Changes in snowpack of the Changbai Mountain region over the last decade in reaction to global warming

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Abstract. As greenhouse gas emissions have been mounting in recent years, the issue of global warming has become more and more serious, sparking a great deal of concern. Among the effects of global warming, the melting of snowpack is particularly pronounced. However, most of the current researches focus on vegetation and biodiversity, and there are some gaps in studies of snow in the mountainous regions of China. This paper analyzes the Landsat8 satellite images of Changbai Mountain area in the past 10 years through QGIS and programming algorithms to study the trend of snowpack change, the correlation between snow melting and vegetation change and causes of snow melting. The analytical methods used in this paper include NDSI, NDVI, supervised classification and image binarization. From 2014 to 2023, the snow-covered areas in Changbai Nature Reserve have decreased dramatically, especially in northwestern part, middle part and edges of Changbai Mountain. The change rate of snowpack has reached a significant 13.979%. The vegetation area shows an increasing trend and is negatively correlated with snowpack change. In order to alleviate the challenge of snow melting, ecological engineering, new energy sources and rigorous regulation of human activities are all essentially necessary. In the future, it is expected that the research in this paper will have a profound positive impact on the ecological management of the Changbai Mountain region, the conservation of snow resources and the mitigation of global warming.

1. INTRODUCTION

With the rapid development of modern industry, carbon emissions are increasing significantly, making the greenhouse effect more and more notable. The accumulation of greenhouse gases has resulted in an increase in global radiative warming by promoting the heat-trapping ability of the atmosphere. Consequently, the temperature gradually rises and extreme weather events become more frequent. Changes in temperature and weather conditions, associated with greenhouse gases, can have wide-ranging impacts on snowpack, hydrology and vegetation. Anthropogenic activities also have a profound impact on ecological changes. Particularly, the problem of snow melting has emerged worldwide. Studying the temporal characteristics of snow melting will help us understand the impact of global warming more deeply, thus alleviating this problem and preserving snow resources and ecosystems. Additionally, monitoring long-term snowpack changes can illustrate the correlation between snow coverage and other land features such as vegetation and water body.

Currently, a growing number of studies concentrate on long-term changes in snow coverage and associated changes in the carbon balance in reaction to climate change [1]. Major scientific investigations include detecting the magnitude of recent snowpack changes, the dependence of snowpack trends on the period examined, and the significance of natural climate variability versus anthropogenic global warming on past and future snowpack changes [2]. Most of these studies nonetheless focus on the snow mountains in Europe or in the America, while long-term studies of snowpack change from the high-altitude Asian region remain very scarce. The Changbai Nature Reserve (CNR) in Northeast China on the border near North Korea provides a rare opportunity to conduct this environmental investigation. The Changbai Nature Reserve, a renowned tourist attraction, is rich in biodiversity and has scarce snow resources that are of high research value. The Changbai Mountain is covered with year-round snow which is a unique and essential component of its ecosystem. The snow is one of the largest sources of drinking water, irrigation water and hydropower generation. It also plays a significant role in modulating the potential release of large stores of carbon and methane into the atmosphere [3]. In addition, snow resources in Changbai Mountain have enormous potential in terms of tourism. The study of snowpack change in Changbai Mountain will be beneficial to address and mitigate the global warming crisis. Consequently, the economic and environmental value of snow resources can be protected to the maximum extent possible. An increasing number of teams have already conducted studies on ecological changes in the Changbai Mountain, but these have been limited to changes in greenhouse gases, vegetation cover or biodiversity [4-6]. One of these studies analyzed the relationship between the treeline

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pattern and topography based on high spatial resolution remote sensing data and a digital elevation model and associated the result with snow coverage [7]. However, this paper focuses on long-term trends in snowpack in the Changbai Mountain and the linkage between snow and vegetation, using QGIS and algorithm to analyze the impact of climate change.

This paper studies the change of snow coverage in Changbai Mountain from 2014 to 2023 and the correlation between snowpack change and vegetation change, using NDSI and NDVI to analyze the changes in snow and vegetation, as well as to study the magnitude of snow melting by supervised classification. Consequently, the quantitative results are derived from analyses of satellite image data.

2. METHOD

2.1 Data source

To monitor long-term changes in the snow coverage of Changbai Mountain, this paper use satellite image data from 2014 to 2023, with the time interval of two years mostly. These satellite image data are from Landsat 8, which carries the Operational Land Imager (OLI) with a spatial resolution of 30m. Specifically, the data set from which the images come is Landsat 8-9 OLI/TIRS C2 L1. In order to control variable, the satellite images used are all acquired in late February, the same time of different years. To generate different band composites for visual analysis, seven bands of images are used. The images are located in row 31, path 116 of the satellite coverage area, which include Changbai Nature Reserve.

