Provisional Maturity Science Review For NOAA-21 VIIRS Cryosphere Products – Snow Cover

Presented by Peter Romanov

Date: 01/25/2024

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.

Provisional Maturity Review - Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Provisional Maturity Performance Validation
- Users/Downstream-Products feedback
- Risks, Actions, Mitigations
  - Potential issues, concerns
- Path forward to Validated Maturity
- Summary

Provisional Maturity Review - Exit Criteria

- Provisional Maturity Performance is well characterized and meets/exceeds the requirements:
  - On-orbit instrument performance assessment
    - Provide summary for each identified instrument and product characteristic you have validated/verified as part of the entry criteria
    - Provide summary of pre-launch concerns/waivers mitigations/evaluation and address whether any of them are still a concern that raises any risk.
- Updated Provisional Maturity Review Slide Package addressing review committee's comments for:
  - Cal/Val Plan and Schedules
  - Product Requirements
  - Provisional Maturity Performance
  - Risks, Actions, Mitigations
  - Path forward to Validated Maturity

PROVISIONAL 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 Snow Product Cal/Val Team

Algorithm Cal/Val Team Members

Name	Organization	Major Task
Peter Romanov	CREST/CUNY	Binary and fractional snow cover algorithm development, product analysis and evaluation
Yinghui Liu	NOAA/NESDIS	Overall JPSS snow and sea ice project management, assistance on analysis and validation
Jeff Key	NOAA/NESDIS	STAR Cryosphere Team Lead

Snow Product Overview

VIIRS Snow Product Suite includes Binary Snow Cover and Snow Fraction Products

- Binary Snow Cover
  Indicates the presence or absence of snow within the sensor FOV

- Fractional Snow Cover
  Provides the area fraction of snow within FOV as seen from the above.
  Disregards snow masked by the tree canopy (so only the viewable snow fraction)

Retrievals of both snow products require daylight and clear sky conditions

Snow Product Requirements

- Binary Snow Cover

Attribute	DPS	Requirement/Threshold	Performance
Geographic coverage	302	Global	
Horizontal Cell Size		1.6 km	
Measurement Range	304	0/1 Binary mask	
Measurement Accuracy	304	90% probability of correct typing	

- Snow Cover Fraction

Attribute	DPS	Requirement/Threshold	Performance
Geographic coverage	302	Global	
Horizontal Cell Size		1.6 km	
Measurement Range	303	0.0-1.0 Snow Fraction	
Measurement Uncertainty	303	20%	

Processing Algorithms

- Binary Snow Cover (2-step algorithm)
  - Threshold-based decision tree classification algorithm
  - Consistency testing of snow identifications with auxiliary climatic datasets

ATBD at https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Cryosphere_Binary_Snow_Map_v1.0.pdf

- Fractional Snow Cover
  - Single-band linear unmixture technique (used with VIIRS, ABI, the GOES Imager, and AVHRR)
    - Uses observations in one (visible, I1) spectral band
    - Two endmembers (snow, snow-free land)
    - Endmember values change with viewing/illumination geometry of observation (kernel-driven BRDF model)
  - Applied to pixels identified as “snow covered” in the Binary Snow Map

ATBD at https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Cryosphere_Fractional_Snow_Cover_v1.0.pdf

Processing Environment

Production site: NCCF (as provided in the product file attributes)
Production Environment: UAT (as provided in the product file attributes)
Processing Version: V3R2

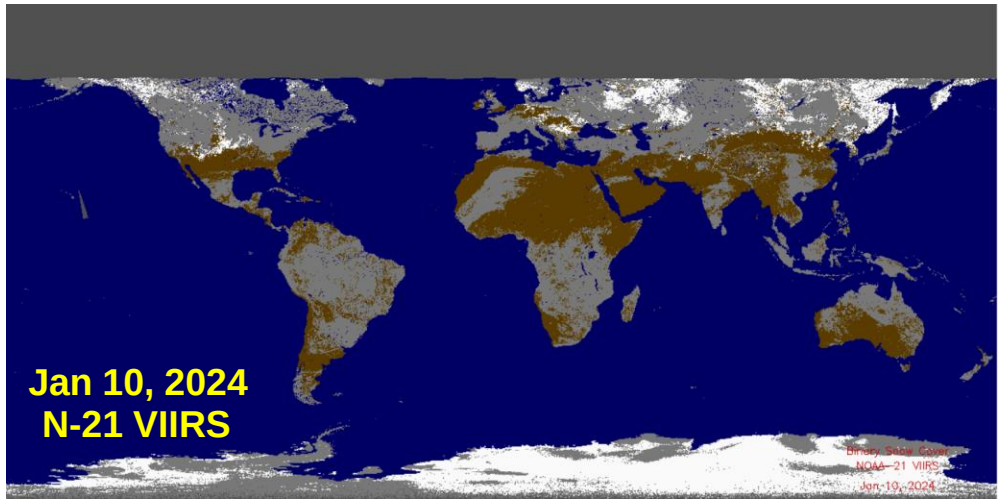
Dates used for validation: 20 Apr 2023 - 15 January 2024
Effective date: May 1, 2023
Starting orbit number: 2436

