Validated Stage 1 Science Maturity Readiness Review for Snow Cover Fraction

Presented by Igor Appel
Cryosphere Products Validation Team

September 4, 2014

Outline (recommended)

- Algorithm Cal/Val Team Members
- Product Requirements
- Evaluation of algorithm performance to specification requirements
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- Documentation
- Identification of Processing Environment
- Users & User Feedback
- Conclusion
- Path Forward

Cryosphere Team Membership

EDR	Name	Organization
Lead	Jeff Key	NESDIS/STAR
Co-Lead	Pablo Clemente-Colón	NESDIS/STAR and NIC
Wisconsin:		
Ice	Yinghui Liu	CIMSS/U. Wisconsin
Ice	Xuanji Wang	CIMSS/U. Wisconsin
Ice	Rich Dworak	CIMSS/U. Wisconsin
Maryland:		
Snow	Peter Romanov	CREST/CCNY
Snow	Igor Appel	IMSG
Colorado:		
Ice	Mark Tschudi	U. Colorado
Ice	Dan Baldwin	U. Colorado
Other:		
All	Paul Meade	DPE

VIIRS Snow Cover Product Users

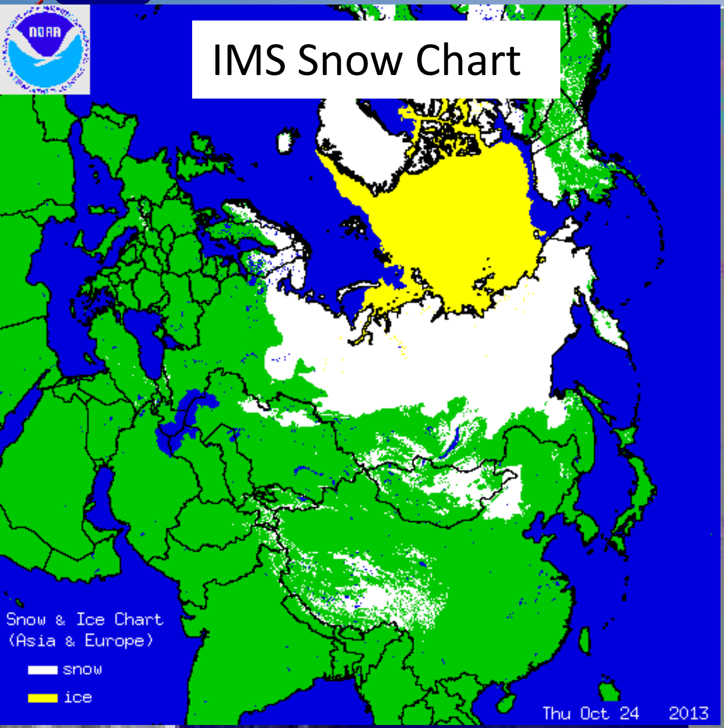
- U.S. Users
  - NSIDC - National Snow Ice Data Center
  - NIC - National/Naval Ice Center
  - OSPO - Office of Satellite and Product Operations
  - NOHRSC - National Operational Hydrological Remote Sensing Center
  - STAR- Center for Satellite Applications and Research
  - CLASS - Comprehensive Large Array-data Stewardship System
  - NWS including Alaska

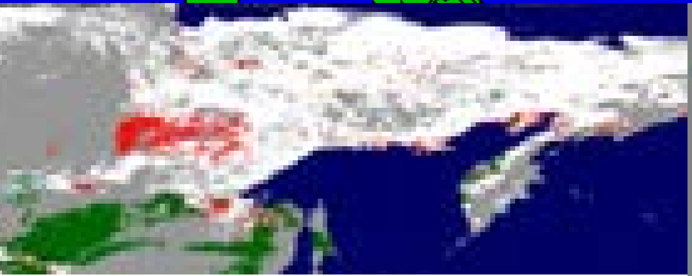
- User Community
  - Agriculture
  - Hydrology
  - Numerical Weather Prediction
  - Transportation
  - Emergency Management
  - DOD

VIIRS Snow Cover EDR

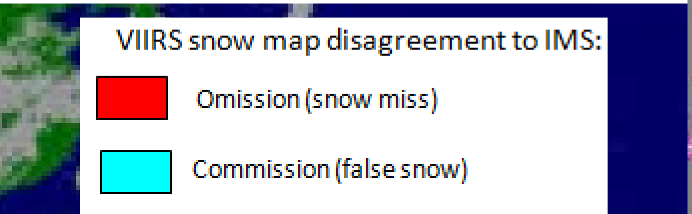
- The VIIRS Snow Cover/Depth Environmental Data Record (EDR) product consist of two products
  1. Snow/no snow binary map
  2. Snow fraction in a horizontal cell
- The objective of the VIIRS retrieval is to achieve the performance specifications designed to meet the requirements stated in the NPOESS System Specification.
- The specifications apply under clear-sky, daytime conditions only. Surface properties cannot be observed through cloud cover by a Visible/Infrared (VIS/IR) sensor.
- The specification for the NPOESS Snow Cover/Depth EDR places requirements on the VIIRS binary map product and the VIIRS snow fraction product.

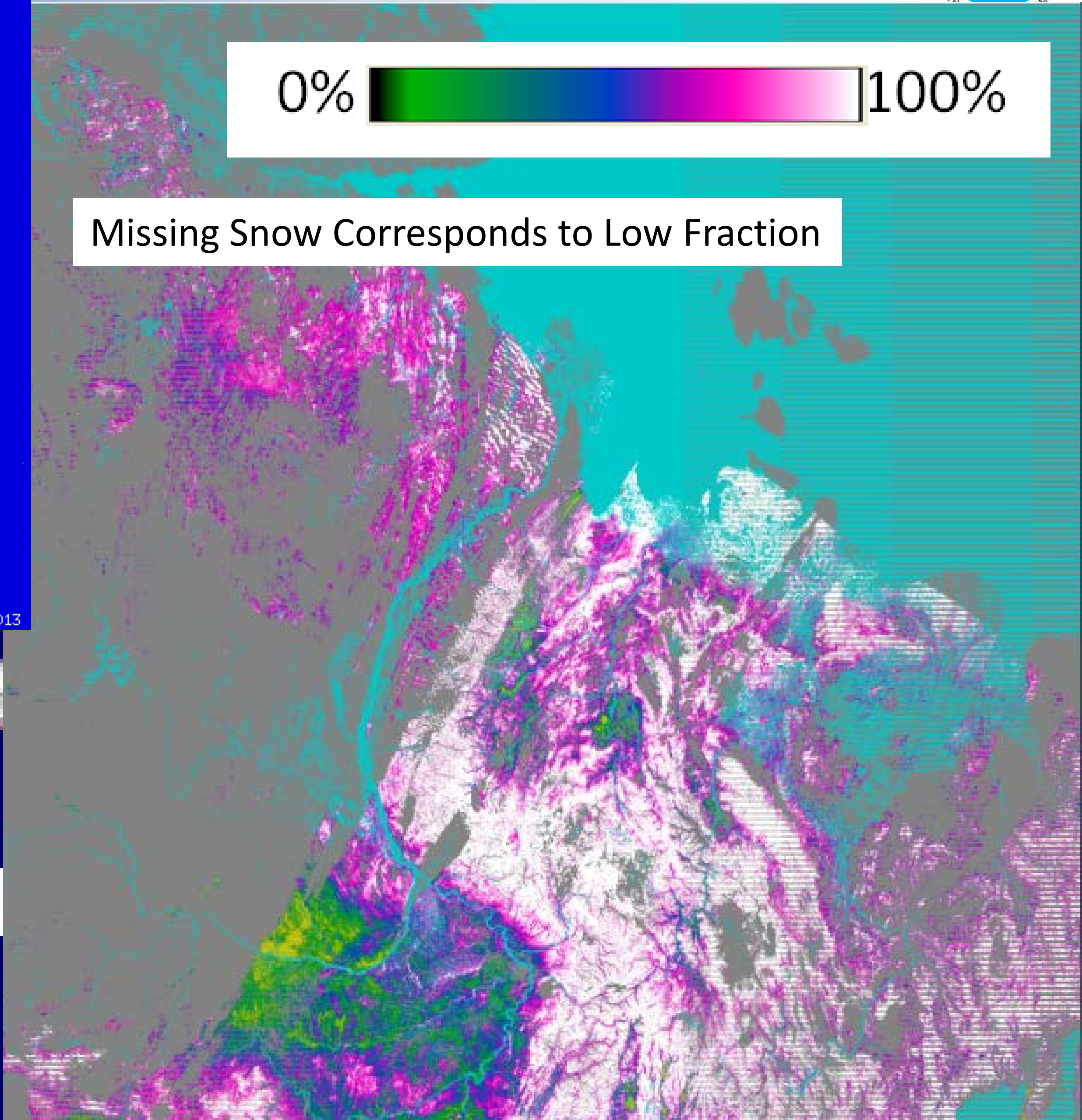
Snow Fraction on 10/24/13 (03:20)





Missing Snow in Binary retrieval





Specification of the VIIRS Snow Fraction

Parameter	Specification Value
a. Horizontal Cell Size,	
1. Clear – daytime (Worst case)	1.6 km
2. Clear – daytime (At nadir)	0.8 km
3. Cloudy and/or nighttime	N/A
b. Horizontal Reporting Interval	Horizontal Cell Size
c. Snow Depth Ranges	> 0 cm (Any Thickness)
d. Horizontal Coverage	Land
e. Vertical Coverage	> 0 cm
f. Measurement Range	0 – 100% of HCS
g. Measurement Uncertainty	10% of HCS (Snow/No Snow)
h. Mapping Uncertainty	1.5 km

Requirements to Snow Fraction Retrieval (Uncertainty)

- Initially, the U.S. Government (USG) threshold requirements formulated by DoD and DOC in the Integrated Operational Requirements Document (IORD) included 10% measurement uncertainty under clear conditions for 1.3 km horizontal cell size.

- The threshold requirements needed for Improved Freshwater Resource Management consider snow information for North America as Mission Critical data with measurement accuracy 10% and horizontal resolution 0.5 km.

- It is logical that the requirement to measurement uncertainty for Fractional Snow Cover remained unchanged in the latest version of the Level 1 Requirements, Supplement.

NPOESS Snow Fraction Retrieval

- Originally, an application of the Multiple Endmember Spectral Mixture Analysis (MESMA) was developed for VIIRS to retrieve snow fraction.

- The spectral mixture analysis defines subpixel proportions of spectral endmembers related to mappable surface constituents.

- It “unmixes” the mixed pixel, determining the fractions of each spectral endmember combined to produce the mixed pixel’s spectral signature.

- The performance analysis indicated that the measurement uncertainty requirement can be achieved, except for scenes with forest canopy.

Transformation of NPOESS Algorithm

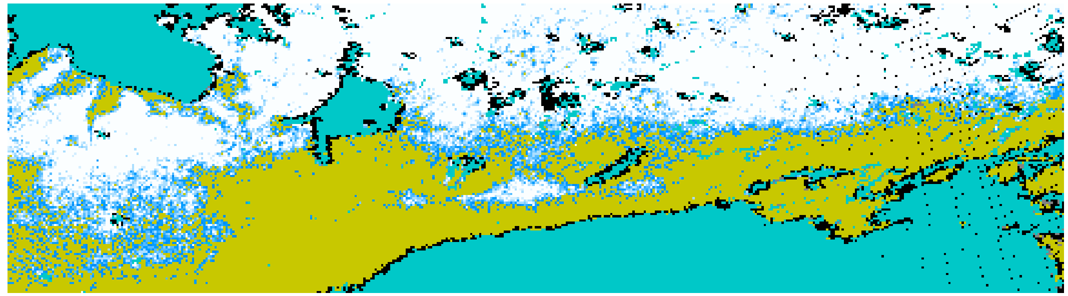
- In the current version of the VIIRS processing system, the MESMA was (temporarily?) replaced by the aggregation of the Binary Snow within 2x2 pixel blocks.