2.2 Data processing

Figure 1 illustrates the methodology of processing satellite image data. First of all, seven bands of satellite images are used to build virtual raster data. Using different band combinations, the true color images and false color images are acquired, which can roughly show the area of snow and vegetation. To highlight snow-covered areas, this paper uses the band combination of band7, ban5 and band4. The snow appears blue in this band combination due to its strong absorption of shortwave infrared and relatively high reflectance of green light, while the vegetation remains green and the land is red. Therefore, it is easy to distinguish snowpack from other land features. Then band ratios are calculated by using raster calculator in QGIS. This paper uses NDSI (Normalized Difference Snow Index) to accentuate snow-covered areas, meanwhile using NDVI (Normalized Difference Vegetation Index) to highlight the vegetation in images. Aiming to validate results obtained by QGIS, this paper also uses algorithms written in Visual Studio to acquire NDSI and NDVI grayscale images. Following the visual analysis, this paper quantifies the change in snow coverage by supervised classification. Finally, postprocessing tools in Semi-Automatic Classification Plugin (SCP) of QGIS are used to get quantitative results. The satellite images used for analysis are taken in 2014, 2015, 2017, 2019, 2021 and 2023 respectively. Each set of images goes through the process flow shown in Figure 1.

The main software used for data processing is QGIS, while algorithms for calculating NDSI and NDVI are written in Visual Studio. Take the NDSI calculation for example, images of band3, band6 and band7 are fed into the algorithm. The final output is a NDSI grayscale image and a binary image. It should be mentioned that the threshold in the binary image is calculated automatically by the algorithm. NDVI maps are calculated in the same way. Supervised Classification is performed via SCP Plugin in QGIS, which has a great variety of functions.

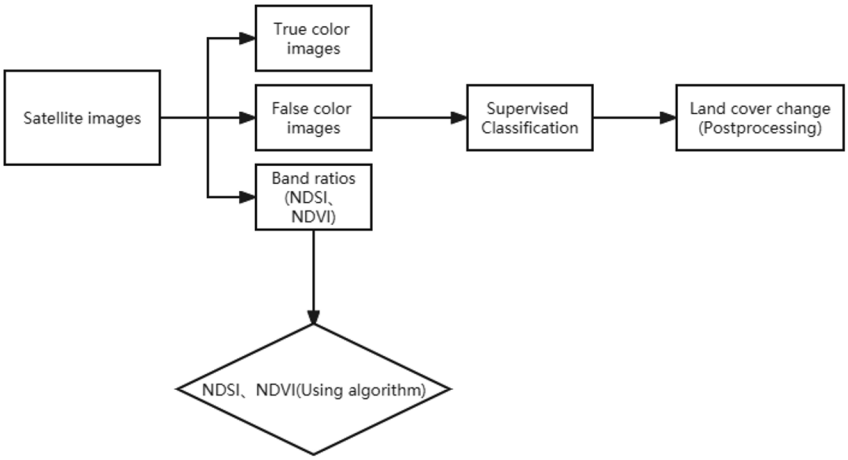

Figure 1. Methodology of processing satellite image data

3. RESULTS AND DISCUSSION

3.1 Ecological changes in Changbai Mountain

3.1.1 Snowpack change

The false color images using the 7, 5, 4 band combination are shown in Figure 2. In these false color images, blue areas which represent snowpack are gradually decreasing from 2014 to 2023. Obviously, there is a growing trend of snow melting in edges of Changbai Mountain, except for surrounding areas where the melting is even more severe. The upper left area and middle area are more heavily snow-melted, particularly in high altitude mountainous areas.