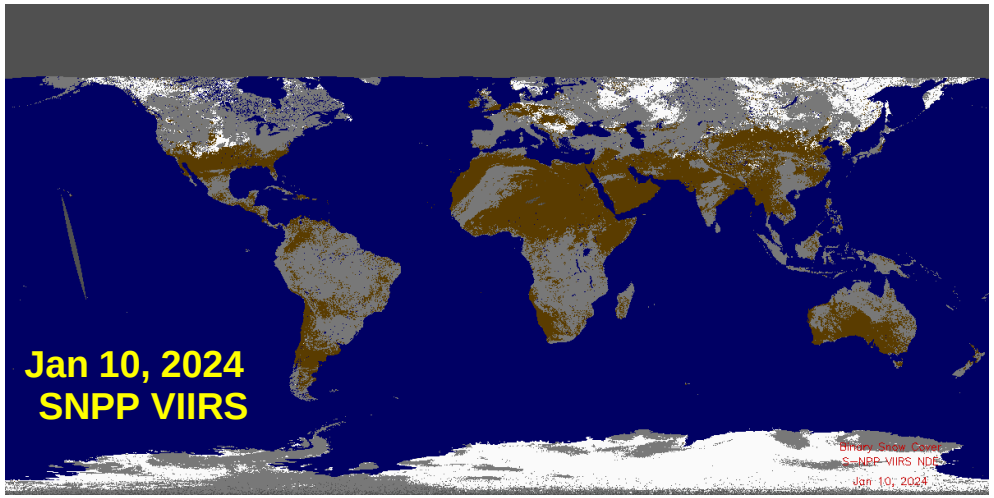
Assessment of Binary Snow Cover

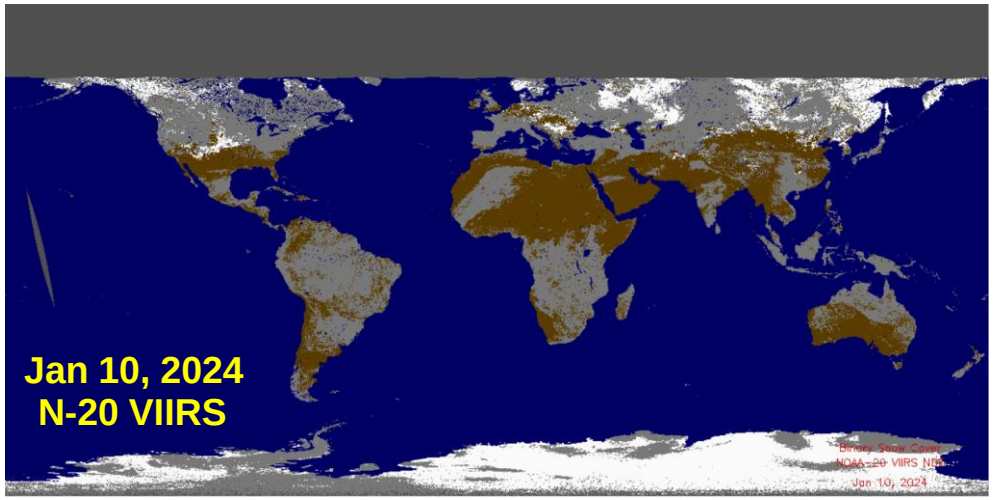
NOAA-21 Binary Snow Evaluation Approach

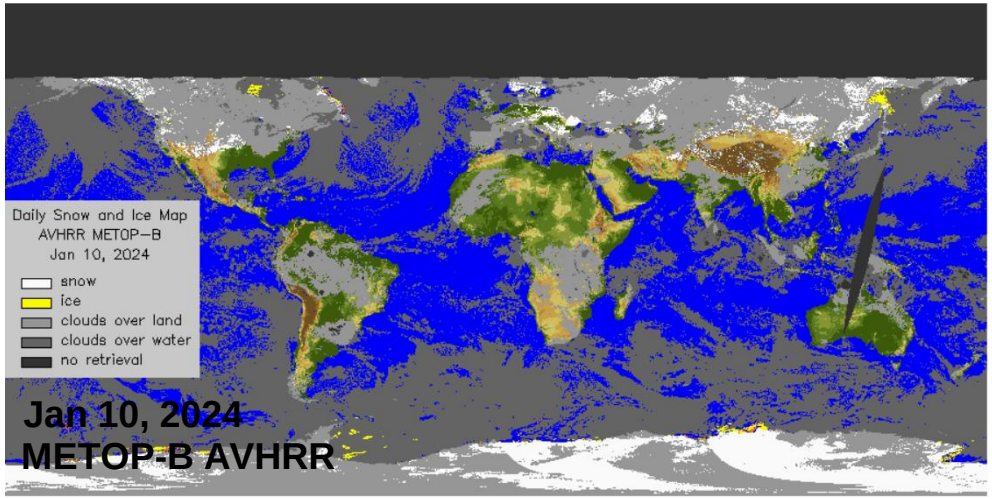
- Comparison with other remotely-sensed snow products
- Comparison with true color imagery (qualitative)
- Validation against NOAA Interactive Snow Maps (IMS)
- Validation against in situ snow depth reports

NOAA-21 Binary Snow vs Other Satellites, Jan 10, 2024





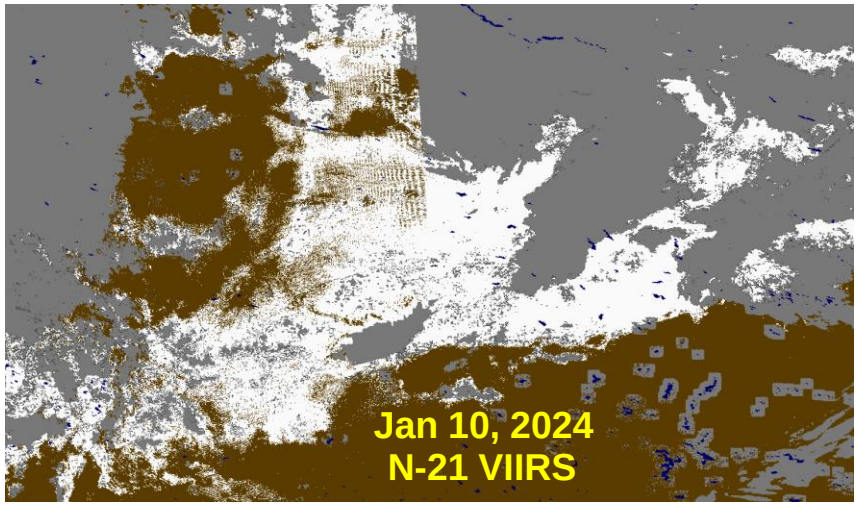


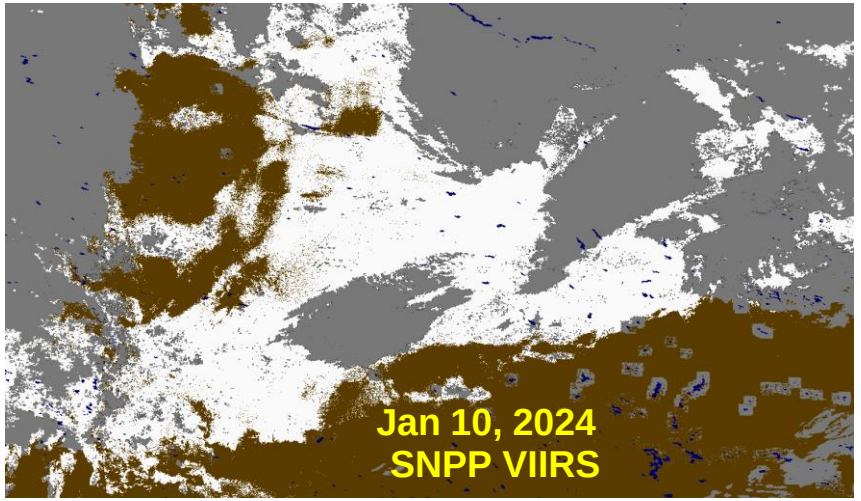


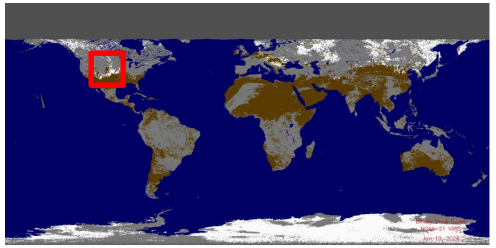
Snow
Cloud
No data

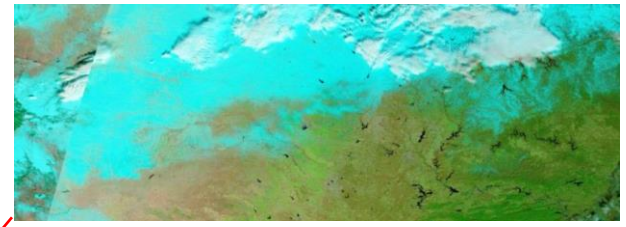
NOAA-21 VIIRS Binary Snow agrees well to similar products from VIIRS and AVHRR
Comparison is possible only in the clear-sky portion of the VIIRS product

