

# SNOW COVER AREA CHANGING ANALYSIS OVER TIBETAN PLATEAU WITH MODIS AND ASTER DATA

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## ABSTRACT:

The Tibetan Plateau is called “the third pole” of the Earth by its highest altitude. So it is the most sensitive area in the world to hydrological cycle and climatic change. Estimating and mapping the snow cover area of the Tibetan Plateau is very important for the regional climatic change and hydrological cycle. The fractional snow cover of an image pixel is estimated within a linear mixture approach, where the reflectance of a “mixed” pixel is represents as the reflectance sum of every land cover type or endmember weighted by their respective area proportion in the instrument field of view (IFOV). A method based on linear spectral unmixing of Moderate Resolution Imaging Spectroradiometer (MODIS) data which were acquired from Tibetan Plateau was presented and validated by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 15m data as ground true data in this paper. Based on this method Snow cover changing of the whole Tibetan Plateau was analyzed. For the year of 2004 snow cover area will be increased very serious from October and continue to improve until January and February next year. And then it will start to decline to be a relative small area until September. SRTM DEM data was applied to find the relationship between snow distribution and altitude by taking the topographical effect into account.

## 1. INTRODUCTION

Estimating and mapping the snow cover area of the Tibetan Plateau is very important for the regional climatic change and hydrological cycle. Traditional in situ surveying and mapping cannot provide enough large-scale snow cover information; in addition it will take much time and money, sometimes even dangerous. In the past two decade, people have proved that remote sensing is the only practical means for mapping snow cover in alpine area. Due to a low reflectance of snow in the near infrared and a high reflectance in the visible, using band ratio can identify the snow cover from the other surfaces. Most research on estimating snow cover area is binary: pixels are verified either “snow” or “not snow”. Most pixels, however, are mixed with snow, vegetation, soil, rock or water. Snow covered area often varies at a spatial scale finer than that of the ground IFOV(the instrument field of view) of the remote sensing sensor. This spatial heterogeneity will produce a mixed pixel problem in that the sensor may measure radiance reflected from snow, rock, soil, and vegetation (Dozier, 1998) . To provide accurate information about snow cover in Tibetan Plateau, more attention should be paid on fractional snow cover estimating.

Spectral mixture analysis is a method of inverting multispectral or hyperspectral data to map land cover at a subpixel scale(Adams et al. 1993, Mertes et al. 1993, Roberts et al. 1998, Okin et al. 2001). Linear spectral mixture analysis is based on the assumption that the radiance measured is a linear combination of radiances reflected from individual surfaces, endmembers , whose spectral signatures are unique and well separated above a random image noise level(Sabol et al.1992).

The linear assumption can be applied on spatial scenarios such as snow and rock where the surface is near planar. The fractional snow cover of an image pixel is estimated within a linear mixture approach, where the reflectance of a “mixed” pixel is represents as the reflectance sum of every land cover type or endmember weighted by their respective area proportion in the instrument field of view (IFOV).

The primary difference between various techniques proposed to derive the snow fraction concerns the selection of endmembers and methods to determine their spectral features. Nolin et al. (1993) first demonstrated spectral mixture analysis for subpixel snow cover estimating by using the hyperspectral aircraft instrument AVIRIS. Rosenthal and Dozier (1996) developed linear spectral mixture analysis for subpixel snow cover area from Landsat TM. Their method is insensitive to the choice of lithologic or vegetation endmembers, the water equivalent of the snow pack, snow grain size, or local illumination angle. Kaufman et al. (2002) developed a statistical method for mapping subpixel snow cover using only two MODIS bands at 0.66 and 2.1  $\mu\text{m}$ . Their analysis showed good agreement with one image classified with the Rosenthal and Dozier (1996) method. Painter et al. (1998) improved subpixel snow mapping by allowing the spectrum of the snow endmember to vary to match the spectral shape of the pixel’s snow reflectance. In his paper multiple snow endmembers of different grain sizes were selected in order to improve the accuracy of the method.

.A method based on linear spectral unmixing of Moderate Resolution Imaging Spectroradiometer (MODIS) data which were acquired from Tibetan Plateau was presented and

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validated by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 15m data as ground true data in this paper.

