Comparison of different methods for monitoring glacier changes observed by Landsat images

View the article online for updates and enhancements.

Comparison of different methods for monitoring glacier changes observed by Landsat images

Q X MAN[1, 2], H D GUO[1], G LIU[1] and P L DONG[3]

[1] Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, 10094, China

[2] Department of Geography, East China Normal University, Shanghai, 200062, China

[3] Department of Geography, University of North Texas, Denton, Texas, 76201, USA

liug@ceode.ac.cn

Abstract. With the acceleration of global warming, it has been increasingly important to investigate the roles of glaciers as freshwater sources and sensitive indicators of climate change. Thus, it is of great significance to acquire accurate information on glacier changes. However, few papers have focused on the comparison of glacier monitoring methods. The objectives of this paper are to (1) present three methods for classifying glacier boundaries, including visual interpretation, ratio between TM channels 4 and 5 as well as Normalized Difference Snow Index (NDSI); (2) compare the tree methods to give users some advice on how to choose an appropriate method; (3) analyze the relationship between glacier change and the trends of precipitation and temperature. Current distribution and glacier changes since the 1980s were mapped using multi-temporal optical remote sensing data from the Landsat series. Thematic maps were then generated using three classification methods. Furthermore, GIS-supported investigation was also conducted to get information of glacier changes. Finally, the results were compared. The results indicated that: (1) the visual interpretation method is accurate but time-consuming and operator-dependent; (2) the ratioing method using channel 4 and 5 of Landsat image is fast, accurate but need too much follow-up work; (3) NDSI cannot classify snow and glacier very well, and it sometimes misclassifies snow into glaciers; (4) analyses of precipitation and temperature indicate that global warming is a major factor affecting changes of glaciers.

1. Introduction

Recently, global climate change has drawn increasing attention from scholars and governments. Mountain glaciers interact sensitively with climate and have been selected as one of the essential climate variables (ECVs) in the global climate observing system [1]. Furthermore, glaciers are the largest freshwater sources in the world. The area, length and mass changes of glaciers are widely recognized as the most reliable and easily observed terrestrial indicators of climate change [2]. Thus, classification of glaciers is of great significance.

Compared with the traditional methods which are always time-consuming, laborsome and sometimes unpractical spatially in isolated areas, remote sensing has been an excellent choice for analyzing glaciers in remote mountains and to monitor numbers of glaciers at the same time [3]. It can

save much money, time, manpower, material resources and also acquire information in isolated areas [4], Automatic classification of glaciers and GIS-based extraction of glaciers from Landsat TM data have been widely recognized as highly valuable methods for glacier mapping. Much of work has been done to analyze glacier changes using remote sensing techniques [5, 6]. A number of methods for mapping glaciers using multispectral data are available, such as visual interpretation [7], band ratioing [8] and Normalized Difference Snow Index (NDSI) [9]. However, few studies have focused on comparison of different glacier mapping methods and selection of an appropriate mapping method.

In this study, three monitoring methods were compared, and the relationships between glacier changes and trends of precipitation/temperature were also analyzed. Finally, recommendations for future studies are provided.

