Effects of Topographic Corrections on Snow Cover Monitoring In Himalayan Terrain Using MODIS Data

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Abstract

Snow cover is the most important and widely used parameter for meteorological, hydrology and avalanche study. In the present work topographic effects on snow cover assessment was studied using MODIS sensor data from October 2010 to June 2011. NDSI has been used to estimate the snow cover area of topographic corrected and uncorrected satellite images. It has been found that the snow cover area of topographic corrected image is less than the snow cover area of the uncorrected image. The quantitative estimation of snow cover was further analysed for North and South aspects of the NW Himalaya after apply the topographic correction. Comparative analysis between the snow cover area of North and South aspect were evaluated respectively with and without topographic correction. The results show that in North aspect the effect of topography is maximum.

Keywords: MODIS, Topographic correction, Slope matching, NDSI.

1. Introduction

Snow cover is the largest component of the earth's cryosphere and covers up to 33 percent of total land surface. About 98 percent of the total snow cover is located in the Northern Hemisphere [1]. The highly reflective nature of snow combined with its large surface coverage makes snow an important component of Earth's radiation balance [2-3]. Study of snow cover plays an important role in hydropower generation system, water management and other developmental activities. In addition, varying snow cover area cause formation of avalanches, which in turn strongly affect the safety of human lives and property. In India, Himalaya is well known for the occurrence of snow avalanches, particularly in the North Western parts. Therefore, monitoring of areal extent of snow is an important.

To obtain snow cover information in highly inaccessible mountainous regions, use of ground based conventional data collection technique is quite difficult, time consuming and area specific only. Satellite remote sensing based techniques are useful tool for real-time, year-round and large spatial coverage for monitoring [4-7]. Different optical sensors of Indian Remote Sensing satellites (IRS) like LISS-III (Linear Imaging Self Scanning), WiFS (Wide Field Sensor) and AWiFS (Advance Wide Field Sensor) are used for the mapping of snow cover area in Himalaya [8-11]. MODIS (Moderate Resolution Imaging Spectroradiometer sensor) is one of the few space borne sensors [7] with an improved ability to map snow cover in good spatial, temporal and radiometric resolution.

Satellite imagery in mountainous terrain is affected due to sharp variations in the topographic parameters such as altitude, slope and aspect. The topographic variability causes a problem of differential illumination due to steep and varying slopes in rugged Himalayan terrain. Sun-facing illuminated slopes (south aspect) show more than expected spectral radiance or reflectance, whereas the effect is opposite in shaded relief area (north aspect) [12].

Therefore, topographic corrections are essential for qualitative and quantitative analysis of snow cover applications. A wide range of commonly used topographic correction methods have been reported in the literature [13-21].These are cosine method, c-correction, Minneart correction and two stage normalization. It is reported [22] that slope match is most suitable technique for topographic correction on Himalayan terrain.

In this present work MODIS sensor data was used to monitor seasonal snow cover. The effect of topographic corrections on quantitative snow cover analysis was investigated using slope matching method.

2. Study Area

The study area of NW Himalaya considered (Figure1) in the present work is located between 30°15'00''N to 36°00'00''N latitude and 73°15'00''E to 79°45'00''E longitudes. This area is divided into three distinct zones on the basis of varying climate conditions [23] i.e. Upper, Middle and Lower Himalaya. The Upper Himalaya zone is characterized by comparatively low temperature, light snowfall and severe wind activity. The Middle Himalaya zone is characterized by fairly cold temperature, heavy and dry snow fall and strong wind action. The Lower Himalaya zone is characterized by moderate temperature, heavy snow fall and short winter period. The area is densely forested in between 2400 and 3100m altitude. Beyond 3100m forest is scanty; however, below 2400m area is hebitated.

3. Satellite Data

Forty five Cloud free satellite images of MODIS sensor from October 2010 to June 2011 are used in the present work to understand the topographic effect on snow cover monitoring. The sensor scans an area 2330km wide swath. Temporal resolution of MODIS sensor is once in a day. The other salient specifications of MODIS sensor are given in Table 1.

