VIIRS Fractional Snow Cover: Current Status and Plans

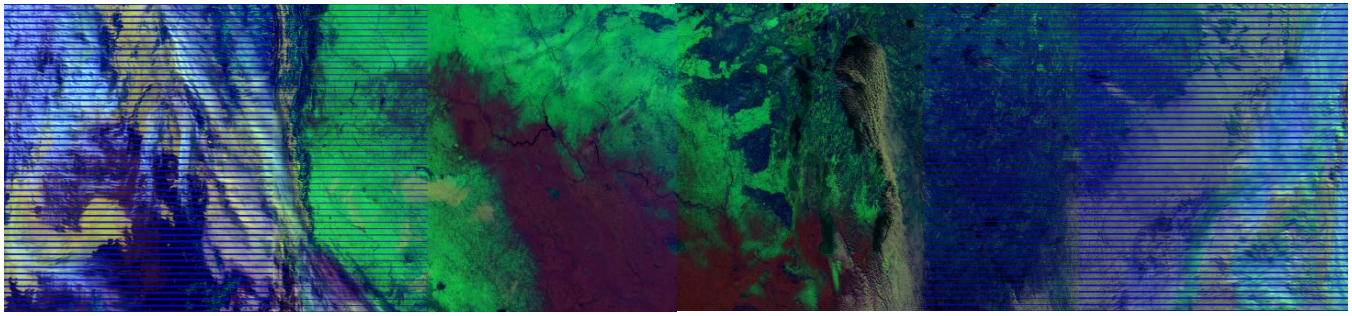
Peter Romanov, CREST/CUNY at NOAA/STAR
Igor Appel, IMSG at NOAA/STAR

27 August 2015

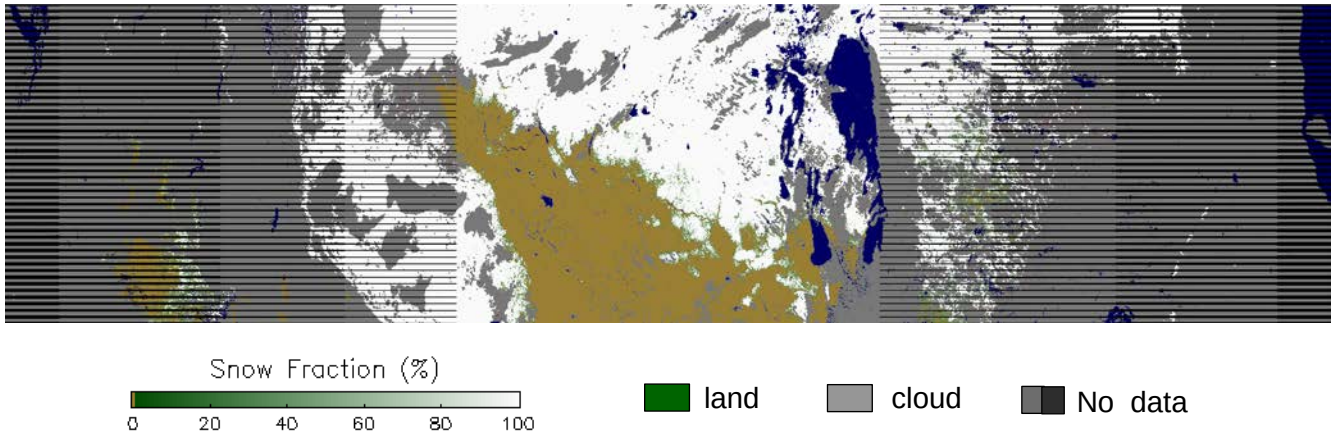
Current VIIRS IDPS Snow Fraction Product

- IDPS Snow Fraction:
  - Aggregation of the binary snow within 2x2 pixel blocks
  - 750 m spatial resolution
- Product depends on
  - Binary snow identification
  - VIIRS cloud mask

Aggregated Snow Fraction

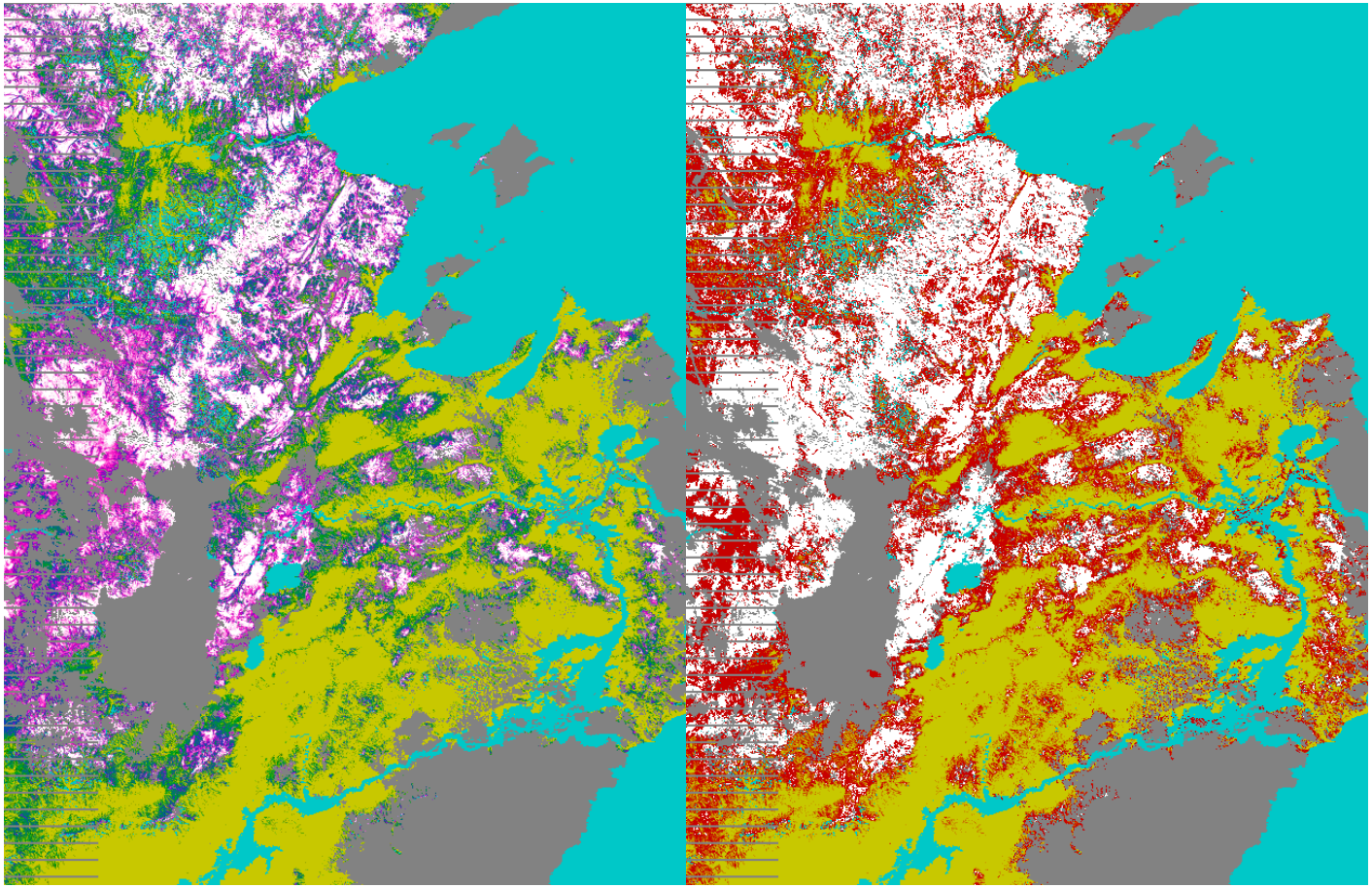


VIIRS IDPS snow fraction: derived through 2x2 binary snow pixel aggregation



- Product
  - Has little to none added value as compared to the binary snow
  - Can not and does not satisfy 10% accuracy requirements
  - Has to be replaced for sub-pixel snow fraction retrievals

Snow Fraction and Binary Snow (10/24/2013 at 03:15)



snow

confidently cloudy

fractional snow cover in areas of non-snow binary retrieval

non-snow in binary and fractional retrievals

water

100 %



0%

Snow Fraction

Comparison with false color imagery shows advantage of snow fraction

“Viewable” vs “True” Snow Fraction

Two Definitions/Perceptions of Sub-Pixel Snow Fraction

(1) Physical fraction of land surface covered with snow (“**true snow fraction**”).

- Characterizes patchiness of snow cover on the ground
- Use to calculate the snow area extent

(2) Snow fraction as “seen” from satellite (“**viewable snow fraction**”)

- Represents a combined effect of patchiness and snow masking by vegetation
- Directly related to the land surface albedo
- Can be converted to the true snow fraction if the forest gap function is known

In satellite remote sensing definition (2) of snow fraction is typically assumed

“Viewable” snow fraction will be derived from VIIRS data

Conclusions from high level fractional snow discussion (July 2014)

Overall Summary:

There are three algorithms:

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

b) NDSI-based, and

c) Single band approach.

