Provisional Maturity Science Review For
NOAA-21 Surface Albedo

Prepared by

STAR Land Product Development/Albedo Team

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Version 1: 01/24/2024

JPSS/GOES-R Provisional Maturity Definition

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

- Surface Albedo Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Processing environment
  - Visual inspection and comparison
  - Ground validation
  - Cross-comparison and Quality flag (input data) analysis
  - Error budget
- User Feedback
- Risks, Actions, and Mitigations
- Documentation (Science Maturity Check List)
- Conclusion
- Path Forward

NOAA-21 Surface Albedo Algorithm Cal/Val Team

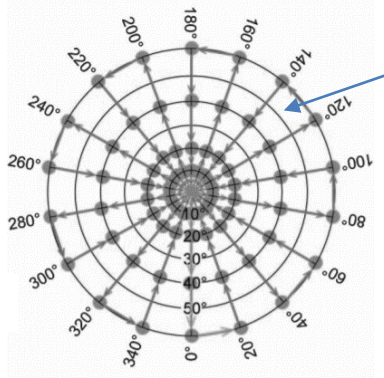
Algorithm Cal/Val Team Members

	Name	Organization	Major Task
JSTAR Science	Land Lead: Ivan Csiszar	NOAA/NESDIS/STAR	Project Management
	EDR Lead: Yunyue Yu	NOAA/NESDIS/STAR	Team management, algorithm development, validation advises
	Jingjing Peng	NOAA Affiliate, UMD/CISESS	product monitoring and validation; algorithm development/improvement
	Lei Ji	UMD/CISESS	product monitoring and validation; software improvement
	Peng Yu	UMD/CISESS	product monitoring and illustration
	Dongdong Wang	UMD/CISESS	algorithm development
ASSISTT	Michael Butler	NOAA/NESDIS/STAR	ASSISTT Lead
	Mingming Yao	NOAA Affiliate, GAMA-1	Algorithm System integration
	Eric Buzan	NOAA Affiliate, GAMA-1	Algorithm System integration
	Wilson, Michael	NOAA Affiliate, ProTech/IMSG	Algorithm System integration
NOAA/EMC	Michael Barlage	NOAA/EMC/NCEP	user readiness
	Fanglin Yang	NOAA/EMC/NCEP	user readiness
	Weizhong Zheng	NOAA Affiliate	user readiness
	Helin Wei	NOAA Affiliate	user readiness
NOAA/OSPO	Hanjun Ding	NOAA/NESDIS/OSPO	NDE operational Land Lead
	Yufeng Zhu	NOAA Affiliate	NDE operational

Product Overview (1)

- Product Overview
  - Surface Albedo (SURFALB), defined as the ratio between solar radiation reflected by Earth's surface and solar radiation incident at the surface, is a function of both solar illumination and the surface reflective properties.
  - The **L2** VIIRS enterprise surface albedo is retrieved with a direct estimation method, which directly links surface broadband albedo with clear-sky VIIRS TOA reflectance through statistical modeling. The algorithm also includes an offline component to generate cloudy-sky albedo from historical data filtering.
  - The L2 albedo product is further processed into a grid-based **L3** albedo product, since the form of granule product may present challenges for users due to differences in pixel size and varying latitude and longitude coordinates.

We built the spectral regression relationship between single TOA reflectance and the daily mean blue-sky-albedo. The regression coefficients vary with each angle combination $(\theta, \vartheta, \phi)$, specific to the latitude on a particular day of the year.



One angular bin (The actual grid size is finer).

$$a^{daily} = c_0 + \sum_{\Lambda=1}^{bands} R(\theta, \vartheta, \phi, \Lambda) \cdot c_\Lambda$$

LUT

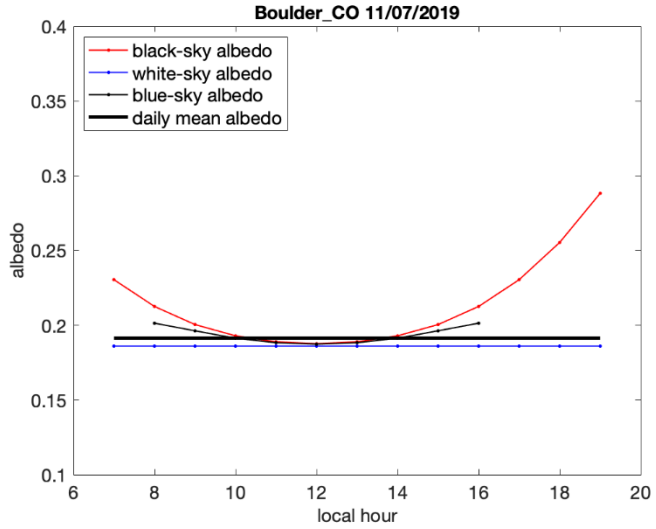
c_0 is the constant item, and

c_Λ is the channel-dependent coefficients

Product Overview (2)

Daily mean albedo definition

$$\alpha^{\text{daily}} = \frac{E_u^{\text{daily}}}{E_d^{\text{daily}}} = \frac{\int_{\text{daytime}} \alpha(t) I_d(t) \mathrm{d}t}{\int_{\text{daytime}} I_d(t) \mathrm{d}t}$$



The daily mean albedo a^{daily} is the ratio between daily upward shortwave radiation E_u^{daily} and daily downward shortwave radiation E_d^{daily} at the surface.

- Surface Albedo (SURFALB), defined as the ratio between solar radiation reflected by Earth's surface and solar radiation incident at the surface, is a function of both solar illumination and the surface reflective properties.
- The daily mean albedo is essential for studying how surface changes affect global climate. The daily mean albedo can be calculated from instantaneous albedo $a(t)$ weighted by the instantaneous downward flux.
- Blue-sky-albedo is a combination of two conceptual values, the white-sky albedo (α_{ws}) and the black-sky albedo (α_{bs}), which are weighted by scattered skylight fraction.

$$a(\Omega_i) = \{1 - S(\theta_i)\}a_{bs}(\theta_i) + S(\theta_i)a_{ws}$$

- The instantaneous black-sky-albedo and white-sky-albedo are calculated as the summation of the angular integration of each kernel. f_x is the kernel parameter. $K_x(\Omega_v, \Omega_i)$ can be calculated from the kernel equations. Here, Ω_i refers to the incident geometry and Ω_v the view geometry. $N(\Omega_i)$ is the normalized sky radiance.

Product Requirements

	JPSS VIIRS LSA	
Attribute	Threshold	Objective
Geographic coverage	The Surface Albedo product shall provide the broad-band earth surface albedo, from 0.4 to 4.0 microns, globally over land and ice, in daytime, in clear conditions, at the refresh rates of the instrument.	The same as threshold
Measurement Range	0 to 1.0 (albedo units)	0 to 1.0
Measurement Accuracy	0.08 (albedo units)	0.02
Measurement Precision	0.05 (albedo units)	0.0125

Joint Polar Satellite System (JPSS) Ground Segment Data Product Specification (GSegDPS)

Processing Environment and Algorithms

- Data used for this provisional review was from NDE/NCCF PDA I&T stream

	NOAA-21 albedo	NOAA-20 albedo	S-NPP albedo
Dataset	To be validated	Reference data	Reference data
Algorithm version	v2r2	v2r2 for Feb 22, 2023 - May 10, 2023 and Jan 5, 2024; v1r4 for May 10, 2023 – Dec 18, 2023	v2r2 for Feb 22, 2023 - May 10, 2023 and Jan 5, 2024; v1r4 for May 10, 2023 – Dec 18, 2023
System	NDE/NCCF	NDE/NCCF	NDE/NCCF
Version of LUTs used	NOAA-21 LUTs	NOAA-20 LUTs	S-NPP LUTs
Version of PCTs used	v2r2	Consistent with the algorithm version	Consistent with the algorithm version
Data period	Feb 22, 2023 - Jan 5, 2024	Feb 22, 2023 - Jan 5, 2024	Feb 22, 2023 - Jan 5, 2024

Evaluation of algorithm performance to specification requirements

- ***Improvements since last version***
  - **Algorithm Improvements**
    1. L2-online code update

       IMS snow/ice mask is used instead of the VIIRS Snow mask and ice concentration. This decision was made because albedo is an all-sky product that requires snow/ice information even under cloudy conditions, which is included in the IMS dataset. The VIIRS snow/ice mask only offers clear-sky information, which is inadequate for maintaining the continuity of the VIIRS albedo requirement.
    2. L2-offline code update

       1) Snow/Snow-free observations separation in offline temporal filtering

          -- Mark snow/snow-free flags for each L2 albedo layers within the filtering window

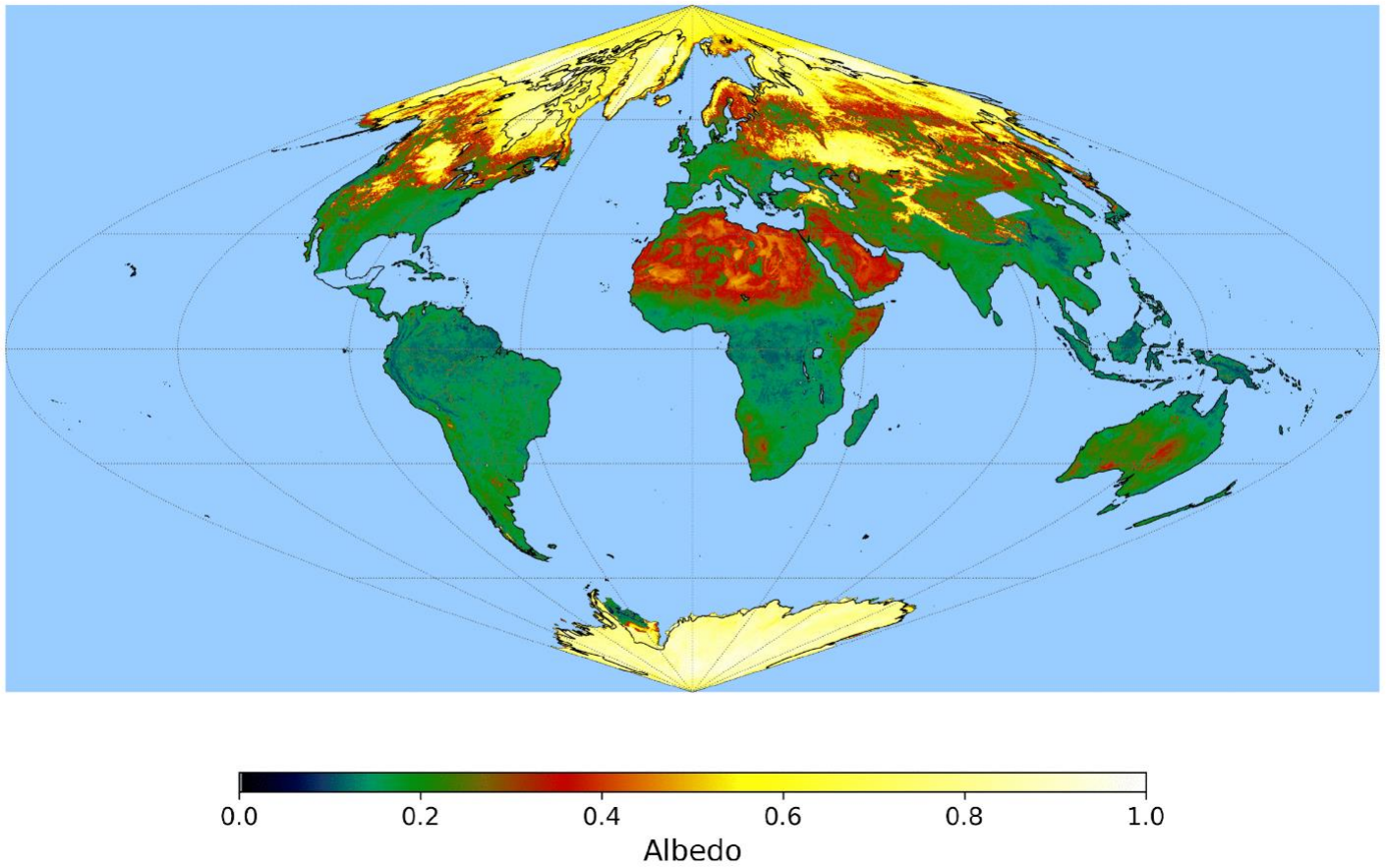
          -- Use snow (snow-free) only observations in temporal filtering for snow (snow-free) pixels in the current day

