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Temporal and Spatial Variation Characteristics of Snow Cover Area in the Pamirs from 2010 to 2020

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Abstract

Scientific and comprehensive monitoring of snow cover changes in the Pamirs is of great significance to the prevention of snow disasters around the Pamirs and the full utilization of water resources. Utilize the 2010-2020 snow cover product MOD10A2, Synthesis by maximum, The temporal and spatial variation characteristics of snow cover area in the Pamirs in the past 11 years have been obtained. Research indicates: In terms of interannual changes, the snow cover area of the Pamir Plateau from 2010 to 2020 generally showed a slight decrease trend. The average snow cover area in 2012 was the largest, reaching 54.167% of the total area. In 2014, the average snow cover area was the smallest, accounting for only 44.863% of the total area. In terms of annual changes, there are obvious changes with the change of seasons. The largest snow area is in March, and the smallest snow area is in August. In the past 11 years, the average snow cover area in spring and summer showed a slow decreasing trend, and there was almost no change in autumn and winter. In terms of space, the snow cover area of the Pamirs is significantly affected by altitude, and the high snow cover areas are mainly distributed in the Karakoram Mountains and other areas with an altitude greater than 5000 meters.

Keywords

Pamirs, Snow Cover Area, MOD10A2, Space-Time Change

1. Introduction

Snow cover is an integral part of the global cryosphere, with its unique physical properties (such as surface reflectivity, heat transfer capacity, and ability to change states) and its wide distribution range having a significant impact on global energy balance, hydrology, climate, and atmosphere. Significant impact and an important driver of global climate change [1] [2] [3]. Over the years, people have not stopped researching snow cover. As early as the 1960s, with the rise of remote sensing technology, scholars at home and abroad have used remote sensing technology to conduct a series of studies on snow cover area, snow cover area change, snow depth change, etc., and have obtained a large number of research results (research results [4] [5] [6]). For example, Liu Junfeng [7] used MODIS snow data to study and analyze the snow area in my country, and found that the stable snow area in my country was 334.4 × 104 km^2, and the unstable snow area reached 490.6 × 104 km^2; Ye Hong [8] used MOD10A2 Snow data have been used to study the temporal and spatial changes of snow cover on the Qinghai-Tibet Plateau; Emmy [9] used MOD10A2 snow data to study the impact of snow on water storage in the Himalayas, and found that the water storage increased in the early snowmelt period and decreased in the late snowmelt period. The increase in temperature led to the early start of snowmelt; Hao Xiangyun [10] used MOD10A2 snow cover data and daily runoff data to analyze the temporal and spatial variation characteristics of snow cover in the Xilin River Basin and its impact on runoff, and found that the change of runoff must be affected by snow cover. Zou Yifan [11] *et al.* used MOD10A2 snow cover products to analyze the temporal and spatial changes of snow cover in Hengduan Mountains and its influencing factors from 2001 to 2019. The results showed that factors such as altitude, slope aspect, precipitation, relative humidity, wind speed, and temperature had an impact. To sum up, it is very necessary to study the temporal and spatial changes of snow cover and its characteristics, which is of great significance to the better utilization and protection of water resources, ecological environment, climate, global temperature, natural disasters and other factors [12] [13].

Most of the mountains in the Pamirs are very tall, with an average altitude of more than 4500 meters. There are more than 1,000 glaciers and mountains in total, with a total area of nearly 10,000 square kilometers. Moreover, the water flow and atmospheric precipitation formed by the snow melting in the Pamirs provide more than 50% of the runoff sources for the surrounding rivers [14] [15] [16], including the Indus River, the Kashgar River, and the Yarkand River [17] [18]. Therefore, it is particularly important to study the temporal and spatial changes of snow cover in the Pamirs. Based on these conditions, this article will focus on the changes in the snow cover area of the Pamirs in spring, summer, autumn and winter from 2010 to 2020, the changes in the interannual snow cover area, and the changes in the annual snow cover area. The research results can help to understand the characteristics of snow cover changes in the Pamirs, and have an important reference role in the prevention of snow disasters and the full utilization of water resources.