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.

Panel recommendation from the maturity review (September 2014)

- **Snow Cover (Snow Fraction) EDR Algorithm**

- Scientific maturity seems sound for NDSI algorithm. Recommend to proceed with NDSI regression approach.

  – Study the inclusion of NDSI into the cryosphere products of the JPSS risk reduction project

  – Inter-comparisons with MODSCAG should be explored by a coordinated GOES-R JPSS effort

Two Snow Fraction Algorithms for NDE

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

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

- Uses band 1 (visible) reflectance

- $\mathbf{R_{land}}$ and $\mathbf{R_{snow}}$ are global and are determined empirically. They change with observation geometry

- Algorithm used with GOES Imager and AVHRR

NDSI-based, recent (2015) enhancement of Salomonson & Appel

$$\textbf{SnowFraction} = (NDSI - NDSI_{non\text{-}snow}) / (NDSI_{snow} - NDSI_{non\text{-}snow})$$

- Slope and Intercept are local and are established on the fly

- MODIS heritage algorithm

- Adopted as the primary algorithm for JPSS

Advantages of Reflectance-Based Snow Fraction

Linear relationship between snow fraction and surface reflectance

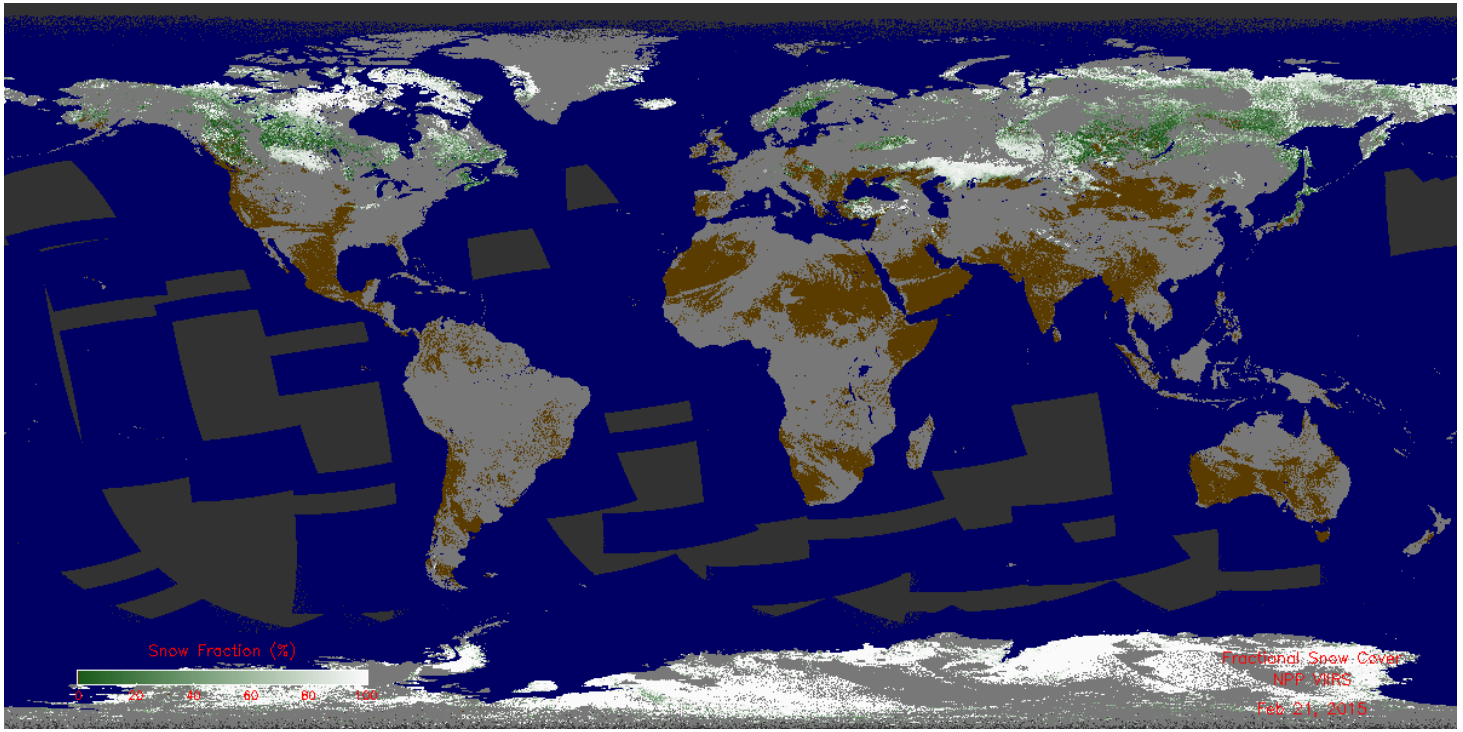
- Employed in land surface models

- Implicitly used when visually estimating the fractional snow cover (e.g. snow course measurements)

Theoretically estimated accuracy is 10-15%

- Mostly due to the end-members uncertainty

Global Daily Snow Fraction



Daily gridded maps of reflectance-based snow fraction are generated daily since Jan 2014. See http://www.star.nesdis.noaa.gov/smcd/emb/snow/viirs/viirs-snow-fraction.html

Snow Fraction Evaluation Approach

Snow fraction is not observed in situ. Proper quantitative validation of the product accuracy is hardly feasible

General approach to the product verification

- Comparison with higher spatial resolution data

- Consistency testing

  Self-consistency:

    Lack of abnormal spatial patterns

    Day-to-day repeatability of spatial patterns

  Consistency with the forest cover distribution

  Consistency with in situ snow depth data over open flat areas.

Comparison with Landsat

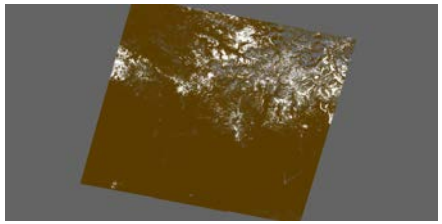
Landsat binary snow cover aggregated within VIIRS pixel is compared to VIIRS sub-pixel snow fraction

Approach

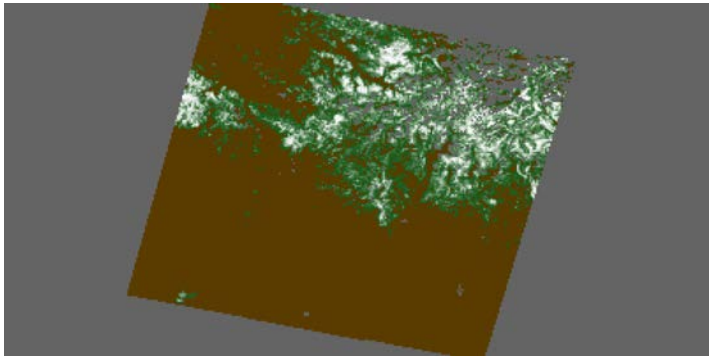
(1) Generate binary snow mask for a Landsat scene at 30 m resolution

(2) Aggregate Landsat binary snow retrievals within VIIRS pixel

(3) Compare with VIIRS snow fraction estimate

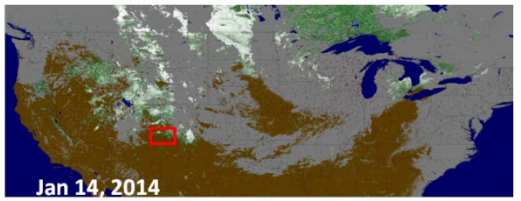


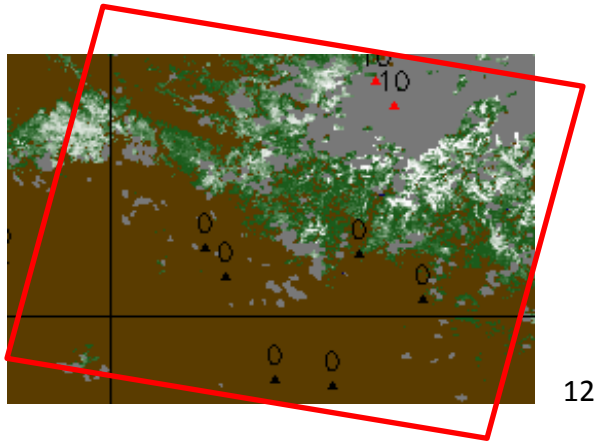
Landsat binary snow



Landsat snow fraction

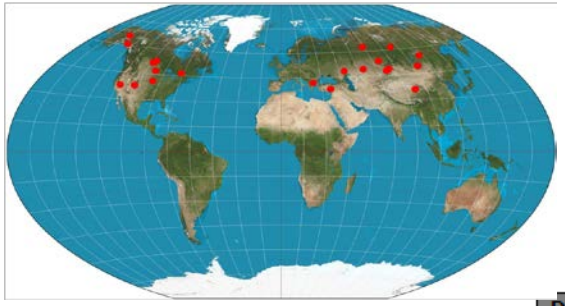
VIIRS snow fraction





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Comparison with Landsat



Location of Landsat scenes used

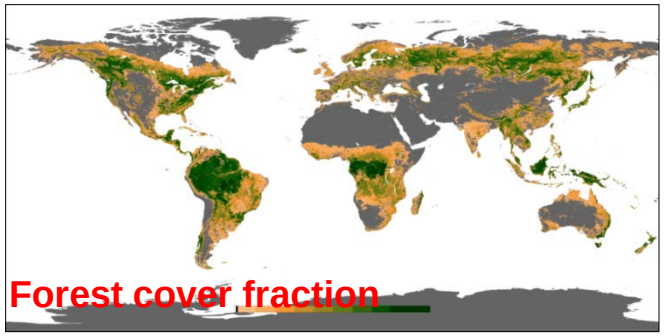
The overall agreement of Landsat aggregated and VIIRS subpixel snow fraction is about 12% for 1 km grid cells and about 8% for 5 km aggregation

