Validated Maturity Science Review For NOAA-20 VIIRS Cryosphere Products – Snow Cover

Presented by Peter Romanov

Date: 2020/06/18

JPSS Data Products 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.

Validated Maturity Review - Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Validated Maturity Performance Validation
  - On-orbit instrument performance assessment
    - Identify all of the instrument and product characteristics you have verified/validated as individual bullets
    - Identify pre-launch concerns/waivers, mitigation and evaluation attempts with on-orbit data
- Users/EDRs feedback
- Risks, Actions, Mitigations
  - Potential issues, concerns
- Path forward
- Summary

Validated Maturity Review - Exit Criteria

- Validated 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 Validated Maturity Slide Package addressing review committee's comments for:
  - Cal/Val Plan and Schedules
  - Product Requirements
  - Validated Maturity Performance
  - Risks, Actions, Mitigations
  - Path forward

VALIDATED 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-20 Snow Products 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
Jeff Key	NOAA/NESDIS	Overall snow and sea ice project management, assistance on analysis and validation

Snow Product Overview

- Binary Snow Cover
  - Presence or absence of snow within FOV

- Fractional Snow Cover
  - Area fraction of snow within FOV as seen from the above, excludes snow masked by tree canopy (viewable snow fraction)

Retrievals require daylight and clear sky conditions

Snow Product Requirements

From Joint Polar Satellite System (JPSS) Ground Segment Data Product Specification (GSegDPS), Dec 30, 2019:

- Binary Snow Cover

Attribute	Threshold	Observed/validated
Geographic coverage	Global	Global
Horizontal Cell Size	1.6 km	1.6 km
Mapping Uncertainty	3 km	3 km
Measurement Range	0/1 Binary mask	0/1 Binary Mask
Measurement Accuracy*	90% prob. correct typing	90% prob. correct typing

* For climatologically snow-covered regions

Snow Product Requirements

From Joint Polar Satellite System (JPSS) Ground Segment Data Product Specification (GSegDPS), Dec 30, 2019:

- Snow Cover Fraction

Attribute	Threshold	Observed/validated
Geographic coverage	Global	Global
Horizontal Cell Size	1.6 km	1.6 km
Mapping Uncertainty	3 km	3 km
Measurement Range	0.0-1.0 Snow Fraction	0.0-1.0 Snow Fraction
Measurement Uncertainty	20%	20%

Snow Product Algorithms (v2r3)

- Binary Snow Cover (2-step algorithm)
  - Threshold-based decision tree classification algorithm (modified MODIS SnowMap)
  - 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 GOES 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

- The snow products that we tested were produced by the STAR ASSIST team with the algorithm version V2R3
  - The algorithm incorporates a major change in the cloud mask
  - This version of the algorithm is not yet operational
  - Planned DAP to NDE: August-September 2020

Provisional (May 2019) Review: Summary

Products generated with Version 2R2 of the algorithm were examined

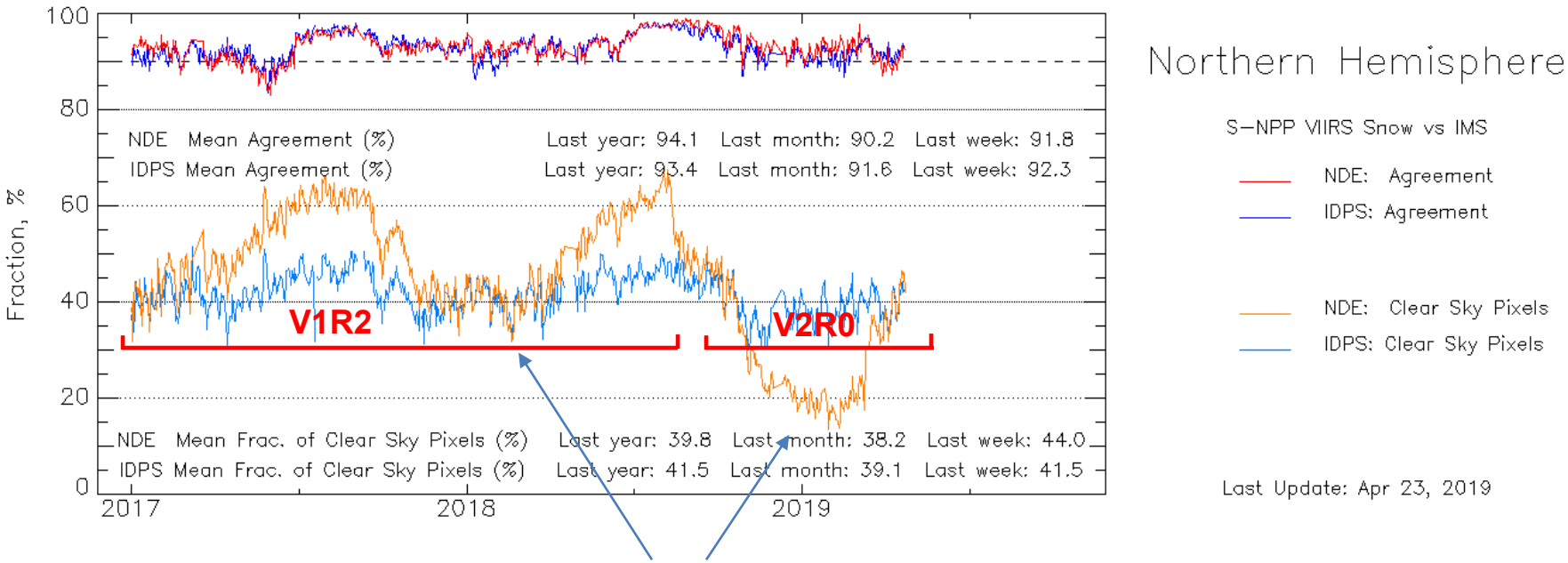
- Overall area coverage has improved (no missing granules) since V1R2
- Good qualitative agreement with SNPP, MODIS, AVHRR on the snow cover
- Good qualitative agreement with SNPP on the snow fraction
- Quantitative agreement to IMS: 93% (daily mean)
- Quantitative agreement to in situ data: 93% (daily mean, CONUS area)

However

- V2R(0-2) cloud mask turned much more conservative compared to V1R2 (20% more clouds in the Northern Hemisphere)
- Only 5% of the snow-covered area was labeled as “confidently clear”
- With greatly decreased effective area coverage the VIIRS Snow product has become virtually useless (e.g., USAF stopped using it)
- Product declared to reach Provisional maturity but not Validated maturity

Snow Cover & Clouds: NDE vs IDPS

(From the Provisional Maturity Review presentation)



Substantial decrease of the cloud clear fraction (i.e. increase of the cloud amount) in the NDE snow product after the switch to V2R0

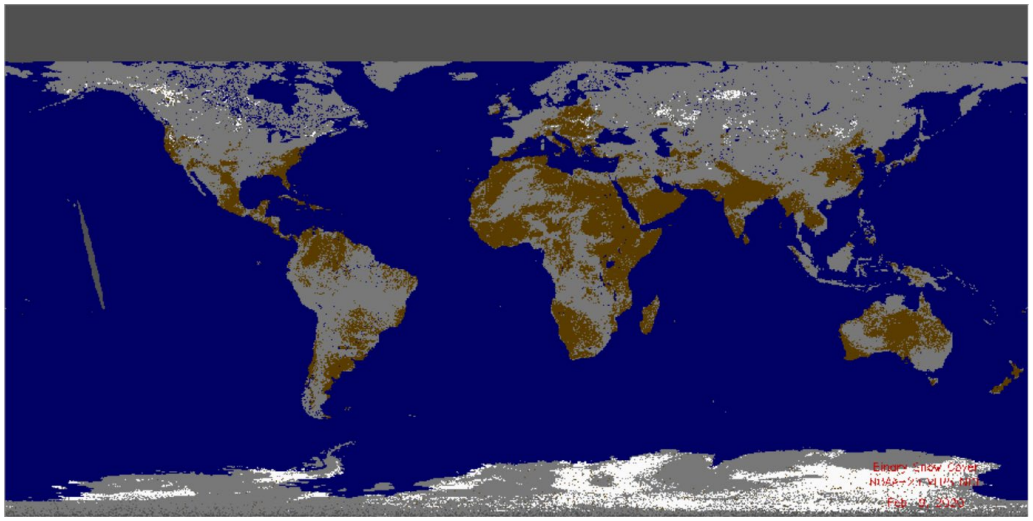
The switch from v1r2 to v2r0 NDE cloud algorithm in October 2018 resulted in a considerable decrease of identified cloud-clear scenes (yellow in the graph above) at least in winter in the Northern Hemisphere. Graphs are for VIIRS SNPP; NOAA-20 results are similar. Visual analysis of the snow product indicates that <u>v2r0 cloud mask tends to overestimate clouds over snow-covered land surface</u>

