

CHANGE DETECTION OF MOUNTAIN GLACIER SURFACE USING AERIAL AND SATELLITE IMAGERY: A CASE STUDY IN IRAN, ALAMCHAL GLACIER

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ABSTRACT:

Glaciers are important components of Earth's natural system and of human environment, and are therefore obvious targets for mapping and monitoring. They serve as sensitive indicators of climate change. The surface topography of mountain glaciers is often subject to continuous spatio-temporal changes due to glacial phenomena. Hence, monitoring glacier changes not only can provide useful information on the glacial phenomena, but it also can reflect the effects of global warming on the dynamics of ice-masses. In Iran, monitoring glaciers is of significant importance, due to the fact that a considerable portion of portable water is supplied by natural glaciers. Five main glacier zones have been identified in Iran of which the focus of this study would be on Alamchal glacier. Various measurement techniques can be applied in order to derive metric information of surface deformation and flow velocity. For this study, Optical image cross-correlation technique was chosen. In general, glacier surface deformation measurement studies are conducted either in short-term or long-term time interval. Satellite Radar Interferometry has proved to be adequate enough for measuring small displacements up to a few tens of cm on cloud covered areas over a short time. However on longer time intervals, interferometry is no more adequate. Long-term monitoring of glacier surface changes due to environmental factors can be used to assess the status of glacier reservoir. In the present work, changes of Alamchal glacier have been measured over a long period using aerial and optical satellite imagery.

1. INTRODUCTION

In recent decades, a spectacular retreat has been observed on most of the monitored glaciers. If this evolution is confirmed in the coming years, it will have some important consequences in terms of water resources, economical development, and risk management in the surrounding areas. Up to now, only a few number of the existing world mountain glaciers have been monitored, mostly by ground measurements, which often provide information only once or twice a year at a few points. Because of the difficulty of reaching high-altitude glaciers in risky mountainous areas, acquisition and processing of remotely sensed data should provide more information to improve glacier monitoring (E. Trouvé et al., 2007)

A high percentage of Iran's portable water is supplied by natural glaciers, therefore monitoring glaciers are of great importance. According to parameters proposed for glacier classification by GLIMS, Iran's glaciers fall within the category of mountain glaciers, Glaciers adhering to mountain sides.

Based on geological structure, Iran's glaciers are divided into two groups: 1) Granite glaciers 2) Karstic glaciers.

The glaciers in Alamkuh and Sabalan regions and around Damavand summit have the Granite structure, whereas Oshtoran kuh and Zard kuh glaciers are karstic.

To understand the dynamics of glaciers accurate displacement measurements are needed. Such measurements contribute to a better knowledge of the rheological parameters controlling the flow of glaciers. They are important to monitor icefalls, glacier surges (Fischer et al., 2003), and glacier hazards (Ka'ā'b et al.,

2003). They can also detect ice-velocity changes caused by global warming (Rignot et al., 2002). Differential Global Positioning System (DGPS), ground surveys, synthetic aperture radar interferometry (InSAR), and optical image cross-correlation are the main ways to determine glacier displacements. The first two methods are the most accurate but present some severe limitations for the monitoring of mountain glaciers. Even with the advent of the DGPS, it remains difficult and time-consuming to perform regular ground-based surveys of glacier flow (E. Berthier et al., 2005)

2. STUDY SITE

Alamchal glacier is located in the western part of the Elburz Mountains (Iran), in the region of the Takht-e Sulaiman massif. Its geographic coordinates are lat. 36°22' N., long. 50°55' E.. The highest peak of the massif, Alam kuh (4,840 m), is the second highest peak in Iran.

The south-north oriented glacier occupy an area of about 3 km². It spans from 3700m above sea level to 4250m. Almost the entire surface is covered by moraines 0.5 to 1.5m thick.

The test site is suitable for investigating the potential of remotely sensed data to monitor glacier activity for several reasons such as the following:

- *Complex surface cover* : The glacier surface is a mixture of snow, ice, and rocks

- *Data availability* : The existence of various data sets from spaceborne to airborne sensors ,which are acquired in different time intervals ,and ground measurements ,which help in the data processing ,information fusion ,and validation of the final results .

3. DATA SOURCES

Remote sensing techniques are commonly used to determine glacier surface displacements. These techniques utilize microwave data and optical imagery .The focus of the present study is to use multi-temporal optical satellite imagery and aerial photographs .In order to measure surface displacement from multi-temporal imagery, the following conditions must be met:

- Surface features have to be detectable in at least two of the multi-temporal optical data sets in order to track them.
- The multi-temporal data sets have to be accurately coregistered.
- The spatial resolution of the image has to be finer than the displacements.

