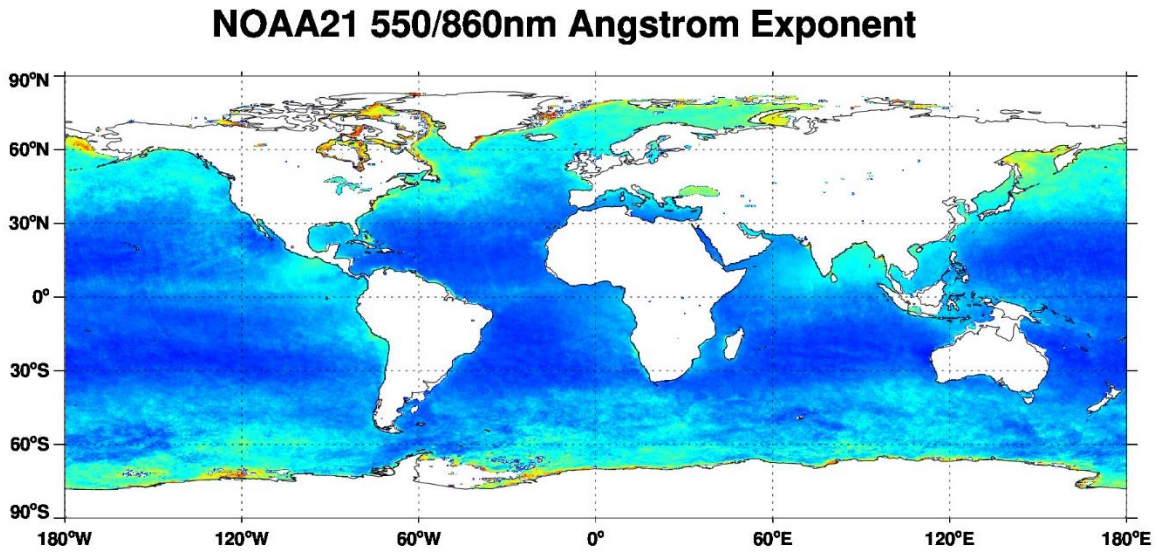
Global Daily Average of NOAA-21, NOAA-20 and S-NPP AOD550

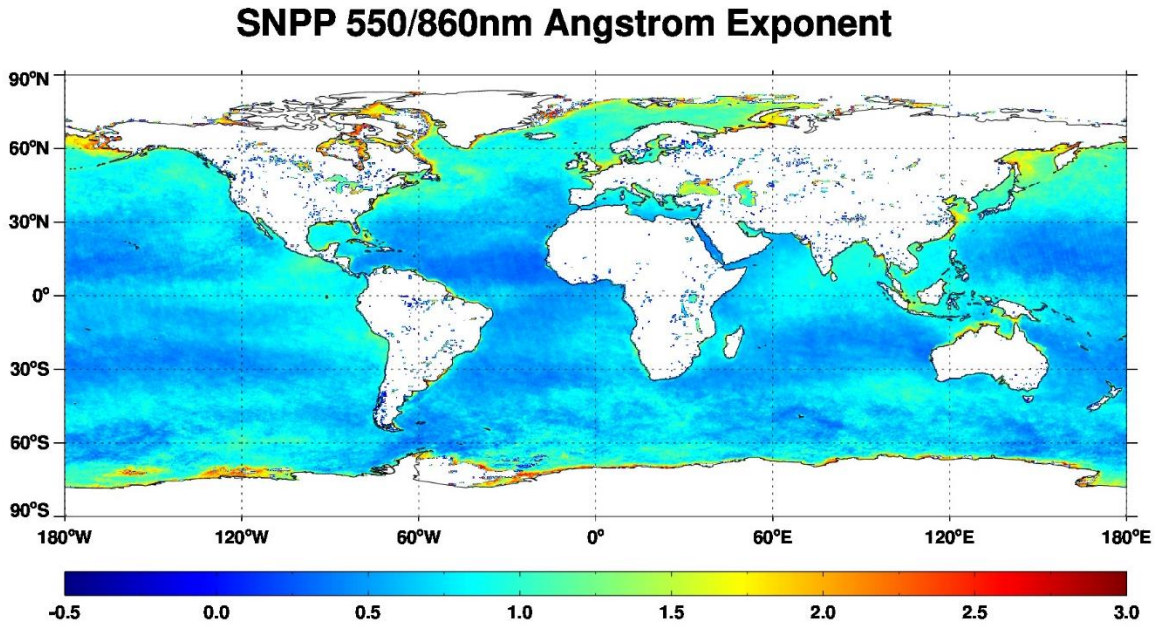


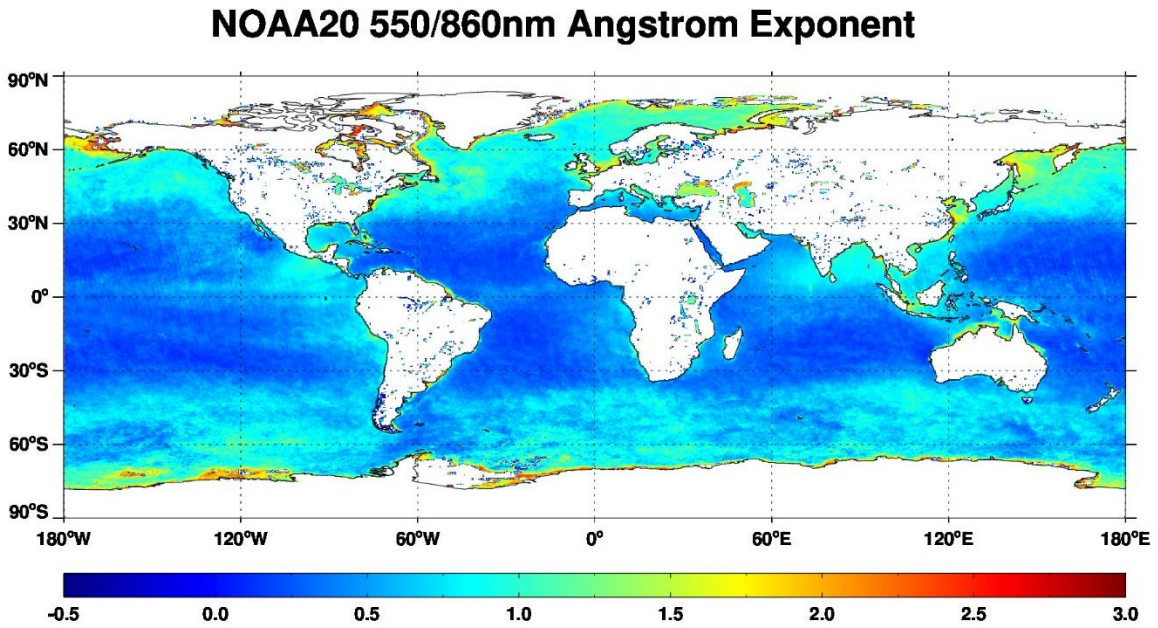


- Similar day-to-day variation of AOD from the three satellites over land.
- Same is true for water, but there is a systematic bias between the three AODs. NOAA21-NOAA20 AOD difference decreases towards the end of the period.

Global Mean Ångström Exponent (2/10/2023 – 6/10/2023)

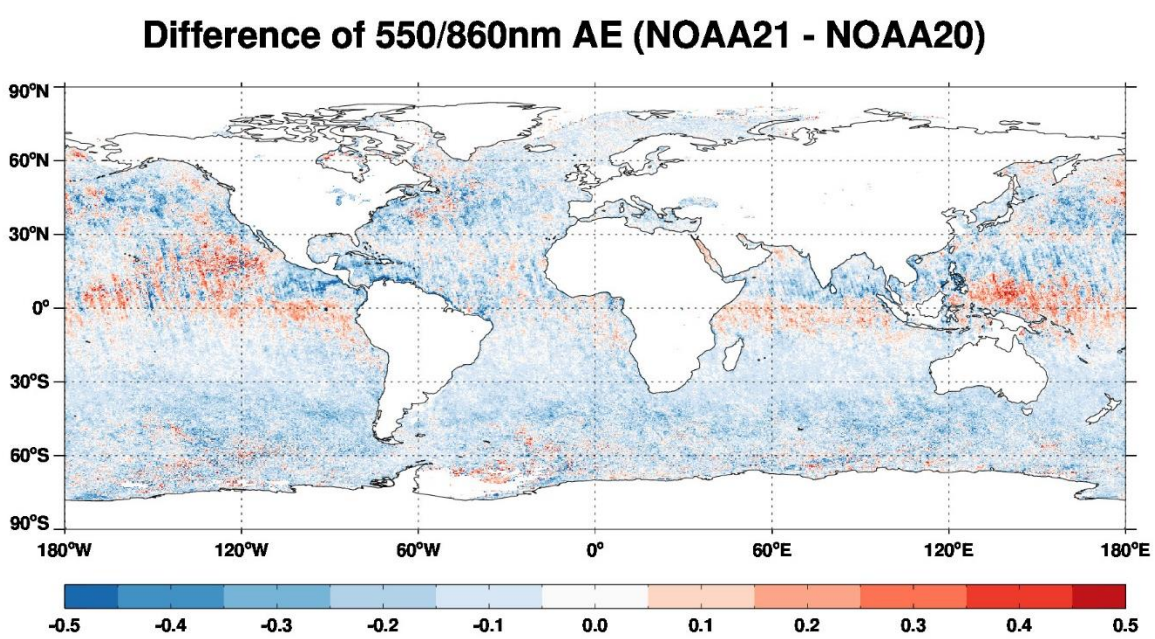


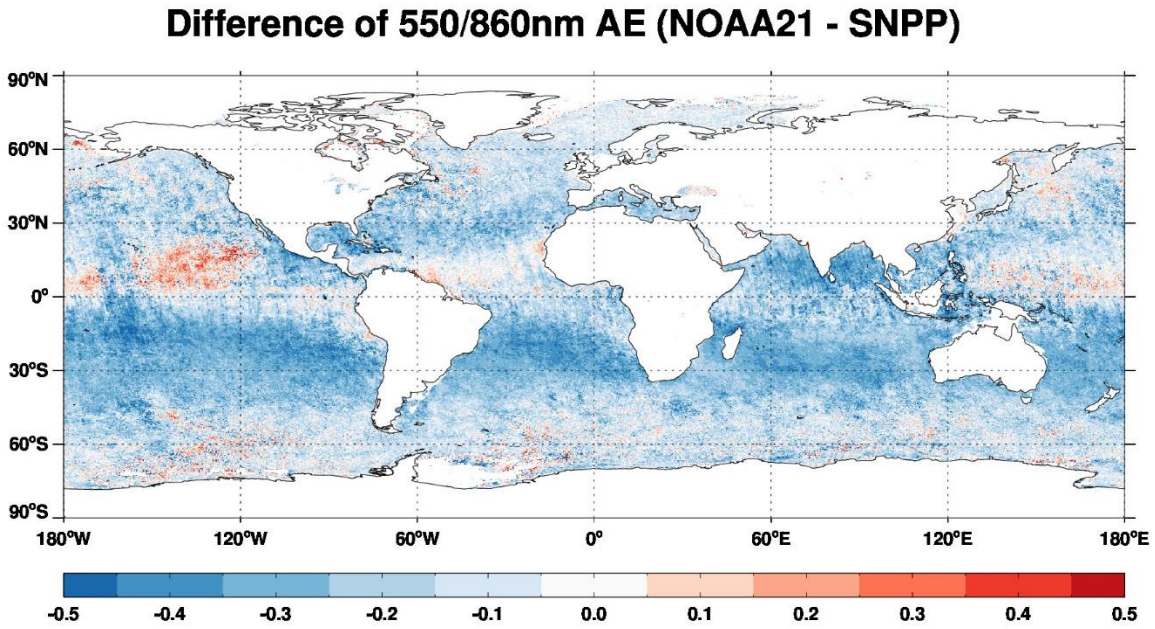




- Short-wavelength (550 vs. 860 nm) AE from three satellites have similar spatial patterns. NOAA-21 and NOAA-20 AEs are more similar to each other than any of them to S-NPP AE.
- Fewer high-quality NOAA-21 AOD retrievals over inland water bodies and some coastal areas due to a change in the land/water mask for NOAA-21 that degrades quality over shallow water.

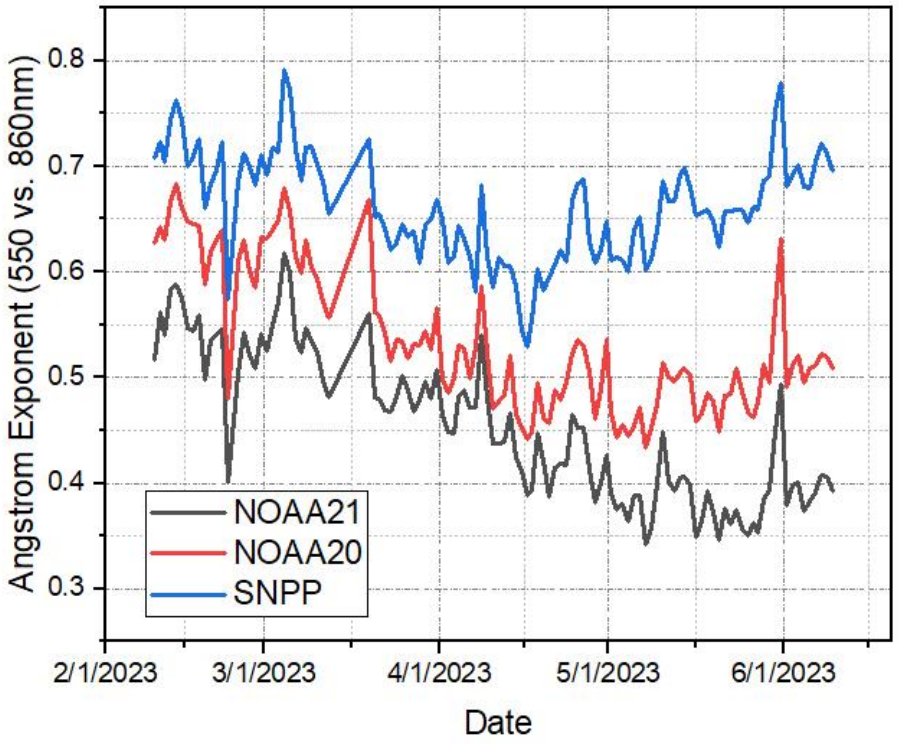
Global Difference of Ångström Exponent (2/10/2023 – 6/10/2023)

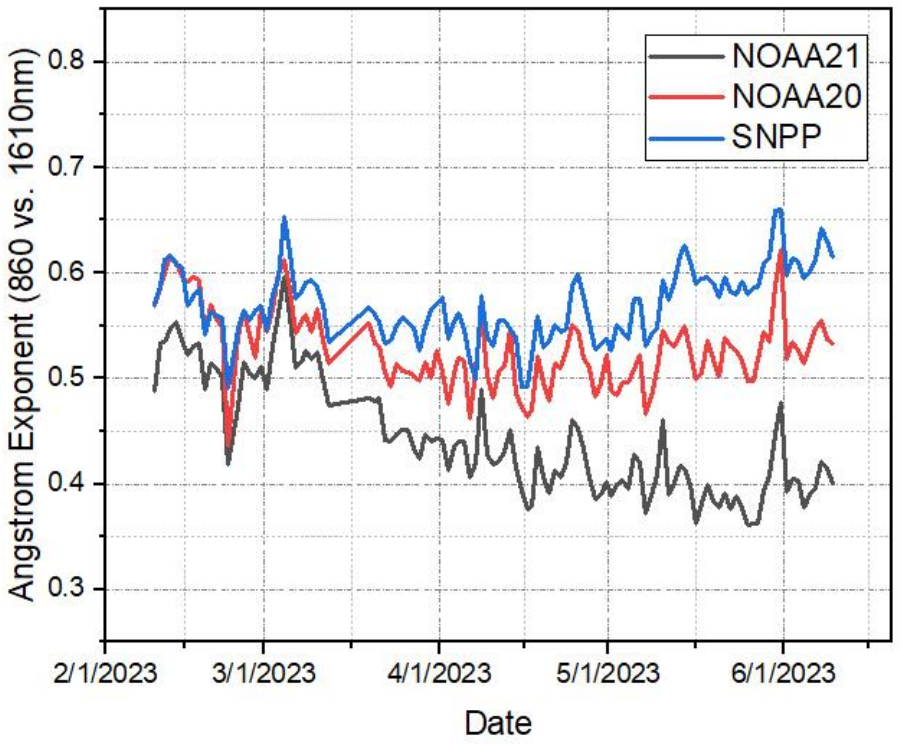




- Relative to NOAA-20 (*left panel*),
  - NOAA-21 AE is somewhat smaller at most mid-latitudes (larger particles), and somewhat larger around the equator (smaller particles)
- Relative to S-NPP (*right panel*),
  - NOAA-21 AE is generally smaller most latitudes (larger particles), except at few places north of equator and at high latitudes.
- Features are largely similar for the 860 vs 1610 nm AE. (See Appendix)