- According to one source, Snow Fraction computed based on a 2x2 aggregation of the binary map replaced the originally proposed Multiple End Member Spectral Mixture Analysis (MESMA) approach due to uncertainty in the effort required to understand complex behavior in the initial results.

- Snow fraction computed based on a 2x2 aggregation of the binary map is not a valid approach and provides no additional information beyond that already provided by the Snow Binary Map.

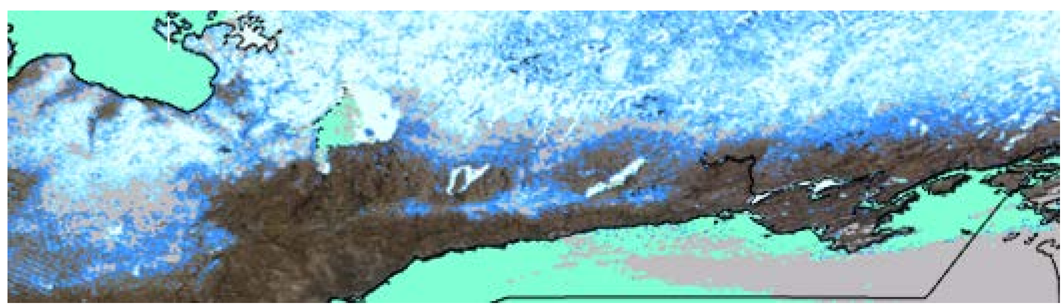
Transition Zones from Snow Covered Regions to Snow Free Areas are Very Narrow

VIIRS fraction



Image

MODIS fraction



In 2x2 snow fraction (top) snow to no snow transition regions are unrealistically narrow compared to the MODIS based snow fractions

SNPP Validation Stages Maturity Definition

Validated Stage 1:

Using a limited set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Validated Stage 2:

Using a moderate set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Validated Stage 3:

Using a large set of samples representing global conditions over four seasons, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Discrepancy Report 4246

- Title: Snow algorithm inconsistent with … requirements
- Submitter: Neal Baker
- Program Officer Monitor: Paul Meade
- Description: … a 10% (uncertainty) value cannot be achieved. We will have to investigate sub pixel snow algorithms.
- Secondary comment of 20130416: … this algorithm … is of little value to a user and it really deserves to be delete and replaced by an alternate algorithm
- Secondary comment of 20131029: … Program Office Monitor set to … Cryosphere EDR JAM to begin work looking at substitute fractional snow cover algorithms, per recommendation of Mitch Goldberg and Jim Gleason during data product Beta Maturity AERB and direction of Cryo Cal/Val Lead Jeff Key

Algorithm Recommendations

Recommendations for IDPS algorithms:

Product	Through Aug 31	NPP after Aug 31	JPSS
Binary Snow Cover	1	1	1 or 3
Fractional Snow Cover	2	2	2

1. NPOESS algorithm has evolved into the NOAA-endorsed JPSS algorithm and any needed improvements should continue.
2. NPOESS (or evolved) algorithm will not meet requirements or effort is too large, replace with NOAA-endorsed JPSS algorithm
3. NOAA-endorsed algorithm should be used even if NPOESS (or evolved) algorithm meets performance because of legacy, enterprise, blended products, and other considerations.

Alternative Snow Fraction Algorithms for VIIRS

Multispectral, multi-endmember linear unmixture (MODSCAG, GOESRSCAG, MESMA – Painter, 2009)
- Most comprehensive approach, uses observations in all reflective spectral bands
- Derives the fraction of each surface type within IFOV including snow
- Spectral properties of all global land cover types to be accurately characterized (reflectance &BRDF)
- Inversion procedure may be unstable (spectrally similar end-members possible)
- Demonstrated application in occasional local-scale studies (mostly mountain regions)

NDSI-based, Salomonson & Appel (2004) modified by G. Riggs for VIIRS
- Assumes linear relationship between NDSI and snow fraction. End-members are static.
- Extremely easy to implement and take specific local conditions into considerations.
- Serious performance issues over forested areas revealed (MODIS snow team has been notified)
- Implemented operationally with MODIS global data

Single band reflectance-based, linear unmixture, Romanov et al (2003)
- Assumes linear relationship between the TOA visible reflectance and snow fraction
- Needs TOA visible reflectance and BRDF of snow and snow-free land surface
- Easier to implement than the multispectral multi-endmember version of the algorithm
- Used routinely with GOES Imager data over North America since 2003 and with METOP AVHRR over the globe since 2013

Snow Fraction Algorithms

Two approaches/algorithms to estimate snow fraction from satellite data:

NDSI-based, following Salomonson & Appel (2004) as reported by G. Riggs

$$\mathbf{SnowFraction = -0.01 + 1.45 * NDSI}$$

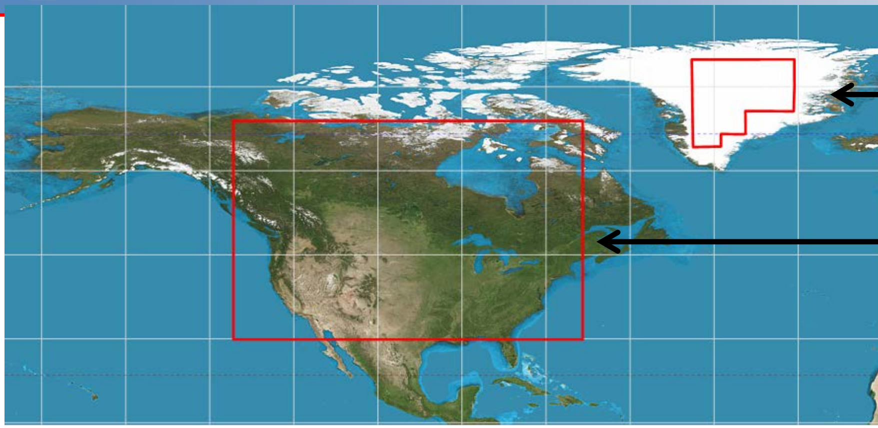
where **NDSI** $= (R_1 - R_3) / (R_1 + R_3)$, and R_1 and R_3 are correspondingly VIIRS-observed reflectances in bands I1 and I3. This is equivalent to a linear mixture algorithm with two end-members representing snow-free land surface and complete snow cover. It has been demonstrated that taking variability of snow and non-snow properties into account increases the quality of snow fraction retrieval. The techniques of geometric optics is used to develop asymptotic analytical equation describing snow bidirectional reflectance with high accuracy and clear physical interpretation applicable to retrieve snow properties. Algorithm has been developed for MODIS and currently used for VIIRS data.

Reflectance-based, modified from Romanov et al (2003)

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

Linear mixture algorithm with two end-members representing snow-free land and fully snow-masked land surface based on VIIRS-observed reflectance in the visible band I1 (**R**). End-member reflectances R_{land} and R_{snow} are determined empirically. The angular anisotropy of the end-memebr reflectance is parameterized with a simple kernel-driven model. Algorithm was first developed for and used with GOES Imager data. A new version of the algorithm with modified parameterization of R_{land} and R_{snow} was applied to NPP VIIRS data. See a more detailed description of the algorithm in a separate document.

BRDF model for Reflectance-based algorithm



Used to determine snow BRDF

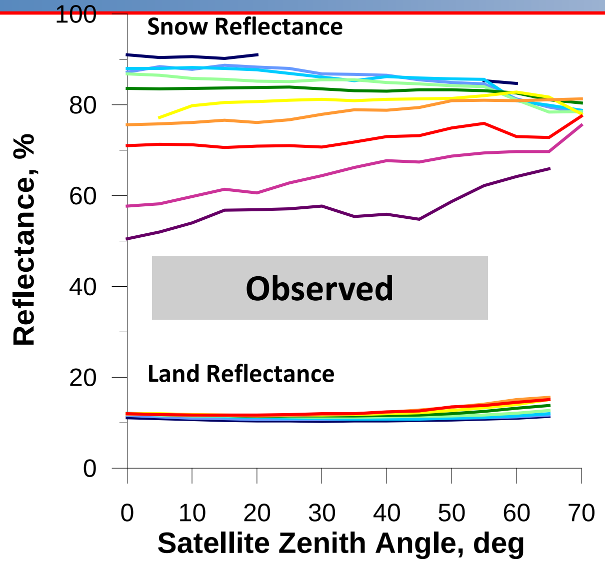
Used to determine snow-free land BRDF

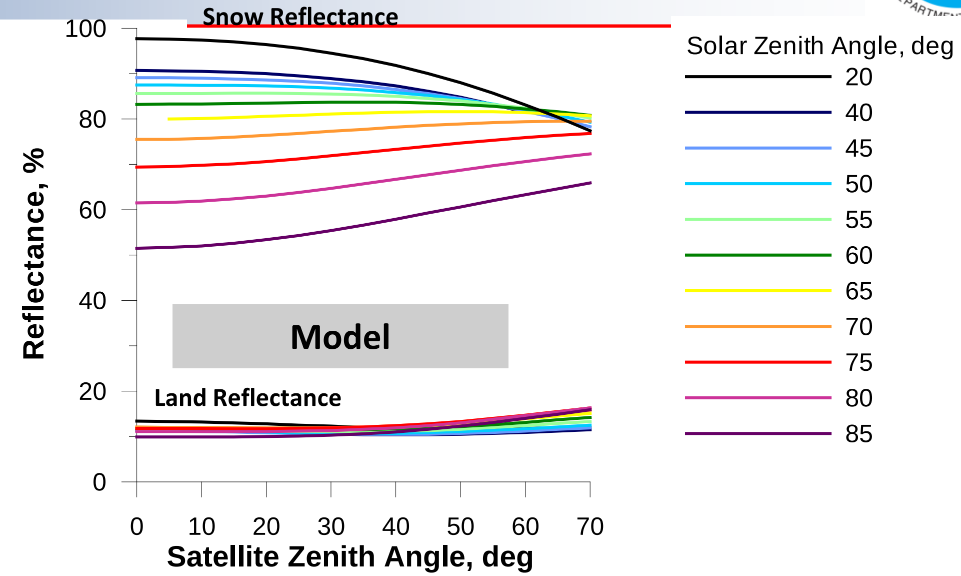
Proposed BRDF model: $\mathbf{R_{snow,\ land} = C_0 + \Sigma_{\ i=1,7}\ C_i\ F_{i,}}$

