

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



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(Presented by Jeff Key)***

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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.

- 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 Checklist)
- Conclusion
- Path Forward

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	NOAA project lead. Overall snow and sea ice project management, assistance on analysis and validation
Jeff Key	NOAA/NESDIS	Overall snow and sea ice project management, assistance on analysis and validation

The VIIRS Snow Product Suite includes **Binary Snow Cover** and **Snow Fraction**:

- 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 (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%	

- Algorithms

 - Binary Snow Cover:

 - Threshold-based classification followed by consistency testing

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

 - Snow Fraction:

 - Single-band linear unmixture technique (2 endmembers)

 - 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

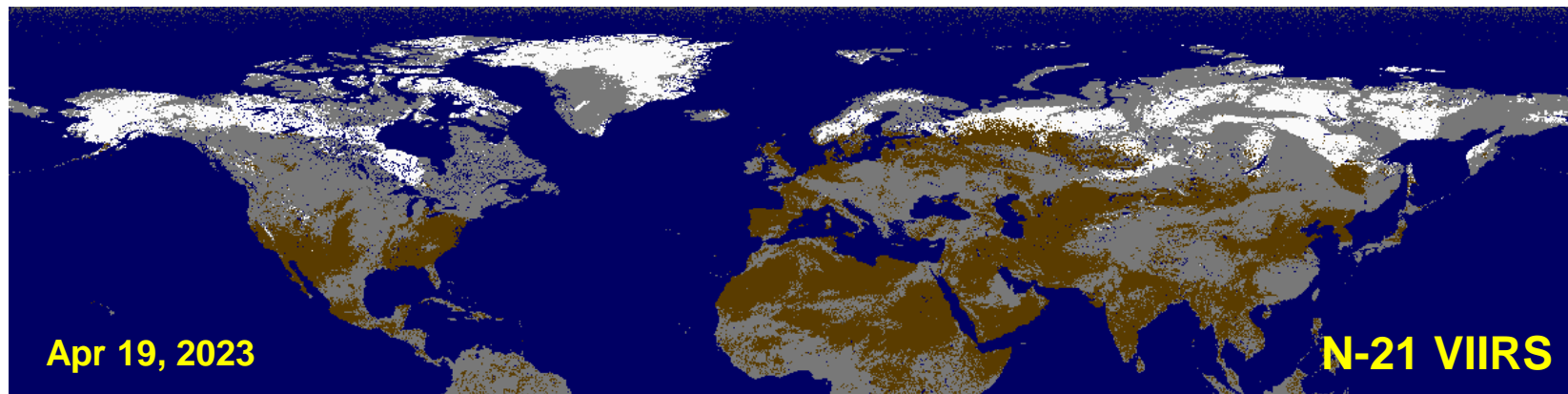
- Effective Dates

 - April 15 (00 UTC, orbit 2209) through July 2023

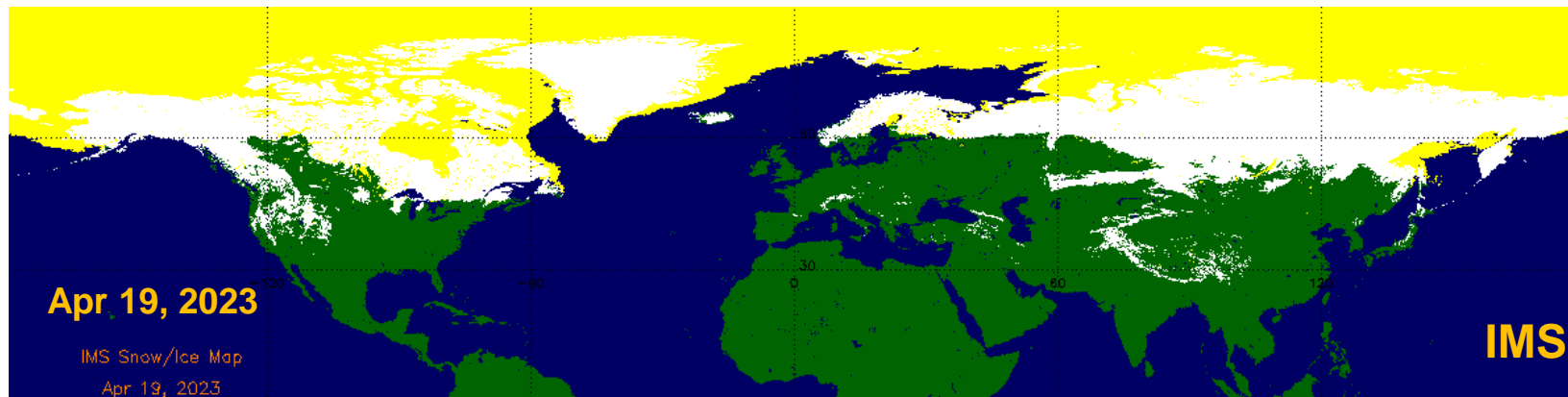
Assessment of Binary Snow Cover

- 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 IMS, Qualitative

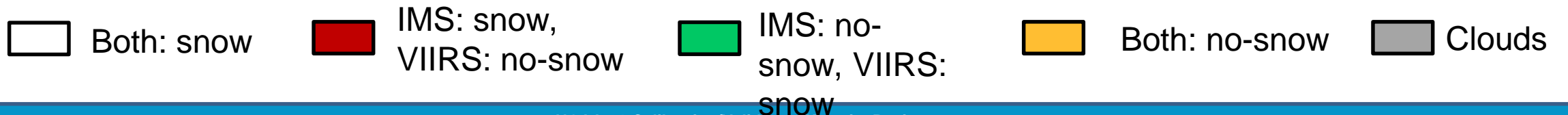
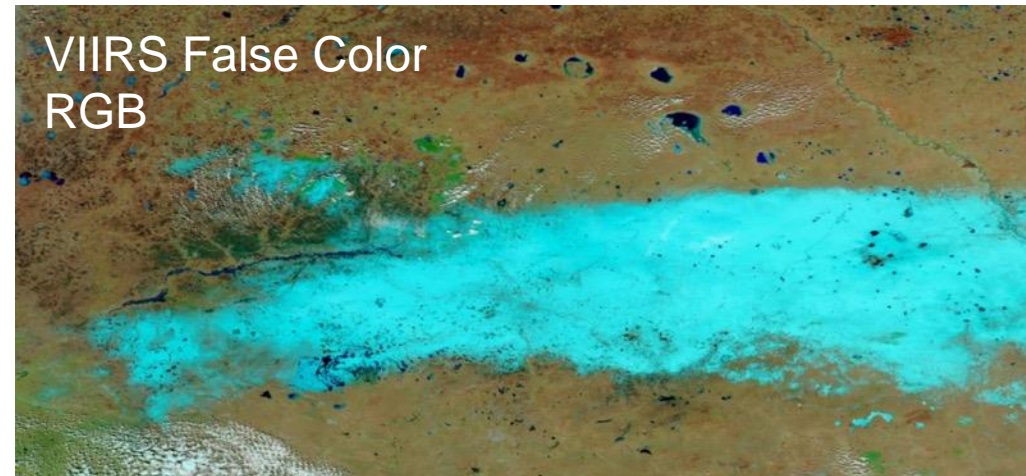
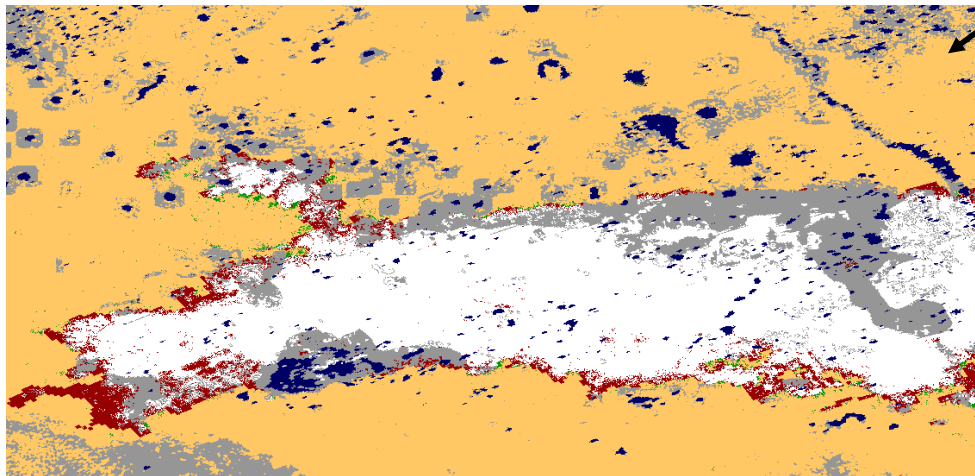
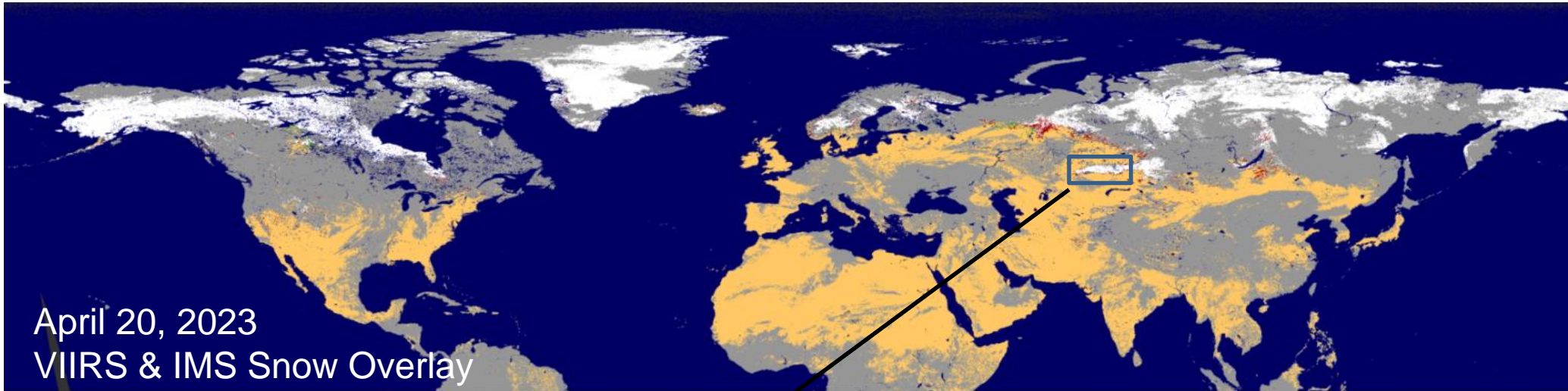