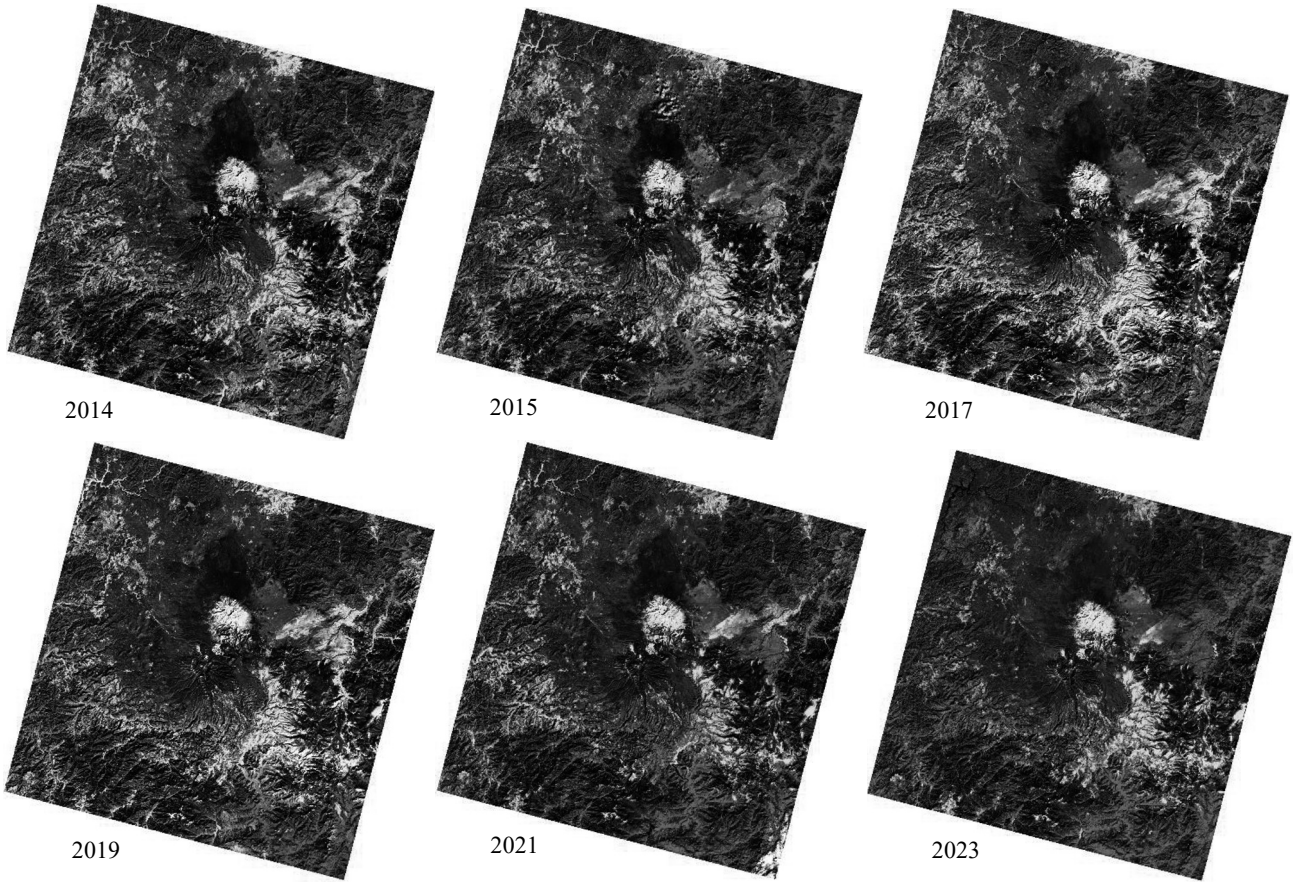

Figure 2. False color images (Band 7, 5, 4)

In order to observe snow changes with more detail, NDSI maps are produced. These NDSI maps were originally grayscale images and single band pseudo color is used for better visual effects. As shown in Figure 3, the NDSI values have been divided into 5 discrete grades. Both light blue and dark blue indicate snowpack, which has changed dramatically in the past 10 years. The snow-covered areas with NDSI values exceeding 0.25 decreased dramatically in upper left area and middle area. Meanwhile on the edges of Changbai Mountain the snow melts apparently. The snow melting trend in NDSI maps is consistent with the result in false color images but NDSI images are obtained by calculating band ratios so they are more detailed.