## 2. METHOD

The majority of existing snow mapping algorithms consider every cloud-clear pixel as either completely snow covered or snow free and thus provide a binary, snow/no snow classification of satellite images. Only few attempts have been made to estimate snow cover at a sub-pixel level. The fractional snow cover of an image pixel is estimated within a linear mixture approach, where the reflectance of a “mixed” pixel is represents as the reflectance sum of every land cover type or endmember weighted by their respective area proportion in the instrument field of view (IFOV). The primary difference between various techniques proposed to derive the snow fraction concerns the selection of endmembers and methods to determine their spectral features.

Here, the measured pixel radiance  $L$  of snow-covered ground can be expressed as a function of trees( $T$ ), snow( $S$ ), bare ground( $G$ ) and irradiance( $I$ ):

$$L = f(T, S, G, I) \quad (1)$$

### 2.1 Linear spectral mixture

Spectral mixture analysis is based on modeling image spectral as the linear combination endmembers. One or more endmembers represent different materials within the image. In spectral mixture analysis, the reflectance of a pixel is obtained by the sum of the reflectance of each endmember within a pixel multiplied by its fractional cover:

$$\rho_{\lambda} = \sum_{i=1}^n f_i \times \rho_{i\lambda} + \varepsilon_{\lambda} \quad (2)$$

where  $\rho_{\lambda}$  is the reflectance of a pixel,  $\rho_{i\lambda}$  is the reflectance of endmember  $I$  for a specific band  $\lambda$ ,  $f_i$  is the fraction of the endmember,  $n$  is the number of endmembers, and  $\varepsilon_{\lambda}$  is the residual error. The modeled fractions of the endmembers are commonly constrained by:

$$\sum_{i=1}^n f_i = 1 \quad (3)$$

### 2.2 Endmember Selection

In this linear spectral mixture model endmembers include snow, vegetation, water, and snow-free ground. Here the sub pixel

snow algorithm is used to obtain the snow cover fraction: Principal Component Analysis (PCA) is used to concentrate the data and to improve the spectral separability and to remove spectral redundancy. Pixels which represent the outer lines of the polygon surrounding the data space of the first two principal component can be extracted by PCA transformation. Convex geometry assumes that those points have the most pure pixel spectra whereas mixed pixel lie within the data cloud. Some of these pixel signatures represent snow and differ from other pure spectral. The number of endmembers and the snow endmember are fixed whereas one endmember type is allowed to vary. These endmember combinations are used to describe the various mixed pixels in the data set. The output of each mixing model is a fraction image of the unknown endmember and the snow endmember.

If no image snow endmember is detected from the convex hull a reference snow spectra will be take. Sub pixel snow cover is calculated from a linear mixing model. In this paper model is applied on MODIS images observed from the Tibetan Plateau to get fractional snow cover area in a pixel. Then the estimated snow cover fractions were compared with snow cover fraction reference images derived from several ASTER images obtained the same days as the MODIS images. In every ASTER scene we used here, every pixel was classified as snow or non snow using the unsupervised isodata classification to identify snow covered pixels and those not covered by snow. Then the percentage of snow cover was calculated for 500m cells. Comparison between linear spectral unmixing method and real percentage of snow cover from ASTER data shows that linear spectral unmixing technique can estimate the fractional snow cover very accurately.

### 2.3 Study area

The data used in this study are MODIS 09GHK surface reflectivity data productions that include 7 bands with 500m resolution. Two MODIS scenes were received over our study area on Ap.12th, 2001 and Jan. 20<sup>th</sup> 2001 respectively. All the data were registered to a 500m grid in a UTM project. The validation data for snow cover area estimations is ASTER data. They are received in the same day with the MODIS data.

## 3. RESULTS AND DISSCUSIONG

It is assumed that the mixed pixel is the linear mixture of the snow, vegetation, soil. So three endmembers are selected based on PCA analysis. Then those endmembers are applied for the linear unmixing method to get the fractional area of snow, vegetation and soil or rock respectively. Figure 1,2 tells the fraction of snow for the two interested fields on Tibetan Plateau.