Since Provisional (May 2019) Review

- Operational NDE Binary and Fractional Snow algorithms unchanged
- New VIIRS cloud mask algorithm introduced (V3R0)
  - Fixed inaccurate cloud masking over snow-covered land
- Striping in the NOAA 20 Snow product was identified and resolved
- V3R0 algorithms have been assembled by the ASSIST team and run in an experimental mode over selected data in 2019 and 2020
- Snow product performance has been qualitatively and quantitatively evaluated with these retrievals using various techniques and independent datasets
- Delivery to operations is scheduled for August-September 2020

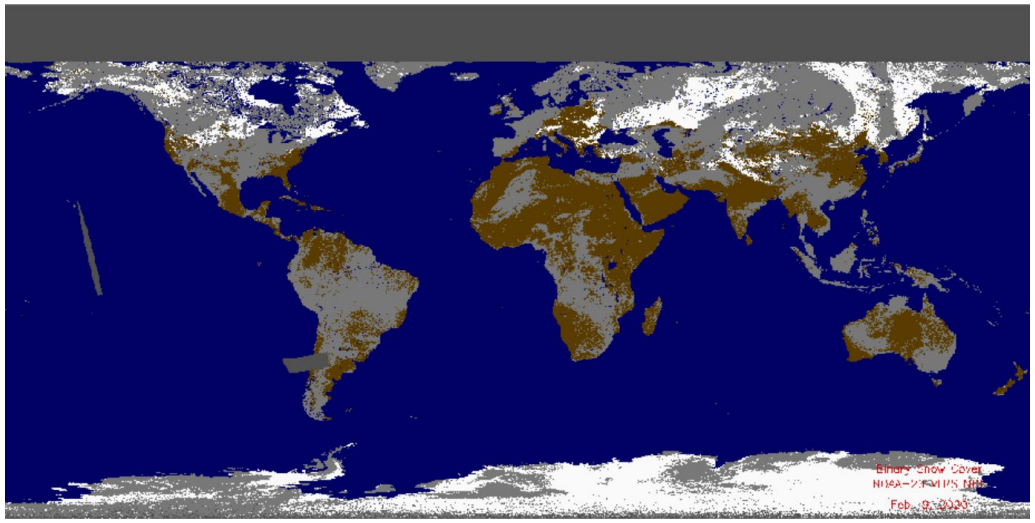
Since Provisional (May 2019) Review (Cont'd)

Cloud masking improvement



V2r2 (currently operational)

Severely overestimated cloud amount in NHemispher, particularly over snow-covered areas



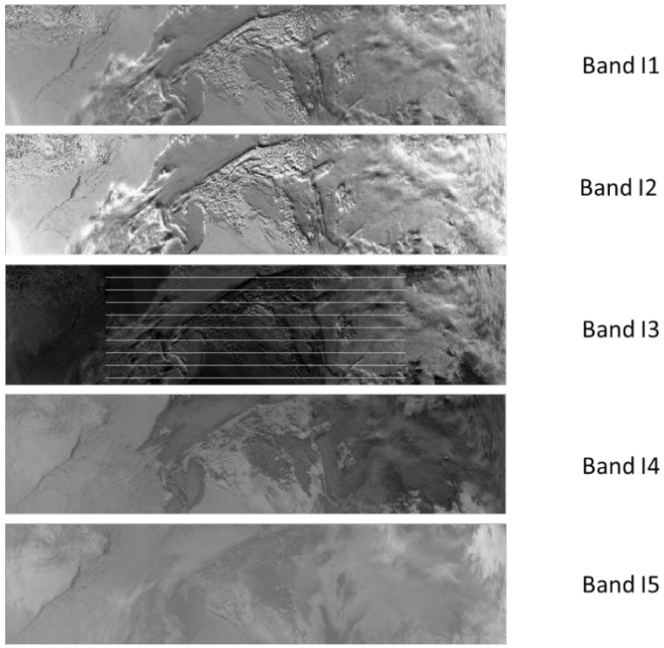
V3r0 (being tested)

Back to realistic cloud masking

- Snow
- Land (no snow)
- Water
- Cloud
- No data

Since Provisional (May 2019) Review (Cont'd)

Striping in NOAA-20 VIIRS Snow product eliminated



Striping in N20 VIIRS I3 band due to a bad detector.

Striping was caused by a bad detector (#29) in the VIIRS I3 band.

Bad detector's reading convert to about 1.6 reflectance value

Bad detector values are supplied with a "valid observation" quality flag in the VIIRS gap-filled SDR and therefore propagate into the snow algorithm.

Corrupted I3 data cause erroneous interpretation of snow-covered scenes as snow-free.

Validity checks of SDR input in the snow algorithm have been modified to eliminate observations with corrupted I3 data.

Data Available and Used for Validation

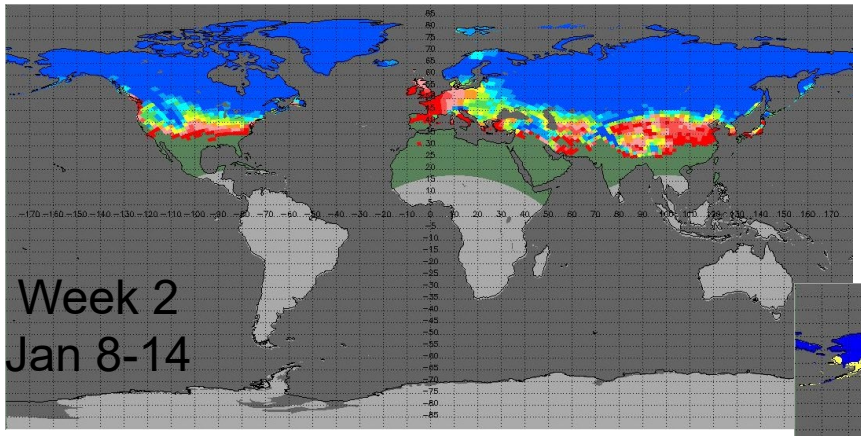
Scope of v3r0 derived data made available for NOAA-20 VIIRS Snow Product accuracy assessment

October 10-17, 2019 (8 days)
February 1-27, 2020 (27 days)
May 16-31, 2020 (16 days)

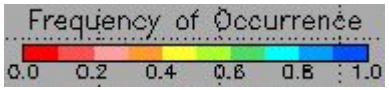
Overall: 51 days (NH late fall, winter, spring)