Time Series of Global Daily Average NOAA-21, NOAA-20 and S-NPP AEs

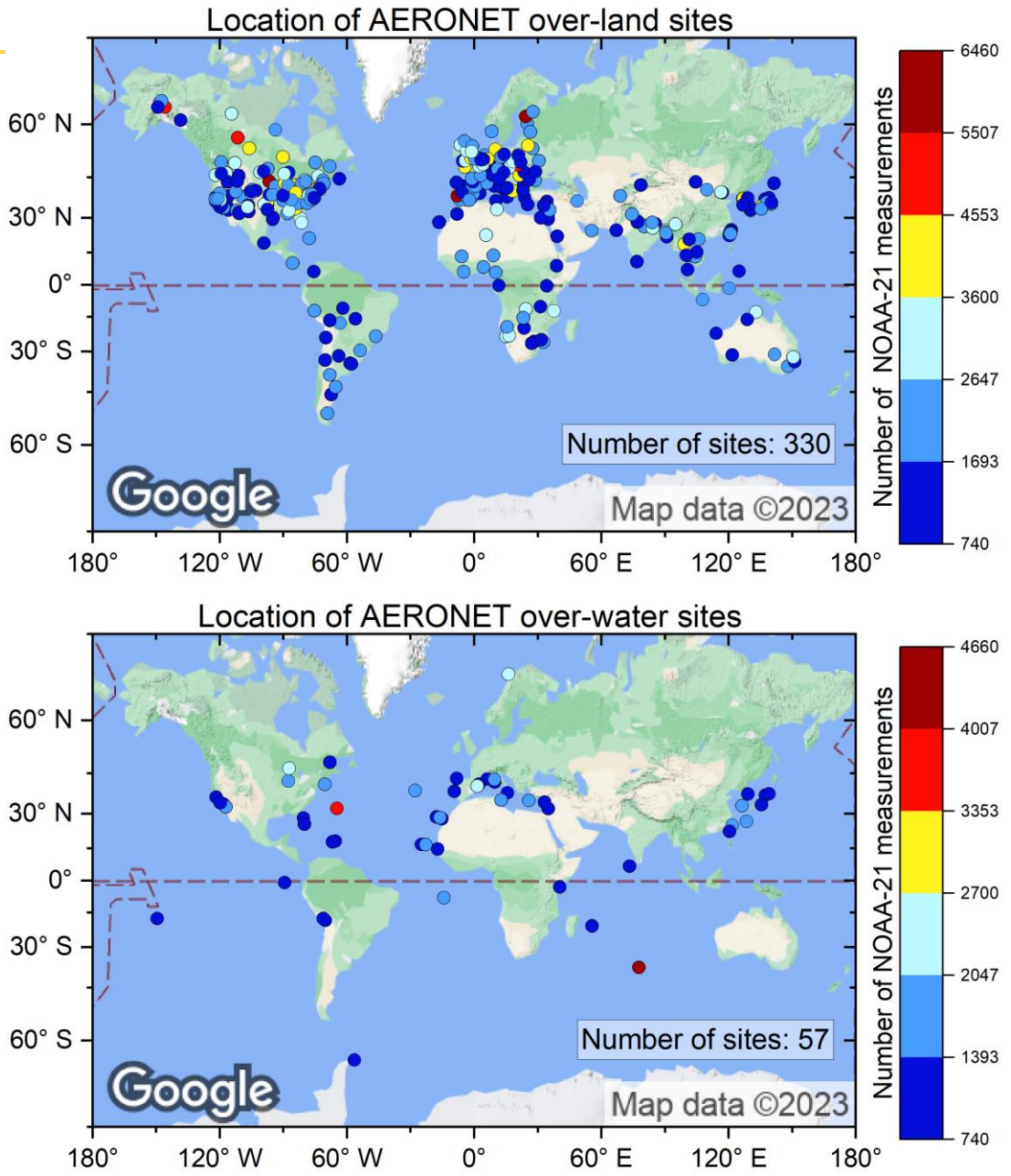




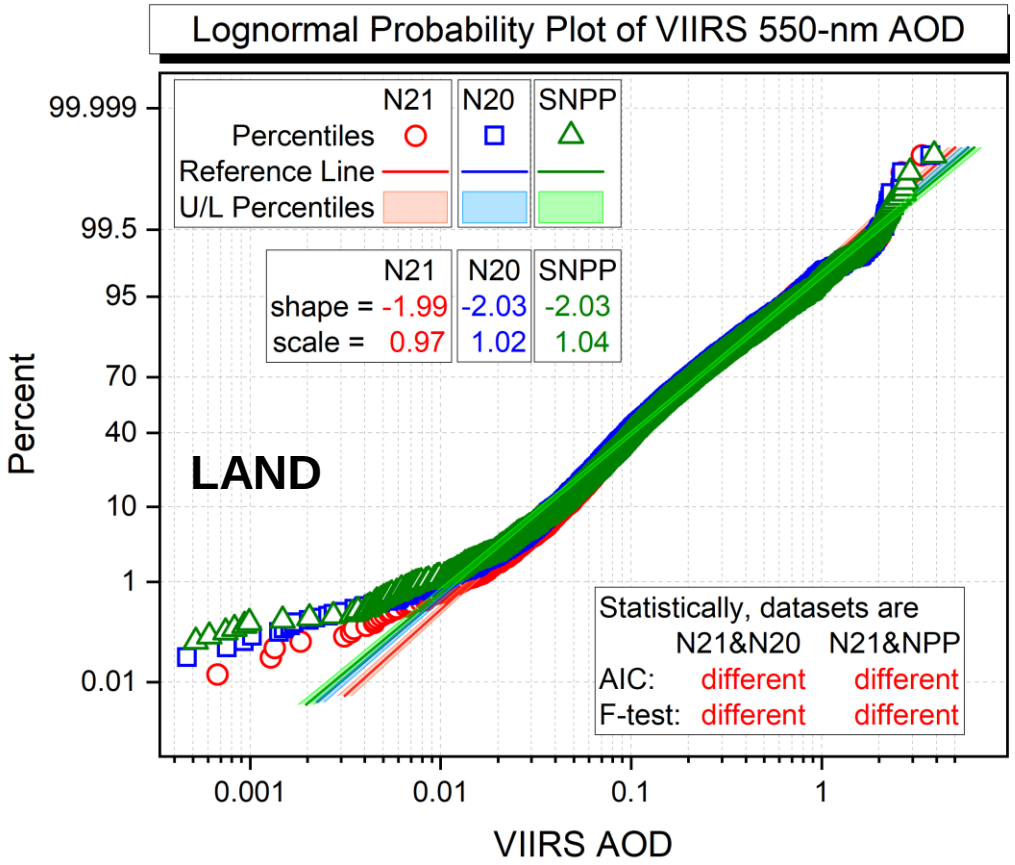
- Day-to-day variations are similar but magnitudes and trends are different.
- NOAA-21 AE is smaller than NOAA-20 and S-NPP AE, suggesting larger particles

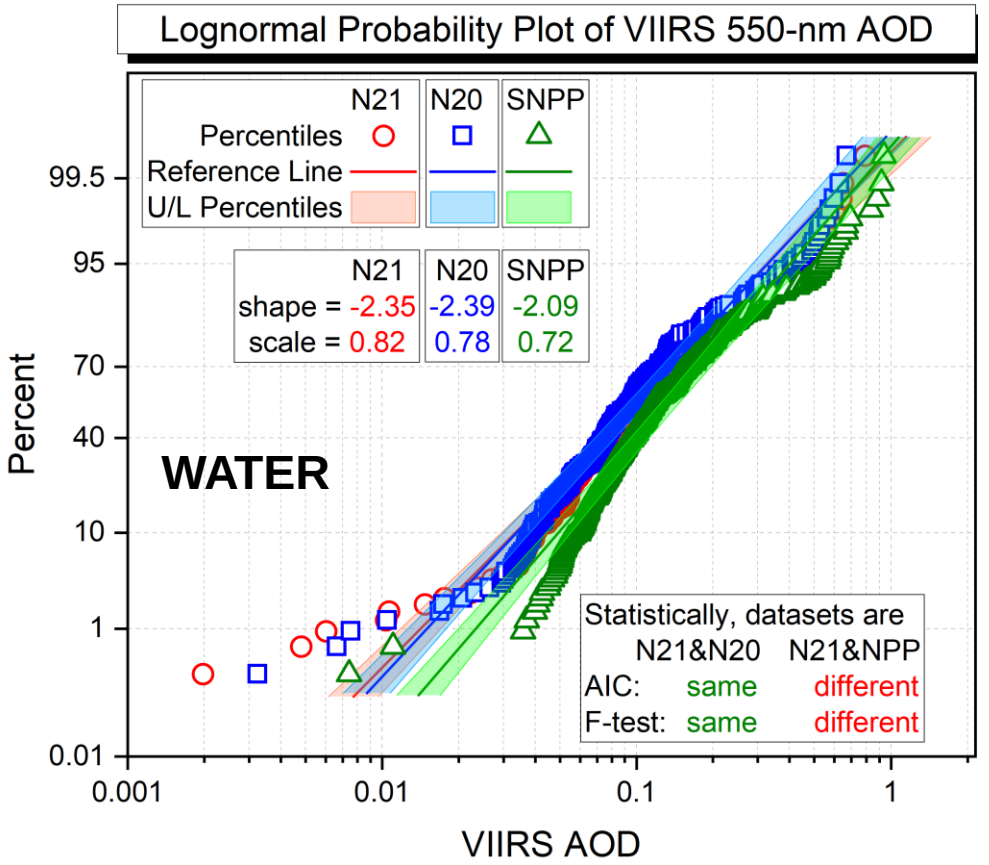
Probability Plots

- Probability plots used to see if NOAA-21, NOAA-20 and S-NPP AODs are coming from statistically similar populations.
- *Data*: high-quality AODs over AERONET sites from *Feb 10 – Jun 10, 2023*.
- Empirical CDF is constructed and fitted; Lognormal distribution is assumed.
  - Reference line, fit parameters shape [mean of ln(AOD)] and scale [std. of ln(AOD)] are compared.
- Level of statistical similarity is measured by:
  - Akaike Information Criteria (AIC)
  - F-test



Probability Plots and Statistical Similarity - Satellite-to-Satellite comparison



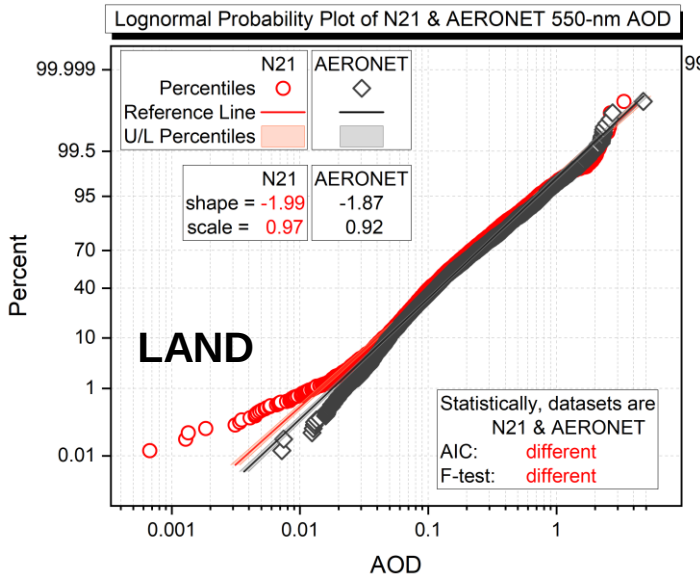


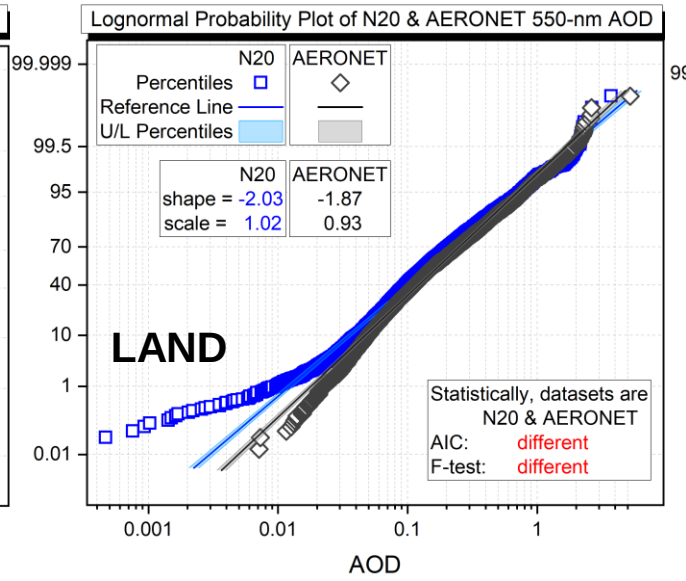
- Over land, shapes and scales are sufficiently different so that all three datasets are statistically different at the 0.05 significance level according to both AIC and F-test.
- Over water, NOAA-21 and NOAA-20 AODs are statistically same (not statistically different at 0.05 significance level), but NOAA-21 and S-NPP AODs are different (also true for NOAA-20 and S-NPP AODs; not shown).

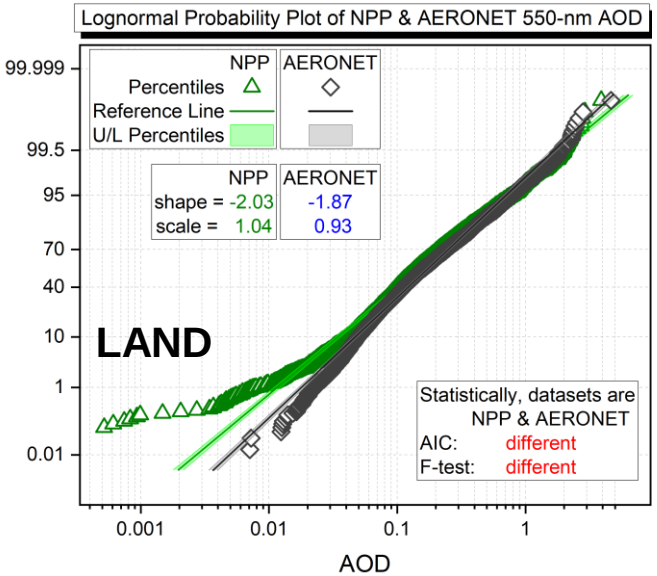
Algorithm Performance Evaluation - Validation with “Ground Truth”

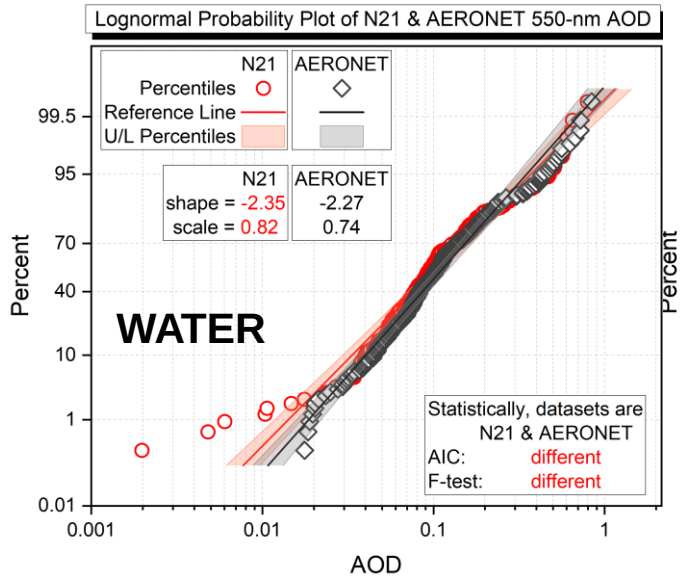
- **Validation data sets**
  - AERONET direct-Sun measurements
  - Period: 2/10/2023 – 6/10/2023
  - Coverage: station locations
- **Validation strategies / methods**
  - Compare Probability Plots of S-NPP, NOAA-20, NOAA-21 and corresponding AERONET matchups for AOD
  - Assess retrieval performance in terms of accuracy and precision relative to AERONET data
  - Examine the daily time series of retrieval error
  - *Differences are expected (due to differences in SDRs and times of observations)*

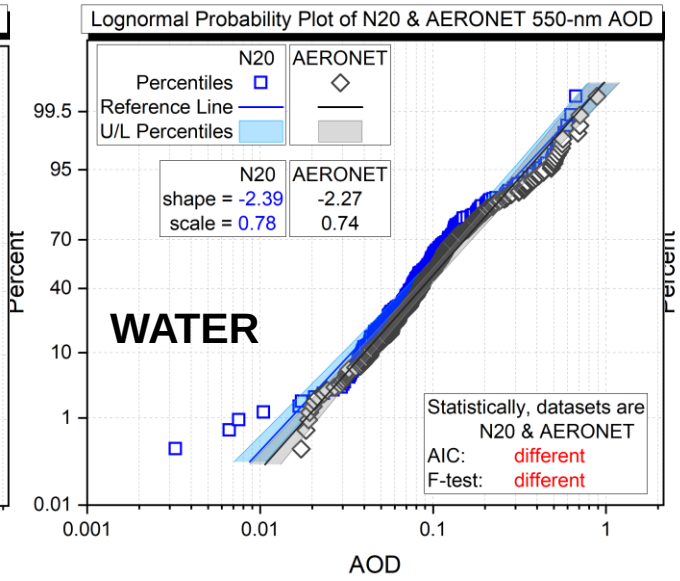
Probability Plots and Statistical Similarity - Satellite-to-AERONET comparison

