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## Improved Snow Mapping Accuracy with Revised MODIS Snow Algorithm

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### ABSTRACT

The MODIS snow cover products have been used in over 225 published studies. From those reports, and our ongoing analysis, we have learned about the accuracy and errors in the snow products. Revisions have been made in the algorithms to improve the accuracy of snow cover detection in Collection 6 (C6), the next processing/reprocessing of the MODIS data archive planned to start in September 2012.

Our objective in the C6 revision of the MODIS snow-cover algorithms and products is to maximize the capability to detect snow cover while minimizing snow detection errors of commission and omission. While the basic snow detection algorithm will not change, new screens will be applied to alleviate snow detection commission and omission errors, and only the fractional snow cover (FSC) will be output (the binary snow cover area (SCA) map will no longer be included). A succinct description of the main revisions for C6 is presented here.

Keywords: MODIS, snow cover, mountain

### SNOW DETECTION ERRORS ALLEVIATED

Snow errors of omission have been observed on some mountain ranges during spring and summer, and along edges of snow covered regions, and in less than ideal viewing conditions, e.g. high solar zenith angles. Snow and cloud confusion associated with cloud detection in the MODIS cloud mask that is used to mask clouds in the snow algorithm can result in snow commission or omission errors. A unique problem impacting the MODIS Aqua snow algorithm is that about 75% of the detectors in band 6 (1.6  $\mu\text{m}$ ) are non-functional, returning no data (MCST, 2012a). The MODIS band 6 is critical to the snow algorithm. Though the MODIS Aqua band 6 data was interpolated across the non-functional detectors the spatial quality of the data was greatly reduced and resulted in degraded snow mapping. The solution implemented was to use MODIS Aqua band 7 (2.1  $\mu\text{m}$ ) in the snow algorithm, however that increases the difficulty of validation of the snow map relative to MODIS Terra snow map.

### Disappearing Mountain Snow Cover

Disappearing mountain snow cover in spring and summer in some mountain ranges in temperate climates is a significant omission error. The cause of that omission error is the surface

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temperature screen applied in the snow algorithm. The purpose of the surface temperature screen is to prevent warm bright surfaces e.g. mineral surfaces or beaches, from erroneously being detected as snow. However the surface temperature screen has been found to be detrimental to snow cover detection on mountains in spring and summer. The surface temperature screen was applied after a pixel was detected as snow cover by the thematic, snow cover area (SCA) algorithm or with some fraction of snow in the fractional snow cover (FSC) algorithm; reversing a “snow” detection to a “not snow” result if the temperature was greater than the 283K threshold. However, surface temperature of a pixel with snow and other features, e.g. vegetation and substrate, can be warmer than that threshold. A time series of FSC on the Sierra Nevada Mountains was analyzed to demonstrate the problem. The amount of error due to the surface temperature screen reversals increased from May to August from about 10% to near 100% during last weeks of snow melt (Fig. 1). The complete time series of imagery and FSC maps used in this time series is available at the project website <http://modis-snow-ice.gsfc.nasa.gov/?c=collection6>.

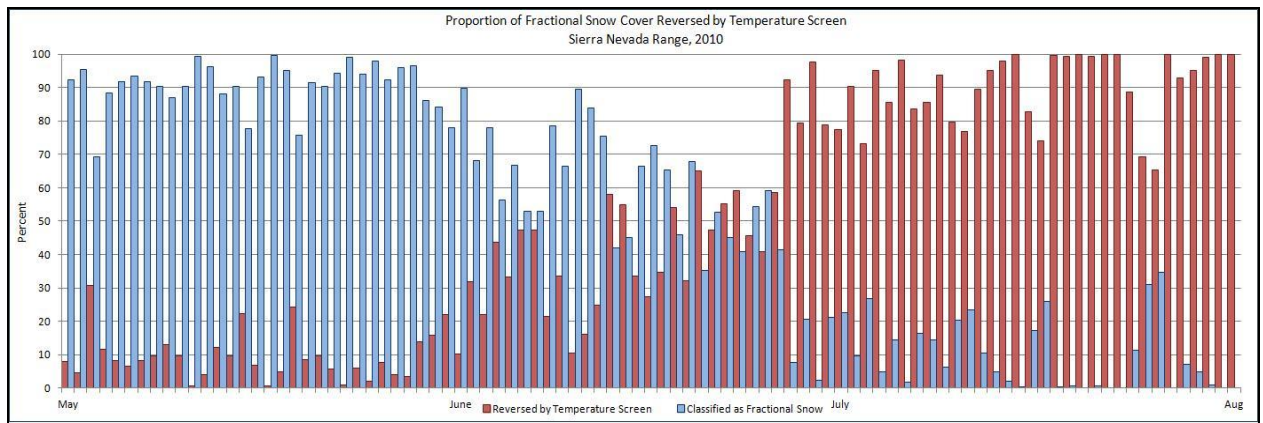


Figure 1. Effect of the surface temperature screen on FSC mapping on Sierra Nevada Mountains.