In this research ,High resolution satellite imagery including Quickbird image with 2,5 m spatial resolution , SPOT 5 panchromatic image (2.5m) acquired at the end of September are utilized along with six aerial photographs of 1:40000 scale.

4. METHODOLOGY

If the two images are correlated, the resulting offsets in the image lines and columns are the sums of the contributions from misregistration, topography, orbits, and attitude as well as the glacier-dynamics signal. To obtain a valid measurement, we must remove all the contributions except the glacier flow (E. Berthier et al., 2005).

4.1 Optical satellite imagery

In order to measure glacier displacement map ,Spot 5 and multi-spectral Quickbird images respectively acquired at September 2003 and 2005 from study site are used .In the first step,for accurate change detection ,images must be radiometriclly normalized. Afterwards,performing image to image co-registration is a necessary step to provide a solid base for image matching and change detection analysis.

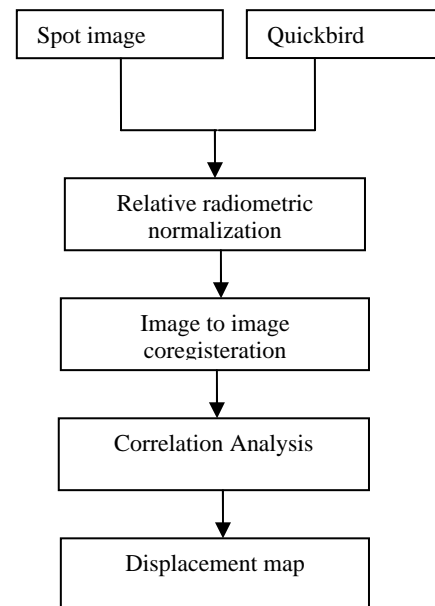


Figure. 1: Flowchart of the methodology followed to measure the surface displacements

4.1.1. Radiometric normalization

The first step of using multi-temporal satellite imagery in this procedure is to perform normalization so that they share the similar radiometry ,one of the conditions for an accurate displacement computation.

Ground reflectance determination from satellite imagery requires, among other things, an atmospheric correction algorithm and the associated atmospheric properties at the time of image acquisition. For most historical satellite scenes such data are not available and even for planned acquisitions or they may be difficult to obtain.In this case a relative normalization using the radiometric information must be performed .In this work ,images were first normalized by ENVI4.4 software using IAR reflectance method. Thereafter accurate relative normalization procedure was conducted utilizing time-invariant objects such as shelter for climbing groups.

4.1.2. Co-registration of multi-temporal satellite imagery

A critical requirement in change detection applications is that multitemporal images must be co-registered accurately. In this study, an image to image co-registration was carried out with a sub-pixel resulting RMSE of about 0.039 pixel.

4.2 Airborne photographs

4.2.1 DEM & ortho-photo generation

As mentioned earlier ,six aerial photos are used in this research. In order to generate DEM, firstly ground control points for photogrammetric processing were acquired through a Bundle Block Adjustments Aerial Triangulation. The DEM was produced using VirtozouNT photogrammetric software. Thereafter ortho image mosaic of the entire area was generated.

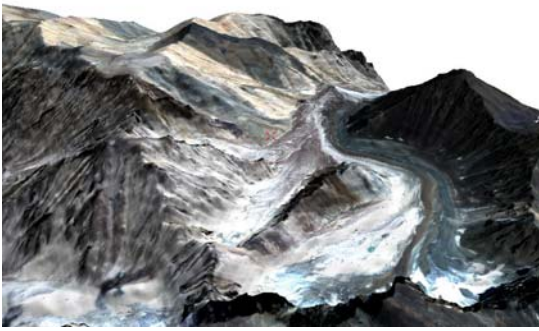


Fig. (2): 3D view of glacier with DEM and Quickbird image color composite (3,2,1)

4.3 Displacement computation using cross-correlation of multi-temporal imagery

In this work ,a pixel-based image matching approach is used to derive metric information on glacier displacement .Two well co-registered orthoimages are matched through correlation analysis. The general principle of offset computation by correlation is the following: around every reference image point, for which one wants to compute the local offset with a secondary image, a so-called rectangular “vignette” is constituted, centered on the reference point. Having a rough knowledge of the local offset, we can center the search on the secondary image around the estimated position. We iteratively build a small vignette on the secondary image, which has the same size as the primary one , and which travels through an area called “research area” .The size of this research area is related to the uncertainty on the position in the secondary image(H.Vadon et al.,2001).