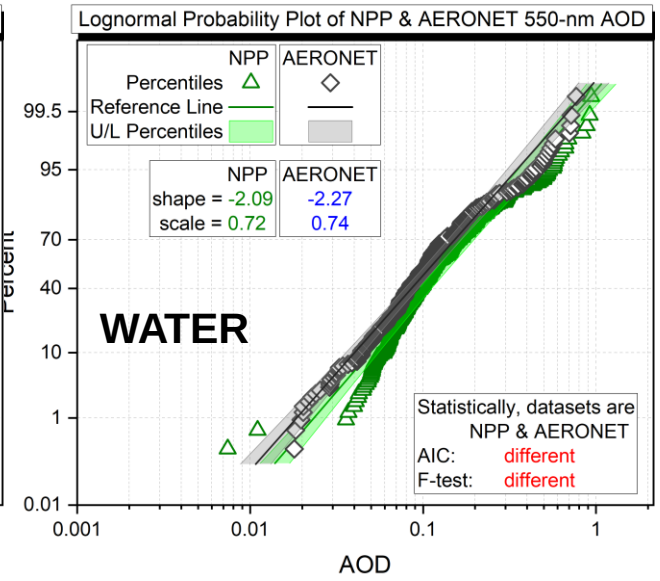








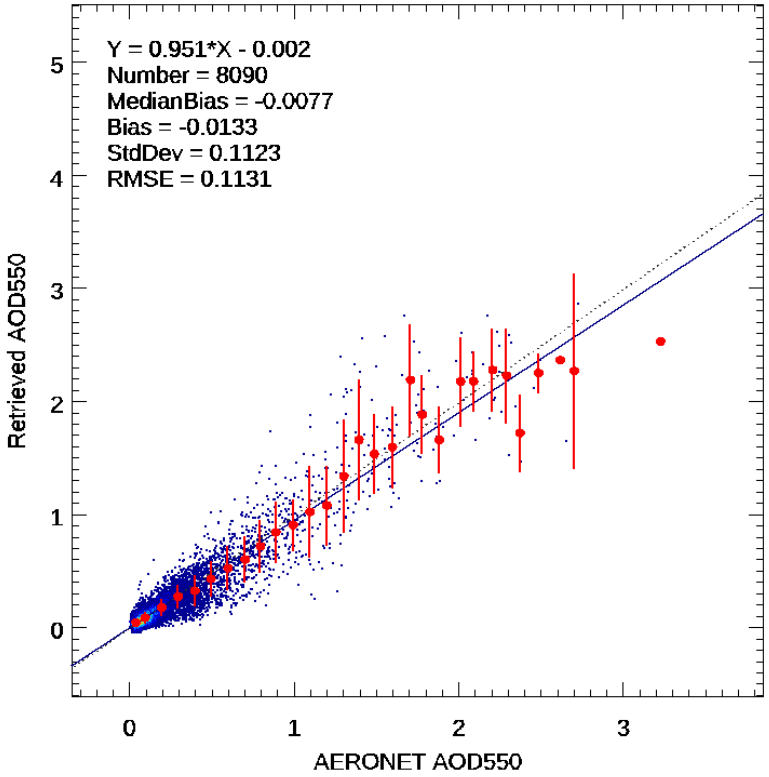




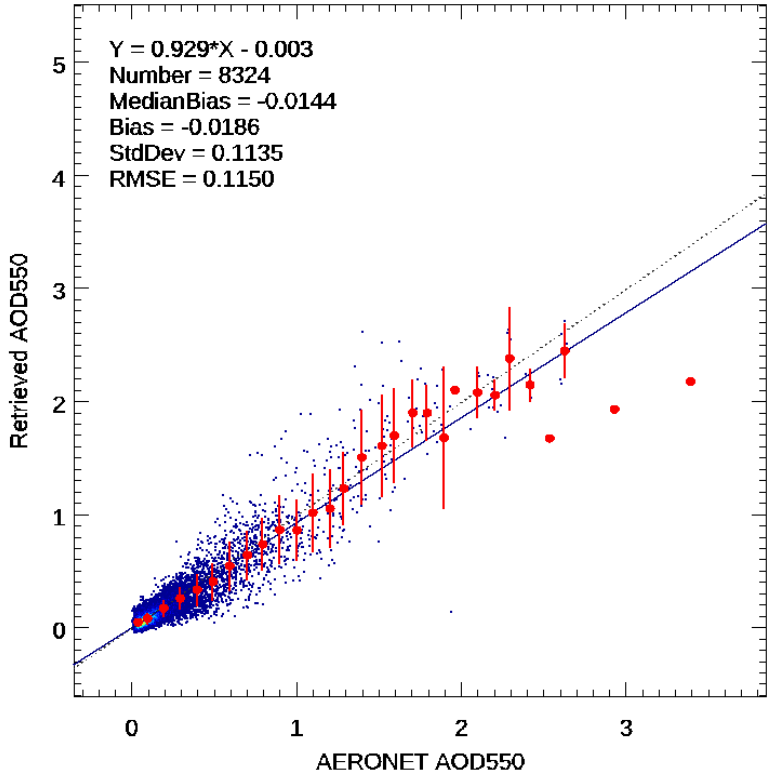
- NOAA-21 and AERONET AODs are statistically different both over land and water.
- The same is true for NOAA-20 and S-NPP AODs.
- That is, **quality of NOAA-21 AOD is similar to (not worse than) quality of NOAA-20 or S-NPP AODs**.
- Scatter plots are in the Appendix.

Validation of AOD550 over Land

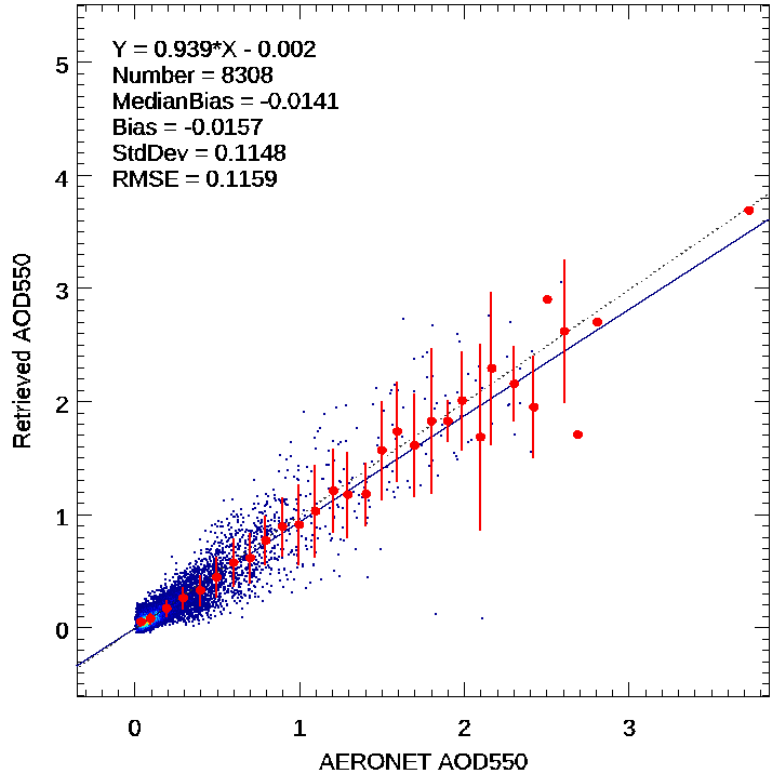
NOAA21



NOAA20

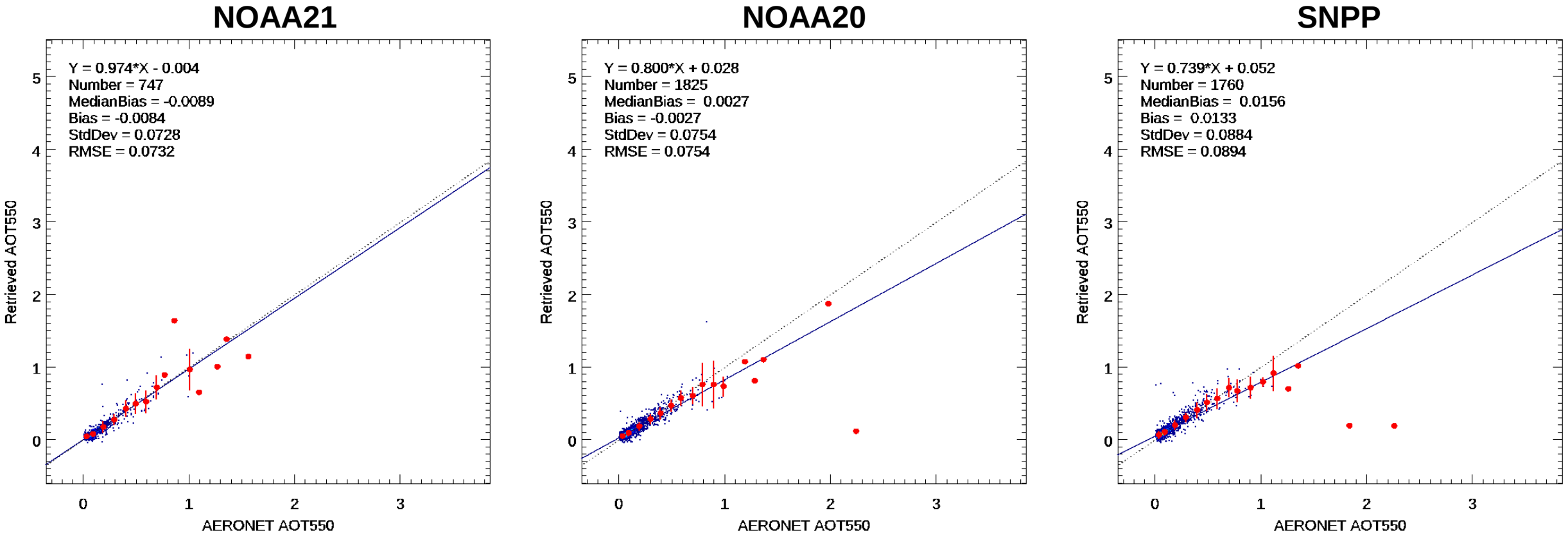


SNPP



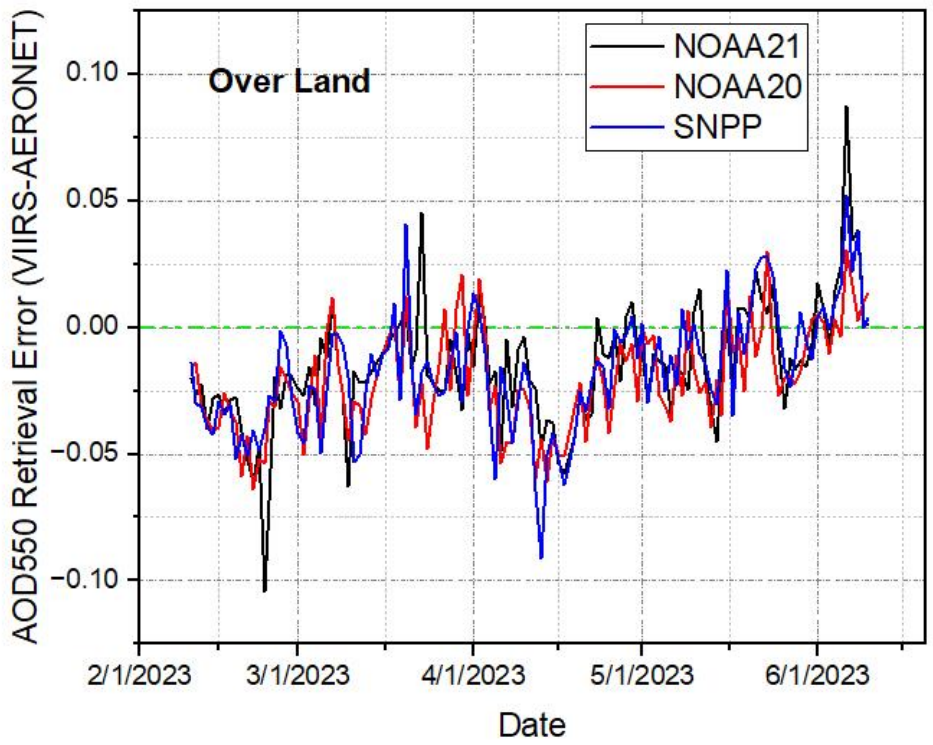
- Biases of VIIRS AOD relative to AERONET are very similar; mean of VIIRS AODs in all three satellites are smaller by 0.01-0.02 than the corresponding mean AERONET AODs.
- Standard deviations are also very similar.

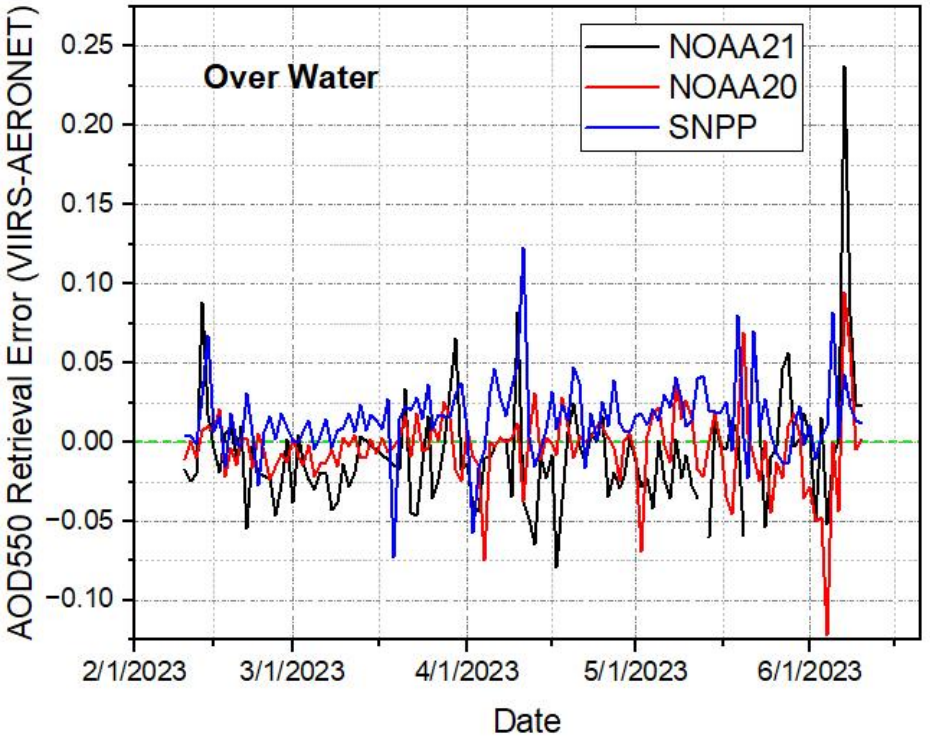
Validation of AOD550 over Water



- Bias of NOAA-21 VIIRS AOD relative to AERONET is larger than NOAA-20 bias, but both negative, and NOAA-21 fit line is closer to 1:1 line.
- Standard deviations are largely similar.
- NOAA-21 AOD sample has less inland and shallow water pixels; sample size is smaller than those of NOAA-20 or S-NPP.

Time Series of Daily AOD Error wrt AERONET

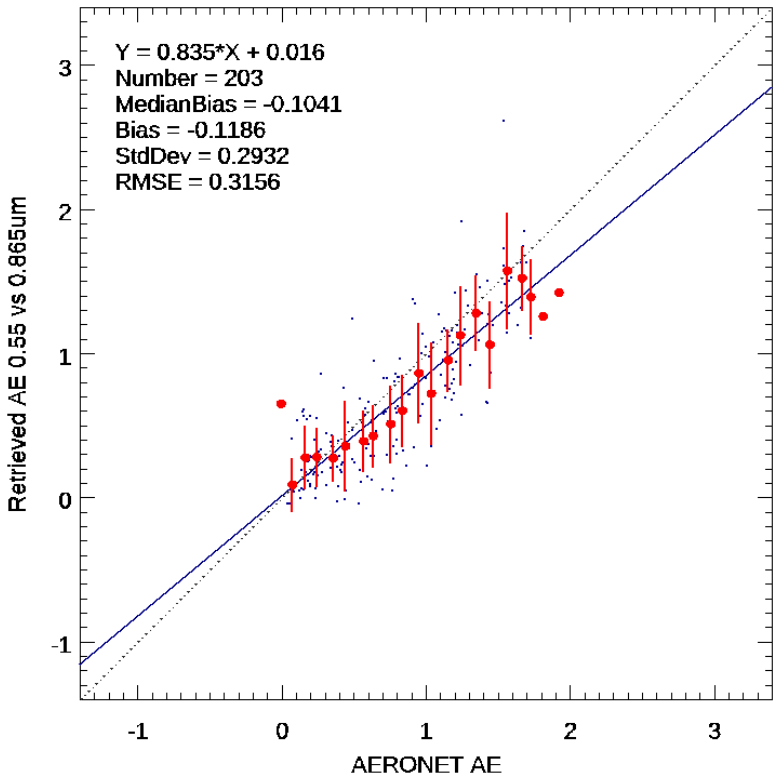




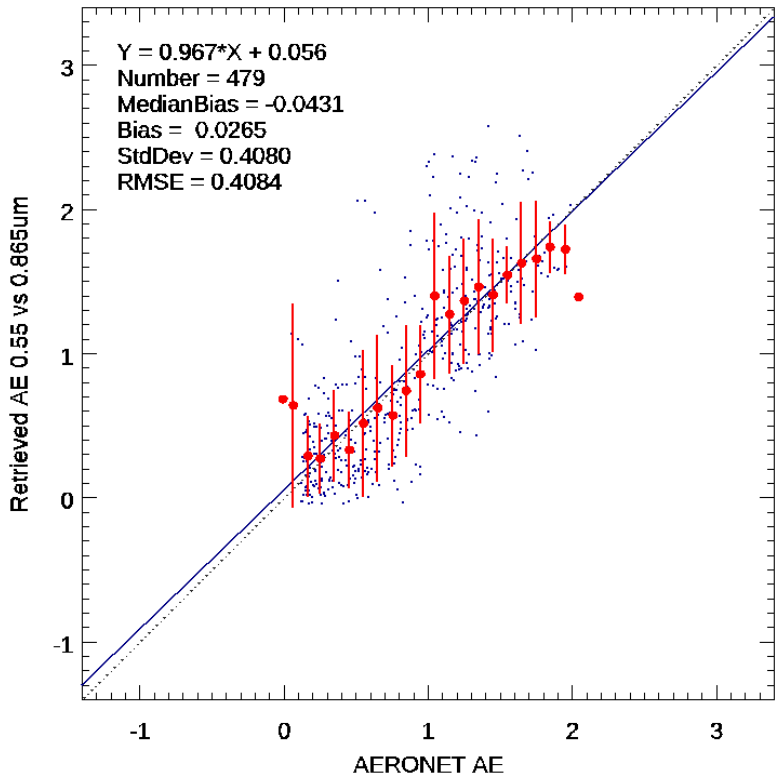
- Over land (*left*), day-to-day variation of retrieval errors in NOAA-21 AOD is similar to those in NOAA-20 and S-NPP. All three shows similar seasonal dependence.
- Over water (*right*), there is no obvious trend in either satellite AODs during this four months period. Daily error (bias) of NOAA-21 AOD tends to be negative with occasional larger positive errors. Daily error of NOAA-20 AOD is similar to that of NOAA-21 AOD but with somewhat more frequent positive excursion.