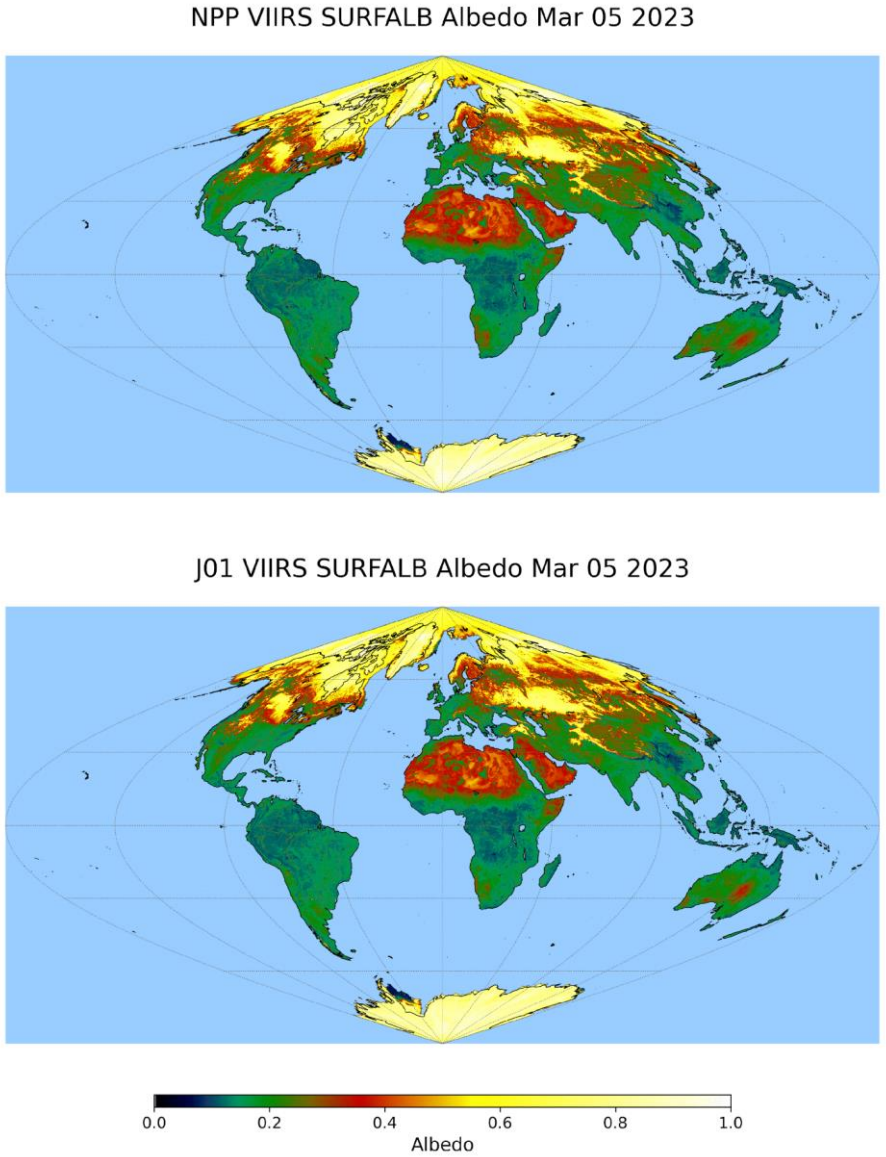
          -- If there are no historical snow (or snow-free) observations on the present day that is classified as snow (or snow-free), the temporal filtering process will utilize all valid observations within the filtering window, following the same approach as in the original algorithm

       2) Handling the updated netCDF format climatology
    3. L3 code update

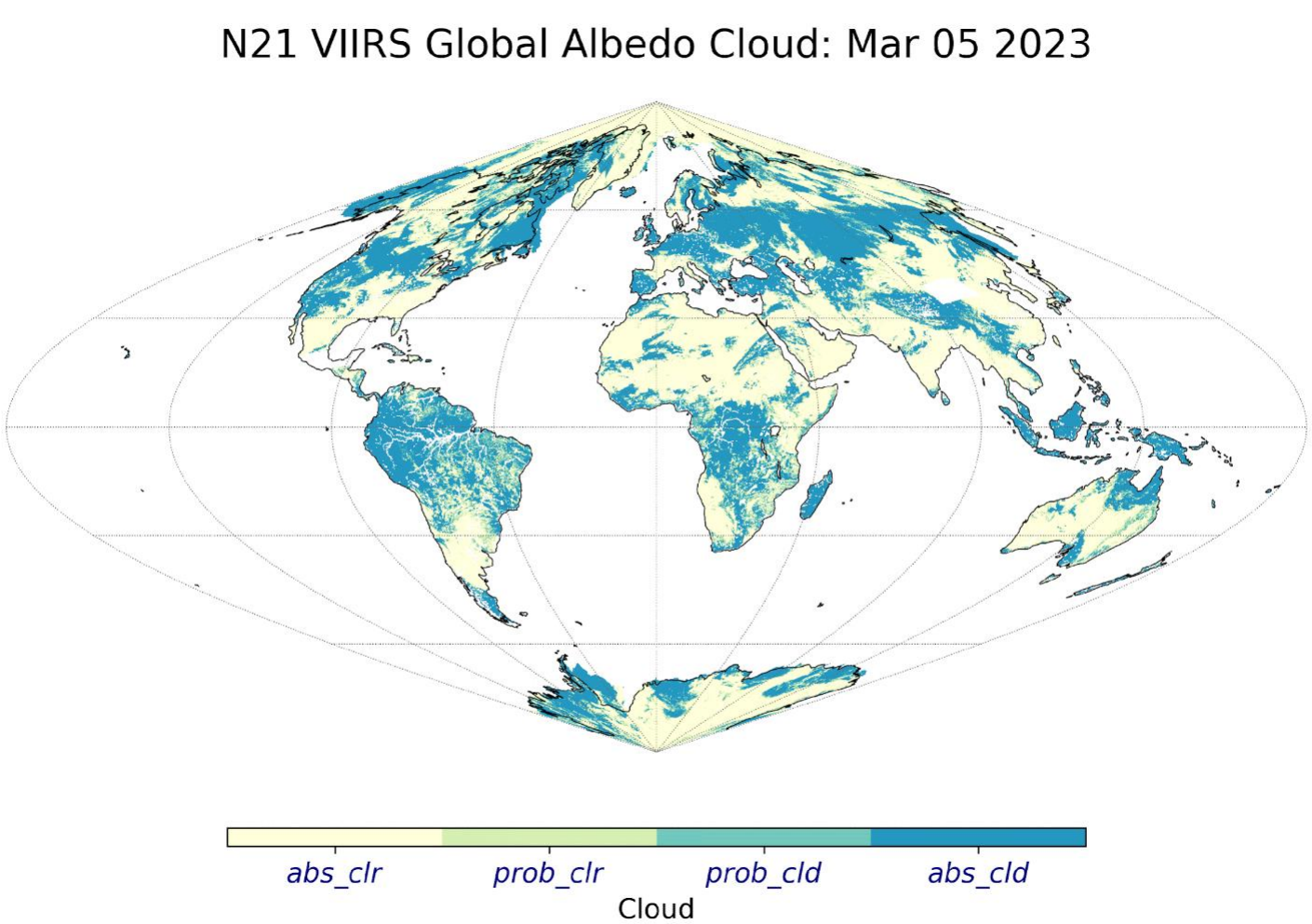
       Handling the netCDF version gridding index (tiles_info)
  - **LUT / PCT updates**
    1. The LUT has been updated according to the spectral response function of NOAA-21
    2. NAN values in the previous NPP and J01 LUTs are filled
    3. Climatology has been updated to Version 5 with upgraded quality, and netCDF format to replace the previous binary (.img) format
  - **LTM adaptation**
    - The local LTM (Long-term-monitoring) system has been adapted to J2 surface albedo product

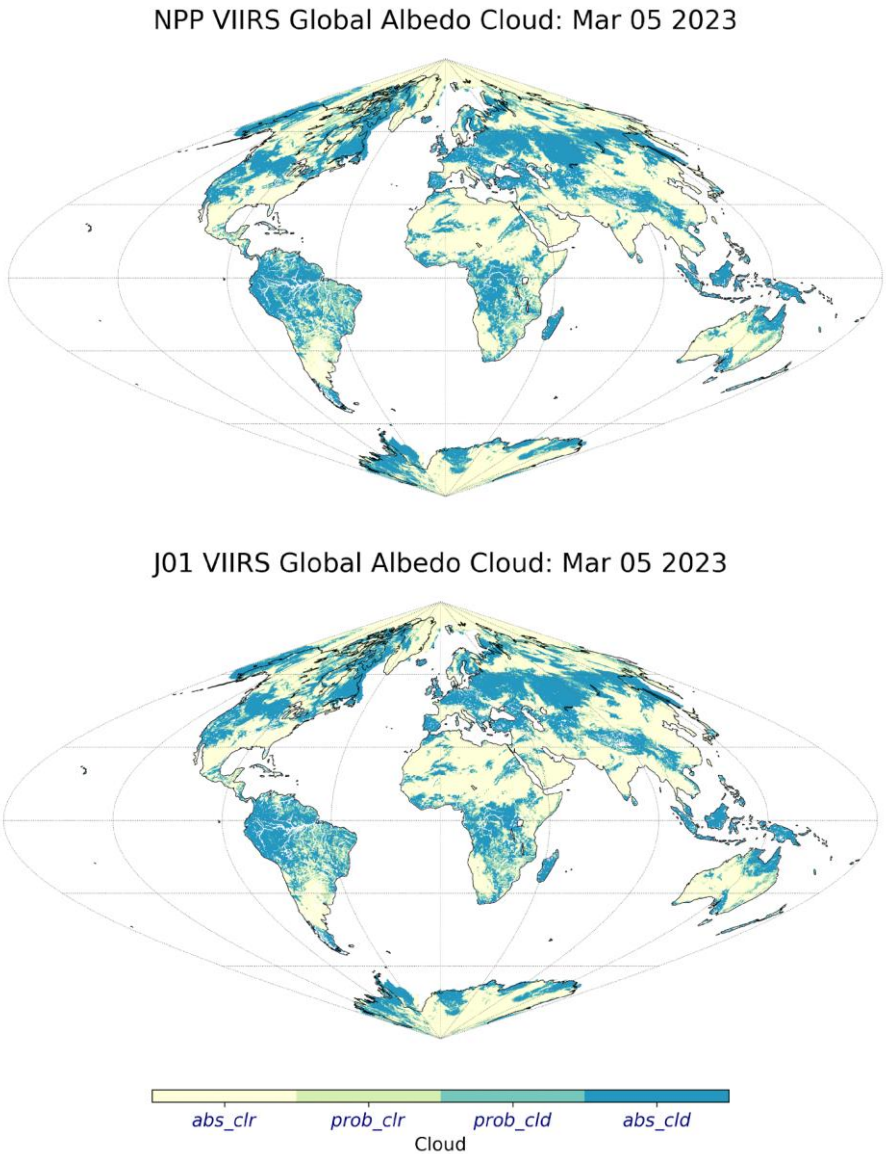
Visual Comparison (Albedo Variable)



