Improvement of MODIS snow cover algorithm for the Hindu Kush-Himalayan (HKH) region

Bohui Tang[1, 2, *], Shrestha Basanta[2], Zhao-Liang Li[1, 3], Gaohuan Liu[1], Hua Ouyang [1, 2], Gurung Deo Raj[2], Amarnath Giriraj[2], and Aung Khun San[2]

[1] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China.

[2] International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

[3] TRIO/LSIIT(UMR7005 CNRS)/ENSPS, Bld Sebastien Brant, BP10413, 67412 Illkirch, France.

Abstract: Snow is an important component of the Earth's surface and plays a key role in a wide variety of scientific studies, water supply, climate change, hydrologic and biogeochemical cycles of the earth (Cess et al., 1991). The estimate of snow cover has been ongoing for several decades with different satellite data at various spatial and temporal resolutions. The NASA Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) provides capabilities to observe snow cover from space and provides global automated snow cover maps by using a normalized difference snow index (NDSI) as well as some additional constraints of threshold value (Hall et al., 1995, 2002, 2006; Hall and Riggs, 2007). Note that the algorithm proposed by MODIS used radiances observed at the top of the atmosphere (TOA) leading to the reflectances used in the NDSI and other thresholds, the effects of atmosphere and terrain as well as viewing angle or bi-directional properties of snow in particular and other materials within a pixel have not been corrected, which may cause some significant errors for estimating snow cover in mountainous areas, especially in heavily rugged Tibet plateau region. To this end, this work aims to propose some improvement of MODIS snow cover algorithm for estimating the snow cover in the Hindu Kush-Himalayan (HKH) region from MODIS data. The surface reflectances are retrieved from the TOA reflectances by using an updated Simplified Method for the

[*] Corresponding to Dr. Bohui Tang, Institute of Geographical Sciences and Natural Resources Reseach, CAS, China. Email: tangbh@igsnrr.ac.cn Tel: (+86) 10 6488 9684

Atmospheric Correction (SMAC) model (Rahman and Dedieu, 1994). In order to correct the topographic shading and shadowing effects over mountainous regions, the Hapke shadowing function (Hapke, 1984) and a high-resolution digital elevation model (DEM) data have been used in this work. In addition, to prevent pixels containing very dark targets such as black spruce forests, the threshold values of the surface reflectance in MODIS bands 2 (0.841–0.876 μm) and 4 (0.545–0.565 μm) are adjusted to >20%. To reduce the effects of the snow/cloud confusion, in particular the snow/cloud confusion errors associated with cloud-shadowed land and thin, sparse snow cover, a normalized difference cloud index (NDCI) model in terms of MODIS bands 1 (0.620–0.670 μm) and 6 (1.628–1.652 μm) has been proposed to discriminate snow/cloud pixels, apart from the use of the MODIS cloud mask product MOD35. Furthermore, MODIS land surface temperature (LST) product MOD11_L2 has also been used to ensure the discrimination accuracy of the snow cover pixels. In order to validate the improved MODIS snow cover algorithm, Several Landsat imageries with 30-m resolution for the Mountain Everest region at different seasons have been used to estimate snow cover and subsequently compared with the MODIS snow cover product MOD10_L2 and the resultant MODIS snow cover estimated by the proposed method. The results showed that MODIS snow cover product overestimates the snow cover areas for the Mountain Everest region by the worst larger than 50%, whereas the improved algorithm can estimate the snow cover for HKH region more feasible with absolute accuracy of 92%.

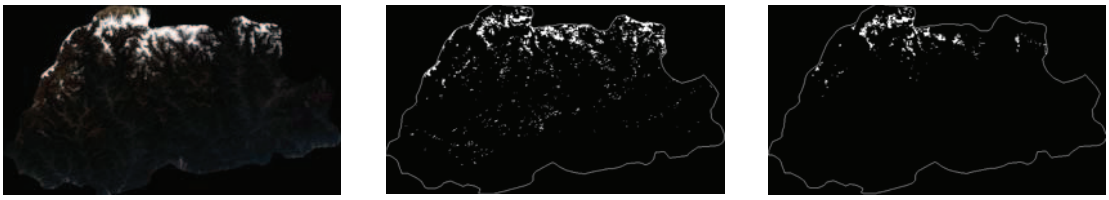
Key words: Snow cover; NDSI; Atmospheric correction; Topographic correction; MODIS

Preliminary Results:

1. Comparison of MODIS snow cover and estimated snow cover for Bhutan

In order to validate the proposed algorithm for HKH region, we firstly estimate the snow cover for Bhutan at different seasons in 2002. Figure 1 shows one of the comparisons between MODIS snow cover product and the resultant snow cover estimated by proposed algorithm on January 5, 2002. Figure 1(a) is a truly colorful imagery fused by MODIS bands 1, 4, and 3. Figure 1(b) and (c) are the MODIS snow cover imageries with 500m resolution obtained from MODIS product MOD10_L2 and estimated using the proposed algorithm, respectively. From

these pictures we can see explicitly that MODIS maps many pixels as snow covers in southern Bhutan. But there are definitely no snow covers in those areas from the seeing of the imagery fused by MODIS raw data.



(a) Fused imagery of MODIS bands 1, 4, 3 (b) MODIS snow cover product MOD10_L2 (c) Estimated MODIS snow cover

Figure 1. Comparison of MODIS snow cover product MOD10_L2 and estimated MODIS snow cover for the whole Bhutan on January 5, 2002.

2. Comparison between resultant snow covers and Landsat ETM+ snow cover

In order to further validate the proposed algorithm, we also select the Mountain Everest region as study area. Figure 2 shows the study area within the red rectangle, obtained from Google earth. Several Landsat imageries with 30-m resolution for the Mountain Everest region at different seasons have been used to estimate snow cover and subsequently compared with the MODIS snow cover product MOD10_L2 and the resultant MODIS snow cover estimated by the proposed method. Table 1 gives the statistics of the snow cover areas derived from different satellite data for this study area. From this table, we can see clearly that MODIS's snow cover algorithm overestimates the snow cover areas and the proposed improved algorithm, at least in this study area, can estimate the snow cover more accurately.

Figure2. Study area selected in the Mountain Everest region

Table 1. Statistics of snow cover area obtained from different methods for Mountain Everest region at different seasons.

Date	ETM+ snow cover (km^2)	MODIS snow cover (km^2)	Estimated snow cover (km^2)
Jan. 05, 2002	618.912	694.750	595.250
May 13, 2002	1356.230	1582.500	1258.000
Aug. 17, 2002	76.721	123.750	78.750
Oct. 04, 2002	1397.530	1592.000	1360.500
Feb. 09, 2009	883.437	992.000	807.750

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