Validation of AE (550 vs 860nm) over Water

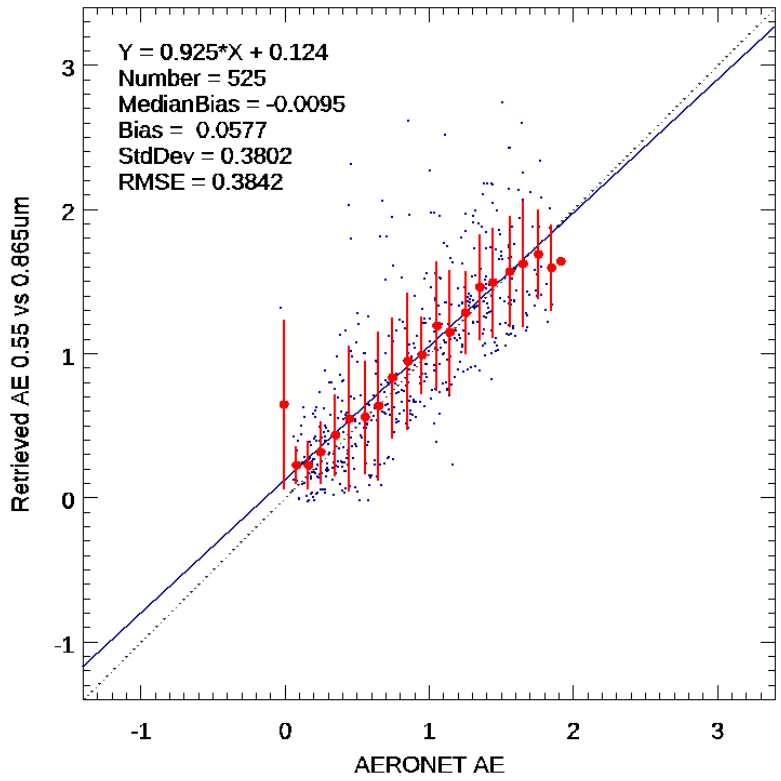
NOAA21



NOAA20



SNPP



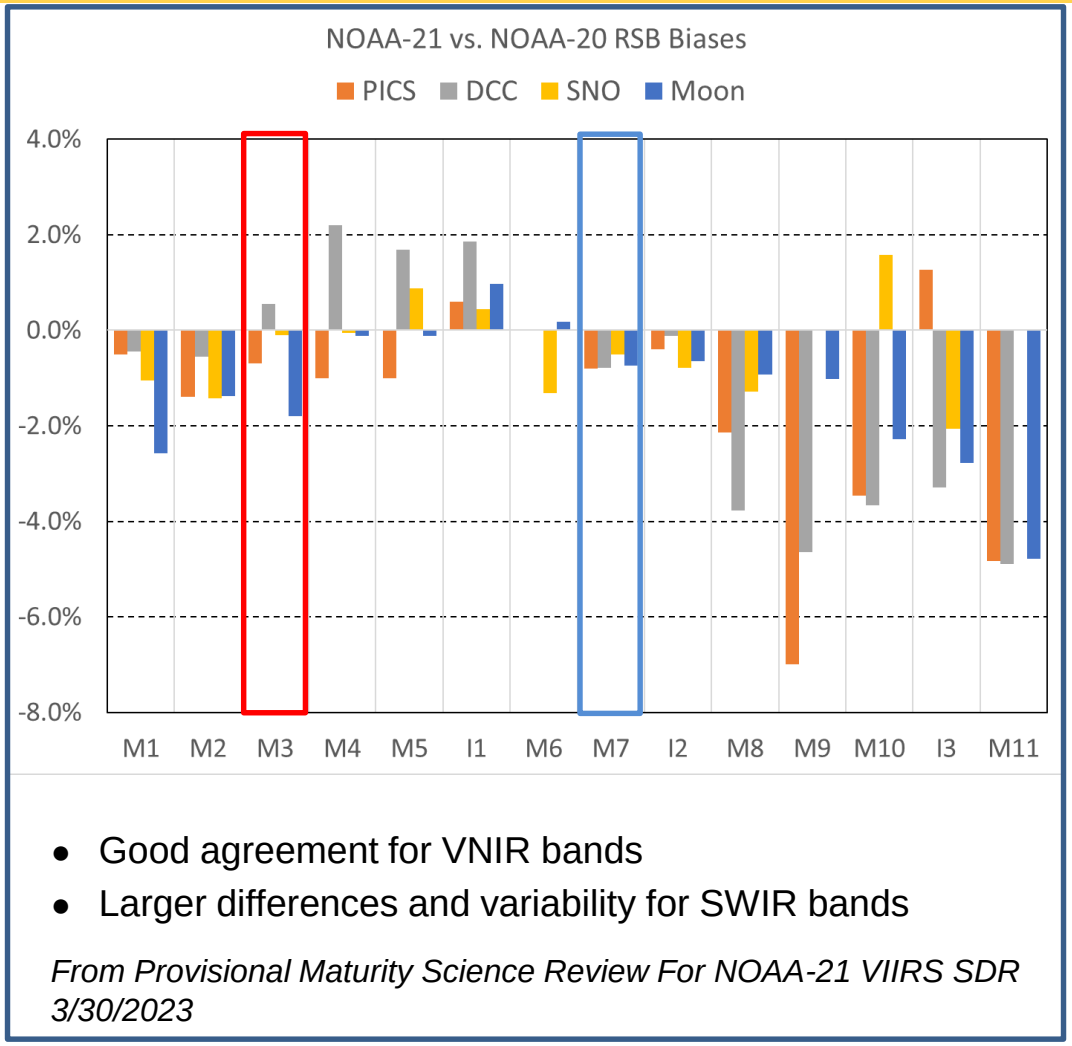
- NOAA-21 short-wavelength AE has the largest bias among the three satellites.
  - Sample size of NOAA-21 AE is less than half of the size of NOAA-20 and S-NPP sample sizes.
- NOAA-21 long-wavelength AE agrees better with AERONET than the NOAA-20 AE does (see Appendix).

Evaluation of the effect of required algorithm inputs

- **Required Algorithm Inputs**
  - Primary Sensor Data
    - NOAA-21 VIIRS M-band SDR (M1-M11, M15, M16) and GEO.
  - Ancillary Data
    - GFS TPW, ozone, wind, surface pressure,
    - Global land surface type.
  - Upstream algorithms
    - Cloud mask, cloud shadow mask, land/water mask, fire mask, snow/ice mask, glint mask, heavy aerosol mask.
  - LUTs / PCTs
    - Aerosol LUT and sunglint reflectance LUT.
    - Coefficients for calculating gaseous absorption, molecular and water spectral reflection, valid input value ranges, thresholds for internal test and quality control, spectral relationship of dark land reflectance, and ratio of bright surface reflectances.

Evaluation of the effect of required algorithm inputs - SDR

- AOD data used in the review are retrieved from SDR after the Jan 12, 2023 calibration update of VNIR bands (M1-M7), but include SWIR bands (M8-M11) prior to the Mar 23, 2023 calibration update.
- N21 M7 band (865 nm), primary band for over-water AOD, is darker than the same N20 band:
  - Partially explains the N21 vs. N20 AOD difference over water.
- N21 vs. N20 bias of M3 band (488 nm), the primary band for over-land AOD, depends on calibration used; interpretation of impact on AOD is not straightforward.
- N21 M11 (2250 nm) is darker than the same N20 band:
  - Compared to N20, reduces N21 surface reflectance but increases AOD *over land* (partial compensation).
  - Potentially impacts aerosol model selection.

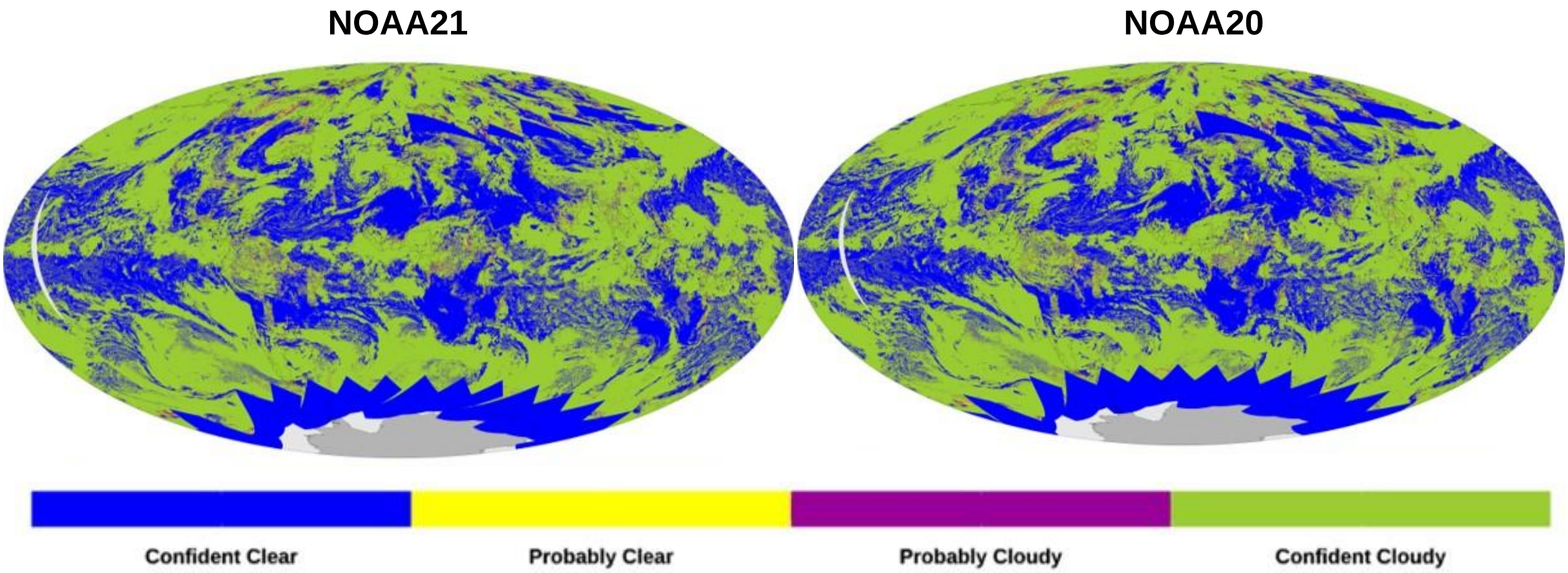


- Good agreement for VNIR bands
- Larger differences and variability for SWIR bands

From Provisional Maturity Science Review For NOAA-21 VIIRS SDR 3/30/2023

… **However, N21 and N20 AODs were shown to have similar qualities.**

Input Cloud Mask (6/7/2023)



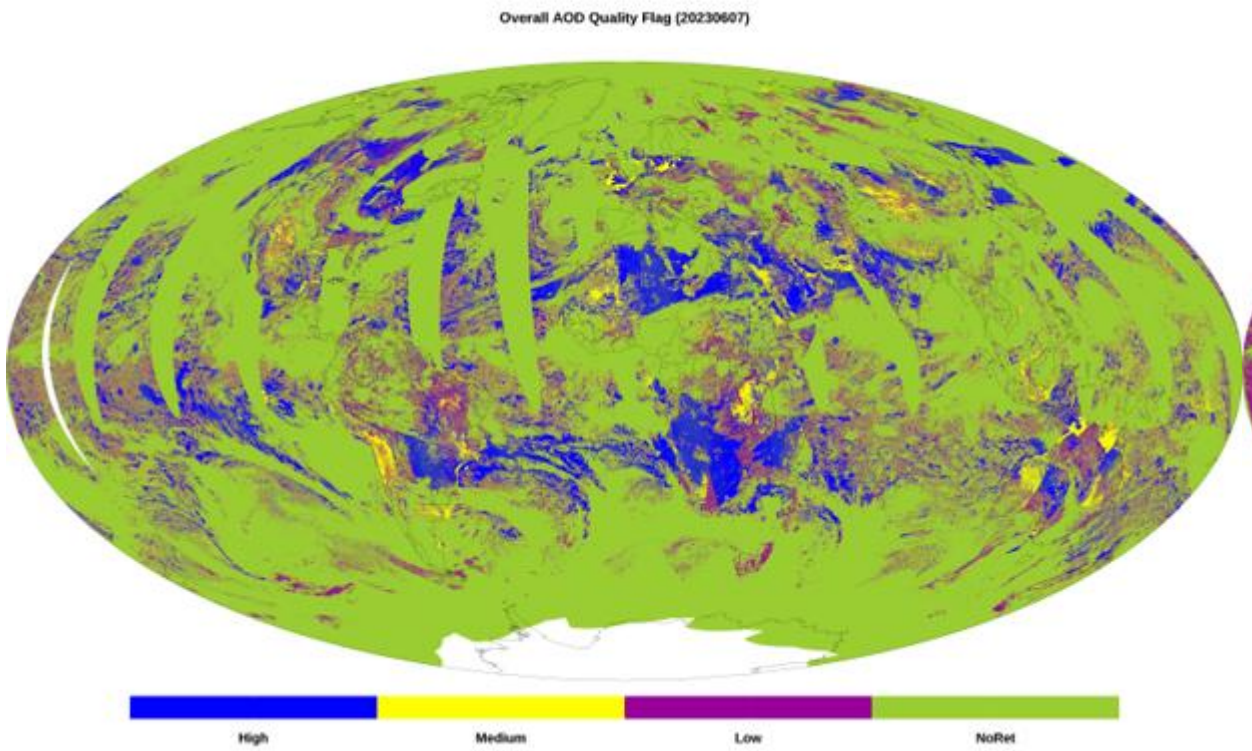
- NOAA-21 and NOAA-20 external cloud masks are visually very similar.

Quality flag analysis/validation

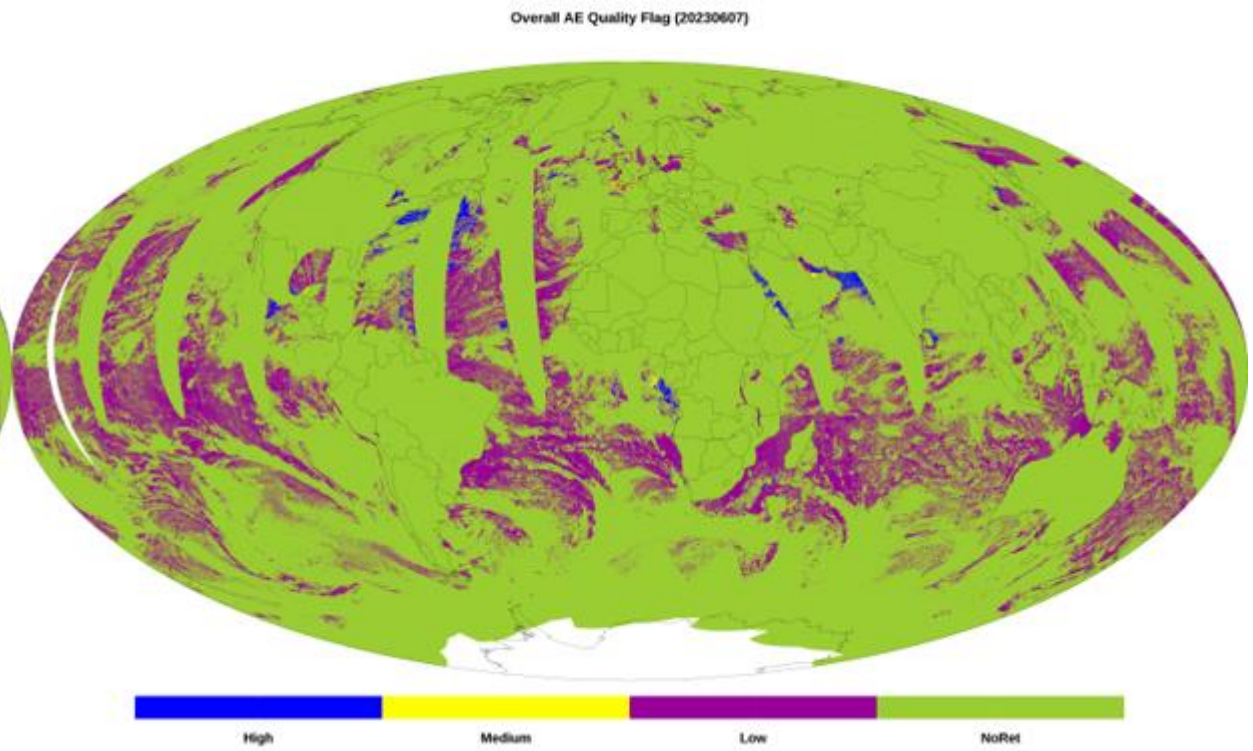
- **Defined Quality Flags**
  - Five categories:
    - **QCExtn**: values of external input masks (cloud, cloud shadow, snow, fire, glint, heavy aerosol, ephemeral water).
    - **QCInput**: quality of coordinates, geometry, ancillary data, reflectance and brightness temperature; input flags of shallow ocean, shallow inland water, coast line.
    - **QCTest**: results of internal tests for cloud, cirrus, thin cirrus, spatial variability, snow/ice, ephemeral and shallow water, and heavy aerosol.
    - **QCPath**: indicates retrieval is over water, over dark or bright land, SW or SWIR path is used.
    - **QCRet**: indicates quality of retrieval and associated condition (failed, large residual, extrapolation is used, adjacent to cloud or snow, SWIR NDVI and/or redness ratio is out of range).
- Detailed descriptions of QFs are in the "*EPS Aerosol Optical Depth (AOD) Algorithm Theoretical Basis Document*".