Assessment of Binary Snow Cover

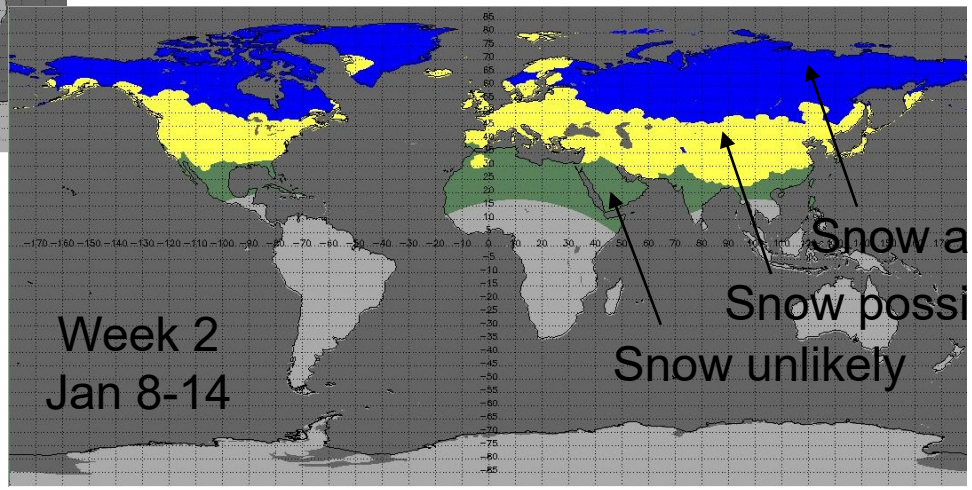
Climatologically snow-affected areas



Weekly climatic snow cover occurrence



Snow cover occurrence categories



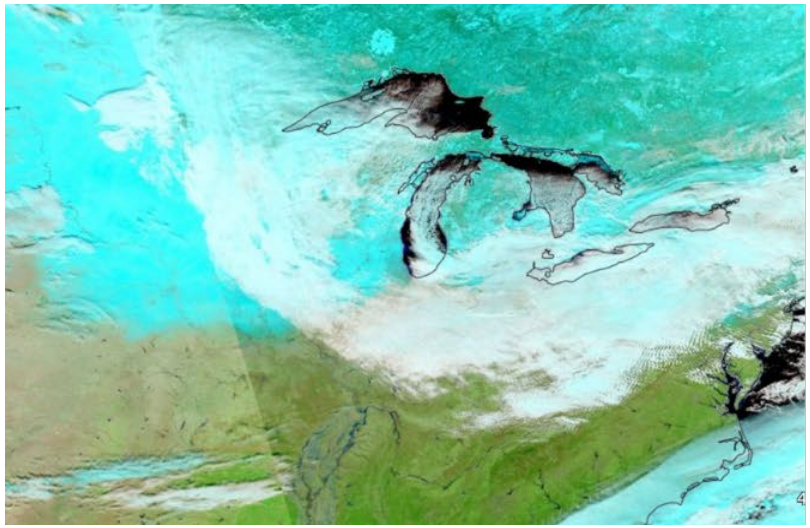
- Accuracy estimates are provided for the “snow possible” region (shown in yellow)
- Boundaries of the “snow possible” region change with time during the year

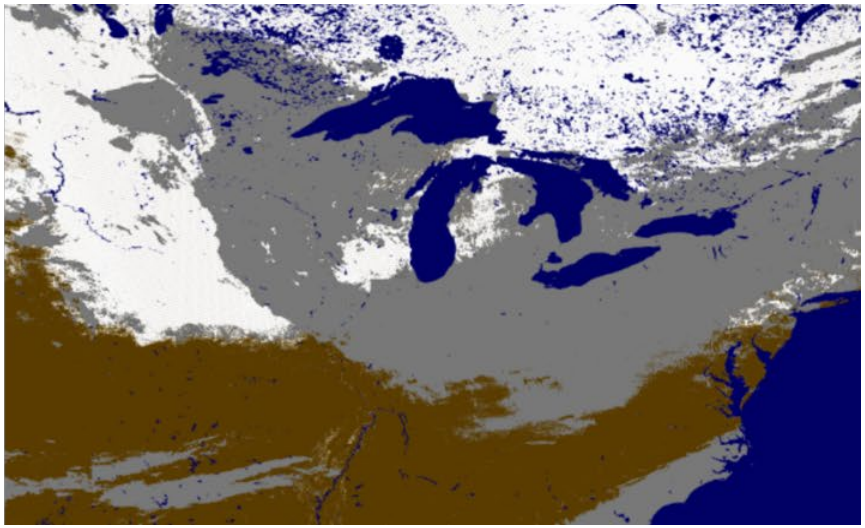
NOAA-20 Binary Snow Evaluation Approach

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

Snow map vs RGB

Cloud masking example

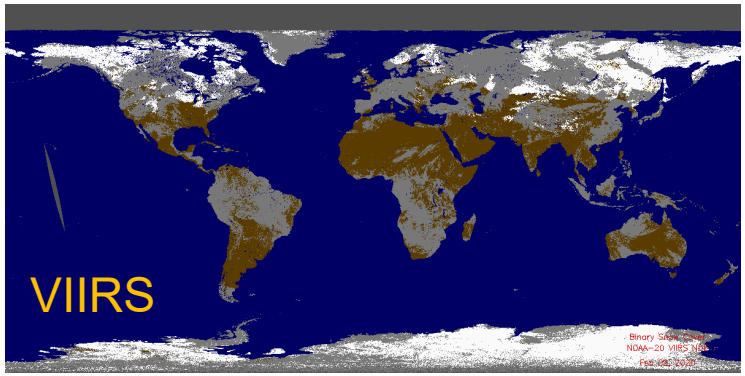




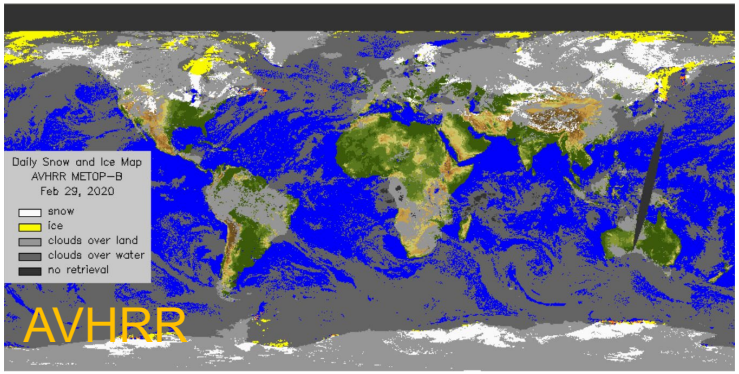
January 19, 2020: Note a good delineation of the cloud-affected area by the new cloud mask (V3r0) both over snow-free and snow covered land surface.

- Snow
- Land (no snow)
- Water
- Cloud
- No data

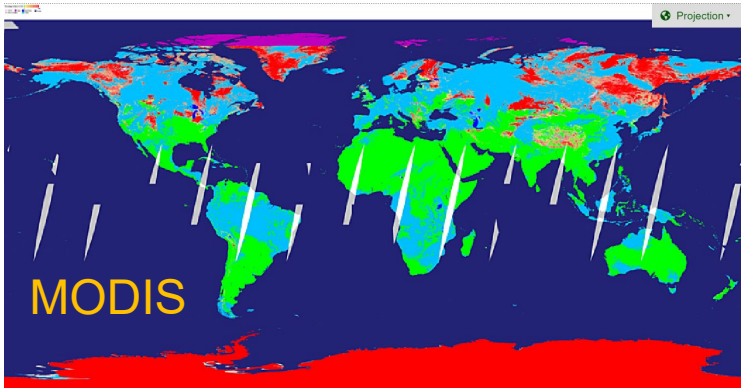
Snow maps from various sensors



Snow
Land (no snow)
Water
Cloud
No data



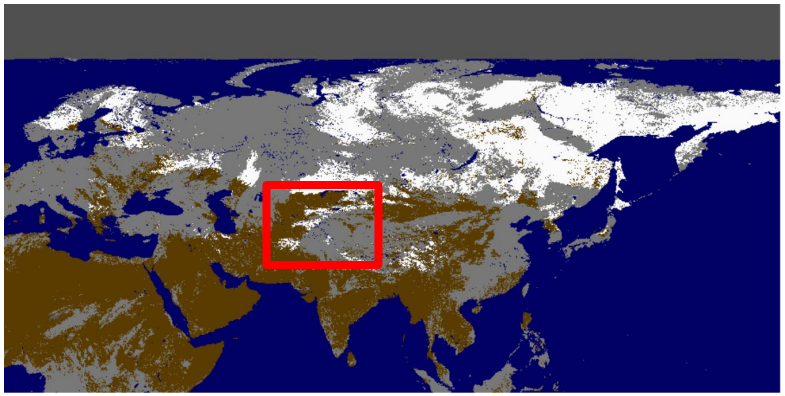
Good qualitative agreement of VIIRS Snow Maps to snow map products derived with similar instruments. Note: Cloud masks may be different.