4. Methodology

4.1 Satellite Data Processing

The master image of MODIS was generated by geo-referencing it with the help of reference of AWiFS sensor image and 1:50,000 toposheet. ASTER (Advances Spaceborn Thermal Emission and Reflection Radiometer) DEM was used to derive slope, Aspect and Illumination for topographic correction.

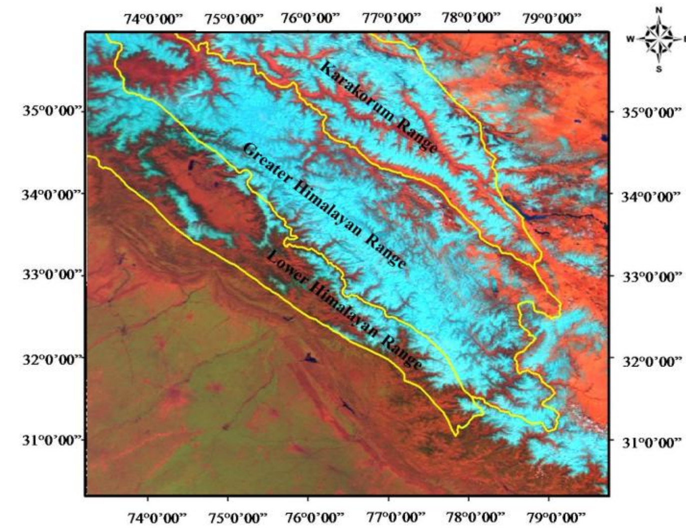


Figure 1 Study area and different zones of North-West Himalaya on MODIS image.

4.2 Estimation of Reflectance

To generate snow cover maps, first scale integer (SI) values are converted into reflectance using equation (1) [1].

$$R_{i\lambda}.\cos\theta = \text{reflectance\_scales}\ (SI - \text{reflectance\_offset}) \qquad (1)$$

Where, $R_{i\lambda}$ refers to the reflectance of a pixel, θ indicates to the solar zenith angle in degrees, the values of reflectance_scales and reflectance_offsets can be inferred from meta information of the satellite data [3].

4.3 Topographic Correction

The topographic correction was applied on MODIS images using slope matching technique [22]. Flow chart for topographic correction is shown in Figure 2. The topographically corrected reflectance using slope matching is estimated using equation (2) [22][24].

$$R_{n\lambda ij} = R_{\lambda ij} + (R_{max} - R_{min}) * \left(\frac{(\{cosi\}_s - cos_{ij}i)}{\{cosi\}_s}\right) C_\lambda \ , \qquad (2)$$

Where $R_{n\lambda ij}$ is the spectral reflectance of topographically corrected image, $R_{\lambda ij}$ is spectral reflectance on the tilted surface, R_{max} and R_{min} is maximum and minimum spectral reflectance and estimated from topographically uncorrected reflectance image, $cos_{ij}i$ is illumination image for

Table 1 Salient specification of MODIS sensor

Spectral bands	Spectral wavelength (nm)	Spatial Resolution (m)	Quantization (bit)	Radiance Scale (mw/cm2/sr/µm)	Radiance Offset	Solar Exoatmostpheric spectral Irradiance (mw/cm2/sr/µm)
B1	620-670	250	12	0.0026144	0	160.327
B2	841-876	250	12	0.0009926	0	98.70
B3	459-479	250	12	0.0027612	0	209.071
B4	545-565	250	12	0.0021087	0	186.4
B5	1230-1250	250	12	0.0021087	0	47.6
B6	1628-1652	250	12	0.0002572	0	23.8
B7	2105-2155	250	12	0.0000787	0	8.7

pixel illumination on the south aspect, cosi is illumination (IL) image[20]. C_λ is [22] normalization coefficient for different satellite bands and estimated using equation (3);

$$C_\lambda = \frac{S'_\lambda - N_\lambda}{N'_\lambda - N_\lambda} , \qquad (3)$$

Where S' is the mean reflectance value on sunny slopes after first stage normalization, N is the mean reflectance value on shady slopes in uncorrected image, N' is the mean reflectance value on shady slopes after first stage normalization.

