Remote Sensing of Environment 130 (2013) 233–244

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Heterogeneous mass loss of glaciers in the Aksu-Tarim Catchment (Central Tien Shan) revealed by 1976 KH-9 Hexagon and 2009 SPOT-5 stereo imagery

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ARTICLE INFO

Article history:
Received 31 May 2012
Received in revised form 16 November 2012
Accepted 17 November 2012
Available online 29 December 2012

Keywords:
DTM
Change assessment
Geodetic glacier mass budget
Central Tien Shan
SPOT-5
KH-9 Hexagon

ABSTRACT

The meltwater released by the glaciers in the Aksu-Tarim Catchment, south of Tomur Peak (Central Tien Shan), feeds the Tarim River which is the main artery for the oases at the northern margin of the Taklamakan desert. The correct modeling of the contribution of the glaciers meltwater to the total runoff of the Tarim River is hampered by the lack of mass balance data. Multi-temporal digital terrain models (DTMs) allow the determination of volume changes for large samples of glacier. Here, we present the mass changes for 12 glaciers using 1976 KH-9 Hexagon, 2000 SRTM3 and 2009 SPOT-5 datasets. The results show that most of the glaciers have been losing mass since 1976. The largest glaciers, Koxkar and West Qongterang, lost -0.27 ± 0.15 m w.e.a^{-1} and -0.43 ± 0.15 m w.e.a^{-1} between 1976 and 2009, despite thick debris cover. However, some smaller glaciers show mass gain at their tongues indicating glacier surges. Using SRTM3 data the volume gain of Qinbingtan Glacier No. 74 could be dated to the time period 1999–2009. The overall mass budget of -0.33 ± 0.15 m w.e.a^{-1} (for 1976–2009) of the investigated glaciers is within the variability range of the global average. However, in the recent years (1999–2009) a slightly decelerated mass loss of -0.23 ± 0.19 m w.e.a^{-1} could be observed.

1. Introduction

The Tarim River in the northwestern part of China is nourished to a high degree by glacier meltwater (Kaser et al., 2010; Mao et al., 1998) and he is the main artery for the oases at the northern margin of the Taklamakan desert. Changes in glacier melt can therefore alter the runoff of the whole Tarim River. Several studies have reported an accelerated glacier retreat and mass loss in the Tien Shan Mountains (Kutuzov & Shahgedanova, 2009; Narama et al., 2010; Sorg et al., 2012; Wang et al., 2009; Xie et al., 2007). Runoff measurements for Aksu River indicate in general an increase of runoff (Fan et al., 2011). However, at Xehera station a deceleration of annual runoff in the last decade comparing to the decades before 2000 were measured (Yu et al., 2011). The contribution of glacial melt, however, is fuzzy and hard to quantify.

Therefore, changes in glacier coverage and mass in the Tien Shan Mountains and in Central Asia should be monitored continuously. While area and length changes can be derived relatively easy from remote sensing imagery (Bhambri & Bolch, 2009; Bolch et al., 2010; Paul et al., 2004; Zhou et al., 2009), only changes in glacier thickness can directly be related to glacier mass changes and the hydrology.

Multi-temporal digital terrain models (DTMs) were shown to be suitable to assess glacier mass changes (Aizen et al., 2006; Berthier et al., 2007; Bolch et al., 2011; Miller et al., 2009). However, missing reliable ground truth in remote mountainous areas hamper the generation of precise elevation datasets. Therefore, several studies related to glacier thickness change calculations rely on ancient topographic maps (Wang et al., 2009) or recent satellite datasets with appropriate sensor and orbit parameters. SPOT-5 stereoscopic imagery, in particular, was proved to be suited to monitor glacier elevation changes (Berthier & Toutin, 2008).

The declassification of Corona and KH-9 Hexagon reconnaissance satellite imagery in 1995 and 2002 offers a huge potential for DTM generation representing conditions in the past (Pieczonka et al., 2011; Surazakov & Aizen, 2010). In comparison to Corona imagery, KH-9 Hexagon offers the advantage of larger footprints without complex panoramic distortions while preserving a high spatial resolution of 6–10 m which is only slightly lower to that of Corona imagery. Working with multi-temporal DTMs necessitates a proper co-registration of all used datasets. Moreover, elevation biases have to be accounted for in order to avoid over- or underestimations of volume changes (Nuth & Kääb, 2011; Pieczonka et al., 2011).

Besides for the Ak-Shirak Range (Aizen et al., 2006) there exists no comprehensive investigation of glacier elevation changes in the Tien Shan (Sorg et al., 2012) including the region south of Tomur Feng (7439 m a.s.l., Kyrgyz name: Jengish Chokusu; Russian name: Pik

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0034-4257/$ – see front matter
http://dx.doi.org/10.1016/j.rse.2012.11.020

Pobedy), which is one of the largest glacierized areas in the Central Tien Shan. Koxkar Glacier (also: Keqicar Glacier), solely, was investigated revealing a surface lowering of 0.5–1.5 m a^{-1} by analyzing 1981 and 2004 GPR measurements (Xie et al., 2007). These results shall be used to classify the results achieved by satellite stereoscopy.

The size of our study region is about 3000 km^2 located between 500 and 7439 m a.s.l.; ~800 km^2 of it are covered by glaciers. The most comprehensive and detailed investigated glacier in the study region with a width of 1–3 km, a length of more than 20 km and an area of 62 km^2 is Koxkar Glacier. Other large glaciers are Tomur Glacier and West Qongterang Glacier with heavily debris-covered glacier tongues and areas of 327 km^2 and 114 km^2 (Fig. 1, Table 1).