- Snow
- Cloud
- No data

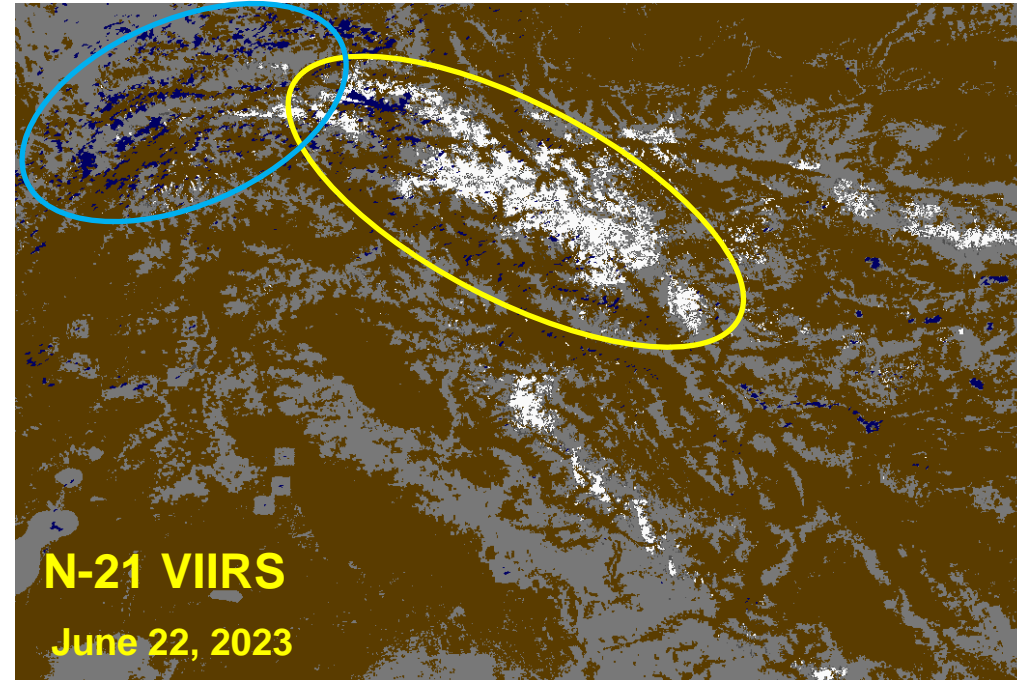
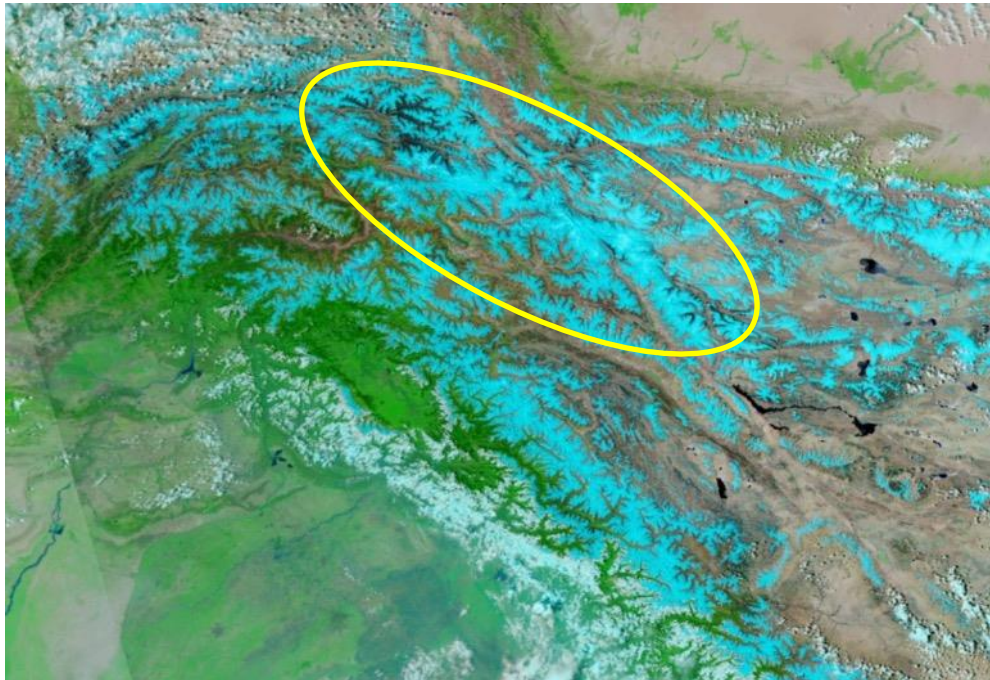





Good qualitative agreement of snow mapped in the NOAA-21 VIIRS product to IMS. Comparison is possible only in the clear-sky portion of the VIIRS product.