Snow disappeared from the SCA and FSC maps as surface temperatures gradually increased over the melt season, which can be seen in the online series of imagery, and the increasing effect (error) of the reversals on mapping snow cover extent is shown by red bars in Figure 1. An example of snow reversals caused by the surface temperature screen for a day is shown in Figure 2. Snow appears in shades of yellow in the false color imagery (Fig. 2a) with the FSC in Fig. 2b showing a lesser extent of snow cover than expected based on visual interpretation. The cause for the ‘missing’ snow is the surface temperature screen. The red in Fig. 2c is snow that was reversed to not snow by the temperature screen. Removal of the temperature screen from the C6 version of the snow algorithm resulted in a very accurate and more detailed FSC map, Fig. 2d that agrees extremely well with interpretation of snow cover Fig. 2a.

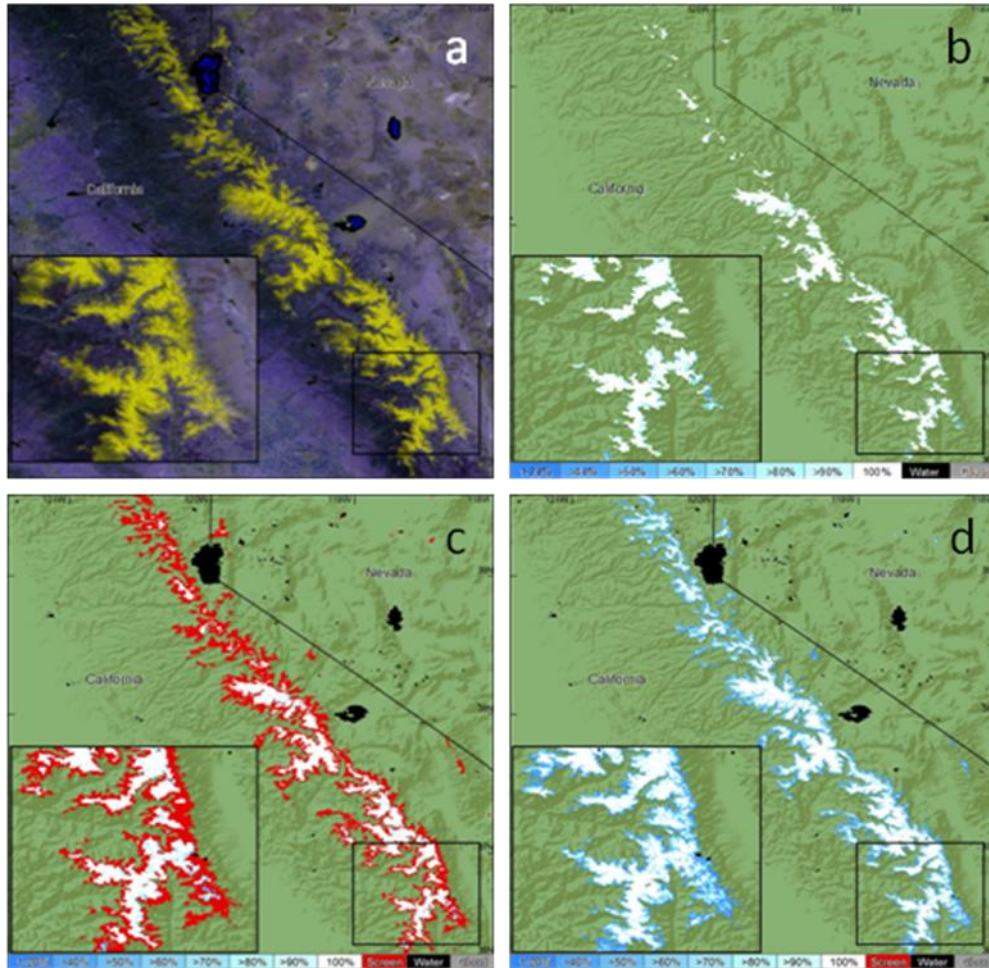


Figure 2. a) MOD02HKM, 14 June 2010 1925 UTC, RGB of MODIS bands 1,4,6, b) MOD10\_L2 C5 FSC, c) MOD10\_L2, C5, with FSC reversed by temperature shown in red, d) MOD10\_L2 C6, no temperature screen applied, FSC. The inset is a higher resolution map of the southern end of the range.