2. Study sites and methodology

2.1. Study area
Kashi (73°20′~79°57′E, 35°20′~40°18′N) lies in the western frontier of China which has a wide glacier distribution. In the east of Pamir, the area of glacier cover is approximately 2200km^2, while on the mountains of Muztagata it is up to 635km^2. Yecheng City was taken as the study area (Figure 1).
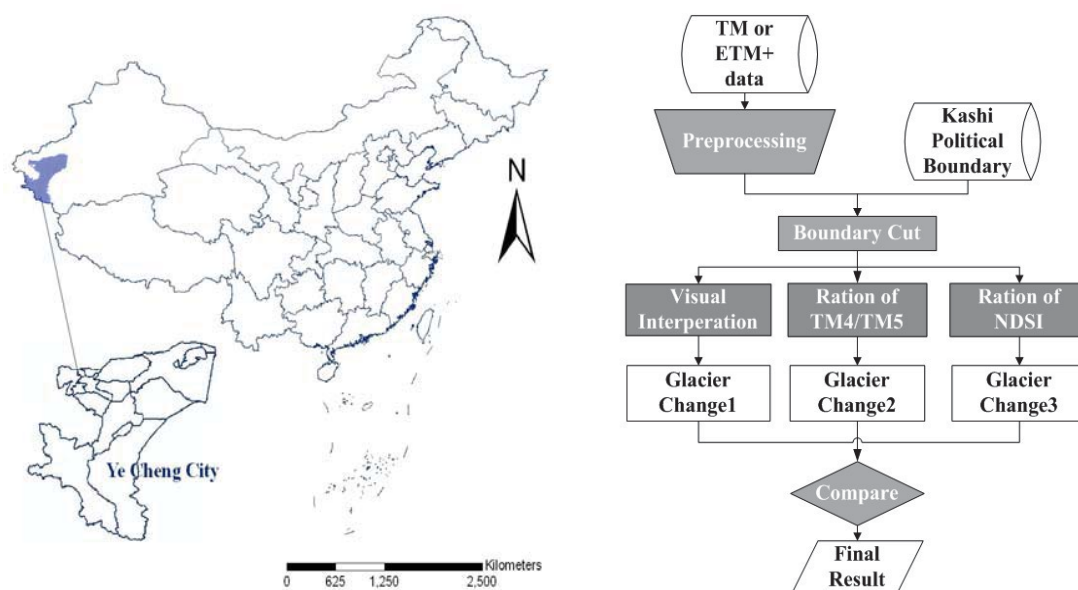

Figure 1. Study area and the flow chart of the study

2.2. Data and methodology
The analysis is based on multispectral optical satellite data. More detailed information can be found in Table 1. After pre-processing, three methods were used to acquire the glacier outlines.

Method 1: visual interpretation through on-screen digitizing. This is a traditional method for quantitative assessment of glacier change (area/length) [7].

Method 2: band ratioing. Band ratios have proven to be able to separate ice and snow zones over glacier surfaces effectively. Ratio images were computed from the raw digital numbers for bands TM4/TM5 [10]. Using a threshold value, ratio images were segmented into two classes: 'glacier' and 'other' [7]. Then a 3x3 median filter (3 by 3 kernel) was applied to the classified binary image to reduce noise and remove isolated pixels outside the glaciers [10].

Table 1. Overview of the satellite scenes applied in this study

Time	Path-Raw	Satellite	Sensor	Resolution（m）
2006/09/05	148-32	Landsat 7	ETM+	30
2006/07/26	149-33	Landsat 7	ETM+	30
2005/08/26	147-35	Landsat 7	ETM+	30
1989/10/09	147-35	Landsat 5	TM	30
1990/07/31	148-32	Landsat 5	TM	30
1990/07/06	149-33	Landsat 5	TM	30

Method 3: Normalized difference snow index (NDSI); NDSI is based on the difference between strong reflection of visible radiation and near total absorption of mid- infrared wavelengths (Hall et al. 1995 a). It can be determined using digital numbers (DN) of two TM bands from the following equation [9]. Normalized difference snow index (NDSI = (Red - SWIR)/ (Red + SWIR) or NDSI = (TM3 - TM5)/ (TM3 + TM5).

Finally, the three methods were compared in order to give users recommendations on how to choose an appropriate method. Here, we also took into account the changes in temperature and precipitation in the area from 1950 to 2010 when analysing glacier changes.

