Snow Mapping with the MODIS Aqua Instrument

GEORGE RIGGS[1] and DOROTHY K. HALL[2]

EXTENDED ABSTRACT

Keywords: MODIS, Aqua, snow, snow mapping

BACKGROUND

The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the NASA Earth Observing System (EOS) Aqua spacecraft is a 36-band instrument covering the region from 0.4 to 14.5 µm in spatial resolutions of 250 m, 500 m and 1 km. There is a similar MODIS instrument onboard the Terra spacecraft. The MODIS is especially suited for remote sensing of snow cover because of the band coverage over the visible and near-infrared wavelengths. Snow characteristically has high reflectance in visible wavelengths and low reflectance in the short-wave infrared at about 1.6 µm (MODIS band 6), a characteristic that allows for detection of snow by a ratio of a visible band and short-wave infrared band. That characteristic of snow is fairly constant over a wide range of land surfaces and illumination conditions. However the Aqua MODIS instrument has degraded data quality in band 6; 70% of the band 6 detectors have been identified as non-functional. The problems with the Aqua MODIS band 6 detectors impact the quality of the Aqua MODIS Level 2 snow data product MYD10_L2, by degrading the quality of the data and through impact to the MODIS cloud mask product that also uses band 6. Because of the band 6 non-functional detector problems an Aqua-specific algorithm using band 7, 2.1 µm, in place of band 6 was developed and is used to map snow. Snow has similar reflectance in bands 6 and 7.

SNOW ALGORITHM SYNOPSIS

The swath level-2 MODIS snow algorithm uses a grouped criteria technique to detect snow and the MODIS cloud mask product to mask clouds; a full description of the algorithm and products may be found in Riggs et al. (2003). The output product is a thematic map of snow cover and other features. Snow detection relies primarily on the normalized difference snow index (NDSI) with the NDSI = (band 4 – band 6)/(band 4 + band 6). The NDSI keys on the snow characteristics of high reflectance in visible wavelengths and low reflectance in the short-wave infrared about 1.6 µm. If a pixel has an NDSI >= 0.4 and band 2 reflectance > 0.10 and band 4 reflectance > 0.10 then the pixel is mapped as snow. To better map snow in dense vegetation, shadows and low illumination

[1]SSAI, Code 971, NASA/GSFC, Greenbelt, 20771
Email: griggs@ltpmailx.gsfc.nasa.gov
[2]Code 971, NASA/GSFC, Greenbelt, MD 20771
Email: dorothy.k.hall@nasa.gov

conditions where reflectance signal is low an NDSI/NDVI decision region was determined (Klein et al., 1998). A pixel is mapped as snow if it has NDSI and NDVI values that fall in that region and band 2 reflectance > 0.10 and band 4 reflectance > 0.10 criteria are also met. Those low visible reflectance criteria function to screen clear water bodies and very low illumination conditions that could be erroneously identified as snow. These snow decision regions are shown in Figure 1.

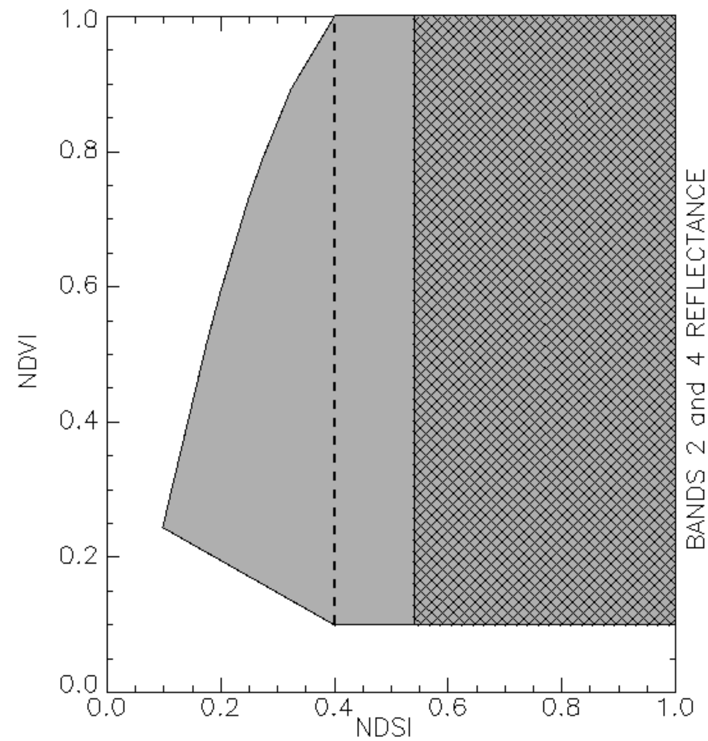

Figure 1. Snow decision regions used in the Terra and Aqua versions of the MODIS snow algorithm. The shaded region is the snow region for the Terra algorithm that includes both the normalized-difference snow index (NDSI) only region where NDSI >= 0.4 and the NDSI/NDVI snow region to the left of the vertical dashed line where NDVI is the normalized-difference vegetation index. The Aqua snow algorithm decision region for snow is limited to only the crosshatched region of the NDSI decision region.

