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

Presented by Peter Romanov

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JPSS NOAA NASA

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.

Provisional Maturity Review - Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Provisional Maturity Performance Validation
- Users/EDRs 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 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
  - 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

- 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% probability of correct typing	90% probability of correct typing

- 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

- 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 within NDE I&T using October 2018 DAP
  - Algorithm version: V2R0
  - Effective dates: November 2018 to April 2019
  - Snow product obtained from STAR SCDR

Product Performance Evaluation: Approach

Evaluation is performed using NOAA-20 snow products transformed to daily global gridded maps with 0.01 degree grid cell size (~1.1 km)

Evaluation involves

- Visual (qualitative) assessment of products
  - Presence of bad/missing scanlines/granules
  - Presence of unusual/unphysical spatial patterns in products
- Visual comparison of NOAA-20 with other similar remotely sensed snow products
- Comparison with independent datasets
  - Comparison with IMS maps, in situ snow depth reports
- Consistency tests

Calibration/Validation Approach (initial) online at
https://www.star.nesdis.noaa.gov/jpss/documents/CalVal/CVP_EDR_VIIRS_Land_Privette_22May2009.pdf
Updated version of the document on google drive at
https://drive.google.com/drive/folders/0B5nZAaI3ehPXVGotSkk4SmxxcWc

Beta and Provisional (Oct 2018) Review: Summary

Products generated with Version 1R2 of the algorithm were examined

- No issues at the scan-line or granule level
- Good agreement with SNPP on snow cover and snow fraction
- Good agreement on snow/no snow (over 95%) with IMS
- Correct Quality Flag values

- Substantial gaps in the area coverage, hence fails to satisfy the refresh rate requirement (90% coverage every 24 hours)
- Available data were insufficient to perform a detailed quantitative analysis of the V1R2 product accuracy and performance
  - Short period covered: Late spring and summer
  - Snow cover confined to high latitudes: No station data for validation

Product has reached Beta Maturity but not Provisional Maturity

Since Beta and Provisional (Oct 2018) Review

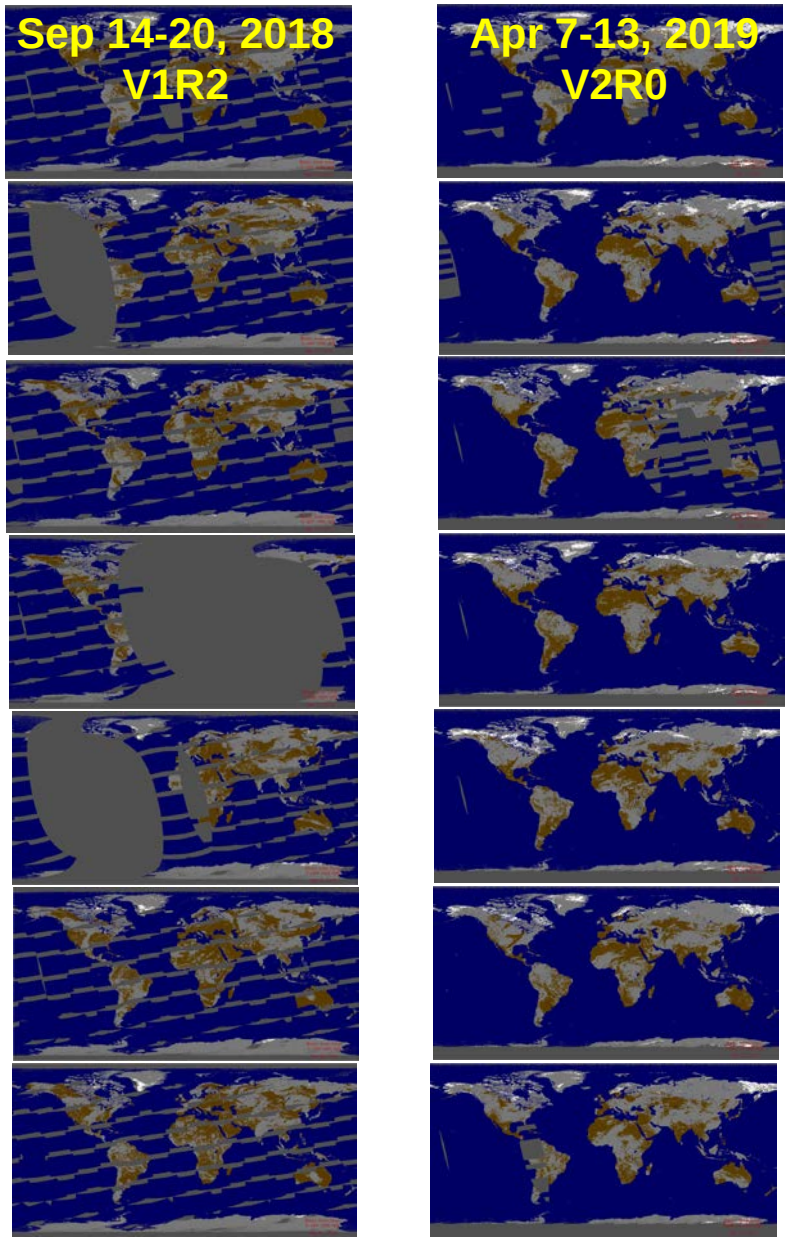
- Snow algorithm/code remained unchanged
- New cloud mask (V2R0) was fully implemented in Oct 2018
- NDE I&T software was updated to eliminate missing granules
- Daily production of gridded snow maps has continued.
- Snow product performance has been qualitatively and quantitatively evaluated during the 2018-2019 winter season over Northern Hemisphere using various techniques and independent datasets

Assessment of Binary Snow Cover

NOAA-20 Binary Snow Evaluation Approach

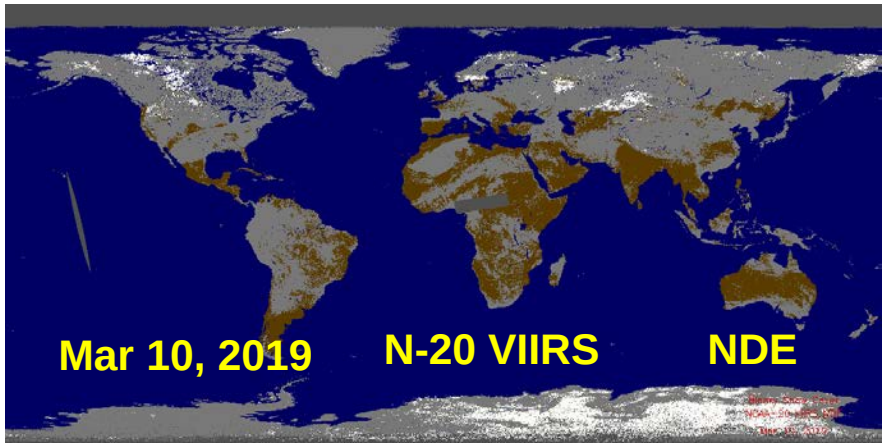
- Comparison with true color imagery
- Comparison with other remotely-sensed snow products
- Validation against NOAA Interactive Snow Maps (IMS)
- Validation against in situ snow depth reports.