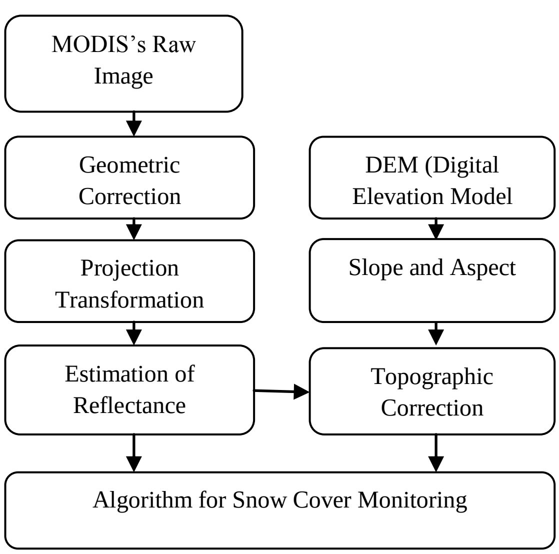


Figure 2 Flow chart for topographic correction

4.4 Algorithm for Snow Area

Normalized Difference Snow Index (NDSI) method is used for snow cover mapping using satellite data [3][7][10]. NDSI uses the high reflectance and low reflectance of snow in visible (Green) and shortwave infrared (SWIR) region respectively. Additionally, the reflectance of clouds remains high in SWIR band, thus NDSI allows in discriminating clouds and snow also. NDSI is estimated using equation (4) ;

$$NDSI = \frac{R_{green} - R_{SWIR}}{R_{green} - R_{SWIR}} , \qquad (4)$$

Where R_{Green} (MODIS band 4) and R_{SWIR} (MODIS band 6) are the reflectances of the green and shortwave infrared bands respectively. A threshold value for NDSI $\geq$ 0.4 [25] is selected to identify the pixels that are approximately 50% or greater covered by snow. This threshold value merges the water body in snow cover area. Water body can be masked using the reflectance of band NIR>11% and the threshold value of NDSI $\geq$0.4. NDSI varies from -1 to +1.

4.5 Snow Cover on North and South Aspect

The snow cover area was retrieved on North and South aspect using topographically uncorrected and corrected reflectance and NDSI image. The North aspect is taken between -45 degree to +45 degree and the south aspect is taken from 135 degree to 225 degree from true North direction. Flow chart for snow cover retrieval on North and South aspect is shown in Figure 3.

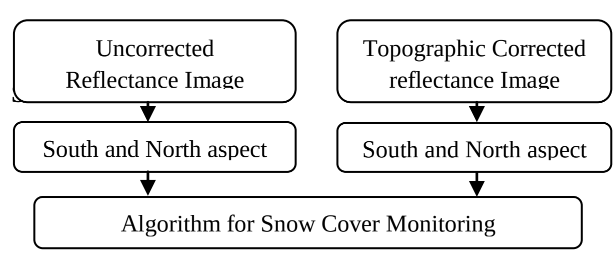


Figure 3 Flow chart for snow retrieval on North and South aspect.

5. Result and Discussion

5.1 Snow Cover Mapping

Figure 4 shows the total percentage SCA (snow cover area) estimated for entire North-West Himalayas using NDSI technique. Snow cover started building up in the month of October 2010 and maximum snow cover area occurs in the month of January 2011. It is also observed that April onwards snow cover has started depleted show onset of melt.