2. Overview of the Study Area

The geographical location of the Pamir Plateau is between 73˚00' - 77˚00'E and 36˚25' - 41˚00'N (**Figure 1**). It is located in the southeastern part of Central Asia

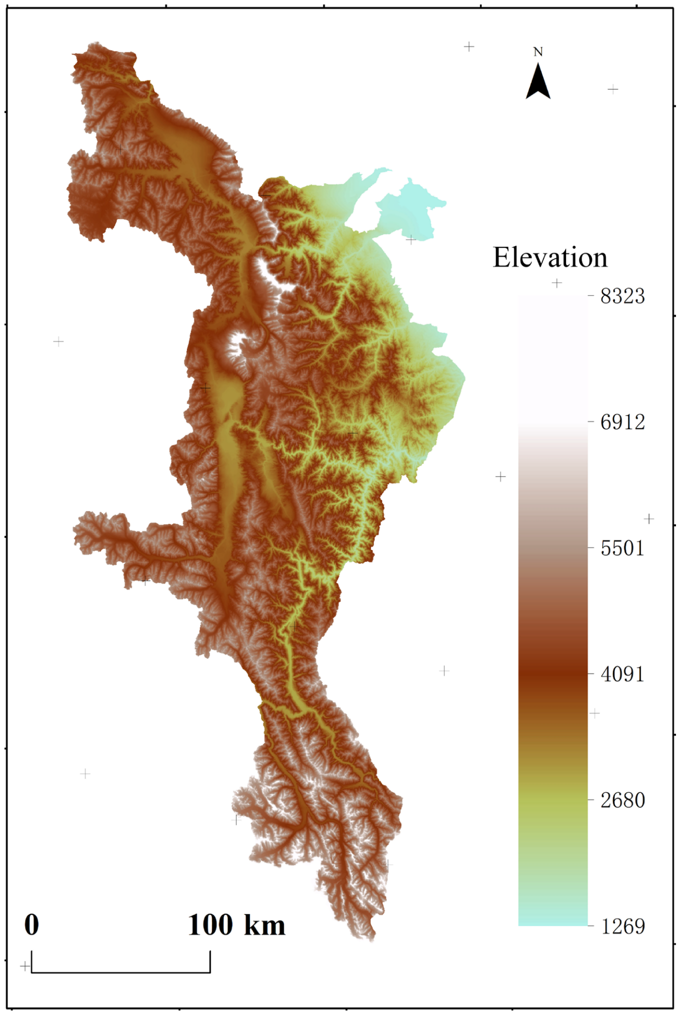

Figure 1. Elevation map of the study area.

as a whole, spanning three countries, including the westernmost part of China, Southeast Tajikistan and northeast Afghanistan, with a total area of about 100,000 km^2. According to its unique topographic features, the Pamir Plateau is divided into two parts, East Pamir and West Pamir. The East Pamir has an open terrain, and its main components are two mountain ranges and a group of river valleys and lake basins. The average altitude is about 3600 meters. The main peaks of the mountains are all over 5000 meters, and their relative heights do not exceed 1500 meters. It belongs to a strong continental alpine climate [19]. The terrain of West Pamir is complex. The main body is composed of many vertical and horizontal mountains and river valleys. The altitude difference between the mountains is large, with a relative height of more than 2000 meters, while the river valleys are low and narrow. A variety of glacial topography is jagged.

