The Snow Cover Product for the GOES-R Advanced Baseline Imager

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Abstract

Snow mapping from the GOES family of environmental satellites has served as a critical and indispensible tool for operational water managers, weather forecasters and climate researchers since the 1970s. The dramatic leap forward in spaceborne imaging technology developed for GOES-R will provide unprecedented accuracy and precision in estimates of snow cover. Earlier snow mapping algorithms have had to rely on only a single visible band of imagery using simple brightness threshold methods to identify pixels that are mostly covered in snow. By contrast, the GOES-R Advanced Baseline Imager spans the solar spectrum with several imaging bands so that, instead of relying on thresholds and thereby necessarily overlooking some of the snow cover, we can now quantitatively retrieve the fractional portion of any pixel that contains even a tiny portion of snow cover.

The GOES-R Snow Cover product has its legacy in imaging spectroscopy and multi-spectral imaging. With the advent of the Advanced Baseline Imager, the enhancement in spectral sampling coupled with frequent acquisitions will allow the more detailed characterization of fractional snow cover and the grain size of that fractional snow cover. The product comes from optimized spectral mixture analysis that uses the broad spectrum from ABI to determine the fractional cover of snow, vegetation, and soils. With the single visible bands of previous GOES sensors, snow cover mapping was constrained to severe assumptions whereas we can now explore what we now know to be the rich variation in the spectral reflectance of snow.

Depending on yearly and seasonal climate variations, snow cover can be the most dominant land surface feature at a continental scale. This is certainly true at regional scales where, for certain parts of the year, snow cover is the only significant feature. The climate that we, as humans, enjoy today is highly dependent upon the location, extent and timing of the annual cycle of snow accumulation, persistence, and depletion. The ebb and flow of continental climate conditions is influenced, to a large degree, by snow's high albedo (ability to reflect the sun's energy) and low thermal conductivity (ability to insulate).

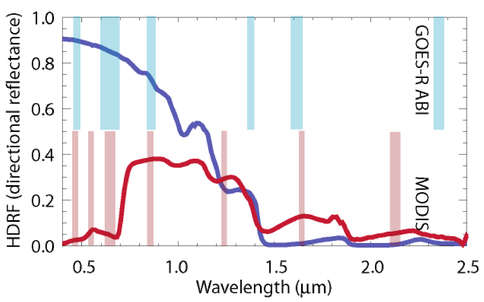
In addition to its impact on climate, snow plays a major role in the hydrologic cycle. Depending on the region, the snow pack can store several months of precipitation which, when it finally does melt, may release a season's worth of precipitation in relatively short order. For some of us, this is seen as a huge benefit where snow may be the single most important source fresh water for industrial, agricultural, energy, recreational and consumptive use. For others, the melting of the snow pack is a harbinger for the onslaught of flooding.

Algorithm Legacy

- 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,* RSE, 2009.
- TMSCAG model for Landsat Thematic Mapper (accounts for frequent saturation over snow in visible bands) *Rittger et al.* in preparation.

The GOES-R ABI Surface Reflectance Spectrum

It is not surprising that the NOAA AVHRR and NASA MOD10A1 binary and fractional products have had relatively unreliable accuracy and precision at the pixel scale. These empirical products, derived from the Normalized Difference Snow Index (NDSI), must employ thresholds derived from high-resolution products that balance errors of omission and commission (Hall et al. 2006). The NDSI however makes sparse use of the MODIS surface reflectance spectrum, which was designed to broadly sample the solar reflected spectrum and facilitate stepwise improvements in algorithms over those used with the NOAA Advanced Very High Resolution Radiometer (AVHRR). More broadly, the MODIS spectrum was developed to support the NASA Earth Science goals of advancing scientific understanding and meeting societal needs.



The Snow Cover model

The GOES-R Snow Cover model comes from the MODIS Snow Covered Area and Grain size (MODSCAG) model. It is based on multiple endmember spectral mixture analysis. Per pixel, MODSCAG uses the spectral mixture equations below but by varying the number of endmembers and the endmembers themselves on a pixel by pixel basis.

$$R_{S,l} = \sum_{i=1}^{N} F_i R_{l,i} + e_l$$

$$e_l = R_{S,l} - \sum_{i=1}^{N} F_i R_{l,i}$$

$$RMSE = \left(\frac{1}{M} \sum_{l=1}^{M} e_l^2 \right)^{1/2}$$

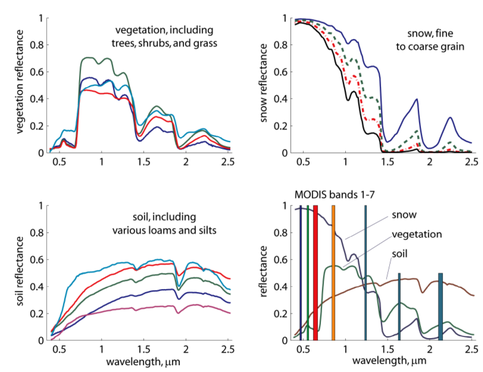
$$f_S = \frac{F_S}{\sum_{p \in S,v,r} F_p} = \frac{F_S}{1 - F_{shade}}$$