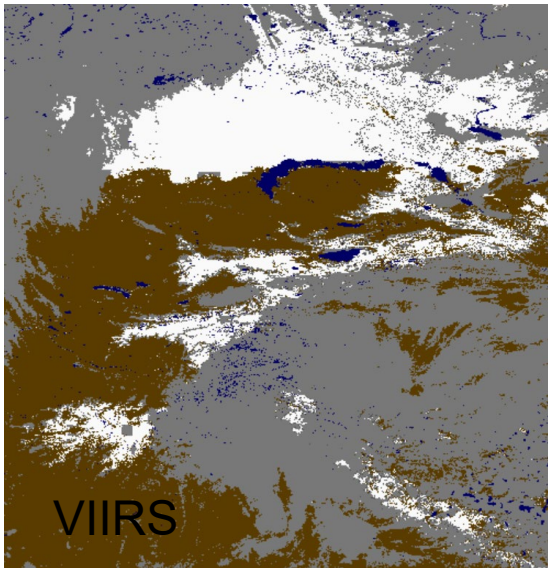
Snow
Land (no snow)
Water
Cloud
No data

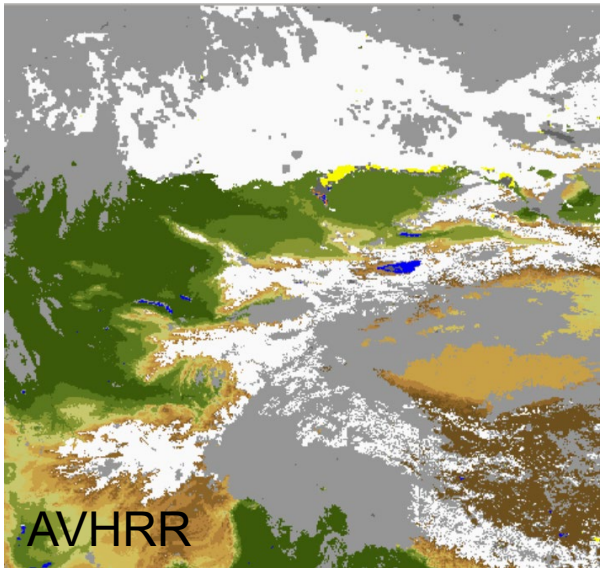
February 29, 2020

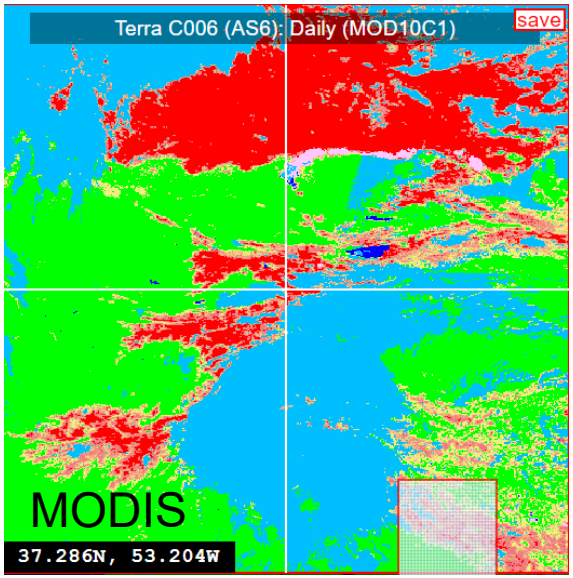
Snow maps from various sensors (Cont'd)