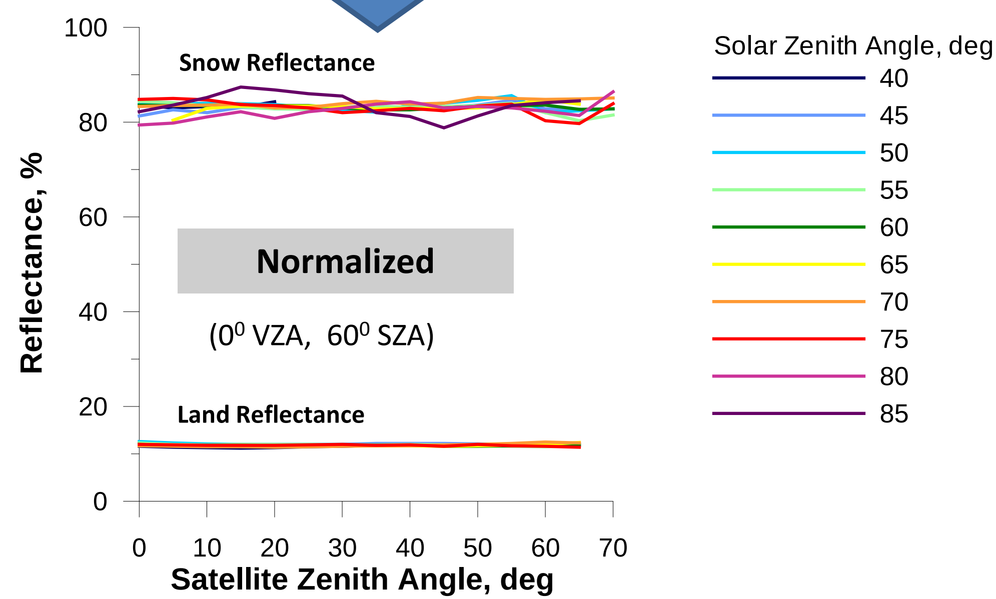
Kernel functions ($\mathbf{F_i}$) and kernel loads ($\mathbf{C_i}$)

Kernel Functions	Kernel Loads	Kernel Load Values	
		Snow-free land	Snow
1.	C_0	19.02	63.45
Cos (θ_{sol})	C_1	9.699	89.90
Cos (θ_{sat})	C_2	-9.944	-16.33
Cos (θ_{sol}) Cos (θ_{sat})	C_3	13.16	61.81
Cos^2 (θ_{sol})	C_4	-36.30	-140.9
Cos^2 (θ_{sat})	C_5	-6.289	-5.114
Cos^4 (θ_{sol})	C_6	20.18	51.62
Cos^4 (θ_{sat})	C_7	5.419	-2.623

Correcting Reflectance for Angular Anisotropy

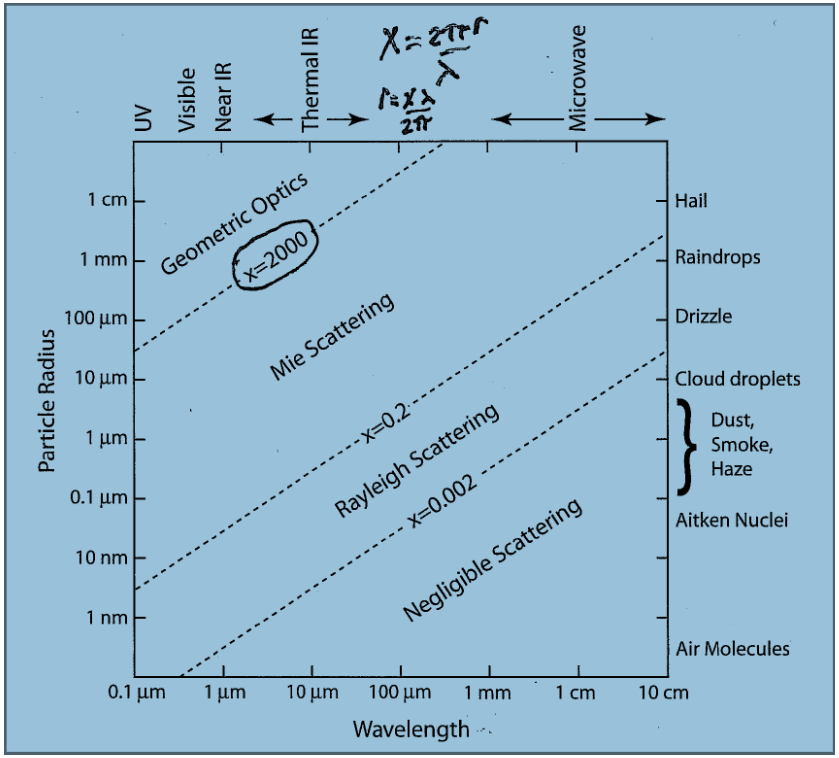






BRDF model helps to reduce the effect of changing observation geometry on the end-member reflectance

Analytical model of snow BRDF



$$R(\mu,\nu,\varphi) = R_0(\mu,\nu,\varphi) - \lambda K_0(\mu) K_0(\eta)$$

where R_0 is taken from precalculated LUT approximated by an analytical function

$$K_0(\xi) = (3/7)(1 + 2\cos(\xi))$$

K_0 – the escape function approximated as

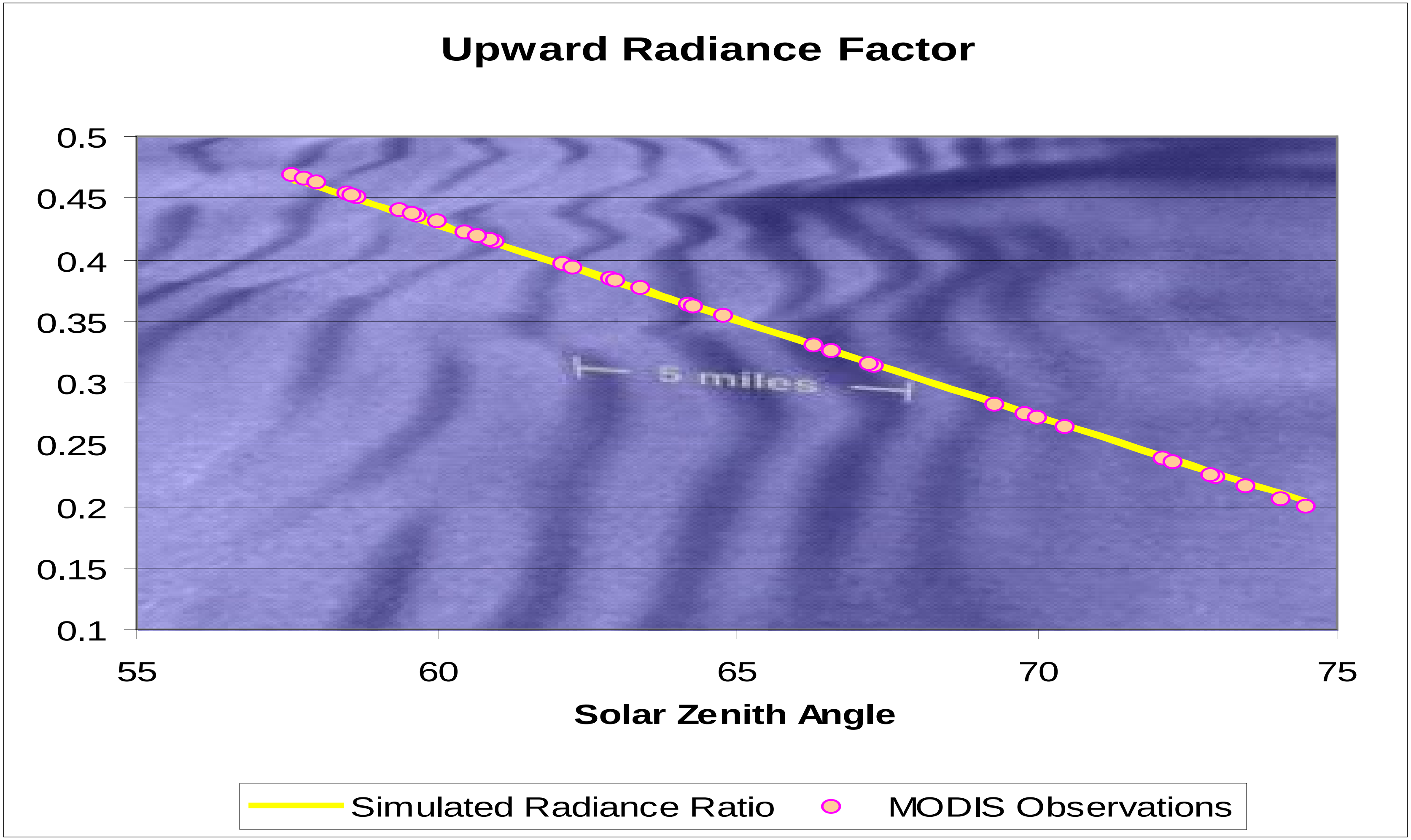
$$\lambda = 4\sqrt{(1-w)/3(1-g)}$$

(λ) - fraction of absorbed energy

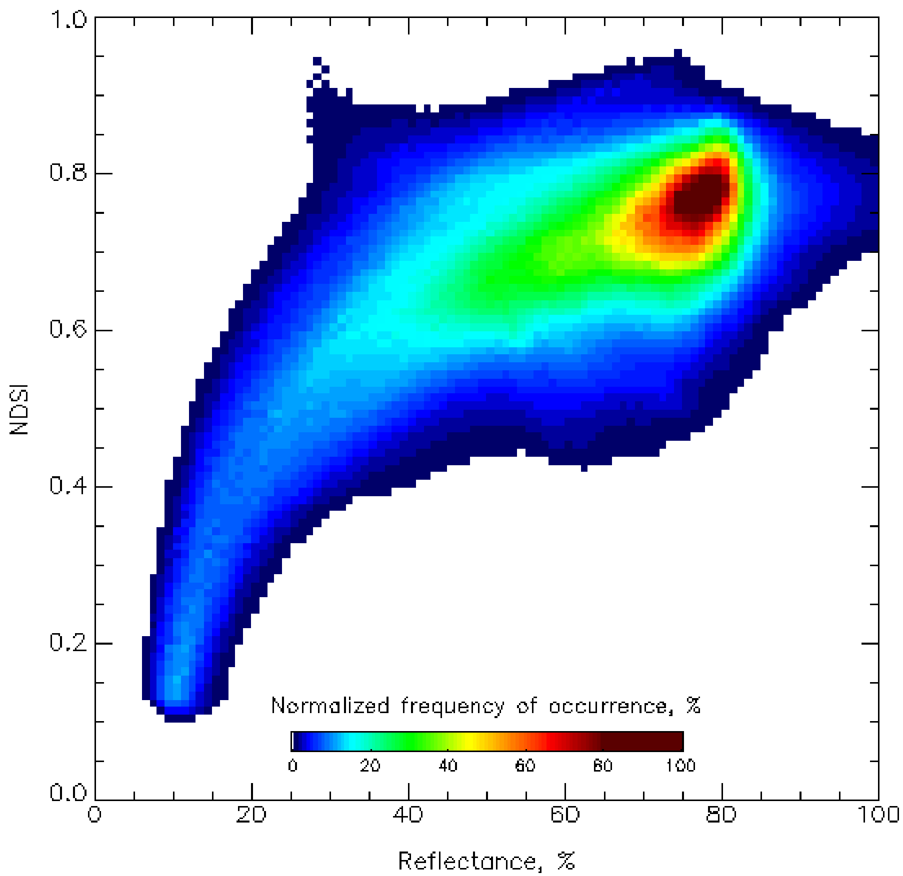
Geometric optics instead of Mie calculations because Mie size parameter > 2000 for snow

Applied asymptotic analytical equation provides simple and highly accurate solution allowing clear physical explanation and interpretation

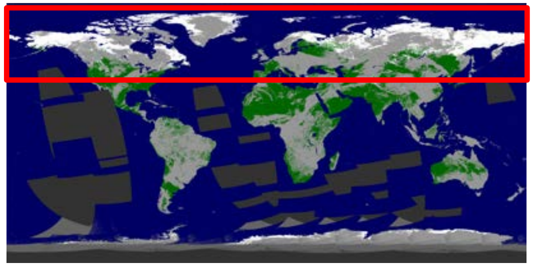
Estimate of Model Accuracy



NDSI vs Visible Reflectance



Scatter plot of VIIRS visible (band 1) reflectance and NDSI for "snow pixels"