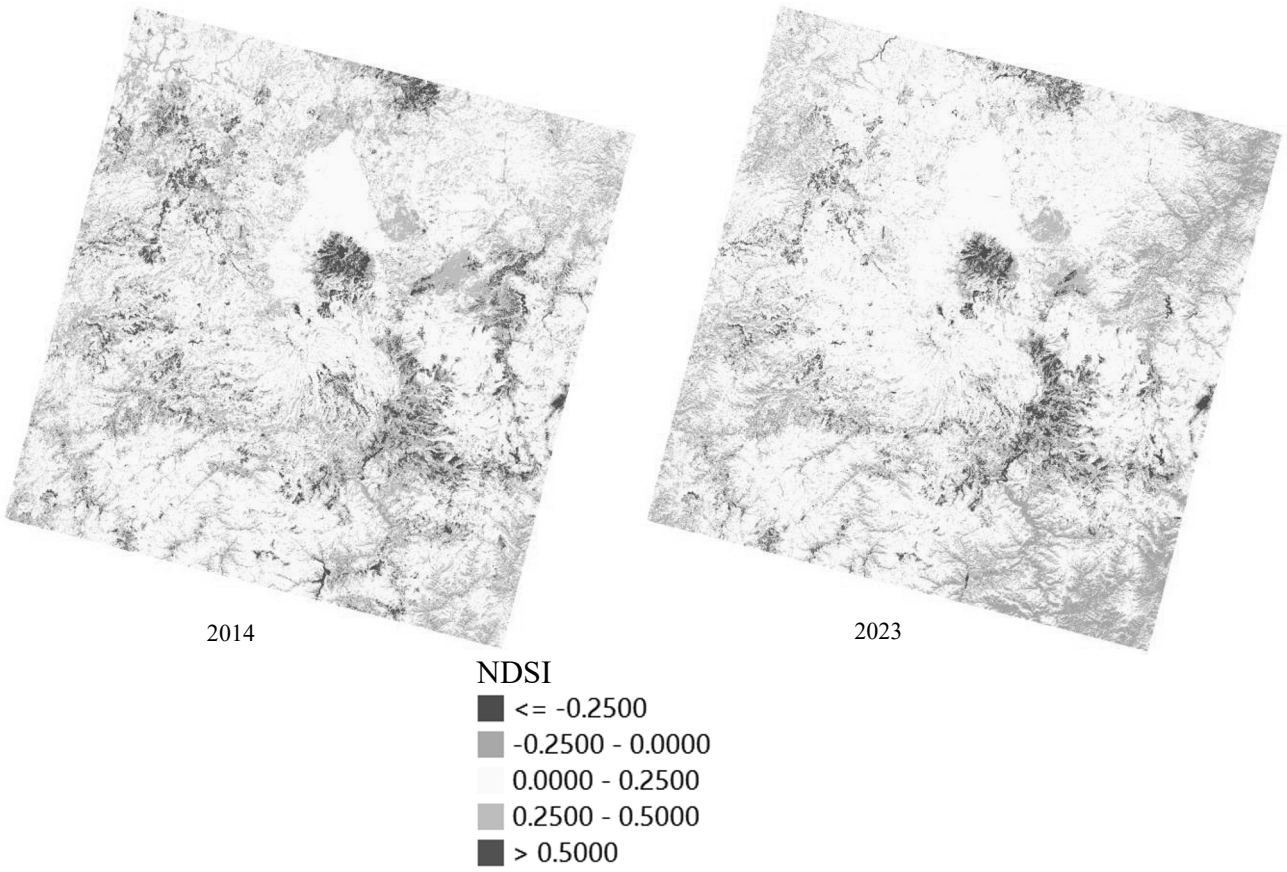

Figure 3. NDSI maps

After visual analysis using false color images and NDSI maps, this paper uses the method of supervised classification to calculate changes in different kinds of land features and obtain quantitative results. Classification maps in 2014 and 2023 are illustrated in Figure 4. The images use a striking red color to represent snow and shows that large areas of snow have melted from 2014 to 2023, while some rivers thaw at the same time of year, indicating higher temperatures compared to 2014. The thawing of rivers in Changbai Nature Reserve can be important evidence for global warming. It should be mentioned that the high similarity between false color images, NDSI images and classification results is also a validation of the analysis in this paper. As the analysis deepens, the results obtained become more and more accurate. These two classification maps can subsequently be used to calculate land cover change using the postprocessing tool.