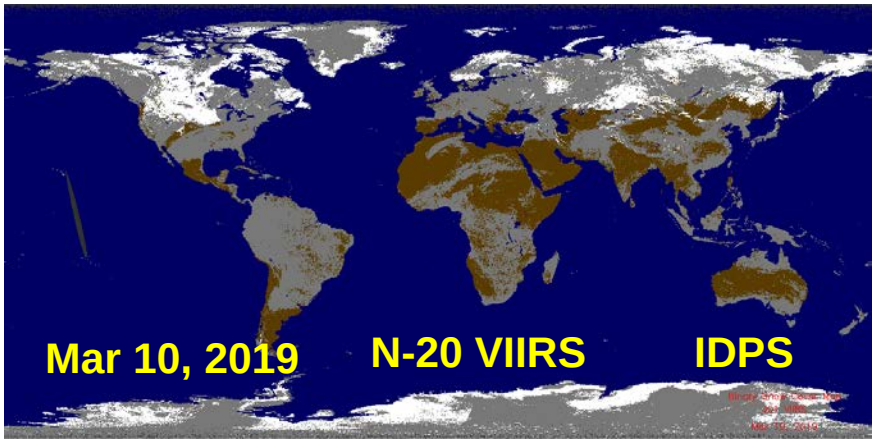
N-20 NDE Snow Product: v1r2 vs v2r0

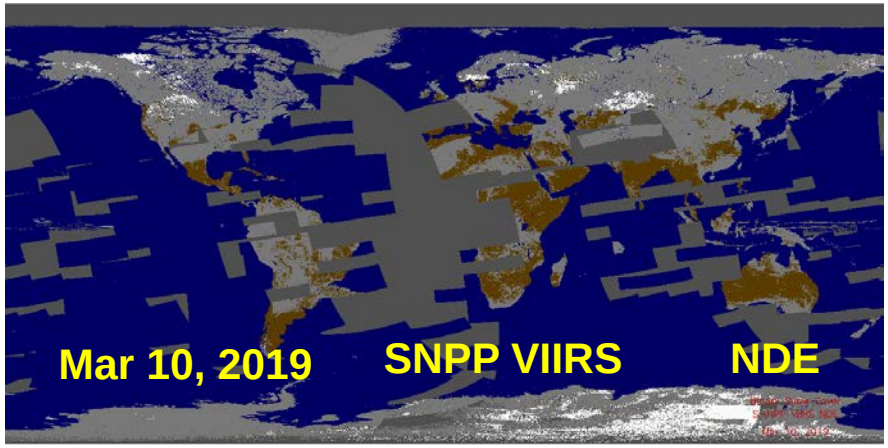


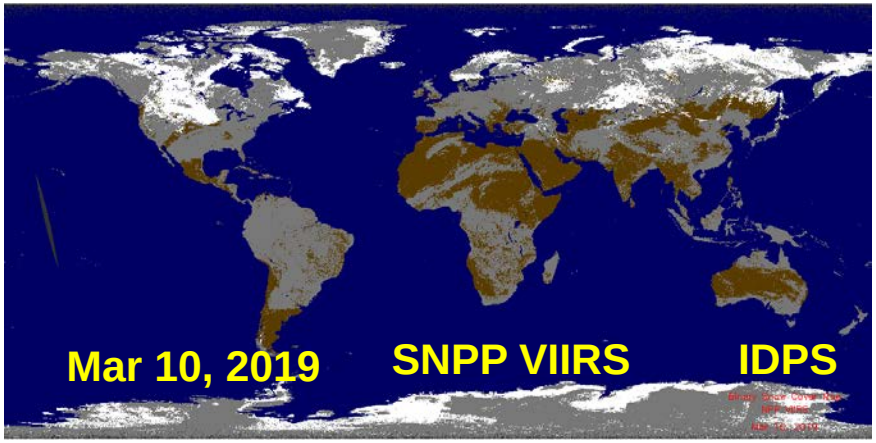
V2R0: The problem of missing granules has been mostly solved. Occasional granule misses still occur.

N-20 NDE Binary Snow vs SNPP and IDPS products





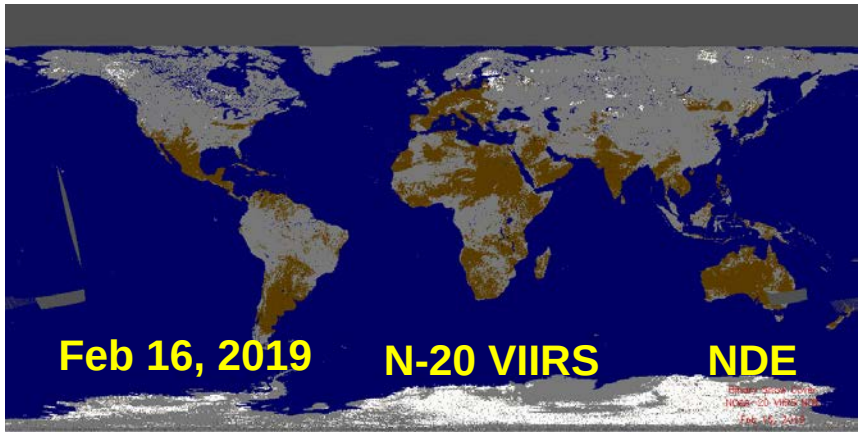


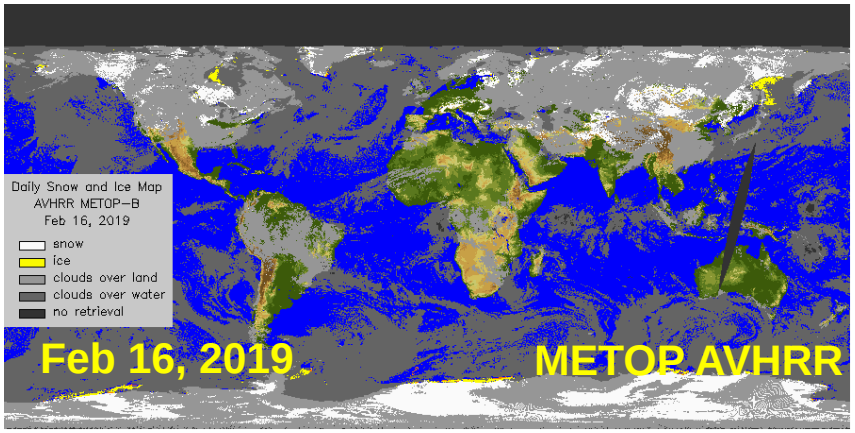


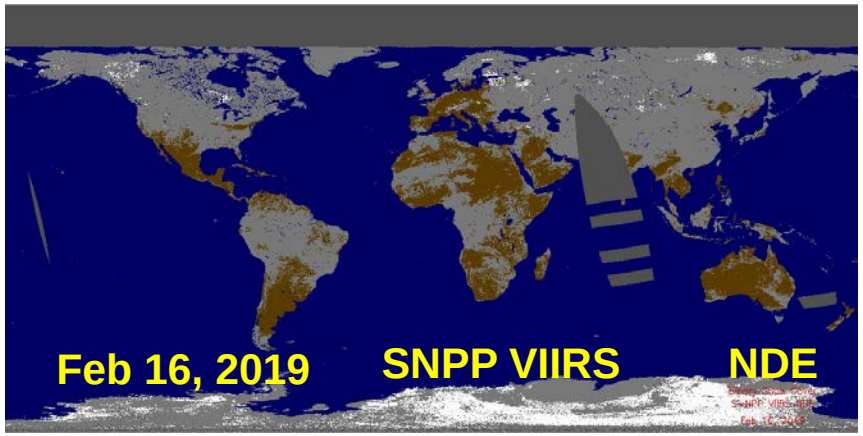
Snow Cloud No data

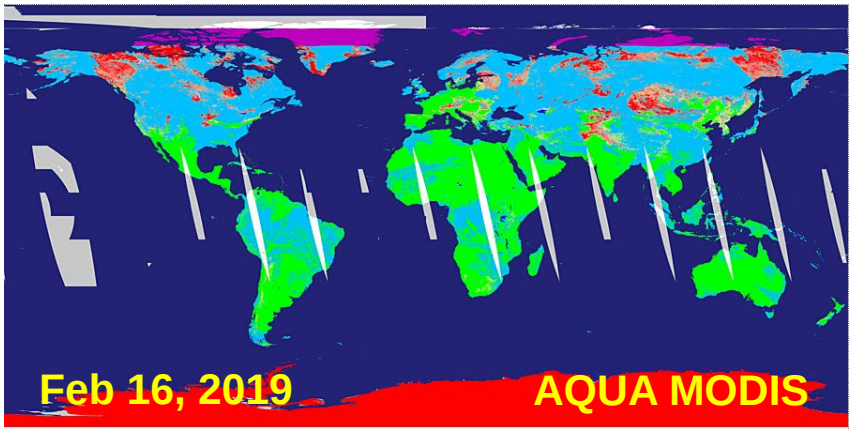
- Good qualitative agreement on the mapped snow cover in N-20 NDE vs other VIIRS products
- More clouds in NDE products than in IDPS, particularly over snow-covered areas

N-20 NDE Binary Snow vs METOP AVHRR







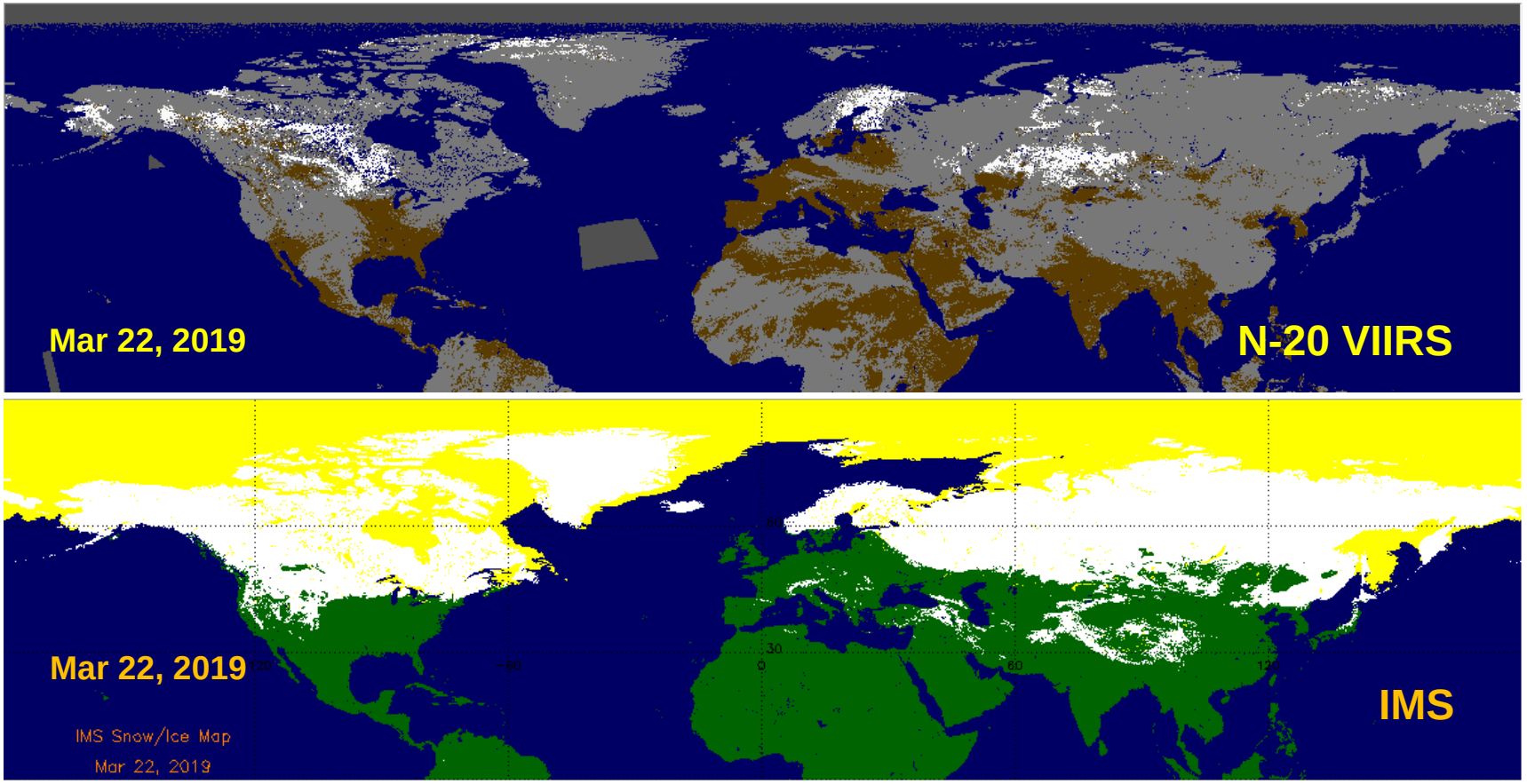


Snow Cloud No data

Snow Cloud No data

- Good qualitative agreement on the mapped snow cover in N-20 NDE product to similar products derived from AVHRR and MODIS
- More clouds in NDE products

