GOES-R AWG Cryosphere Team: Snow Cover Algorithm

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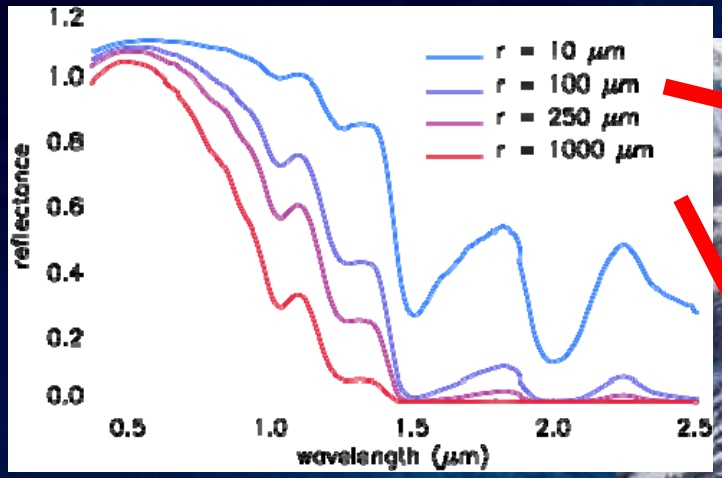
Outline

- Executive Summary
- Algorithm Description
- ADEB and IV&V Response Summary
- Requirements Specification Evolution
- Validation Strategy
- Validation Results
- Summary

Executive Summary

- This ABI Snow Cover Algorithm (Fractional Snow Cover - FSC) generates the Option 1 product of Snow Cover with intermediate products of grain size, fractional green vegetation cover, and fractional soil cover.
- Version 5 was delivered in May. ATBD (100%) is on track for a July delivery
- The physically-based spectral mixture model uses the full solar spectrum of ABI to retrieve fractional snow cover.
- High resolution Thematic Mapper and moderate resolution MODIS data have been used for validation. Landsat Data Continuity Mission and NPP/NPOESS VIIRS data will be used for future validation studies.
- Thematic Mapper and MODIS analyses indicate spec compliance for snow cover product.

Physical Description: Spectral Gradients



With the sensitivity of snow directional reflectance to grain size, solar zenith angle, view geometry, and impurities, and the variation of all of these across continents, there are substantial spectral gradients in snow reflectance that must be accounted for.

Physical Description; Snow Reflectance

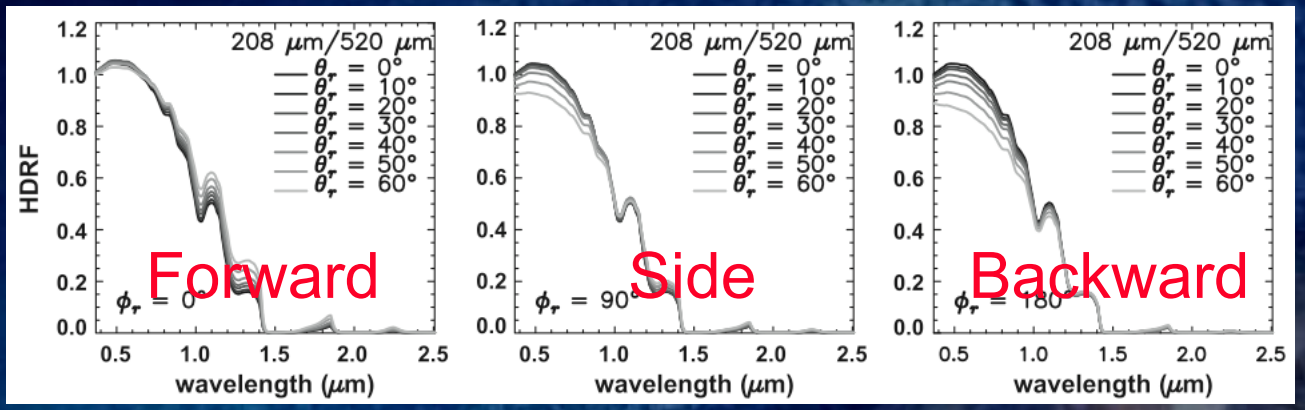
Spectral reflectance for different angles