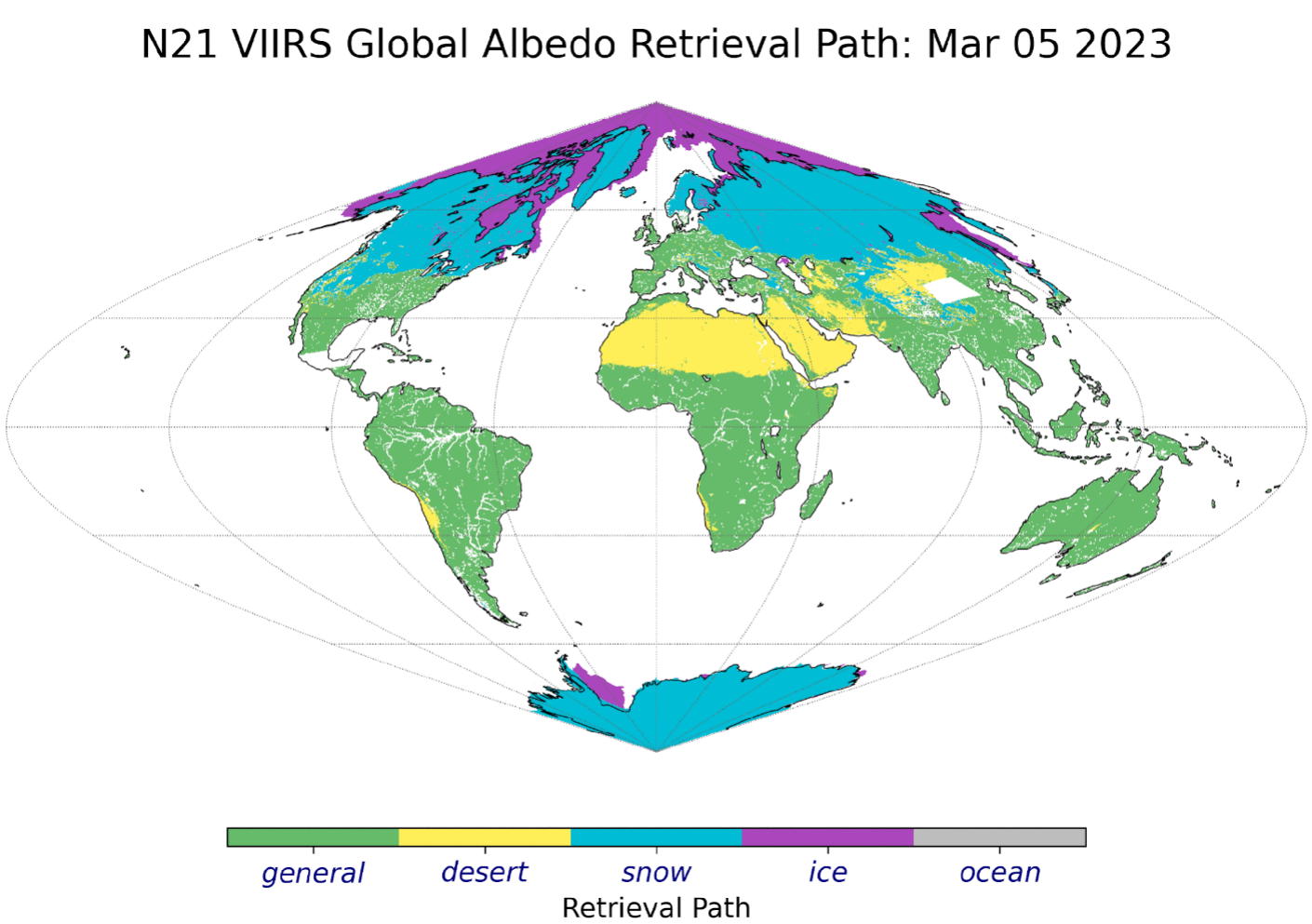


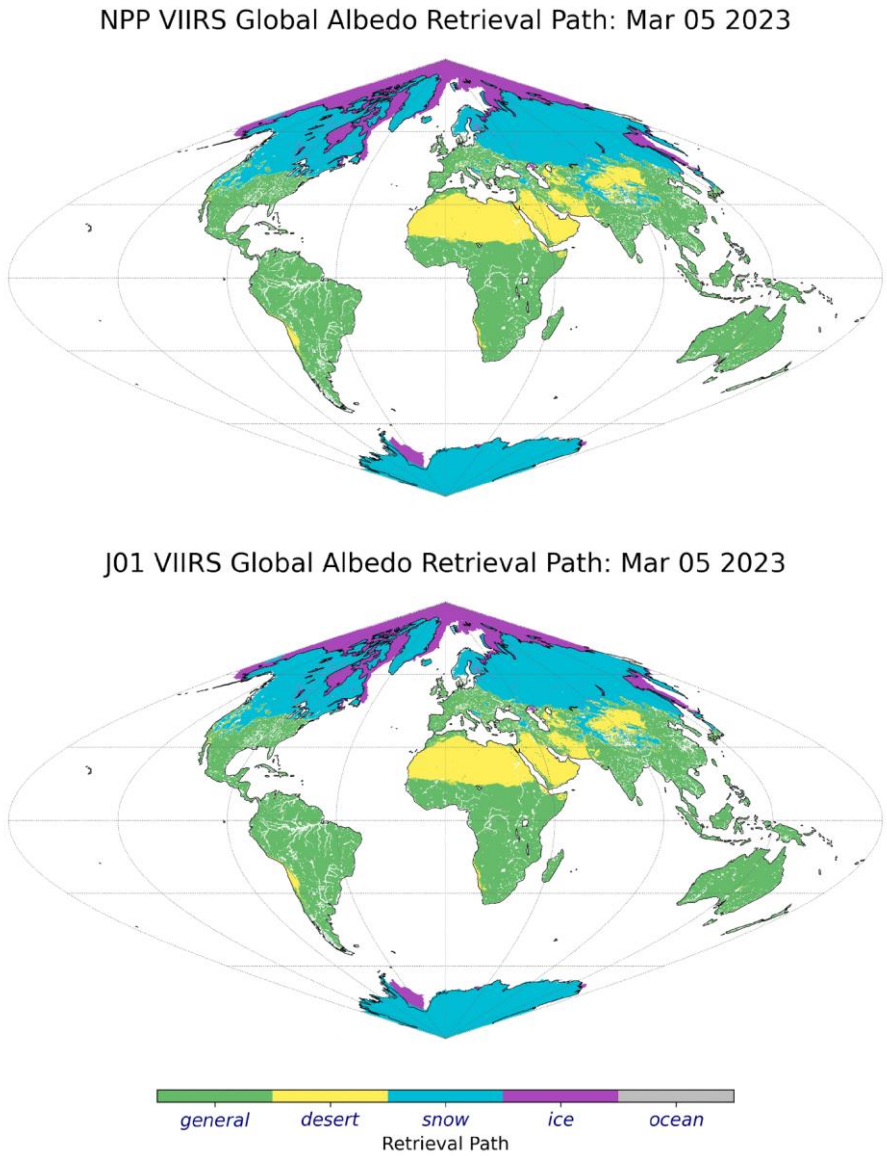
Visual Comparison (Cloud Flag)



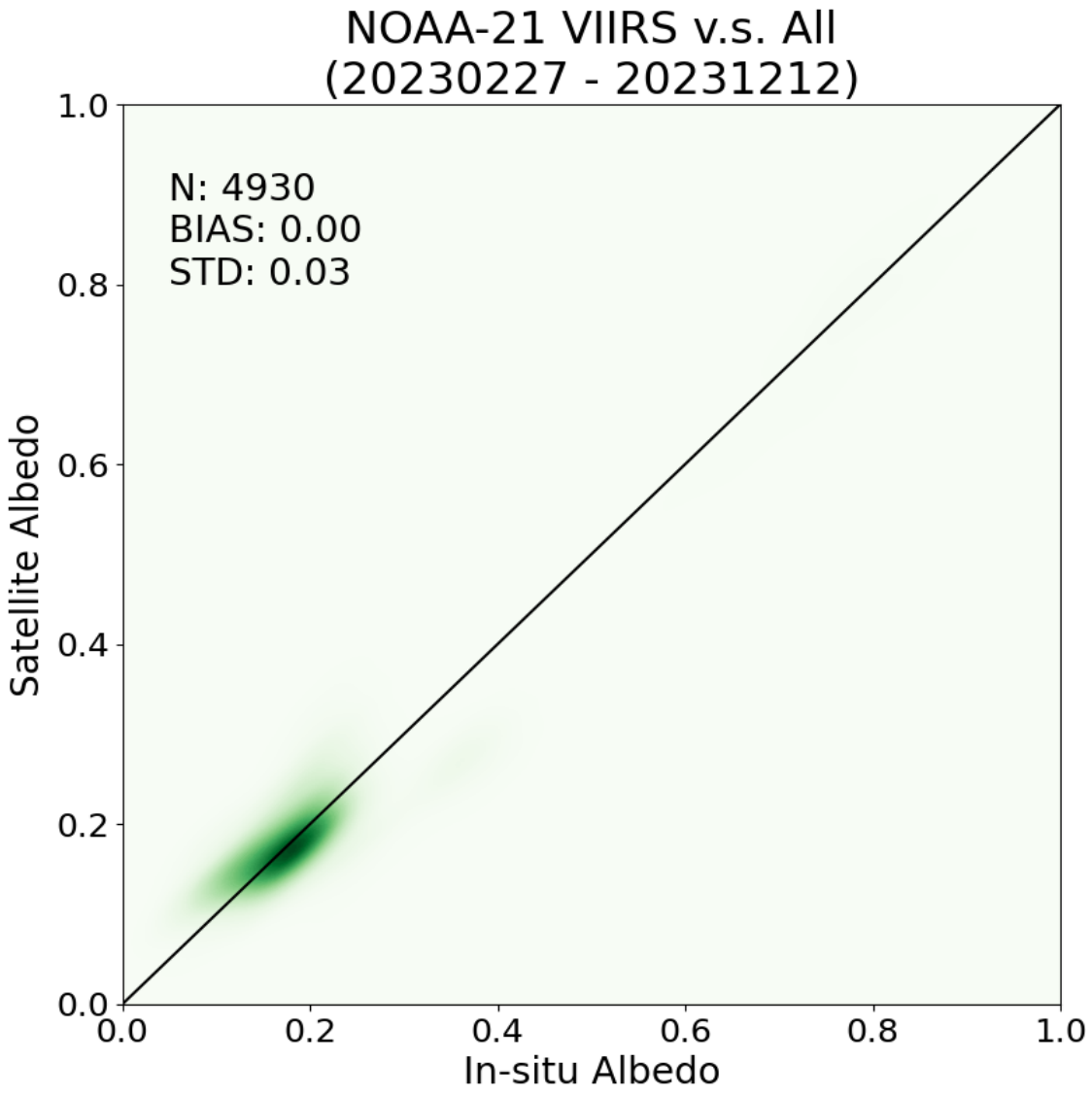


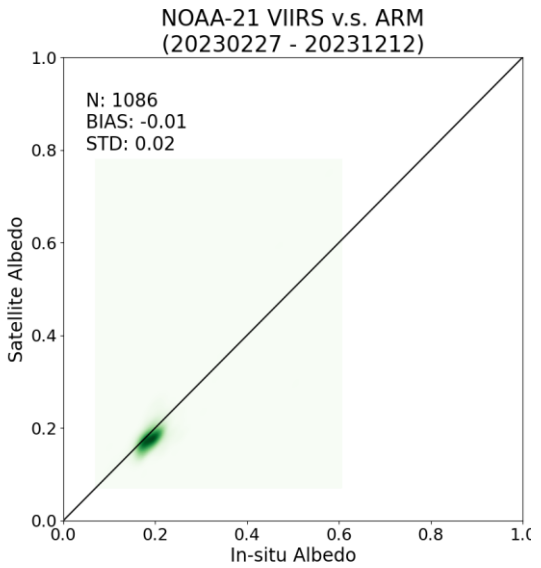
Visual Checking (LUT type)

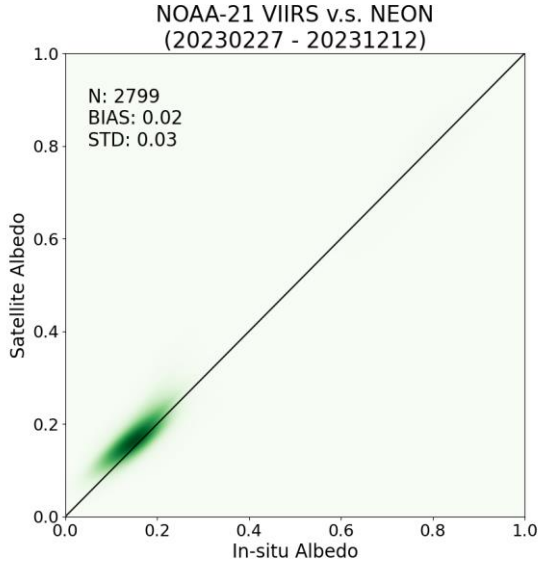


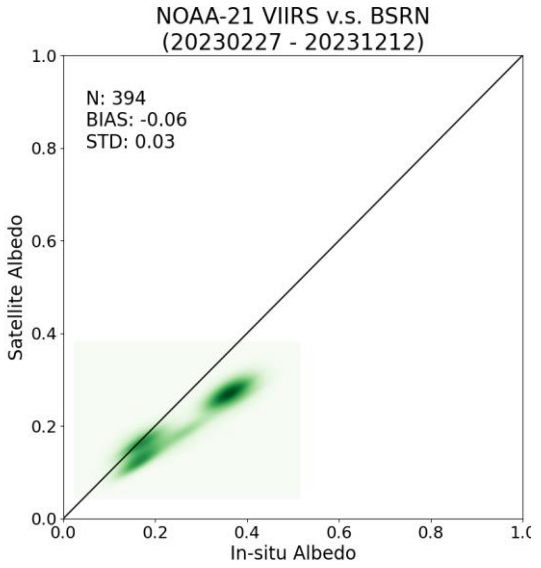


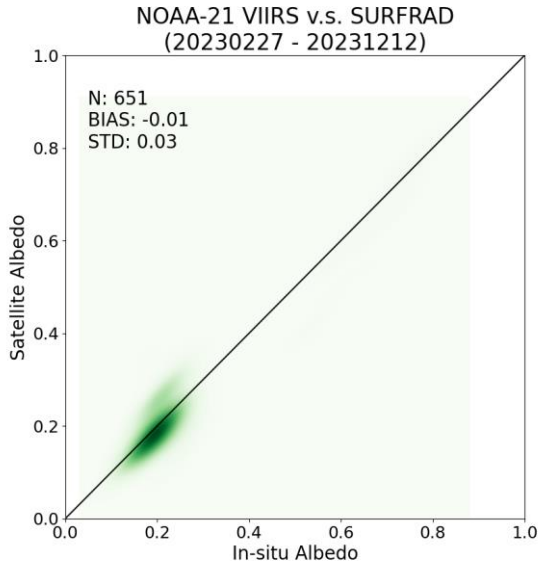
Ground network validation (NOAA-21)