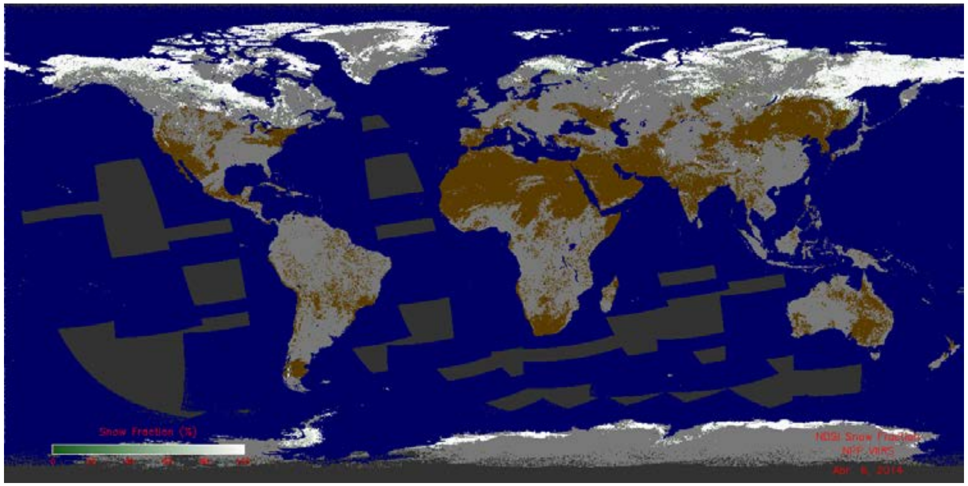


VIIRS snow map , April 9, 2014

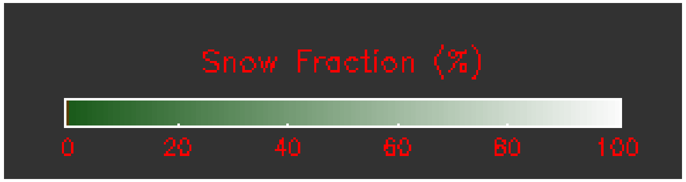
On the whole, the increase in NDSI corresponds to the increase in the visible reflectance, though the relationship between those parameters is clearly non-linear

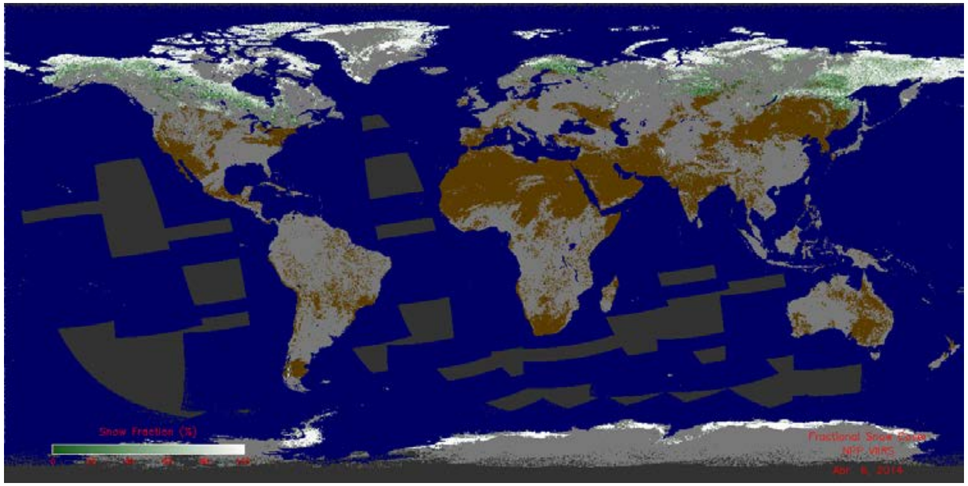
Global Snow Cover Fraction Maps

Since January 2014 VIIRS global gridded snow fraction maps have been derived on a daily basis, see http://www.star.nesdis.noaa.gov/smcd/emb/snow/viirs/viirs-snow-fraction.html.



NDSI-based

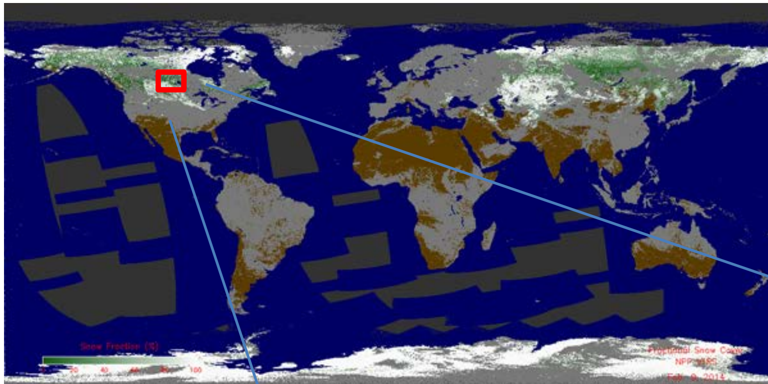




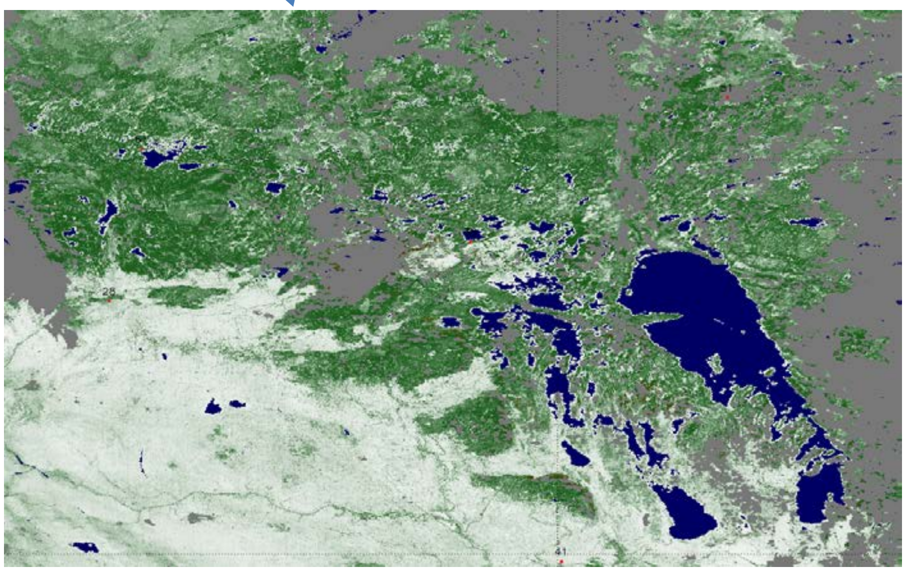
Reflectance-based

Clouds are shown in gray, snow-free land surface is brown.

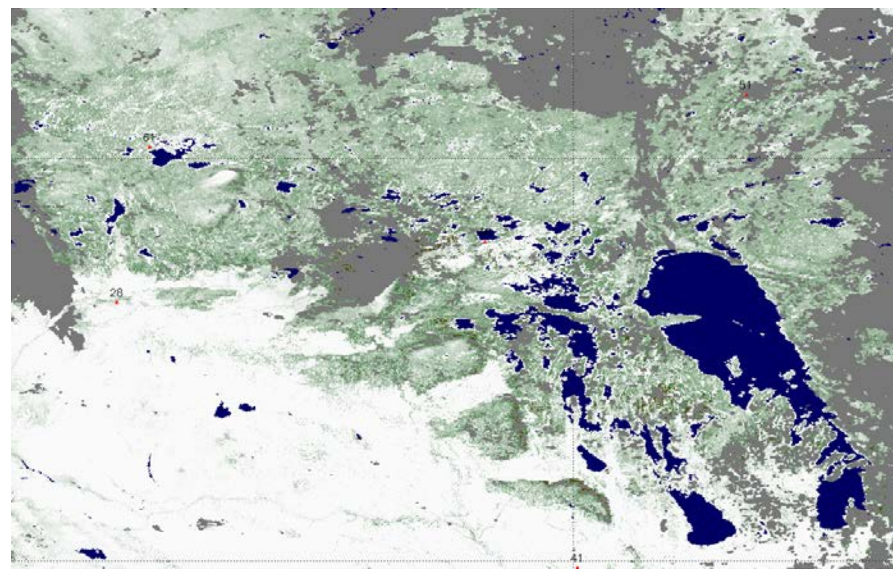
Difference between Snow fraction Maps



There is obvious similarity in the snow fraction patterns in the two products on the regional scale. However NDSI-based snow fraction is much larger in the forest

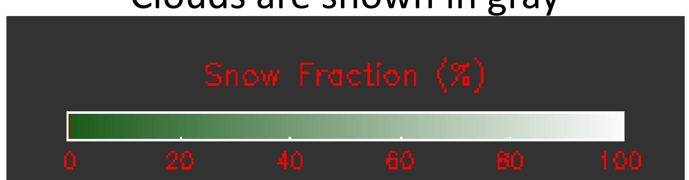


Reflectance-based snow fraction

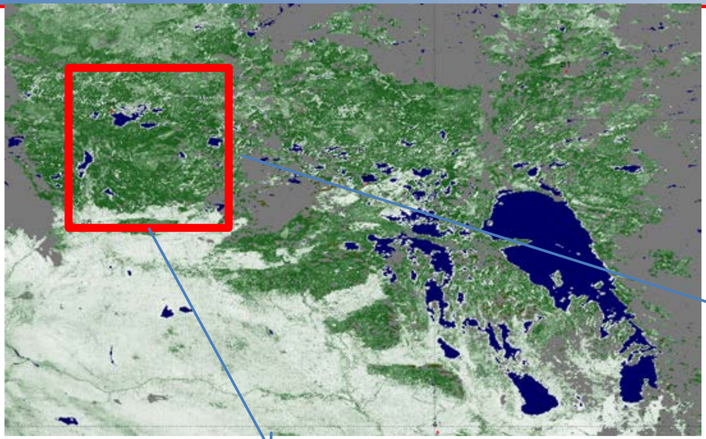


NDSI-based snow fraction

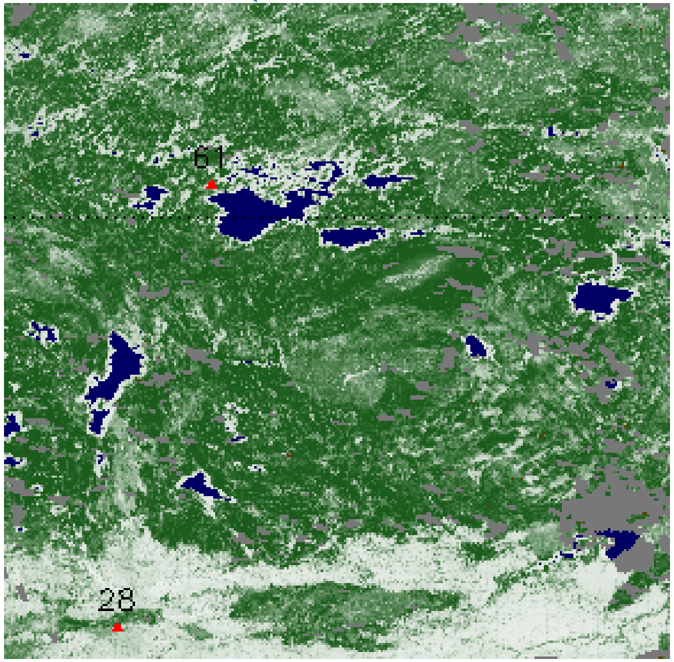
Clouds are shown in gray



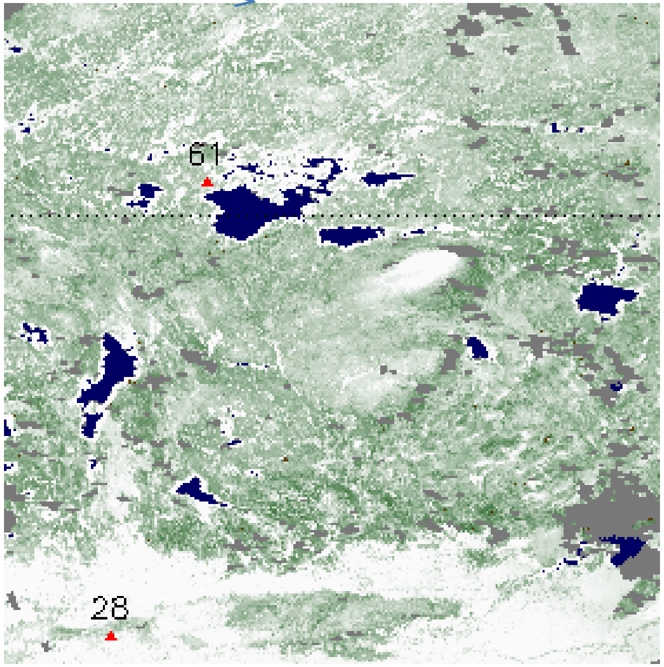
Difference between Snow fraction Maps



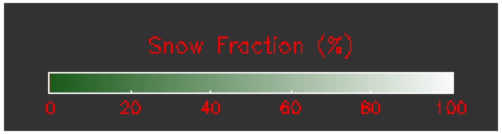
There are noticeable differences in the two snow fraction products at the local scale