Then in order to verify the accurate of this method, two ASTER images which were received with the MODIS in the same day were used. It takes the ASTER 15m data as ground true data to calculate the percentage of snow cover for 500m cells. In every ASTER scene we used here, every pixel was classified as snow or non snow using the unsupervised isodata classification to identify snow covered pixels and those not covered by snow.

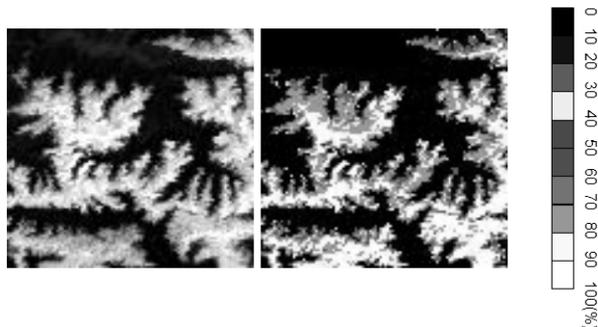


Figure1. The comparison of MODIS image (left) and the result of fractional snow cover area (right) based on linear spectral unmixing method for the no1 image which was obtained on Ap.12th, 2001.

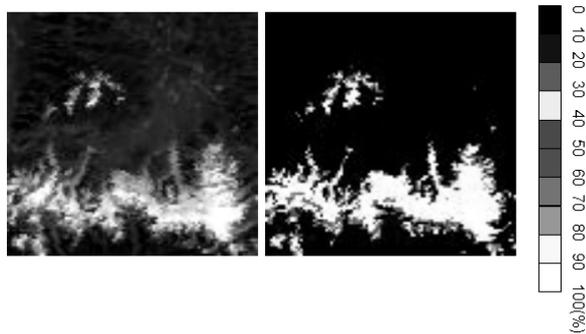


Figure2. The comparison of MODIS image (left) and the result of fractional snow cover area (right) based on linear spectral unmixing method for the no2 image which was obtained on Jan. 20th 2001.

Then the percentage of snow cover was calculated for 500m cells. Comparison between linear spectral unmixing method and real percentage of snow cover from ASTER data shows that linear spectral unmixing technique can estimate the fractional snow cover very accurately. At present, it seems that spectral mixture method would have the best performance in estimating fractional snow cover within a pixel. But these approaches haven't been applied to a very large area such as the whole Tibetan Plateau. To provide accurate information about snow cover in Tibetan Plateau, more attention should be paid on fractional snow cover estimating.

Based on this method Changing analysis of sub-pixel snow cover over Tibetan Plateau was analyzed.

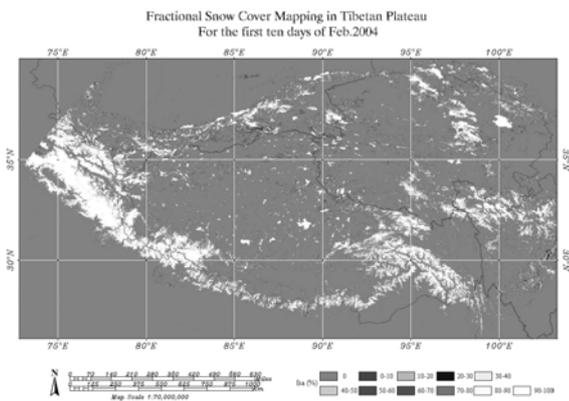


Figure3. The extent and distribution of fractional snow cover area in Tibetan Plateau.

Firstly, a decision tree was set up to identify cloud cover. With a great deal repeating scenes coming from the same area the cloud pixel can be replaced by "its" real surface types, such as snow pixel or vegetation or water. Here the repeating time is set up among 10 days. Secondly, Sub pixel snow mapping using linear spectral unmixing method is done. Then Images mosaicking based on georeferenced methods was showed and changing analysis was done according as time series. Snow cover changing of the whole Tibetan Plateau was analyzed.

We can find the extent and distributing of snow cover (figure 3) is very similar with the exact scope of the Tibetan Plateau. Snow cover area is vast and continual in the Karakorum Mts., Himalayan Range, Hengduanshan, Altyn Tagh Mts., Qilian Mts., and Tanggula Mts. For every year snow cover area will be increased very serious from October and continue to improve until January and February next year. And then it will start to decline to be a relative small area until September. Here we give a statistic figure from the year of 2004 (figure 4).