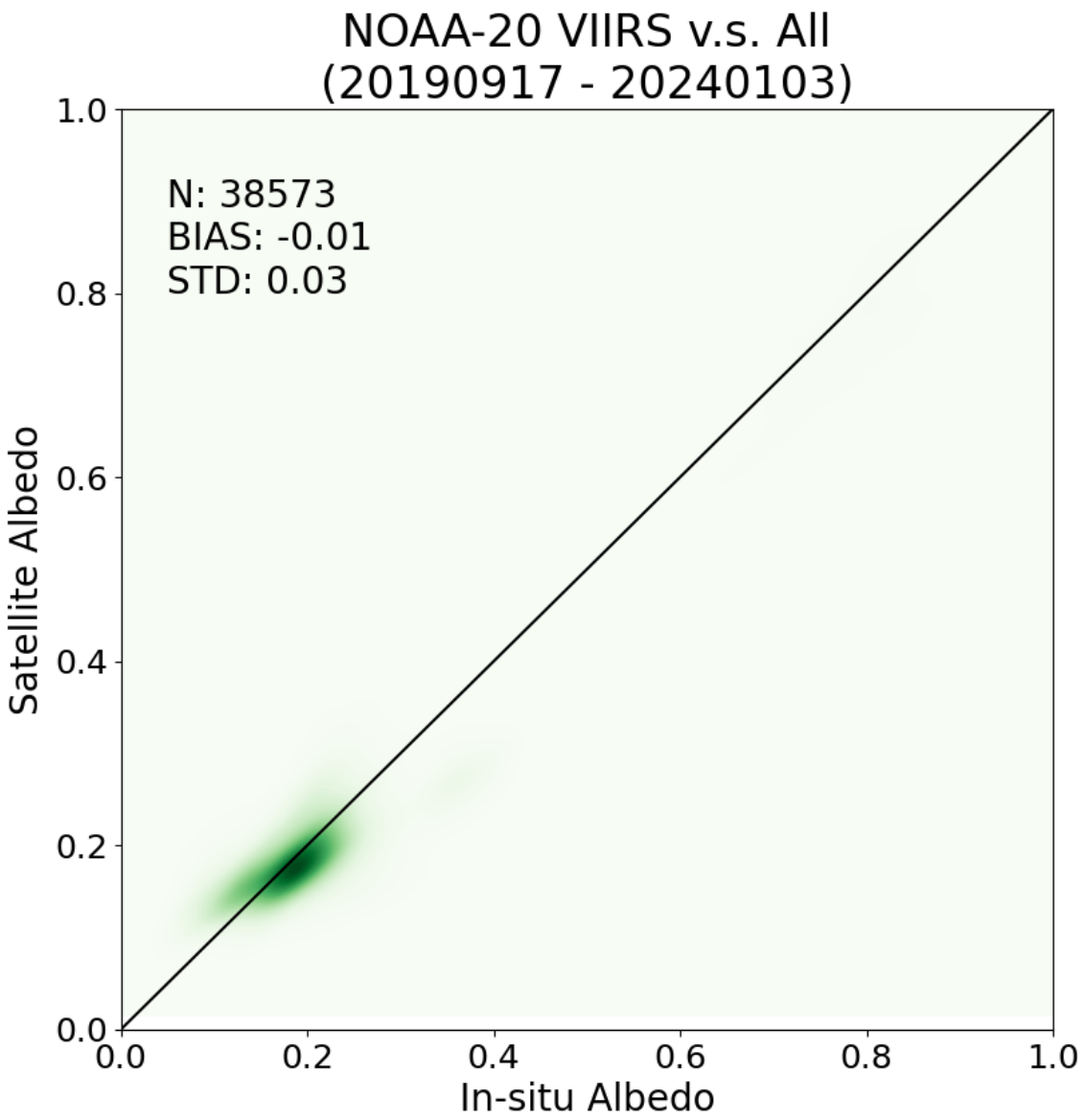


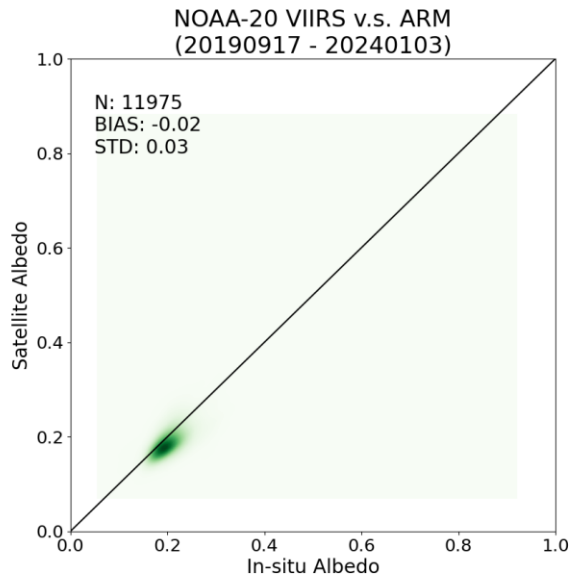


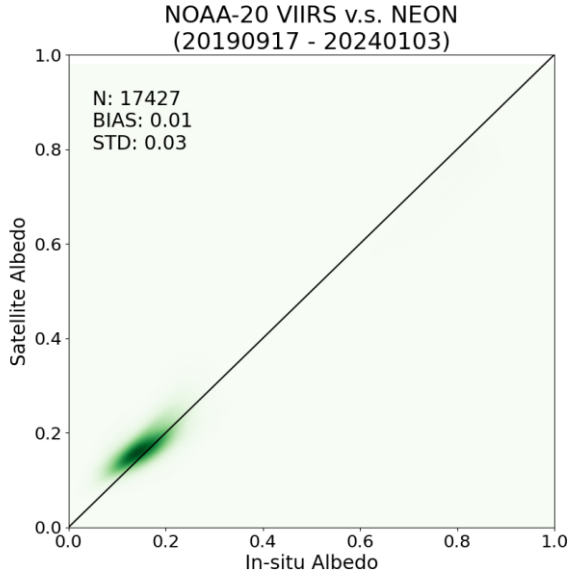


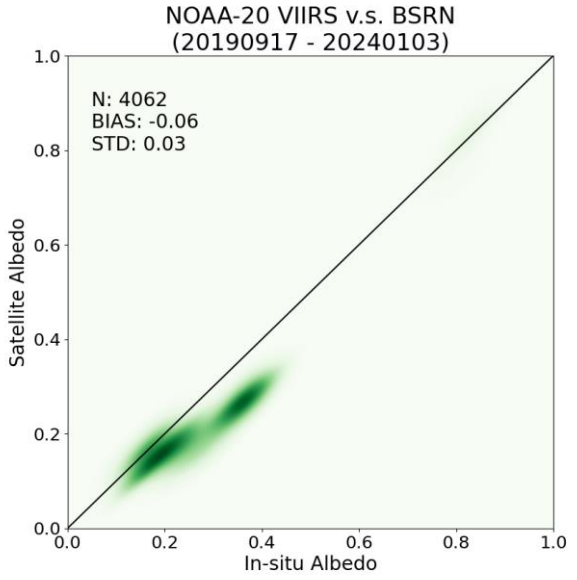


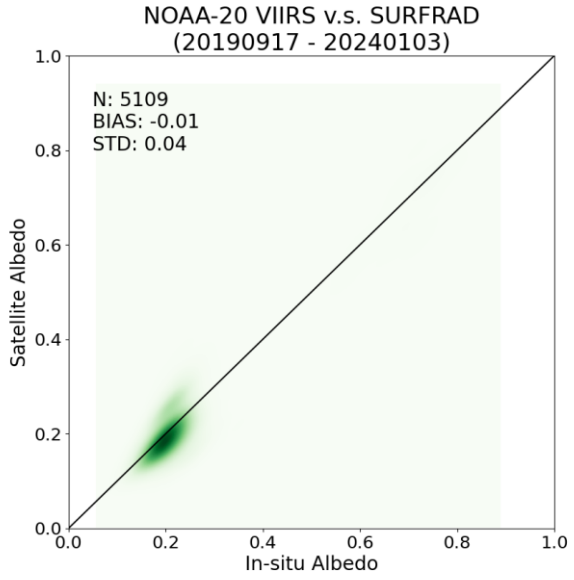
Ground network validation (NOAA-20)



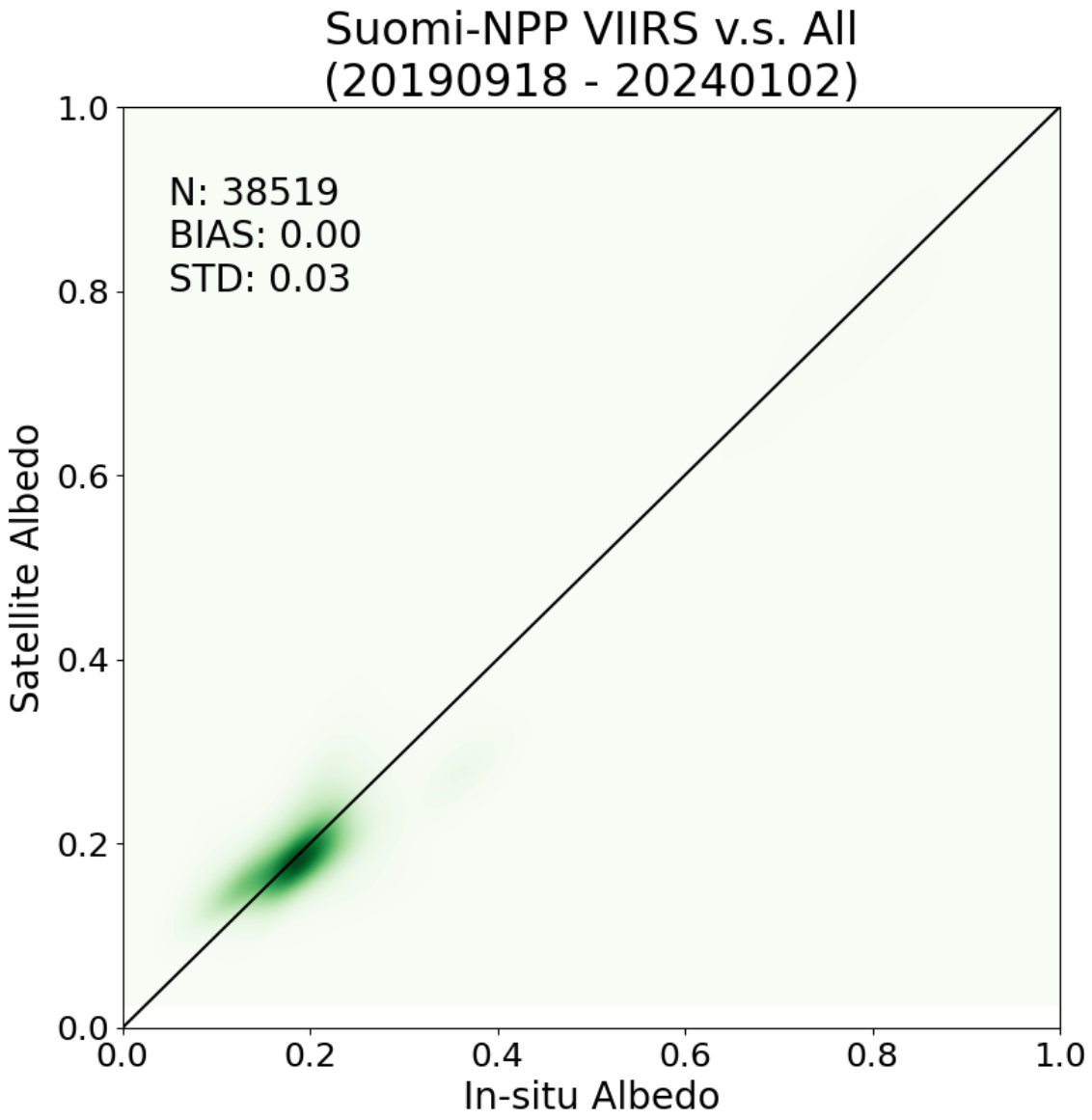


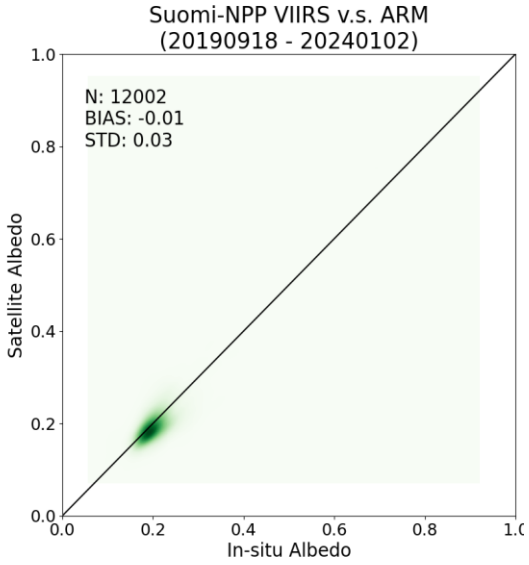


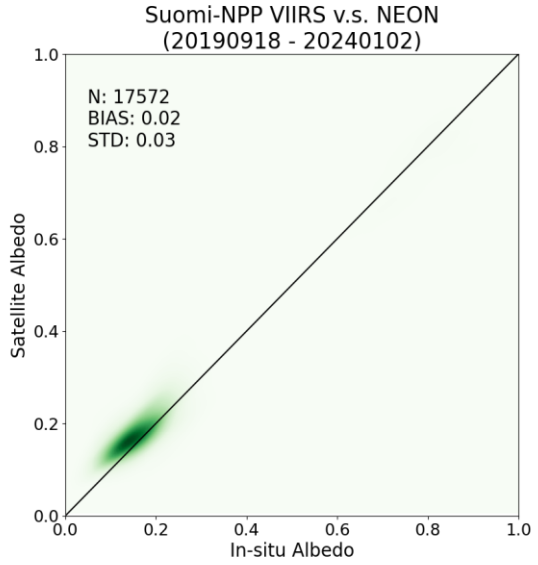


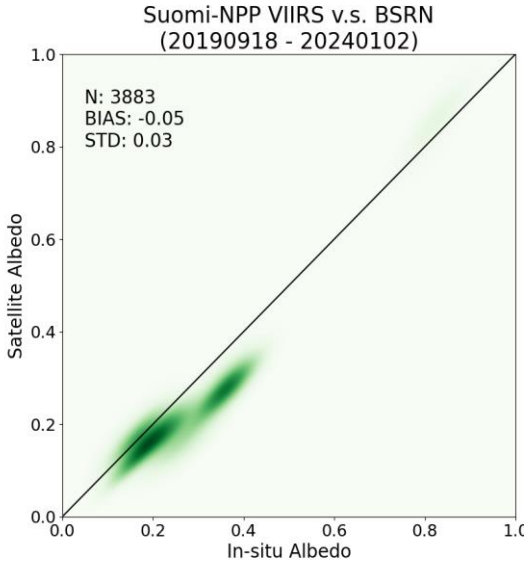


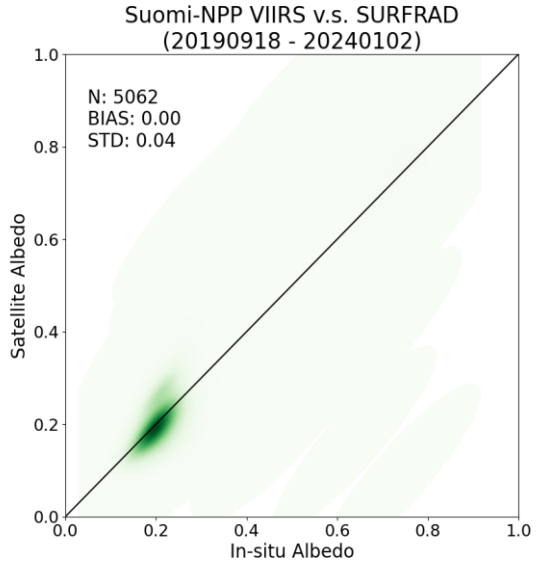
Ground network validation (S-NPP)