Reflectance-based



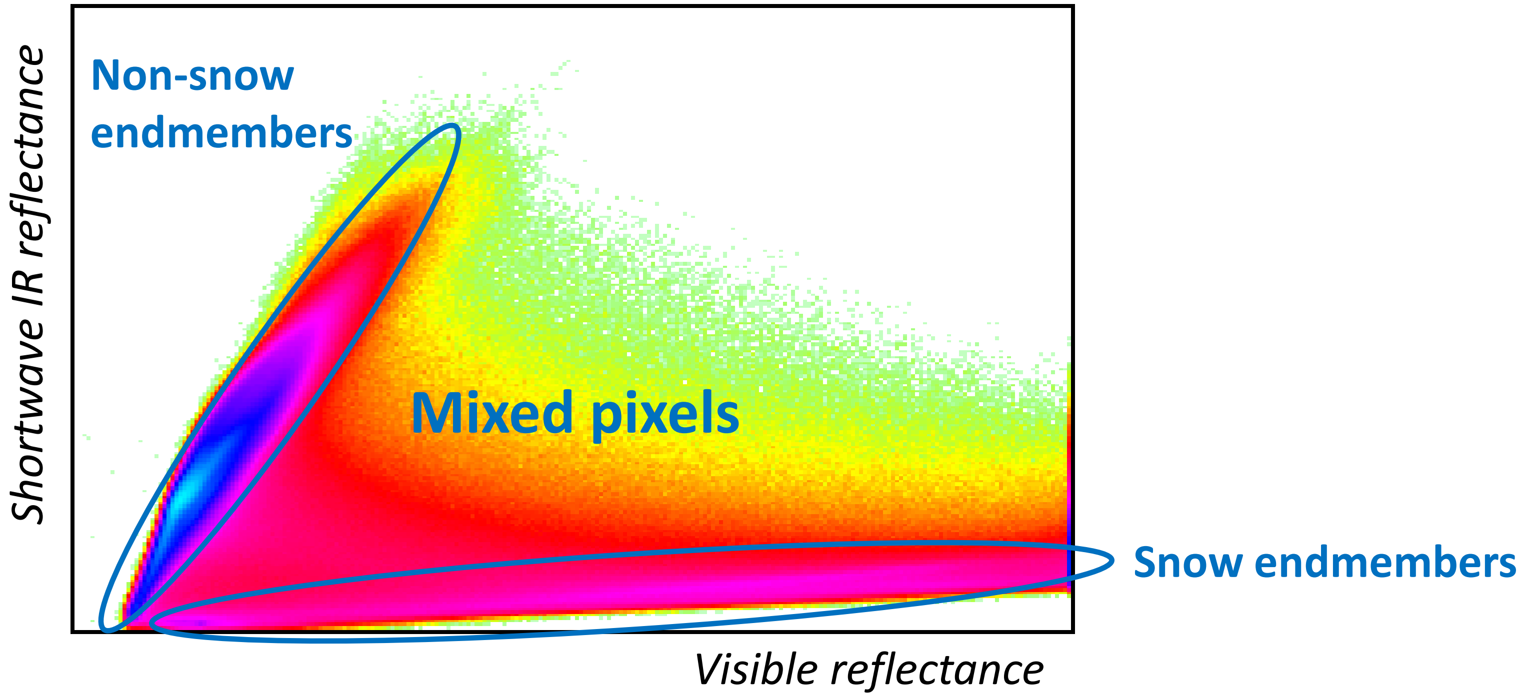
NDSI-based



Role of Changes in Endmembers

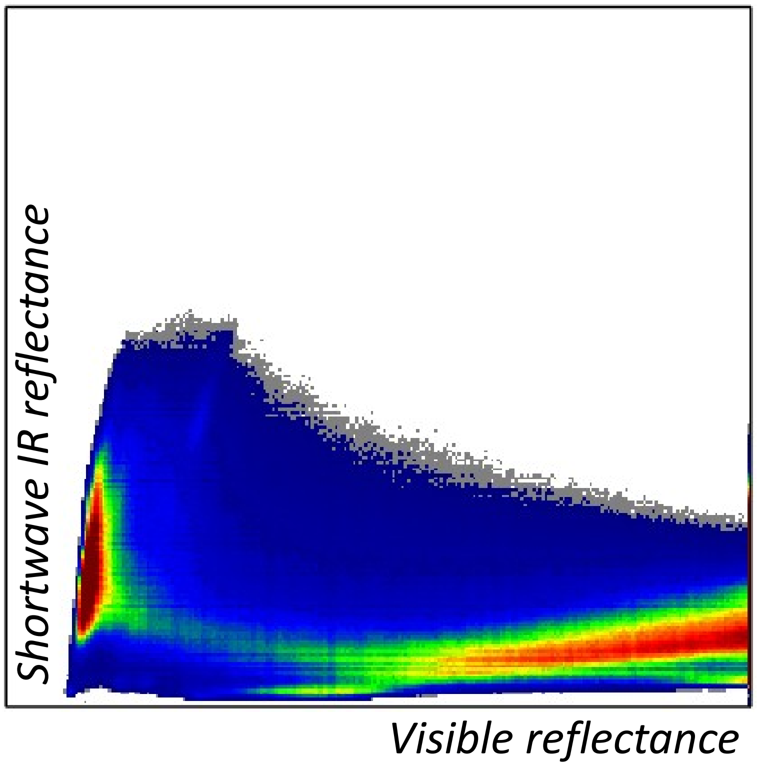
- The quality of snow cover information provided by remote sensing varies from region to region as well as from day to day depending on
  - snow and background surface types
  - the geometry of satellite observations
  - the state of the atmosphere
- Observed changes in pixel reflectances should not be ascribed exclusively to variable fraction, because they depends also on local variability in spectral signatures of the endmembers
- Allowing for local variability in spectral signatures of endmembers within a scene is a key requirement to snow algorithms

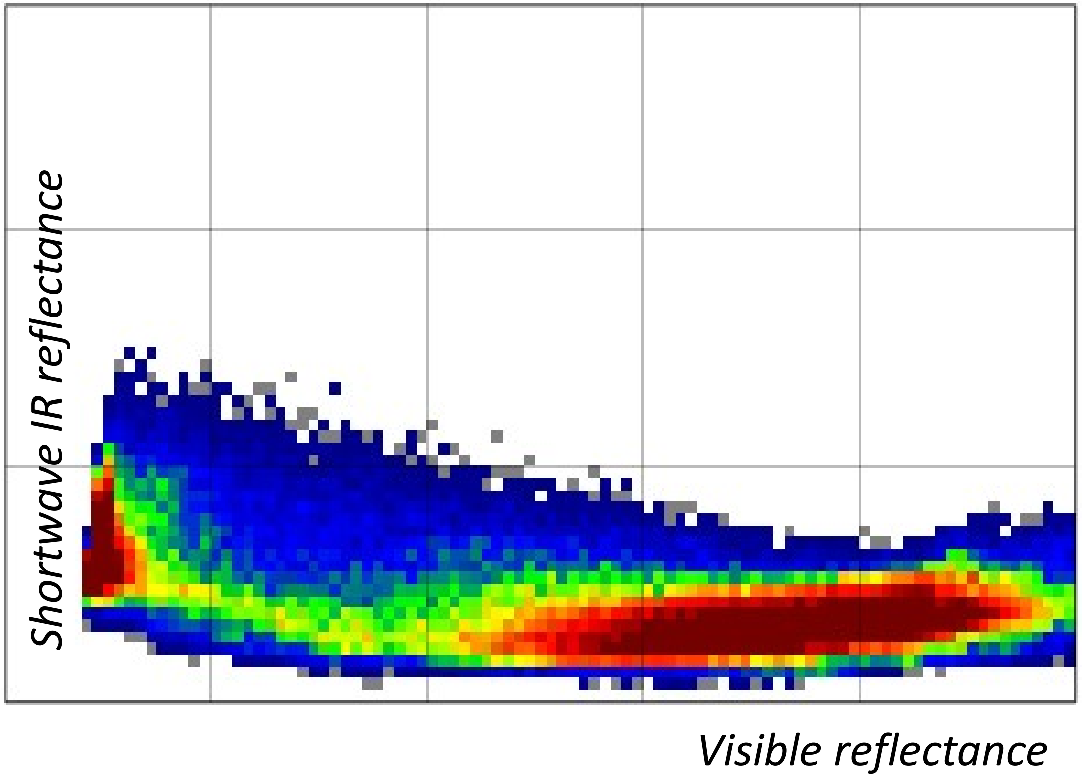
Variability of snow & non-snow reflectances (within a scene)



The simplest case of a two-dimensional histogram presenting the joint probability densities for Landsat band 2 (X axis) corresponding to VIIRS band M5 (0.64 µm) and Landsat 5 (Y axis) corresponding to VIIRS band M10 (1.61µm) illustrates significant variability in reflections characterizing snow and non-snow endmembers.

Variability of snow & non-snow reflectances (within the same scene)





High resolution observations

Moderate resolution observations

Evaluation of NDSI-based and Reflectance-based Snow Fraction Retrievals

FRACTIONAL SNOW DISCUSSION of 07/08/2014

Overall Summary: There are three algorithms:

a) Spectral unmixture (aka MODSCAG, GOESRSCAG, Painter algorithm),

b) NDSI-based, and

c) Single band approach (aka Romanov).

Overall agreement that an enterprise algorithm approach is a good idea, but need to assess and compare the results of the three algorithms in order to make a recommendation on which to implement.