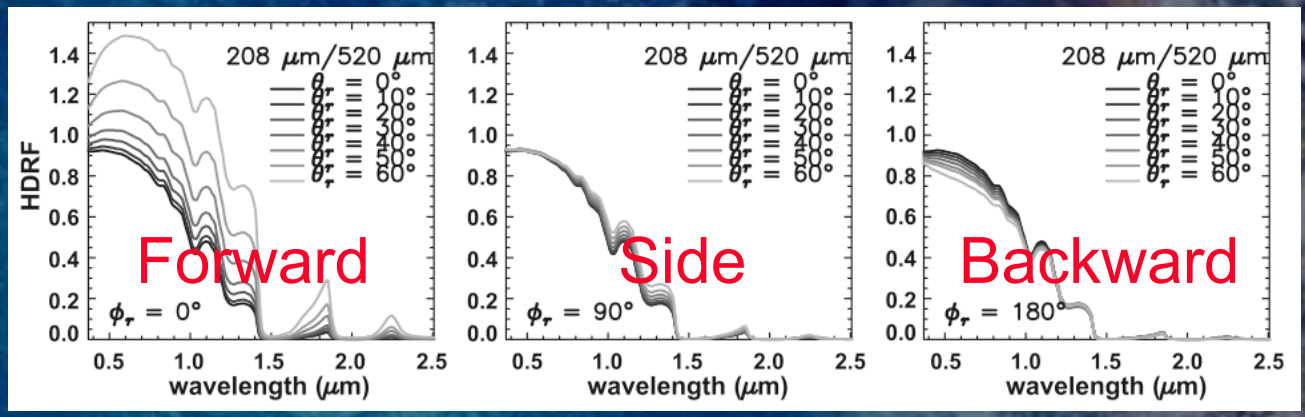
View azimuth

$\theta_0 = 30°$

Solar zenith

$\theta_0 = 60°$





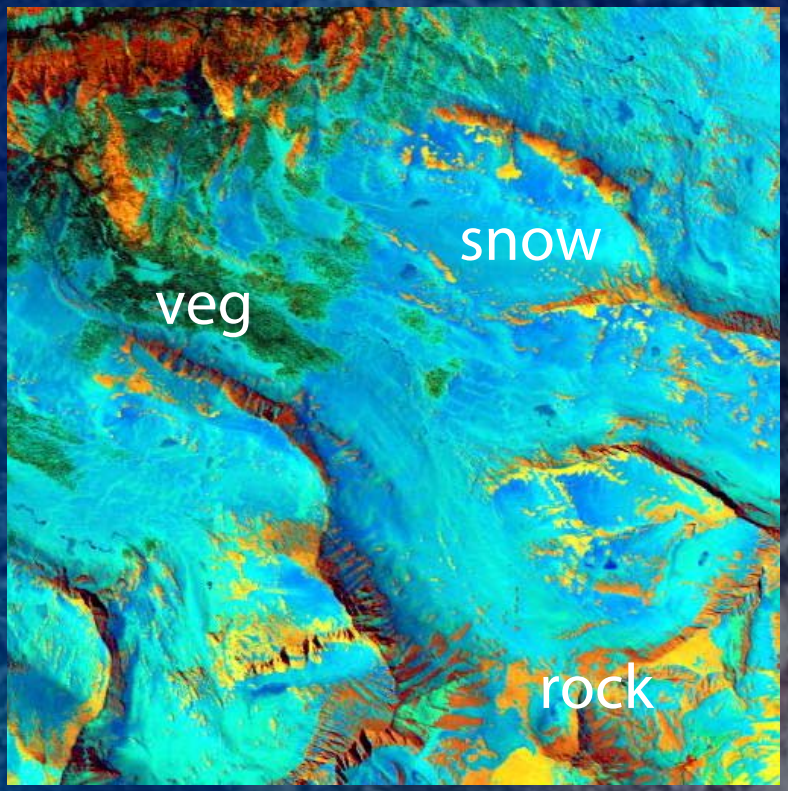
Algorithm Motivation: Snow Cover

The pixel radiance from the surface that reaches the sensor is a mixture of contributions of radiances from snow, vegetation, soils, lake ice, etc.

This scene is from the Sierra Nevada with 17 m imaging spectrometer data with the vast majority of radiances within a single pixel coming from a single surface.

2 km

2 km



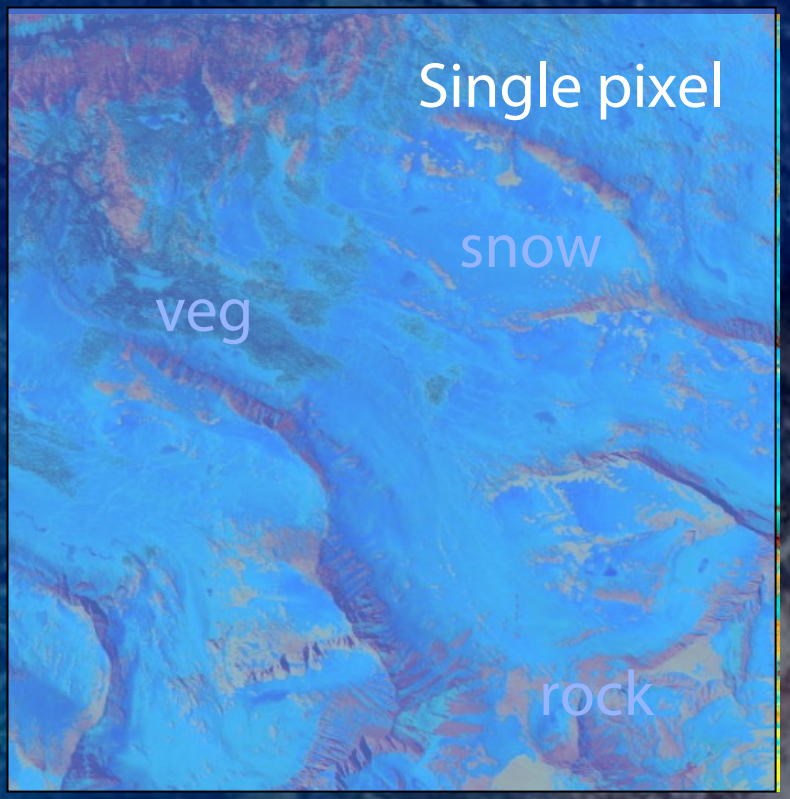
AVIRIS

Algorithm Motivation: Snow Cover

The pixel radiance from the surface that reaches the sensor is a mixture of contributions of radiances from snow, vegetation, soils, lake ice, etc.

2 km

In this case, a single GOES-R ABI pixel is presented showing the underlying mixture of radiances from snow, vegetation, and exposed rock



Snow Cover Algorithm Heritage

- **GOESRSCAG Algorithm (FSC – Fractional Snow Cover)**
  - **Description:** Retrieves sub-pixel fractional snow cover and grain size estimates via computationally efficient spectral mixture modeling
  - **Heritage:**
    - MEMSCAG (Multiple Endmember Snow Covered Area and Grain size) was original model - benchmark algorithm for imaging spectrometers (AVIRIS, Hyperion, HYDICE, ARTEMIS) - *Painter et al.,* 2003, RSE
    - MODSCAG (MODIS-based fractional snow cover and grain size) algorithm. Measurement accuracy < 0.08 fraction. *Painter et al,* 2009, RSE.
    - TMSCAG model for Landsat Thematic Mapper (accounts for frequent saturation over snow in visible bands) *Painter et al.* in preparation.
  - GOESRSCAG derives from MODSCAG accounting for differences between the MODIS and GOES-R ABI band passes, geometry, etc. This model is the only that can achieve fractional snow cover in all terrain with no sensitivity to changes in irradiance.
  - Coordination with polar-orbit products:
    - MODSCAG has been recently proposed to replace the current Normalized Difference Snow Index based products delivered by NSIDC.
    - VSCAG (VIIRS Snow Covered Area and Grain size) has been recently proposed to replace the NDSI fractional snow cover product