NOAA-21 Binary Snow vs Other Satellites, Jan 10, 2024









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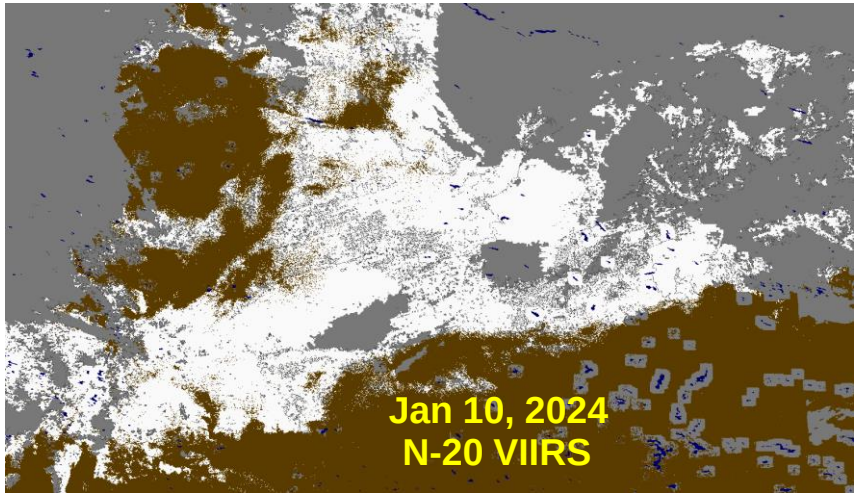
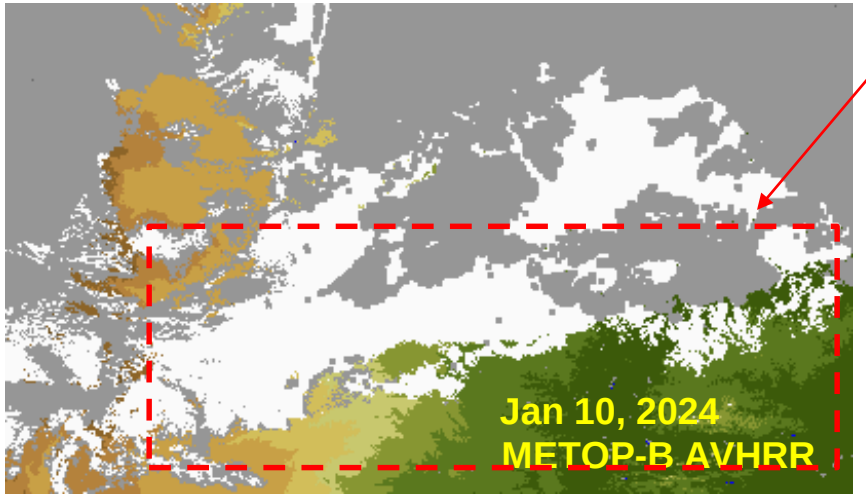
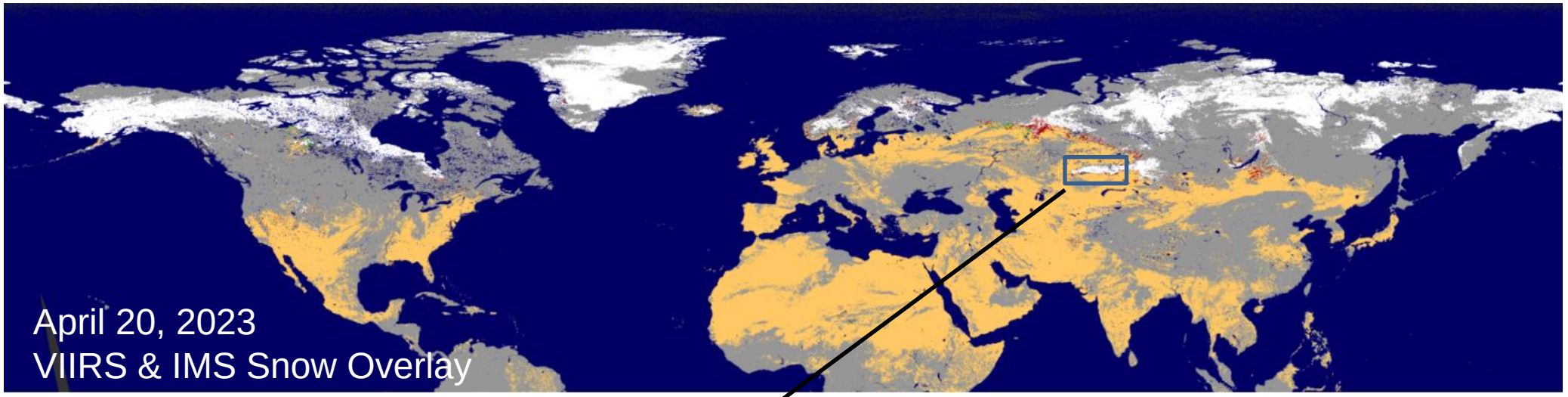


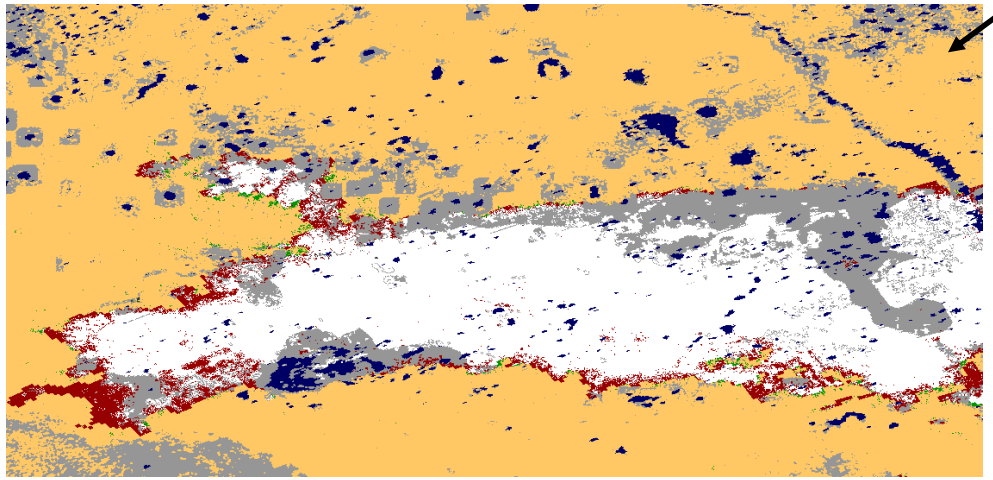


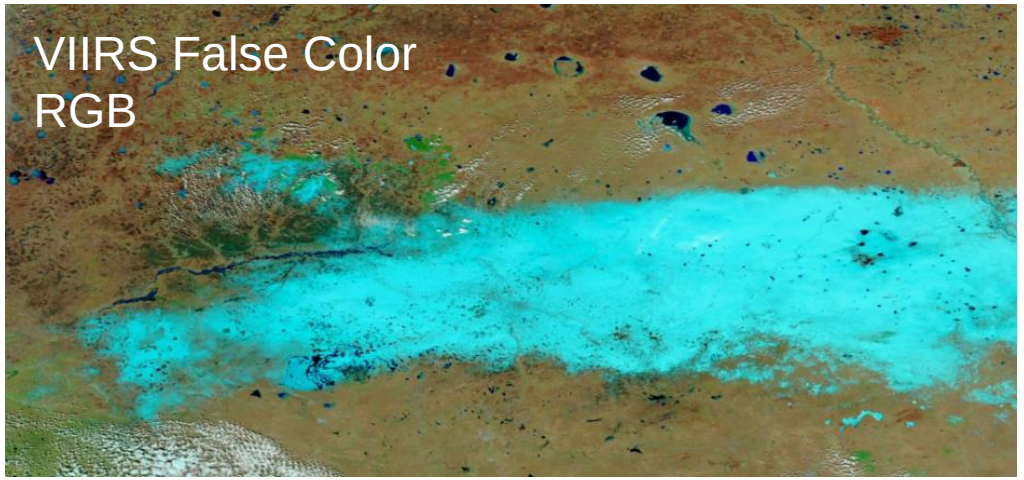
Snow
Cloud
No data

NOAA-21 VIIRS Binary Snow agrees well to similar products from VIIRS and AVHRR
Differences are mostly due to different observation geometry and time of observation