"No independent observations of snow fraction are available, direct validation can not be performed" (Romanov)

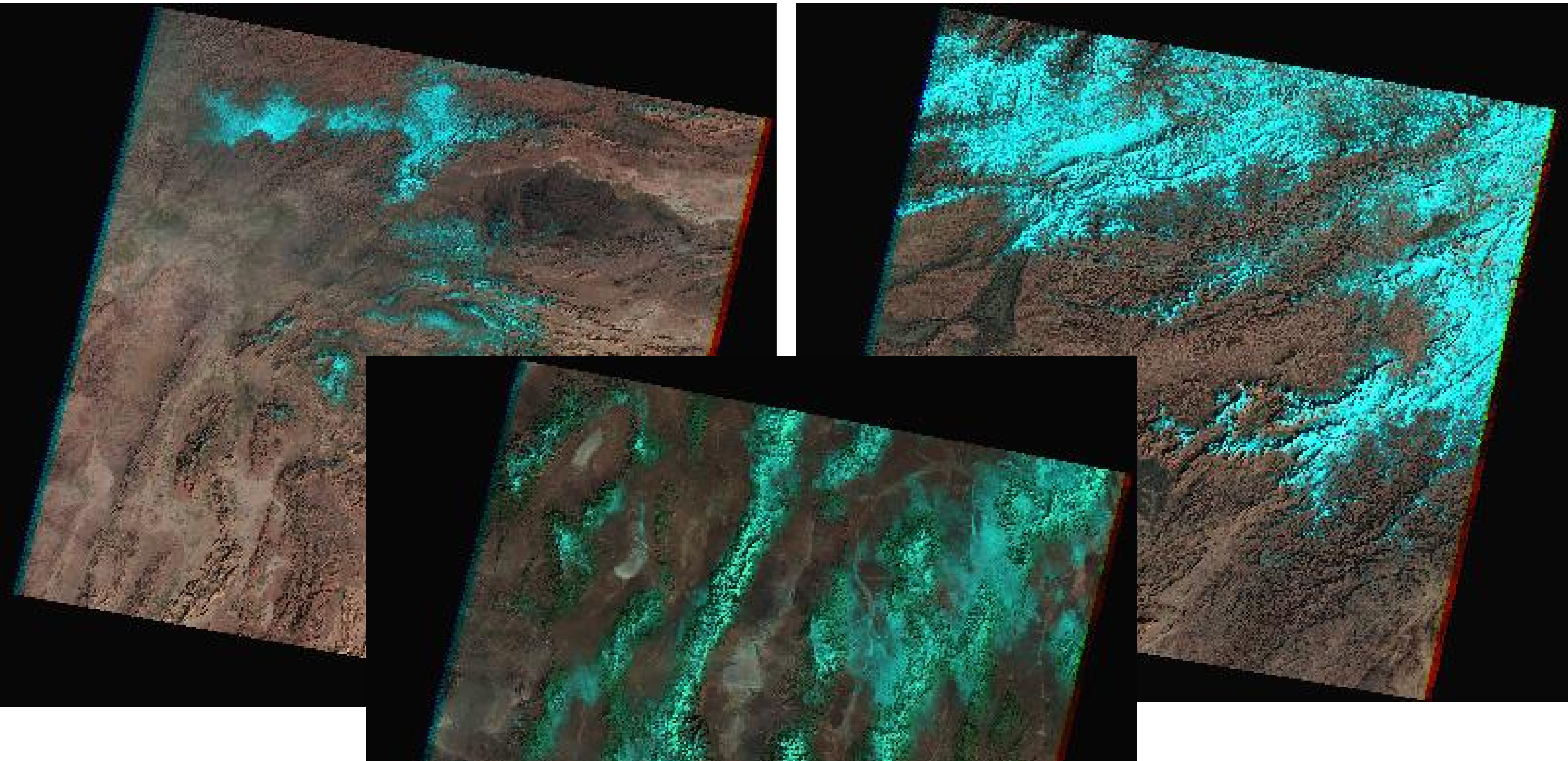
Alternative algorithm for sub-pixel snow fraction retrieval

- Different points of view were formulated during discussions regarding possible alternatives.
- Selection needs to be based on the quality of results that need to meet existing requirements (10% uncertainty).
- NDSI-based (Solomonson/Appel, Hall/Riggs)
  - Linearly relates snow fraction to NDSI (Normalized Difference Snow Index)
  - Easy to implement, routinely applied to MODIS
- NASA's fractional snow cover product is based on the NDSI approach. Their estimates show that VIIRS could provide better snow fraction at finer resolution. Accuracy estimates for VIIRS snow fraction using the NDSI algorithm are at about 85-98% depending on viewing conditions, surface and snow cover (George Riggs).

False color Landsat images

Images combining false colors – blue for visible, green for near infrared, and red for short-wave infrared – clearly identify snow (cyan), vegetation (green) and bare ground (brown-redish)

Snow looks very similar in all scenes despite variability of its reflectance



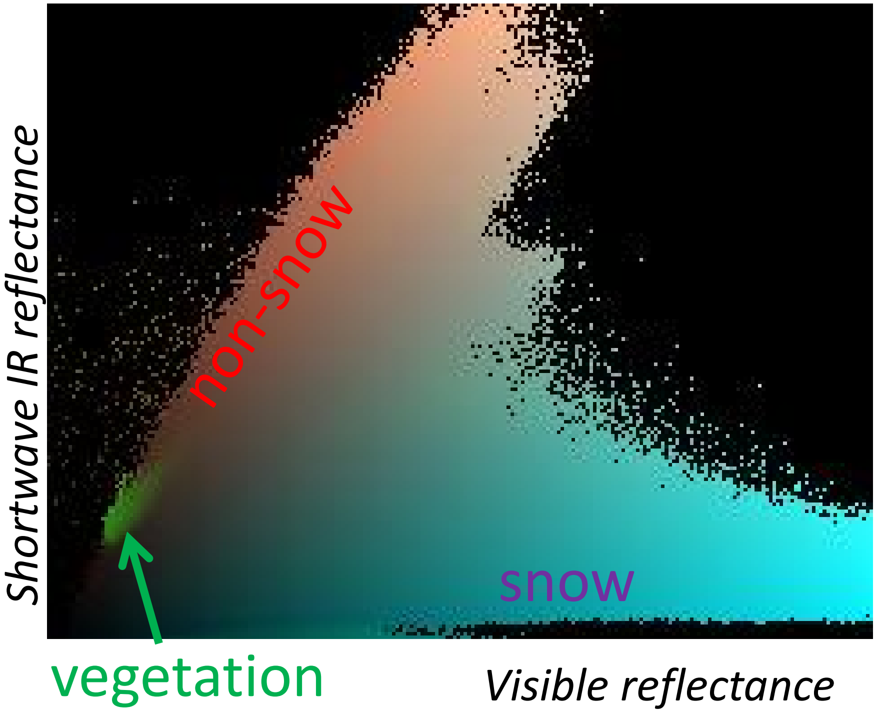
False color Landsat pixels in spectral space

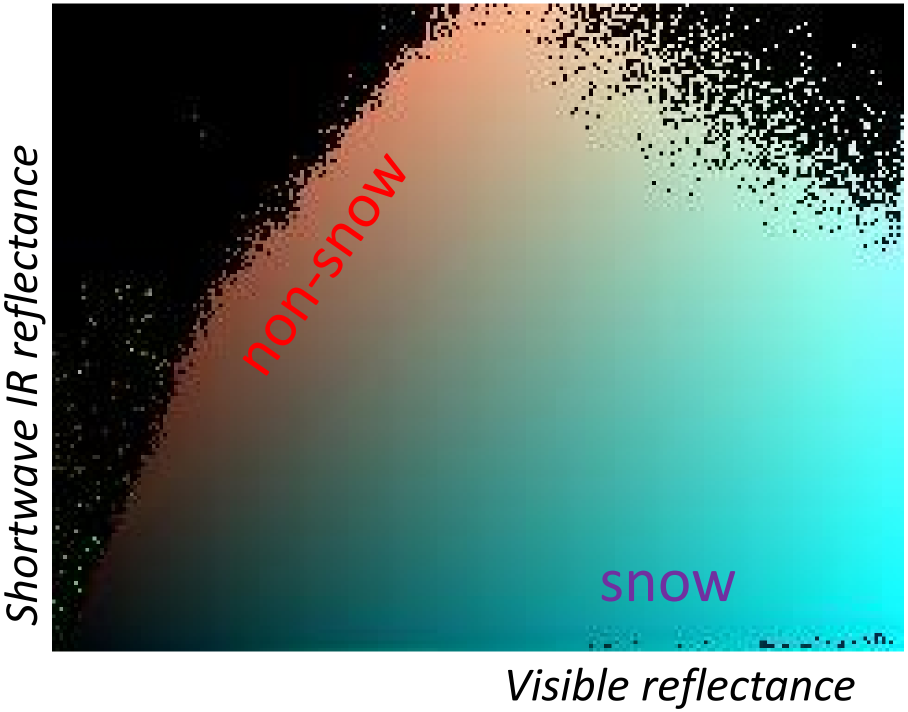
The same false color pixels are presented in the spectral space defined by visible (X axis) and short-wave infrared (Y axis) reflectances