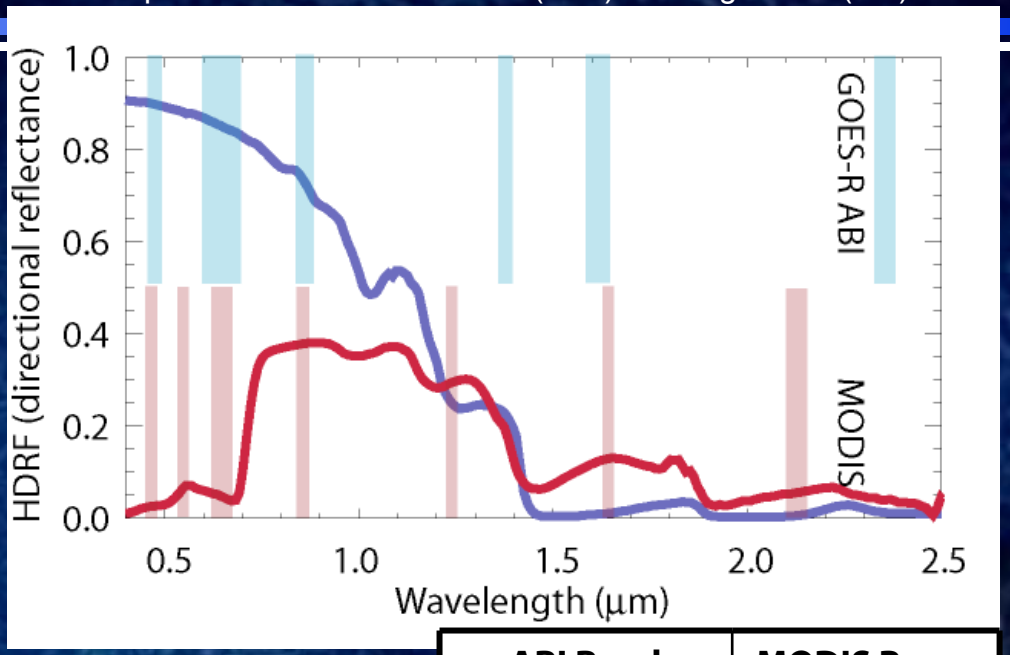
Snow Cover Algorithm

$$\overline{R_\lambda} = \sum_{i=1}^{N} F_i R_{\lambda i} + \varepsilon_\lambda$$

$$\varepsilon_\lambda = \overline{R_\lambda} - \sum_{i=1}^{N} F_i R_{\lambda i}$$

$$RMSE = \sqrt{\frac{1}{M} \sum_{\lambda=1}^{M} \varepsilon_\lambda^2}$$

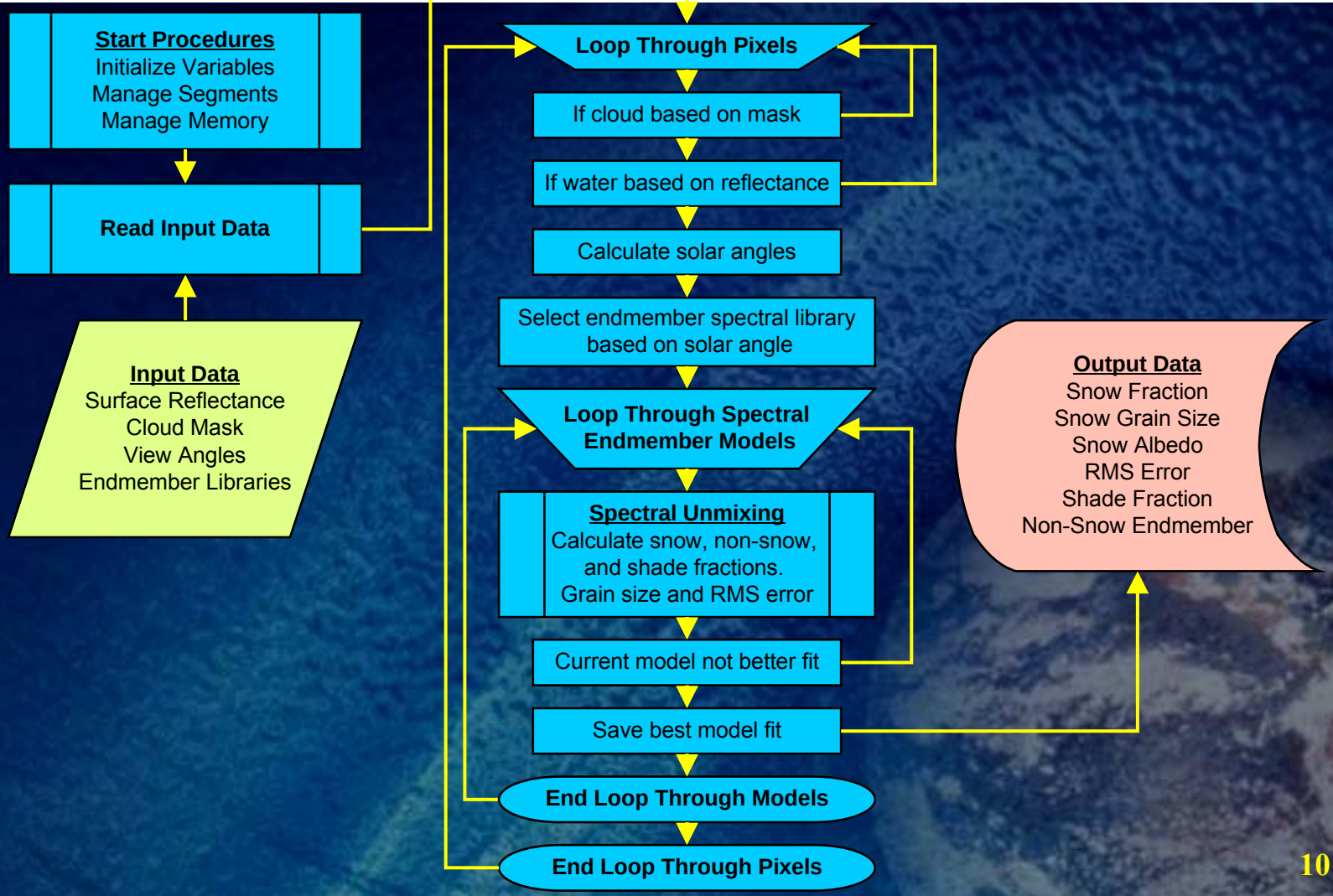
Spectral reflectance of snow (blue) and vegetation (red)



ABI Band	MODIS Proxy
1	1
2	3
3	4
5	6
6	7

GOESRSCAG spectrally unmixes allowing numbers of endmembers and the endmembers themselves to vary on a pixel by pixel basis. *R* is surface reflectance, *N* is the number of endmembers, *M* is the number of spectral bands, and *F* is the coefficient (fraction) determined from the Modified Gram-Schmidt Orthogonalization.

Basic Flowchart for Snow Cover



Algorithm Summary

The GOES-R ABI Snow Cover algorithm consists of the following general steps:

1. Determine pixel non-snow endmember (based on preprocessing of ABI data)
2. From solar and view geometry, select spectral library per pixel
3. Given pixel non-snow endmember, unmix pixel spectral reflectance into snow fraction and non-snow fraction
4. In unmix step, determine grain size of snow fraction
5. Use ABI cloud map and Snow Cover grain size to determine pixel cloud cover
6. Shade-normalize snow fraction to pixel fractional snow covered area

Motivation for Algorithm Channel Selection

• The FSC represents a new approach for remote sensing of snow from GOES. The model represents a spatially explicit, physically-based retrieval of fractional snow cover as opposed to previous empirical approaches.