Example of Quality flags – Product quality for 6/7/2023

AOD550

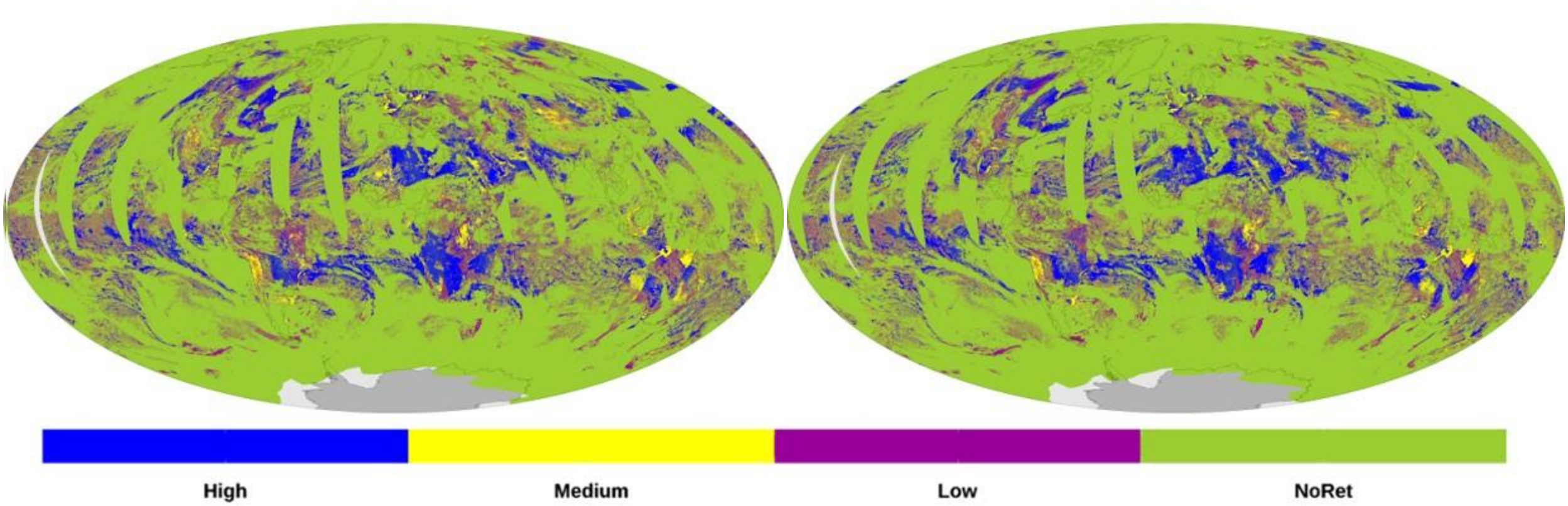


Angstrom Exponent



- Four levels of Product Overall Quality: High, Medium, Low and No Retrievals.
- Stringent requirements for AE result in only few high-quality retrievals.

NOAA-21 and NOAA-20 AOD Retrieval Quality flag (6/7/2023)



- NOAA-21 and NOAA-20 AOD quality flags are visually very similar.

Error Budget

Attribute Analyzed Accuracy		L1RD Threshold	On-orbit Performance			Meet Requirement?	Additional Comments
			NOAA-21	NOAA-20	S-NPP		
AOD550 over Land	AOD550 <0.1	0.06	0.005	0.002	0.004	Yes	
	0.1 ≤ AOD550 ≤ 0.8	0.05	-0.02	-0.03	-0.03	Yes	
	AOD550 > 0.8	0.20	-0.03	-0.06	-0.05	Yes	
AOD550 over Water	AOD550 < 0.3	0.08	-0.009	0.003	0.018	Yes	
	AOD550 ≥ 0.3	0.15	-0.003	-0.05	-0.03	Yes	
APS over water (0.55 vs 0.86 µm AE)		0.3	-0.12	0.027	0.058	Yes	
APS over water (0.86 vs 1.61 µm AE)		0.3	-0.015	0.054	0.007	Yes	

Attribute Analyzed Precision		L1RD Threshold	On-orbit Performance			Meet Requirement?	Additional Comments
			NOAA-21	NOAA-20	S-NPP		
AOD550 over Land	AOD550 <0.1	0.15	0.04	0.04	0.05	Yes	
	0.1 ≤ AOD550 ≤ 0.8	0.25	0.10	0.11	0.11	Yes	
	AOD550 > 0.8	0.45	0.36	0.35	0.38	Yes	
AOD550 over Water	AOD550 < 0.3	0.15	0.05	0.04	0.05	Yes	
	AOD550 ≥ 0.3	0.35	0.16	0.19	0.23	Yes	
APS over water (0.55 vs 0.86 µm AE)		0.6	0.29	0.41	0.38	Yes	
APS over water (0.86 vs 1.61 µm AE)		0.6	0.26	0.33	0.31	Yes	

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations

- Pre-Beta NOAA-21 AOD data. No feedback from users yet.

Downstream Product Feedback

Algorithm	Product	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts
Surface Reflectance (SR)	Surface Reflectance	The SR team did a preliminary assessment of the SR product using the AERONET data and found that the quality of the NOAA-21 SR product is similar to that of the NOAA-20 product. (From Yunyue Yu, SR team lead)

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Internal Test	Thresholds in internal tests of sea ice and heavy aerosol over water need to be updated.	Misidentification.	CLOSED: Updated in NOAA20 algorithm and used in the NOAA-21 algorithm
Bright-surface misidentification	When heavy aerosol is present over a dark pixel the internal test may incorrectly indicate bright surface but bright-surface relationship is not available for that pixel.	No retrieval.	CLOSED: Updated the algorithm to use dark-surface retrieval if bright land spectral reflectance ratio is not available. This update is used in the NOAA-21 algorithm
QF	Quality flag is needed to indicate when dark surface is misidentified as bright surface and dark-target retrieval is performed.	Incorrect retrieval path indicated.	CLOSED: Added flag to indicate dark-target retrieval is used for misidentified bright pixel
Aerosol models	Candidate aerosol models are not well representative over global scale	Errors in the retrieved AOD and APS.	OPEN: Update the aerosol models based on the long-term AERONET ground measurements

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
PCT	Land-surface spectral reflectance relationships currently used in NOAA-21 AOD retrieval are based on S-NPP spectral TOA reflectances.	Errors in over-land AOD and APS.	OPEN: Collect at least one-year of NOAA-21 TOA reflectances, AERONET AODs and re-derive surface reflectance relationships. This update should be coordinated with the aerosol model update.

Documentations (Check List)

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
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	At team meetings ~quarterly.

Check List - Beta Maturity

Beta Maturity End State	Assessment
Product is minimally validated, and may still contain significant identified and unidentified errors	Concur (Product quality has been demonstrated globally and at ground sites using four months of data.)
Information/data from validation efforts can only be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose	Concur (but STM believes product quality is sufficient for quantitative assessment)
Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists	Concur (Product performance is shown in this presentation, no anomalies were found)

Conclusion

- **Cal/Val results summary:**
  - Team recommends algorithm Beta maturity
    - NOAA-21 EPS AOD and APS (AE) meet requirements.
    - Quality of NOAA-21 EPS AOD and APS products wrt to NOAA-20, S-NPP and ground-truth AERONET are similar.
    - The systematic difference between NOAA-21, NOAA-20 and S-NPP global AOD over water is likely be due to differences in the SDRs (e.g., band M7).
    - **Note**:
      - *Data used: extensive, global 4 months including winter and spring and 4 independent products.*

Path Forward (1)

- **Lessons learned for NOAA-21 Cal/Val**
  - No new lessons were learned compared to NOAA-20 cal/val.
- **Planned improvements**
  - Update spectral land-surface reflectance relationships derived from NOAA-21 VIIRS observations. (*short term*)
  - Eliminate calculation of residual over bright surface. (*short term*)
  - Attempt to improve regional and seasonal performance by expanding/revising candidate aerosol models and surface reflectance relationships. (*long term*)
  - Continue pursuing application of ML in determining surface reflectances needed in AOD retrieval over land. (*long term*)

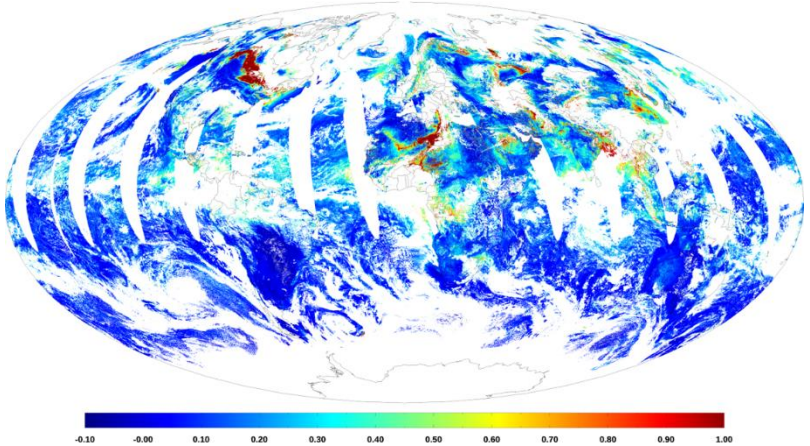
Path Forward (2)

- **Future Cal/Val activities / milestones**
  - Make corrections and updates to algorithm – *When needed*
  - Reach Provisional of NOAA-21 VIIRS AOD and APS product – *Nov 2023*
  - Re-build and add NOAA-21 AOD to routine and long-term monitoring – *Feb 2024*
  - Reach Full validation of NOAA-21 VIIRS AOD and APS product – *Jun 2024*
  - Develop new aerosol models and surface reflectance relationships and evaluate their merits – *Aug 2024*
  - Update enterprise AOD and APS ATBD – *Sep 2024*
  - Deliver pixel-level bias estimates updated for NOAA-21 – *FY25*
  - Generate and evaluate 3-satellite merged AOD product – *FY25*

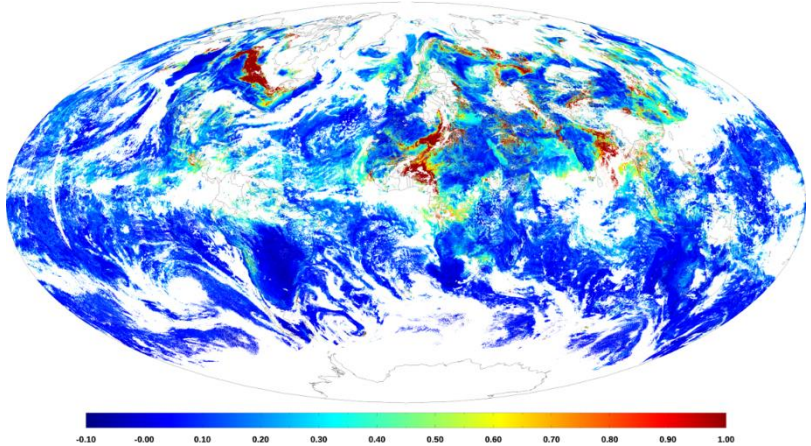
More details are in the "FY24 Program Management Review for Aerosols"

Two- and Three-Satellite High-Quality VIIRS AOD (5/15/2023)