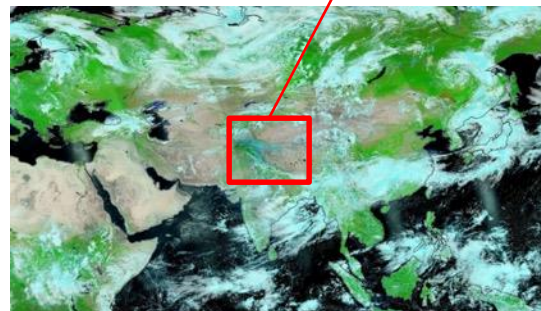
NOAA-21 Binary Snow vs IMS, Qualitative



NOAA-21 Binary Snow vs False Color RGB

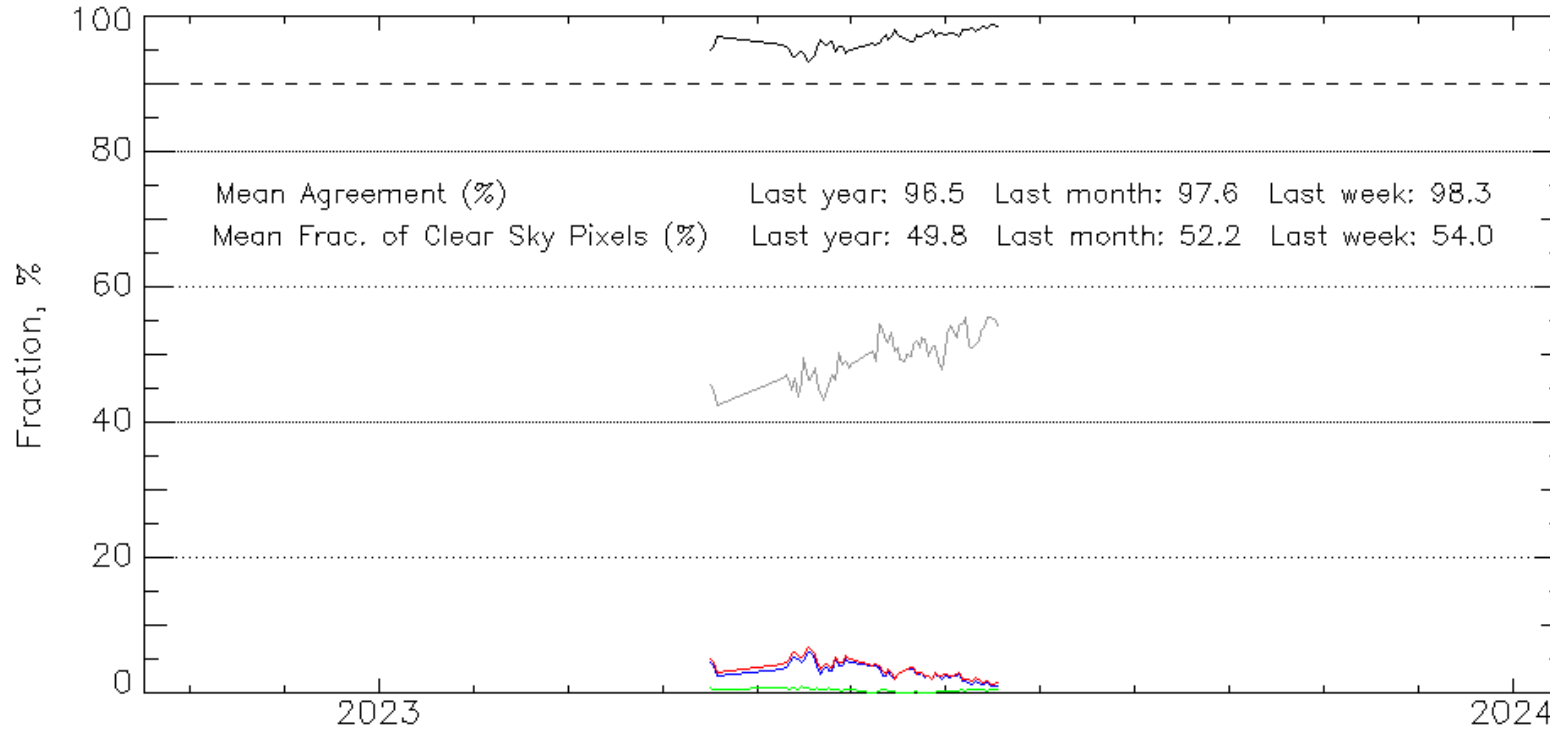


-  Snow
-  Cloud
-  No data
-  Water



- Tibet Region: In the false color image snow is light blue
- Correctly identified snow cover (yellow oval) if clear sky
 - Overestimated cloud cover, clouds frequently confused with snow in alpine areas
 - Spurious water bodies in the alpine area (light blue oval):
Incorrect land/water mask or misinterpretation of topographical shadows?