Therefore, one aim of this study is to calculate glacier thickness changes for a large sample of glacier south of Tomur Feng, Xingjiang Uighur Autonomous Region. Secondly, we want to show the suitability of KH-9 Hexagon stereoscopic images to derive glacier volume changes and to discuss the advantages and disadvantages of this data source.

2. Remote sensing datasets

Regarding the size of the study area and with respect to the desirable time span of more than 40 years which wanted to be covered by optical stereo satellite imagery we used KH-9 Hexagon and SPOT-5 stereo satellite images captured in 1976 and 2009 (Table 2). Glacier thickness investigations based on multi-temporal stereo satellite imagery necessitate, in dependency upon spatial resolution of input datasets, horizontal and vertical ground truth for GCP measurements. In remote mountain areas there is often a lack of precise ground truth datasets. Therefore, Landsat ETM+, SRTM3 and ICESat GLA 14 altimetry data were utilized as horizontal and vertical references.

2.1. KH-9 Hexagon

KH-9 Hexagon, the successor of the Corona missions, operated between 1971 and 1986 where 19 successful missions were accomplished (Center for the Study of National Reconnaissance, 2011). The sensor used a frame mapping camera similar to the Large Format Camera (LFC) with a 23×46 cm frame and a focal length of 30.5 cm (Surazakov & Aizen, 2010). The images of our study site were delivered by the USGS with a scan resolution of about 14 µm. Due to the long time of storage the image quality is impaired by age related mechanical damages like scratches. Additionally, we noticed vertical stripes which are well known artifacts in Corona imagery. Galiatsatos et al. (2008) traced them to the digital scanning where dust particles or calibration errors can affect the radiometric precision of a CCD scanner. Subsequently, radiometric discontinuities between successive matrix positions can occur.

2.2. SPOT-5

SPOT-5 was launched in May 2002 and is equipped with a HRS sensor and a HRG sensor; both offer stereoscopic capabilities. SPOT-5 HRS

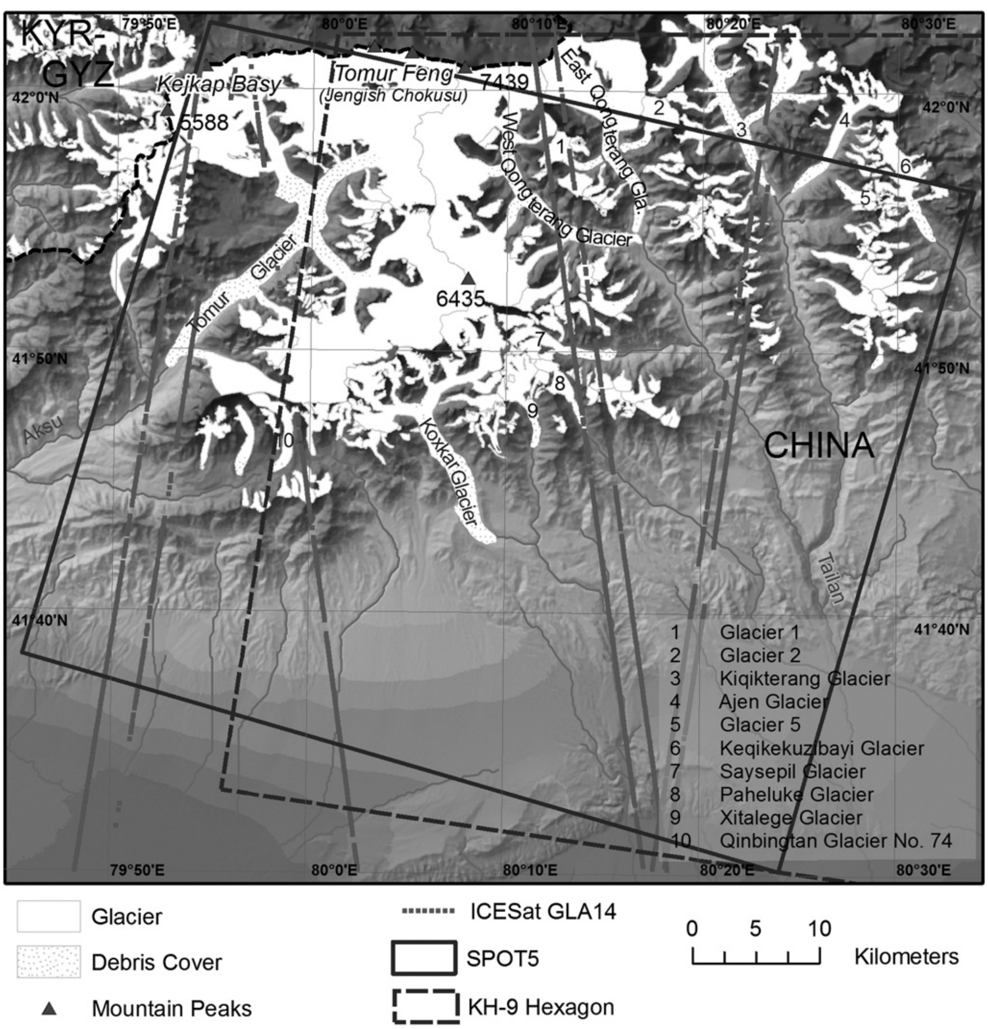

Fig. 1. Study area; names and location of the largest glaciers, coverage of the utilized satellite data. Background: SRTM3 GGIAR Vers. 4; glacier outlines based on 2009 SPOT-5 data.