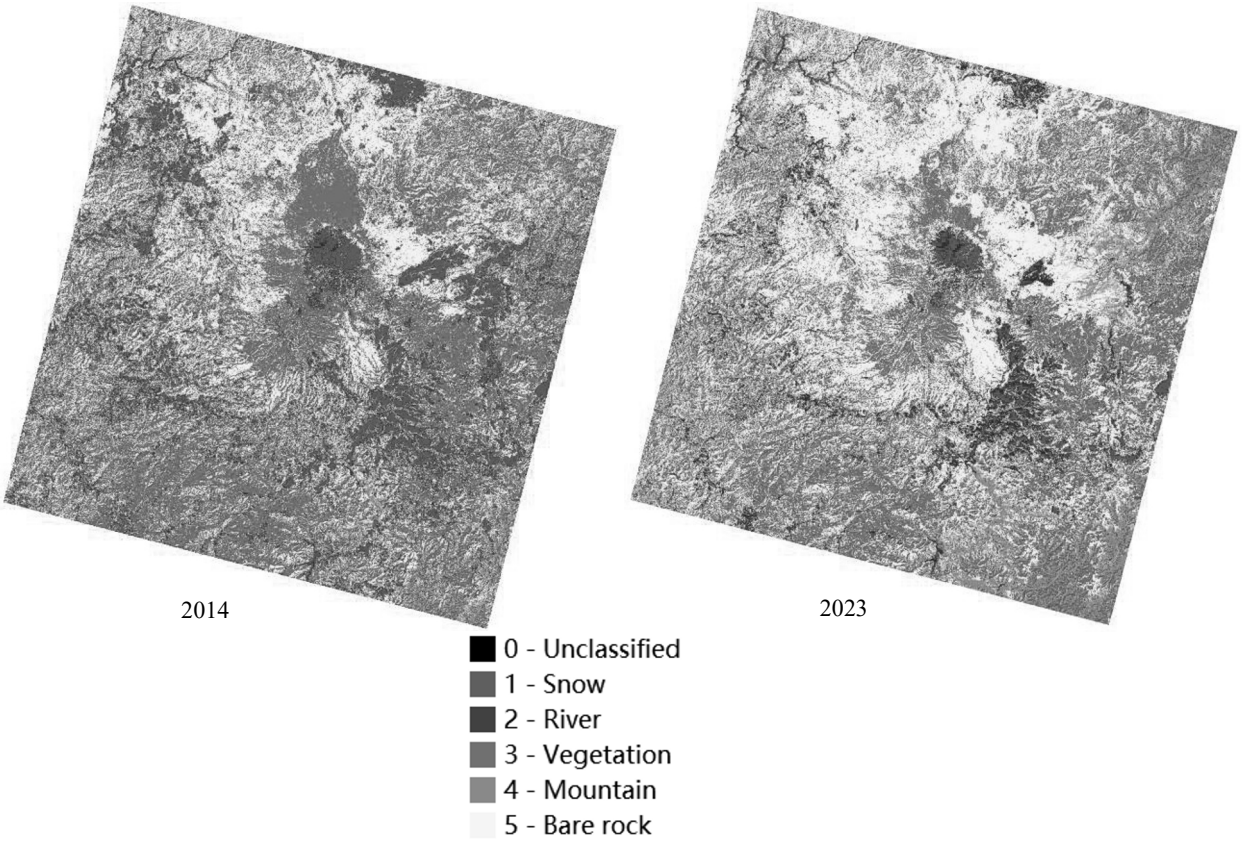

Figure 4. Classification maps

The land cover change map between 2014 and 2023 is shown in Figure5. In this map unchanged snowpack is highlighted in blue and areas without interest are black. The orange and red areas represent different magnitudes of snow melting. Unsurprisingly, severe melting occurs mainly in the north-western and middle parts. The snow melts heavily on the edges of Changbai Mountain, meanwhile slight melting happens in Tianchi, a lake at central point on the summit of Changbai Mountain. Snowpack change is mild in high altitude areas where the temperature is lower, while in low altitude areas the snow melts significantly. In addition to visual image results, quantitative results are obtained by the land cover change tool. The change rate of snowpack from 2014 to 2023 can be obtained by calculating the number of changed pixels. Finally, the calculated change rate of snowpack is 13.979%, which indicates that snow melting is very serious in the past 10 years.