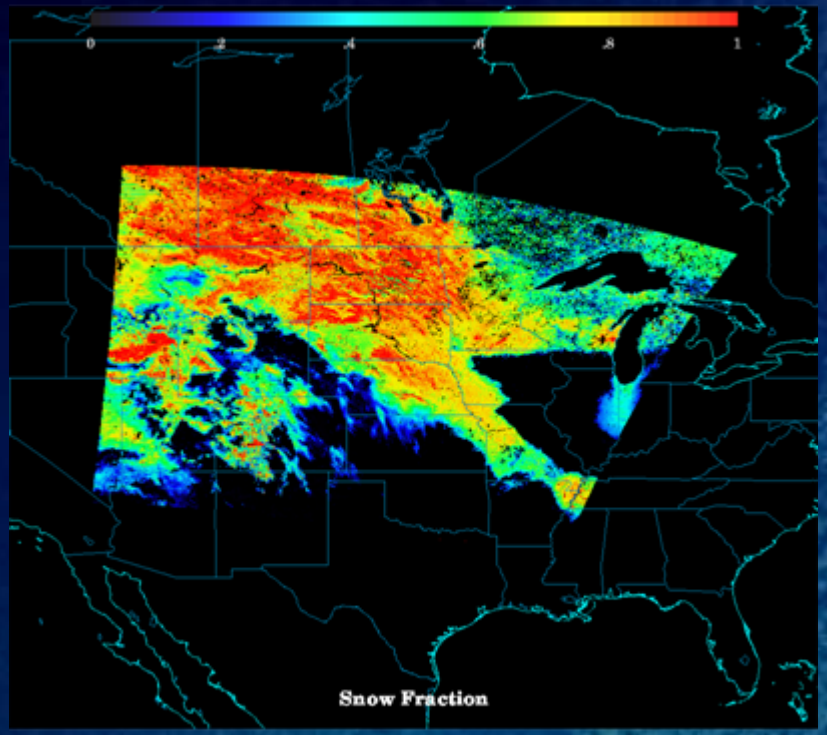
• FSC uses the full ABI surface reflected spectrum to determine the fractional abundances of snow, vegetation, and soil. Additionally, FSC determines the grain size of that fractional snow cover per pixel, facilitating estimate of the fractional snow albedo and discrimination of snow from clouds.

• FSC uses reflectance bands 1, 2, 3, 5, and 6. Band 4 (~1.38 μm) allows detection of cirrus and in most regions will saturate with absorption at the surface due to water vapor absorption.

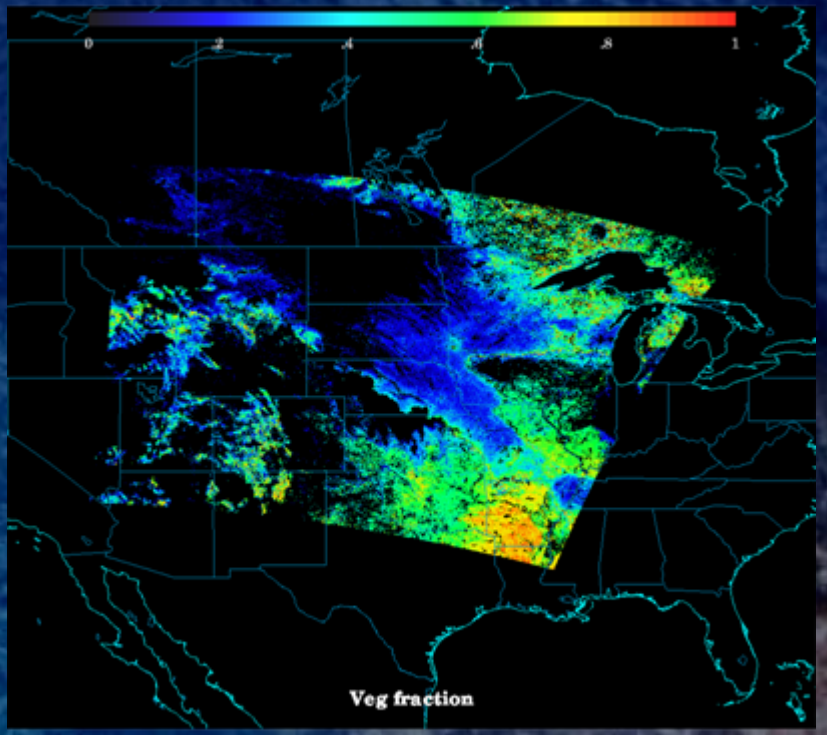
• Brightness temperatures in bands 7 () and 11 () are used for discrimination of desert playa and other surfaces that have spectral signatures similar to snow and clouds.