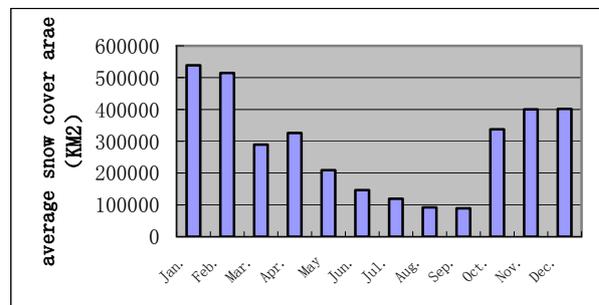


Figure4. The average snow cover of 2004

For 2004, the biggest snow cover area from January to February are the widest, the average snow cover is about 17%. And the smallest snow cover area is from August to September. The detail results are table 1.

months	FSA	months	FSA
1	0.172459	7	0.038293
2	0.164869	8	0.029485
3	0.092662	9	0.028575
4	0.104363	10	0.108072
5	0.066902	11	0.128105
6	0.04696	12	0.128729

Table 1. The average snow covers of very months for the year of 2004

From the distribution of snow cover, snow cover presents a kind of specific structure which is related with topography. Commonly, snow cover of mountain regions presents a typical dendritic structure. The bright tone is ridge; and the dark tone is valley. At Himalayan, the distribution of snow cover resembles not only a dendrite but also is exposed discontinuously along the E-W-trending. It can serve as a good reference to the Tibetan Plateau.

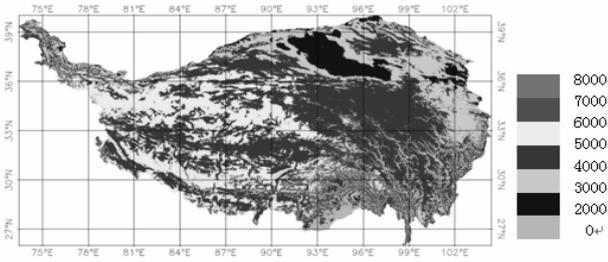


Figure5. The topographic map of the Tibetan Plateau from SRTM DEM data

Taking the topographical effect into account on retrieval of snow cover, SRTM DEM data was applied to find the relationship between snow distribution and altitude. The resolution of SRTM DEM data is about 90m. all the data cover the whole Plateau is 32 longitudes and 15 latitudes. The range of coordinate is from E73 to E104; and from N26 to N40. The total data is 480 scenes. In order to compare with MODIS snow cover conveniently, SRTM DEM data is reprojected to 500m and mosaiced together.

Accordance with mean elevation six altitude levels are divided into. They include below 2000m, 2000-3000m, 3000-4000m, 4000-5000m, and 5000-6000m, above 6000m. And then snow cover area of Jan., Jul, Sep., and Oct. is computed separately with every level. The snow cover area information coming from above four months is showed based on different altitude level (figure 6).

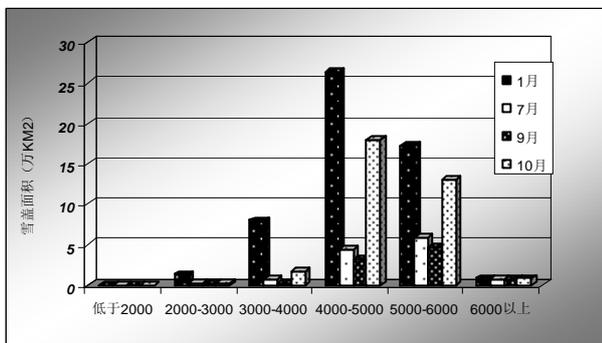


Figure6. The snow cover area coming from 1,7,9,10 based on different altitude.

So this is little or no snow cover below 3000m; this is a huge difference between summer and winter. It is very evident between 4000 to 6000m of altitude because Seasonal snow cover owned almost of the proportion. For above 6 km, snow cover area among every month is very close to each other. It means it is composed of perennial ice and snow at altitude above 6km.

Snow cover is a very important director for the global climite changing. So it is very useful and efficient to map the snow cover over Tibetan Plateau using MODIS data.

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