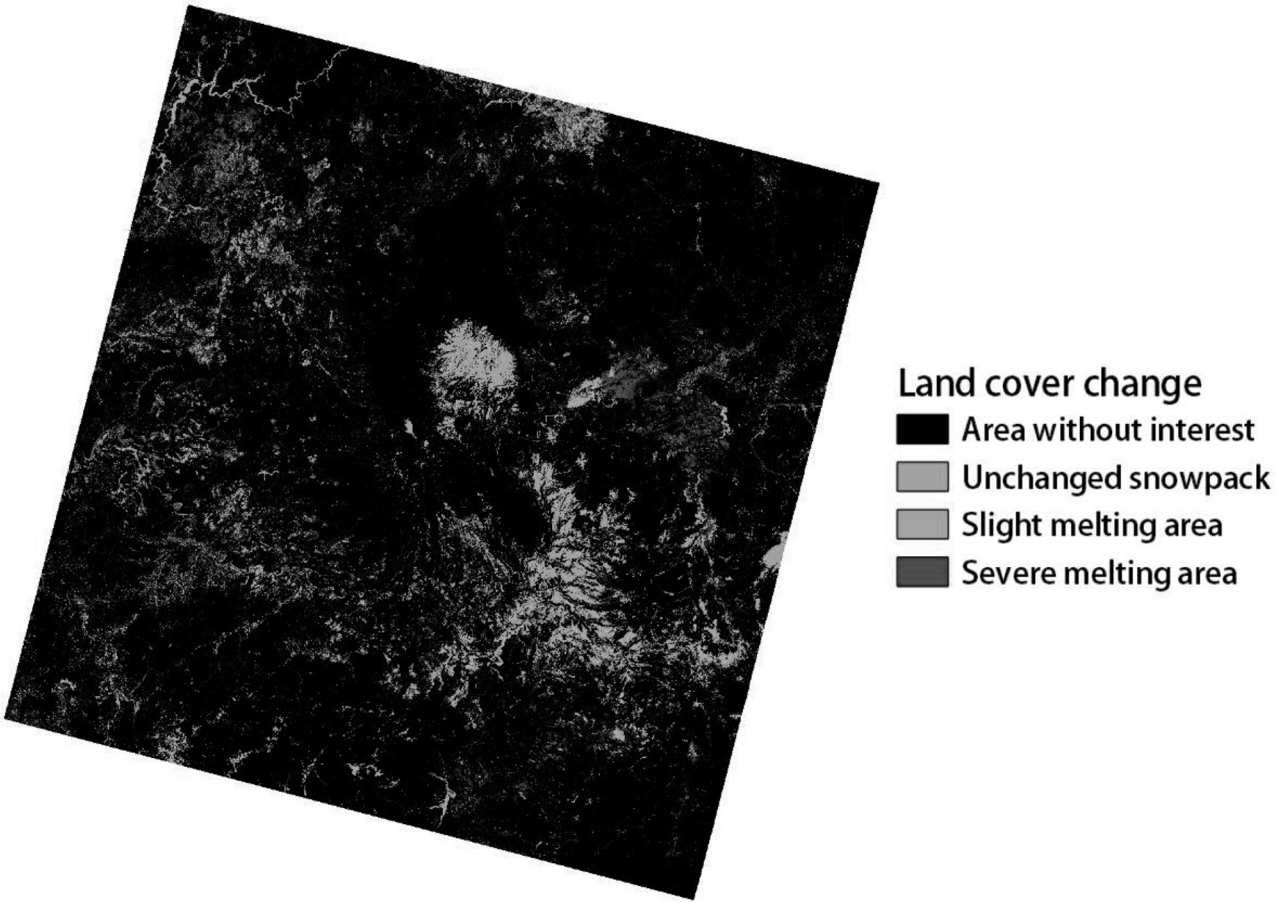

Figure 5. Land cover change map between 2014 and 2023

3.1.2 Vegetation change

The NDVI maps which are divided into 5 discrete classes are shown in Figure 6. Areas with NDVI values greater than 0.125, which means the vegetation cover is relatively dense, are shown in green. There is an increasing trend in the area of vegetation from 2014 to 2023 according to NDVI images. On the one hand, vegetation becomes lusher due to higher carbon dioxide emissions, on the other hand, there may be a correlation between vegetation change and snowpack change which requires more in-depth study [4]. Research on the Tibetan Plateau has shown that the maximum value of NDVI is positively correlated with temperature, and negatively correlated with the number of snow days and the lower boundary of the first frozen layer, which indicates that vegetation change may have negative correlation with snowpack change [8]. In addition, the advancement of the vegetation phenology and the influence of artificially planted vegetation also need to be taken into account. Higher temperatures are more suitable for the growth of vegetation, prompting the emergence of vegetation earlier. Anthropogenic implantation of green plants in large areas will also increase the vegetation coverage.