NOAA-21 Binary Snow vs IMS, Qualitative







Both: snow

IMS: snow, VIIRS: no-snow

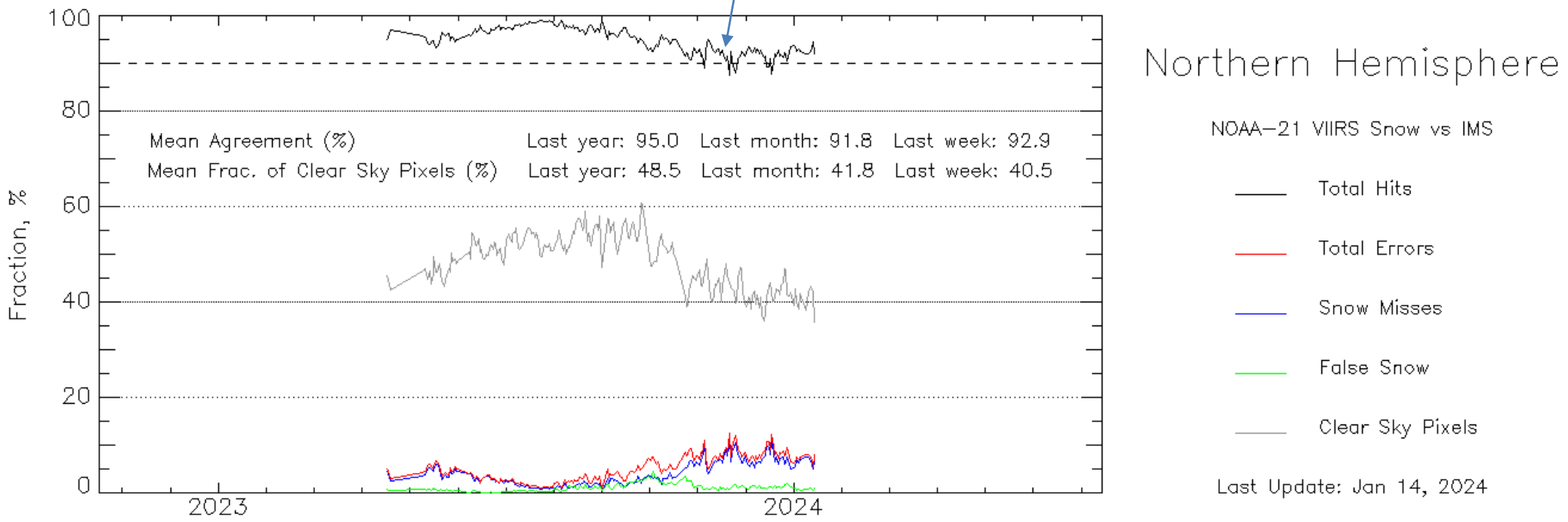
IMS: no-snow, VIIRS: snow

Both: no-snow

Clouds

NOAA-21 Binary Snow vs IMS, Quantitative Comparison

Daily rate of agreement between N21 VIIRS Binary Snow and IMS

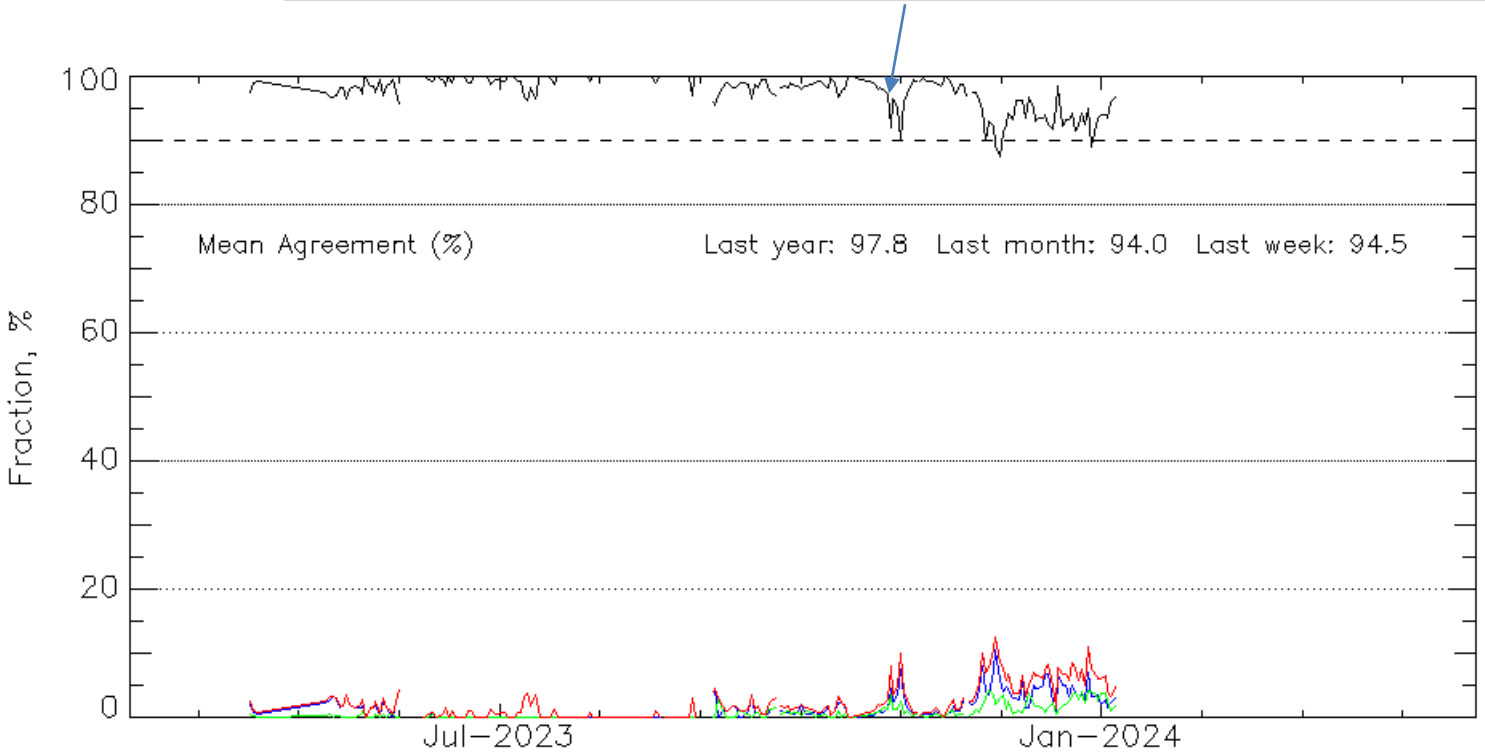


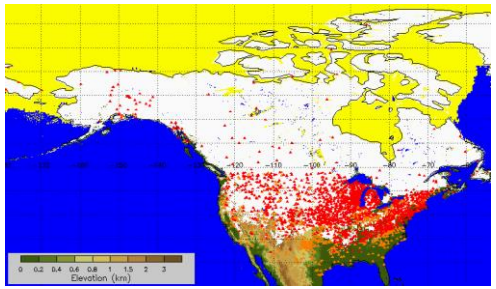
Mean daily agreement of VIIRS NOAA-21 Binary Snow Product to IMS is over 95% for the April 2023-January 2024 time period. **This satisfies the requirement of 90% correct typing.**

Disagreement is mostly due to less snow mapped by VIIRS (or overestimated snow by IMS analysts ?)

NOAA-21 Binary Snow vs Station data, Quantitative Comparison

Daily rate of agreement of VIIRS to In Situ observations of snow





Daily snow depth reports

VIIRS Snow vs In Situ

Accuracy

Error Rate

Snow Misses

False Snow

Last Update: Jan 5, 2024

NOAA-21 VIIRS validation: May 2023 to January 2024 over North America
Around 1000 reports are used daily for VIIRS snow map validation
Daily rate of agreement VIIRS snow to in situ data in the middle of winter season: 89-99%
Mean daily rate of agreement: 94%. **This satisfies the accuracy requirements of 90%**

Assessment of Fractional Snow Cover

NOAA-21 Snow Fraction Evaluation Approach

"Viewable" Snow Fraction is a remotely sensed parameter, it is not observed in situ and therefore its accuracy can not be directly evaluated. Theoretical estimates of the snow fraction accuracy have been performed.

Precision of the product was estimated by comparing N21 VIIRS snow fraction estimates to the snow fraction derived from different satellite platforms and sensors (e.g., N20 &NPP VIIRS, AVHRR)

Validity of VIIRS Snow Fraction Product may also be assessed using various consistency tests (i.e. consistency with the forest cover fraction, with snow depth, temporal stability, etc.).