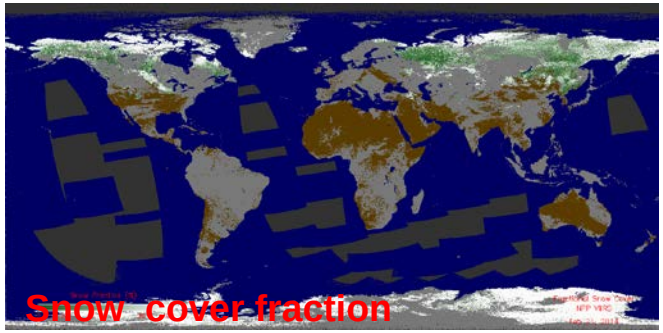
Date of year 2014	Path	Row	Sol Elev	Lat	Lon	Mean Fraction VIIRS	Mean Fraction Landsat	1 km		5 km	
								Correl	RMSE	Correl	RMSE
01/09	16	27	18	47.4	-75.5	0.21	0.23	0.71	0.173	0.87	0.112
01/09	32	28	20	46.0	-100.8	0.77	0.83	0.40	0.17	0.41	0.157
01/13	28	33	26	38.8	-96.9	0.19	0.06	0.67	0.106	0.92	0.078
01/14	35	24	14	51.7	-103.0	0.74	0.74	0.89	0.131	0.97	0.072
01/14	35	25	17	50.2	-103.6	0.89	0.90	0.72	0.098	0.84	0.054
01/14	35	34	28	37.5	-108.2	0.26	0.27	0.84	0.140	0.94	0.069
01/15	42	34	28	37.4	-119.0	0.11	0.10	0.82	0.112	0.92	0.061
01/15	131	26	18	48.8	107.4	0.42	0.47	0.84	0.157	0.83	0.142
01/15	147	26	18	48.8	82.7	0.67	0.70	0.89	0.101	0.95	0.069
01/15	147	27	19	47.4	82.1	0.66	0.68	0.91	0.051	0.96	0.031
03/14	169	26	36	48.4	48.6	0.42	0.47	0.95	0.094	0.99	0.068
03/14	185	31	41	41.7	21.3	0.34	0.31	0.91	0.145	0.97	0.094
03/15	160	26	36	48.8	62.5	0.86	0.90	0.72	0.070	0.80	0.055
03/15	128	20	29	57.3	116.0	0.59	0.53	0.69	0.203	0.80	0.125
03/24	159	15	27	64.1	72.9	0.74	0.77	0.89	0.111	0.98	0.049
03/24	175	34	48	36.5	35.49	0.72	0.70	0.79	0.146	0.94	0.114
03/25	134	35	50	36.0	98.4	0.56	0.56	0.90	0.132	0.97	0.070
03/25	150	23	37	53.1	79.8	0.43	0.44	0.90	0.078	0.98	0.040
04/23	72	14	37	65.5	-151.5	0.32	0.34	0.90	0.103	0.97	0.054
04/27	141	16	40	62.6	99.7	0.35	0.36	0.81	0.098	0.90	0.055
05/15	66	17	47	61.5	-145.2	0.67	0.65	0.80	0.131	0.94	0.069
Mean								**0.80**	**0.121**	**0.90**	**0.078**

Consistency Tests

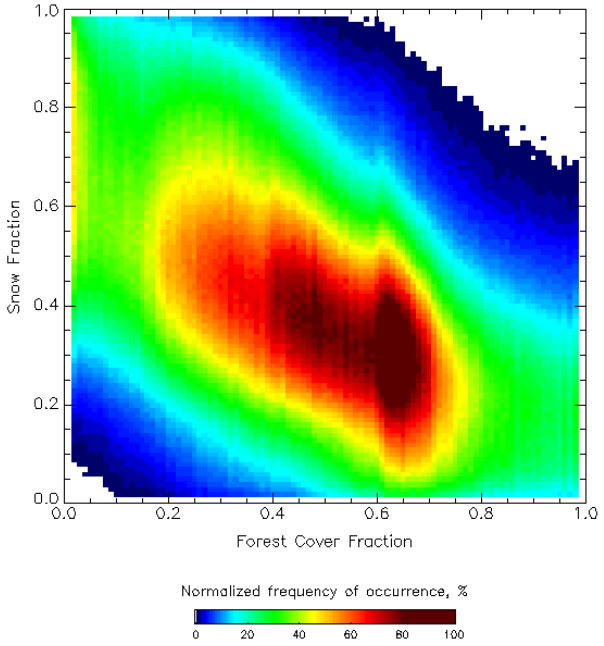
VIIRS reflectance based snow fraction satisfies all consistency tests
In particular it demonstrates:

- Strong negative correlation (-0.5 to -0.8) with forest fraction
- Positive correlation (0.2-0.6) with snow depth over non-forested areas
- Strong positive (0.7-0.9) day-to-day autocorrelation





Forest fraction vs snow fraction



Further Enhancements of Reflectance-based Approach

- Improved characterization of end-members
  - Location-dependent or surface-type-dependent values
  - Improved angular anisotropy parameterization of endmembers
- Testing multi-endmember multispectral approach
  - Add shadows as a separate land surface category besides snow and snow-free land
-

Advantages of NDSI-Based Snow Fraction

- The Normalized Snow Difference Index (NDSI) characterizes snow reflective properties: high snow reflectance in the visible wavelengths and low reflectance in the near infrared wavelengths
- NDSI is widely considered as an indicator of the presence of snow on the ground
- NDSI is sensitive enough to provide the snow fraction within a pixel of moderate resolution observations
- NDSI presenting relative ratio of reflectances to a large degree suppresses the influence of varying illumination conditions