3. Data Sources and Research Methods

3.1. Data Sources

MODIS (Moderate-resolution Imaging Spectroradiometer) snow cover data comes from MOD10A2 obtained by Terra satellite released by earthdata search (https://search.earthdata.nasa.gov/search), the time resolution is 8 days, and the spatial resolution is 8 days. The distance is 500 m, and the data format is .hdf. In order to obtain more accurate snow cover data, this paper removes the data with cloud coverage greater than 10%, and only obtains the data with cloud coverage less than or equal to 10%. The data contains two data sets, which are the maximum snow extent over the 8-day period and the average snow area within 8 days (Eight day snow cover chronobyte). This article selects a total of ten years of data from 2010 to 2020. Since there are two images covering the Pamirs in each period, the orbit numbers are h23v05 and h24v05 respectively. Previous studies have pointed out that in the absence of clouds, the accuracy of MOD10A2 snow cover data exceeds 87.5% [19] [20] [21]; Cai Dihua [22] *et al.* used MOD10A2 snow cover data to study the temporal and spatial variation characteristics of snow cover in the Qilian Mountains and compared meteorological stations The accuracy of MOD10A2 snow data is found to be 85.54%; therefore, this data is a good data for monitoring plateau snow.

3.2. Data Preprocessing

MRT (Map Reproject Tools) can process data in batches and has complete functions.So we use MRT (Map Reproject Tools) to splicing the downloaded data for each period of two MOD10A2 snow images, and then convert the data format, convert the coordinate system to Albers area projection, resample, and convert the HDF format to Geotiff format, and finally use ENVI and the vector boundary of the Pamir Plateau to crop the spliced data, and finally obtain the remote sensing image of the study area. As shown in **Table 1**, according to the meaning represented by the MOD10A2 product code, the pixels whose coding values are 200 (snow), 50 (cloud) and other pixels are processed separately. First count the proportion of pixels whose code value is 50 (cloud). Then use the ENVI tool to binarize the image, that is, to reassign the pixel with a coding value of 200 (snow) to 1, and to assign the coding value of other pixels to 0, and reclassify the pixels to obtain the study area. Finally, use the obtained remote sensing images to analyze the characteristics of snow cover changes in the Pamirs.

3.3. Snow Cover

The snow cover ratio (SCR) indicates the percentage of snow coverage to the total area of the study area. In order to obtain a more accurate proportion of snow

Table 1. MOD10A2 code and its meaning.

coding	Surface Types and Their Significance
0	missing data
1	no decision
11	night

cover, this paper allocates a very small number of places defined as clouds, that is, the part with a pixel value of 50, and the proportion of snow cover is as follows (1):

$$\text{Scloudsnow} = \frac{\text{Ssnow}}{\text{Sall}} \times \frac{\text{Scloud}}{\text{Sall}} \quad (1)$$

Among them, Scloudsnow represents the snow coverage rate in the cloud coverage area, Ssnow represents the snow coverage area, Scloud represents the area occupied by clouds, and all represents the area of the entire study area. Therefore, the snow coverage rate is defined as the following formula (2):

$$\text{SCR} = \frac{\text{Ssnow}}{\text{Sall}} + \text{Scloudsnow} + 100\% \quad (2)$$

4. Results and Analysis

4.1. Interannual Variation Characteristics of Snow Cover

In order to study the interannual variation of the snow cover area of the Pamirs, this paper made statistics on the 11-year snow cover area of the Pamirs from 2011 to 2020, and made a characteristic map of the 11-year average annual snow cover change (**Figure 2**). It can be seen from the figure that the annual average snow cover rate of the Pamirs has a complex and fluctuating change, mainly fluctuating between 44.863% and 54.167%, and the maximum snow cover rate appeared in 2012, which was 54.167%, the minimum snow cover rate appeared in 2014, which was 44.863%. On the whole (**Figure 3**), the snow coverage rate of the Pamirs shows a slight downward trend, and the snow coverage rate is the largest at the beginning or end of each year when the temperature is the lowest. Snow cover is at its smallest during the hottest time of year, which is the middle of the year. Judging from different time periods, it shows a gradual upward or downward trend. Among them, the annual average snow coverage rate in 2011-2012, 2014-2015, 2016-2017, and 2018-2020 showed an upward trend, and the rate of increase bigger. The annual average snow cover rate in 2010-2011, 2012-2014, and 2017-2018 showed a downward trend. After 2012, the annual average snow cover rate began to decline significantly. From 2012 to 2014, the decline was the largest, and in 2014 reached its lowest level in nearly 11 years. Combining **Figure 2** and **Figure 3**, it can be seen that the average snow cover rate of the Pamirs from 2010 to 2020 has little inter-annual change, and generally shows a slight downward trend.