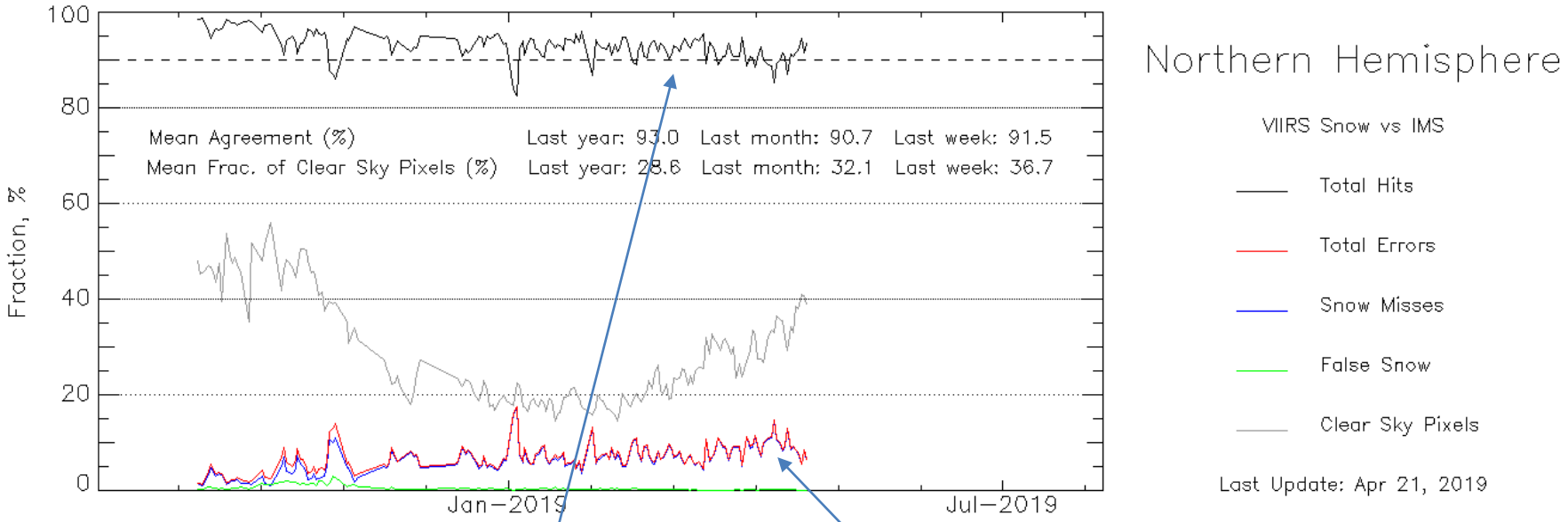
NOAAA-20 NDE Binary Snow vs IMS, Qualitative



Good qualitative agreement of snow mapped in the NOAA-20 VIIRS product to IMS

NOAA-20 Binary Snow vs IMS, Quantitative

Statistics of daily pixel-by-pixel comparison of N-20 VIIRS Binary Snow Maps to IMS for clear sky scenes over Northern Hemisphere.

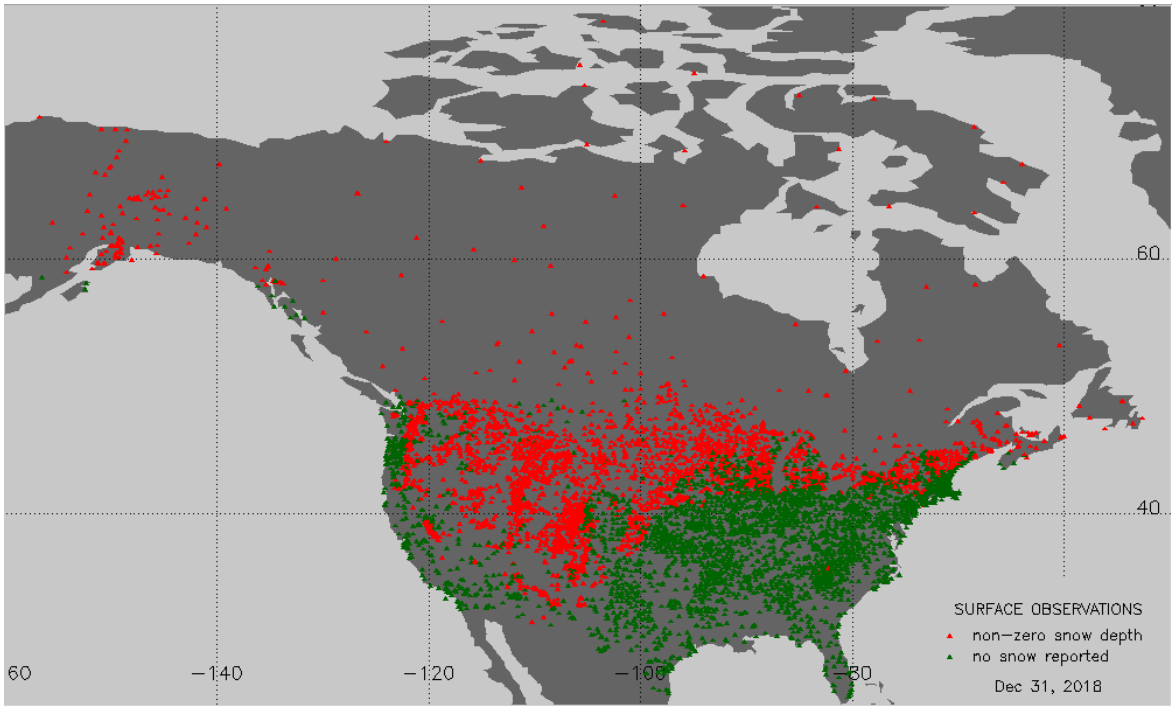


Mean daily agreement to IMS is 93% for the 2018-2019 winter season. This satisfies the requirement of 10% correct typing

Disagreement is due to less snow mapped by VIIRS (snow misses)

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)