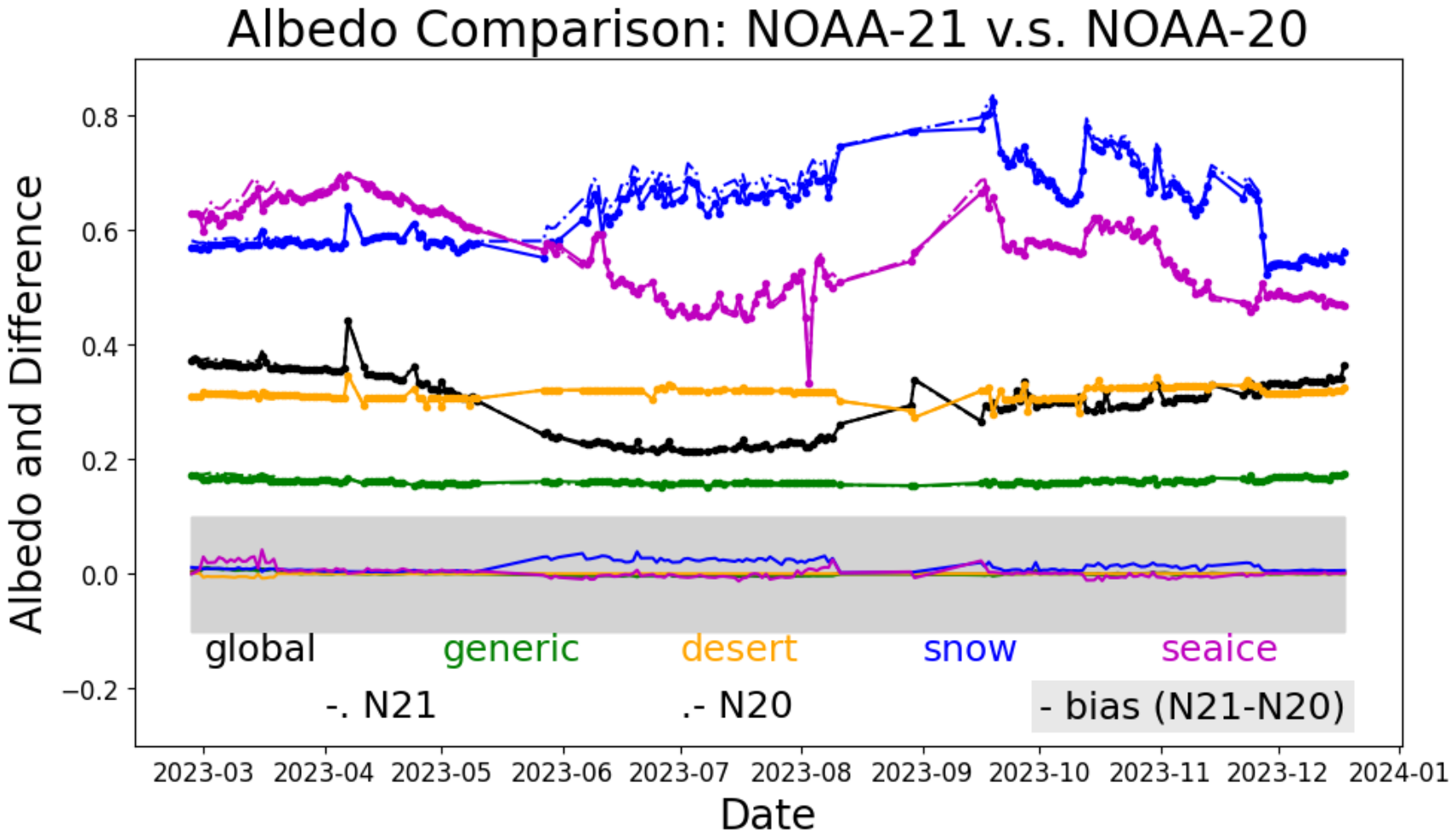
Ground network validation Summary

	Sample Number	Accuracy	Precision
NOAA-21	4930	0.00	0.03
NOAA-20	38573	-0.01	0.03
S-NPP	38519	0.00	0.03
Requirements	--	0.08	0.05

Good performance from the satellites based on the routine in-situ network data.

- The three satellites albedo products are with good accuracy and precision values which are lower than the requirement.
- NOAA-21 and S-NPP are consistent with zero-bias, while NOAA-20 is slightly off but still be within an acceptable margin.

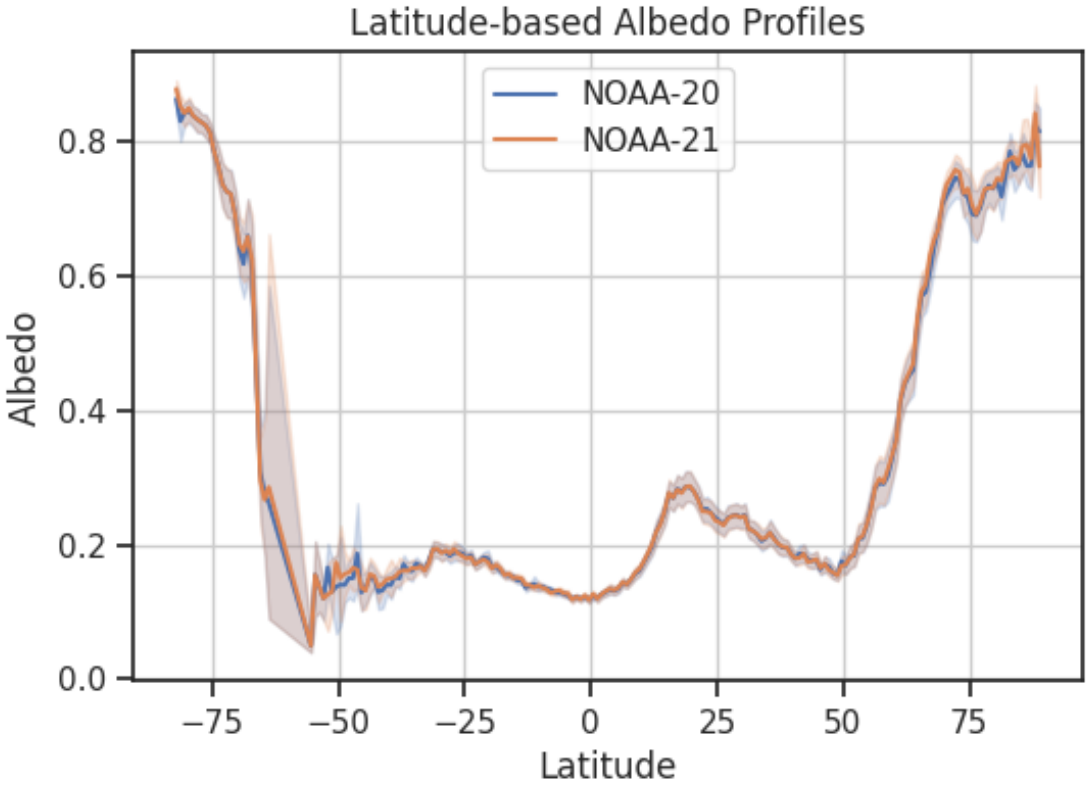
Cross-comparison (Time-series comparison)



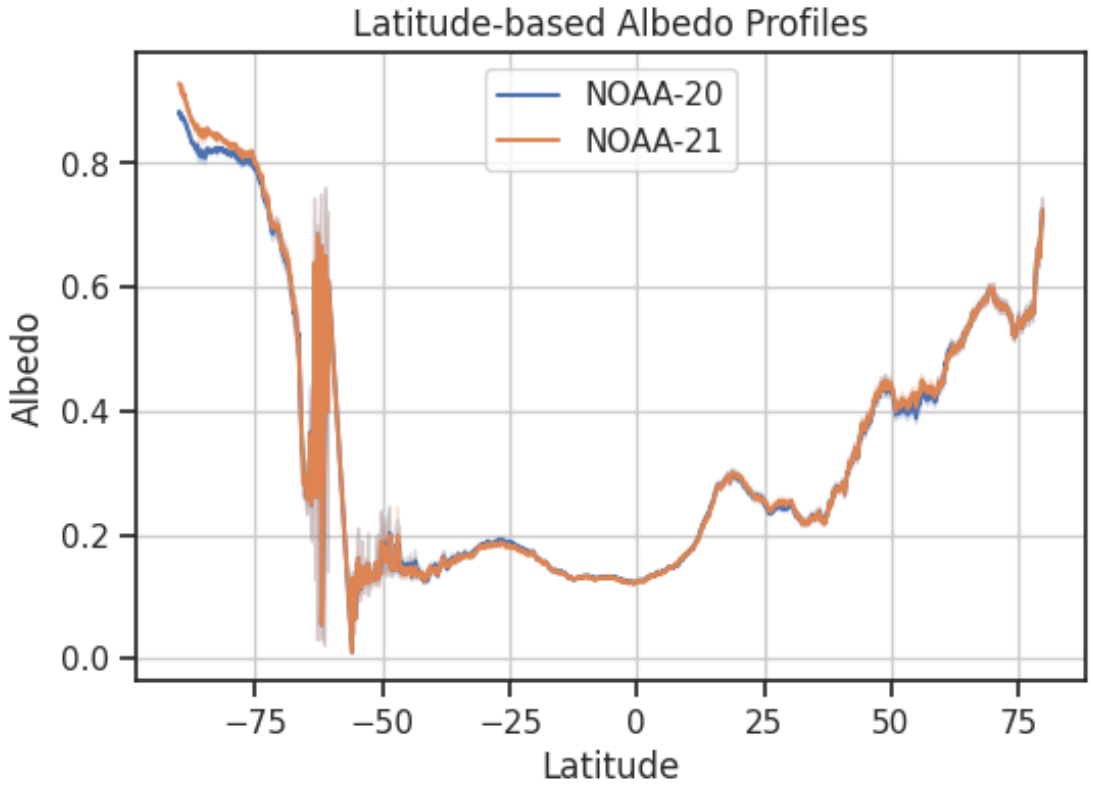
- The figure illustrates the consistency or discrepancies between NOAA-21 and NOAA-20 albedo data.
- Albedo values fluctuate over time, due to seasonal changes and weather patterns.
- The figure suggests that their bias is relatively small for the most part, considering the gray area does not show large fluctuations.
- There are no extreme spikes or dips that would suggest a drastic change in albedo.

Cross-comparison (Albedo-Latitude Profiles)

- Spring case (Apr 28, 2023)



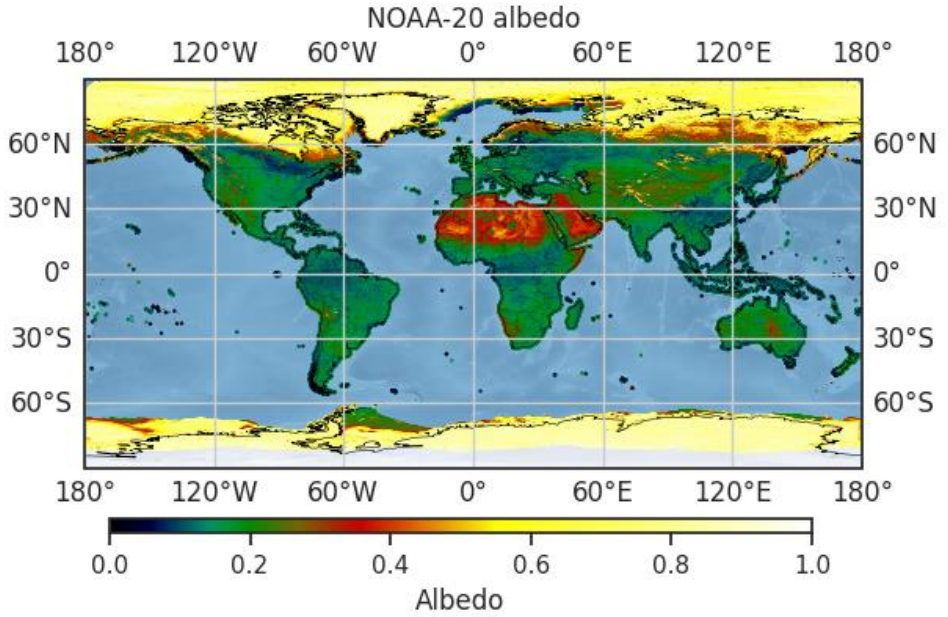
- Winter case (Jan 05, 2024)



1.Data Similarity: The albedo profiles for NOAA-20 and NOAA-21 are quite similar across all latitudes in both cases, suggesting consistent measurements between the two satellites and the overall trends are aligned.
2.Differences between the Graphs: While the overall patterns are similar, there are noticeable differences at certain latitudes, such as around -60° to -50° and 50° to 60°, where the albedo values diverge. This could be due to differences in snow and ice mask.
3.Two cases are from the same version: These two cases are from the periods when both NOAA-20 and NOAA-21 are from v2r2. As we mentioned, the NOAA-20 albedo was from v1r4, causing additional differences in cross comparison, from May 10 to Dec 18.