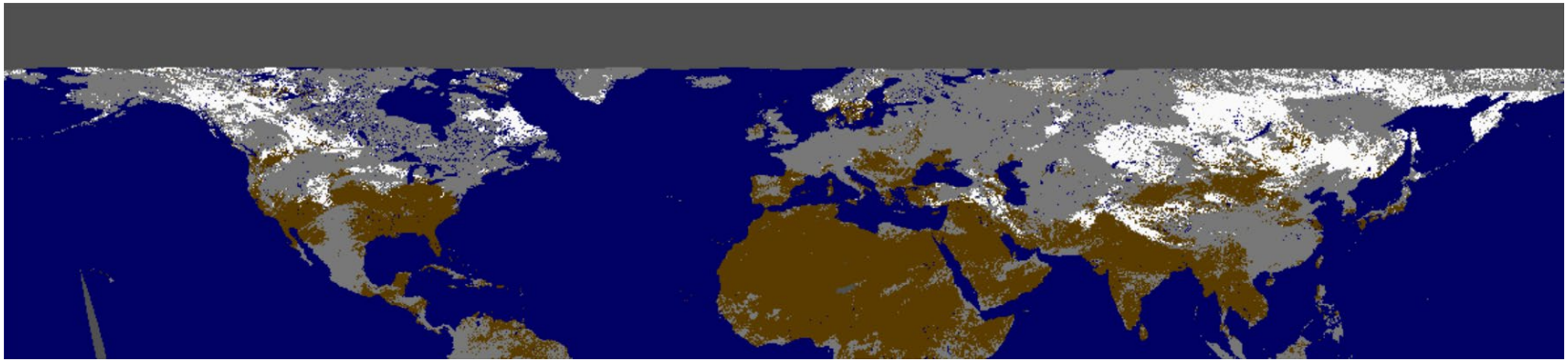
February 29, 2020



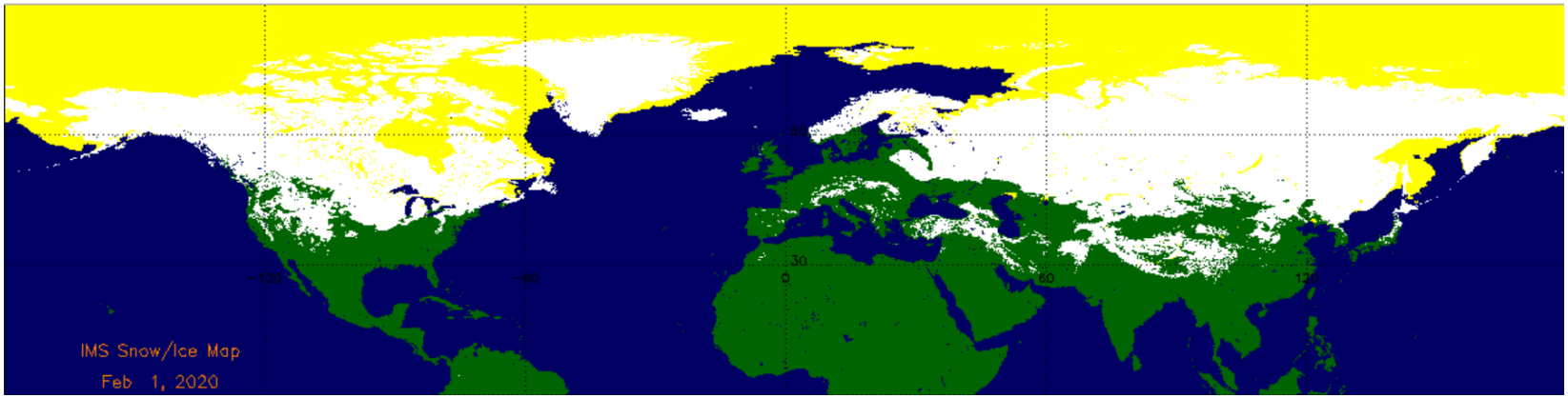




VIIRS Snow map vs IMS: Qualitative

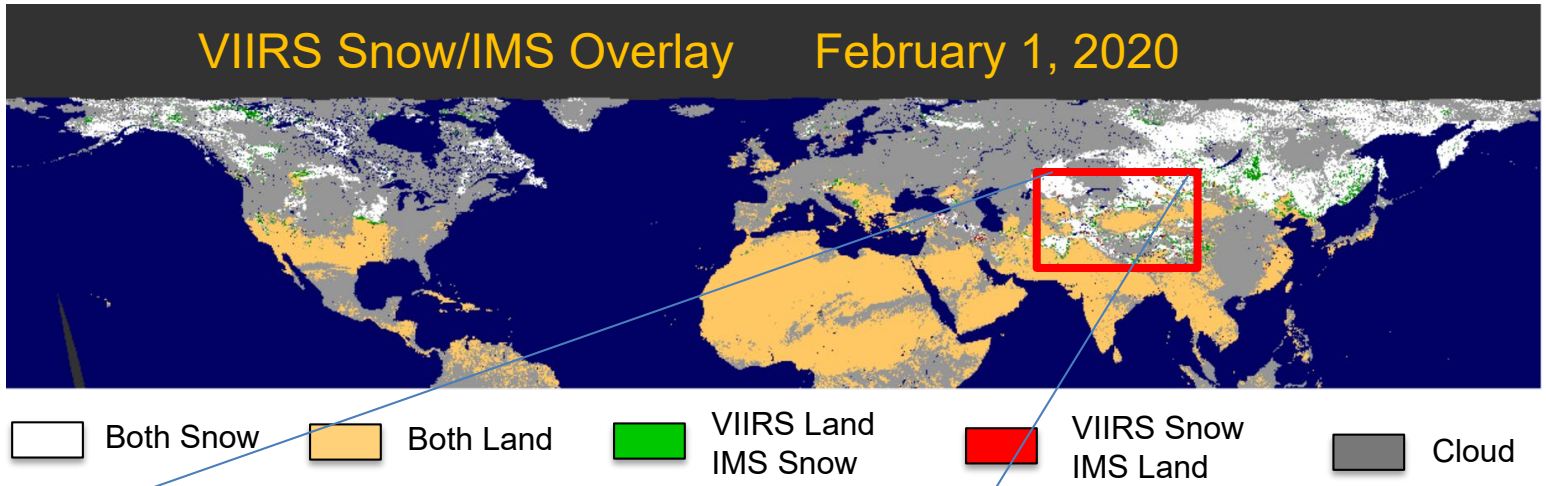


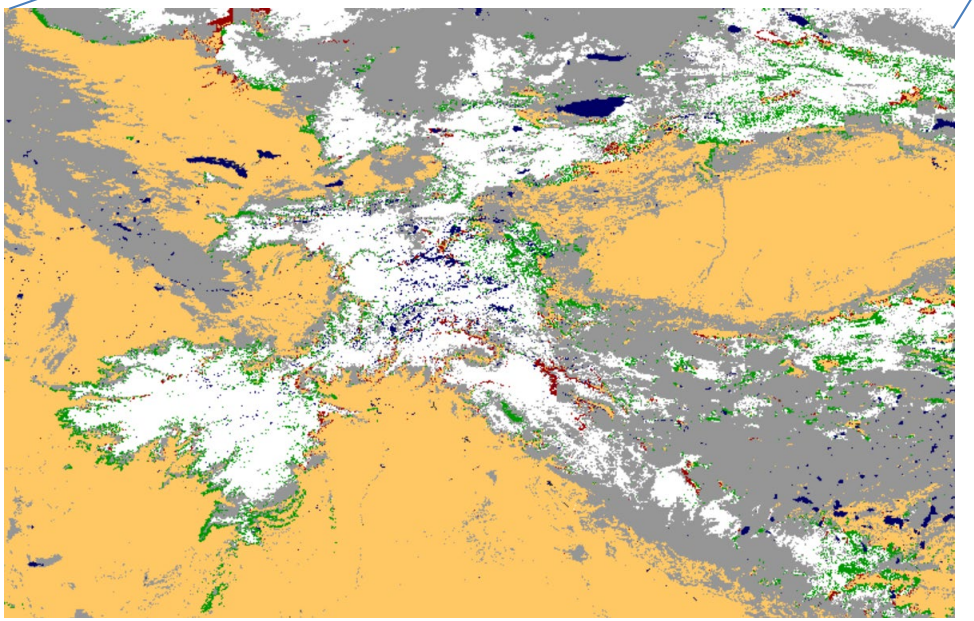
Snow | Land | Water | Cloud | No data



Good qualitative agreement between VIIRS and IMS on the snow cover where VIIRS retrievals are available

VIIRS Snow map vs IMS: Quantitative Comparison





Agreement rate (snow/no-snow)

<u>All land area</u>

Eurasia	96.9%
North America	95.2%
N.Hemisphere	96,7%

<u>Snow climatologically possible</u>

Eurasia	91.5%
North America	93.7%
N.Hemisphere	92,0%

VIIRS Binary Snow vs IMS

VIIRS snow/no-snow correct discrimination (%)

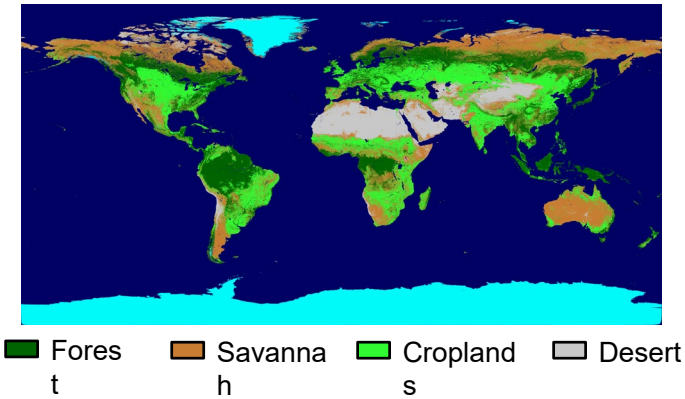
	Oct 2019	*Feb 2020*	*May 2020*
North America	90.3±1.5	90.8±2.4	93.2±1.7
Eurasia	94.1±0.9	91.4±1.2	95.2±1.2
N.Hemisphere	92.5±1.4	91.3±1.0	94.8±1.1

Over climatologically snow-covered areas

Disagreement between VIIRS Snow and IMS is mostly due to less snow mapped by VIIRS (snow misses)

VIIRS Binary Snow vs IMS by Surface Type

VIIRS snow/no-snow correct discrimination (%) by surface type

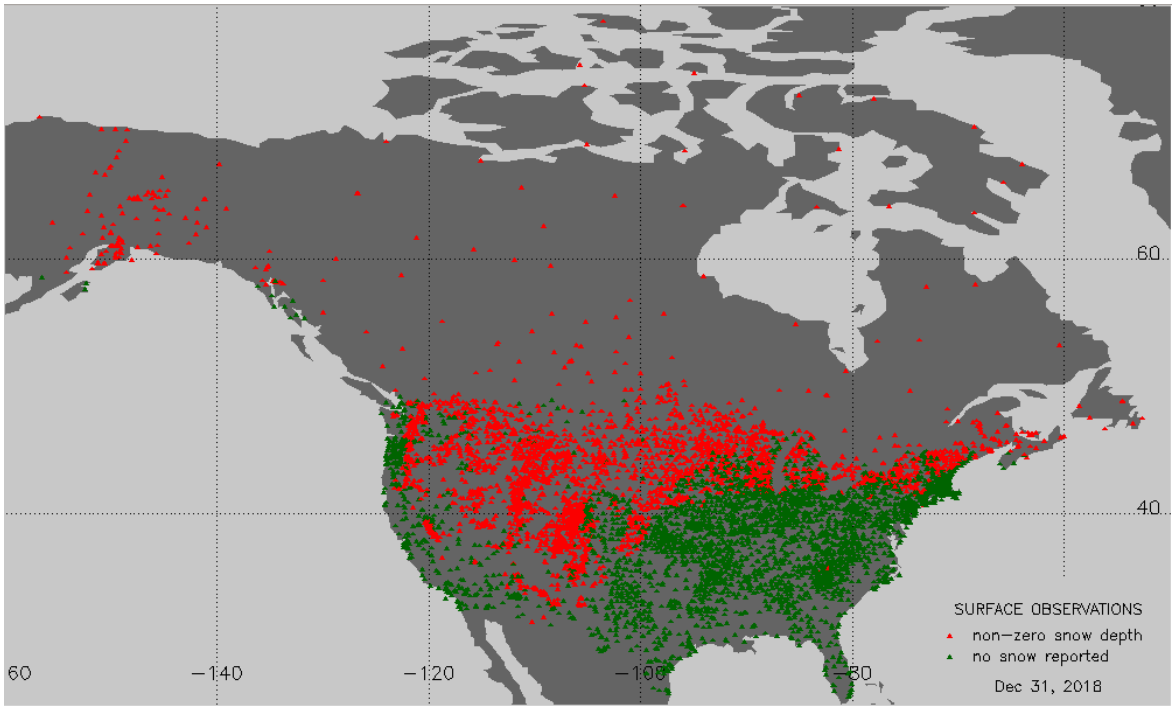


	Northern Hemisphere	*North America*	*Eurasia*
	Mean Agreement (%)		
Forest	89.2	88.4	90.5
Savannah/Tundra	91.6	91.5	91.6
Croplands	92.5	92.6	92.5
Desert	94.2	93.7	94.4

October 2019, February 2020, May 2020

In Situ Snow Depth Reports

Validation of VIIRS snow maps was performed with snow depth reports from ground-based stations over North America. Most stations are located in US and Southern Canada. Station data were acquired from NCEI (Global Historical Climate Network Daily, GHCN-D dataset)



GHCN-D includes data from
- First-order stations
- US COOP
- CoCoRAHS
- SnoTel
- US ASOS
- Environment Canada
- Other regional networks

Reports from over 8,000 stations were acquired daily. The number of daily in situ-satellite match-ups varied from about 1,000 to 4,000 depending on the cloud cover.