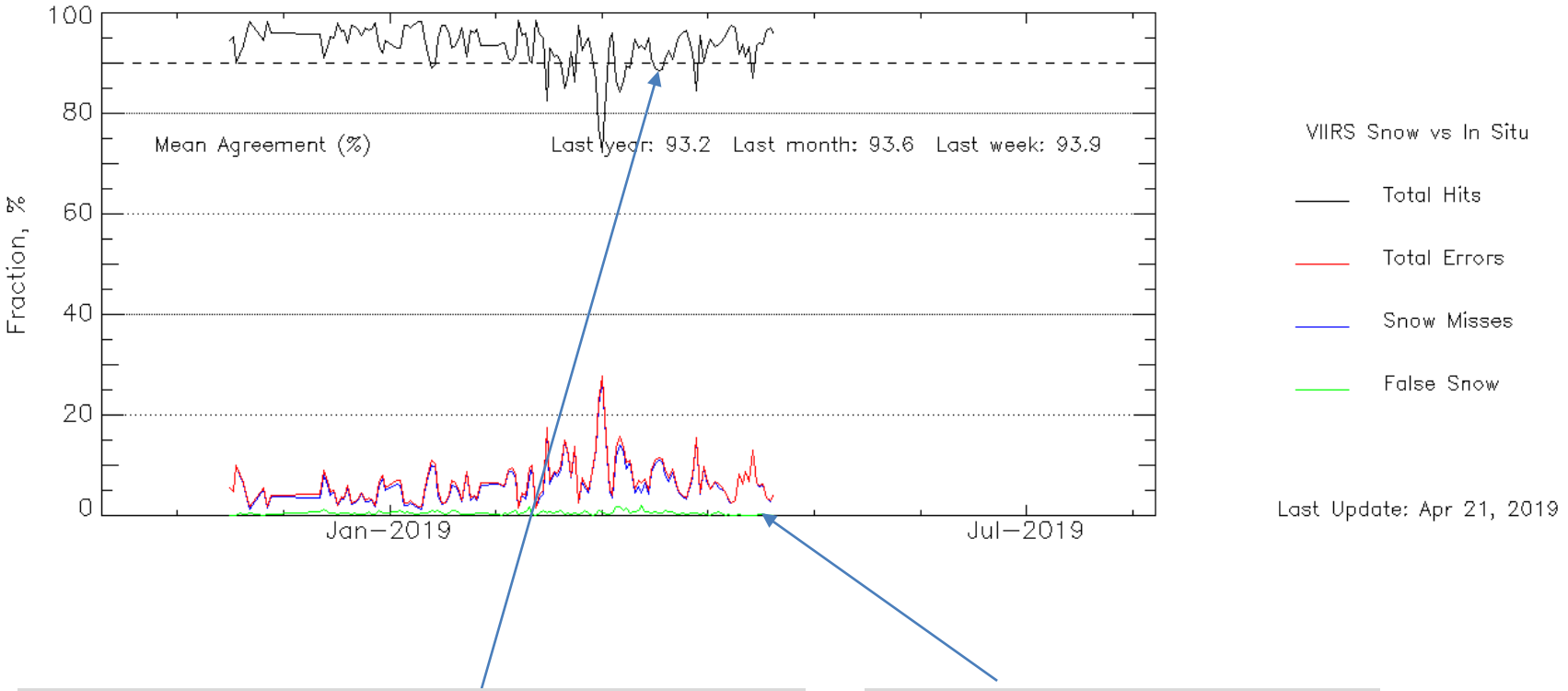


GHCN-D includes data from
- First-order stations
- US COOP
- CoCoRAHS
- SnoTel
- US ASOS
- Environment Canada
- Other regional networks

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.

NOAA-20 Binary Snow vs in situ observations

Statistics of daily pixel-by-pixel comparison of N-20 VIIRS Binary Snow maps to in situ data for clear sky scenes over US and Northern Canada. Land surface was assumed snow-covered if any non-zero snow depth was reported

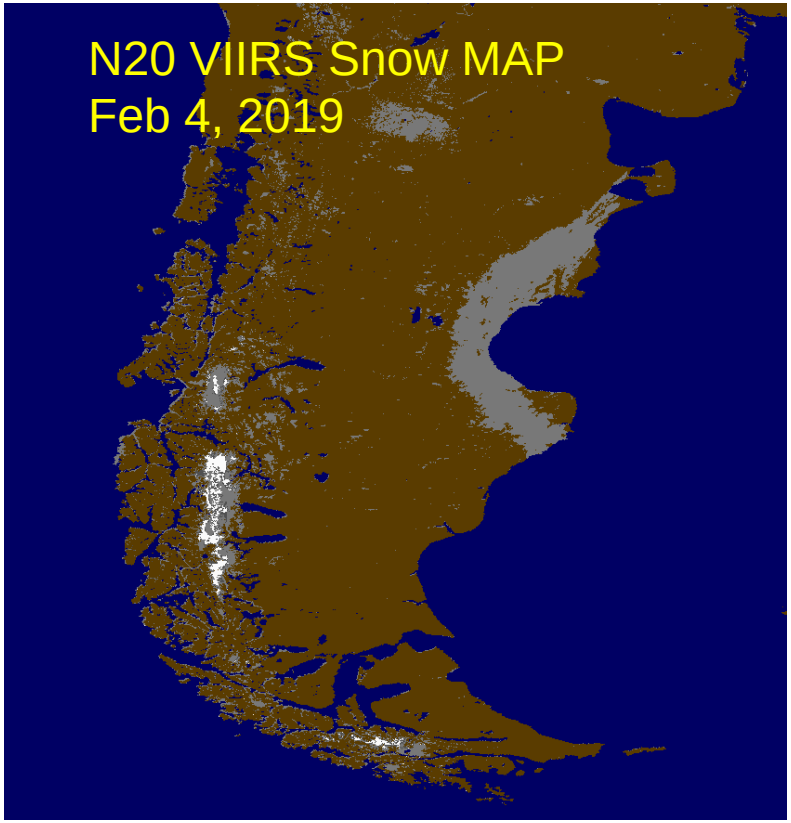


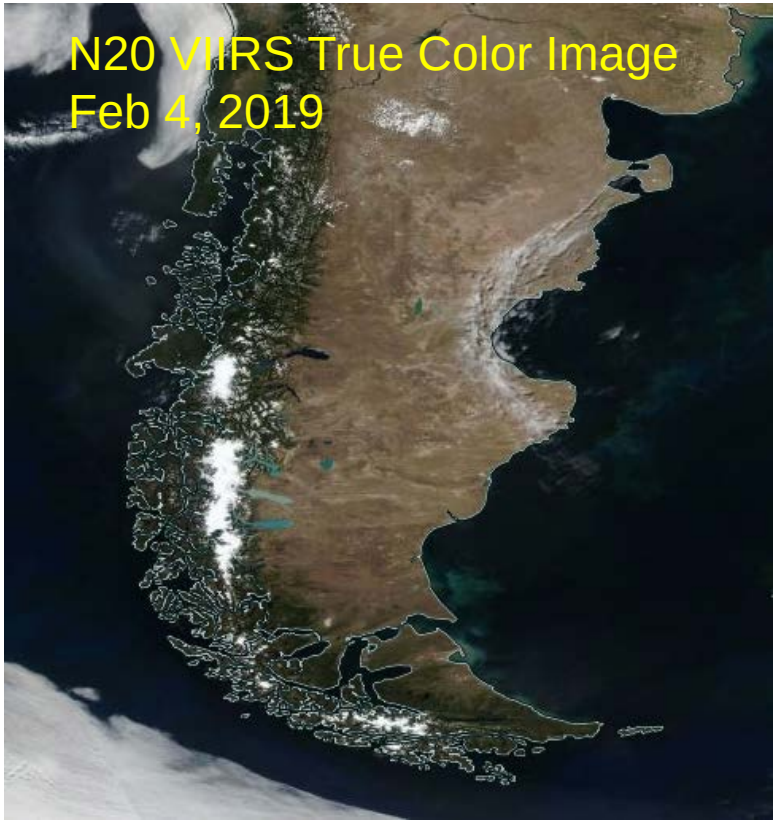
Mean daily agreement to in situ data is 93.2%. This satisfies the requirement of 10% accuracy

VIIRS snow omission errors dominate

VIIRS Binary Snow: Southern Hemisphere

Southern Hemisphere: No IMS, no station data. Snow products are evaluated qualitatively.





Cloud cover over glaciers may be overestimated.

Assessment of Snow Fraction Product

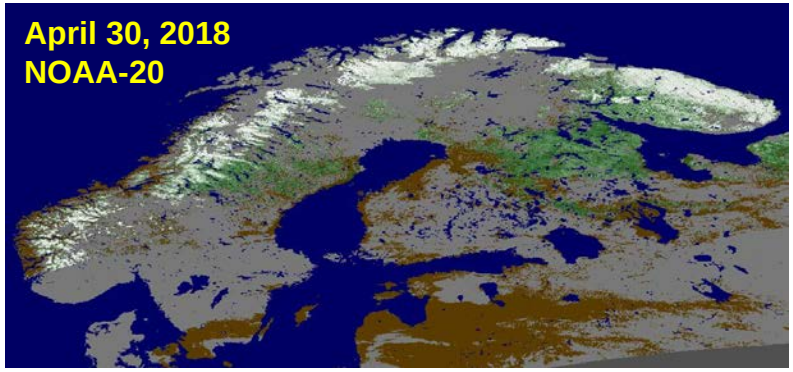
NOAA-20 Snow Fraction Evaluation Approach

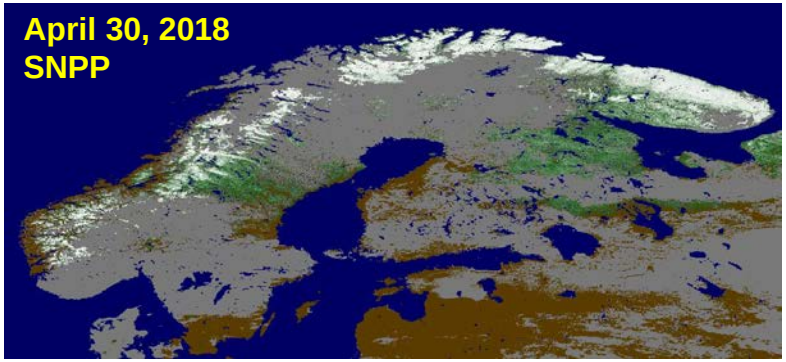
"Viewable" Snow Fraction is a remotely sensed parameter, it is not observed in situ and therefore its accuracy can not be directly evaluated.