3. Comparison of methods and discussion

Here, we used visual interpretation as a standard to compare with the other two methods. The figures and tables below indicate that the results from band ratios are close to those from visual interpretation, whereas the results from NDSI differ from visual interpretation results greatly. From Table 2, it can be seen that during the recent twenty years, the glacier area increased 95 km^2 according to NDSI, whereas it decreased 61 km^2 and 76 km^2 according to the results from band ratio and visual interpretation respectively. Compared with the results from the other two methods, the NDSI results showed a much larger area of glacier cover. . A possible reason for this is that NDSI may not accurately separate snow from ice.
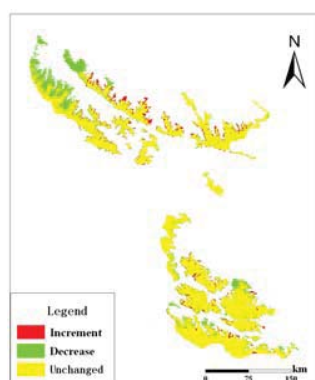

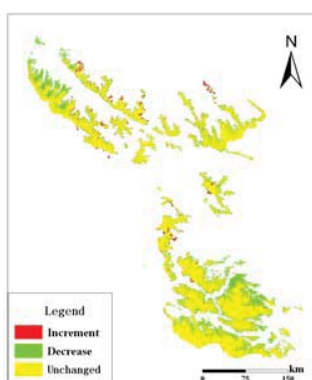**Figure 2.** Glaciers change in Yecheng City gotten by visual interpretation

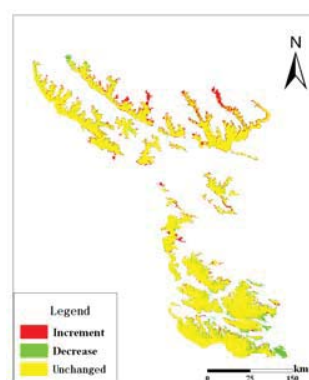**Figure 3.** Glaciers change in Yecheng City gotten by TM4/TM5

Figure 4. Glacier change in Yecheng City gotten by NDSI

In figures 2, 3, and 4 below, red represents increased glacier areas, green represents decreased glacier areas whereas yellow represents no change in the glaciers. From the figures, we can also conclude that changes generally take place at the glacier boundary, especially in the northwest and southeast part of the study area. There are several reasons for this. First, it may be caused by different

mapping methods. Second, it is difficult to map glaciers in long and narrow glaciers valleys due to the relatively low resolution of Landsat TM images.

Although field investigation is needed for more detailed accuracy assessment, it seems that visual interpretation is the most accurate method of the three methods. However, visual interpretation also takes more time than the other two methods, and depends on operators' experiences. Band ratio method is quick and its results are close to those from visual interpretation. However, band ratios do not separate urban areas from glaciers very well. Results from the band ratio method still need much follow-up processes. NDSI can separate snow, glaciers from other categories very well, but it does not separate snow from glacier very well.

It would be helpful to review the annual/summer mean temperature and precipitation of the study area when analyzing the results. The trends of the precipitation and temperature from 1950 to 2010 are shown in Figure 6. The increased temperature showed in Figure 6 suggests that global warming might be an important factor which caused glaciers to melt.

Table 2. Changes in glacier area in Kashi obtained from three different methods

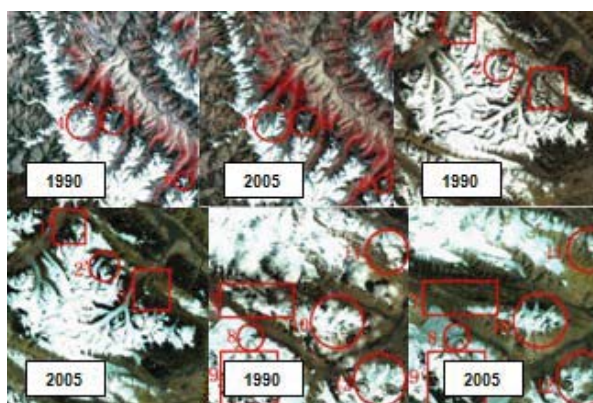| Method	Glacier area in 1990(km^2)	Glacier area in 2005(km^2)	Gain(km^2)	Lose(km^2)	change(km^2)
Band Ratio	2903	2842	214	275	-61
Visual Interpretation	2720	2644	147	223	-76
NDSI	2897	2992	384	289	95