$R_{S,l}$ is the MOD09 surface reflectance, F_i is the fraction of endmember i, $R_{l,i}$ is the hemispherical-directional reflectance factor of endmember i at wavelength λ, N is the number of spectral endmembers, and ε_l is the residual error at λ for the fit of the N endmembers. The least-squares fit to F_i can be solved by several standard methods.

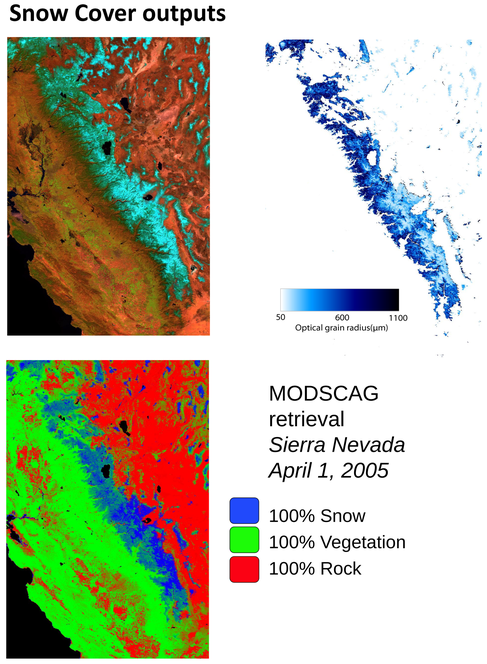
Shade normalization for snow cover and grain size from endmember selection

Snow, Vegetation, Soil Spectral Libraries

The snow spectral library comes from the DISORT radiative transfer model for snow grain sizes of 10 to 1100 µm. The non-snow spectral library (vegetation, soil, ice) comes from field and laboratory measurements with a spectrometer. All of these have then been convolved to MODIS spectral response functions and ABI spectral response functions.