VIIRS Binary Snow vs In Situ

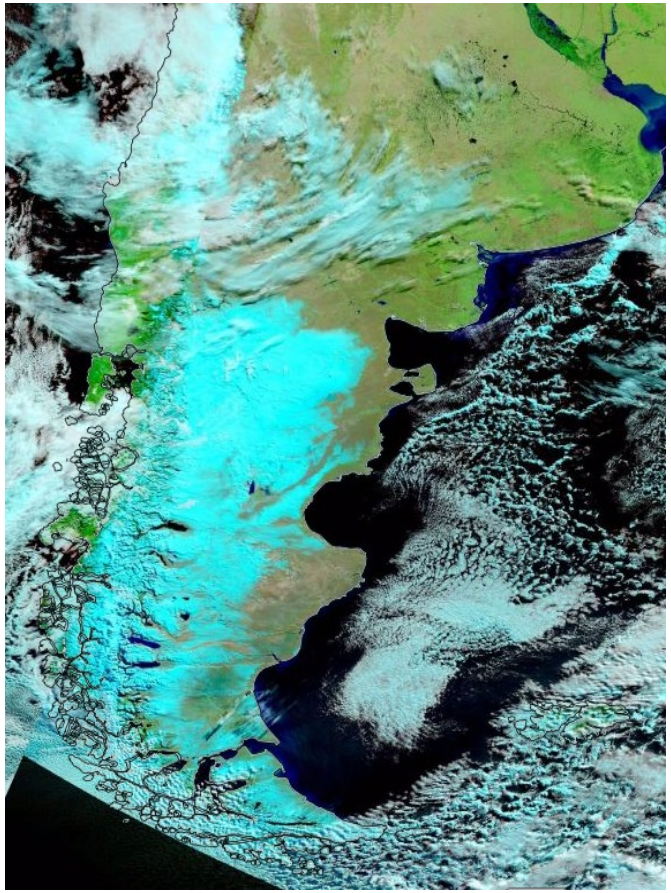
VIIRS snow/no-snow correct discrimination (%), North America

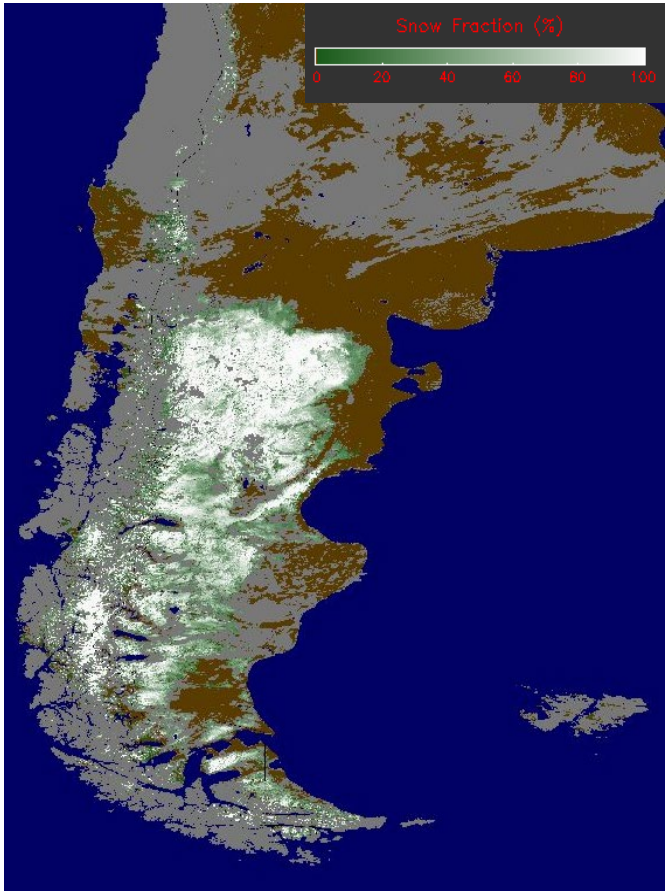
	Oct 2019	*Feb 2020*	*May 2020*
Agreement rate	94.1±2.5	91.4±2.9	96.2±3.8
Snow miss	3.7±1.7	5.6±2.9	3.7±3.7
False snow	2.1 ±1.0	3.0±0.9	0.1±0.3
# Matchups	407	15920	123

Over climatologically snow-covered areas

Assessment of Snow Fraction Product

VIIRS Snow Fraction: South America





NOAA-20 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 accuracy estimates are feasible

Validity of NOAA-20 VIIRS Snow Fraction Product has been 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 (e.g., from SNPP)

Snow Fraction: Theoretical Accuracy Estimate

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

Error propagation ($F = SnowFraction$)

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

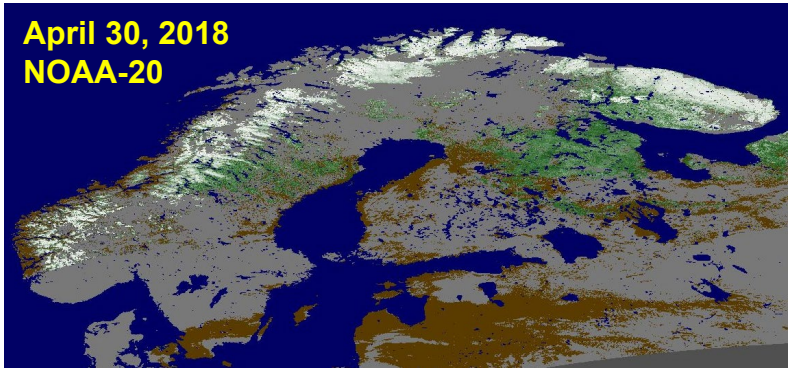
Assumed uncertainties:

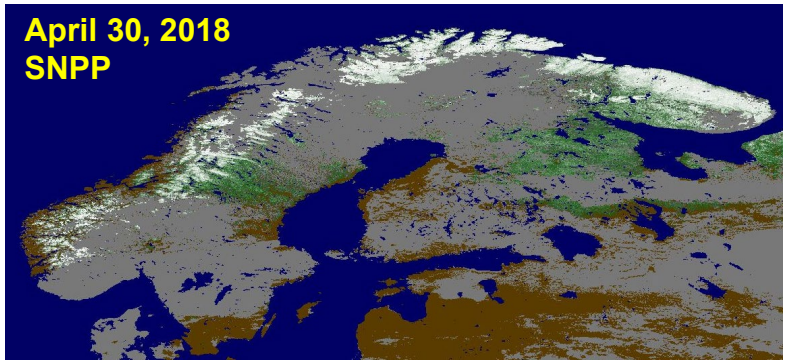
δR_{land} = 0.10 (anisotropy correction + natural variability)

δR_{snow} = 0.15 (anisotropy correction + natural variability)

Theoretical accuracy estimate of snow fraction retrieval for realistic snow and snow-free land visible reflectance values: ~0.15-0.20.