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

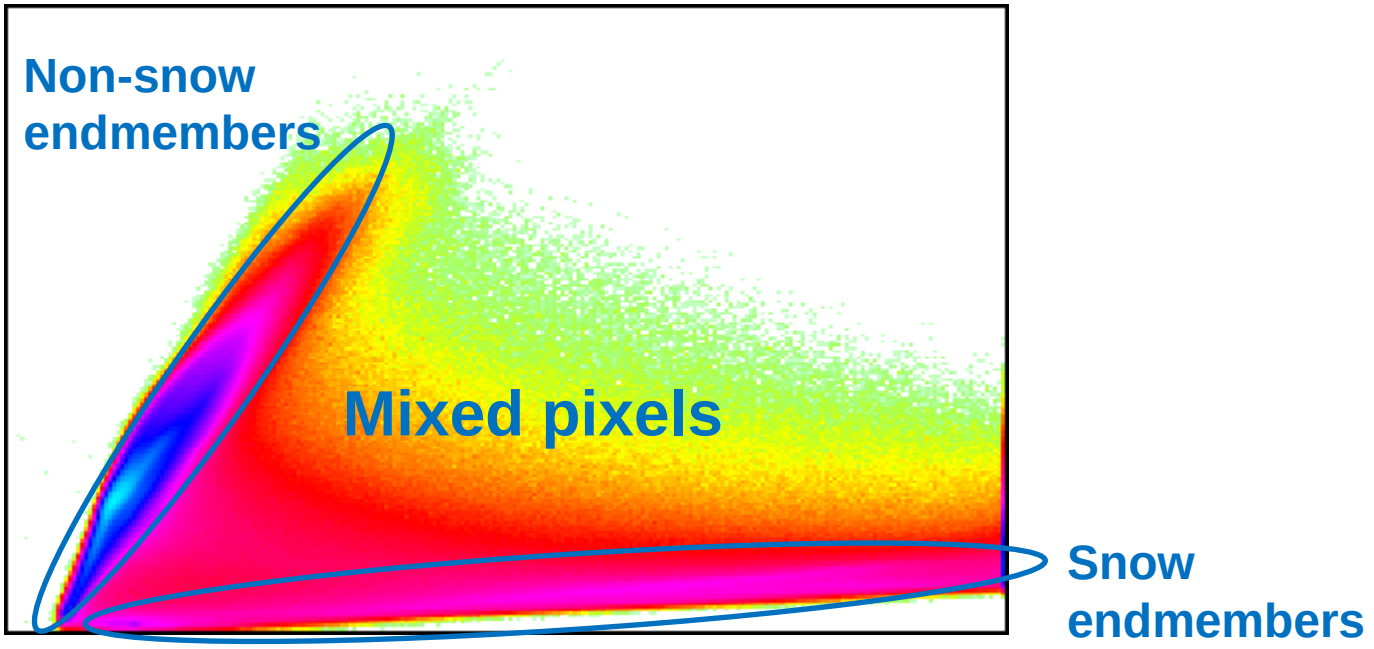
NDSI variability

VIIRS observations	NDSI		
Location	**Snow**	**Non-snow**	**50% fraction**
Beijing	0.70	-0.05	0.46
Altay	0.92	-0.12	0.59
Xinjiang 1	0.92	-0.20	0.52
Xinjiang 2	0.87	-0.25	0.42
Nevada	0.71	-0.23	0.31
Sierra	0.71	-0.18	0.31
Tian Shan	0.90	0.03	0.65
W Mongolia	0.92	0.10	0.61
Gobi	0.92	0.05	0.61
Pakistan	0.83	-0.37	0.16
S Mongolia	0.89	0.21	0.59
Dakotas	0.83	0.38	0.66
Spokane	0.93	-0.30	0.58
Oregon	0.91	-0.18	0.61
N Afghanistan	0.71	-0.23	0.37
C Afghanistan	0.79	-0.16	0.49
Average	0.84	-0.09	0.50

Reflectance variability

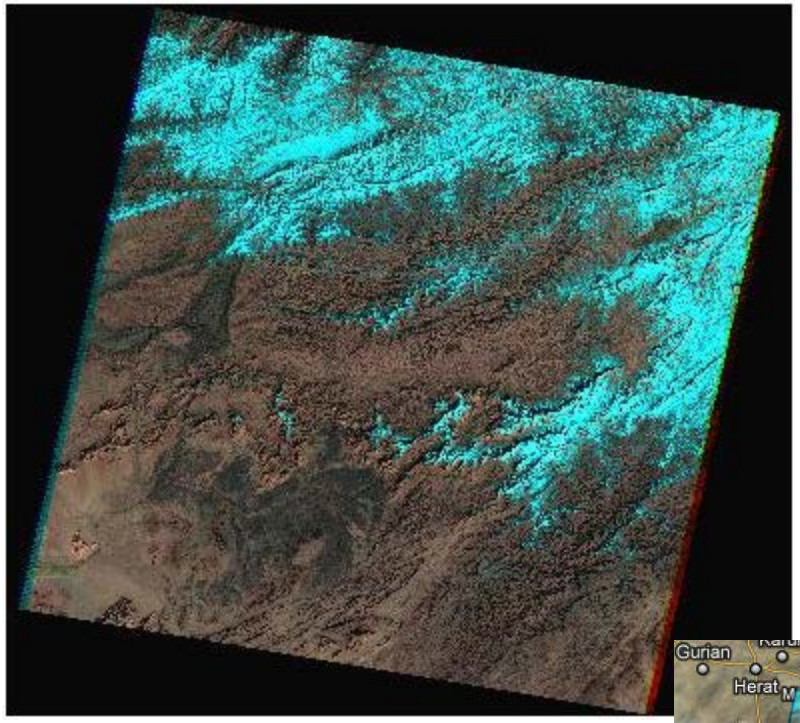
VIIRS observations	Snow reflectance (%)		Non-snow reflectance %	
Location	**Visible**	Near Infrared	**Visible**	Near Infrared
Beijing	39	7	10	11
Altay	72	3	15	19
Xinjiang 1	69	3	16	24
Xinjiang 2	71	5	19	32
Nevada	35	6	12	19
Sierra	35	6	14	20
Tian Shan	73	4	16	15
W Mongolia	69	3	23	19
Gobi	73	3	22	20
Pakistan	53	5	23	50
S Mongolia	71	4	35	23
Dakotas	65	6	29	13
Spokane	55	2	8	15
Oregon	43	2	7	10
N Afghanistan	47	8	12	19
C Afghanistan	60	7	13	18

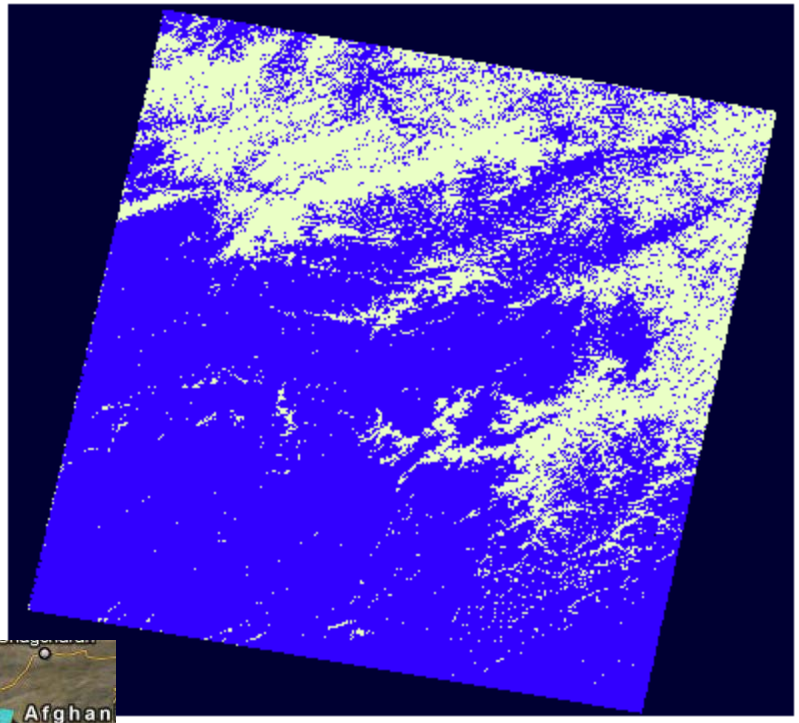
Variability of snow & non-snow reflectances (within a scene)



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

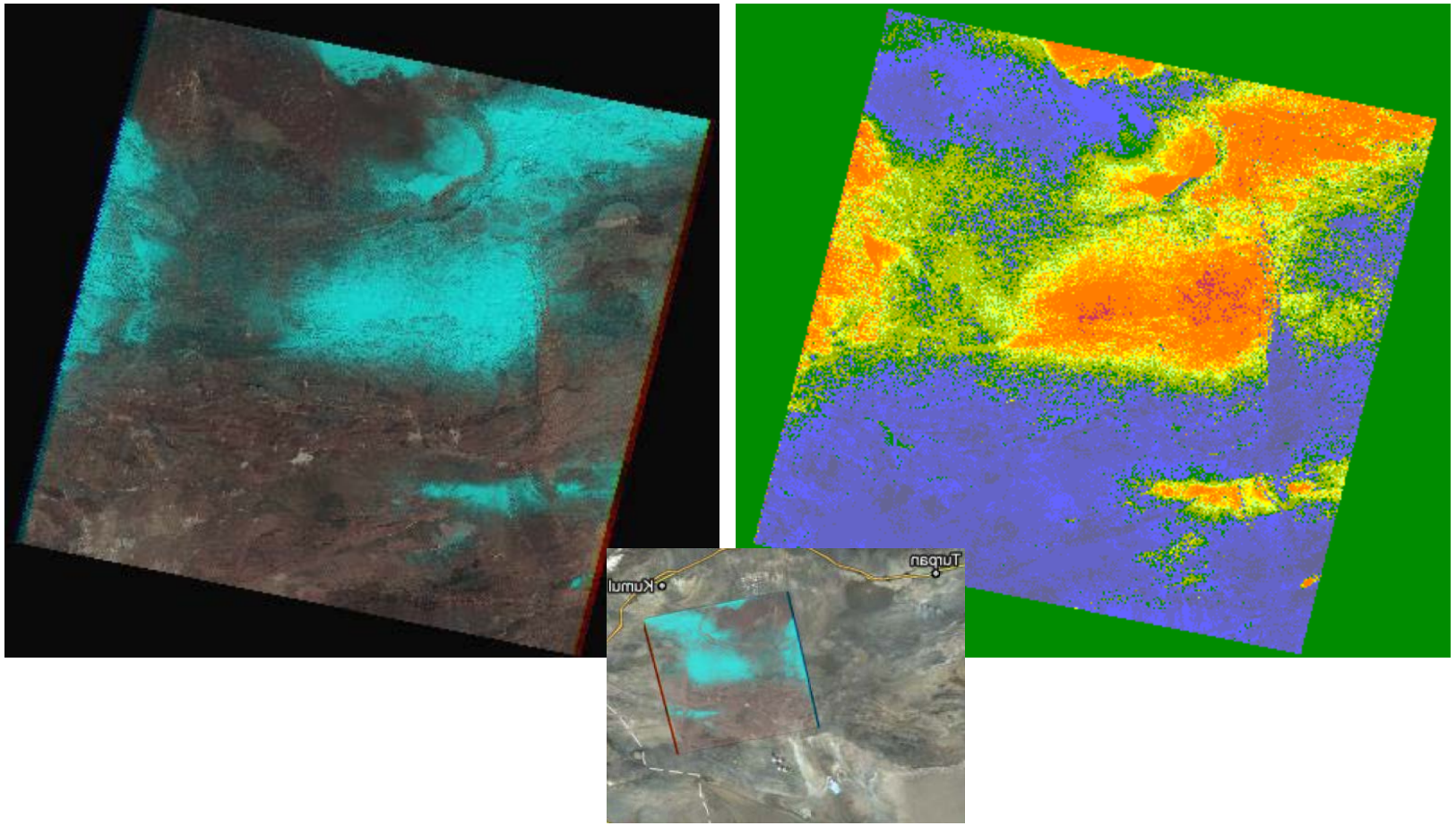
Landsas false color image and pixel classification (Afghanistan)