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)

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

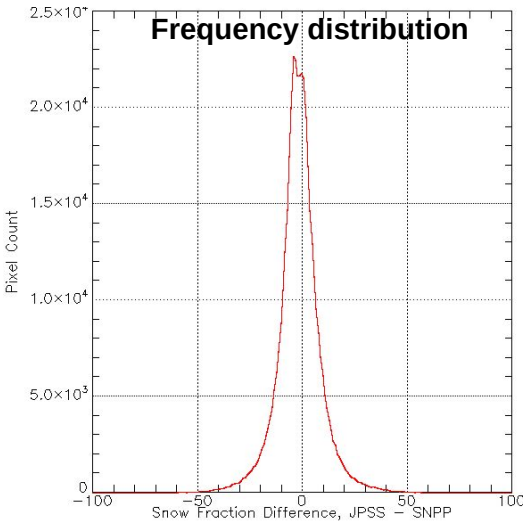
Snow Fraction, N-20 vs SNPP

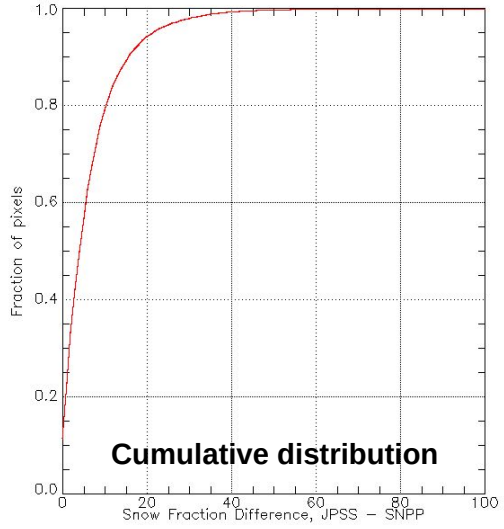




N20 vs SNPP snow fraction
FSC comparison statistics
for 0.02<FSC<0.98

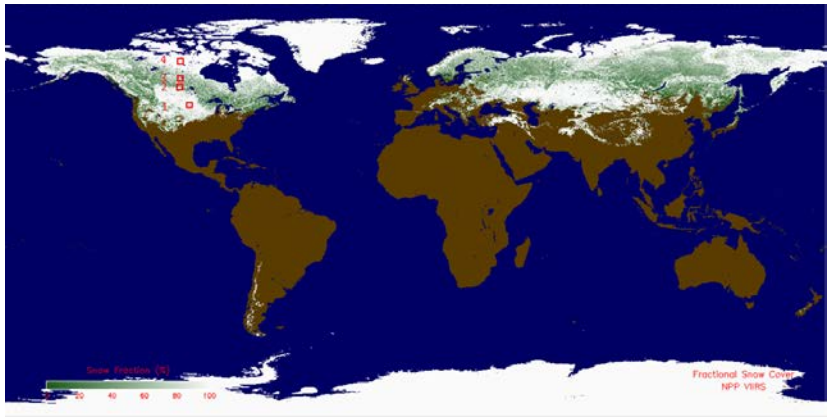
Correlation: 0.94
RMSD: 0.07
Bias: 0.01





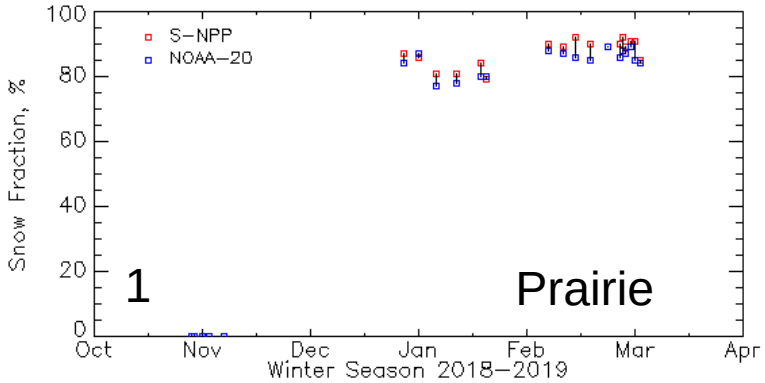
NOAA-20 vs SNPP FSC:
- Strong spatial correlation between FSC estimates
- Small RMSD (< 0.1) with negligible bias

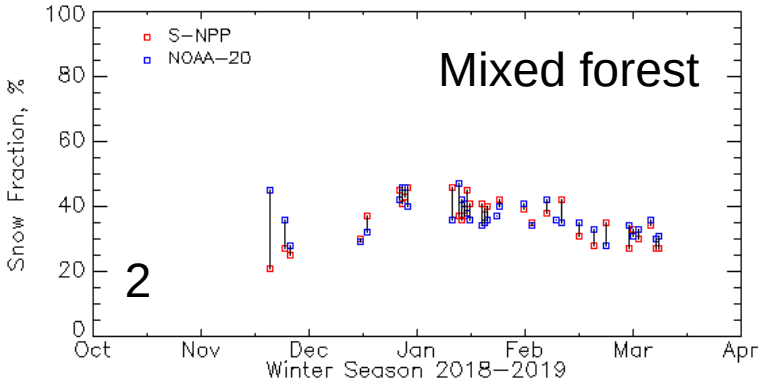
N-20 vs SNPP Snow Fraction: Time Series

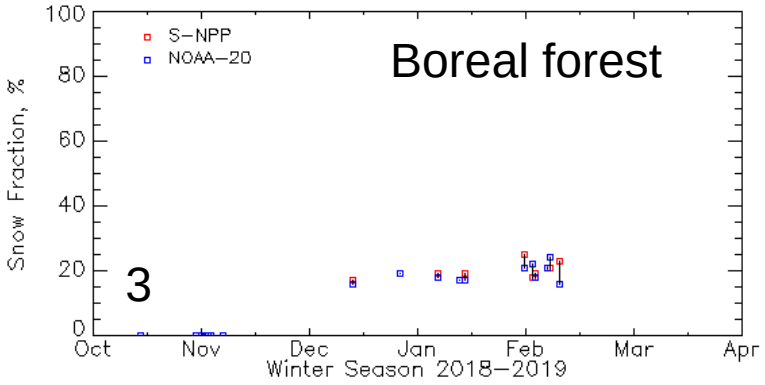


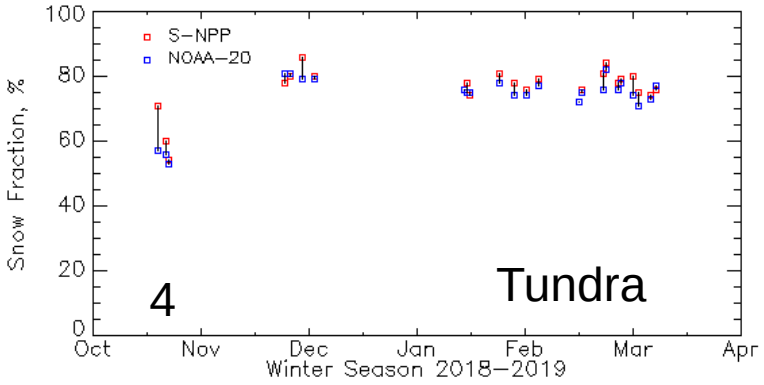
N-20 and SNPP Snow Fraction difference was mostly within 0.1 throughout the winter season with the mean difference of 0.053.

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



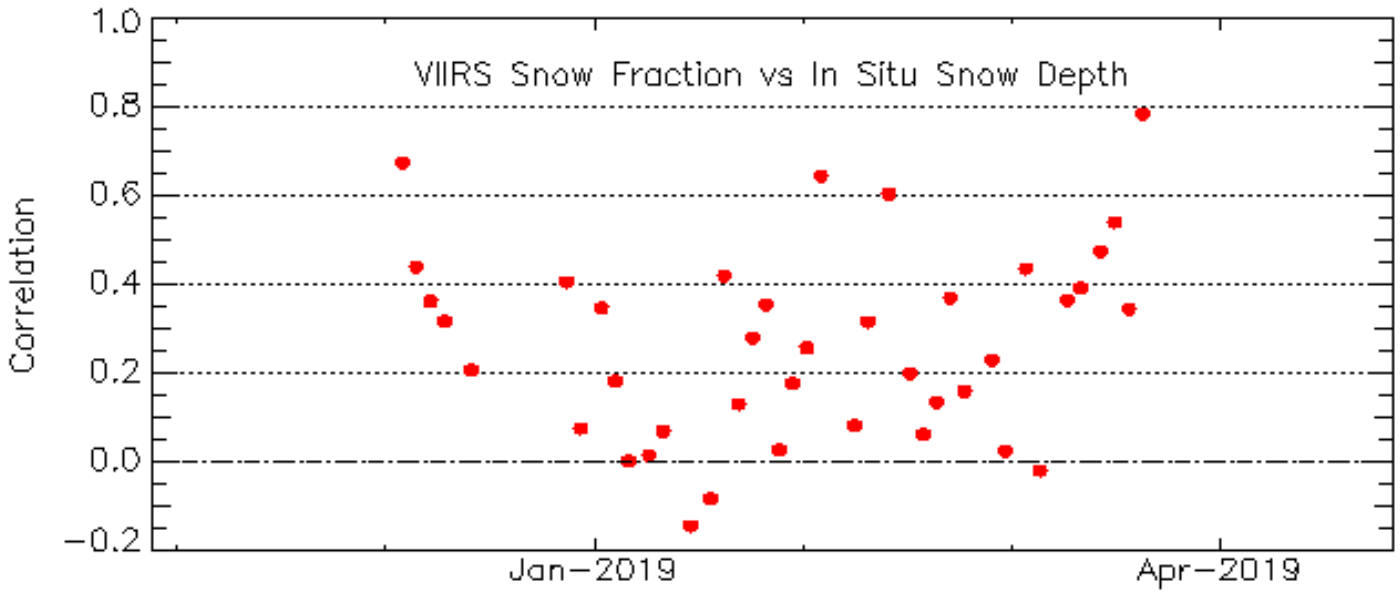






VIIRS Snow Fraction vs Snow Depth

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

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.

Long Term Monitoring Readiness

Collection of daily snow granules and generation of daily gridded snow maps is performed daily.

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 is provided as the percent of correct snow/no snow identifications.

Accuracy estimates are avaialble for the Northern Hemisphere only.