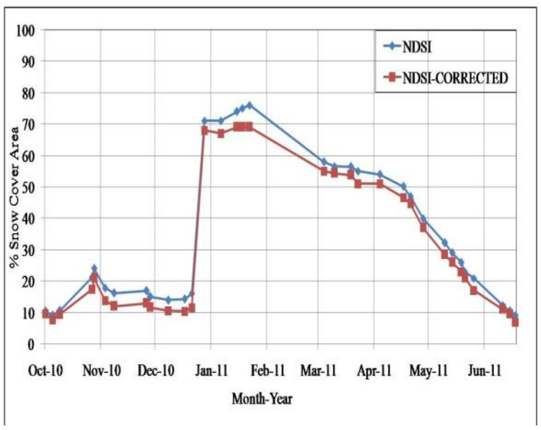


Figure 4 Seasonal snow cover variation in NW Himalaya using MODIS data

5.2 Topographic Effects

5.2.1 Solar Zenith, Solar Azimuth, Terrain Slope and Aspect and Illumination

The solar geometry parameters, viz., solar zenith angle and solar azimuth angle, were computed for each pixel using the equation given in the literature [14][26]. Solar zenith angle for MODIS images from October 2010 to June 2011 varying from 13^o to 55^o. Solar azimuth angle varies approximately from 121^o to 170^o. Terrain slope, aspect and illumination (IL) are the three important inputs required in topographic correction models for Himalayan terrain. The terrain slope and aspect image of the study area are shown in Figure 5a and Figure 5b respectively. The altitude in the entire study area varies approximately from 12m to 7000m with a mean 3129m. The slope in the study area varies from 1^0-80^o with mean 15^o and aspect ranges from 0^0-360^o with mean 180^o.

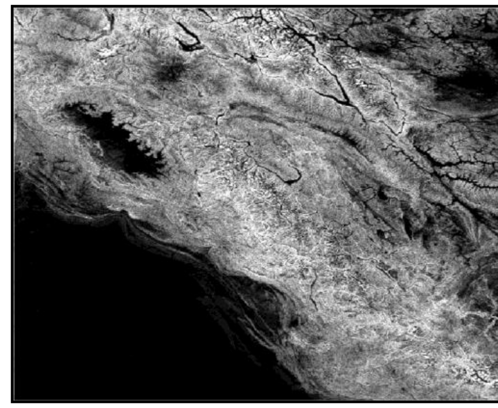


Figure 5 (a) Slope of the study area

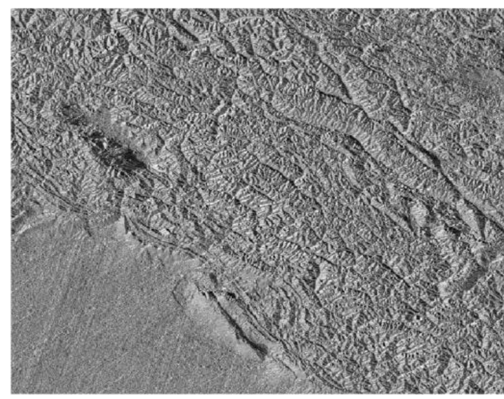


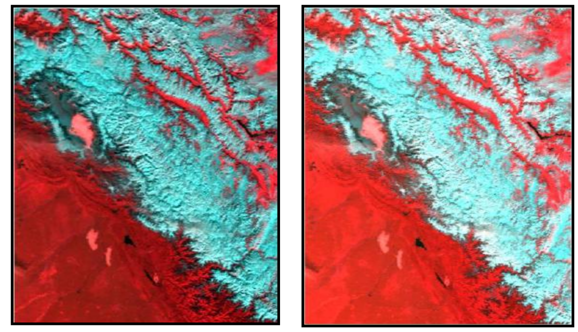
Figure 5 (b) Aspect of the study area

Figure 5c shows the IL image of the study area for topographic correction and computed using the equation given in the literature [12][20]\. The IL vary from -1(low illumination) to +1 (high illumination) which is rescaled to a range of 0–255 for the topographic models. The mean IL for MODIS imageries from October 2010 to June 2011 vary from 210^0 to 245^0.

5.2.2 Estimation of Coefficients for Topographic Models

The results of coefficient C values were estimated from equation (3) for different date images of MODIS and shown in Table 2. It can be inferred that these coefficients are not same for different date images. These differences in the coefficients are attributed to different Illumination condition, solar zenith and azimuth angle and temporal changes in snow surface physical properties.

Figure 5(c) Illumination (IL) image



(a) (b)

Figure 6 MODIS images of (a) Uncorrected (b) Topographically corrected

5.3 Visual Analysis

The Visual analysis of topographic corrected image using slope matching method show flat view of the terrain and the three dimensional relief effects is minimized as shown in Figure 6a,b.

