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Spatio-temporal changes of snow cover and its response to climate change over Tibetan Plateau

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Introduction

Snow cover, as an important part of land cover, is one of the most active natural elements on the earth surface. This program used the MODIS/Terra-Aqua daily snow products (MOD10A1 and MYD10A1) and AMSR-E/Aqua daily snow water equivalent product (AE_DySno) from 2003 to 2010 of Tibetan Plateau (TP), together with systematic study on MODIS daily snow cover product composite and a merging of multi-sensor and snow line approaches (Liang *et al.* 2008) to put forward a new snow cover mapping algorithm. Daily cloud-free snow cover images were calculated based on the new algorithm and the response of climate change on snow cover dynamics was analysed.

Methods

MODIS daily cloud free snow product composite algorithm

To eliminate cloud obscuration, we propose a daily cloud-free snow cover composite algorithm, and the procedure is mainly including the following four steps:

- 1) MODIS daily snow cover product composite (MOYD10A1);
- 2) Adjacent temporal deduction (MTS10A1);
- 3) Snow line (SNOWL) identification (MSL10A1);
- 4) MODIS/AMSR-E image composite (MA10A1).

Snow classification accuracy analysis

Overall accuracy O_a (%) and snow classification accuracy S_a (%) were calculated by the following formulas:

$$O_a = \frac{S_b + L_b}{S_b + S_s + L_b + L_s} \times 100$$

$$S_a = \frac{S_b}{S_b + S_s} \times 100$$

where, S_b is the sampling number of snow pixel seen by both climate stations (snow depth over 0.5 cm) and satellite; S_s is the number of snow pixel seen only by stations but misclassified into land by satellite; S_c is the number of snow pixel seen only by stations but classified into cloud by satellite; L_b is the number of snow-free land pixel seen by both climate stations and satellite; L_s is the number of snow-free land pixel seen by only the stations but misclassified as snow by satellite; and L_c is the number

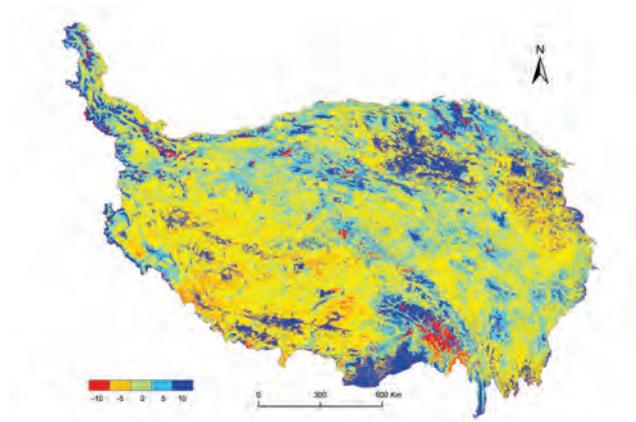


Figure 1. The change trend of SCD in each grid unit during 8 years in TP region.

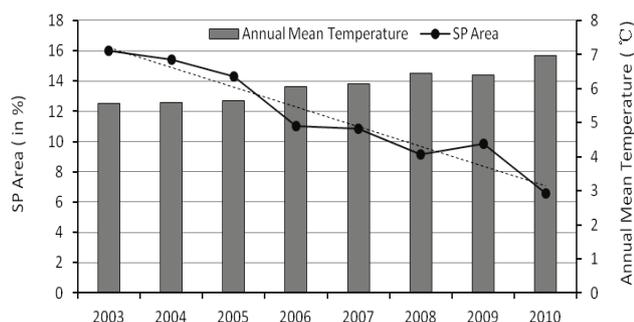
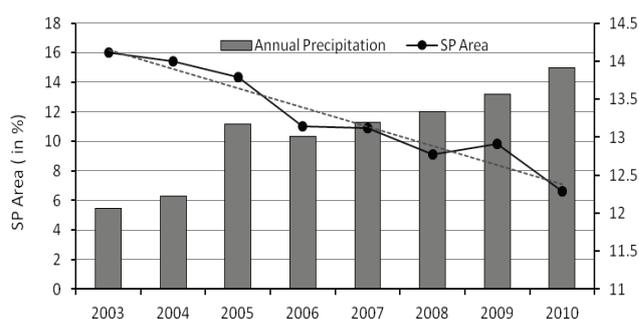
of snow-free land pixel seen by only the stations but classified as cloud by satellite.

Results

The changes of snow cover duration (SCD) in the 8 years (2003-2010) illustrates that the SCD in northeast and southwest of the plateau presents a decreasing tendency ($-10 < S < -5$) and the decreasing area of SCD in the entire region of TP is 70.32%. The SCD in several parts of southern areas has a significant declining trend ($S \leq -10$). But an increasing in local areas of northern and southern plateau ($5 < S < 10$), and SCD increases obviously in some low-lying areas ($S > 10$). The areas of the SCD maintains invariant ($-5 < S < 5$) are mainly distributed in the middle area of the plateau and the surrounding area where the SCD increases or decreases (Fig. 1). Overall, the SCD of the whole plateau shows a reducing tendency. Combined with the annual mean temperature and annual precipitation data of 106 meteorological stations, the permanent snow cover image of the 8 years were analyzed, the result indicates that the permanent snow cover area during 2003-2010 declines at the rate of 1.35% annually and the total rate is 9.43% (Table 1). However, the annual mean temperature and annual precipitation are increasing. The annual mean temperature has increased at the rate of 0.21°C annually and the total rate is 1.41°C while the annual precipitation has increased at the rate of 0.26 mm annually and the total rate is 1.85 mm (Fig. 2, Fig. 3).

Table 1. Snow classification accuracy for MODIS SCA images from 2003 to 2010.

SCA image	S-S	S-L	S-C	L-L	L-S	L-C	Snow classification accuracy (%)	Overall accuracy (%)
mod10a1	1936	448	3855	139735	797	102290	81.21	99.13
myd10a1	1452	613	4326	122914	1486	114580	70.31	98.34
moyd10a1	2552	546	2733	179275	2372	63011	82.38	98.42
mts10a1	3110	663	2183	200816	2461	41204	82.43	98.49
mssl10a1	3850	781	1736	215291	2558	26368	83.14	98.5
ma10a1	4929	1175	0	245364	5199	0	80.75	97.52

**Figure 2. Relationship between the permanent snow cover area and annual mean temperature from 2003 to 2010.****Figure 3. Relationship between the permanent snow cover area and annual precipitation from 2003 to 2010.**

Conclusions

The new daily snow product MA10A1 not only has a higher resolution, but also can completely eliminate the influence of clouds compared with other composite images. Therefore, MA10A1 has the ability to accurately monitor daily snow cover dynamics in the study area. Through the monitoring of the snow cover dynamics during 2003-2010, we found that permanent snow cover area and snow-covered days in the study area shows a decreasing trend under the influence of the regional climate change while the maximum snow cover area tends to increase.

Acknowledgments

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