Snow Fraction: Theoretical Accuracy Estimate

$$SnowFraction=(R-R_{land})/(R_{snow}-R_{land})$$

Error propagation ($F = SnowFraction$)

$$\delta F=\sqrt{\left(\frac{\partial F}{\partial R_{land}}\delta R_{land}\right)^2+\left(\frac{\partial F}{\partial R_{snow}}\delta R_{snow}\right)^2}$$

Where

R_{land}: Visible reflectance of snow-free land surface

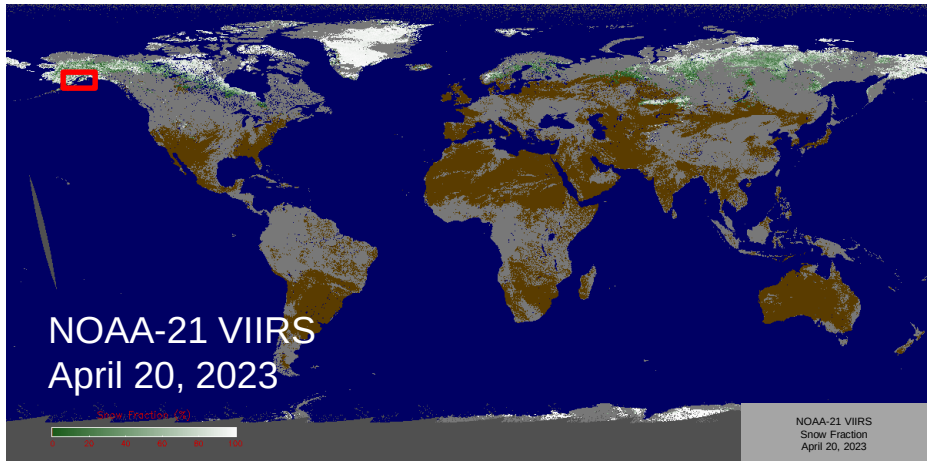
R_{snow} : Visible reflectance of snow

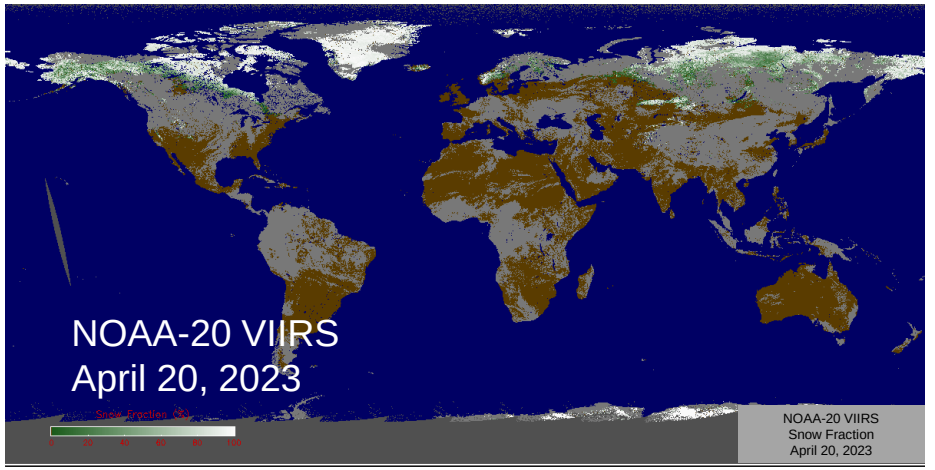
Factors contributing to the uncertainty in the estimated snow fraction

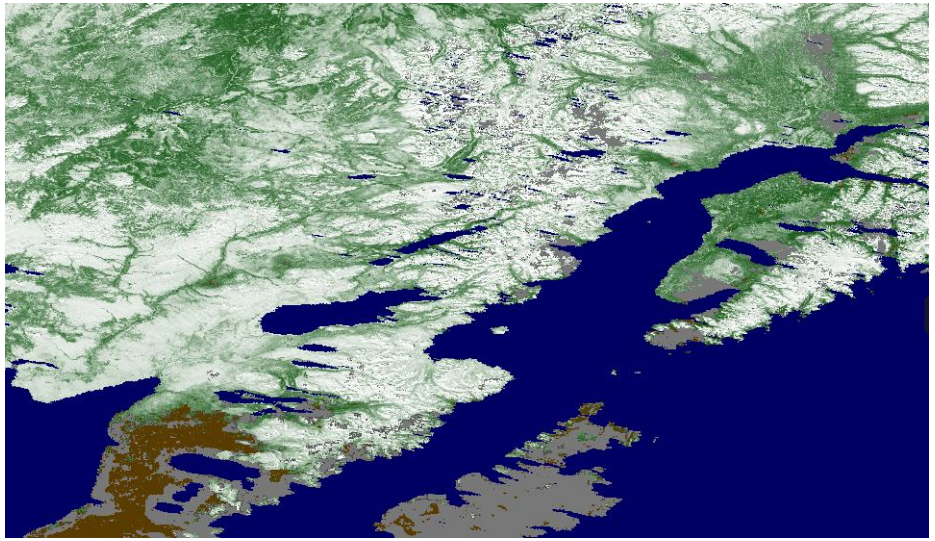
Factor	Affected Reflectance	Assumed uncertainty	Estimated uncertainty in the derived snow fraction
Visible reflectance measurement noise and calibration error	Observed Band I1 reflectance	0.005	0.006
Variable atmospheric composition	Observed Band I1 reflectance	0.1	0.11
Variable reflective properties of the snow-free land surface in band I1	Snow-free land visible reflectance (R_{land})	0.1	0 to 0.11
Variable reflective properties of snow	Snow visible reflectance (R_{snow})	0.1	0 to 0.06
Residual uncertainty of snow reflectance due to angular anisotropy	Snow visible reflectance (R_{snow})	0.03	0 to 0.04
Residual uncertainty of snow-free land reflectance due to angular anisotropy	Snow-free land visible reflectance (R_{land})	0.03	0 to 0.04
All factors combined			0.14 to 0.23

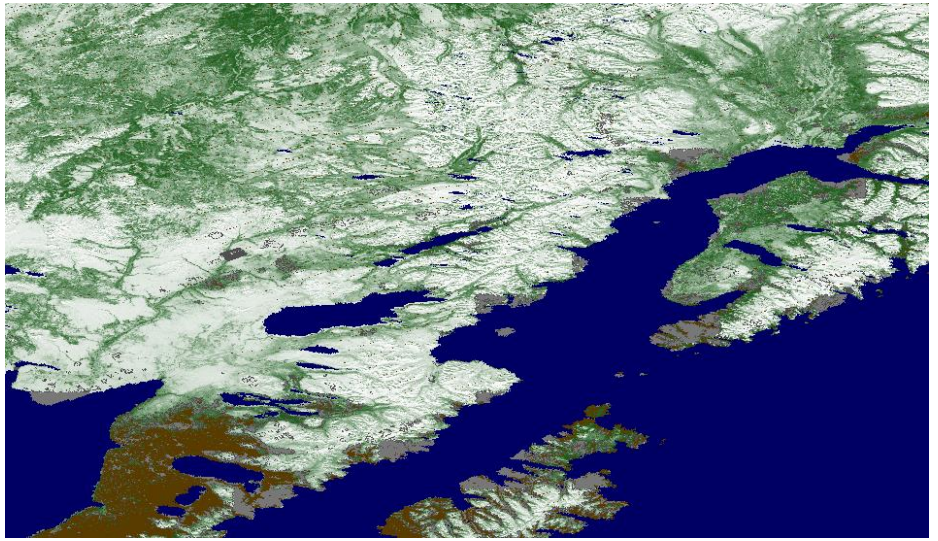
Theoretical accuracy estimate of snow fraction retrieval for realistic snow and snow-free land visible reflectance values: ~0.14-0.23.