Example FSC Output

Fractional Snow Cover



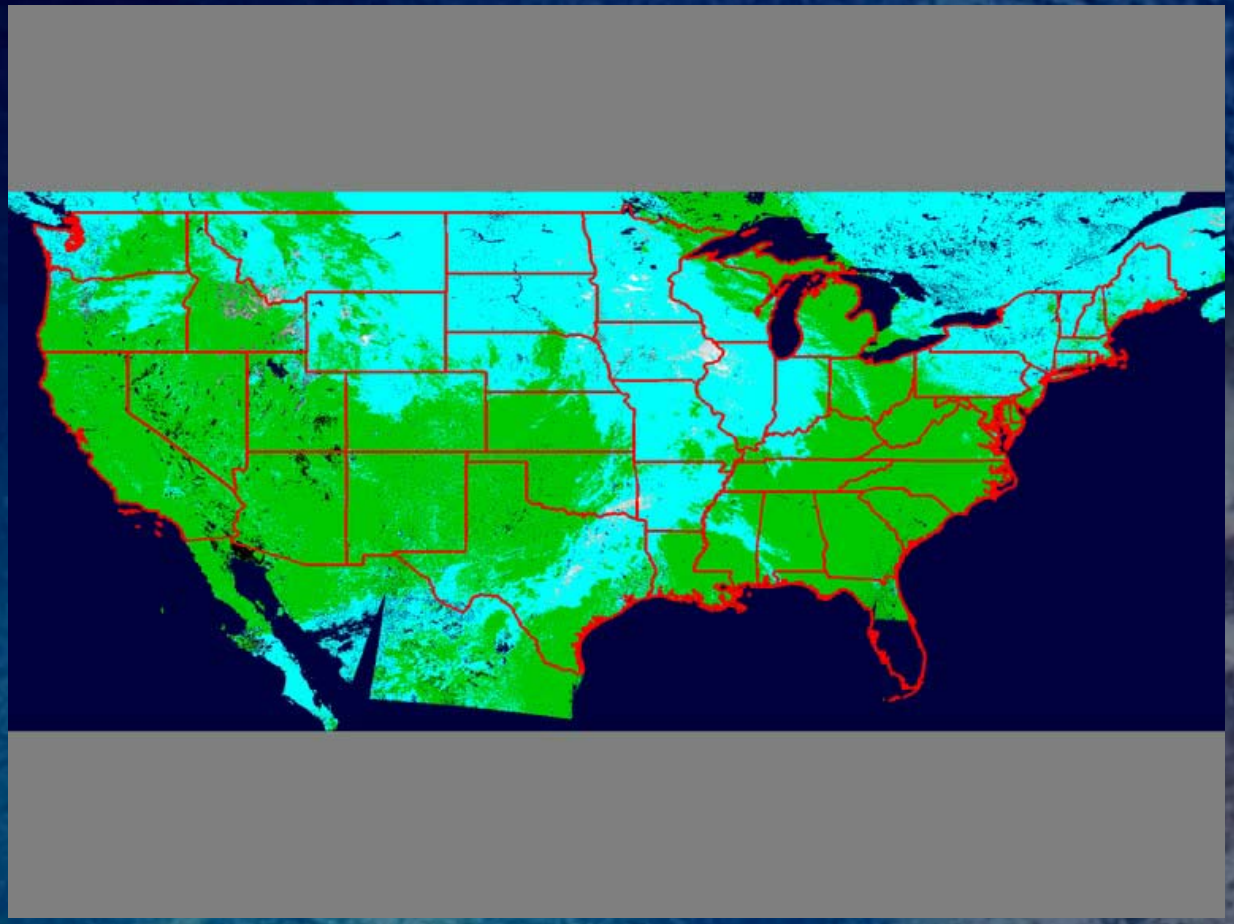
Fractional Vegetation Cover



Simulated GOES-R ABI Snow Fraction (left) and Green Vegetation Fraction (right) from GOESRSCAG processing of proxy ABI data from MODIS, March 1, 2009.

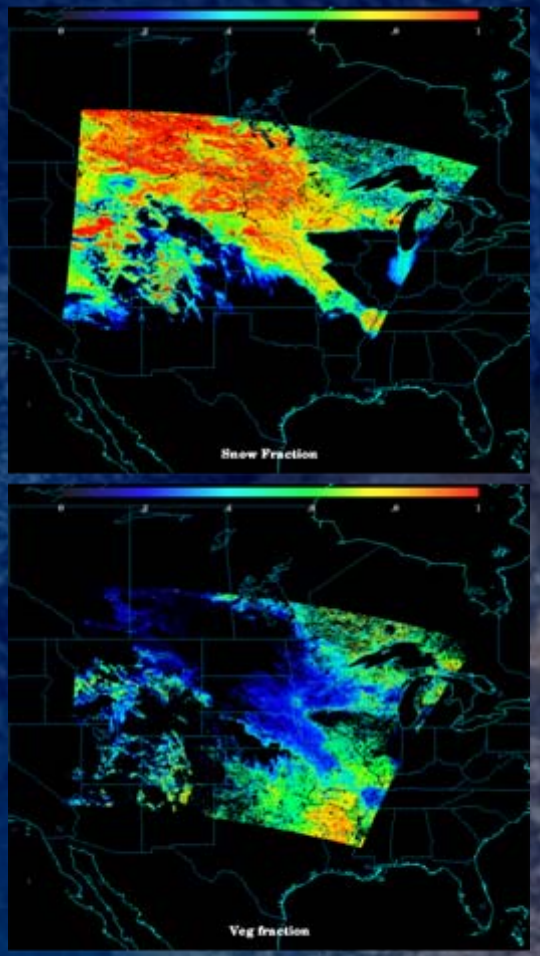
Example FSC Output

Winter/Spring 2010



Algorithm Changes from 80% to 100%

- No major changes to logic or geographical dependencies in code.
- Optimization of handling of non-snow endmember map.



ADEB and IV&V Response Summary

- All ATBD errors and clarification requests have been addressed.
- The review revealed an inconsistency between the algorithm retrievals and the product specifications. This resulted from an erroneous product requirement specification (next slide).
- No substantive modifications to the FSC algorithm were required.

Requirements

Product	*Accuracy (e_c> 0.8)*	*Precision (e_c >0.8)*	*horizontal resolution*
Snow Cover (present, erroneous)	30%	15%	
Snow Cover (corrected)	15%	30%	Fractional at

Fine, be sloppy but be consistent about your sloppiness

Be consistent with your accuracy but we'll accommodate some pixel to pixel uncertainty ….

Qualifiers

Snow cover is generated with the following qualifiers.

- Temporal: generated for solar zenith angle ≤ 67°
- Product extent: quantitative for sensor zenith angle < 55°
- Product extent: qualitative for sensor zenith angle ≥ 55°
- Cloud cover: reported for clear sky but generated to assist with cloud mapping
- Product statistics: over specified geographic area

Validation Approach

Three-prong approach for validation (high spatial resolution and greater spectral sampling)