High visible and low short-wave reflectances correspond to snow

Low visible and high short-wave reflectances correspond to non-snow

This is the basis of using NDSI to distinguish snow from non-snow

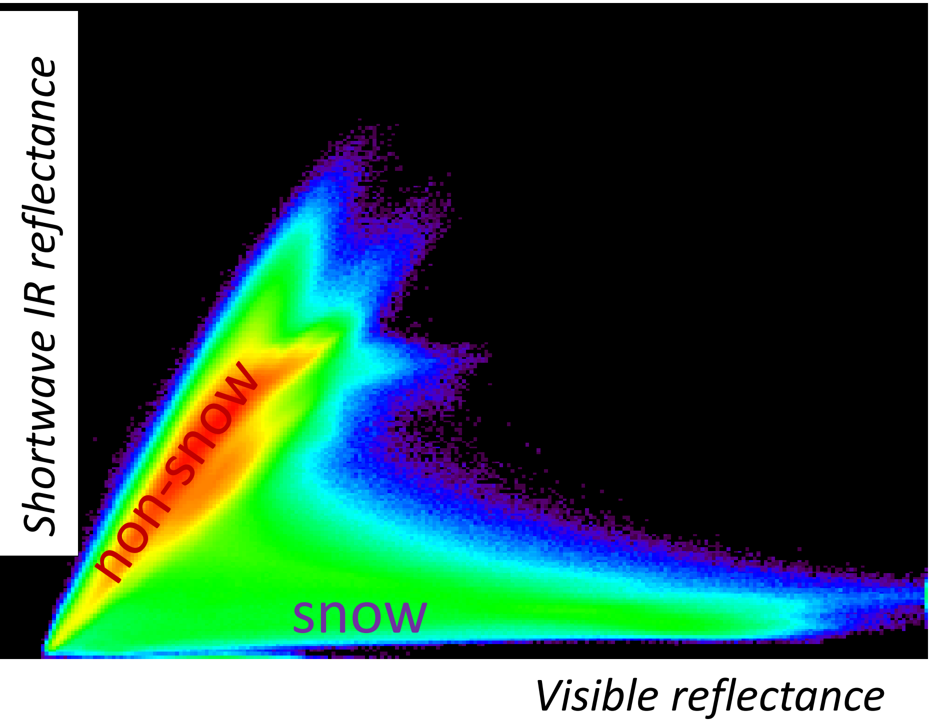


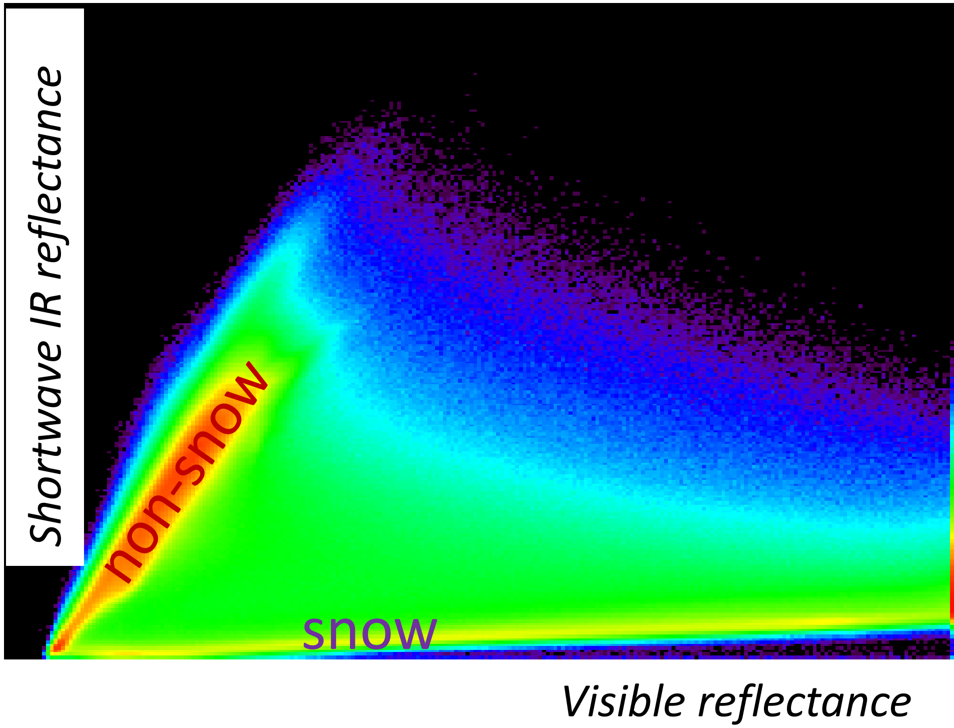


Two dimensional histograms in spectral space

The probability density functions illustrate very typical concentration of snow and non-snow pixels along straight lines characterizing the most probable reflectances of snow and non- snow

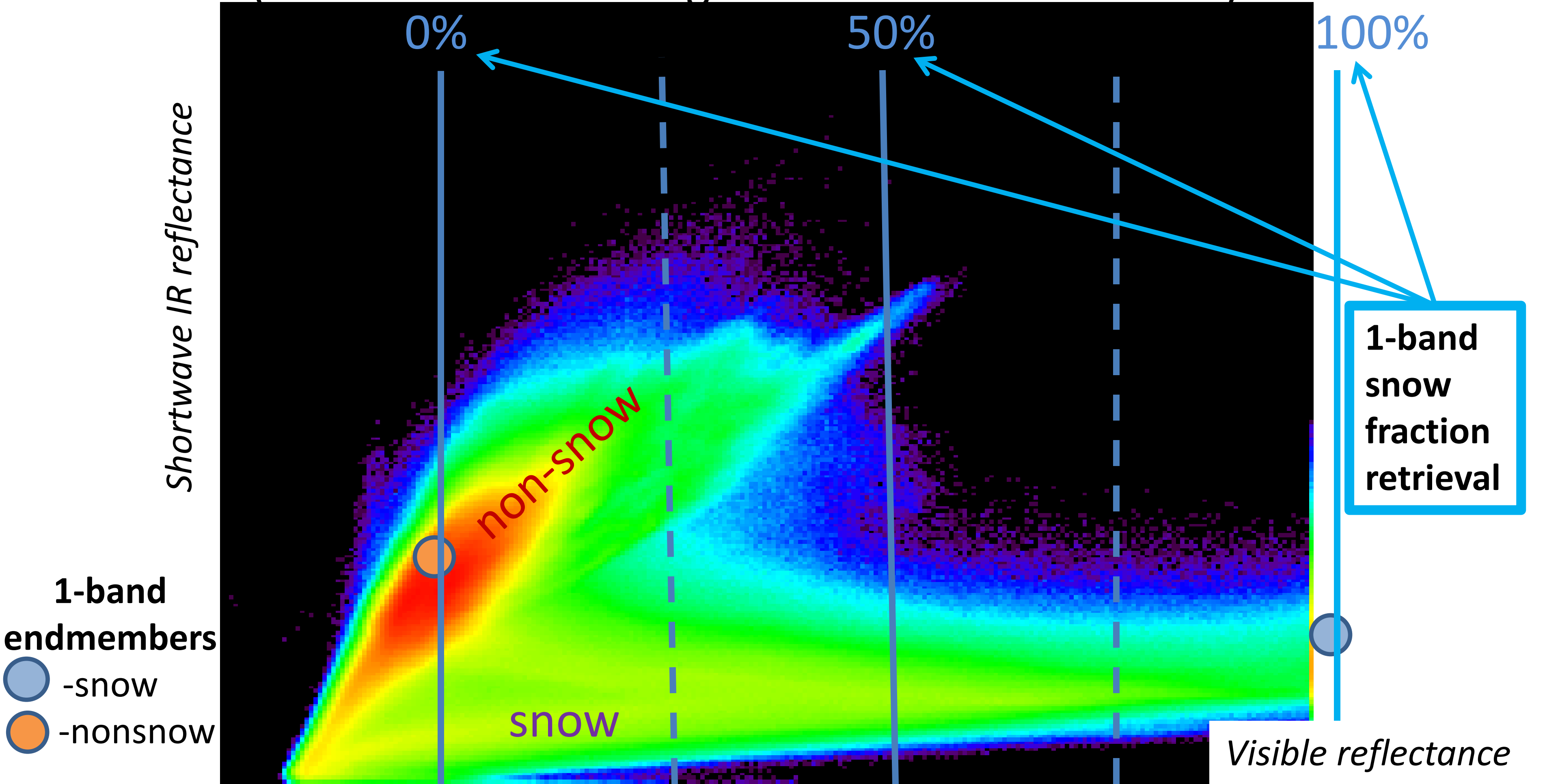
Allowing for the features of spectral signatures enhances the retrieval





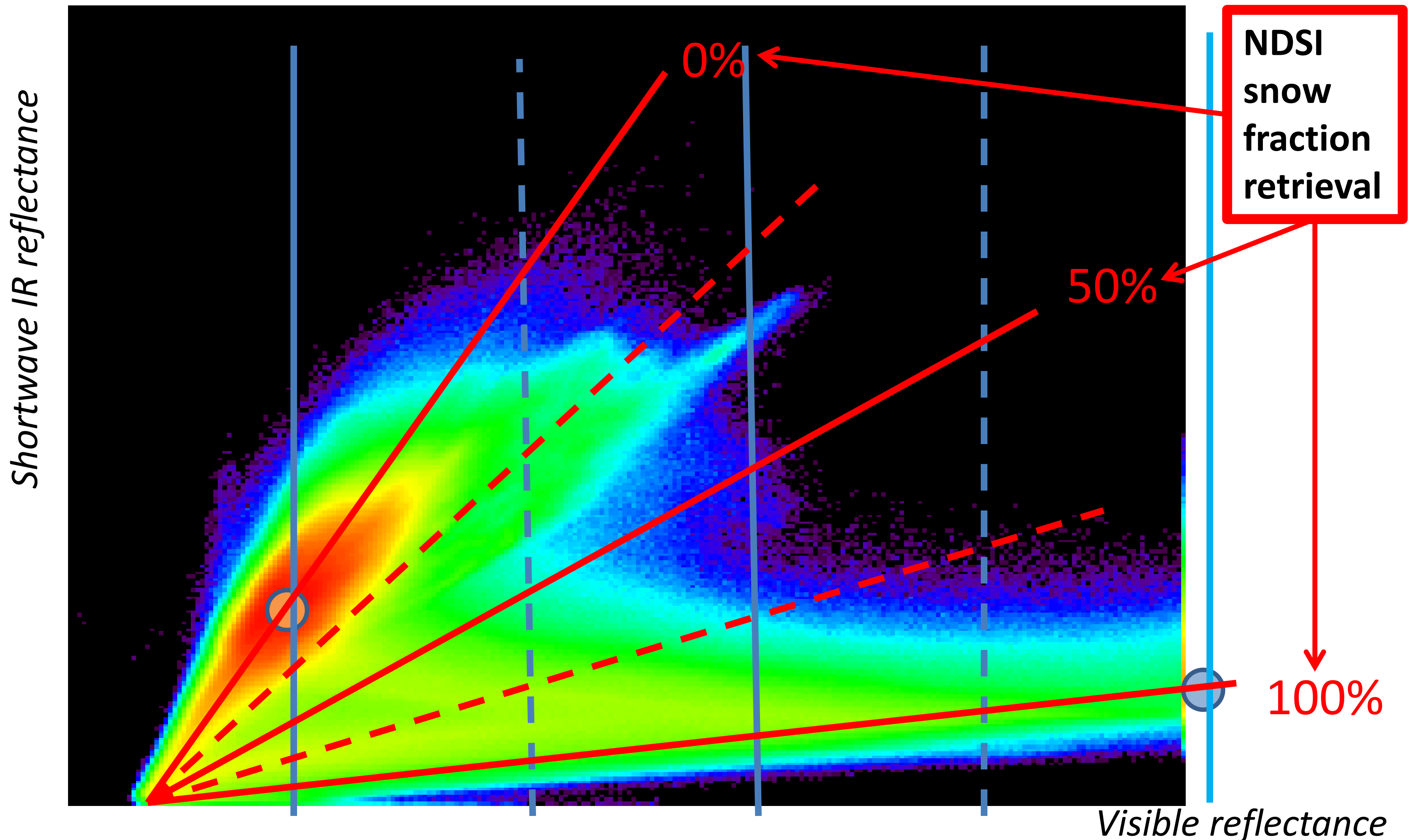
1-band Snow fraction retrieval

Most Landsat pixels could be classified as pure snow or non-snow The algorithm assigns intermediate fractions to those pure pixels – radically underestimates fraction of snow and retrieves snow in non-snow areas (for moderate and high resolution information)



NDSI - based retrieval

The NDSI based retrieval fundamentally differs from a 1-band approach. The results of using NDSI (depicted in red color) provide snow fraction using the relationship between reflectances that corresponds to observations.