The analysis of the average snow coverage rate of the Pamirs in different seasons (**Figure 4**) shows that the average snow coverage of the Pamirs fluctuates greatly with the seasons, with the highest in winter and the lowest in summer. The linear trend shows that the average snow cover rate in spring and summer in the Pamir Plateau decreased significantly. There is almost no change in autumn and winter, which shows that the main reason for the slight downward trend in the annual average snow cover rate of the Pamirs is the reduction of snow cover area in spring and summer. Most of the snow cover in summer is

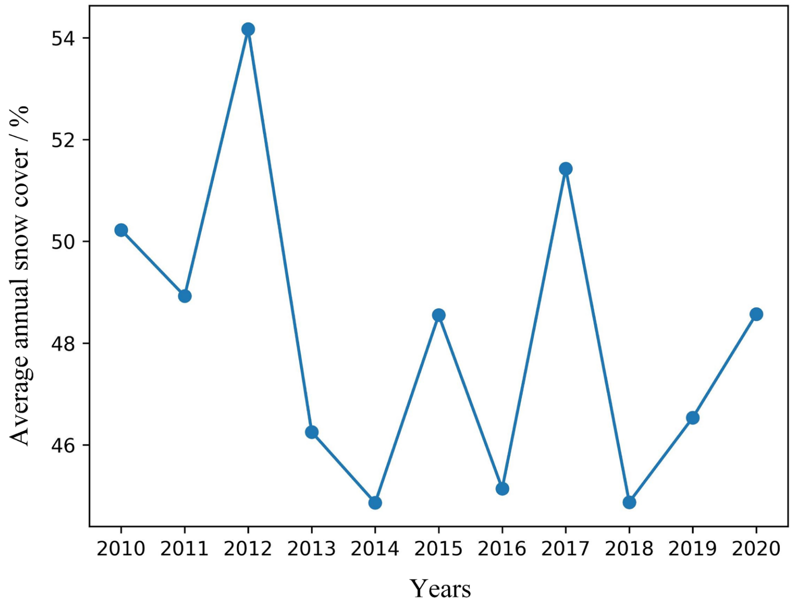

Figure 2. The annual average snow cover rate of the Pamirs from 2010 to 2020.

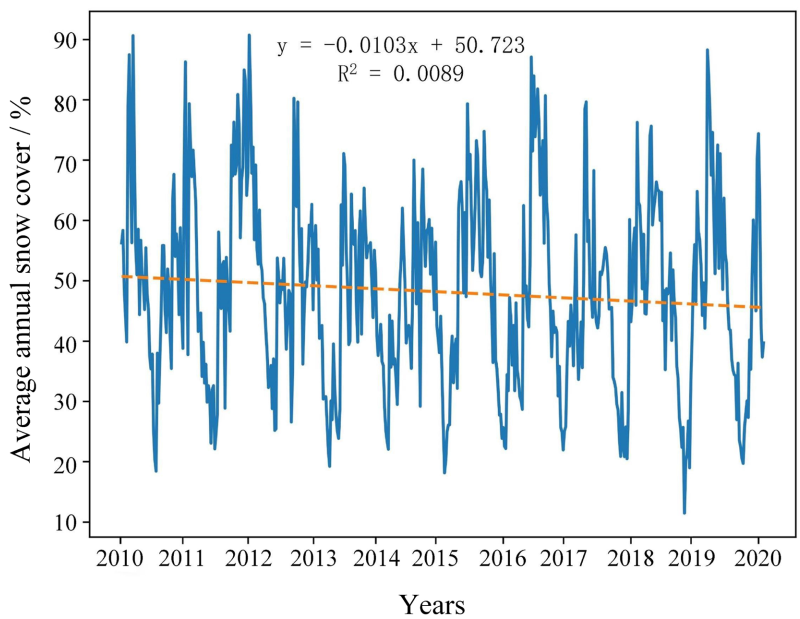

Figure 3. Time series changes of snow cover ratio in the Pamirs.

composed of stable snow cover and glacial snow cover on the top of mountains. The decrease in the average snow cover rate in summer also shows that the stable snow cover in the Pamirs has decreased, which is consistent with the overall decreasing trend of glaciers in China in recent years [23].