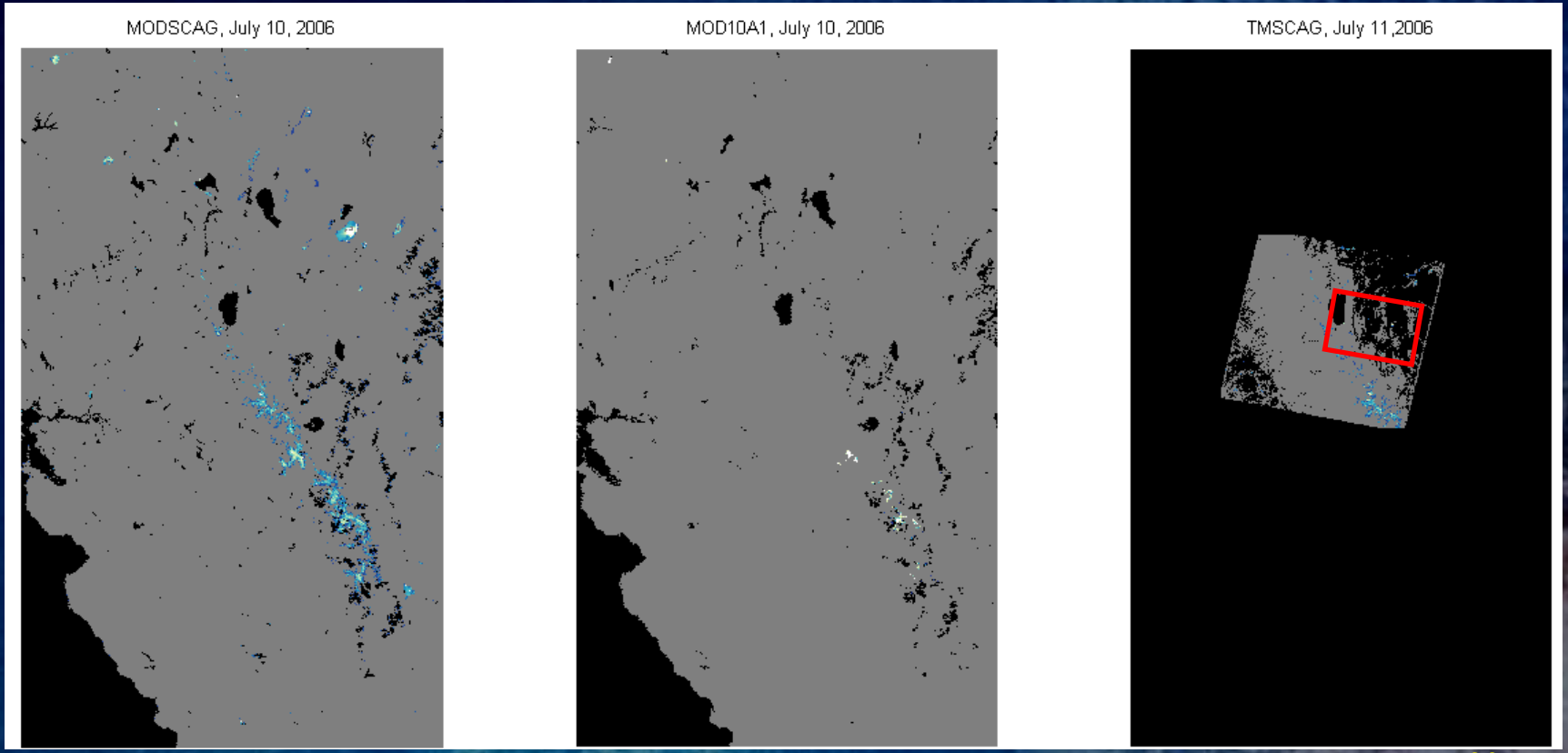
1.High spatial resolution validation from Thematic Mapper and ASTER fractional snow cover data mapped at native resolution and then coarsened to 2 km GOES-R ABI sampling

2.Validation from MODIS 7 band fractional snow cover at 0.5 km and 2 km and post-MODIS instruments

3.In situ measurements and spatial snow modeling

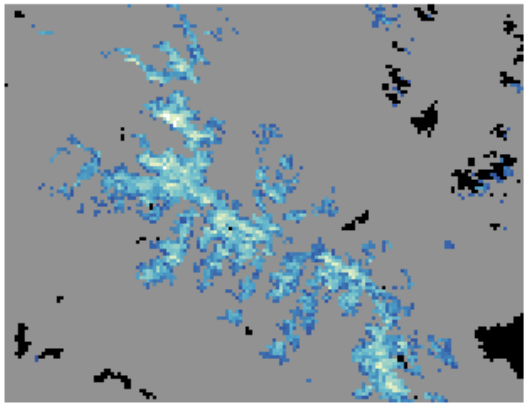
Validation Approach

High spatial resolution validation



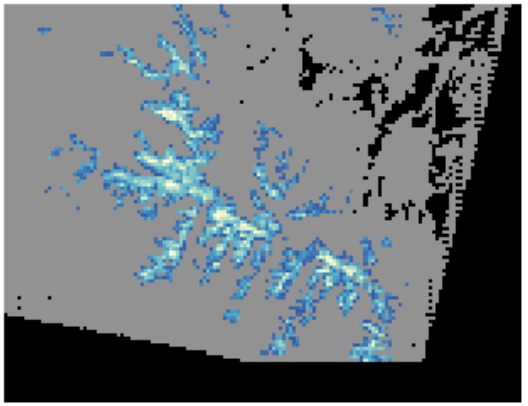
Validation Approach

MODSCAG, July 10, 2006



MOD10A1, July 10, 2006

TMSCAG, July 11,2006

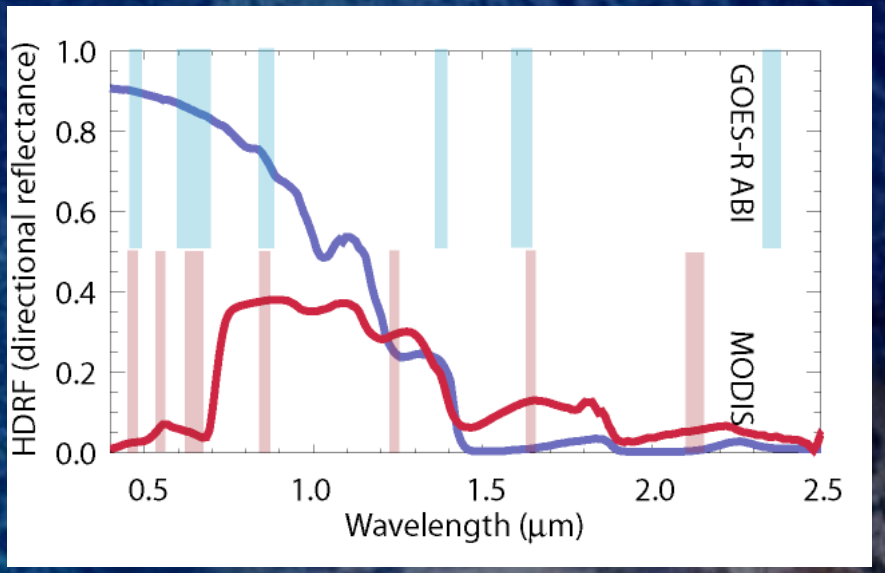


Validation Approach

Proxy data validation

Goes-R ABI Channel Number	GOES-R ABI Wavelength (µm)	MODIS Proxy Band Number	MODIS Wavelength (µm)
1	0.45 – 0.49	3	0.459-0.479
2	0.59 – 0.69	1	0.620-0.670
3	0.85 – 0.88	2	0.841-0.876
5	1.58 – 1.64	6	1.628-1.652
6	2.22 – 2.28	7	2.105-2.155

Testing and validation of the GOES-R FSC algorithm is conducted using MODIS data as proxy for GOES-R ABI data



Spectral reflectance of snow (blue) and vegetation (red)

Pre to Post Launch Validation

In near launch and post-launch of GOES-R, Terra and Aqua MODIS are likely to have experienced partial if not complete failures. At that time, NPOESS and NPP VIIRS (Visible Infrared Imaging Radiometer Suite) data should be available.

These will supplant MODIS as proxy data for ABI and in bridge temporal validation of the FSC product.