NOAA-21 Binary Snow vs IMS, Quantitative Comparison



Northern Hemisphere

NOAA-21 VIIRS Snow vs IMS

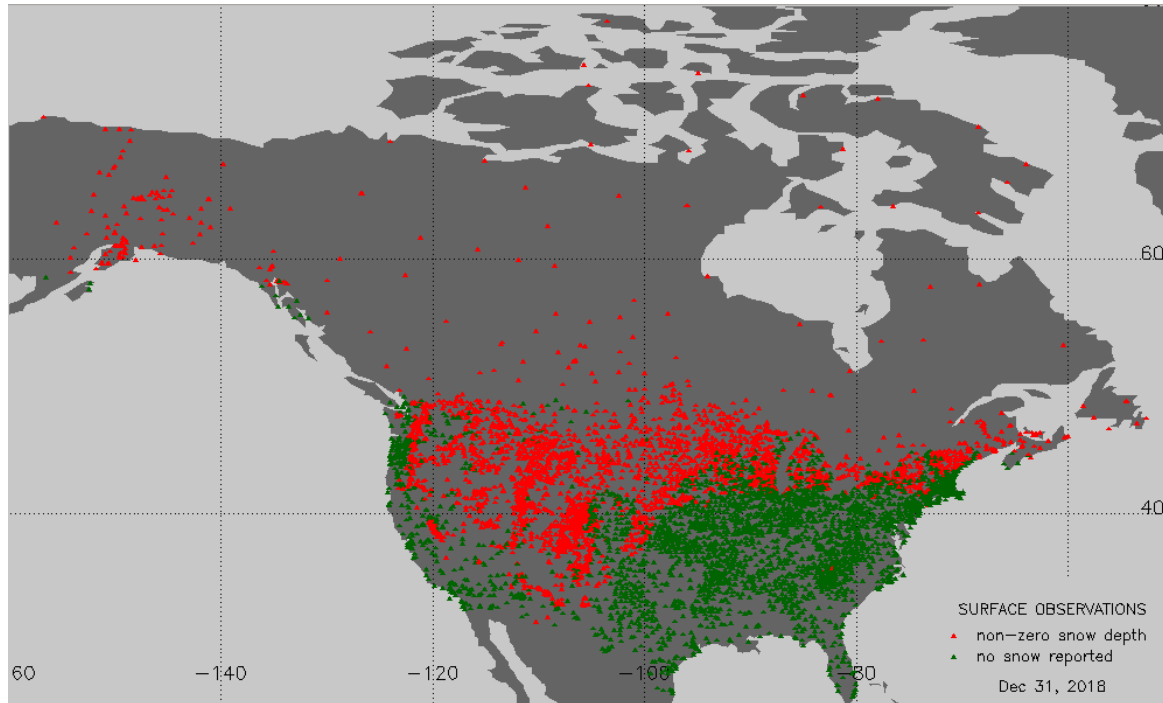
- Total Hits
- Total Errors
- Snow Misses
- False Snow
- Clear Sky Pixels

Last Update: Jul 19, 2023

Mean daily agreement to IMS is over 96% for the April-July 2003 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



In situ observations of the snow depth are acquired from GHCN-D dataset maintained by NCEI

In the peak of winter season snow depth reports are available from over 8,000 stations globally.

Most stations are located in midlatitudes. In summer months the number of in situ snow depth reports substantially decreases.

NOAA-21 VIIRS validation: May 2023 over North America
 300-400 daily reports available, but only 20-30 stations reported snow on the ground
 Rate of agreement: 97-99%.
This satisfies the accuracy requirement.