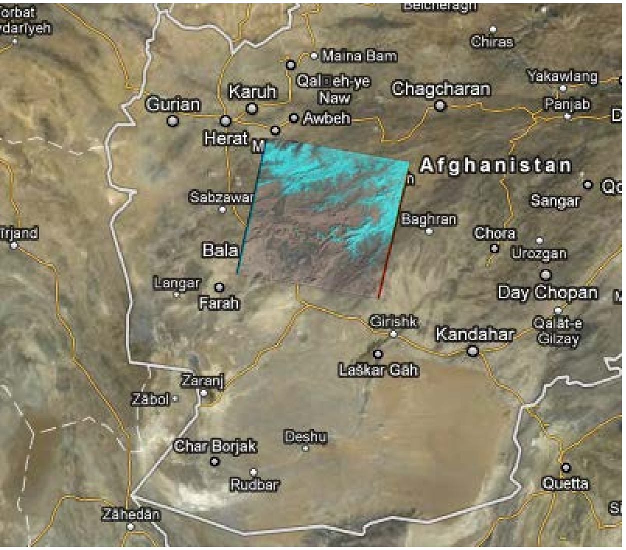


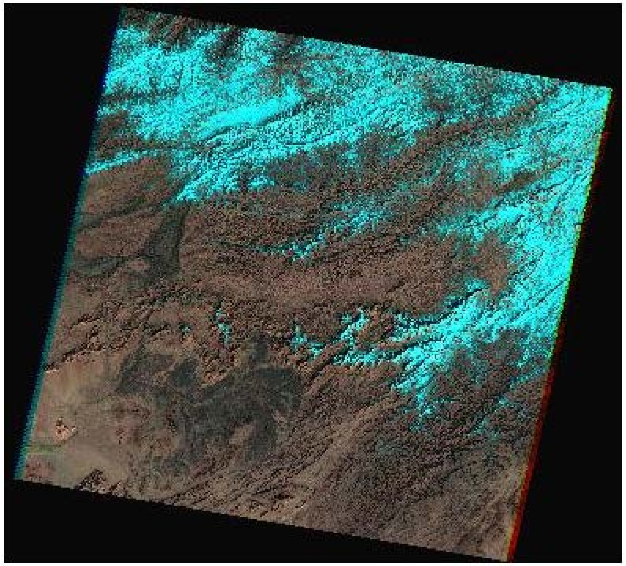
Quantitative estimate of NDSI regression for VIIRS

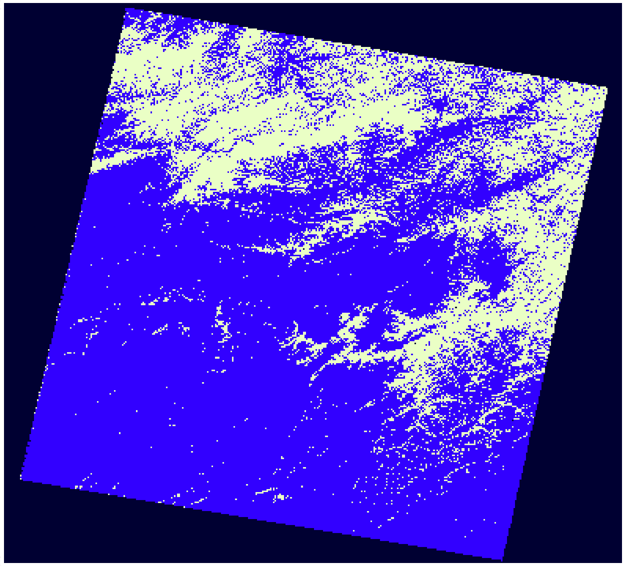
Landsat scenes selected to validate VIIRS snow products

Date	Path	Row	Sun elevation	Latitude	Longitude	Region
33	123	32	28	40 N	117 E	E China
33	139	29	24	45 N	93 E	W China
33	139	30	25	43 N	93 E	W China
33	139	31	27	42 N	92 E	W China
34	41	33	29	39 N	117 W	Nevada
34	41	34	30	37 N	118 W	Nevada
34	146	29	25	45 N	83 E	W China
35	137	29	25	45 N	96 E	Mongolia
35	137	30	26	43 N	96 E	W China
35	153	39	36	30 N	67 E	Afghanistan
36	128	30	26	43 N	110 E	Mongolia
37	30	28	24	46 N	98 W	N Dakota
39	44	27	24	47 N	119 W	Washington
39	44	31	28	42 N	121 W	Washington
40	156	35	33	36 N	64 E	Afghanistan
40	156	37	35	33 N	64 E	Afghanistan

Quantitative estimate of NDSI regression for VIIRS



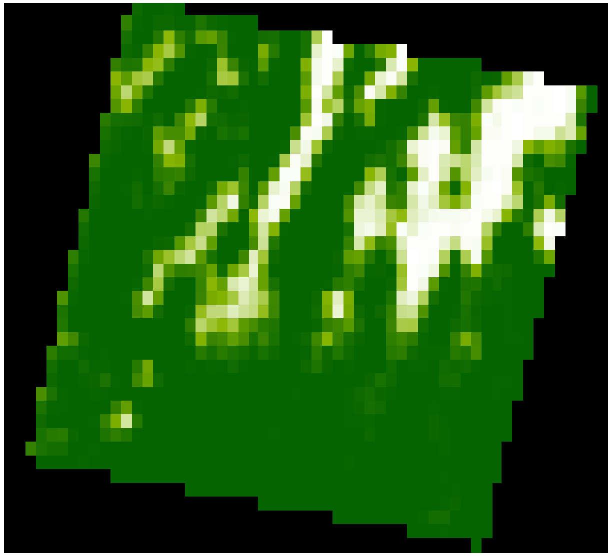


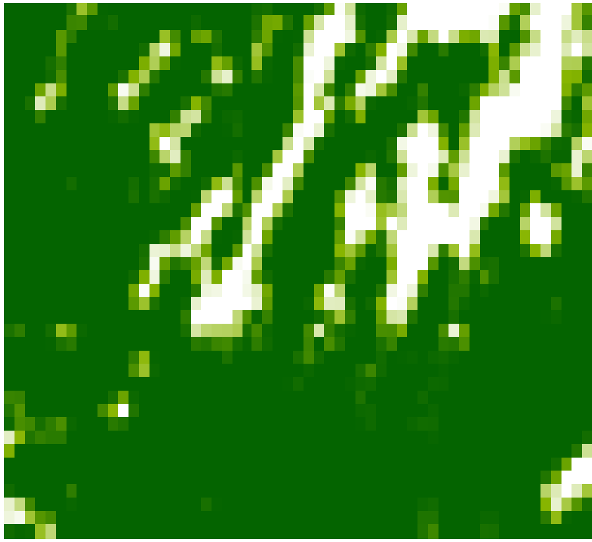


Location of Landsat scene | false color image | pixel classification

on 02/09 (path - 156, row – 37)

Quantitative estimate of NDSI regression for VIIRS





Location of Landsat scene true and VIIRS fraction

on 02/03 (path - 41, row – 33)

0  1

snow fraction palette

Quantitative estimate of NDSI based snow fraction for VIIRS

Statistics characterize high quality of regression on ground truth

Date	Path	Row	Corr. Coeff.	Inter-cept	Slope	Mean true	Mean VIIRS	Location
33	123	32	0.87	-0.09	1.02	0.20	0.11	Beijing
33	139	29	0.95	-0.03	0.97	0.40	0.36	Altay
33	139	30	0.95	-0.07	1.06	0.61	0.57	Xinjiang 1
33	139	31	0.97	-0.01	1.00	0.20	0.19	Xinjiang 2
34	41	33	0.98	-0.01	0.92	0.20	0.18	Nevada
34	41	34	0.96	-0.01	1.02	0.07	0.06	Sierra
34	146	29	0.94	-0.03	1.06	0.68	0.68	Tian Shan
35	137	29	0.95	-0.03	1.00	0.52	0.49	W Mongolia
35	137	30	0.96	0.01	0.94	0.35	0.34	Gobi
35	153	39	0.78	-0.01	0.65	0.05	0.02	Pakistan
36	128	30	0.90	0.08	0.93	0.92	0.94	S Mongolia
37	30	28	0.94	0.24	0.78	0.80	0.87	Dakotas
39	44	27	0.95	-0.01	1.04	0.19	0.18	Spokane
39	44	31	0.91	0.03	1.07	0.22	0.26	Oregon
40	156	35	0.96	-0.01	1.06	0.09	0.09	N Afghanistan
40	156	37	0.94	-0.05	1.18	0.27	0.26	C Afghanistan

Summary of quantitative estimate of NDSI regression approach

- average regression coefficient is 93% despite a couple of low magnitudes
- average intercept of linear regression line is less than 1% (negative)
- average slope of linear regression line is 0.98
- average bias of data is less than 1%
- average standard deviation is 10%

Because the standard deviation varies between 4% for snow coverage close to 0% and 100% to 14% for snow coverage in the range 40% - 60%, the uncertainty for entire areas covered by snow will be certainly less than 10% (the requirement) even before any modification/enhancement.

Additional Supporting Documentation

- **Publications and Presentations.**

Key, J. R., R. Mahoney, Y. Liu, P. Romanov, M. Tschudi, I. Appel, J. Maslanik, D. Baldwin, X. Wang, and P. Meade, 2013, Snow and ice products from Suomi NPP VIIRS, J. Geophys. Res. Atmos., 118, doi:10.1002/2013JD020459.

Appel I. (2011) Improvement of the NPP VIIRS fractional snow cover EDR for creation of a climate data records using MODIS and VIIRS. Remote Sensing and Geoinformation, 182 -190.

Romanov P., Appel I. (2012) Mapping Snow Cover with Suomi NPP VIIRS, EUMETSAT Conference, Gdansk, Poland, September 2012.

Romanov P., Appel I. (2012) Snow cover products from Suomi NPP VIIRS: Current status and potential improvements, IGARSS, Munich, Germany, July 2012.

Romanov P., Appel I. (2012) Mapping Snow Cover with Suomi NPP VIIRS, NOAA 2012 Satellite Science Week. Meeting. Summary Report. April 30 – May 4, 2012. Kansas City, Missouri.

Appel. I. (2012) Improved VIIRS Snow Cover Information for Terrestrial Water Cycle Applications. AGU Chapman Conference on Remote Sensing of Terrestrial Water Cycle, Kona, Hawaii, February 2012.

Appel. I. (2012) Validation and Potential Improvements of the NPP Fractional Snow Cover Product Using High Resolution Satellite Observations. 32nd EARSeL Symposium and 36th General Assembly, Mykonos, Greece, May 2012.

Appel I. (2013) Remote Sensing Information for Snow Monitoring. Third International Symposium on the Arctic Research, Tokyo, Japan, January 2013.

Appel I. (2014) The Influence of Uncertainty in Cloud Masking on the Quality of VIIRS Snow Products. Land product Validation and Evolution Workshop, Rome.

Appel I. (2014) The Influence of Observation Geometry on the Quality of VIIRS Snow Products. 7th EARSeL LISSIG Workshop, Bern

Appel I. (2014) Retrieval and Validation of VIIRS Snow Cover Information for Terrestrial Water Cycle Applications *in Remote Sensing of the Terrestrial Water Cycle, edited by Venkataraman Lakshmi, AGU, Washington, D. C. and Wiley, Hoboken, N. J.*

Conclusions

- VIIRS observations give the opportunity of daily snow fraction mapping at 375 m (or at least 800 m) at nadir, that is adequate for most applications

- A number of needed enhancements to algorithms are foreseen to improve the accuracy of snow retrievals to meet requirement to the uncertainty of the VIIRS snow fraction

- The optimal approach to improve moderate resolution remote sensing information on snow fraction will allow for the variability of snow and non-snow properties within a scene-specific snow algorithm

Path Forward

- To meet the product accuracy requirements the current **VIIRS Fractional Snow Cover Algorithm** has to be replaced by a more advanced algorithm estimating the sub-pixel snow cover fraction

- Recommendation: Implement the NDSI-based algorithm in the IDPS.

- Longer-range plan: Improve, test and implement the spectral unmixing algorithm.

Possible Approach to Replace Algorithm

To begin doing the following

- Implement a simple algorithm making some enhancements to improve the retrieval quality
- Consider potential use of other algorithm advantages
- Make the emphasis on the comparative quantitative estimate of fractional snow product quality for global coverage

In the case if further improvements are needed

- It is very reasonable to assume that the uncertainty requirements could be met only if specific local conditions are taken into consideration
- Estimate applicability of scene specific approaches to modify the algorithms

Long-Range Plans, Milestones

	Suomi NPP	JPSS J1
FY15	• Implement, test, and deliver new fractional snow cover algorithm • Continued validation of snow products • Recommendations on snow/ice gridding	JPSS Risk Reduction Projects: • Consider applicability of GOES-R algorithms for VIIRS products • Minor algorithm improvements
FY16	• Algorithm maintenance and minor improvements	• Hold algorithm preliminary design reviews • Define enhanced validation plan
FY17	• Long-term validation of VIIRS snow products	• Hold algorithm critical design reviews • Begin transitioning to JPSS • Redefine products if needed
FY18	• Long-term validation of VIIRS snow products	• J1 launch • Beta maturity status