In order to measure correlation rates, we used weighted correlation co-efficient which is calculated as follows :

$$\rho_{st} = \frac{\sum_{i=1}^n \sum_{j=1}^m w(x_i, y_j) (g^s(x_i, y_j) - \bar{g}^s) (g^t(x_i, y_j) - \bar{g}^t)}{[\sum_{i=1}^n \sum_{j=1}^m w(x_i, y_j) (g^s(x_i, y_j) - \bar{g}^s)^2 \cdot \sum_{i=1}^n \sum_{j=1}^m w(x_i, y_j) (g^t(x_i, y_j) - \bar{g}^t)^2]^{\frac{1}{2}}}$$

First, correlation rates are computed for every vignette position in the research area. The best correlation corresponds to the position in the research area of the secondary image that maximizes the radiometric resemblance between the two vignettes. Then sub-pixel search with similar principle is iteratively performed until the required localization accuracy is reached and afterwards offset computation is done(H.Vadon et al.,2001).

After correlation analysis, the displacement map is produced.

5. RESULTS AND DISCUSSION

Fig. (3) Shows the horizontal displacement of the ground surface of Alamchal glacier .On this glacier , no overall displacement measurement had ever been performed.

This research shows a significant retreat in glacier front over a long period of time, indicating a decrease in glacier reservoir. Furthermore, the results demonstrated the occurrence of major surface displacements in the central region of the glacier due to both accumulation and ablation.

In the course of this study, some problems appeared. No displacement could be measured for areas in shadows and at high elevation on the accumulation zone, even with a low gain, the noise remained noticeable.

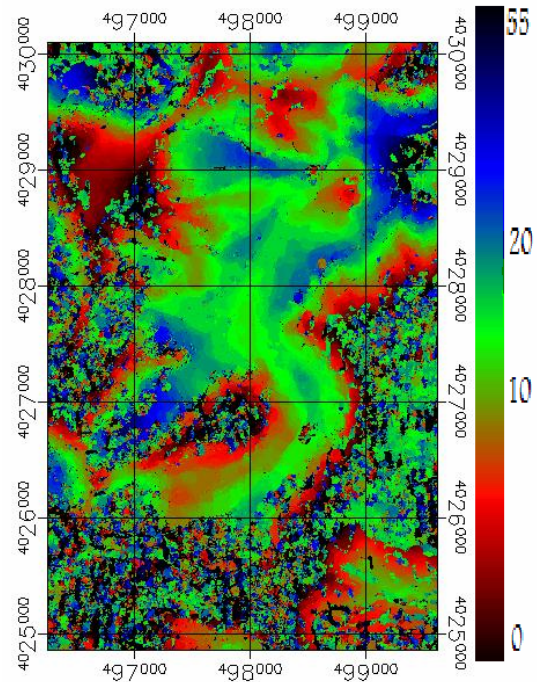


Figure. (3): displacement image of glacier displacement

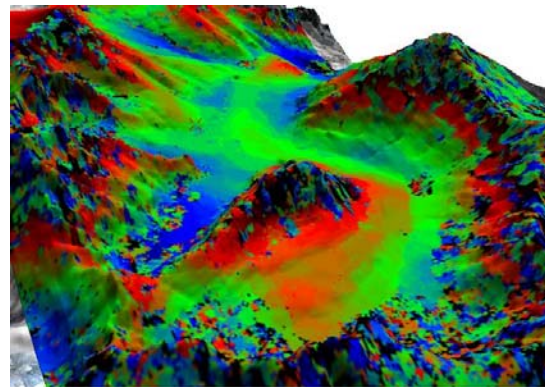


Figure. (4): 3D view of displacement of glacier

The apparent displacement of the shadows is negative and oriented mainly parallel to image lines. The strength of the correlation is weakened by a secondary correlation peak due to the shifted shadows. However, on the glaciers, this shadowing effect does not cause a systematic error in our measurements. Shadows are only created by the surface debris and the surrounding mountains. The best way to ensure a limited bias is to retain only the measurements with the highest correlation coefficient. The effect could be larger for other applications such as landslides, especially if images are acquired during different seasons.

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