5.4 Graphically Representation of Topography Effects on SCA

Figure 4 shows the snow cover area with and without topographic correction, it is observed that the estimated snow cover area is less by using topographic correction than without topographic correction. It is inferred that snow cover area is overestimated without inclusion of topographic corrections.

5.5 Effect of Topographic Correction on Different Aspects

After evaluating the topographic effects in NW Himalaya, Aspect wise snow cover monitoring has been carried out to understand the topographic influence on it. This analysis not only provides the aspect-wise snow cover mapping but also provides qualitative and quantitative changes in the snow cover on these two aspects. It can be observed from the Figure 7 that topographic influence on the south aspect is not significant and almost show comparable results of snow cover estimation. Whereas, the result on the north aspect is significant as shown in the Figure 8. Inclusion of topographic models for NDSI using spectral reflectance improve the snow cover analysis on the north aspect.

Table 2 Values of normalization coefficient for different MODIS passes.

Dates	B1	B2	B3	B4	B5	B6	B7
09-Oct-2010	.045	.138	.032	.048	.204	.273	.214
07-Nov-2010	.021	.100	-.005	.008	.261	.298	.240
05-Dec-2010	.046	.110	.141	.035	.210	.251	.251
10-Jan-2011	.226	.286	.189	.212	.399	.437	.365
08-Mar-2011	-.070	.016	-.080	-.062	.074	.132	.111
08-Apr-2011	-.212	-.058	-.24	-.213	0	.170	.135
14-May-2011	-.0295	-.083	-.33	-.306	.173	.490	.480
15-June-2011	-.107	.021	-.085	-.116	.066	.285	.282

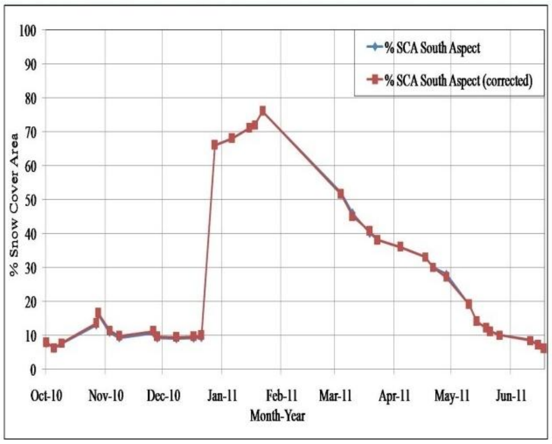


Figure 7 Snow cover variation in South aspect

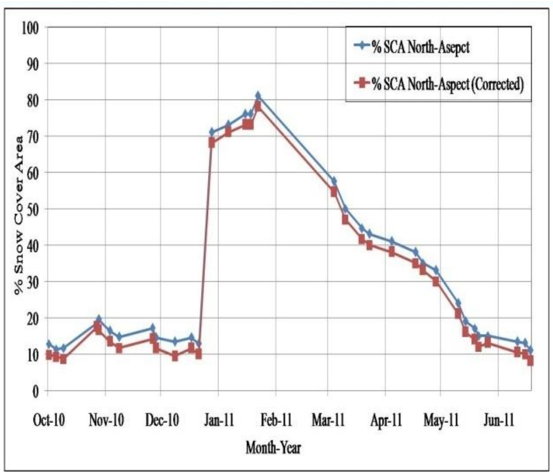


Figure 8 Snow cover variation in North aspect

6. Conclusion

The influence of topography has been studied on the quantitative estimation of seasonal snow cover variation using MODIS data. The analysis is considered for the complete winter period from October to June. Slope matching model for topographic correction is implemented for estimation of NDSI. The snow cover area is overestimated by considering NDSI>=0.4 and reflectance in NIR band >11% without considering topographic model. The results show no significant change in snow cover area on the south aspect with topographic inclusion. The influence of topography on snow cover on the north aspect is significant. It is concluded that considering topographic corrections improve the results of snow cover analysis. Topographic correction are very useful for further application as sub-pixel snow mapping, climatic modelling, snow melt run-off modelling, change detection analysis, avalanche hazard analysis, etc.

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