NOAA-21 Snow Fraction: Qualitative Comparison



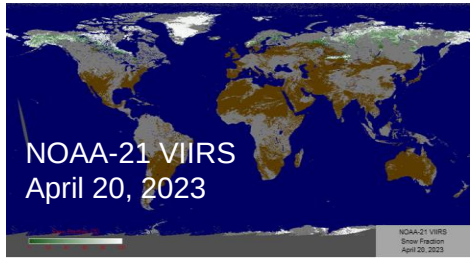






NOAA-21 vs NOAA-20 VIIRS Snow Fraction: Close values of the snow fraction but some differences in the cloud mask.

Snow Fraction RMSD: N21 vs N20 and NPP

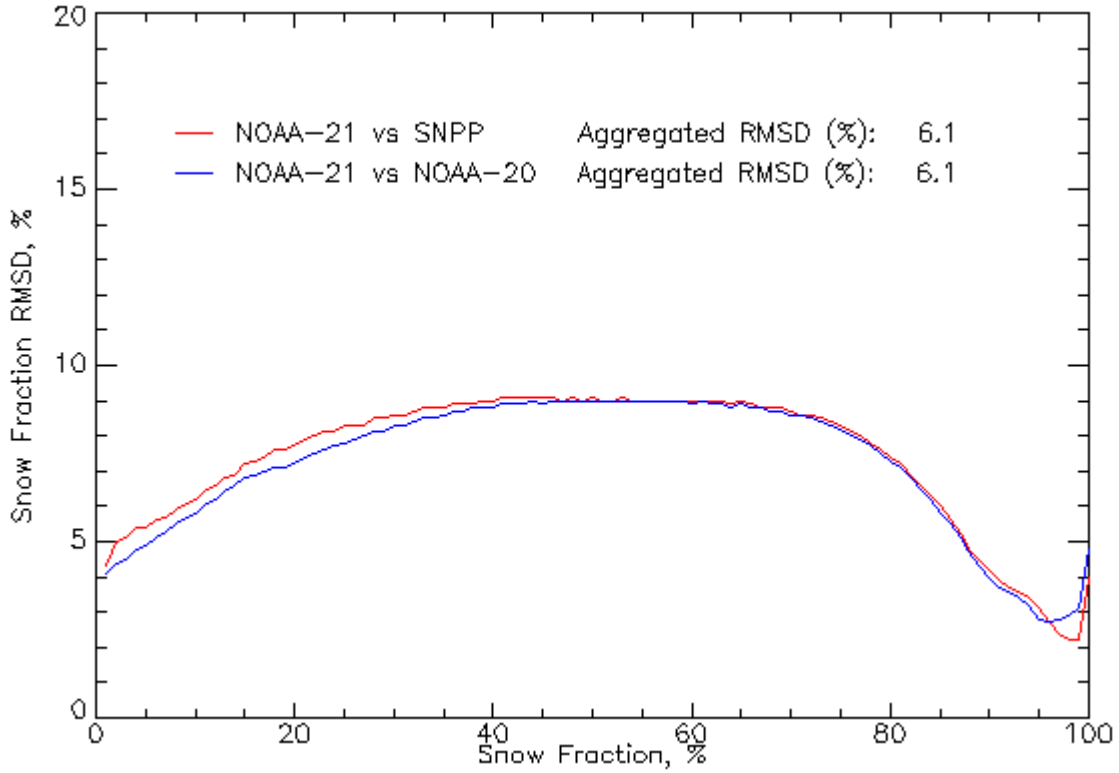


Snow fraction from three sensors (N21, N20 and NPP) was compared by directly matching the retrievals over the Northern Hemisphere.

Snow Fraction RMSD of N21 vs N20 and SNPP
- Aggregated (across all Snow Fractions): 6.1%
- Maximum (at medium Snow Fractions): 9.0%
- Range: 3-9%

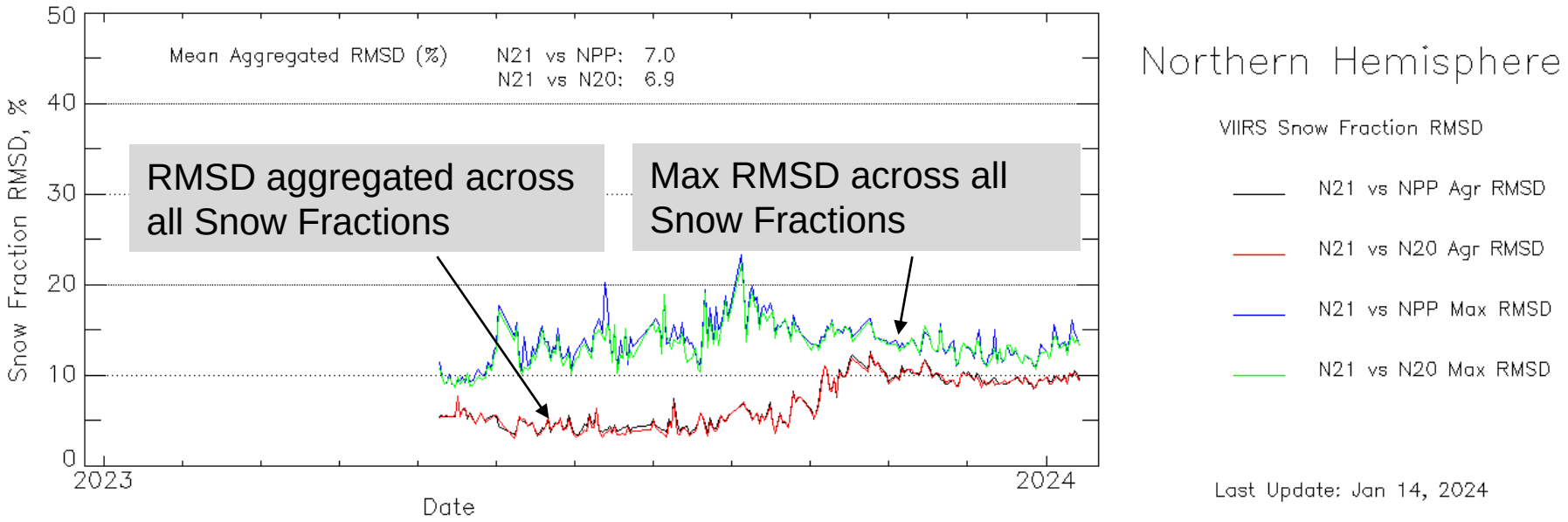
This satisfies the product uncertainty requirement of 20%.

Snow Fraction RMSD
VIIRS N21 vs SNPP and N20
Northern Hemisphere, April 20, 2023



Snow Fraction RMSD: N21 vs N20 and NPP, Time Series

Snow Fraction RMSD, N21 vs N20 and NPP

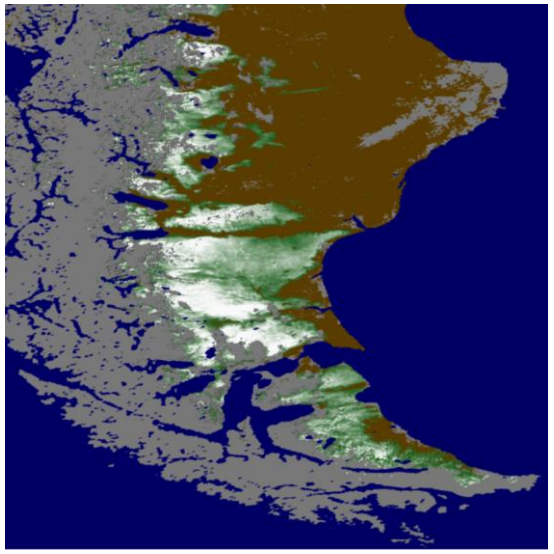


Snow Fraction RMSD of N21 vs N20 and NPP, from May 2023 to Jan 2024

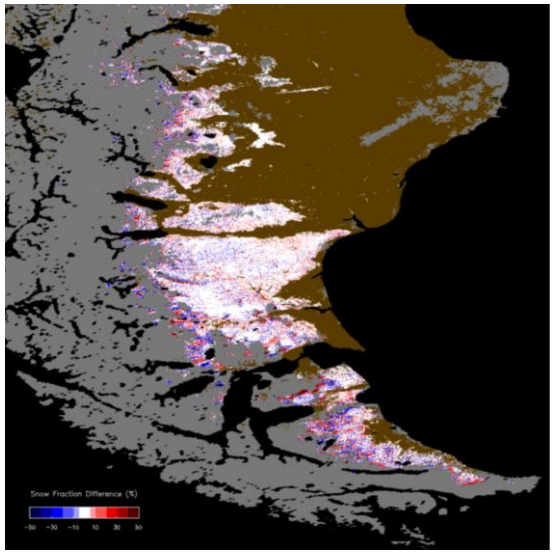
- Aggregated (across all Snow Fractions): 3-12%
- Maximum (at medium Snow Fractions): 9-23%

This generally satisfies the product uncertainty requirement of 20%.