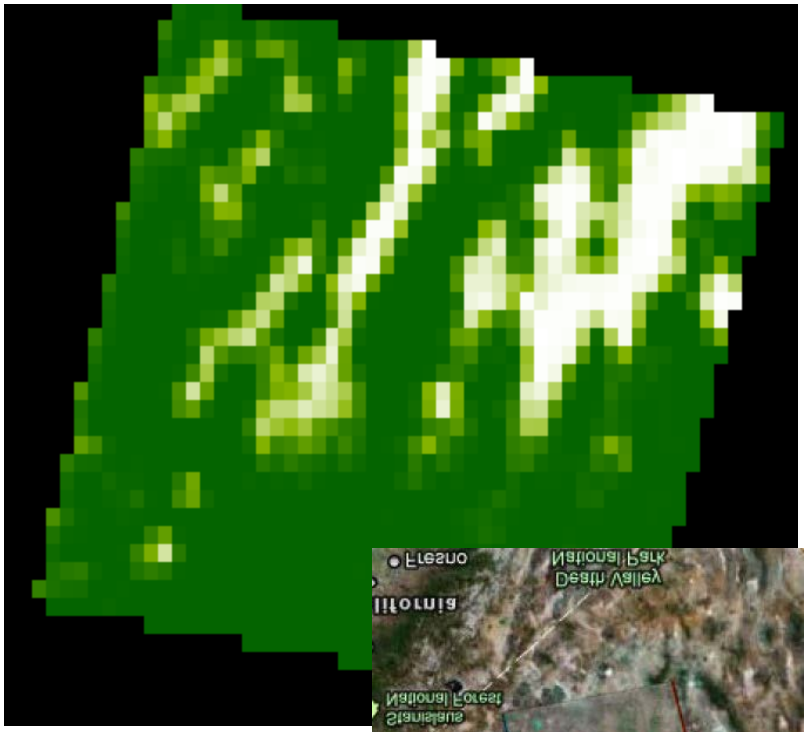




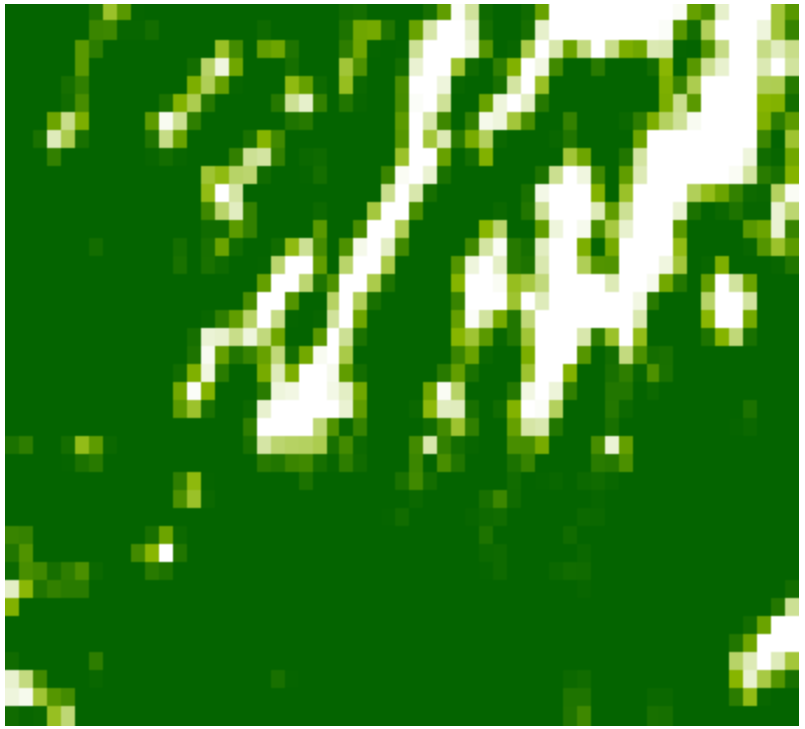
Landsat false color image and NDSI map (Xinjiang, W China)



True and VIIRS snow fraction at 5 km resolution cells (Nevada)







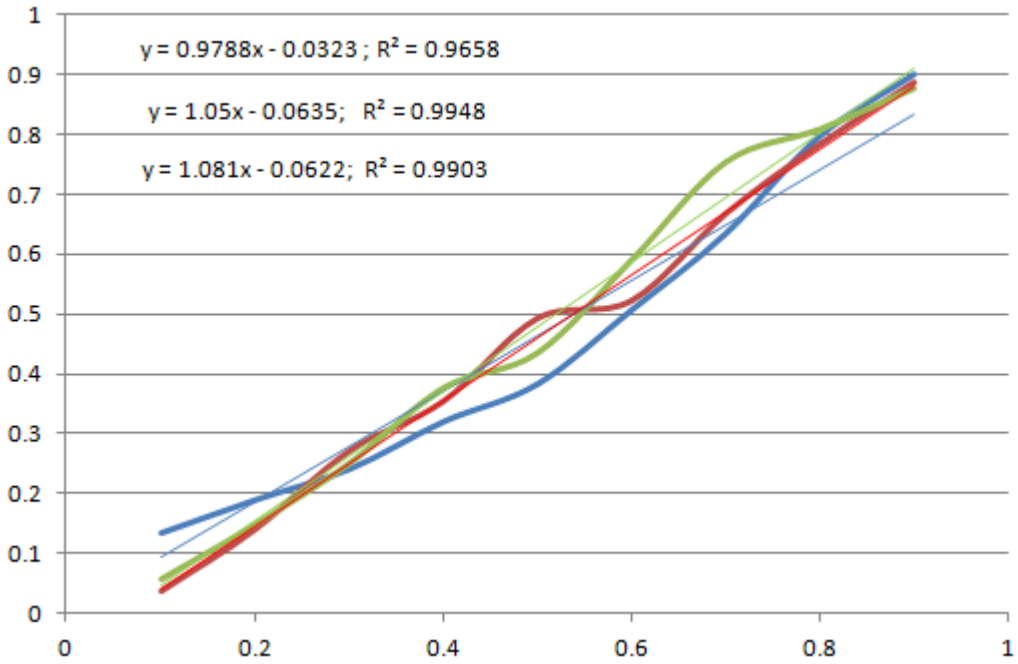


0% 100%

Snow fraction

Stratified Quantitative Assessment of NDSI-Based Algorithm Performance

Comparison of ground truth with NDSI algorithm results (thick lines) and trends (thin lines) for intermediate fractions demonstrates stratified performance for individual scenes



Validation of NDSI-based Snow Fraction

Corr. Coeff	Inter-cept	Slope	Mean true	Mean VIIRS	Location
0.84	-0.14	1.08	0.20	0.08	Beijing
0.89	-0.12	0.98	0.40	0.27	Altay
0.92	-0.14	1.10	0.61	0.53	Xinjiang 1
0.95	-0.03	1.00	0.20	0.17	Xinjiang 2
0.96	0.01	1.06	0.20	0.22	Nevada
0.96	-0.01	1.11	0.07	0.07	Sierra
0.92	-0.05	1.09	0.68	0.68	Tian Shan
0.91	-0.16	1.09	0.52	0.60	W Mongolia
0.89	-0.12	0.98	0.35	0.22	Gobi
0.74	-0.01	0.62	0.05	0.02	Pakistan
0.88	-0.07	1.09	0.92	0.93	S Mongolia
0.84	0.33	0.72	0.80	0.91	Dakotas
0.95	-0.00	1.07	0.19	0.20	Spokane
0.88	0.06	1.20	0.21	0.32	Oregon
0.95	-0.01	1.07	0.09	0.09	N Afghanistan
0.93	-0.06	1.17	0.27	0.25	C Afghanistan