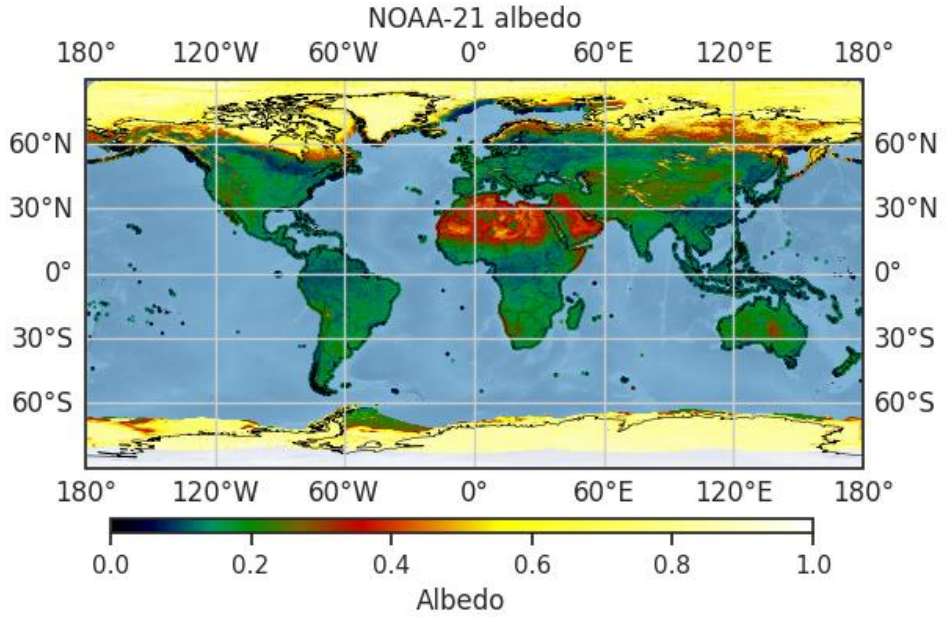
Cross-comparison (Albedo)

- Spring case (Apr 28, 2023)

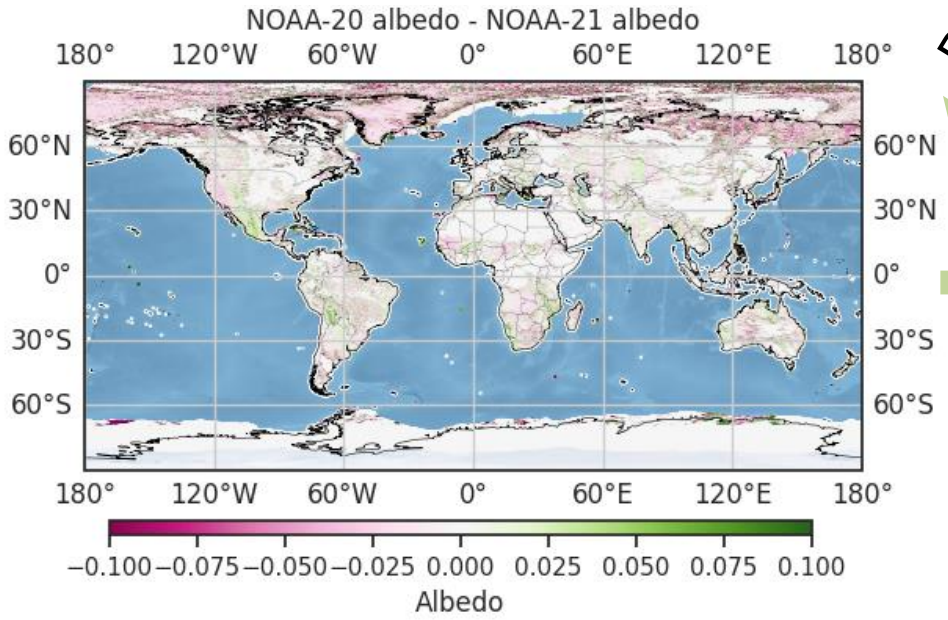


High consistency

NOAA-20 v.s. NOAA-21

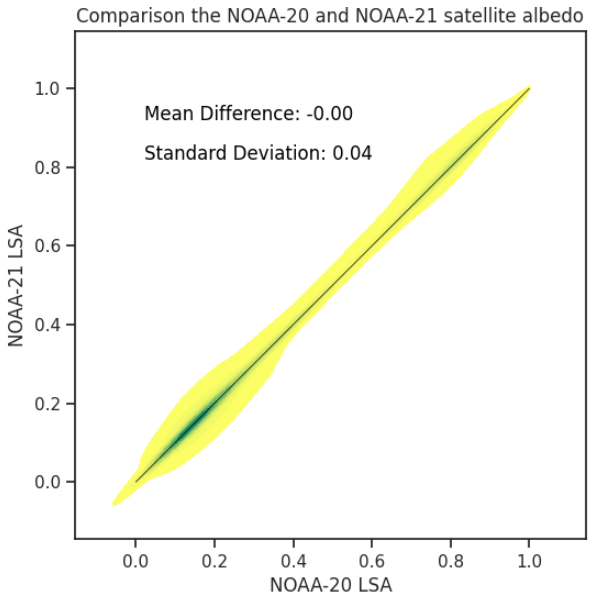


Difference Map



Statistics

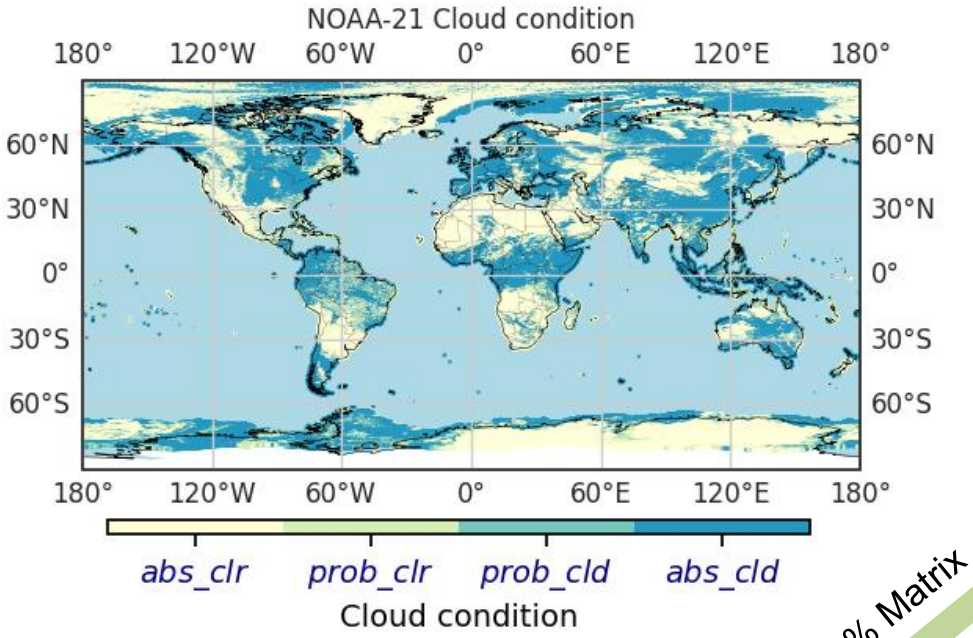
Bias and Std

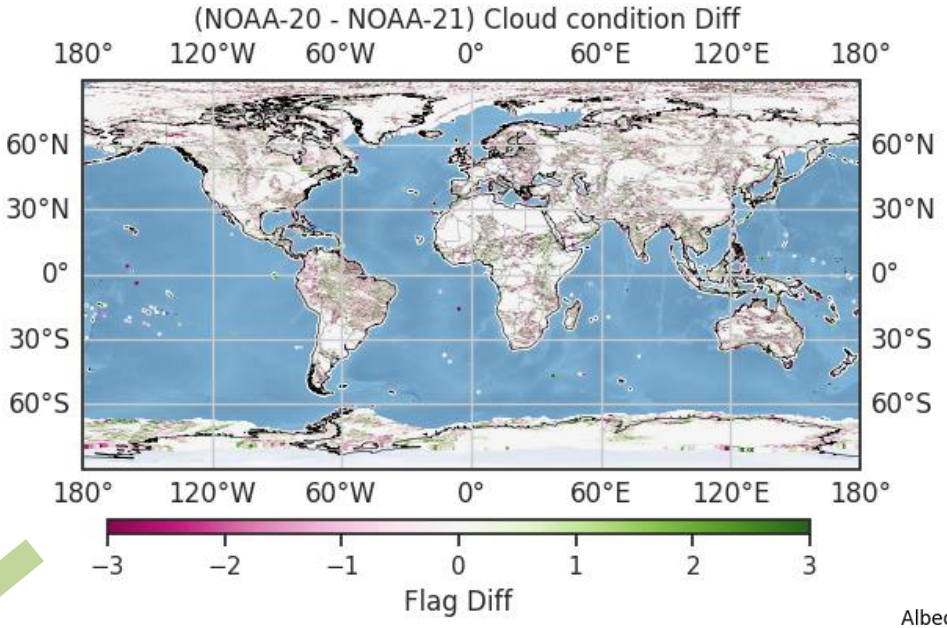


- Zero bias exists between NOAA-20 and NOAA-21 albedo measurements.
- Some scattered differences are related to cloud conditions and variations in input data.

Cross-comparison (Input-QF-Albedo)

- Spring case (Apr 28, 2023)



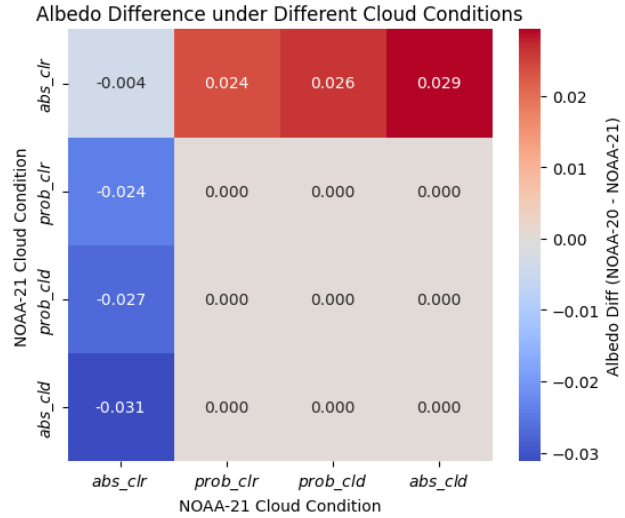


% Matrix

Pixel Percentage (%)		NOAA-21 Cloud Condition			
		Abs_clear	Prob_clear	Prob_cloudy	Abs_cloudy
NOAA-20 Cloud Condition	Abs_clear	38.16	1.77	0.77	3.85
	Prob_clear	1.67	1.7	0.59	1.67
	Prob_cloudy	0.86	0.6	1.1	2.13
	Abs_cloudy	3.91	1.73	1.9	37.59