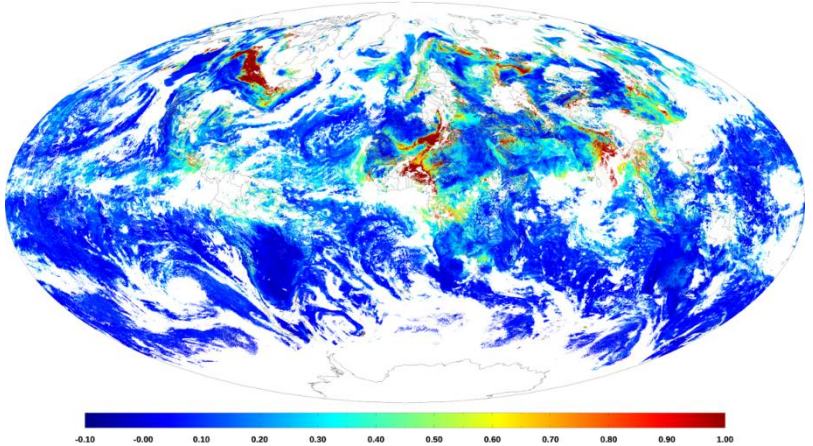
SNPP



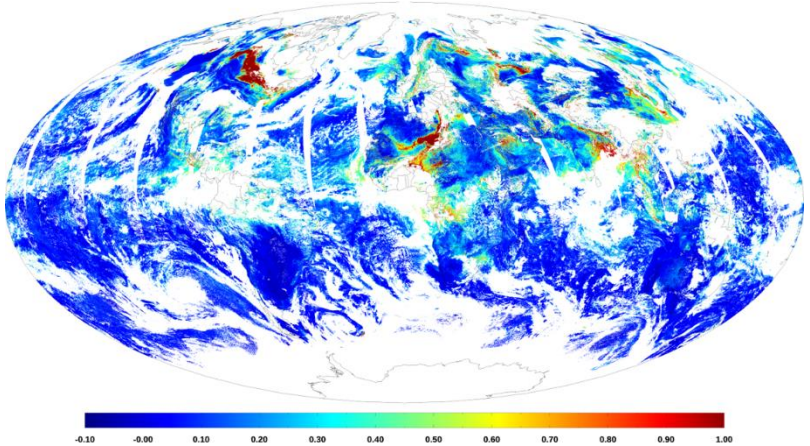
SNPP + NOAA20



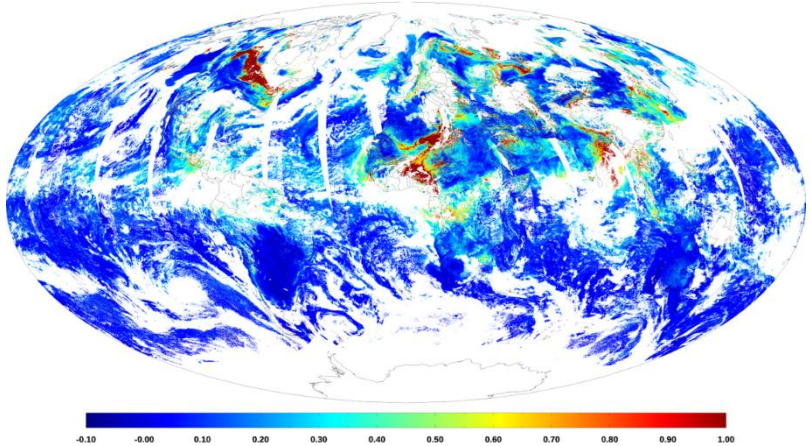
SNPP + NOAA20 + NOAA21

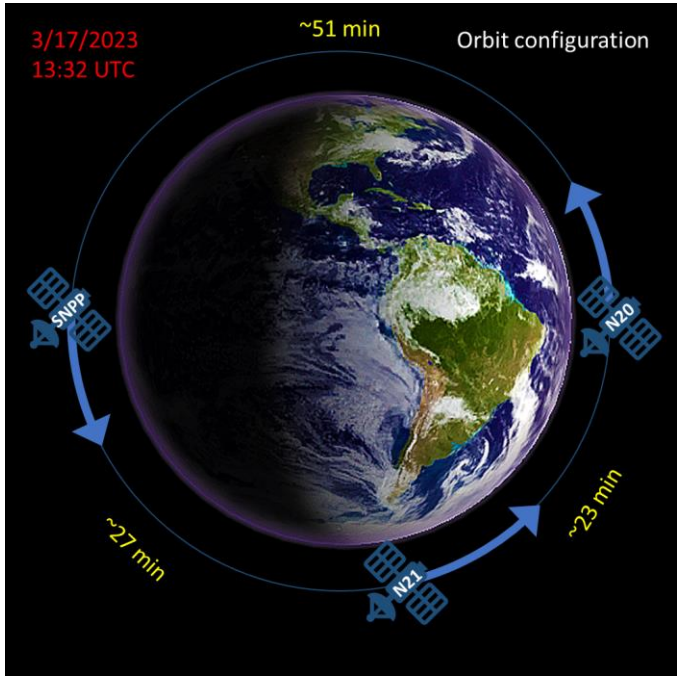


SNPP + NOAA21



NOAA20 + NOAA21

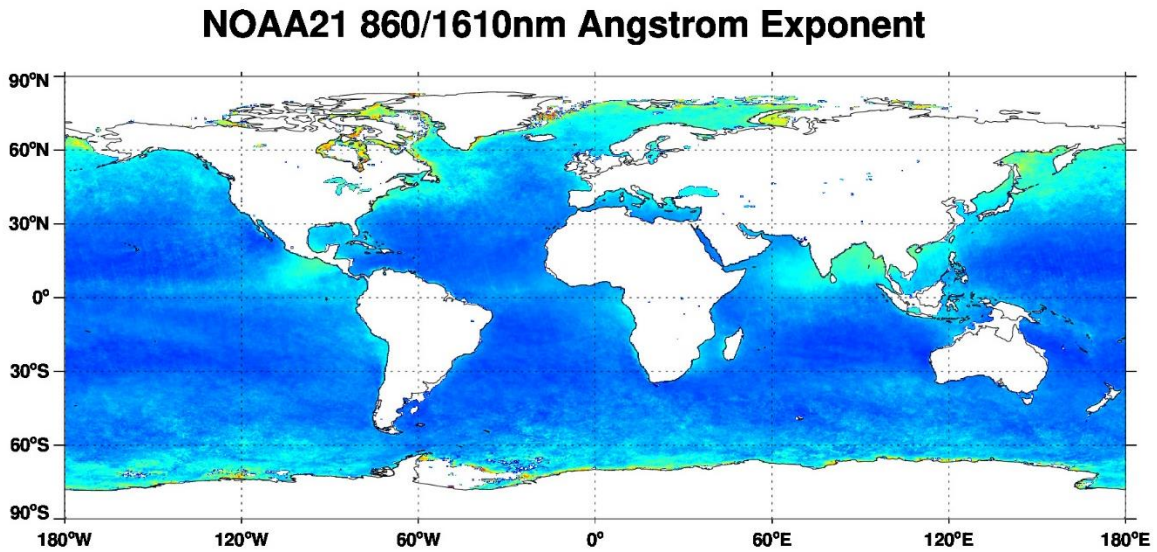


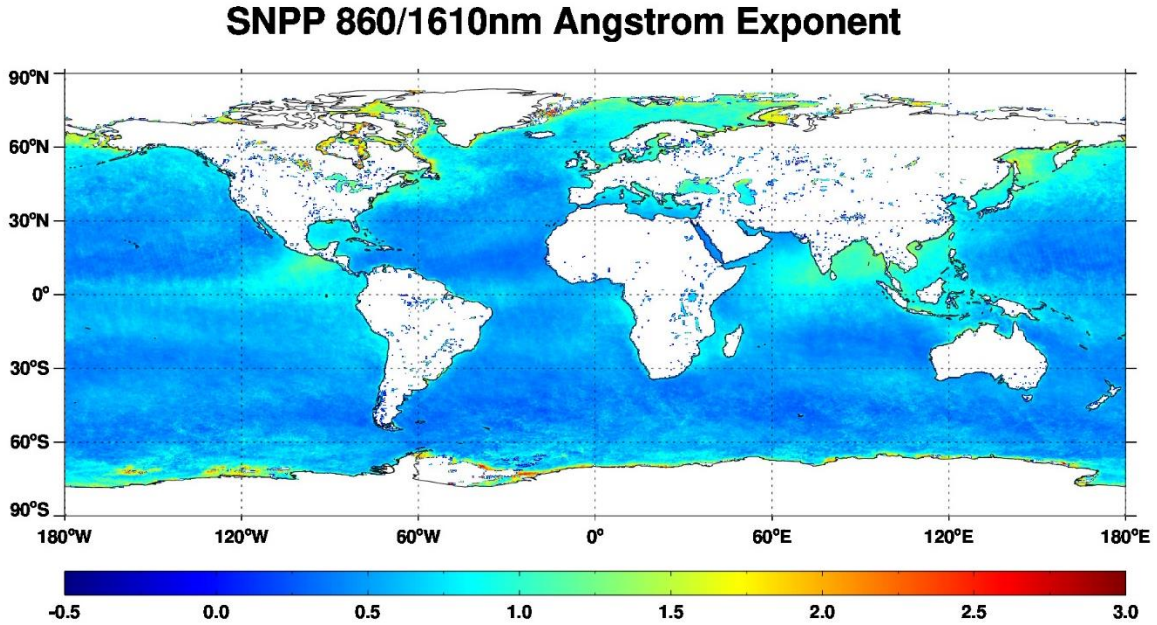


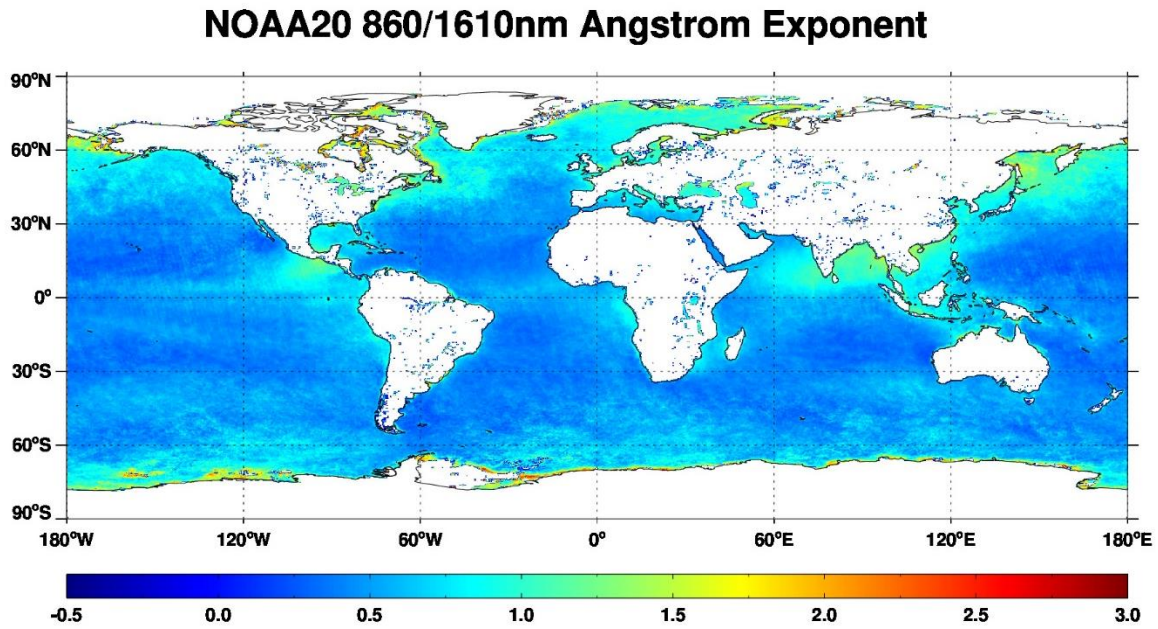
- Most effective filling of gaps (due to sunglint, cloud) is from all 3 satellites
- Best combination of two satellites is SNPP+NOAA20. Merging NOAA21 with either SNPP or NOAA20 “only” reduces size of gaps.

APPENDIX

Global Mean Angstrom Exponent (2/10/2023 – 6/10/2023)

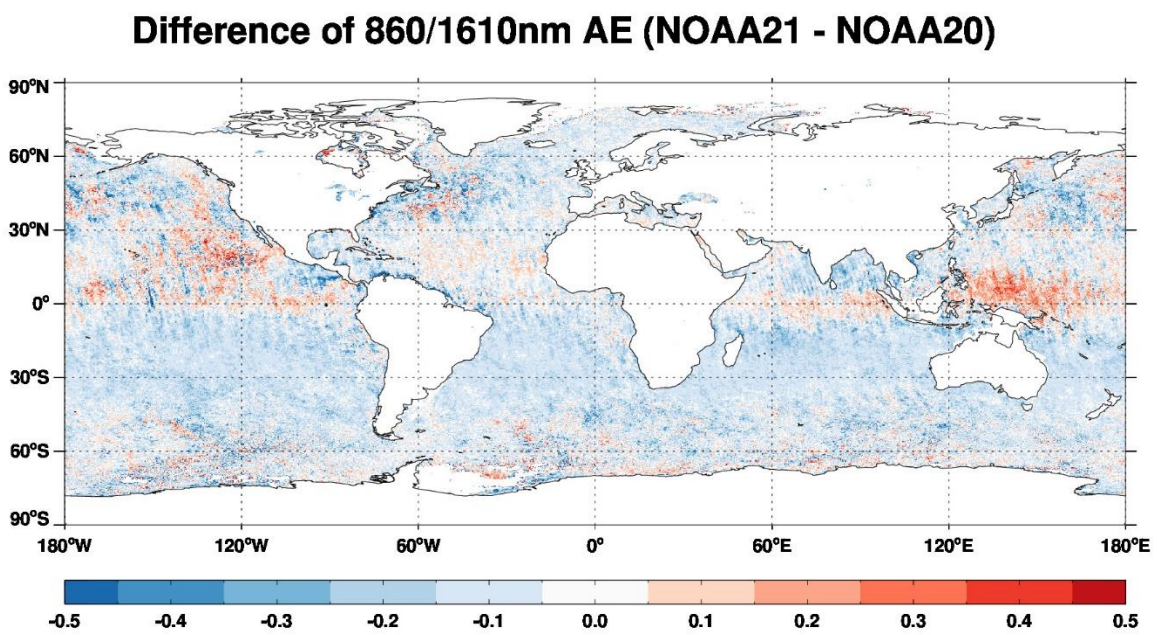


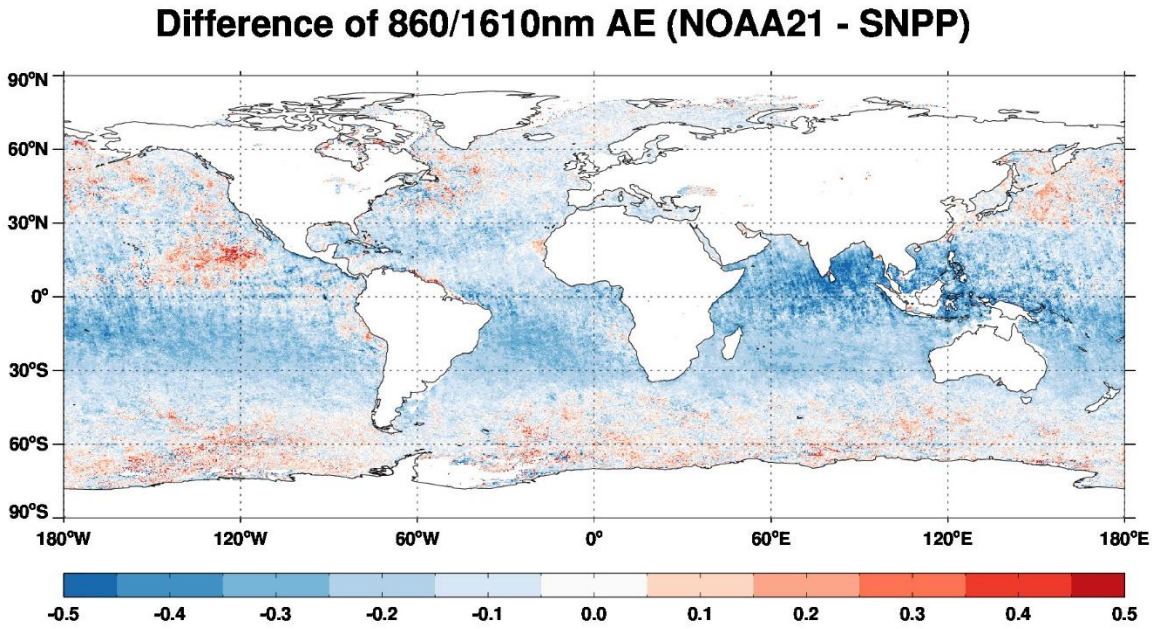




- Long-wavelength (550 vs.1610 nm) AE from three satellites have similar spatial patterns. NOAA-21 and NOAA-20 AEs are more similar to each other than to S-NPP AE.
- Fewer high-quality NOAA-21 AOD retrievals over inland water bodies and some coastal areas due to a change in the land/water mask for NOAA-21 that degrades quality over shallow water.

Global Difference of Angstrom Exponent (2/10/2023 – 6/10/2023)

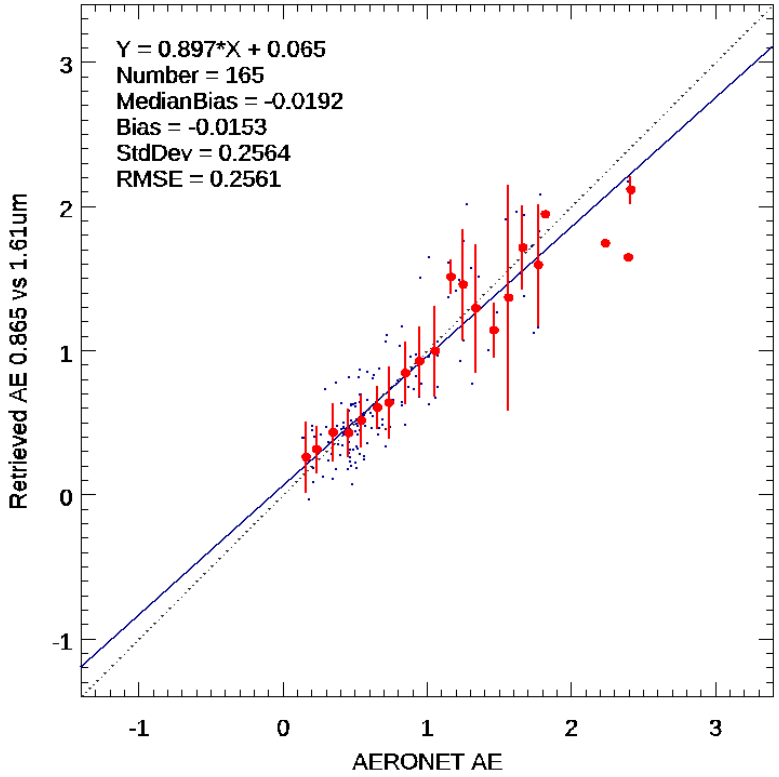




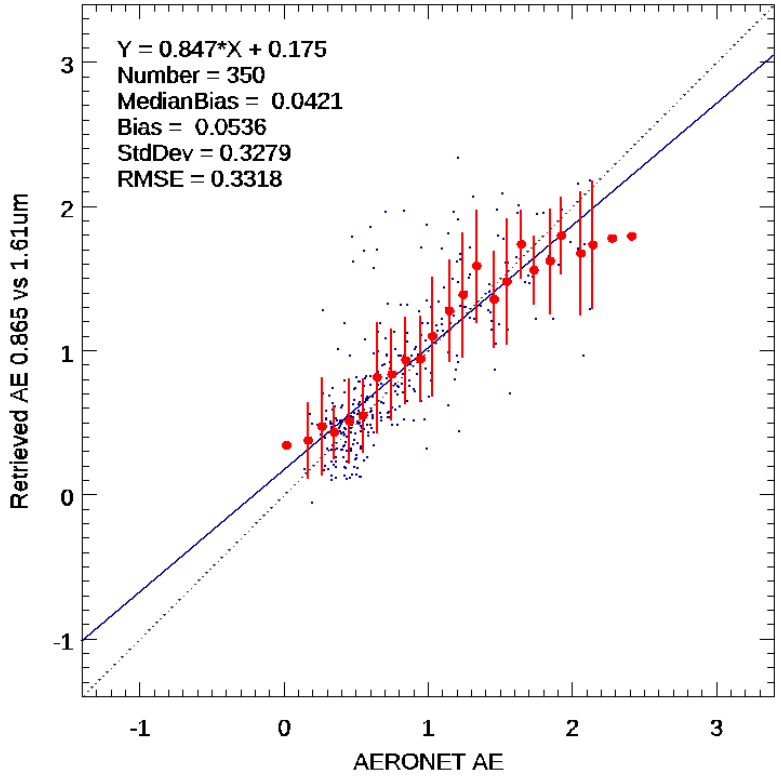
- Relative to NOAA-20 (*left panel*),
  - NOAA-21 AE is somewhat smaller at most mid-latitudes (larger particles), and somewhat larger around the equator (smaller particles)
- Relative to S-NPP (*right panel*),
  - NOAA-21 AE is generally smaller most latitudes (larger particles), except north of equator over the Pacific and at high latitudes.