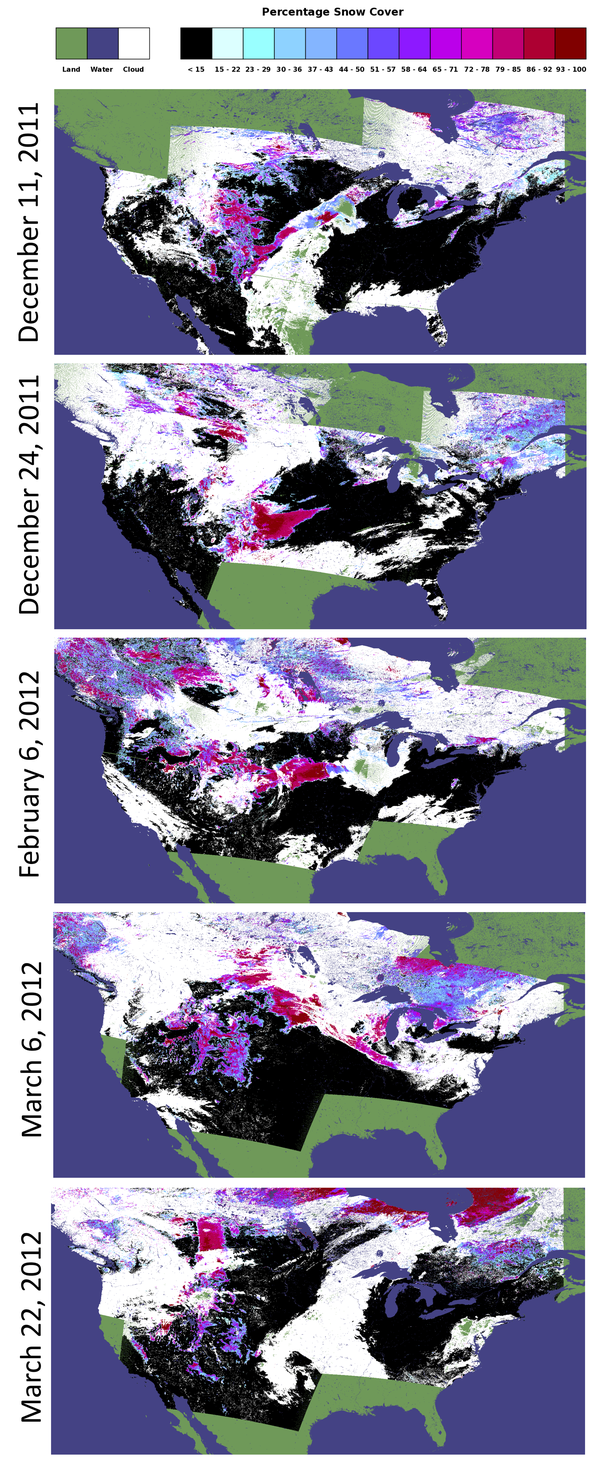


Snow Cover outputs



Snow Cover Products

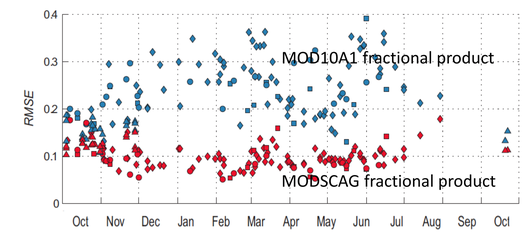
As described before, the ABI spectrum is not yet available on any geostationary platform. Therefore, we are compelled to use the polar-orbiting MODIS surface reflectance products that are currently being retrieved to perform the ongoing validation and assessment. Below we present fractional snow covered area data, just as those that will be generated from GOES-R ABI, for the CONUS in Water Year 2012.



Algorithm Validation

Here we present the validation of the Snow Cover product. The product has been compared directly against Landsat Thematic Mapper data and head-to-head in MODIS form against the current NASA MOD10A1 fractional snow cover product. We have also compared the GOES-R ABI 5-band version (as will be implemented post-launch) against the 7-band MODIS version. As we progress toward launch of GOES-R, two additional polar-orbiting missions will provide data that we can use for validation that will span pre-launch across launch to post-launch. These are the NPOESS Preparatory Project Visible Infrared Imaging Radiometer Suite (NPP-VIIRS) (already launched) and the Landsat Data Continuity Mission (> Jan 2013). These will allow similar spectral band sampling and product generation, the former at 750 m spatial resolution, the latter at 30 m spatial resolution. Finally, the United States has a water-related infrastructure that leads the globe in detailed information. We will use the NRCS Snow Telemetry – SNOTEL network – and the SNODAS modeling framework of the National Operational Hydrologic Remote Sensing Center (NOHRSC).

Direct Comparisons based on Thematic Mapper

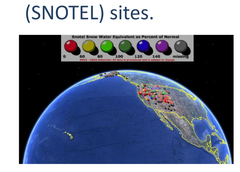


Direct Comparisons between GOES-R ABI and MODIS

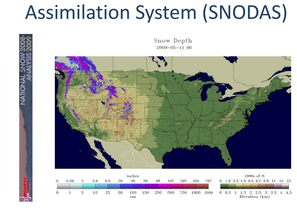
Validation Configuration	Accuracy (spec)	Precision (spec)
Fractional Snow Cover MODSCAG vs. Landsat (snow only)	-1.0% (15%)	8.9% (30%)
Fractional Snow Cover MODSCAG vs. Landsat (snow and snow-free)	-0.5% (15%)	4.9% (30%)
Fractional Snow Cover 5 band vs. 7 band ABI proxy (snow only)	3.7% (15%)	11.9% (30%)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

Pre- to Post-Launch Validation

NRCS Snow Telemetry (SNOTEL) sites.



NWS NOHRSC Snow Data Assimilation System (SNODAS)



References

Dong, J.R., & Peters-Lidard, C. (2010). On the relationship between temperature and MODIS snow cover retrieval errors in the Western US. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 3*, 132-140.

Hall, D.K., G. A. Riggs, V. V. Salomonson, N. E. DiGirolamo, and K. J. Bayr (2002). MODIS snow-cover products. *Remote Sensing of Environment, 83*, 181-194.

Hall, D.K., Riggs, G.A., & Salomonson, V.V. (2006). MODIS Terra/Aqua snow cover daily L3 global grid V005. Boulder, CO. National Snow and Ice Data Center. Digital Media. In: National Snow and Ice Data Center

Painter, T.H., Rittger, K., McKenzie, C., Slaughter, P., Davis, R.E., & Dozier, J. (2009). Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. *Remote Sensing of Environment, 113*, 868-879.

Rittger, K., T.H., Rittger, K., & Dozier, J. (2010a). Assessment of the accuracy of current snow cover mapping algorithms for MODIS. In preparation.

Salomonson, V.V., & Appel, I. (2004). Estimating fractional snow cover from MODIS using the normalized difference snow index. *Remote Sensing of Environment, 89*, 351-360