Impact on

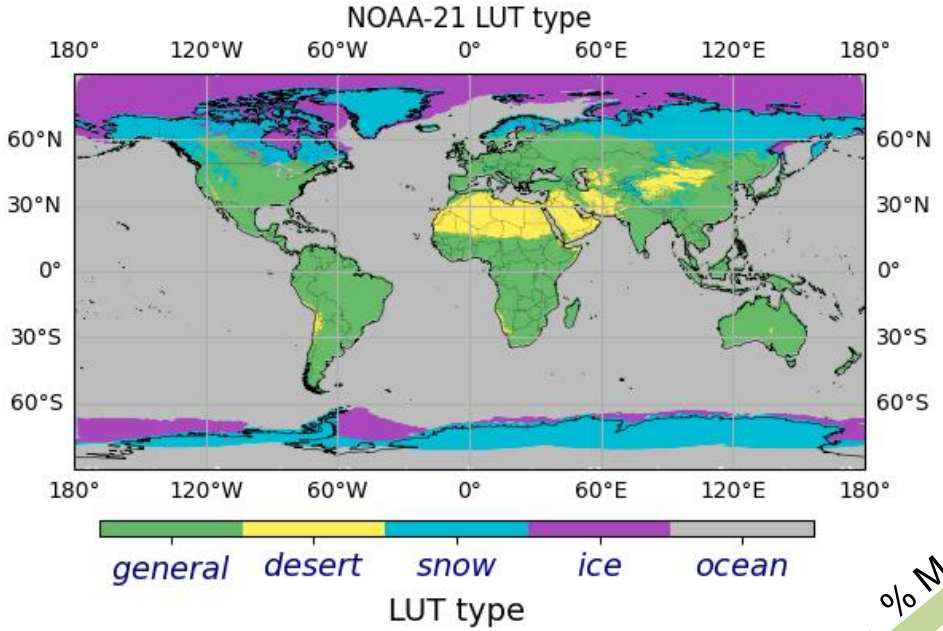
Albedo Diff

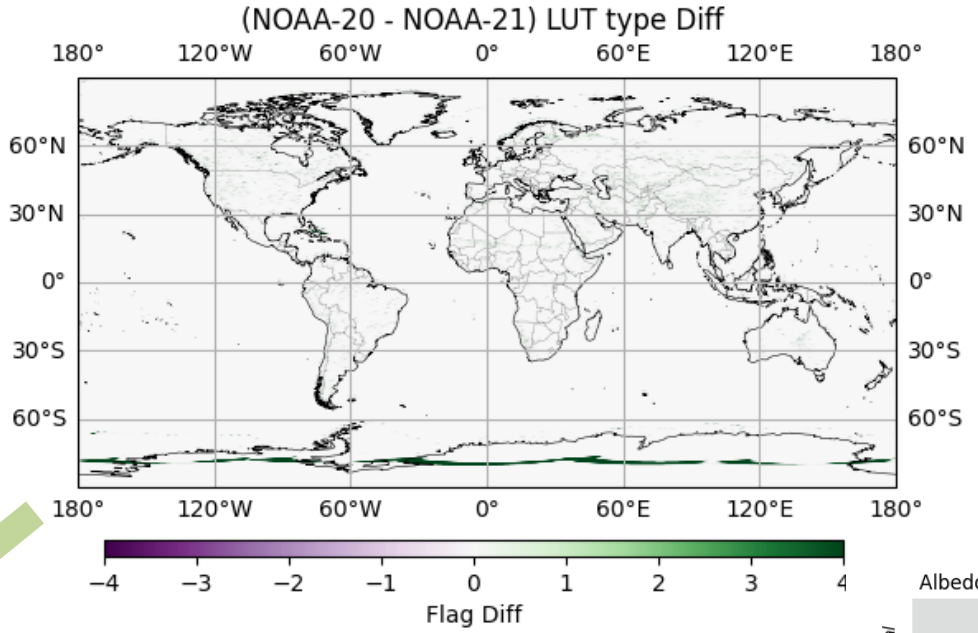


- Differences in cloud conditions between NOAA-20 and NOAA-21 are normal, considering the time elapsed between their observations.
- The albedo retrieval method is different from absolutely clear to other types of conditions.
- The cloud inconsistency caused retrieval path difference leads to the scattered difference (larger group bias) in albedo

Cross-comparison (QF→ Albedo)

- Spring case (Apr 28, 2023)



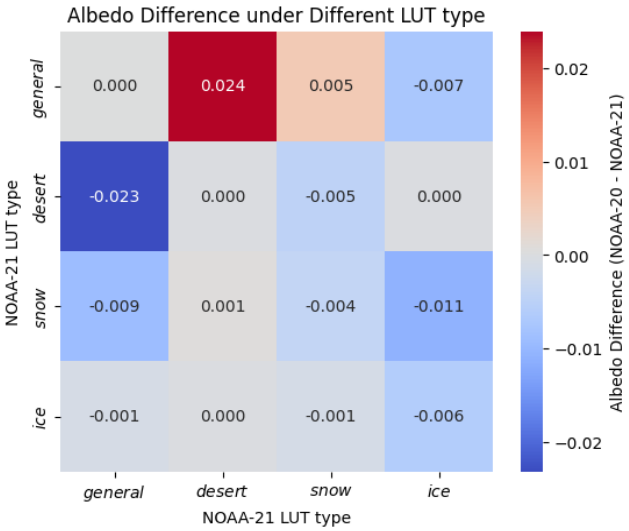


% Matrix

Pixel Percentage (%)		NOAA-21				
		General	**Desert**	**Snow**	**Ice**	**Ocean**
NOAA-20	**General**	54.52	0.15	0.07	0.0	0.0
	Desert	0.16	11.35	0.01	0.0	0.0
	Snow	0.07	0.01	21.53	0.03	0.0
	Ice	0.0	0.0	0.04	12.06	0.0
	Ocean	0.0	0.0	0.0	0.0	0.0

Impact on

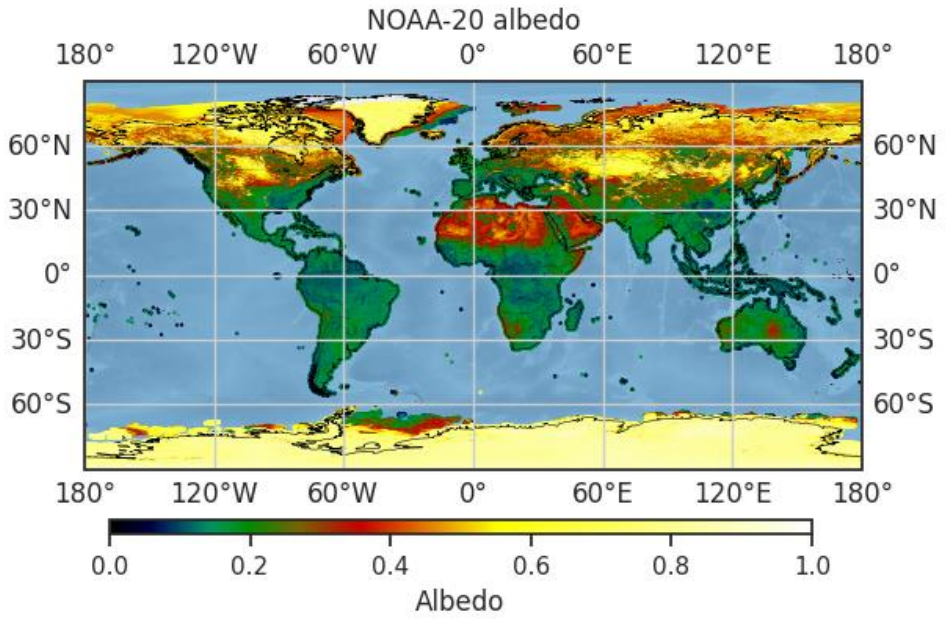
Albedo Diff



- The differences in surface type are smaller. The largest discrepancy occurs when there is a difference in the recognition of bare soil pixels. Another source of difference is the mapped snow/ice mask data. As they all lead to different LUT type during albedo retrieving.

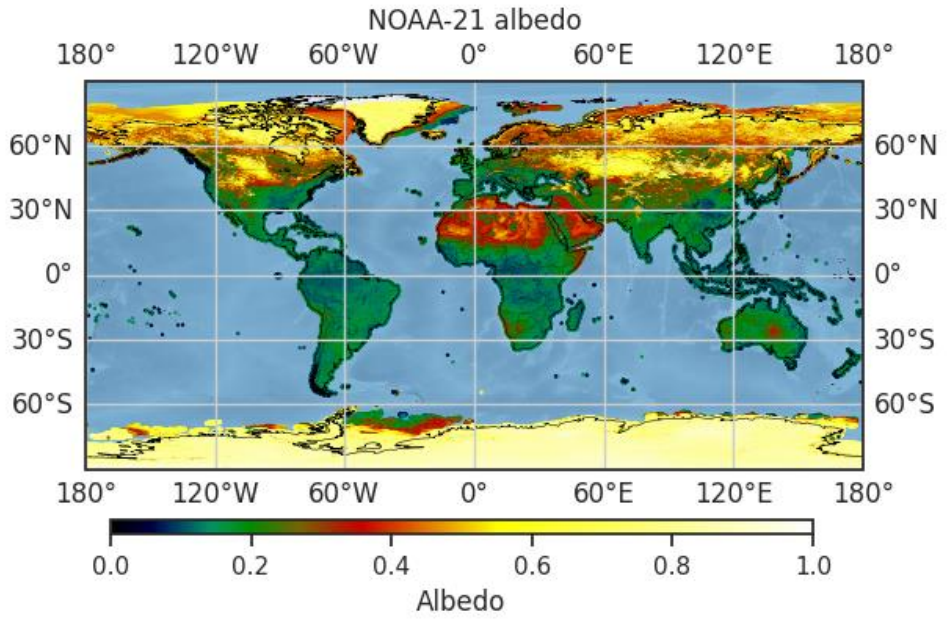
Cross-comparison (Albedo)

- **Winter case (Jan 5, 2024)**

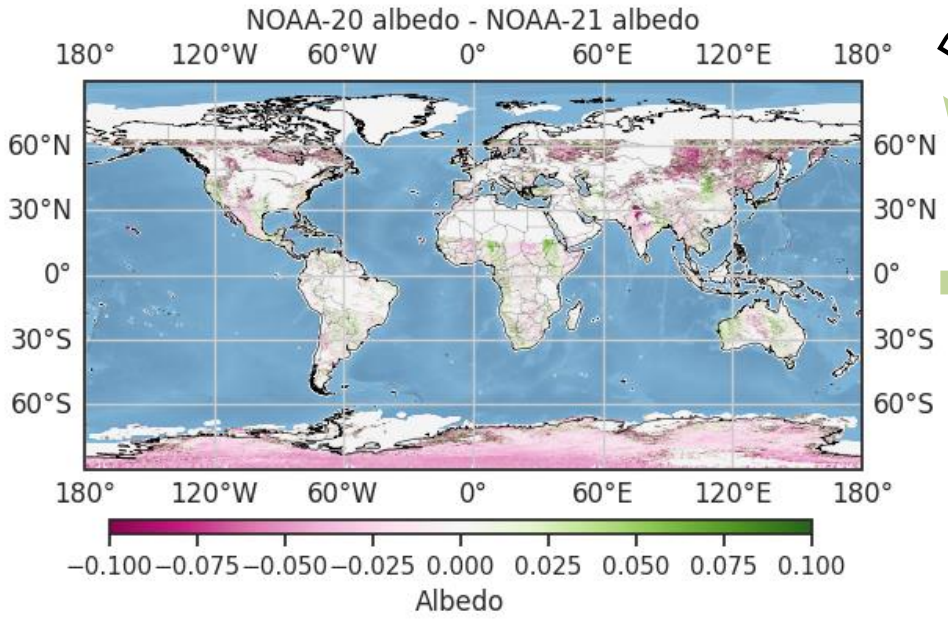


High consistency

NOAA-20 v.s. NOAA-21

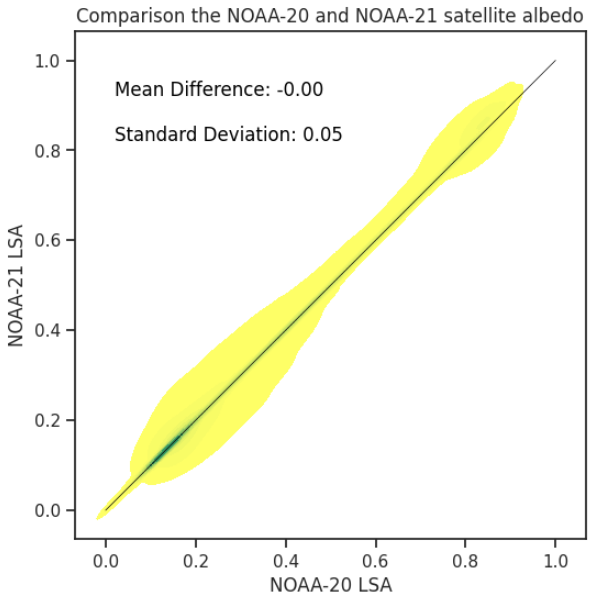


Difference Map



Statistics

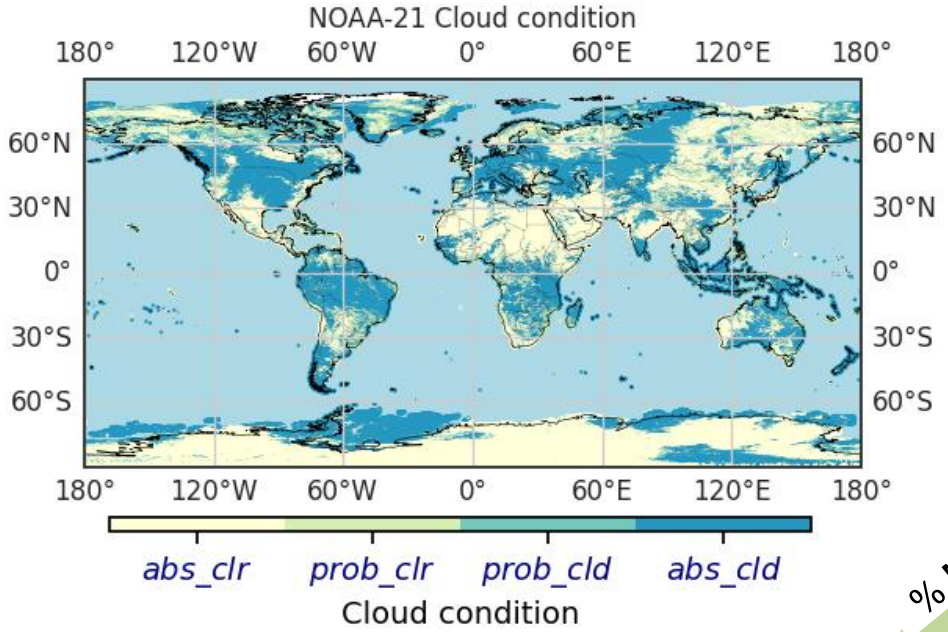
Bias and Std

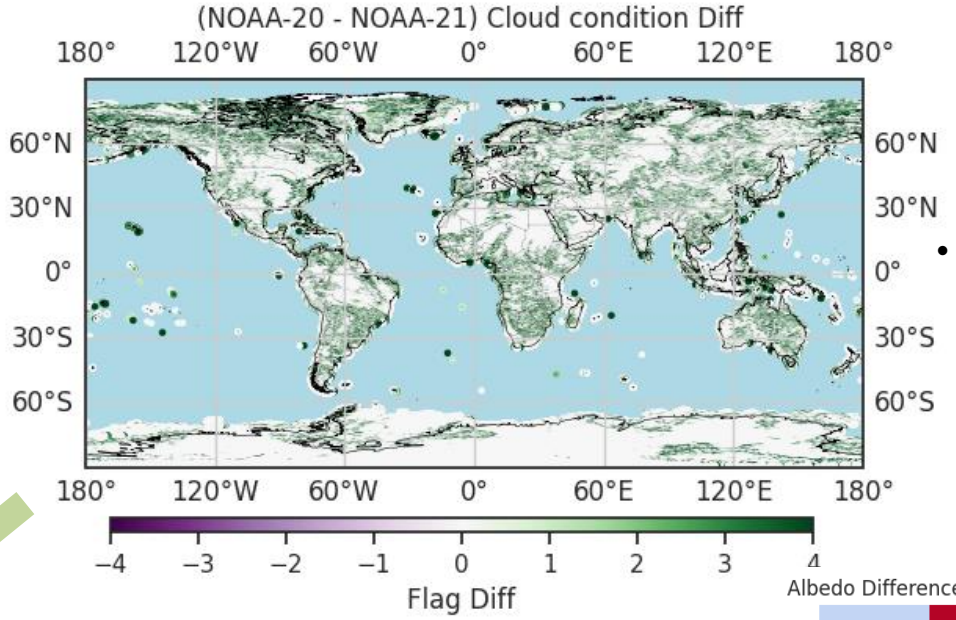


- Zero bias exists between NOAA-20 and NOAA-21 albedo measurements.
- Some scattered differences are related to cloud conditions and variations in input data.