NDSI-based Approach: Conclusions

- The optimal approach to improve moderate resolution remote sensing information on snow fraction allows the variability of local snow and non-snow properties
- Reliable evaluation of the VIIRS fractional snow algorithm quality is based on using Landsat scenes covering a wide variety of snow conditions, first of all, the areas including both snow and snow free surfaces
- Preliminary results of validation demonstrate that NDSI-based retrieval of snow fraction meets uncertainty requirements
- A scene-specific snow algorithm creates unbiased and consistent information on fractional snow cover distribution required for global studies, regional and local scale applications (including hydrological)

Further Enhancements of NDSI-based Approach

- It is necessary to explore and improve the quality of the following Look Up Tables
  - » NDSI LUT used to estimate scene-specific snow and non-snow NDSI (parameters of processed histograms)
  - » Cloud conditions LUT (cloud shadow, cloud confidence used for snow retrieval)
  - » Exclusion LUT defining conditions when snow fraction is not retrieved (dark pixels, climatic limitations)
- Investigate non-linear NDSI / snow fraction relationship
- Improve validation of the NDSI-based snow fraction for different scales, seasons, and conditions of observations
- Implement 250 m Land/Water mask
- Consider using cloud mask at imagery resolution

Reprocessing, Long-Term Monitoring

No plans for reprocessing so far

NDE long term product monitoring will include

- Generation global gridded snow fraction maps
- Visual examination of snow fraction estimates
- Comparison with Landsat
- Consistency testing

NOAA vs NASA Approach

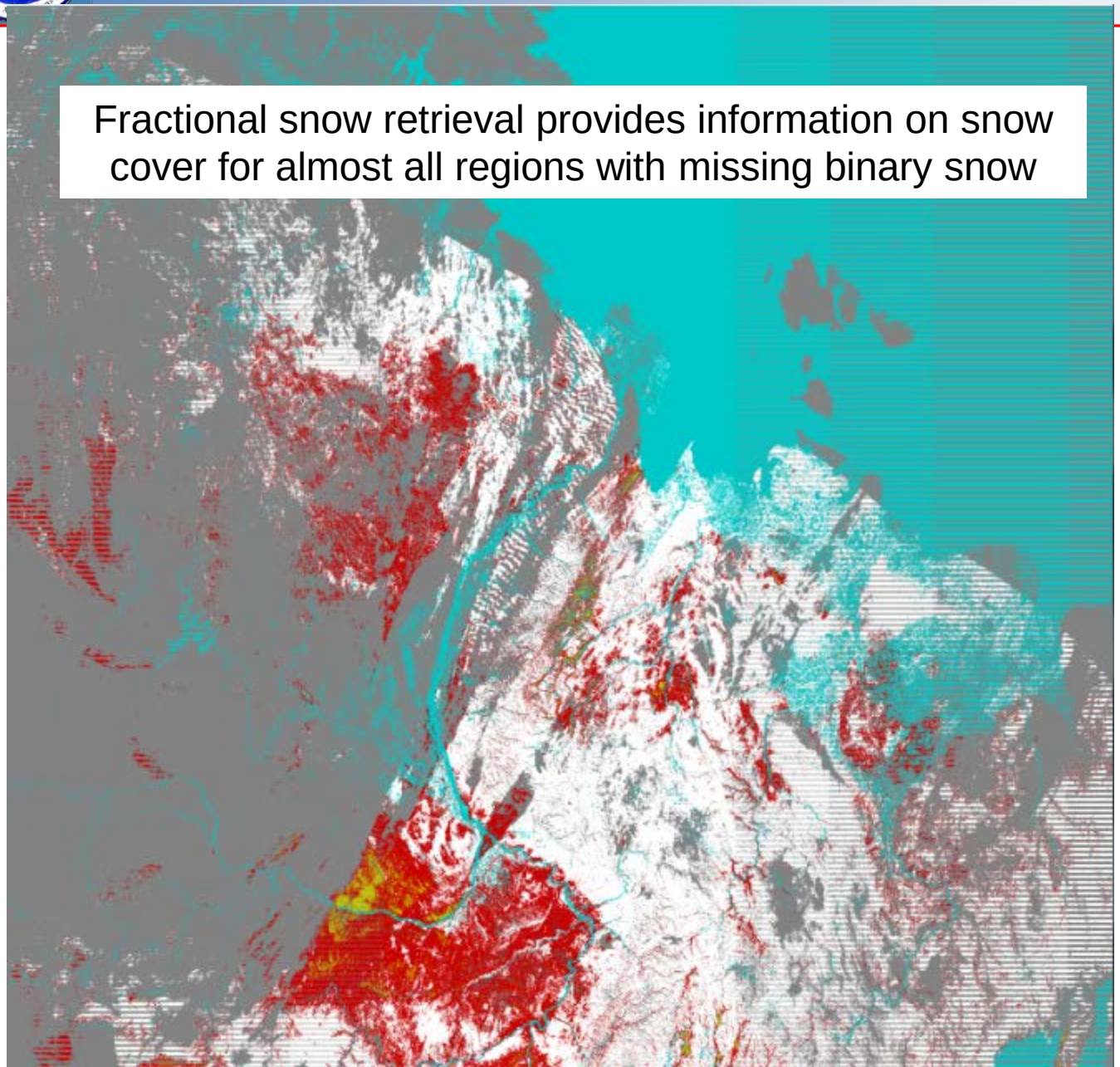
NASA:

- NDSI-based snow fraction

NOAA:

- Two snow fraction products

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



snow

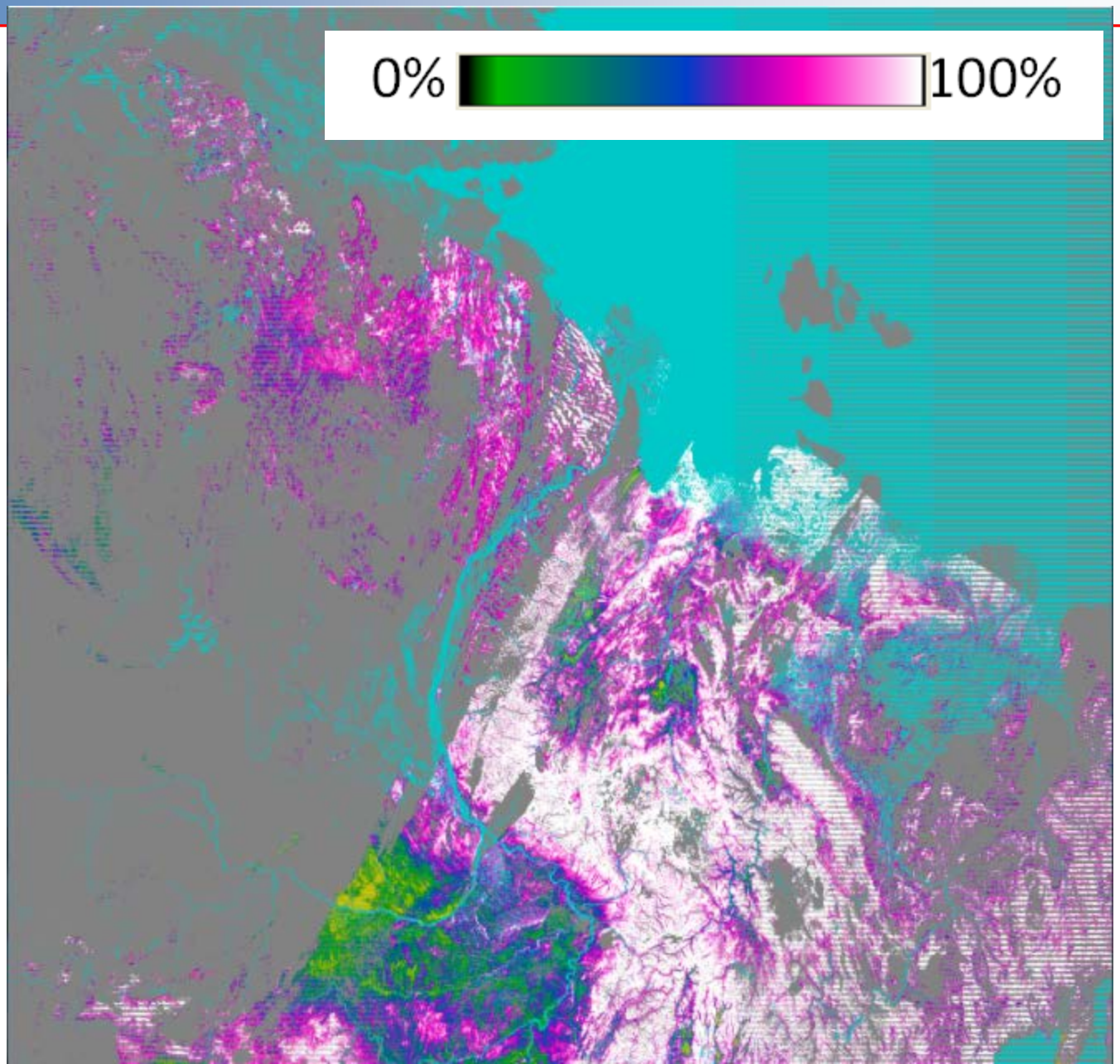
confidently cloudy

fractional snow cover in areas of non-snow binary retrieval

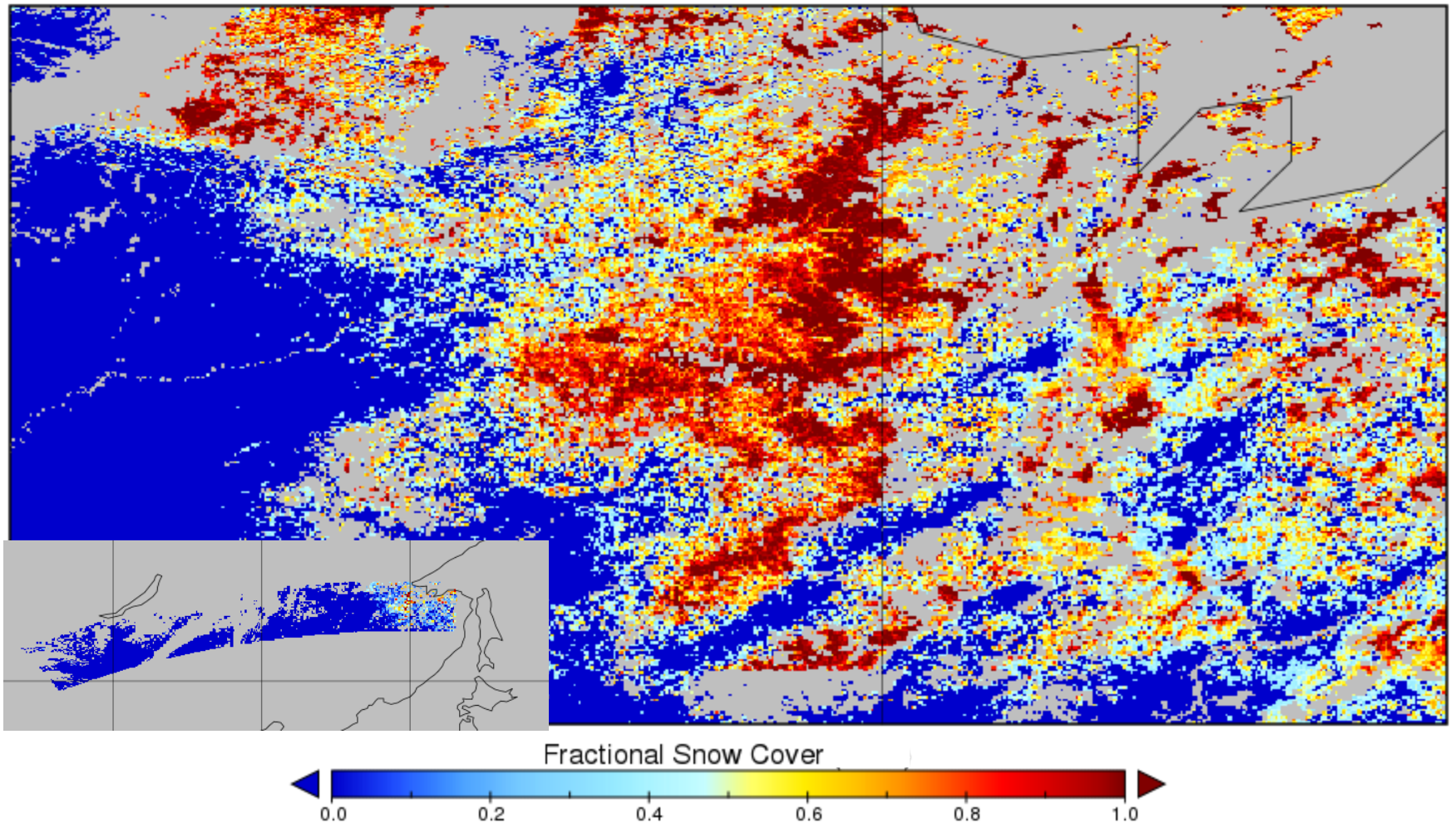
non-snow in binary and fractional retrievals

water

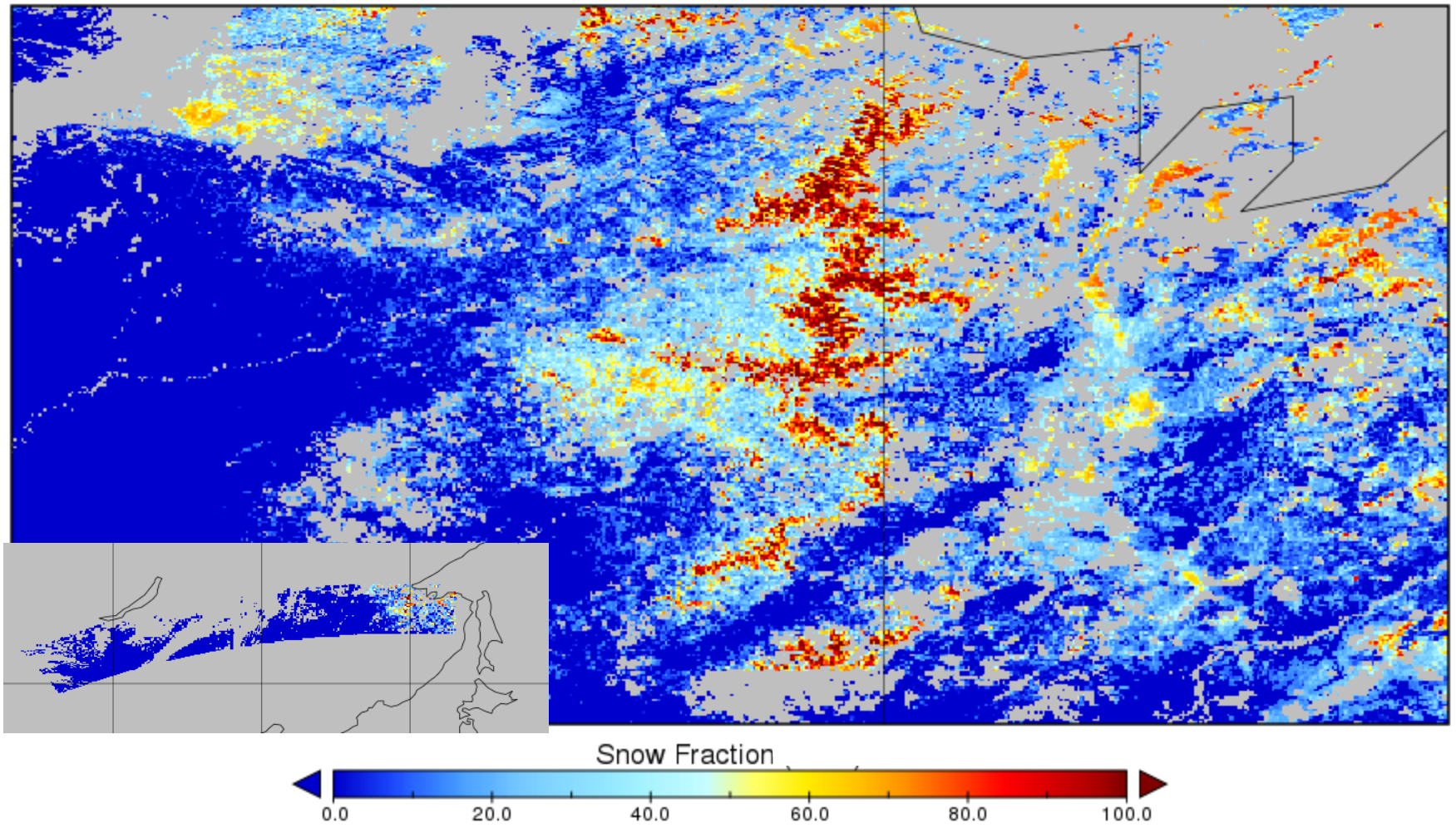
Snow Fraction on 10/24/13 (03:20)



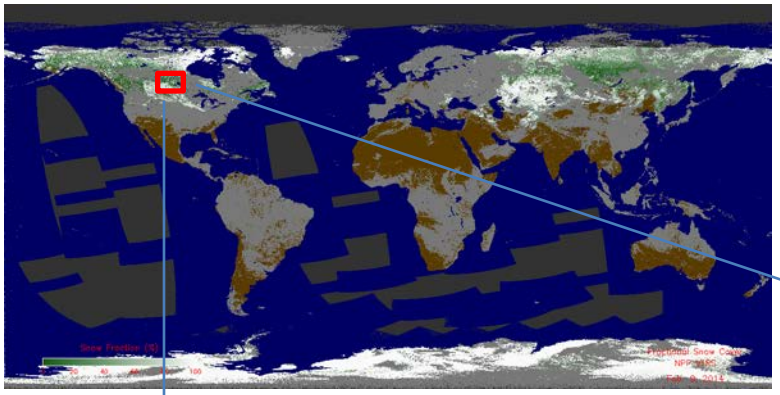
NDSI-based Snow Fraction (April 13, 2014)