4.2. Intrannual Variation Characteristics of Snow Cover

From 2010 to 2020, the annual snow cover rate of the Pamir Plateau is significantly affected by the season. From Figure 5, it can be seen that it is in a "concave" shape as a whole, and the snow cover rate reaches its peak at the end of

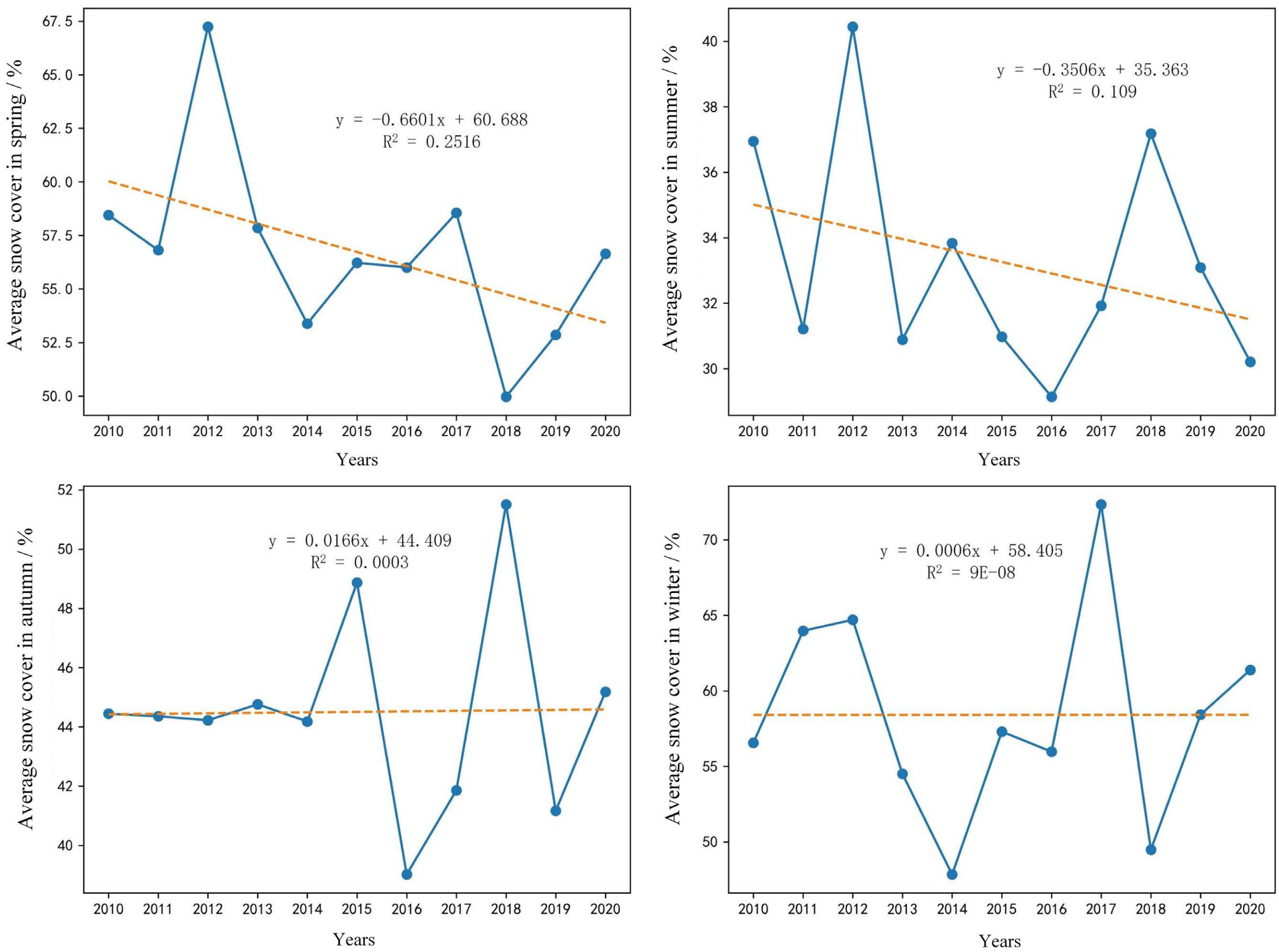

Figure 4. Snow cover of the Pamirs in different seasons from 2010 to 2020.

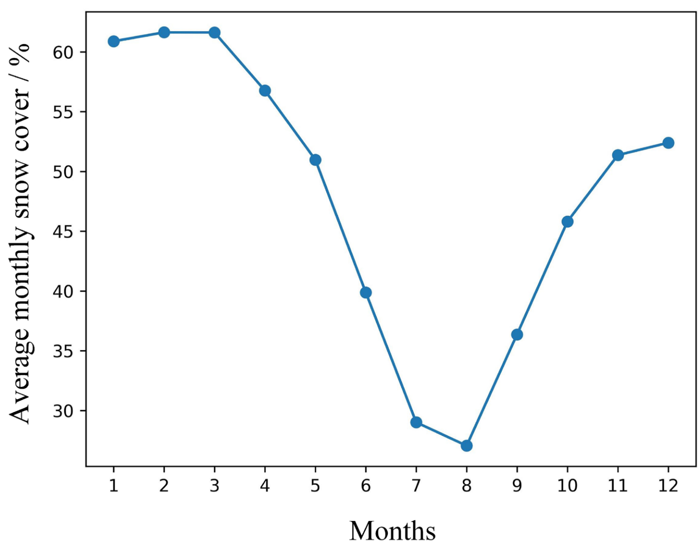

Figure 5. Monthly average snow cover in the Pamirs from 2010 to 2020.

February and the beginning of March. But as the temperature continued to rise, the snow cover area continued to decline until it dropped to the lowest point at the end of July and the beginning of August, which was 27.06%. At this time, the temperature began to drop, and the snow cover rate also began to slowly rise to the peak, reaching a maximum value of 61.63%.