### Screens for Snow/Cloud Confusion Errors

Analysis of snow omission and commission errors in situations of low illumination, and of snow/cloud confusion where the cloud mask does not flag clouds as certain cloud has been done. To alleviate snow commission errors in low illumination situations where reflectance from a feature is too low to make reliable snow detection, e.g. a surface in cloud shadow, a low visible screen has been developed and applied. This low reflectance screen is similar to that used in the C5 algorithm but revised to be more restrictive, thus more no decision results are anticipated and a slight reduction in errors anticipated in C6.

Several screens are being developed and analyzed for effectiveness at alleviating snow commission errors associated with snow/cloud confusion common to some cloud types and situations. These types of errors vary spatial and temporally, yearly and globally and though the extent of errors is typically in range of 0-3%, a very small quantitative number, of all pixels in a swath. Though a small percentage, they have a large negative qualitative impact on the snow products. A lengthy discussion of these situations is beyond the scope of this paper so only the basic concept is presented. Comparisons of spectral plots across MODIS bands 1-7 of actual snow and snow commission errors associated with clouds are analyzed for differences in spectral characteristics that could be used to discriminate a pixel of snow commission error from that of real snow. If spectral characteristics are observed that are distinctive of an error situation then a screen is developed and analyzed for ability to consistently alleviate the error without reversing

true snow detections in other viewing situations. Several potentially useful screens have been developed, that show consistent results over a wide range of detection situations in alleviating snow commission errors. It is anticipated that these screens will be integrated into the snow algorithm for C6.

### MODIS Aqua band 6 restoration

About 75% of Aqua MODIS detectors in band 6 are non-functional (MCST, 2012a). Band 6 imagery is currently made by interpolating over those detectors leaving artifacts of striping and banding in the imagery. However in C6 that interpolation will not be done. Instead, fill values will be output for the non-functional detectors (MCST, 2012b) The snow algorithms use Aqua MODIS band 7 in place of band 6, to avoid the data loss in band 6, which makes Terra and Aqua snow algorithms slightly different and thus challenging to compare directly.

The Quantitative Image Restoration (QIR) algorithm (Gladkova *et al.*, 2011, 2012) applied to Aqua MODIS L2 radiance data, restores band 6 to what it would be if all detectors were functional, thus making it possible to use the same snow algorithm for Terra and Aqua, allowing the two FSC products to be easily compared or combined. The QIR produces a high quality restored image, Fig. 3 right image, compared to the standard interpolated image; Fig. 3 left image, and the ground truth image, Fig. 3 center image. The greatest restoration effect of the QIR technique is observed for spatially heterogeneous surfaces where non-functional detector artifacts are most pronounced.

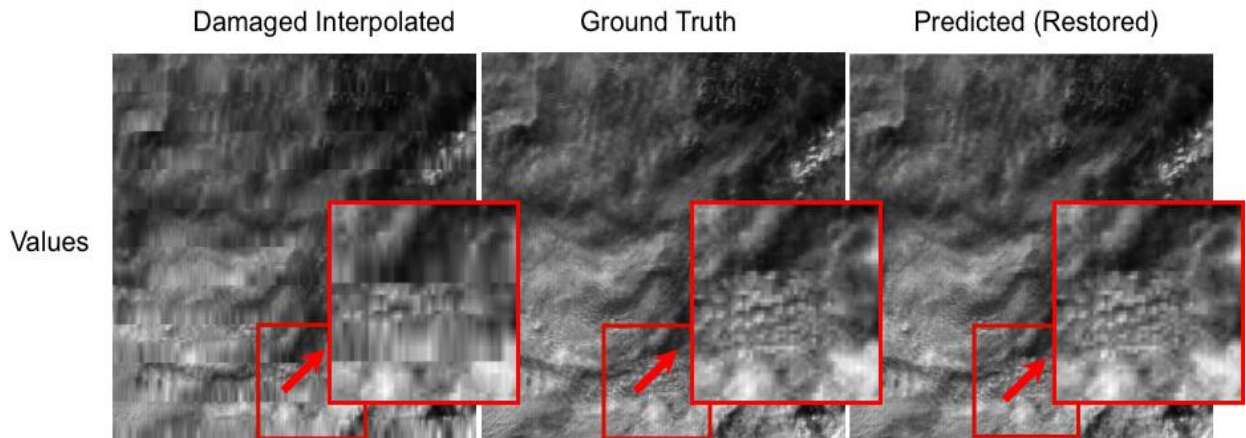


Figure 3. MODIS Aqua band 6 images. MODIS band 6 image with interpolation over non-functional detectors, left image. Ground truth image, center. MODIS Aqua restored band 6, right image.

### Output only the FSC

The SCA and FSC algorithms are both based on the NDSI (Riggs *et al.*, 2006). FSC is based on the full range of NDSI values, 0.0 – 1.0 with regression equation of,  $FSC = -0.01 + 1.45 * NDSI$ . The SCA is a binary snow map that is determined by two criteria; 1) snow if  $NDSI \geq 0.4$  and 2) for vegetated surfaces based on an NDSI and NDVI relationship over an NDSI range of 0.1 – 0.4. This was done to enhance snow mapping in vegetation (Klein *et al.*, 1998). The SCA does not indicate by which criteria snow was detected.