Reflectance-based Fraction(April 13, 2014)



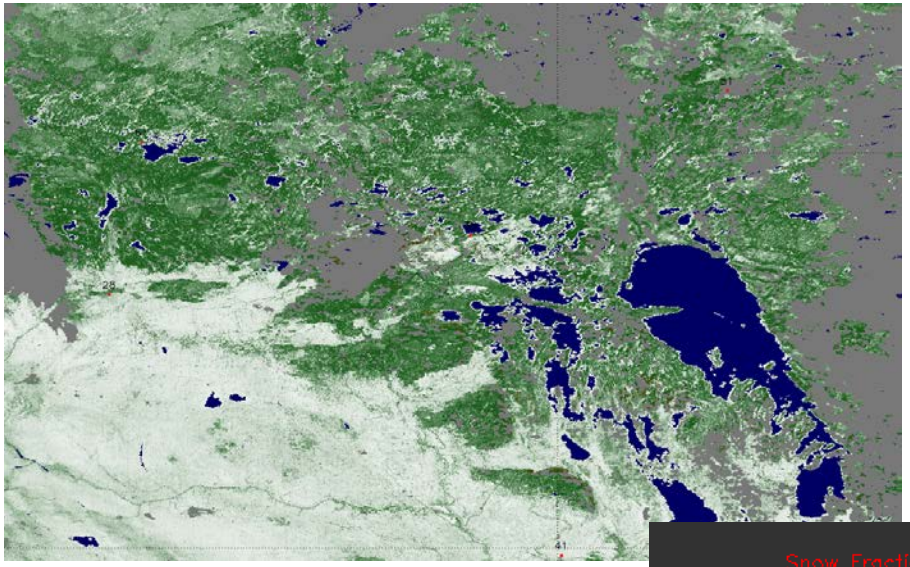
Reflectance-based vs NDSI-based Snow Fraction

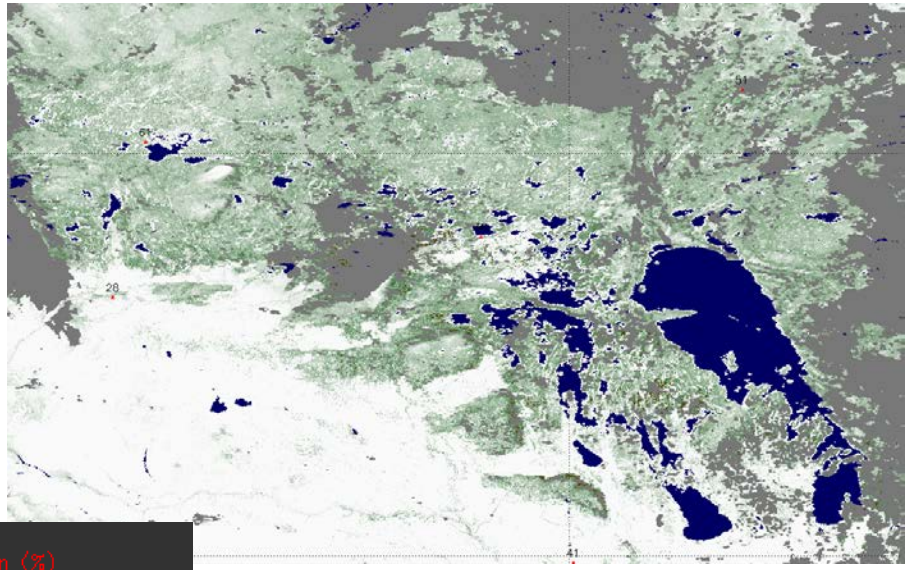


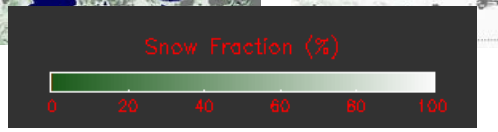
There is some similarity in the snow fraction patterns in the two products on the regional scale. NDSI-based snow fraction is much larger in the forest

Reflectance-based snow fraction

NDSI-based snow fraction

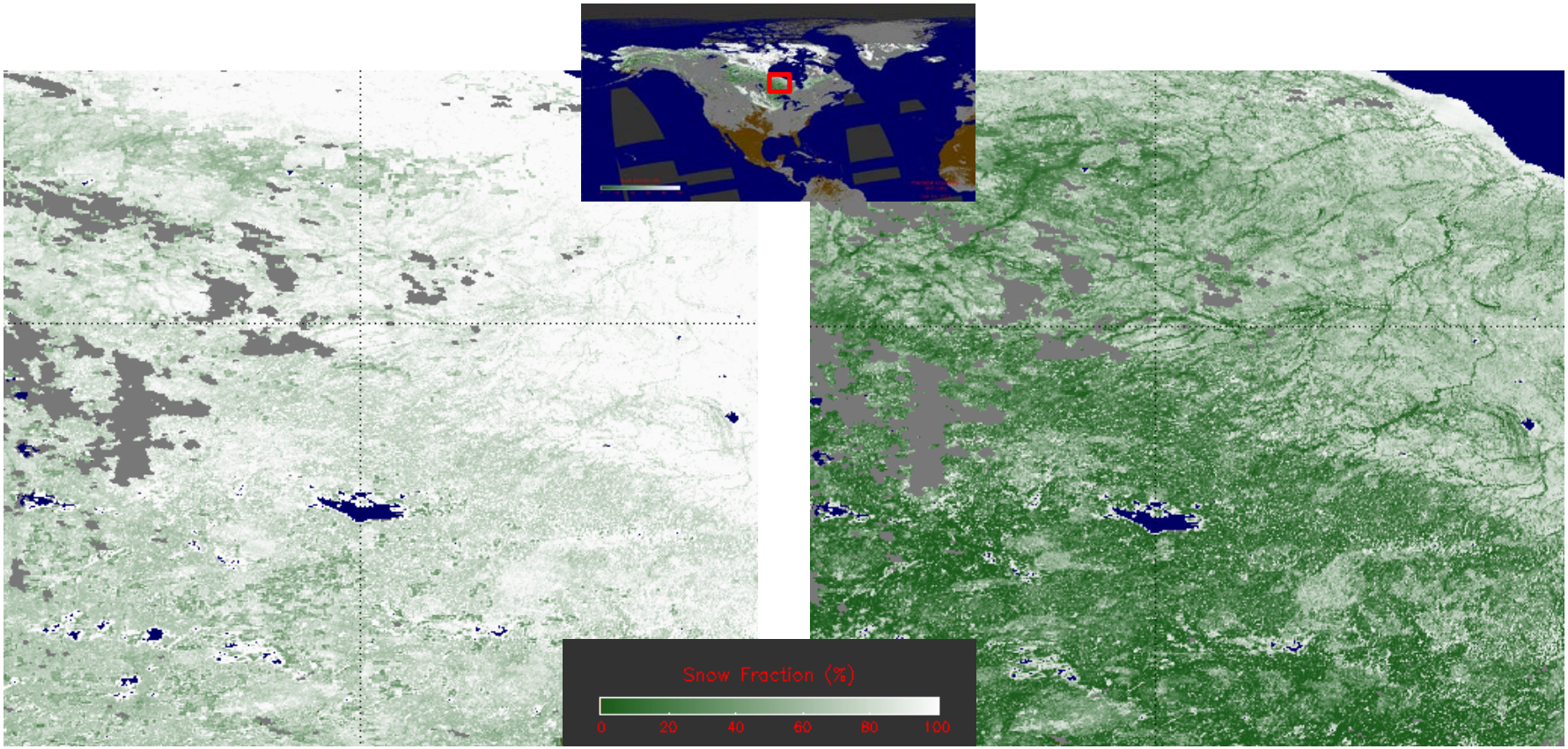






Clouds are shown in gray

Reflectance-based vs NDSI-based Snow Fraction



NDSI-based **Mean fraction: 83.4 %** **Reflectance-based** **Mean fraction: 36.8 %**

Questions Requiring Special Consideration

Consistency between algorithms retrieving binary snow mask and fractional snow cover

- comparable physical bases and algorithm realizations
- strict definition of binary snow product meaning
- excluding possible contradictions between binary and fractional products

Consistency between alternative algorithms of fractional snow cover retrieval

- Comparable outputs of fractional snow cover retrievals
- Explainable and acceptable differences between fractional snow cover products provided by two algorithms
- Estimated risk related to the difference between two retrievals