Assessment of Fractional Snow Cover

NOAA-21 Snow Fraction Evaluation Approach

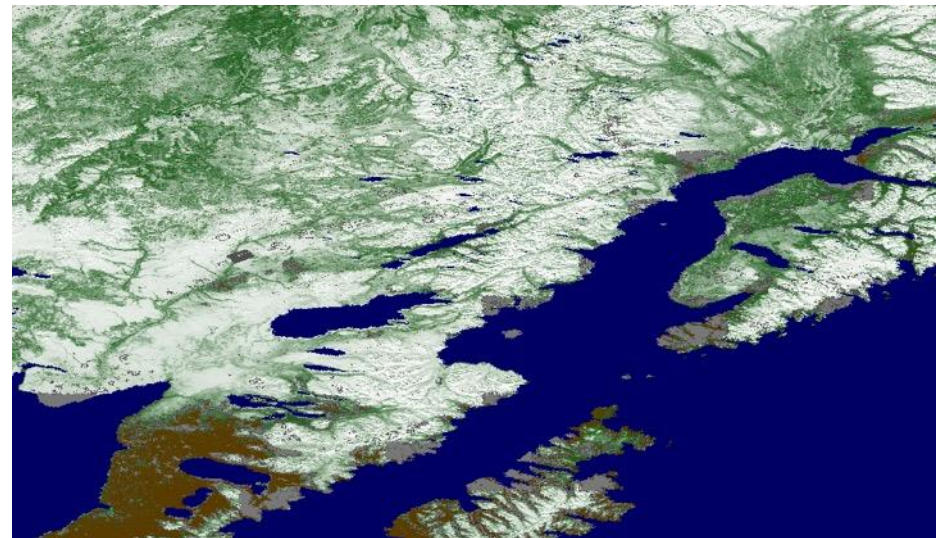
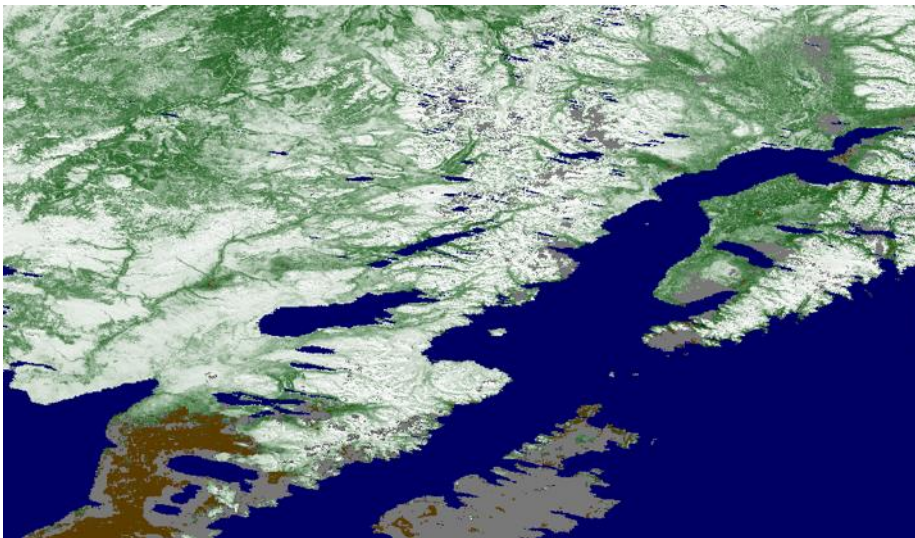
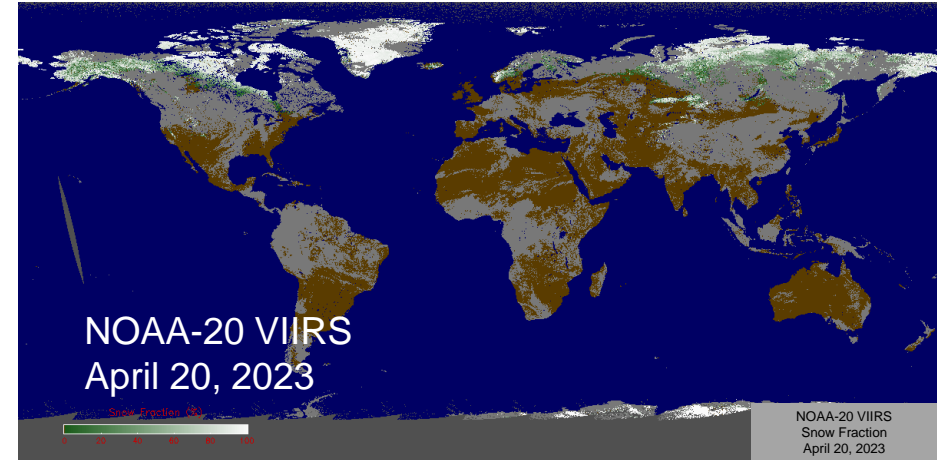
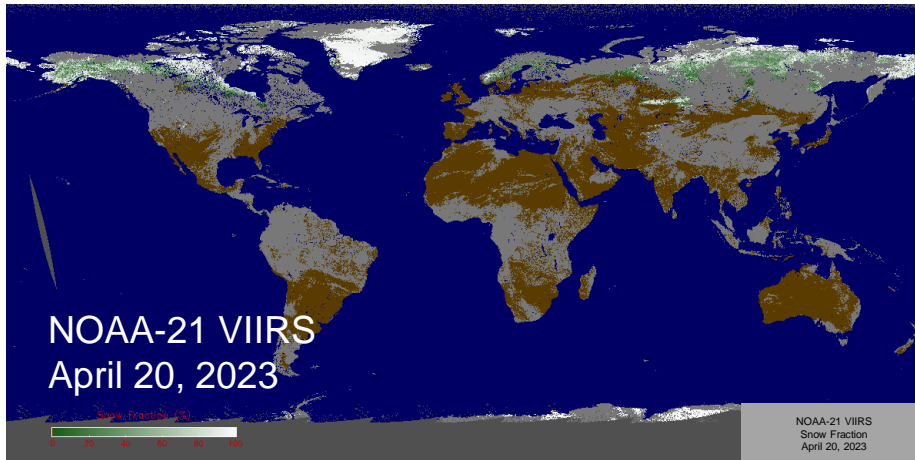
“Viewable” Snow Fraction is a remotely sensed parameter, it is not observed in situ and therefore its accuracy can not be directly evaluated.

The validity of the VIIRS Snow Fraction Product is generally assessed through various consistency tests (i.e. consistency with the forest cover fraction, with snow depth, temporal stability, etc.) and by directly comparing snow fraction estimated from other satellite platforms and sensors.

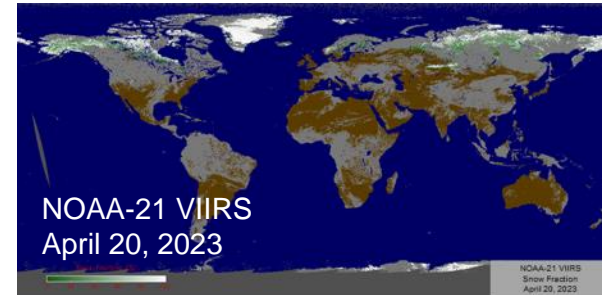
Theoretical accuracy estimate of snow fraction with the existing algorithm ranges from 15-20%.

So far the validity of NOAA-21 VIIRS Snow Fraction product was assessed by its comparison with snow fraction retrievals from the two other operational VIIRS sensors: NOAA-20 and S-NPP.