Validation of AE (860 vs 1610nm) over Water

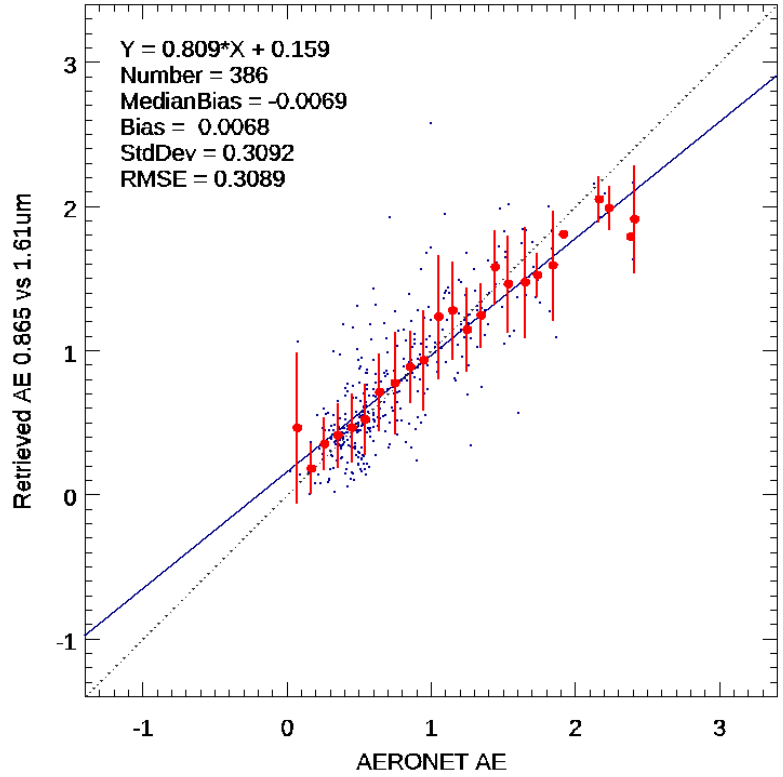
NOAA21



NOAA20

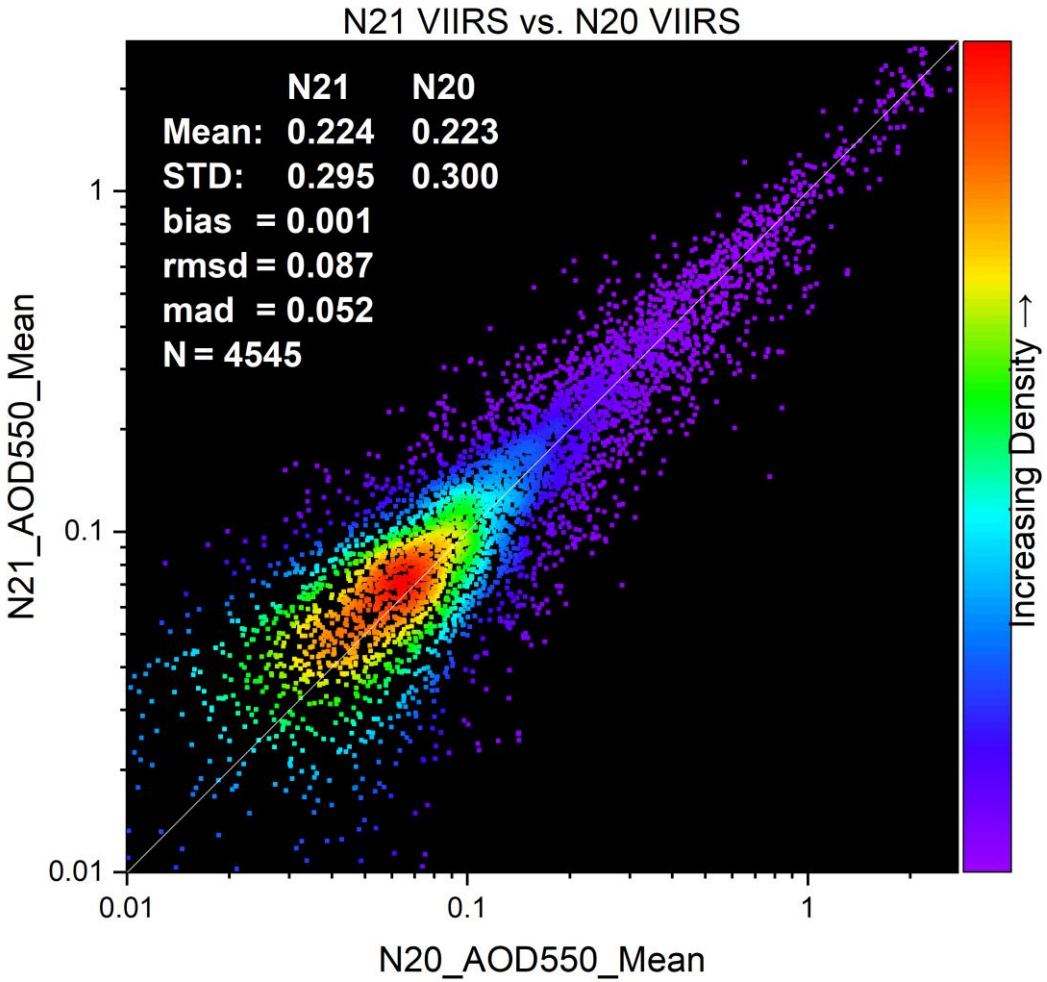


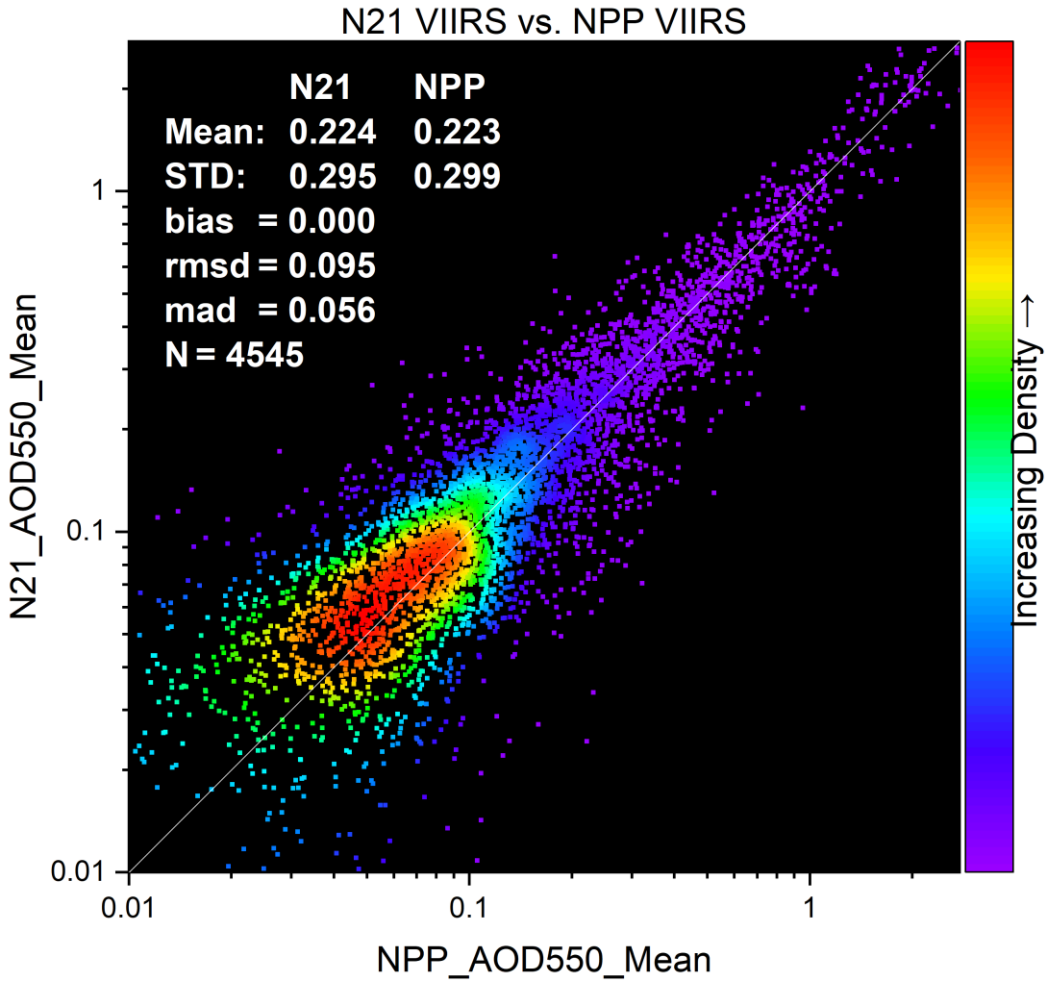
SNPP



- NOAA-21 long-wavelength AE agrees better with AERONET than the NOAA-20 AE does.
- Sample size of NOAA-21 AE is only about half of the size of NOAA-20 and S-NPP sample sizes.

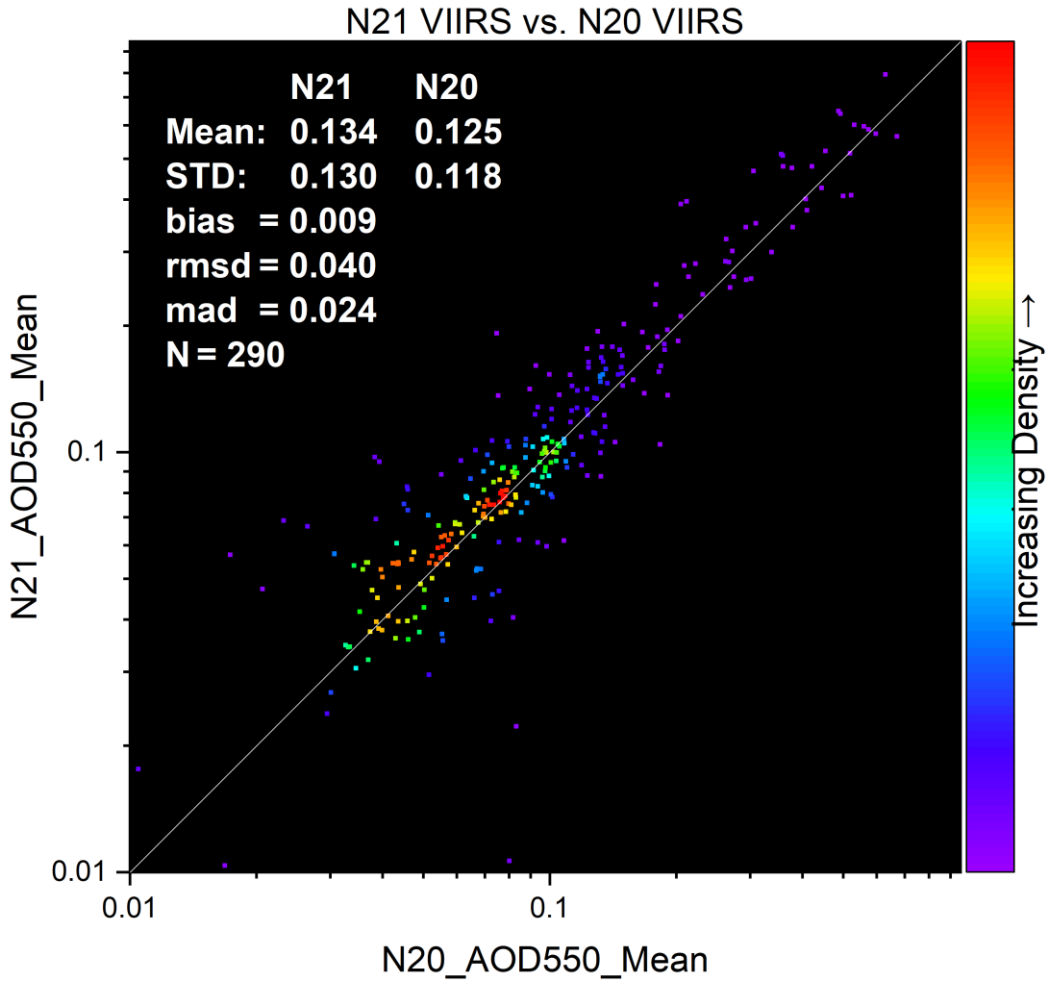
Scatter Plots: Satellite-to-Satellite AOD Comparison over Land

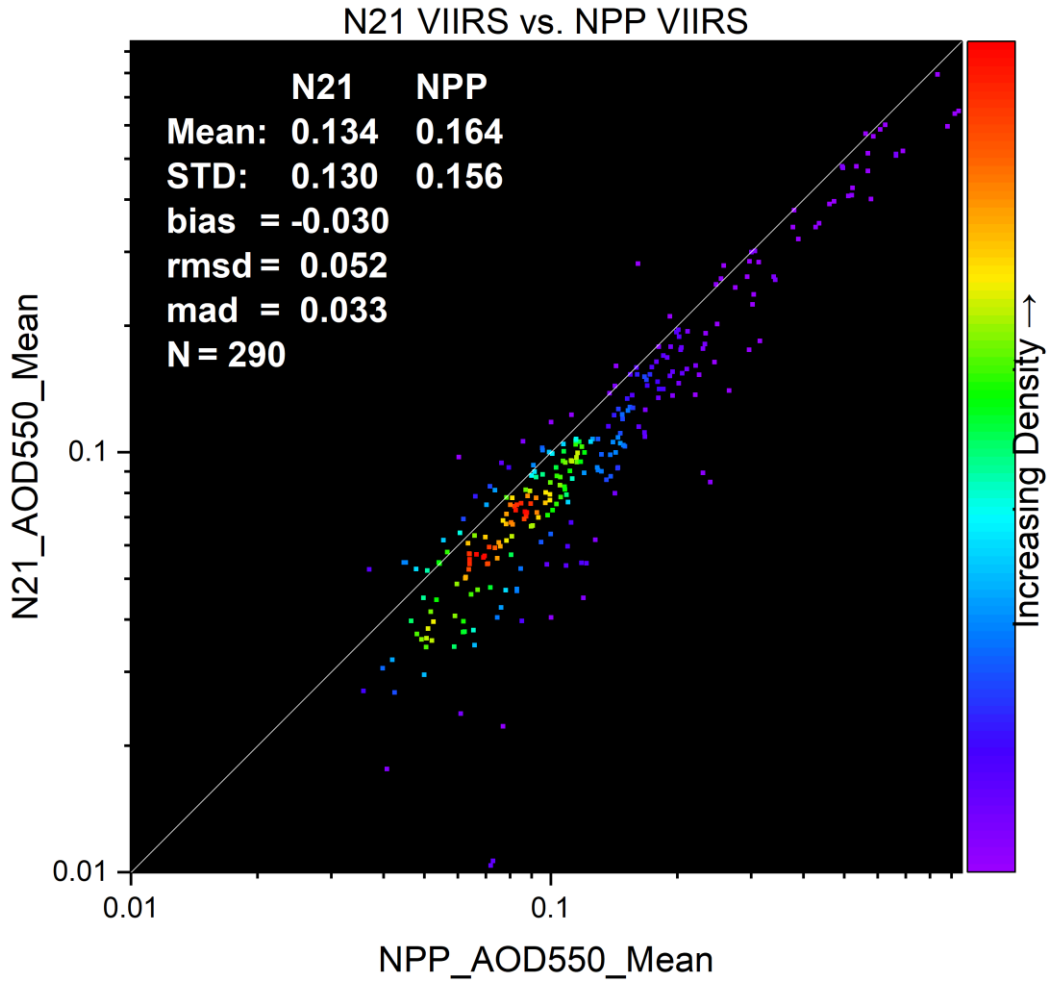




- Data: High-quality AODs over AERONET sites from Feb 10 – Jun 10, 2023.
- Over land, mean differences of NOAA-21 AODs relative to NOAA-20 and S-NPP are close to zero.
- Standard deviation of satellite-to-satellite differences are similar.

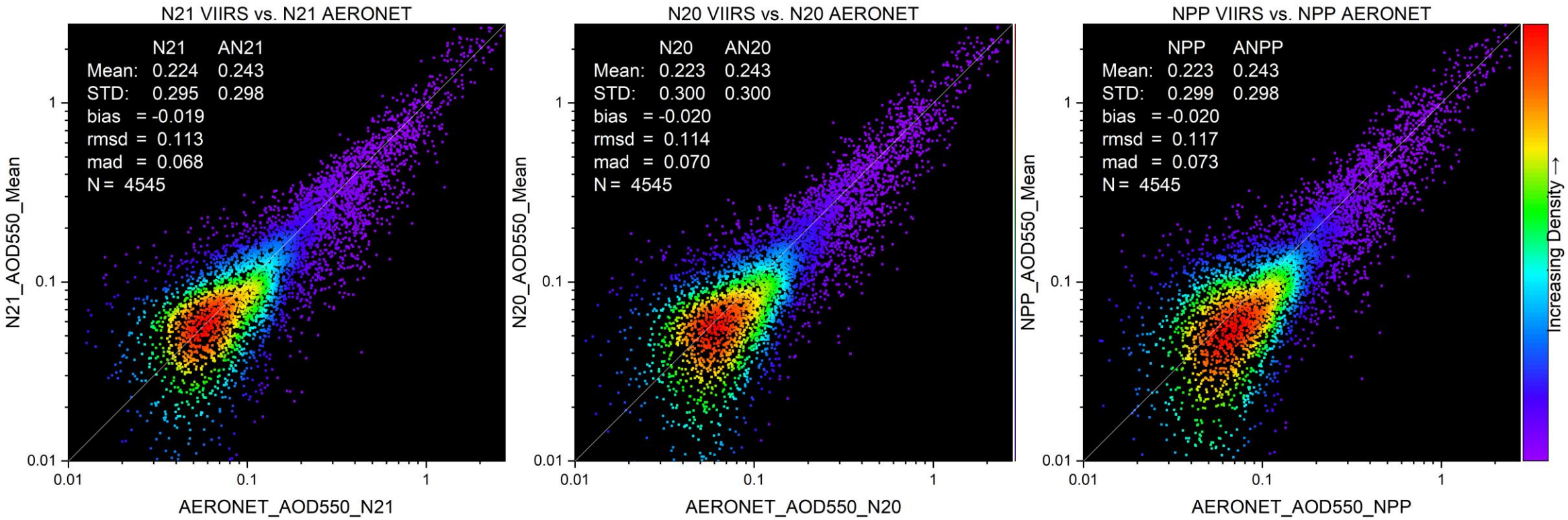
Scatter Plots: Satellite-to-Satellite AOD Comparison over Water





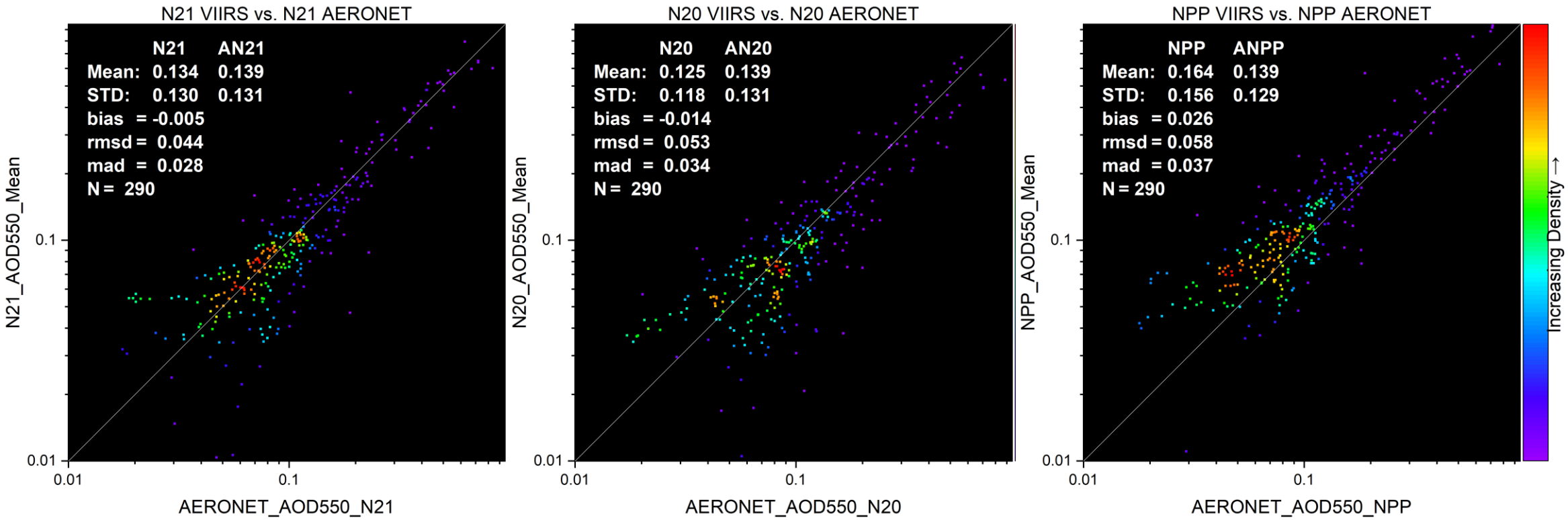
- Data: High-quality AODs over AERONET sites from Feb 10 – Jun 10, 2023.
- Over water, NOAA-21 AODs largely agree with NOAA-20 AODs; difference of mean NOAA21-NOAA20 values is 0.009. Compared to S-NPP, NOAA-21 AODs are smaller; difference of mean NOAA21-SNPP values is -0.03.