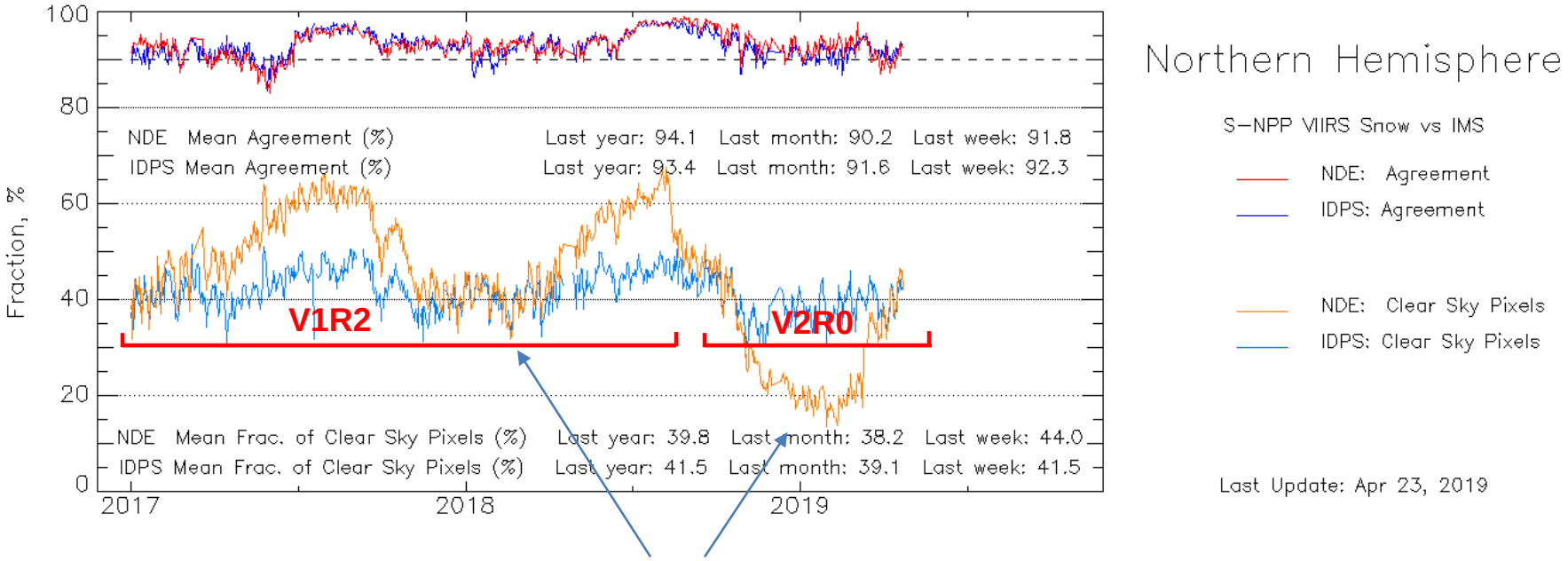
Required algorithm inputs

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

Evaluation of the effect of required algorithm inputs

- Cloud mask is the most critical algorithm input. It affects the snow product accuracy and effective area coverage
- The VIIRS snow product uses the most conservative cloud mask (only “confidently clear” pixels are processed to identify snow)
- A considerable change in the snow product effective area coverage occurred with the implementation of the V2R0 cloud mask in September 2018.

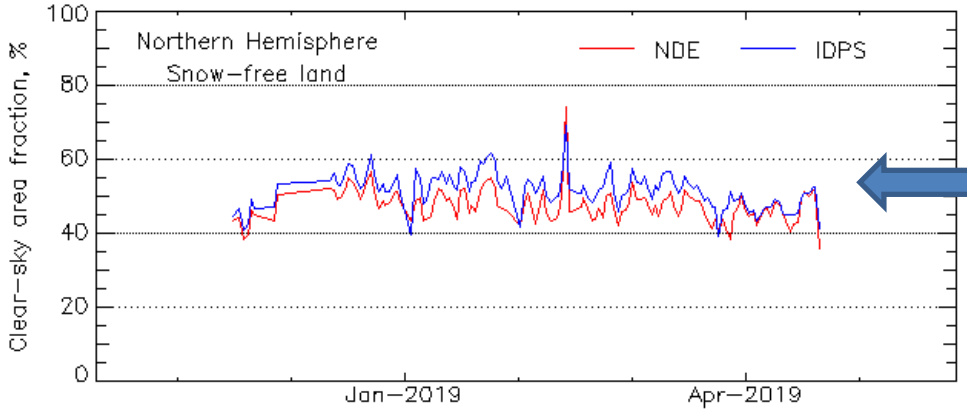
Snow Cover & Clouds: NDE vs IDPS



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 v2r0 cloud mask tends to overestimate clouds over snow-covered land surface

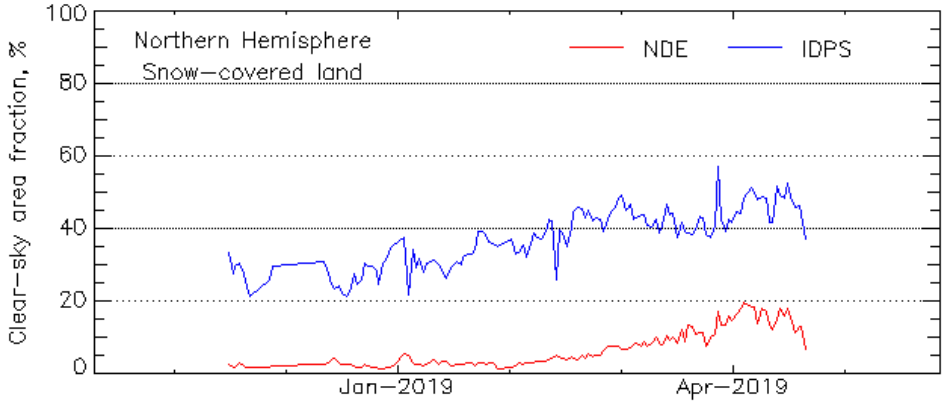
Snow Cover & Clouds: NDE vs IDPS



VIIRS NOAA-20

Snow-free land:
NDE and IDPS cloud masks are similar, changes in the cloud amount are well correlated

Snow-covered land:
NDE cloud mask: More clouds, less clear-sky scenes. Very few identified clear sky scenes during winter months



Quantitative comparison of NDE and IDPS cloud masks over snow covered and snow-free land confirmed the conclusion based on the qualitative analysis of the products. NDE v2r0 cloud mask maps considerably more clouds over snow-covered land surface than IDPS.

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

User Feedback

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

- At this time the 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 is too conservative over snow-covered land surface	Reduced product effective area coverage in high latitudes	Contacted Cloud Team, will work to resolve the issue

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	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)	JPSS Annual Meeting

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-20 VIIRS Snow Products have been extensively evaluated and validated during the 2018-2019 winter season
- Both products (Binary Snow Cover and Snow Fraction) adequately reproduce snow cover properties, demonstrate robust performance and generally satisfy accuracy requirements
- Information is sufficient to make qualitative assessment of the product
- Required documentation exists
- **NOAA-20 Snow products have reached Provisional Maturity**

Path Forward

- Planned improvements
  - Conduct testing of the Cloud Mask at different confidence levels. A more relaxed cloud mask will increase the effective area coverage of the product
  - Expand the quality flag to include cloud shadows

- Future Cal/Val activities / milestones
  - Continue evaluation of the product in 2019-2020 focusing on both Northern and southern Hemisphere
  - Assess the product performance over various surface cover types and topography.
  - Modify quality flags to incorporate all categories of the cloud mask
  - Validated Maturity later this year