NOAA-21 Snow Fraction: Qualitative Comparison

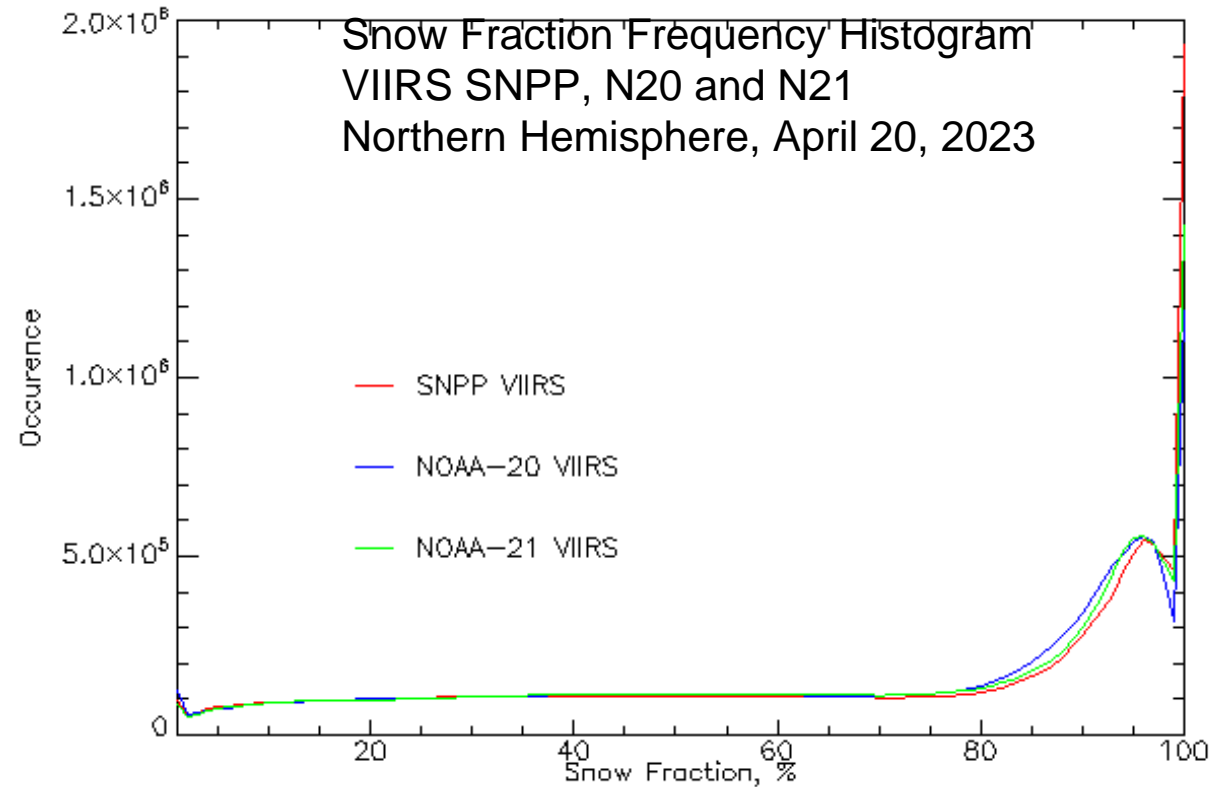


NOAA-21 vs NOAA-20 VIIRS Snow Fraction: Close values of the snow fraction but some differences in the cloud mask.

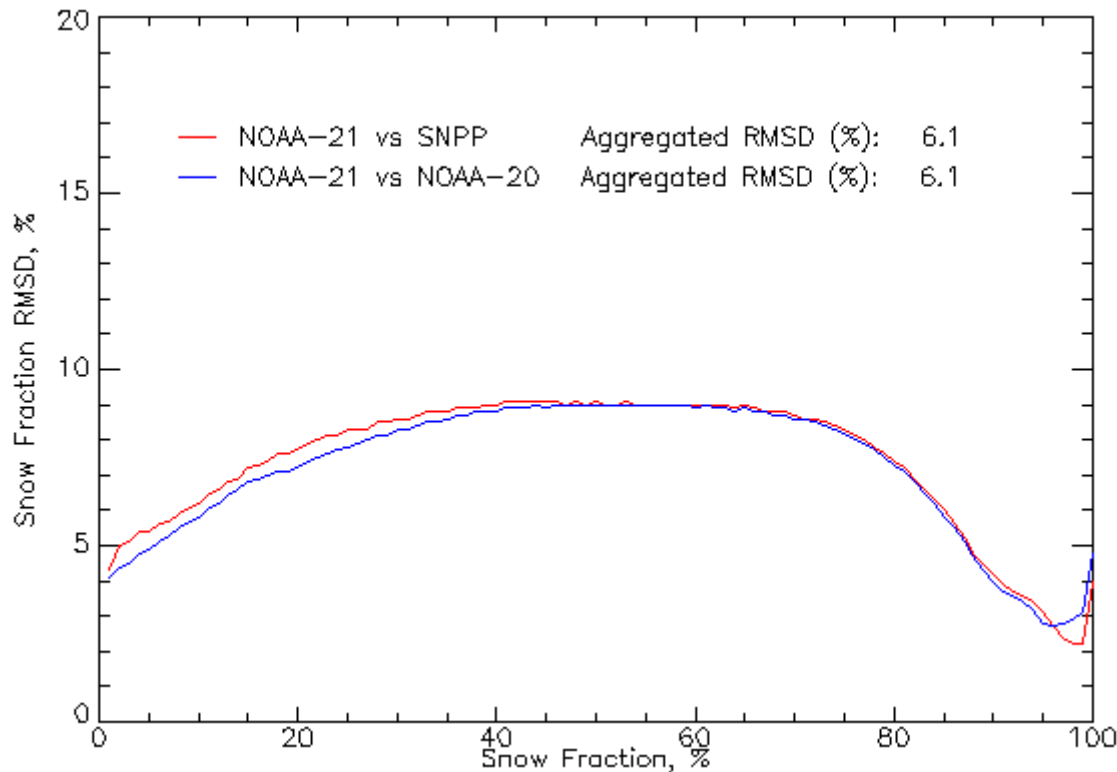
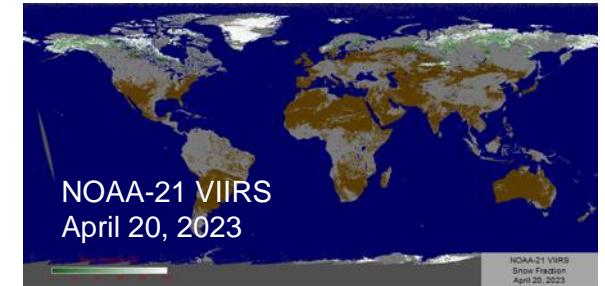