Goes-R ABI Channel Number	GOES-R ABI Wavelength (μ m)	Used in FSC	MODIS Proxy Channel	VIIRS Proxy Channel
1	0.47	✓	1	M3
2	0.64	✓	3	M5
3	0.86	✓	4	M7
4	1.38			
5	1.61	✓	6	M10
6	2.26	✓	7	M11

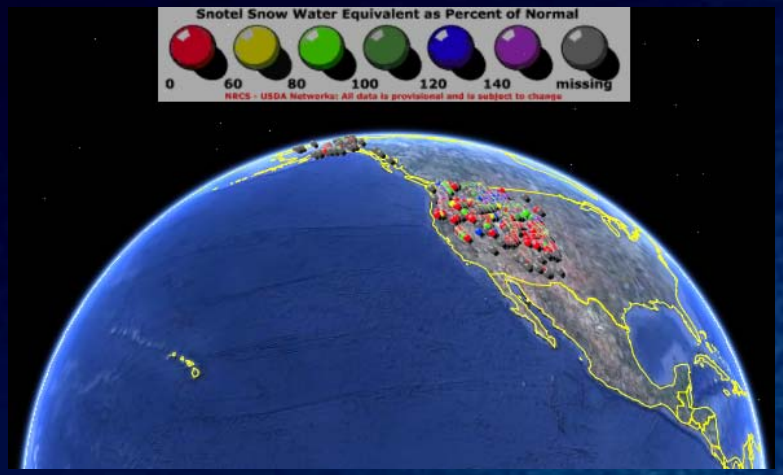
From GOES-R ABI Snow Cover Validation Plan (2009)

Pre to Post Launch Validation

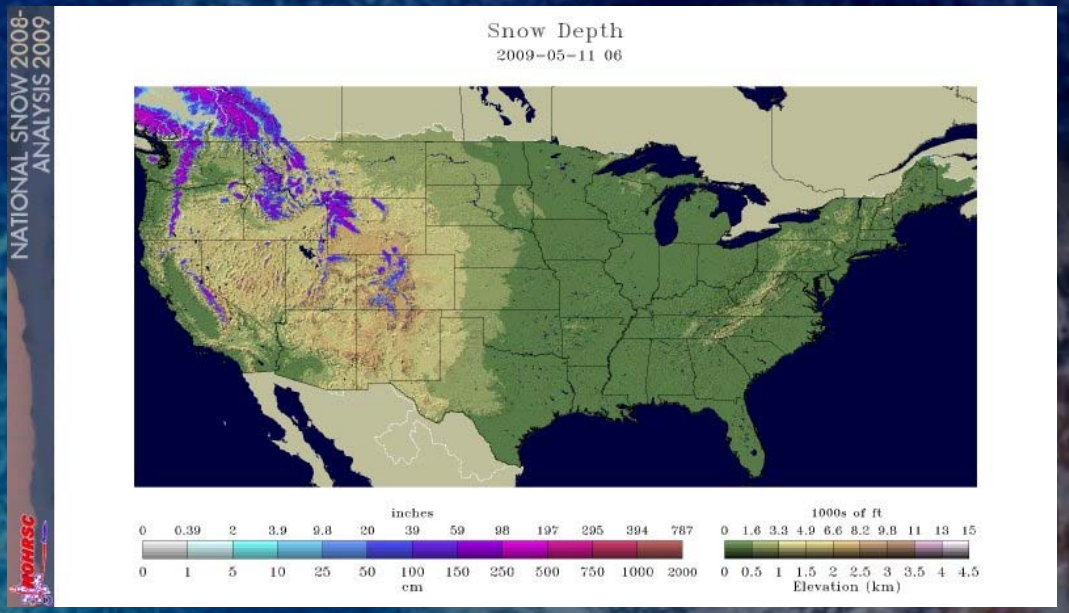
The Landsat Data Continuity Mission (LDCM) is scheduled to be launched in December 2011.

These data will be used for validation of GOES-R ABI Snow Cover in pre-launch (proxy ABI data) and post-launch (ABI data) for high resolution validation.

Post-Launch Validation



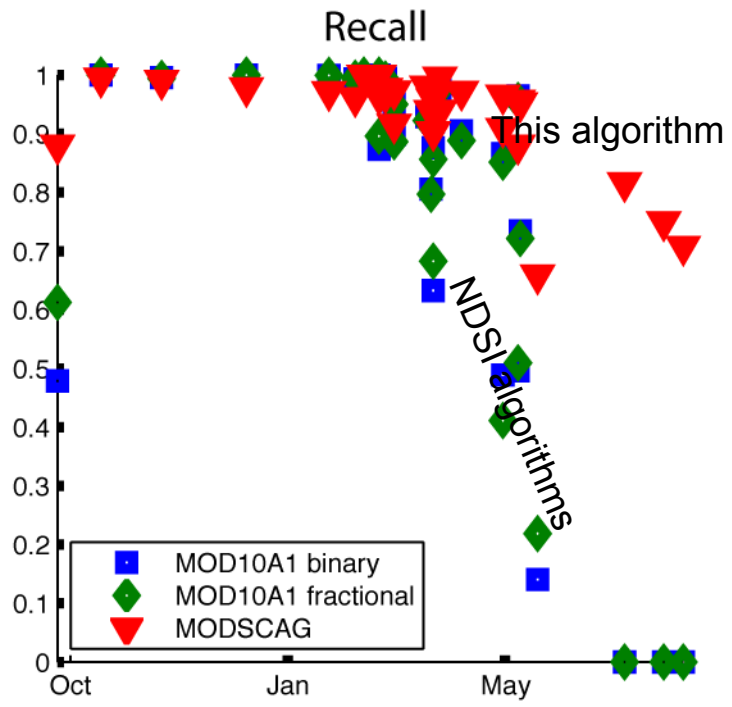
NRCS Snow Telemetry (SNOTEL) sites.



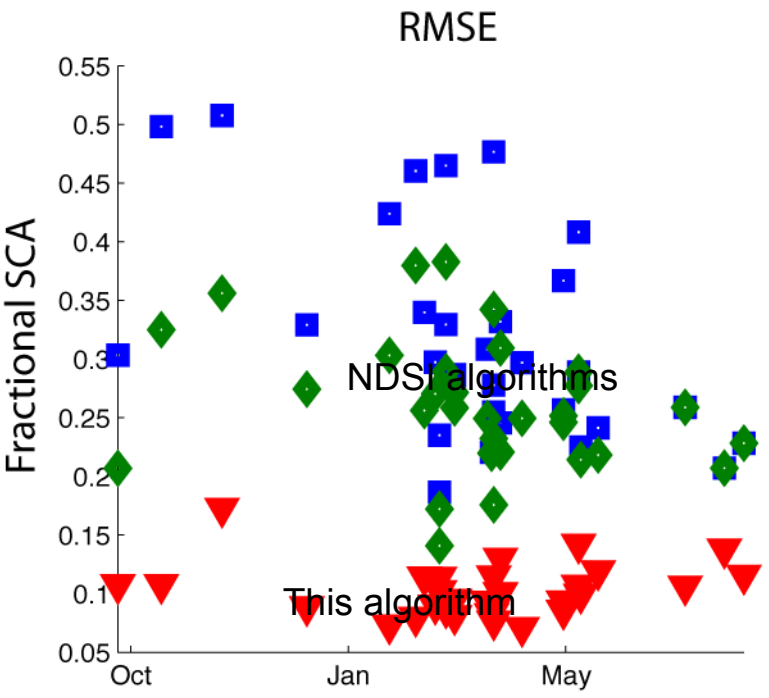
NWS NOHRSC Snow Data Assimilation System (SNODAS)