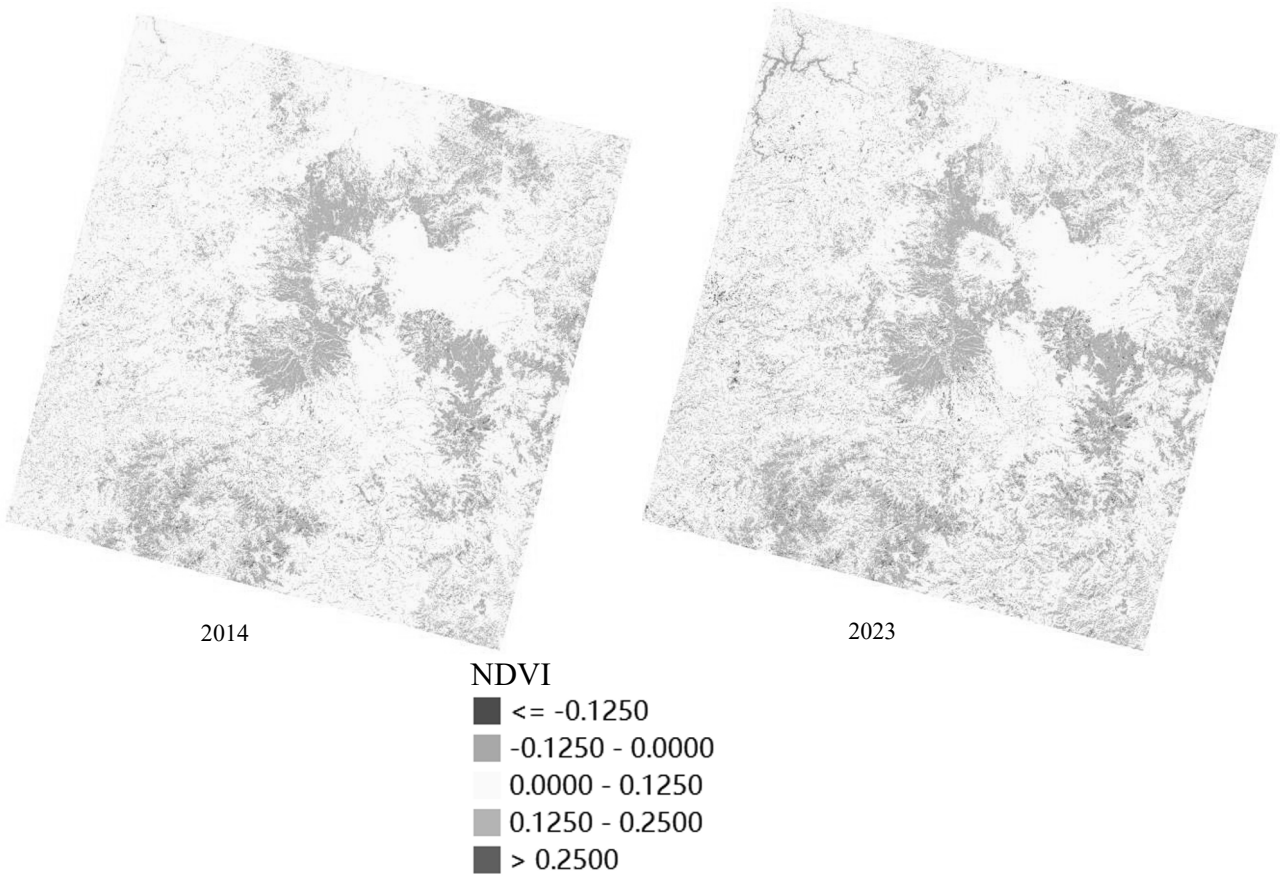

Figure 6. NDVI maps

3.1.3 Correlation between vegetation change and snowpack change

In order to study the correlation between vegetation change and snowpack change, this paper uses algorithms to produce binary NDSI and NDVI images. Firstly, the algorithms produce index maps using different bands of satellite images. Afterwards, they transform grayscale images into binary images through automatically calculated threshold. As shown in Figure7, white areas in NDSI maps indicate snow-covered areas, while in NDVI maps vegetation is shown in white. Expectedly, the snow coverage has decreased a lot in the past 10 years. Conversely, there is a trend towards gradual increase in the area of vegetation according to NDVI maps. What's more, more rivers thawed at this time in 2023 which indicates the temperature is higher and melting snow can provide more water for vegetation growth. Therefore, the snow melting will promote the increase of vegetation coverage to some extent. Additionally, both snowpack and vegetation are affected by climate change. Higher temperatures will stimulate the growth of green vegetation at an earlier time of year.

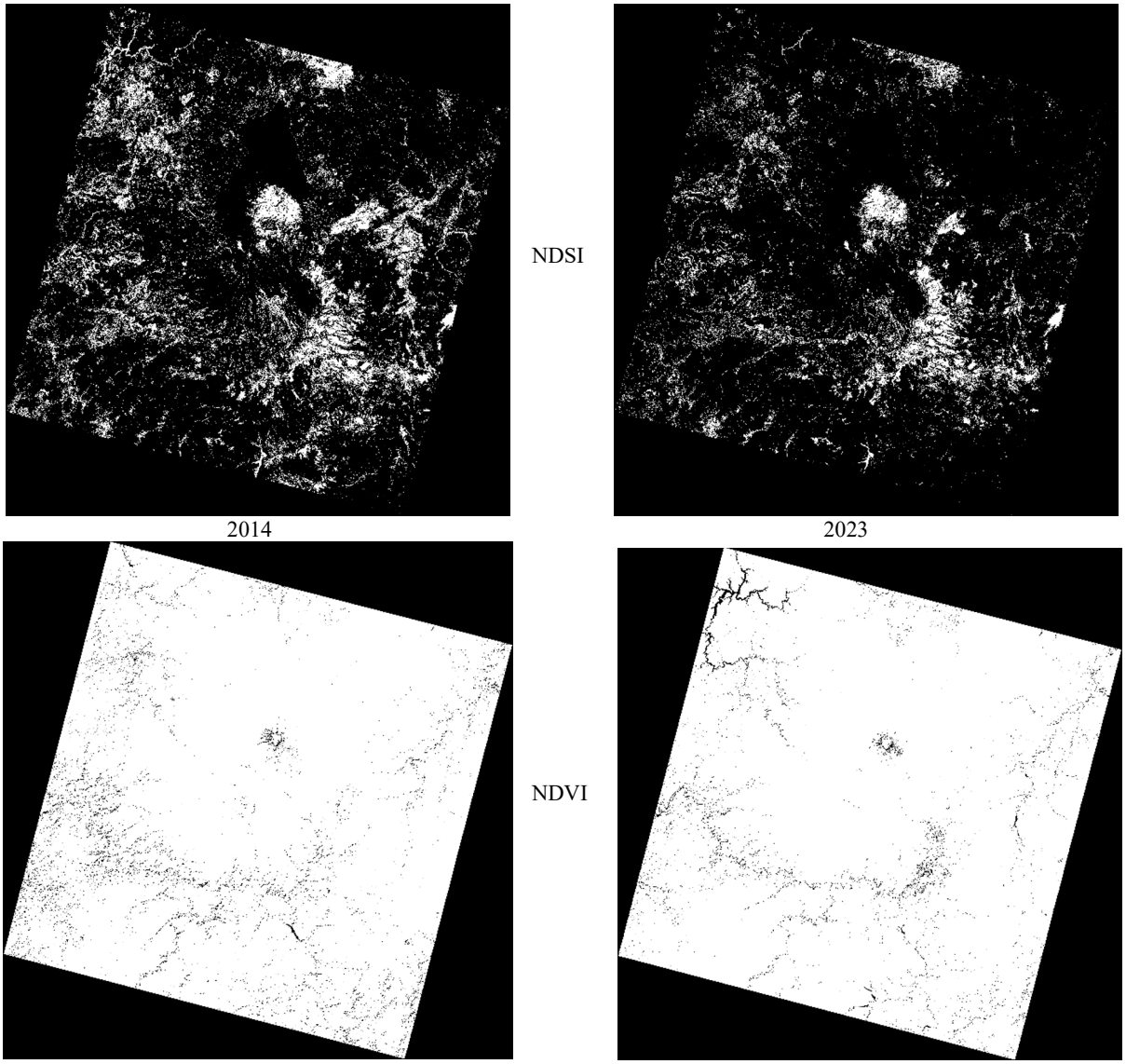

Figure 7. Binary images of NDSI and NDVI

To sum up, the snow-covered areas in Changbai Nature Reserve have decreased dramatically in the past 10 years, especially in northwestern part, middle part and edges of Changbai Mountain. The change rate of snowpack from 2014 to 2023 is 13.979% which shows the issue of snow melting is quite severe. Meanwhile there is a growing trend towards the area of vegetation. The change of vegetation is not only affected by global warming, but also affected by snowpack change and there is a negative correlation between vegetation change and snowpack change.