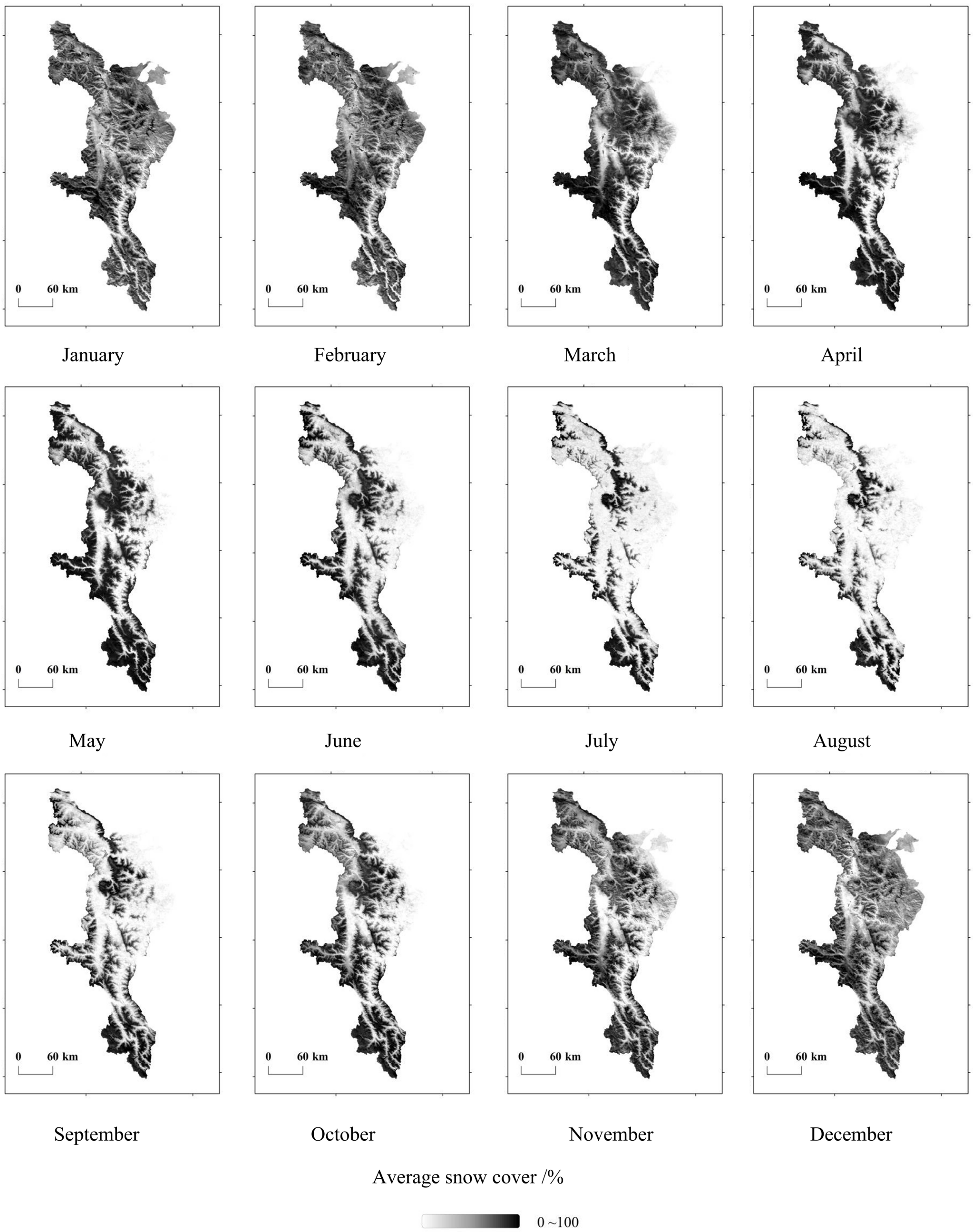

Figure 6. Spatial variation of monthly average snow cover rate from 2010 to 2020.

4.3. Spatial Distribution Characteristics of Snow Cover

The spatial distribution of snow cover in the Pamirs is significantly different due to the influence of regions. From **Figure 1** and **Figure 6**, it can be seen that high snow cover areas (more than 70% of the annual snow cover time) are widely distributed in areas above 5000 meters above sea level, mainly in high altitude areas such as the Karakoram Mountains.

5. Conclusions

Using EOS/MODIS data, this paper analyzes the intra-annual/inter-annual/seasonal temporal and spatial variation characteristics of snow cover in the Pamirs from 2010 to 2020, and draws the following main conclusions:

1) In terms of the interannual variation of snow cover area, the snow cover area of the Pamirs showed a slight decrease from 2010 to 2020. The average snow cover area in 2012 was the largest, reaching 54.167% of the total area. The average snow cover area in 2014 was the smallest, only 44.863% of the total area. The months with the largest snow cover mostly occur in February or March, and the months with the smallest snow cover mostly occur in July or August.

2) In terms of annual changes in snow cover area, the average monthly snow cover area of the Pamirs over the past 11 years is generally in the shape of a "concave", which has obvious changes with the change of seasons. During the snow cover period, the snow cover area, the area increases significantly, and the month with the largest snow accumulation in March. During the snowmelt period, the snow cover area decreased significantly, and the minimum snow cover area was in August. From a seasonal point of view, the Pamirs have the highest snow coverage in winter and the lowest in summer, and the average snow coverage in spring and summer has dropped significantly. There is almost no change in autumn and winter.

3) In terms of space, the snow cover of the Pamirs is significantly affected by the altitude, and the high snow cover areas are mainly distributed in the Karakorum Mountains and other areas with an altitude of more than 5000 meters.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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