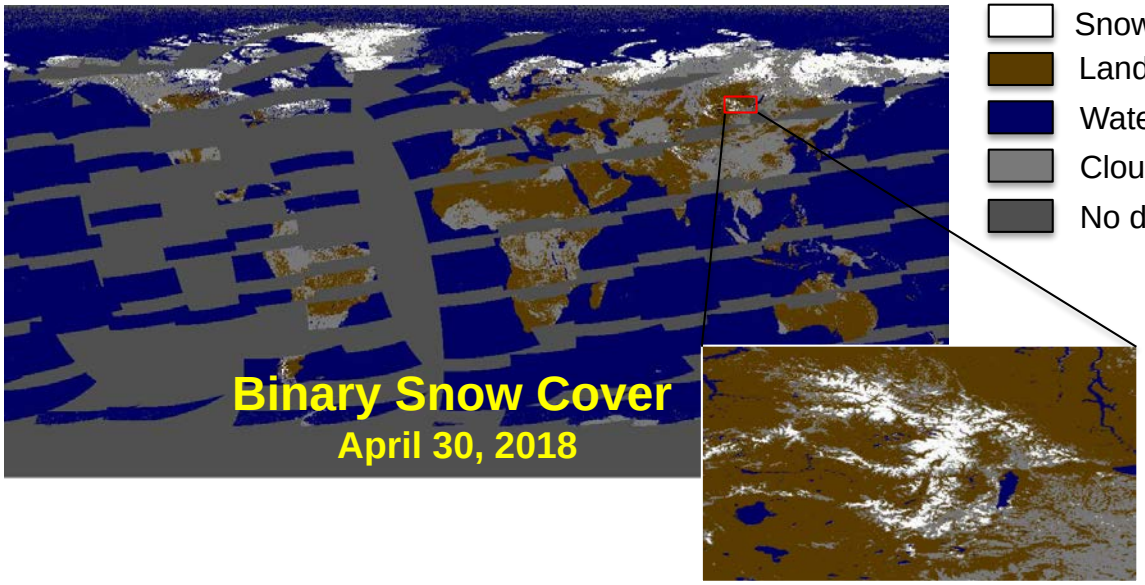
Extra Slides

Requirement Check List – Snow Cover

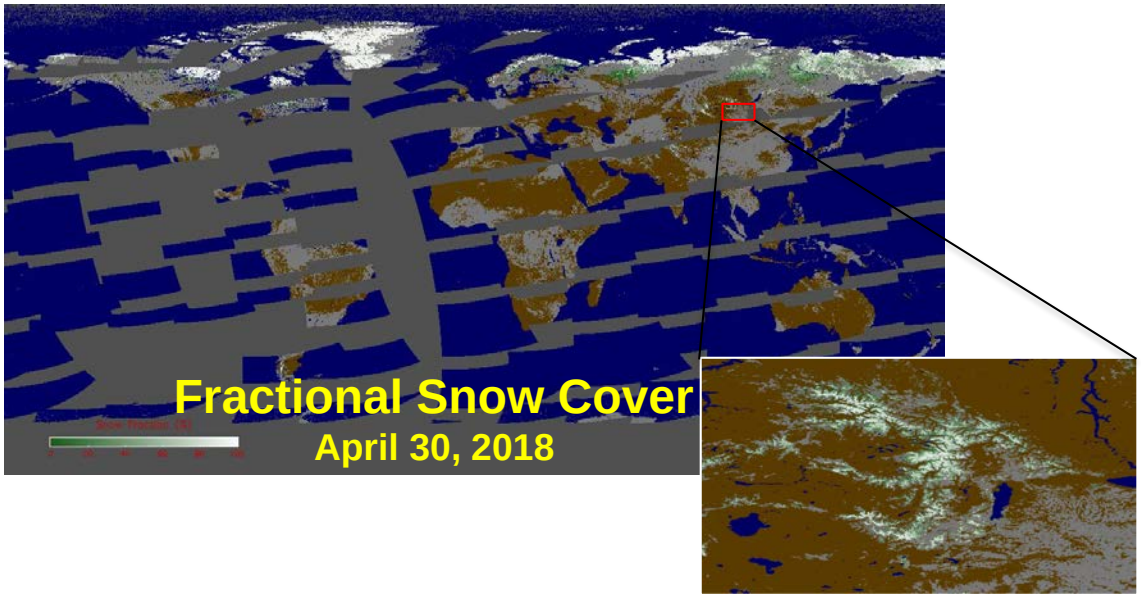
JERD	Requirement	Meet Requirement (Y/N)?
JERD-2439	The algorithm shall produce a snow cover product that has a horizontal cell size of 1.6 km (edge of scan) for clear pixels	Yes
JERD-2520	The algorithm shall produce a snow cover product that has a measurement range, snow cover, of:	
	0-100% area fraction	Yes
	0 or 1 binary mask	Yes
JERD-2521	The algorithm shall produce a snow cover product that has a mapping uncertainty (3 sigma) of 3 km for clear pixels	Yes
JERD-2522	The algorithm shall produce a snow cover product that has a measurement uncertainty of:	
	20% snow fraction	Yes
	90 % probability of correct snow/no-snow classification for clear pixels	Yes

Results from Beta Maturity Review and Provisional Maturity Review of October 2018

Beta Review: Qualitative Evaluation



Snow
Land (no snow)
Water
Cloud
No data



Qualitative analysis has shown

- No obvious issues at the scan-line or granule level

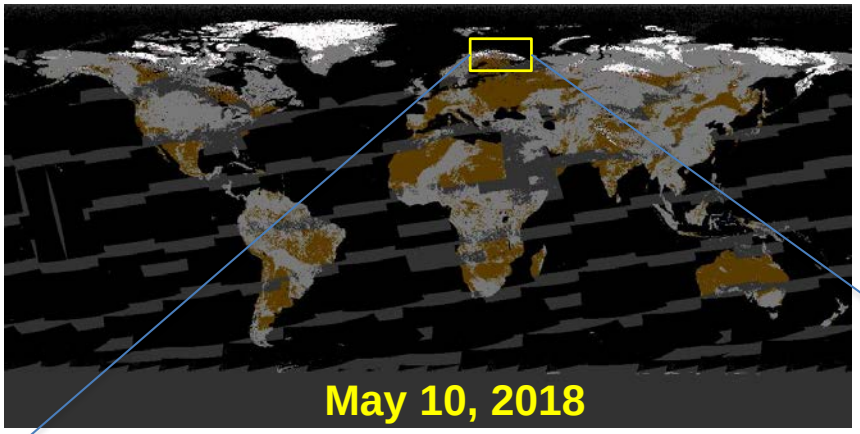
- No unusual/unphysical spatial patterns/features in the mapped snow

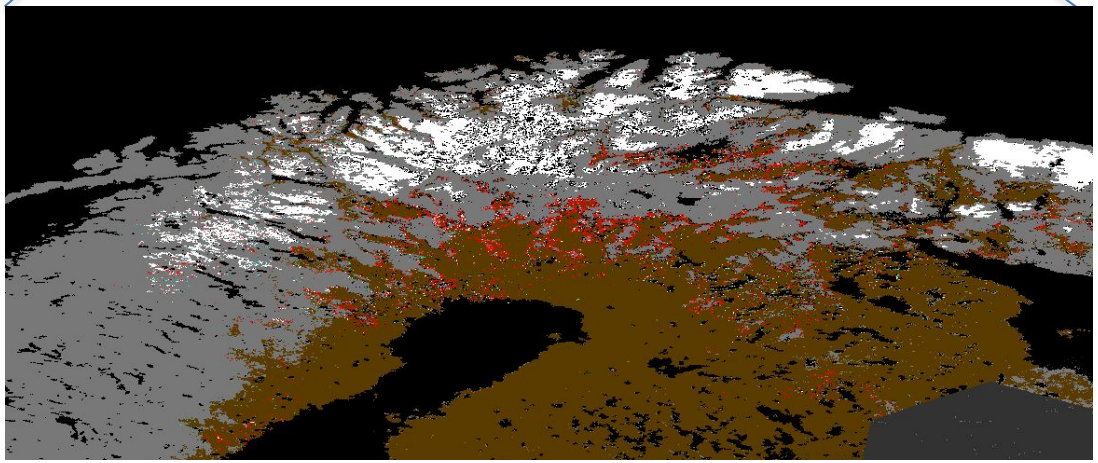
- Generally realistic characterization of the global snow cover distribution

- Large fraction (about 20-25%) of all daytime snow product granules is not available. The issue was fixed in the next code delivery.