Cross-comparison (QF→ Albedo)

- **Winter case (Jan 5, 2024)**



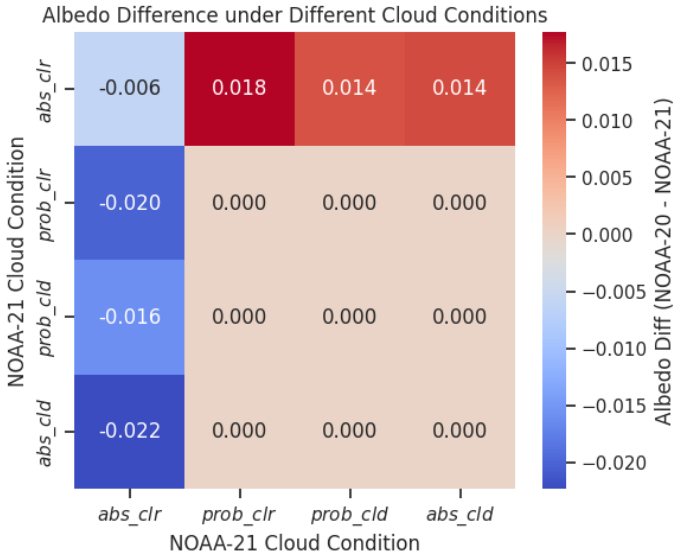


% Matrix

Pixel Percentage (%)		NOAA-21 Cloud Condition			
		Abs_clear	Prob_clear	Prob_cloudy	Abs_cloudy
NOAA-20 Cloud Condition	Abs_clear	38.155	2.265	1.268	4.428
	Prob_clear	1.61	2.148	1.106	1.872
	Prob_cloudy	0.819	0.695	1.355	2.078
	Abs_cloudy	3.488	1.437	1.603	35.671

Impact on

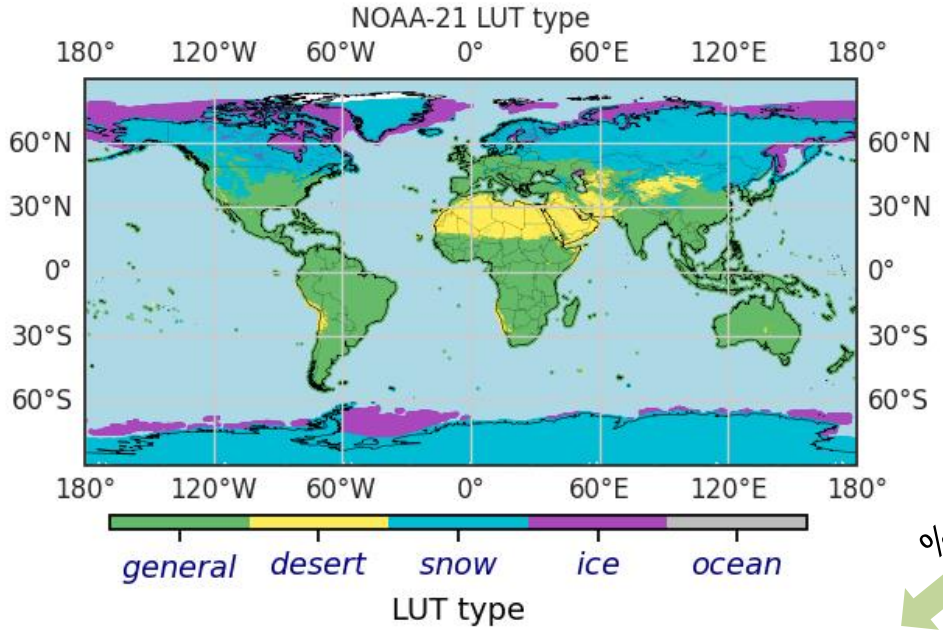
Albedo Diff

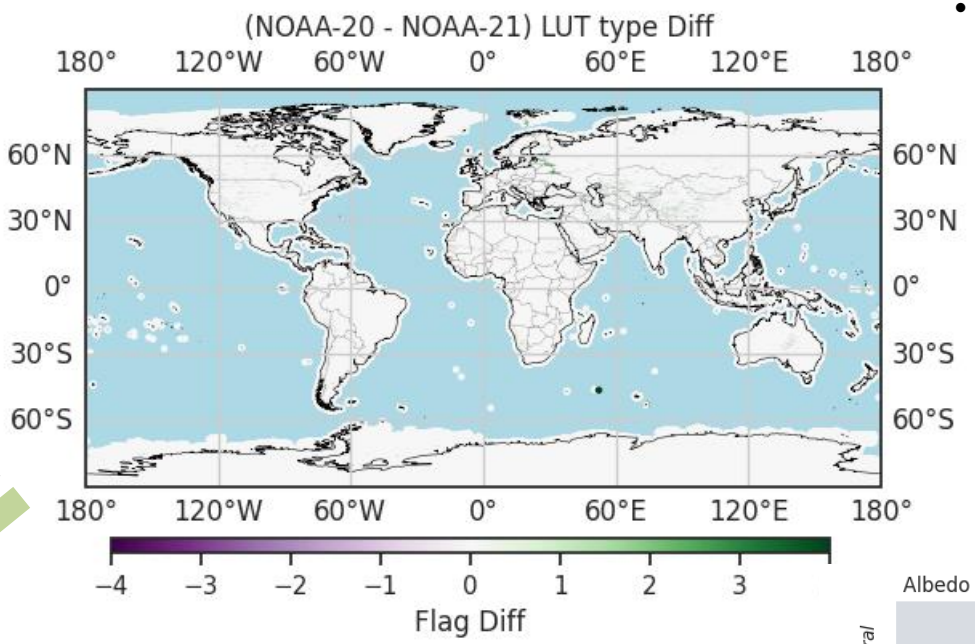


- Differences in cloud conditions between NOAA-20 and NOAA-21 are normal, considering the time elapsed between their observations.
- The cloud inconsistency caused retrieval path difference leading to the scattered difference (larger group bias) in albedo

Cross-comparison (QF→ Albedo)

- **Winter case (Jan 5, 2024)**



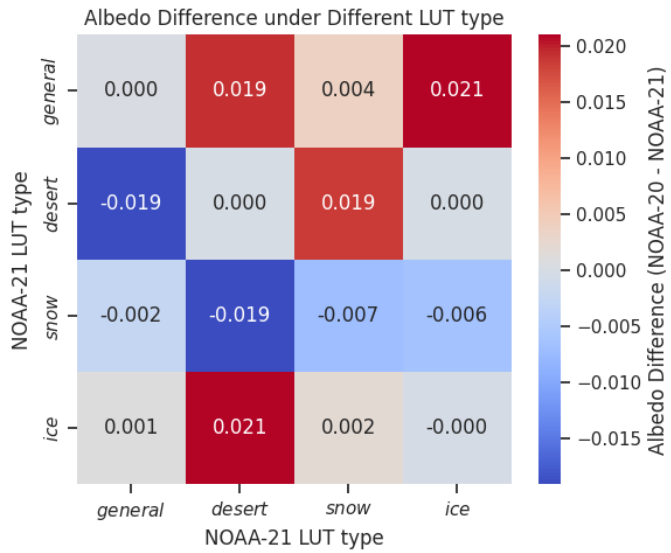


% Matrix

Pixel Percentage (%)		NOAA-21				
		General	**Desert**	**Snow**	**Ice**	**Ocean**
NOAA-20	**General**	46.583	0.145	0.062	0.001	0.0
	Desert	0.14	11.331	0.01	0.0	0.0
	Snow	0.106	0.01	33.418	0.043	0.0
	Ice	0.001	0.0	0.045	8.105	0.0
	Ocean	0.0	0.0	0.0	0.0	0.0

Impact on

Albedo Diff



- The differences in surface type are smaller. The largest discrepancy occurs when there is a difference in the recognition of bare soil pixels. Another source of difference is the mapped snow/ice mask data. As they all lead to different LUT type during albedo retrieving.

Error Budget

Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Accuracy	DPS-376	0.08	NA	0	-0.01	0	Yes	NA
Precision	DPS-377	0.05	NA	0.03	0.03	0.03	Yes	NA

- The results indicate an overall nearly zero bias and a precision of approximately 0.03 in NOAA-21 VIIRS albedo, consistent with other precedent VIIRS albedo products. This performance significantly **exceeds the required standards**.
- The validation covers different surface types and seasons, indicating the performance of the Look-Up Tables (LUTs) used for snow, desert, and other surfaces. **Good agreement** between satellite and ground measurements **across different types of land cover**, including **grassland, forest, and shrub**. Although the current Look-Up Tables (LUTs) still result in relatively small inversion errors, this is the best that can be achieved with existing technology.
- **Some variations and biases are noted in specific cases like shrub surfaces and urban sites**. This is due to a combined effect of **inherent heterogeneity and terrain effect** on albedo comparison between ground measurements and satellite retrieval. Heterogeneity, particularly in urban or residential areas, leads to variations in albedo measurements. Terrain effects, like micro-area topography, can alter the sun and view angles on the surface, impacting the accuracy of albedo measurements (Details). These factors result in biases, especially in complex environments, and suggest a challenge in ground measurement validation.

User Engagement

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Michael Barlage	NCEP/EMC	EMC NWP Models	Soil albedo dataset and albedo diurnal variation from VIIRS albedo could be applied in the Noah-MP model; EMC Priority product for Land Data Assimilation.
CLASS	NOAA	Archive	VIIRS L2 and L3 surface albedo data are archived in the NOAA CLASS system, where they are available to the public
Barry Baker	NOAA ARL	Fengsha Dust Model	The VIIRS BRDF climatology and future NRT BRDF could improve the dust prediction ability

Risks, Actions, and Mitigations

- The risks/actions identified during the Beta maturity review(s) have been resolved.
- No new risks.

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Production error in NDE	Unexpected data gap in VIIRS albedo	No valid value over cloudy pixels (pixels other than absolutely clear)	Solved in NDE. The data since Aug 30, 2023 became normal

Documentations (Check List, 1 slide)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	Yes (For NOAA-21 Provisional Maturity specifically)
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)	Yes*

The asterisk (*) indicates a document shared with NOAA-20 and S-NPP counterpart albedo products.

Check List - Provisional Maturity

Provisional Maturity End State	Assessment
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.	Yes. The product has been validated using ten months of ground data, demonstrating the accuracy and precision are satisfied.
Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.	Yes. The validation basically demonstrates a large probability that the product is qualified, referring to the consistency between NOAA-21 and the NOAA-20, SNPP counterparts which are both qualified.
Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.	Yes. This document has recorded the performance of the product in both albedo values and quality.
Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.	Yes. The product is recommended for operational use.

Conclusion

- The NOAA-21 VIIRS Surface Albedo Product was evaluated using data from February 2023 to January 2024.
- Comparisons with ground measurements and counterpart products from NOAA-20/S-NPP indicate that its performance meets the specified product requirements and exceeds that of the provisional maturity level.
- The Land Albedo Team recommends releasing the NOAA-21 albedo product as a provisional maturity version on the date specified in the Provisional Maturity Readme file.

Path Forward

- Future Cal/Val activities
  - Implement the LTM adaptations with routine NOAA-21 albedo data
  - Routine cross-comparisons
- Future Cal/Val activities
  - Validated maturity Review
  - Climatology update
- User engagement
  - Application in NOAA climate models
- Improved albedo products
  - Blended Albedo product with S-NPP and NOAA-20 VIIRS Albedo
  - Apply NOAA-21 data into BRDF/BSA/WSA/NBAR algorithm