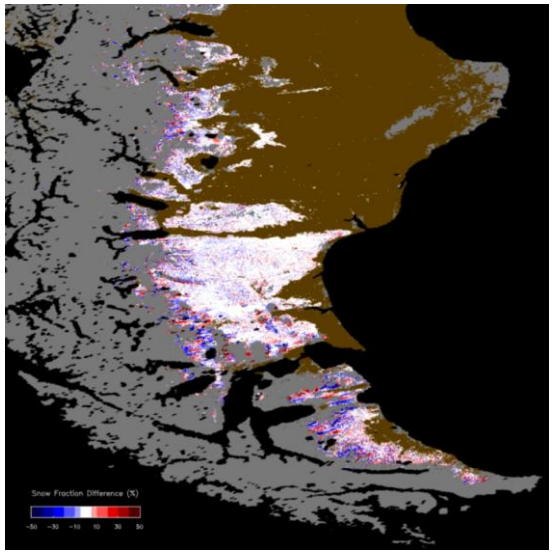
NOAA-21 Snow Fraction vs N20 and NPP: South America



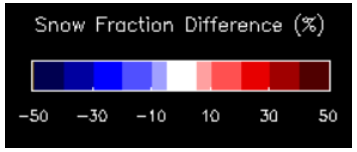
NOAA-21 VIIRS Snow fraction



Snow Fraction Difference: N21-N20

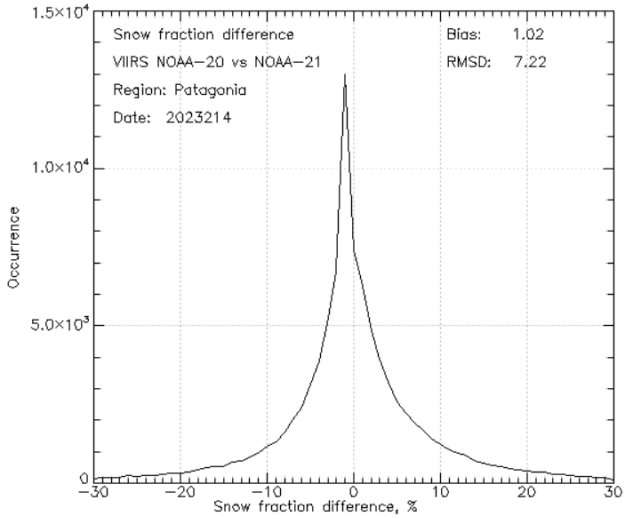


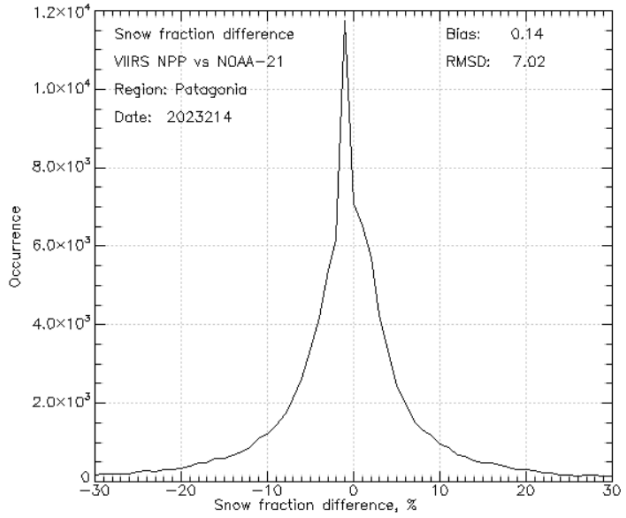
Snow Fraction Difference: N21-NPP



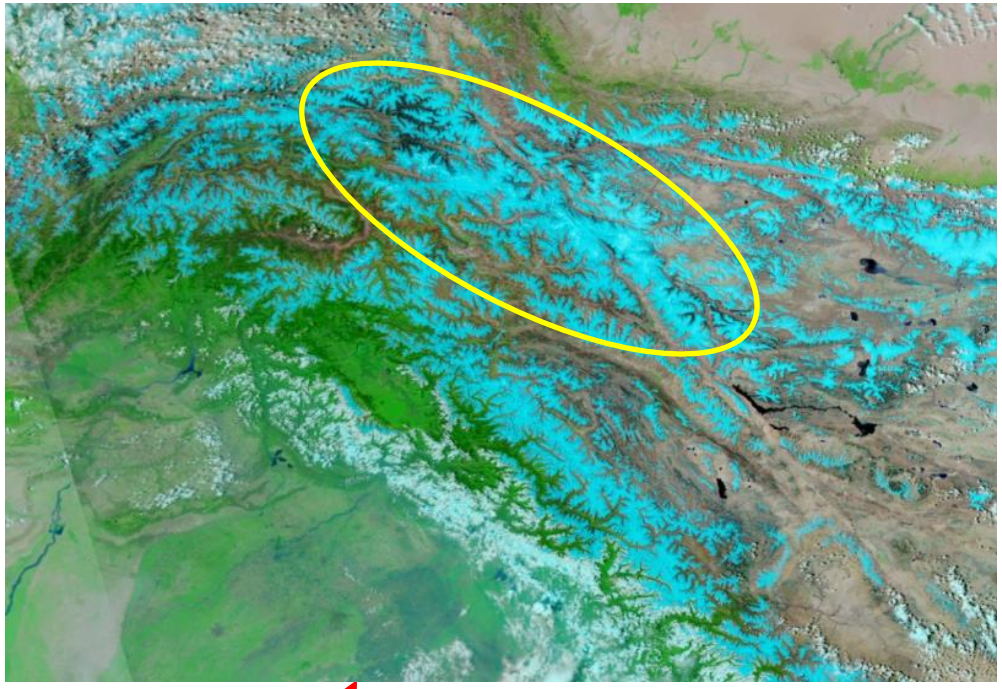
N21 vs N20 & SNPP Snow Fraction: Estimates of the snow fraction from three sensors are very close with
Bias: < 1%
RMSD: < 8%