Snow cover extent is best determined by the FSC algorithm and also has a visual relationship to surface conditions. A comparison of SCA and FSC extents is shown in Fig. 4. Snow cover appears in shades of yellow in the false color image in Fig. 4a. The thematic SCA snow map, snow or other feature and FSC are mapped Figures 4b and 4c, respectively. FSC (Fig. 4c) covers



a slightly greater snow extent than does SCA. The FSC extent beyond the SCA map is depicted by the yellow regions in Fig. 4d. Also the FSC extents and amounts relate visually to the snow covered plains and forests in the scene.

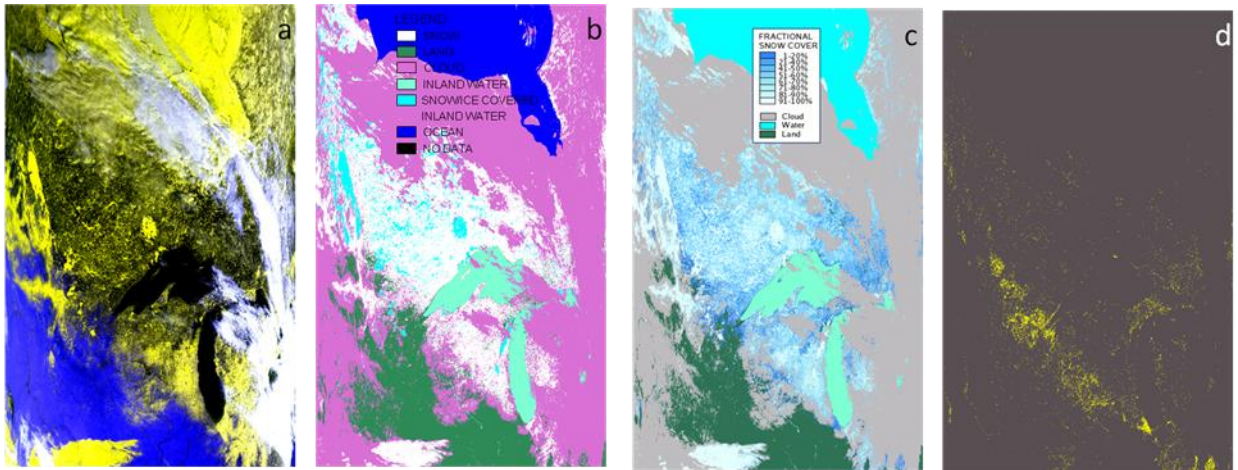


Figure 4. MODIS imagery, SCA and FSC from 12 February 2012, 1700 UTC imaging part of the Great Plains, Great Lakes, boreal forest and ice covered Hudson Bay. MOD02HKM, bands 1,4,6 (a). Thematic SCA map (b) with the FSC map (c). Snow extent in FSC with no corresponding SCA is shown in yellow (d).

#### Quality Assessment Information

The plan for C6 Quality Assessment (QA) information is to include more information in the snow products to facilitate usage of the products and to investigate issues related to snow errors. There will be a general QA result to report if a pixel result is good or otherwise. The general QA will be given as a coded integer that users can easily use to assess the QA of the product. In addition it is planned to include a QA layer that is composed of QA bit flags that report on results of screening applied to each pixel through the snow algorithm. These QA bit flags can be extracted and used to see where snow results were affected by the error screens.

#### IMPACT OF C6 REVISIONS

The accuracy of snow cover detection is increased by removing the surface temperature screen from the algorithm thus greatly lowering the snow omission error in some snow covered mountains in the spring and summer. The flip side to elimination of the surface temperature screen is that bright surface features, e.g. Bonneville Salt Flats, will probably always be detected as snow-covered, resulting in a snow commission error. However, those bright surfaces are static features that users can screen from their applications, and in the future a global map of these features may be developed for general use. Occurrence of snow commission errors associated with snow/cloud confusion should decrease, based on analysis of effectiveness of screens being developed for such error situations. Small changes in accuracy attributable to screens applied to reduce error are anticipated in FSC in C6.

Increased QA information will allow users to investigate issues related to accuracy and error to a greater level that is possible with the QA information in C5 products.

Implementing the Aqua MODIS Quantitative Image Restoration (QIR) restores band 6 for use in the Aqua snow algorithm thus the same snow algorithm can be used for Aqua and Terra, greatly increasing the ability to combine the Terra and Aqua snow products.

Updates related to C6 MODIS snow algorithms and products will be posted on the project website <http://modis-snow-ice.gsfc.nasa.gov/>.

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