Beta Review: NOAA-20 vs SNPP Binary Snow

Overlay of VIIRS NOAA-20 and SNPP daily snow masks

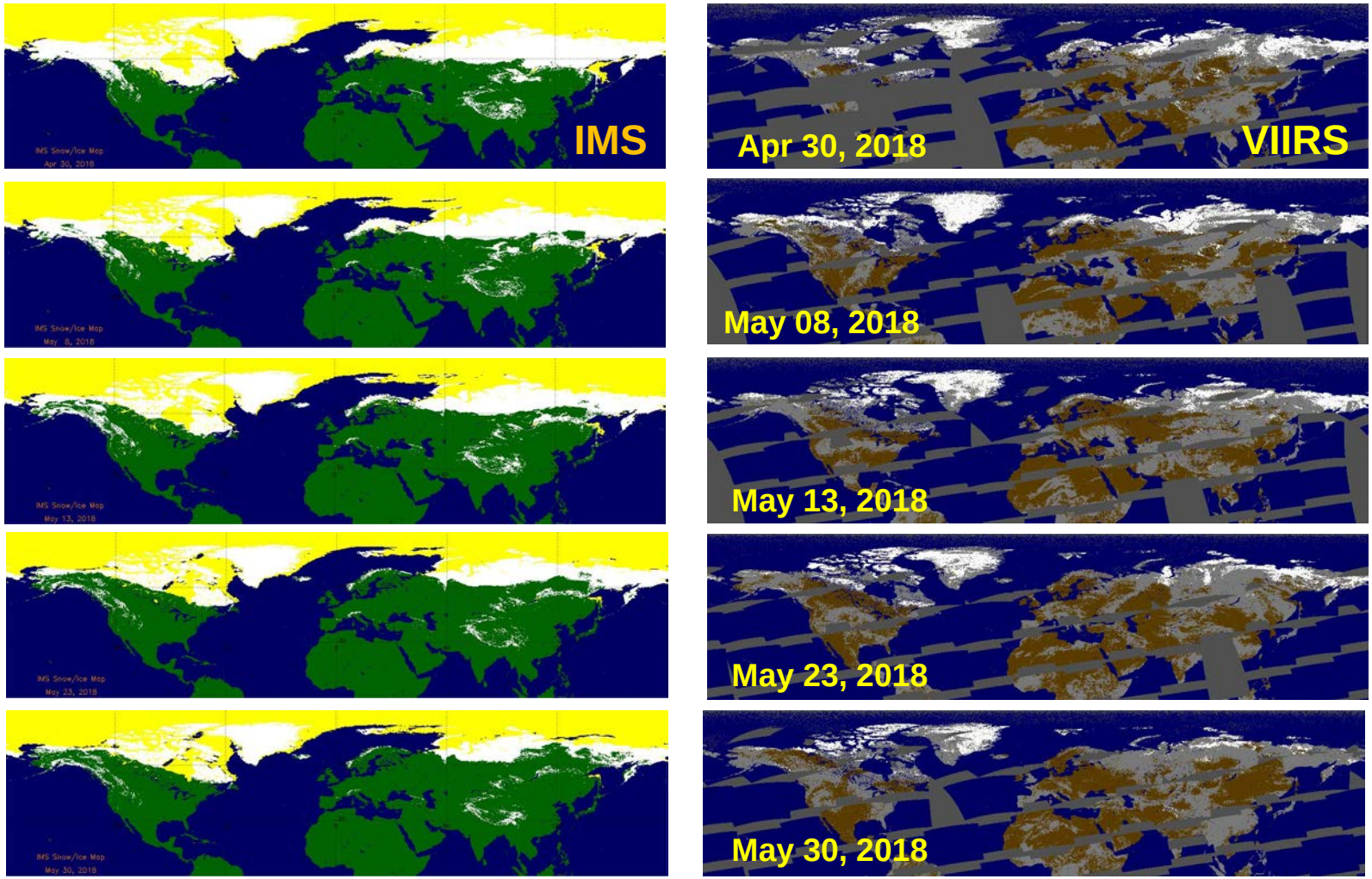




N20: Snow, NPP: Land
N20: Land, NPP: Snow
Both: Snow
Water
Cloud
No data

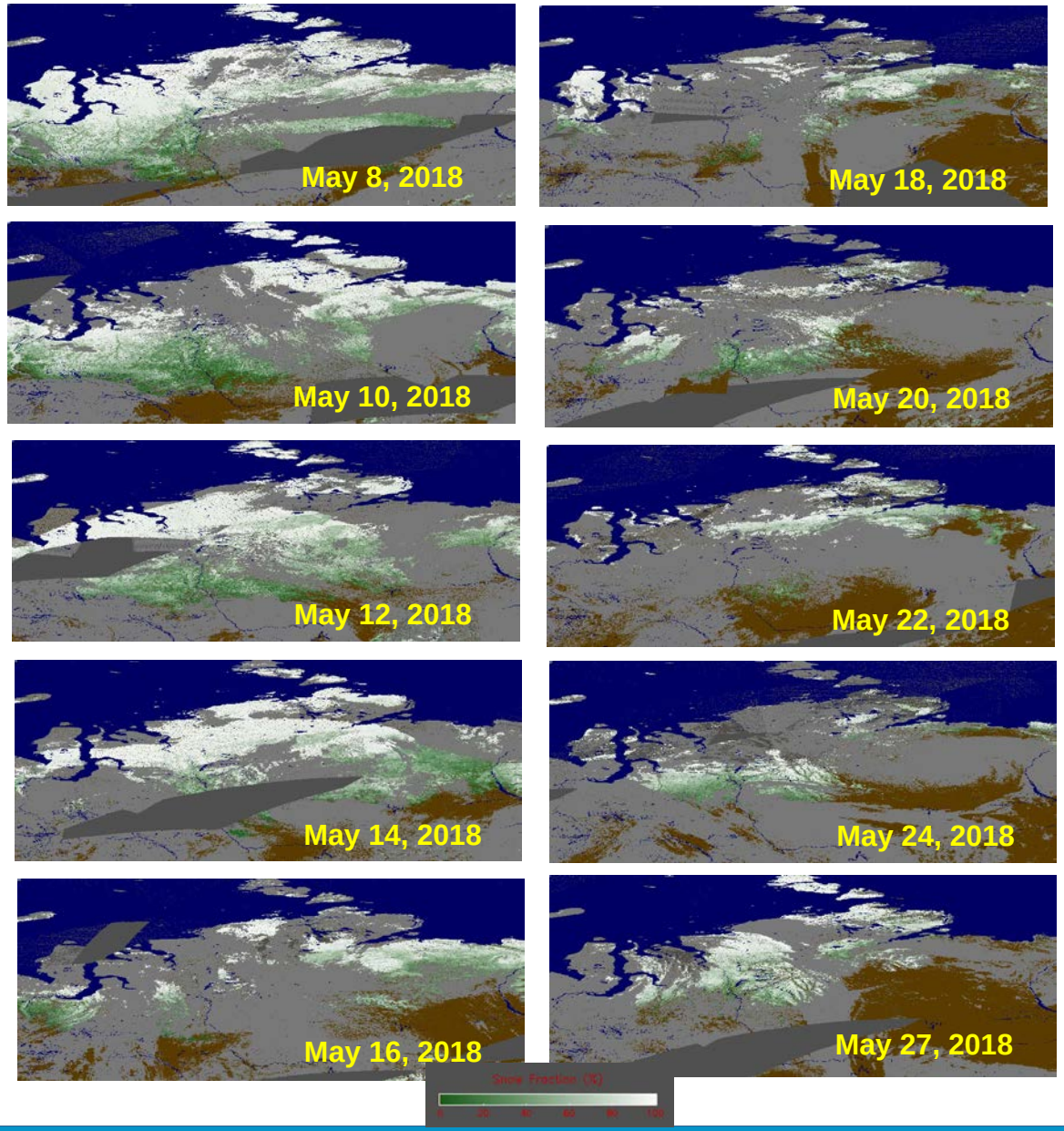
NOAA-20 vs SNPP NDE Binary Snow Mask:
- Over 98% agreement on snow/no snow in the N. Hemisphere
- Differences are mostly in the transition snow/no-snow region

Beta Review: NOAA-20 vs IMS



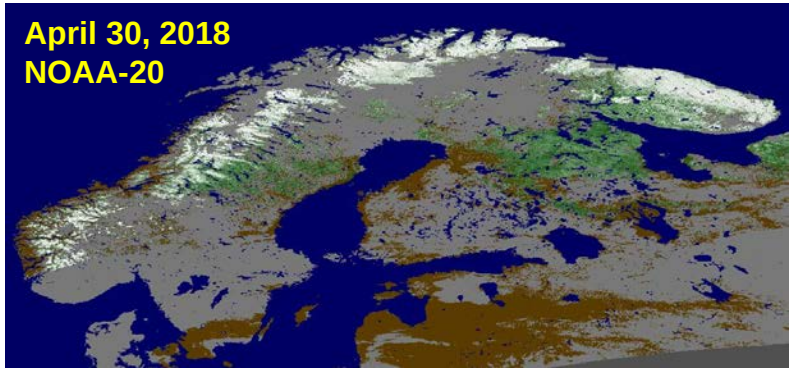
Good qualitative agreement between NOAA-20 Binary Snow and NOAA Interactive Snow Maps

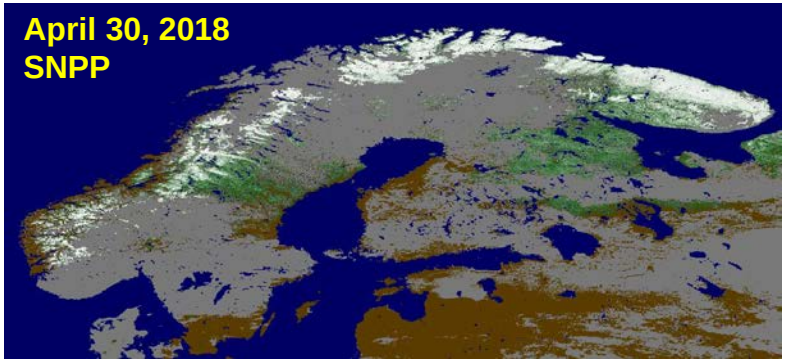
Beta Review: Snow Fraction



Derived snow fraction maps realistically reproduces gradual changes in the snow fraction and snow extent during springtime snowmelt.

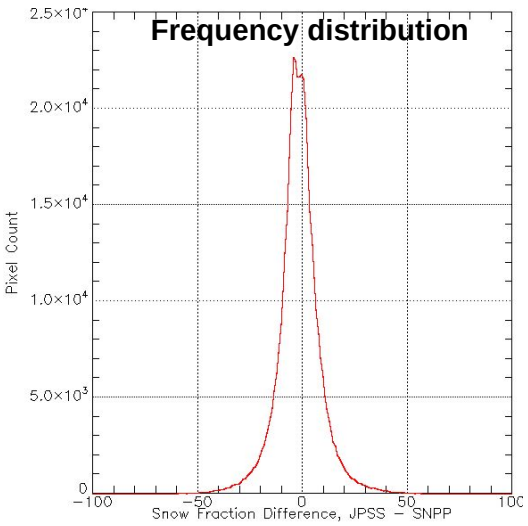
Beta Review: Snow Fraction, N-20 vs SNPP

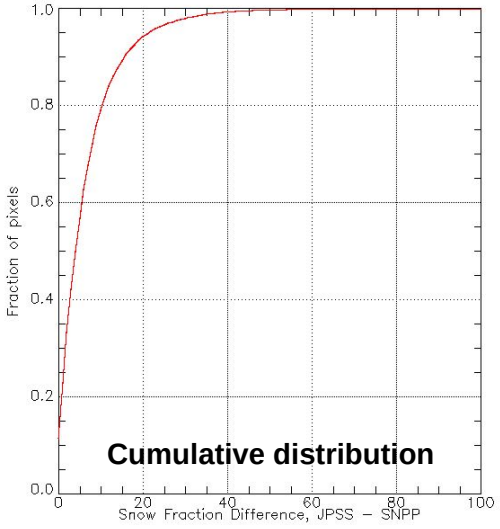




N20 vs SNPP snow fraction
FSC comparison statistics
for 0.02<FSC<0.98

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