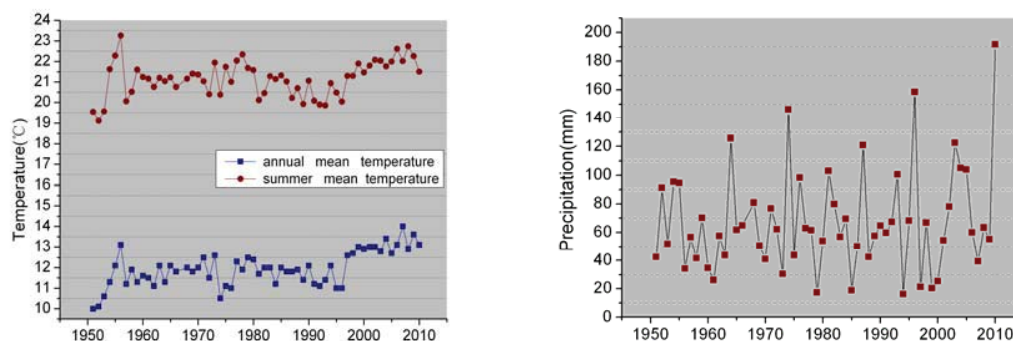**Figure 5.** Examples of glacier changes in three different regions

Figure 6. Changes in temperature and precipitation in Kashi from 1950 to 2010.

4. Conclusion and perspectives

Visual interpretation seems to be relatively accurate in mapping glacier changes, but it is time-consuming and depended on operators' experiences. Band ratio method is a robust and time effective approach compared with manual digitization. It also enables identification of snow and ice in shadows. However, selecting a proper threshold for the post-processing of band ratio images can be a problem. In some cases, band ratios do not separate urban areas from glaciers very well. NDSI can be also considered as a robust means of delineating glacial boundaries, but it does not separate snow from glacier very well which resulted in larger glacier areas compared with the results from the other two methods. In the future, more Landsat TM images should be processed to derive more accurate results, and field investigation and other data sources such as digital elevation models (DEM) and high resolution remote sensing images should be used for accuracy assessment.

References

[1] Oerlemans J 1994 Quantifying global warming from the retreat of glaciers *Science* **264** 243-245.

[2] Gruber S, Hoelzle M and Haeberli W 2004 Permafrost thaw and destabilization of Alpine rock walls in the hot summer of 2003 *Geophys. Res. Lett.* **31** L13504.

[3] Paul F, Huggel C and Kääb A 2004 Combining satellite multispectral image data and a digital elevation model for mapping debris-covered glaciers *Remote Sens. Environ.* **89** 10-518.

[4] Hall D K, Benson C S and Field W O 1995 Changes of glaciers in Glacier Bay Alaska, using ground and satellite measurements *Phys. Geog.* **16** 27-41

[5] Bishop M P, Kargel J S and Kieffer H H 2000 Remote-sensing science and technology for studying glacier processes in high Asia *Ann. Glaciol.* **31(1)**: 164-170.

[6] Ventura A D, Rampini A and Rabagliati R 1987 Development of a satellite remote sensing technique for the study of alpine glaciers *Int. J. Remote Sens.* **8(2)**: 203-215.

[7] Paul F, Huggel C and Kääb A 2004 Combining satellite multispectral image data and a digital elevation model for mapping debris-covered glaciers *Remote Sens. Environ*. **89(4)**: 510-518.

[8] Bayr K J, Hall D K and Kovalick W M 1994 Observations on glaciers in the eastern Austrian Alps using satellite data *Int. J. Remote Sens.* **15** 1733-1742

[9] Salomonson V V 2006 Development of the Aqua MODIS NDSI fractional snow cover algorithm and validation results *IEEE Geosci Remote S.* **44(7)**: 1747-1756.

[10] Andreassen L M, Paul F and Kääb A 2008 Landsat-derived glacier inventory for Jotunheimen, Norway, and deduced glacier changes since the 1930s *Cryosphere* **2(2):** 131-145.