Results demonstrate a good agreement on the statistics of the derived snow fraction between all three VIIRS products.

Peak at 100% snow fraction is primarily due to the Greenland Ice Sheet. Peak at 90-95% is apparently caused by high snow fraction in the tundra area.



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



The mean difference in the estimated snow fraction between the N21 snow product and snow products from two other JPSS satellites is within 5-7%. In this particular case it is 6.1%.

Disagreement between the products increases to 9-10% at medium snow fraction values of 40-60% and decrease to 4-5% at small and large snow fractions.

With uncertainties in the NOAA-21 Snow Fraction estimates within 4 to 10%, **the snow fraction product satisfies the uncertainty requirement of less than 20%.**

Long Term Monitoring Readiness

The collection of NOAA-21 VIIRS snow product granules and the generation of **global gridded snow maps are 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 SNPP and NOAA-20 data, and is ready for operational implementation.

Retrieval accuracy statistics are provided as the percent of correct snow/no snow identifications.

Quantitative accuracy estimates are most reliable over the Northern Hemisphere.

- 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. Apart from the SDRs and the Cloud Mask, all other inputs are static. If any of the required inputs is absent, product generation fails.

Quality flag analysis/validation

The product has one 8-bit quality flag that indicates 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

The quality flag performance has been checked; no inconsistencies have been found.

Error Budget

Attribute Analyzed	DPS	Requirement / Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Binary Snow Cover								
Accuracy	304	90% correct typing	> 90%	96.5% ²	91-93%	91-93% ¹	yes	
Snow Fraction								
Uncertainty	303	20%	Within 20%	4-10% RMSD ³	4-10% RMSD ³	12% ⁴	Yes	

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

² Accuracy estimated in late spring- early summer 2023. Due to the limited analysis period this assessment may not adequately characterize the product accuracy throughout the year.

³ Compared to S-NPP

⁴ Compared to Landsat

- Actual users include:
 - Department of Defense
- Potential users include
 - IMS at National Ice Center
 - NCEP/EMC
- At this time NOAA-21 snow product is not provided to the users, therefore no user feedback is available.

Downstream Product Feedback

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

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Cloud Mask	Frequent failures to identify clouds (low stratus) over snow-covered land were identified earlier in the NOAA-20 snow product.	Missed clouds are not identified as snow and hence attributed to snow-free land	It is not clear whether this issue has been addressed in the NOAA-21 Cloud Mask. If not, additional tests in the snow algorithm to filter out this type of clouds has to be introduced in the snow algorithm

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 - Beta Maturity

Beta Maturity End State	Assessment
<p>Product is minimally validated, and may still contain significant identified and unidentified errors</p>	<p>Yes</p>
<p>Information/data from validation efforts can only be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose</p>	<p>Yes</p>
<p>Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists</p>	<p>Yes</p>

Check List - Provisional Maturity

Provisional Maturity End State	Assessment
<p>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.</p>	<p>Yes</p>
<p>Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.</p>	<p>Yes</p>
<p>Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.</p>	<p>Yes</p>
<p>Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.</p>	<p>Yes</p>

- NOAA-21 VIIRS Snow Products have been evaluated using a limited set of products generated in late spring-early summer of 2023.
- Both products (Binary Snow Cover and Snow Fraction) adequately reproduce snow cover properties, demonstrate robust performance and generally satisfy accuracy requirements.
- Required documentation exists.
- **The analyses presented here clearly demonstrate that the NOAA-21 Snow products meet the criteria for Beta Maturity. Furthermore, the Team feels that the snow products also meet the criteria for Provisional Maturity.**

- Planned improvements
 - Develop additional cloud filters to compensate for VCM weakness over snow-covered land
 - Introduce physically-based BRDF models in the Snow Fraction algorithm
- Future Cal/Val activities / milestones
 - 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
 - Prepare for Provisional Maturity Review later this year, if necessary. (The Team recommended Provisional Maturity here.) For the next review, more data will be processed, with days selected from Autumn and Winter in addition to Spring.