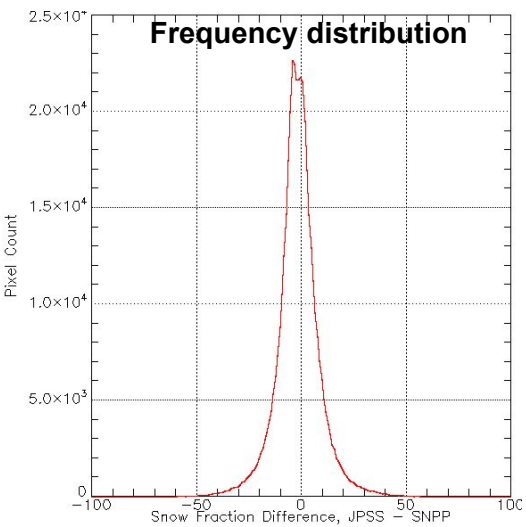
NOAA-20 vs SNPP Snow Fraction

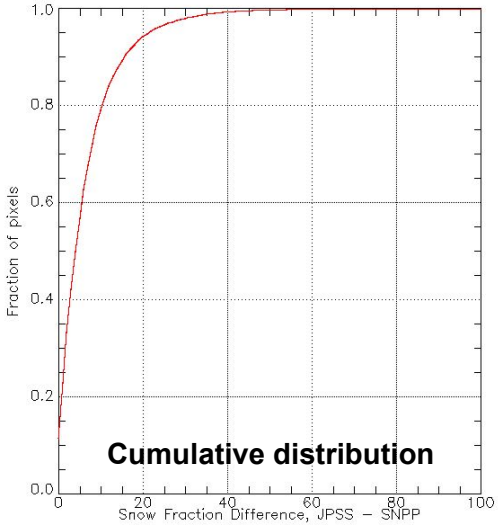




N20 vs SNPP snow fraction
FSC comparison statistics
for 0.02<FSC<0.98

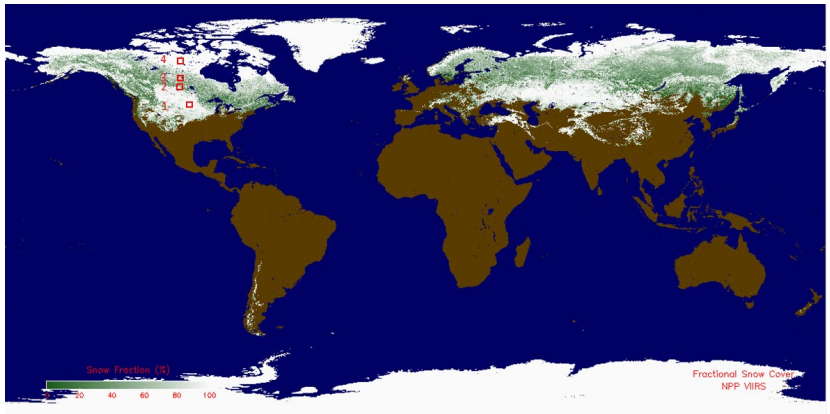
Correlation: 0.94
RMSD: 0.07
Bias: 0.01





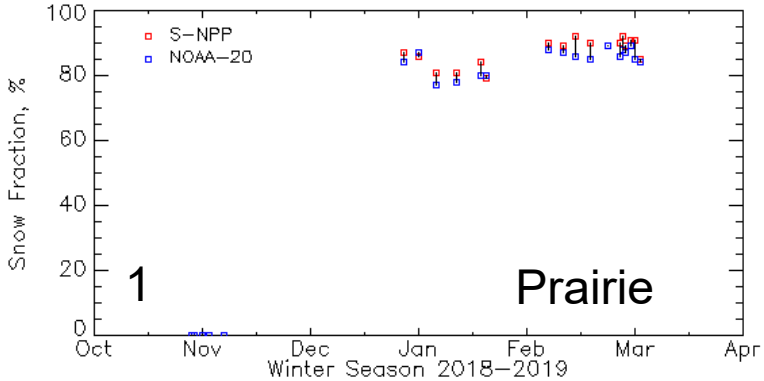
NOAA-20 vs SNPP FSC:
- Strong spatial correlation between FSC estimates
- Small RMSD (< 0.1) with negligible bias

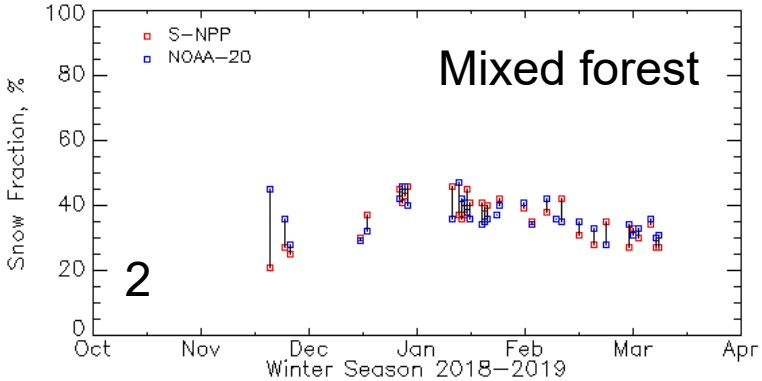
N-20 vs SNPP Snow Fraction: Time Series

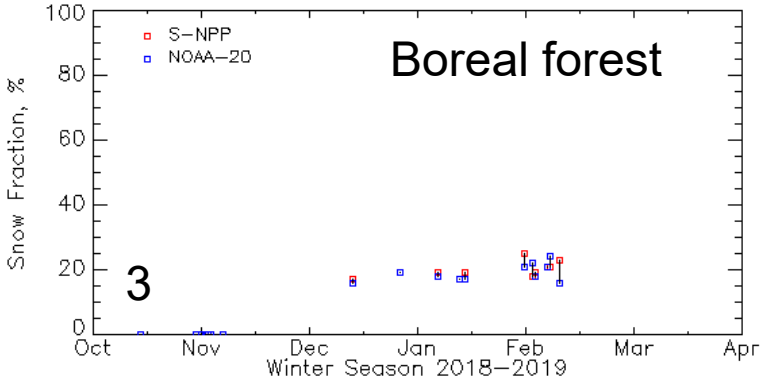


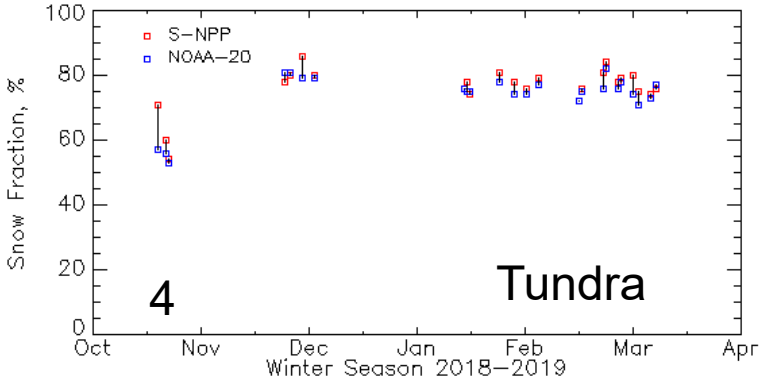
N-20 and SNPP Snow Fraction difference was mostly within 0.1 throughout the winter season with the mean difference of 0.053.

Small, within ~0.2, mid-winter snow fraction variation for all sites is indicative of a robust performance of the retrieval algorithm



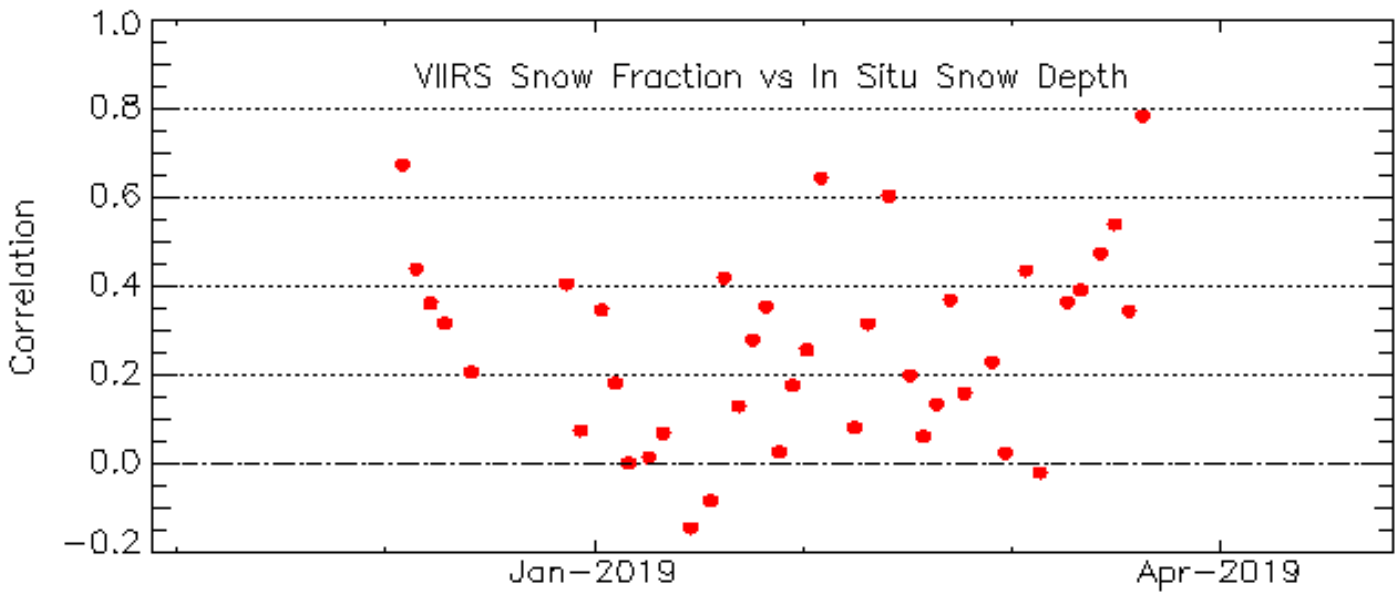






VIIRS Snow Fraction vs Snow Depth

Correlation of VIIRS snow fraction and in situ snow depth calculated daily for US stations located in the plains with no forest cover.