3.2 Causes of ecological changes

According to analyses based on satellite image data in this paper, there is a noticeable trend in ecological change, which is linked to global warming. Temperature data from China Meteorological Data Service Centre shows that the temperature gradually rises in Changbai Mountain under the influence of greenhouse effect. When the satellite images were acquired in 2014, the temperature in Changbai Nature Reserve was -19 to -5 ℃, while by the same time in 2023, it would be -16 to 0 ℃. Moreover, the average temperature in February has risen by one degree Celsius over the decade, which is a significant change in terms of temperature. As the Changbai Mountain region gets warmer, snow melting becomes inevitably more serious. Snowpack thickness is sensitive to changes in temperature. Due to climate change, the snowpack in China has changed dramatically in recent years, including the snow in Changbai Mountain. There is a strong positive correlation between global warming and snow melting.

Only by mitigating the greenhouse effect can scarce snow resources in Changbai Mountain be preserved.

As for vegetation change, some studies suggest that global warming promotes earlier spring phenology in plants, which means that vegetation growth shifts to an earlier date because of higher temperature [7]. Meanwhile some investigations have shown that the response of vegetation dynamics was stronger for precipitation than temperature, which indicates melting snow may contribute to vegetation cover growth [7]. The satellite images studied in this paper are acquired in late February in winter. The uplift in vegetation cover at this time of year does not necessarily indicate that the environment is improving, but rather that temperatures are getting higher and global warming is getting increasingly severe. In summary, global warming will bring forward the growth cycle of spring vegetation and provide more adequate external conditions such as water and soil for plant growing. The implementation of ecological engineering is also a significant driving force of increased vegetation coverage and has improved environmental quality of Changbai Nature Reserve [9]. Under the combined influence of these factors, there is a tendency for the area of vegetation to increase in winter.

In addition to global warming, anthropogenic activity is also an important factor in ecological changes. As Changbai Mountain is a nationally renowned tourist destination, frequent human tourism activities undoubtedly interfere with the local ecosystem. Due to the rise of tourism industry, the population of the areas around Changbai Mountain has exploded over the decades, which exacerbates the ecological disturbance. The hunting of wild animals and cutting down of rare plant species also have negative impacts on the environment. Most significantly, various anthropogenic activities will scale up carbon emissions and consequently aggravate the crisis of global warming. The change rate of snowpack calculated in 3.1 has already indicated the seriousness of snow melting problem and the necessity to take measures.

3.3 Measures to counteract the issue of snow melting

The research in this paper discovers that the issue of snow melting is becoming increasingly severe due to global warming. To alleviate this problem, a number of measures need to be taken in Changbai Nature Reserve. First of all, plants are an efficient, sustainable solution for alleviating climate change impacts [10]. Some studies have shown that cover crops can be used to mitigate and adapt to climate change due to their ability to reduce greenhouse gases and change surface albedo [11]. By planting and maintaining beneficial plant species, greenhouse gas emissions are cut down and biodiversity can be restored, ultimately mitigating global warming. Secondly, it is necessary to further reduce the use of fossil energy sources such as coal. What's more, stricter controls and restrictions on tourism activities are needed to minimize disturbance to Changbai Mountain ecosystem. Excessive hunting and logging should be strictly prohibited as well. Last but not least, it is essential to strengthen the management of the Changbai Nature Reserve and attach greater importance to the protection and restoration of biodiversity, which can alleviate the greenhouse effect by improving the ecological environment. All in all, snow melting can only be mitigated or even reversed if the effects of climate change and human activities are minimized.

4. CONCLUSION

Based on the analysis of Landsat8 satellite images using QGIS software and algorithms, changes in snowpack and vegetation around Changbai Mountain from 2014 to 2023 are detected. Over the last decade, the snowpack in Changbai Nature Reserve has undergone relatively severe melting, especially in the northwestern and central regions and on the edges of Changbai Mountain. The vegetation area in late February has a trend of growth but this does not mean that the vegetation in Changbai Mountain has really increased because global warming advances the growth cycle of plants, making green vegetation appear earlier. In order to verify whether the vegetation cover has increased, further research is needed, for example, analysis using satellite images in summer. There is a negative correlation between vegetation area and snowpack coverage. The causes of these ecological changes are diverse, mainly global warming and anthropogenic activities. To alleviate the problem of snow melting, plant ecosystem engineering, new energy development and stricter regulation of anthropogenic activities are urgently required in purpose of minimizing the impact of climate change and human activities. It is believed that in the future this study will help people to learn more about the ecological changes in Changbai Mountain, be aware of the severity of snow melting, and provide feasible suggestions and ideas for snow protection and restoration.

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