Current Validation Results

Validation Approach - Comparison



Fraction of true snow detected



Fractional snow cover

Validation

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ELSEVIER

Retrieval of subpixel snow covered area, grain size, and albedo from MODIS

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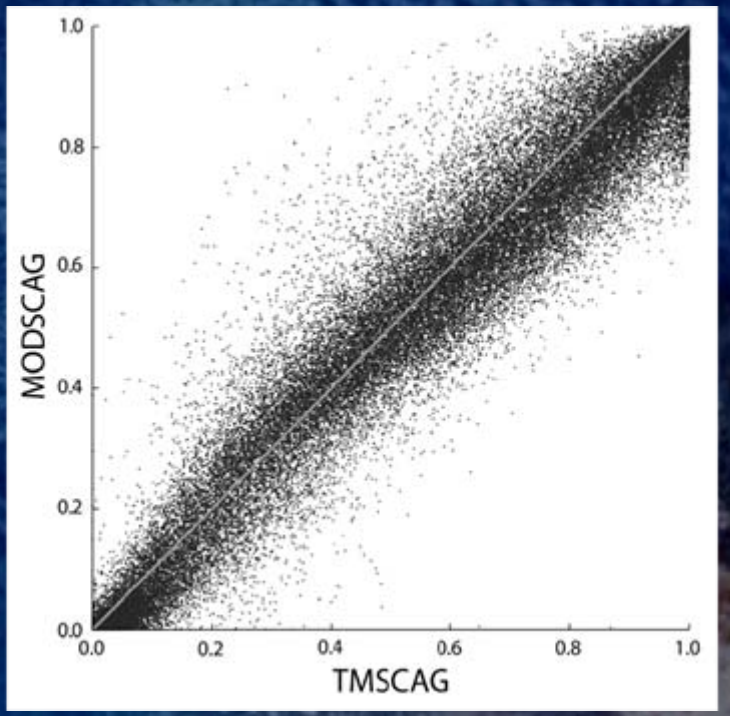
MODSCAG validation with high spatial resolution Thematic Mapper data.

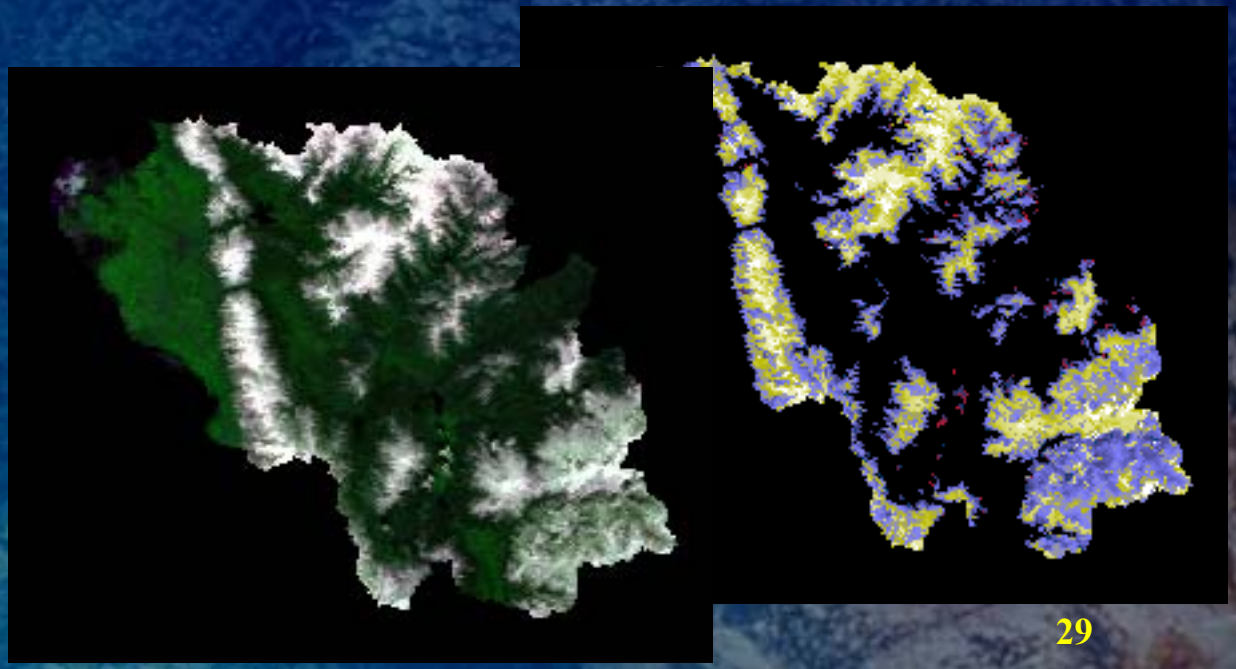
Accuracy: -0.5% (w/ 0's) to -1.0% (just snow)
Precision: 4.9% (w/ 0's) to 8.9% (just snow)



Validation – ABI Proxy Data

Validation with 5-band proxy ABI data from MODIS with 7-band MODIS spectra.

Accuracy 2.3% (w/ 0's) - 3.7% (just snow)
Precision 7.7% (w/ 0's) - 11.9% (just snow)



Validation Results Summary

Validation Configuration	Accuracy (spec)	Precision (spec)
Fractional Snow Cover MODSCAG vs. Landsat (snow only)	-1.0% (15%)	8.9% (30%)
Fractional Snow Cover MODSCAG vs. Landsat (snow and snow-free)	-0.5% (15%)	4.9% (30%)
Fractional Snow Cover 5 band vs. 7 band ABI proxy (snow only)	3.7% (15%)	11.9% (30%)
Fractional Snow Cover 5 band vs. 7 band ABI proxy (snow and snow-free)	2.3% (15%)	7.7% (30%)

Summary

- ABI Snow Cover algorithm provides critical snow cover information at fractional coverage
- Version 5 is delivered and the 100% ATBD is on track for timely delivery.
- Snow Cover meets the specifications (upside down and right-side up)
- We look forward to collaborating with the Cloud Cover team to improve cloud/snow discrimination