Correlation is mostly positive (larger snow fraction for larger snow depths) indicating adequate performance of the snow fraction algorithm

Long Term Monitoring Readiness

Collection of VIIRS snow granules and generation of daily gridded snow maps (binary snow and snow fraction) is performed daily.

Gridded products are displayed at STAR EDR Long Term Monitoring (LTM) Website.

Archiving of gridded products is performed on developer's local servers, but is not guaranteed 24/7/365. Gaps/data loss due to network, hardware issues.

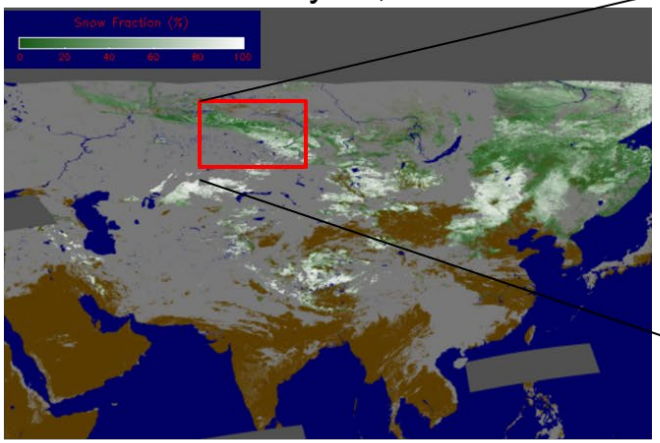
Product validation software is available, it has been tested with SNPP and NOAA-20 data, and is ready for operational implementation. Routine monitoring of the product accuracy is performed by the team.

Required algorithm inputs

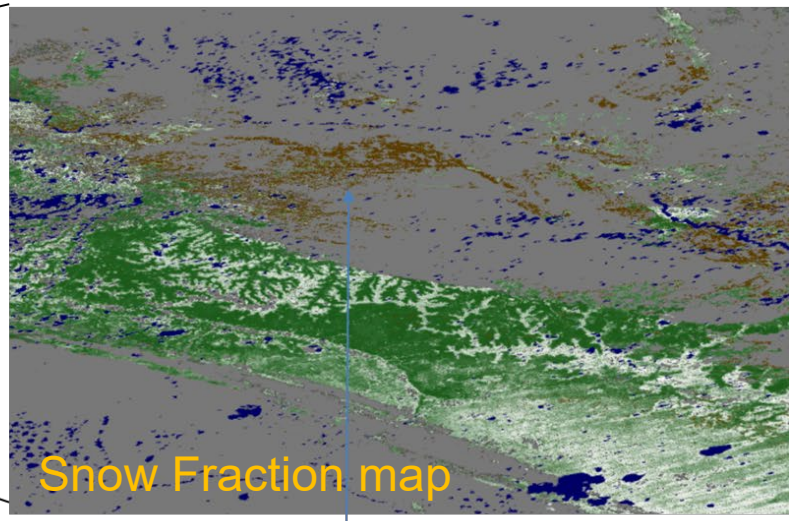
- Cloud Mask
- Algorithm parameters
- Ancillary data
  - Snow cover climatology
  - Surface temperature climatology

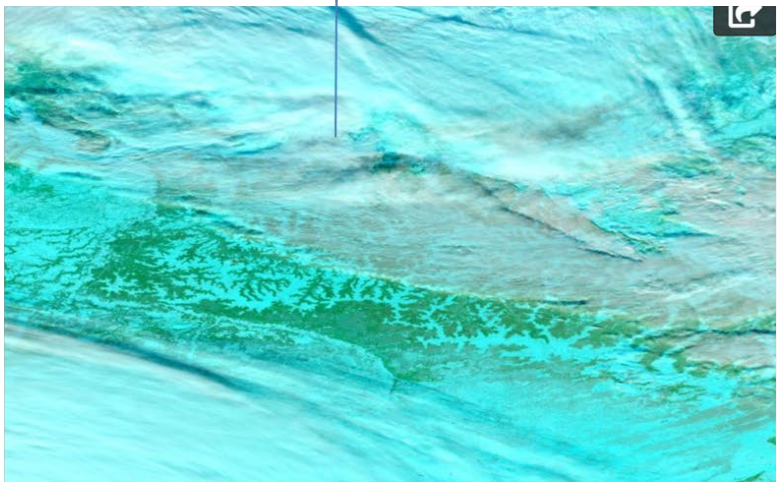
Effect of limited accuracy of the cloud mask

January 20, 2020



Land Cloud Not derived





V3R0 cloud mask tends to miss low-level clouds over snow. These missed clouds are not recognized as “snow” and causing snow misses in the snow product.

Quality flag

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

Pixel quality flags values are as follows

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 errors have been found.

Snow Products: Error Budget

Attribute	L1RD Requirement	On-orbit Performance	Meet specs	Comments
Binary Snow Cover	90% Correct Typing	93% vs IMS and in situ data	yes	
Snow Fraction	20% Uncertainty	10-20% uncertainty (theoretical estimate & comparison with SNPP)	yes	Ground truth data is unavailable

Requirement Check List – Snow Cover

DPS	Requirement	Performance
DPS-302	The Snow Cover product shall provide fractional snow cover and binary snow cover mask, globally, in daytime, under clear conditions, at the refresh rates of the instrument	Meets requirement
DPS-303	The Snow Cover product shall provide fractional snow cover with a measurement uncertainty of 20%	Meets or exceeds requirement
DPS-304	The Snow Cover product shall provide the binary snow cover mask with a 90% probability of correct snow/no-snow classification	Meets or exceeds requirement

User Feedback

- Potential user include
  - IMS at National Ice Center
  - NCEP/EMC

- At this time the new (V3r0) snow product is not delivered operationally to the users, therefore no user feedback is available.

Downstream Product Feedback

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

Risk, Actions and Mitigations

Identified Risk	Description	Impact	Action
Cloud mask	Cloud mask misses low-level and semitransparent clouds over snow	Missed clouds are not interpreted as snow and therefore result in snow misses in the snow cover map.	Reported the problem to the Cloud Team, will work to improve cloud mask performance over snow.
Product not yet operational	V3R0 DAP is scheduled for August-September 2020	Quality of snow products will remain suboptimal until v3r0 is implemented	Implement V3R0 of the algorithm

Documentations (Check List)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	Yes (NOAA-20)
Algorithm Theoretical Basis Document (ATBD)	Yes
Algorithm Calibration/Validation Plan	Yes
(External/Internal) Users Manual (ASSIST-produced)	Yes
System Maintenance Manual (ASSIST-produced)	Yes
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	Yes
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	JPSS Summit, AMS,

Check List - Validated Maturity

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	Yes
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.	Yes
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	Yes
Product is ready for operational use based on documented validation findings and user feedback.	Yes, once implemented into operations
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	Yes

Conclusion

- NOAA-20 VIIRS Snow Products generated in an experimental mode by STAR ASSIST have been evaluated and validated during October 2019, February and May 2020
- Both products (Binary Snow Cover and Snow Fraction) adequately reproduce snow cover properties, demonstrate robust performance and satisfy accuracy requirements
- Information is sufficient to make qualitative assessment of the product
- Required documentation exists
- **NOAA-20 Snow products produced with v3r0 algorithms have reached Validated Maturity**
- **New products will be available to the users once v3r0 is operational**

Path Forward

- Lesson Learned
  - Additional cloud identification tests should be implemented in the snow algorithm to improve cloud screening over snow-covered land

- Planned improvements
  - Upgrade to higher resolution snow cover climatology.
  - Cloud shadows: Need to improve accuracy, set exclusion
  - Predict topographical shadows, set exclusion

- Future Cal/Val activities / milestones
  - Evaluate the product once it becomes operational
  - Continue long-term monitoring of derived snow cover properties.