AQUA SNOW ALGORITHM AND PRODUCT

In the MODIS L1B data processing, data from the good band 6 detectors are linearly averaged over the non-functional detectors to make a good quality image of the L1B data but that is not good for quantitative analysis of the band 6 data. In some places, e.g., rugged terrain with sparse snow cover and low illumination, effects of linear averaging of L1B data can be seen. A secondary problem is that the cloud mask is generated at 1km resolution using band 6 500m data aggregated to 1km resolution; however, the non-functional band 6 detector data are not used in the aggregation calculation which results in lines of no data in the cloud mask algorithm. The cloud mask algorithm also calculates NDSI and uses that in an initial guess of snow cover to determine the processing path in the algorithm (Ackerman et al., 2002) so the cloud mask defaults to cloud for those lines of no data. That results in stripes of “cloud” over snow-covered regions in the snow product.

Because of the impact of the degraded data quality on the snow and cloud mask algorithms, we decided to use Aqua MODIS band 7 as the replacement for band 6 in an Aqua-specific snow algorithm. Since snow has similar reflectance in bands 6 and 7 changes to the algorithms were minimal and the resulting snow maps are very similar. The cloud mask algorithm was also revised to use band 7 in place of band 6 and that eliminated the stripes of "cloud" over snow in the snow map.

ALTERNATIVE BAND 7

Determination of how using band 7 would affect the snow algorithm was investigated using Terra data so that snow maps developed using the Terra algorithm (utilizing band 6) and the Aqua algorithm could be compared quantitatively. The Terra MOD10_L2 snow map was used as the base for comparing snow maps derived using band 6 and using band 7. The standard snow map was used as a mask to extract data from MODIS bands 2, 4, 6 and 7. The NDSI was calculated using both band 6 (NDSI 6) and band 7 (NDSI 7). The difference in NDSI 7 to NDSI 6 was calculated for each of the 2,458,290 snow pixels in the swath. Because the apparent band 7 reflectance of snow is typically lower than band 6 apparent reflectance the NDSI is higher when band 7 is used. Overall the snow maps generated with NDSI 6 or NDSI 7 are similar. Detailed examination of the results in the snow by NDSI region only and in the snow by NDSI and NDVI region revealed that the difference between NDSI 7 and NDSI 6 was smaller in the snow by NDSI only region by an average of 0.156 (variance 0.0068) compared to average difference of 0.256 (variance 0.0072) in the NDSI/NDVI snow decision region. Perusal of the two snow maps found that the low illumination areas of snow determined primarily by the NDSI/NDVI region tended to have too much snow detected and that the results were questionable. That caused us to focus analysis on the NSDI only region where results were more consistent and reliable.

Similar analysis was done on 11 other swaths containing snow cover in different regions of the Northern Hemisphere and in different seasons to determine a global NDSI 7 threshold to use for the Aqua-specific snow algorithm. From analysis of those swaths, approximately 19,200,000 snow pixels, a global NDSI 7 threshold value of 0.54 for snow was set based on the global average difference of NDSI 7 – NDSI 6 of 0.14 for snow. The two snow maps, using NDSI 6 or NDSI 7 were typically very similar with the NDSI 7 snow extent typically being 0 to 3%–5% greater. Differences were typically found in areas of low illumination and in dense forests.

SUMMARY

The Aqua MYD10_L2 snow product being produced in Collection 4 is from the Aqua-specific algorithm using MODIS band 7 and with snow decision limited to only the NDSI decision region with the threshold NDSI value for snow set to 0.54 (Fig.1) as an adjustment to the lower apparent reflectance of snow in band 7 as compared to band 6. The NDSI/NDVI snow decision region in the Aqua snow algorithm has been disabled in this collection because of the frequent occurrence of snow errors found in that region during development and testing. The quality of the Collection 4 MYD10_L2 snow maps is greatly improved by the switch to the use of band 7 in both the snow and cloud mask algorithms. Snow extent between same day Terra and Aqua products is very similar under the best of viewing conditions but differences emerge under less favorable viewing conditions. Instances of erroneous snow attributable to snow/cloud confusion exist in both versions and sensitivity of the algorithm to low illumination conditions has not yet been fully explored. We will continue to assess snow mapping accuracy and quality using Aqua band 7 data in the snow-mapping algorithm.

REFERENCES

Ackerman S, Strabala K, Menzel P, Frey R, Moeller C, Gumley L, Baum B, Seeman SW, Zhang H. 2002. *V4.0: Discriminating Clear-Sky from Cloud with MODIS—Algorithm Theoretical Basis Document ATBD-MOD-06*. http:// modis-atmos.gsfc.nasa.gov/MOD35_L2/atbd.html.

Klein AG, Hall DK, Riggs GA. 1998. Improving snow cover mapping in forests through the use of a canopy reflectance model. *Hydrologic Processes* **12**:1723–1744.
Riggs GA, Hall DK, Salomonson VV. 2003. *MODIS Snow Products User Guide*. http://modis-snow-ice.gsfc.nasa.gov/userguides.html.

Relevant Web sites

MODIS snow and sea ice global mapping project http://modis-snow-ice.gsfc.nasa.gov/
National Snow and Ice Data Center http://nsidc.org (Information and product ordering.)
Terra website http://terra.nasa.gov
Aqua website http://aqua.nasa.gov
EOSDIS Core System http://ecsinfo.gsfc.nasa.gov