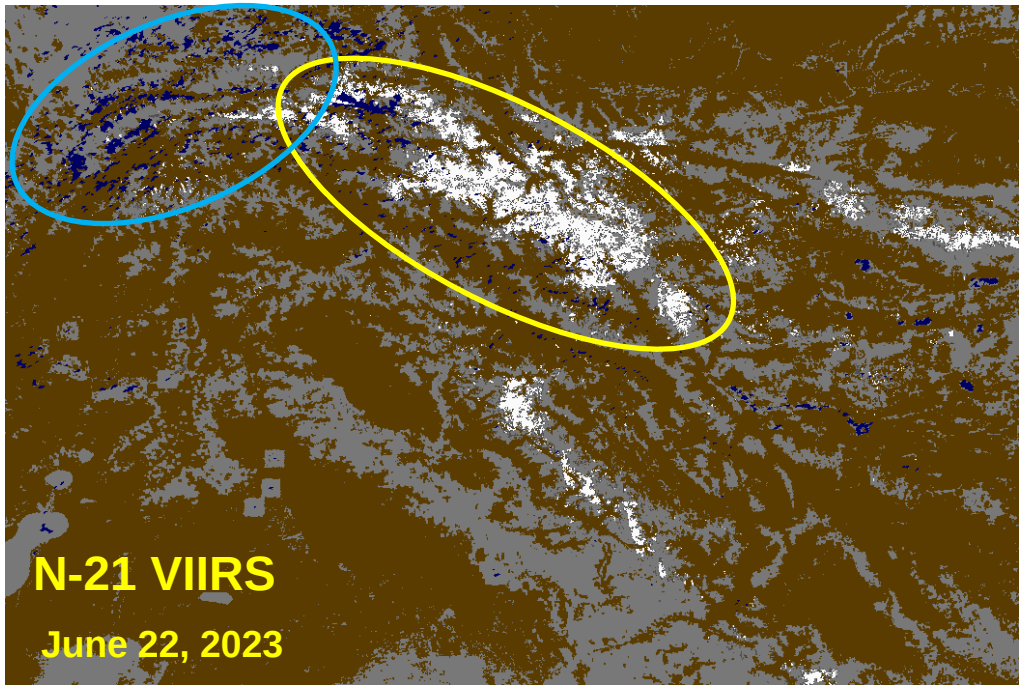
This satisfies the uncertainty requirement of 20%

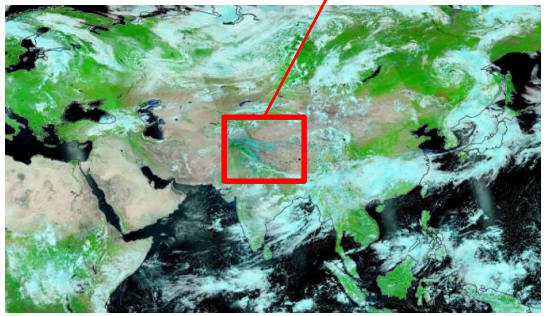




Noteworthy Issues: Alpine Areas







In Alpine areas

- Overestimated clouds (confused with snow)
- Spurious water bodies:
  - Incorrect land/water mask ?
  - Misinterpreted topographic shadows ?

This reduces the quality of both VIIRS snow products

Noteworthy Issues: Persistent Clouds in Coastal Areas

VIIRS Cloud Mask persistently reports (spurious) clouds in coastal areas

Information on the snow cover properties in these areas is rarely available

Long Term Monitoring Readiness

Collection of NOAA-21 VIIRS snow product granules and generation of global gridded snow maps is performed daily. Gridded Binary Snow and Snow Fraction maps are archived locally.

Accuracy assessment of the snow product are performed on a daily basis. Software to compare gridded VIIRS products with IMS and station data is available, it has been tested with NPP and NOAA-20 data, and is ready for operational implementation.

Retrieval accuracy statistics is provided as the percent of correct snow/no snow identifications. Snow fraction retrievals from N21,N20 and NPP are being compared on a daily basis

Quantitative accuracy estimates are most reliable over the Northern Hemisphere.

Required algorithm inputs and their effect

- VIIRS SDR (I1,I2,I3,I5)
- Cloud Mask
- Algorithm parameters
  - Threshold values for the image classification algorithm (Binary Snow)
  - Kernel weights for BRDF models (Snow Fraction)
- Ancillary data
  - Snow cover climatology
  - Surface temperature climatology

All inputs are critical for proper performance of the algorithm

Except SDR and the Cloud Mask all other inputs are static

Lack of any of the required inputs results in the product generation failure

Quality flag analysis/validation

- The product has one quality 8-bit flag reporting a good quality retrieval (zero, “0” value) or the reason for the snow retrieval was not performed/failed

Pixel quality flags values:
0: good retrieval
105: water
110: cloud
111: rejected snow due to inconsistency with snow climatology
112: rejected snow, inconsistent with surface temperature climatology
113: rejected snow, failed spatial consistency test
114: rejected snow, failed temperature uniformity test
121: night, insufficient solar illumination
122: undetermined
124: bad pixel SDR
125: fill value

Quality flag performance has been checked, no inconsistencies have been found.

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	NPP		
Binary Snow Cover								
Accuracy	304	90% correct typing	> 90%	94-95%[2]	91-93%	91.-93%[1]	yes	
Snow Fraction								
Uncertainty	303	20%	14-23% (theoretical estimate)	3-12% RMSD[3]	3-12% RMSD[3]	12%[4]	yes	

[1] Yearly mean accuracy derived through comparison with IMS and station data over Northern Hemisphere

[2] Accuracy estimated from April 2023 to January 2024

[3] Compared to NPP, N20

[4] Compared to Landsat, based on earlier studies

User Feedback

- US National Ice Center (USNIC) analysts use VIIRS snow and ice products from all three satellites. Feedback is forthcoming.
- DoD (used VIIRS snow cover in the past; current use to be confirmed)
- NCEP/EMC: There have been discussions with EMC and other modeling centers on their needs for snow cover information. They are aware of the VIIRS snow cover products. We are in close contact with Michael Barlage (EMC).

Downstream Product Feedback

- None. No VIIRS products directly use snow cover products as input

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
Cloud Mask	Failure to identify low stratus over snow-covered land was noted earlier in the NOAA-20 snow product. The same deficiency is expected to affect NOAA-21 snow products.	Missed clouds are not identified as snow due to high shortwave infrared reflectance and hence attributed to snow-free land	Additional tests to identify and properly label this type of clouds may need to be introduced in the snow algorithm.
Cloud Mask	Spurious clouds frequently occur along land/water boundaries in middle and high latitudes.	Information on the snow cover in coastal areas may be unavailable for long periods of time	Corrections to the ECM algorithm are needed to eliminate these errors
Spurious water bodies	Spurious water bodies in alpine areas were noted in the VIIRS land/water mask.	Spurious water bodies result in errors in the VIIRS snow cover product	Spurious water bodies are apparently the result of misinterpretation of topographic shadows. A separate algorithm to predict topographic shadows in VIIRS observations is needed.

Documentations (Check List)

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

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 select locations, periods, and associated ground truth or field campaign efforts.	Yes
Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).	Yes
Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.	Yes
Product is ready for operational use and for use in comprehensive cal/val activities and product optimization.	Yes

Conclusion

- NOAA-21 VIIRS Binary Snow and Snow Fraction have been evaluated using a relatively large but still limited set of products.
- Both qualitative and quantitative assessment have been performed
- Both products adequately reproduce global snow cover properties, demonstrate robust performance and generally satisfy accuracy requirements
- Several weaknesses mostly associated with the cloud mask performance have been identified. The effect of these weaknesses on the snow product performance is noticeable but not critical.
- Required documentation exists
- Product is recommended for potential operational use after consulting product status documents
- **The Team recommends NOAA-21 Snow products Provisional Maturity.**
- **Results indicate that the products likely meet the Validated Maturity requirements.** Validation data cover late winter (mid-April) 2023 through early winter (mid-January) 2024. However, no validation data was available for mid-winter (mid-January through mid-April).

Path Forward

- Planned improvements
  - Develop additional cloud filters
  - Introduce physically-based BRDF models in the Snow Fraction algorithm similar to the one in GOES-R ABI algorithm.

- Future Cal/Val activities / milestones
  - Continue generating global gridded Binary Snow and Snow Fraction products with N21 VIIRS
  - Continue evaluation of the product during the 2023-2024 Northern Hemisphere winter season
  - Assess product performance over various surface cover types and topography.
  - Provide comprehensive comparison of NOAA-21 with surface snow observations
  - Get ready for Validated Maturity Review later this year