Scatter Plots: Satellite-to-AERONET AOD Comparison over Land



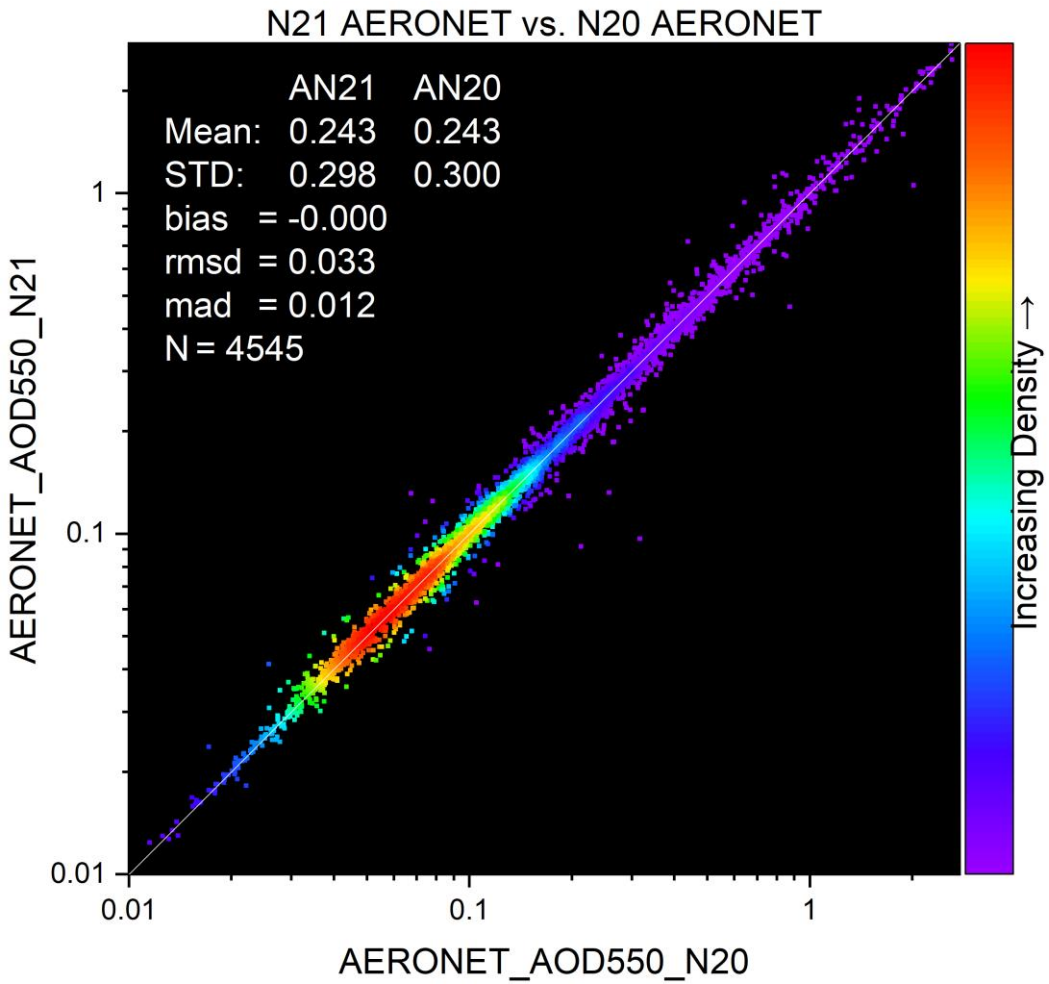
- Data: High-quality AODs over AERONET sites from Feb 10 – Jun 10, 2023.
- Over land, mean differences of all three satellite AODs and their standard deviation relative to AERONET are essentially the same or very similar.

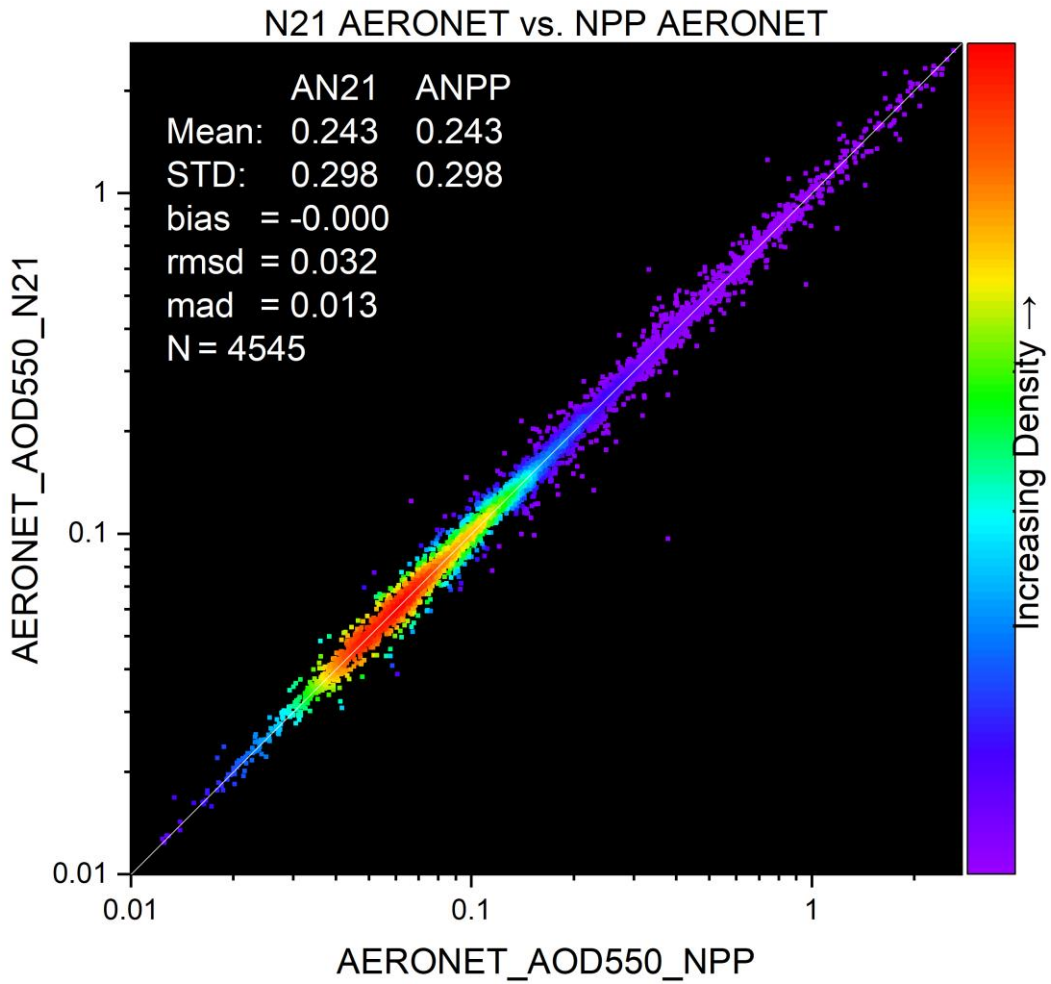
Scatter Plots: Satellite-to-AERONET AOD Comparison over Water



- Data: High-quality AODs over AERONET sites from Feb 10 – Jun 10, 2023.
- Over water, relative to AERONET, NOAA-21 AOD has the smallest bias and standard deviation among all three satellite AODs.

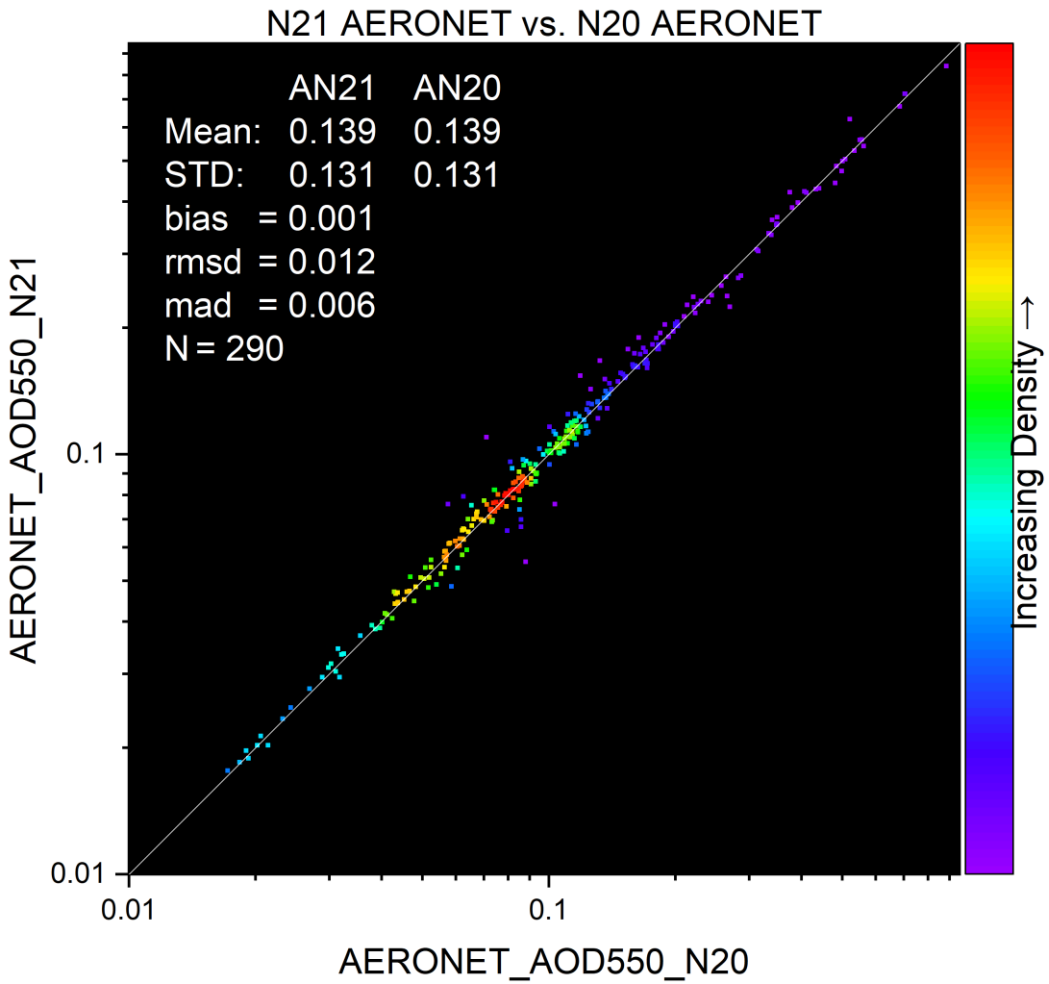
AERONET AOD in NOAA-21, NOAA-20 and S-NPP over-land matchups

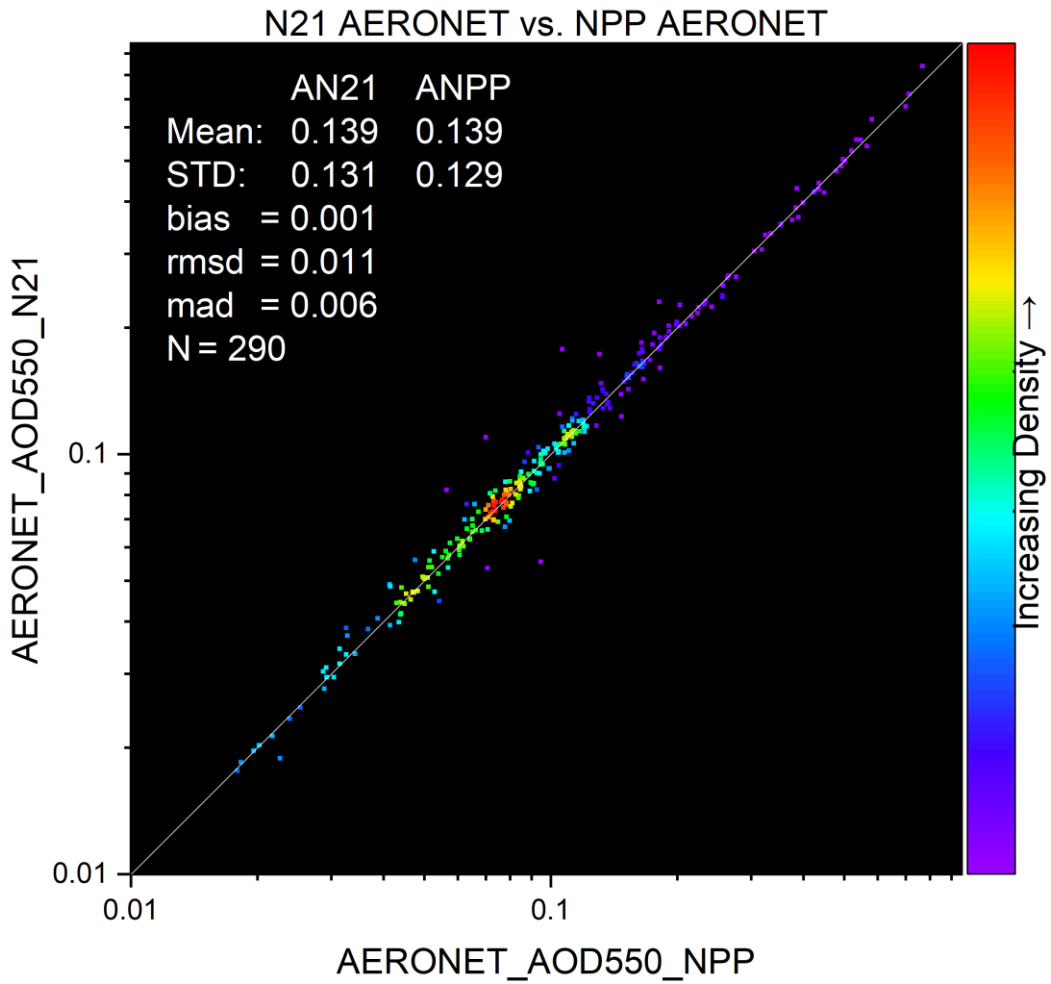




- Over land, differences in AERONET AODs matched up with all three satellites are essentially negligible.

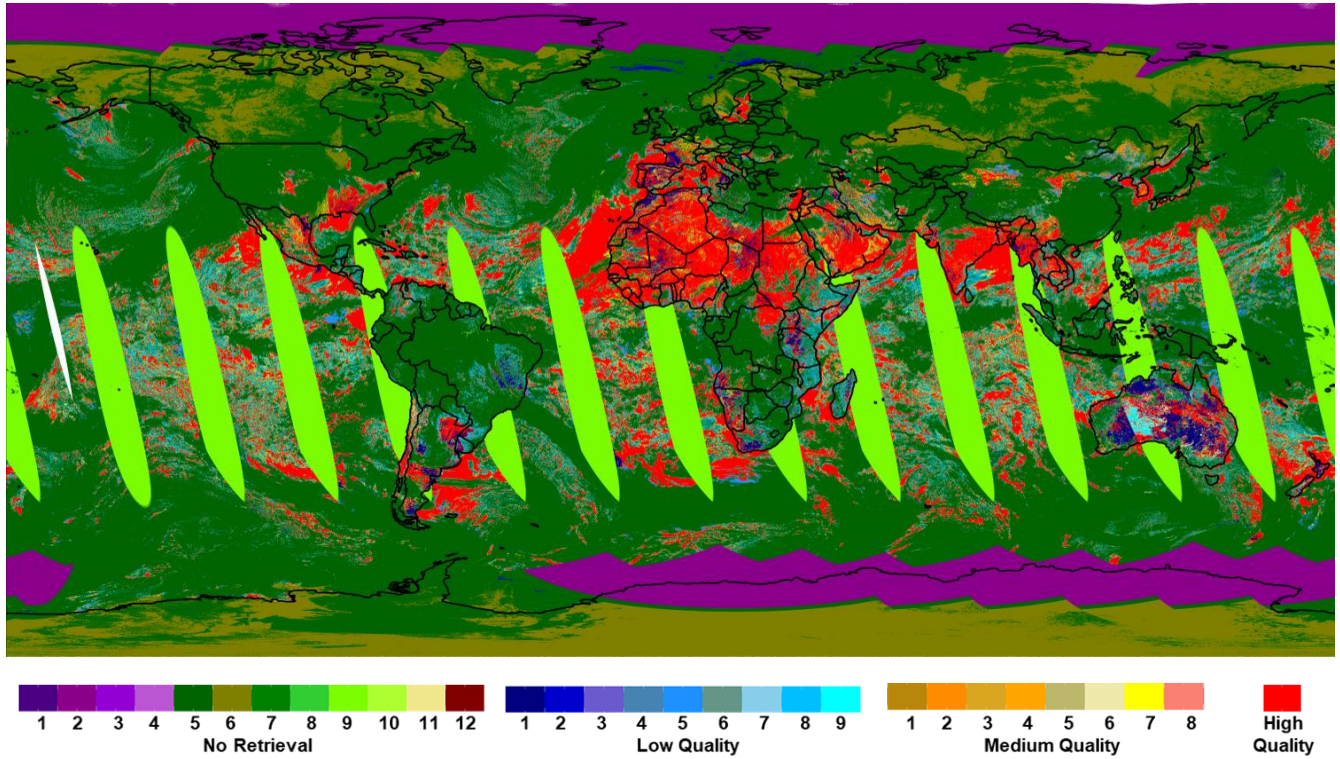
AERONET AOD in NOAA-21, NOAA-20 and S-NPP over-water matchups





- Over water, differences in AERONET AODs matched up with all three satellites are essentially negligible.

Quality flags – Example for NOAA-20 (2/13/2019)



No Retrieval	
1	Invalid longitude/latitude
2	Geometry not applicable
3	Missing model data
4	Missing reflectance
5	Cloudy
6	Snow/ice
7	Shallow water
8	Ephemeral water
9	Glint over water
10	Fire
11	No surface data over bright surface
12	Failed retrieval

Low Quality	
1	AOD out of range
2	Large solar zenith angle
3	Cloudy (internal test)
4	Cirrus (internal test)
5	Cloudy (ECM)
6	Coastal pixel
7	Extrapolation
8	Spatial inhomogeneous
9	Large retrieval residual

Medium Quality	
1	Cloud shadow
2	Thin cirrus
3	Adjacent to cloud/snow
4	Barren dark land surface
5	NDVI out of range
6	Redness ratio out of range
7	Inhomogeneous scene
8	Large retrieval residual

- **No retrievals**: majority is due to the presence of clouds.
- **Low/Medium quality**: high spatial variability of scenes is the main cause of degraded quality.
- Example is from the NOAA-20 Validated Maturity Review; NOAA-21 flags are the same