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Glacier status during the period 1973–2014 in the Hunza Basin, Western Karakoram

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ABSTRACT

Glacier changes in the Karakoram have shown a complex pattern since the recent decades with the coexistence of advancing, retreating, and stable glaciers, but the mechanisms driving these changes remain, for the most part, unclear. We examined the changes in glacier length, area, and elevation in the Hunza Basin of the upper Indus River region, western Karakoram, using CORONA remote sensing data, Landsat MSS/TM/OLI imagery, SRTM digital elevation model (DEM), and GLAS/ICESat altimeter data. We delineated 108 glaciers within the study area. The total area of these glaciers decreased 28.86 km^2, or 1.36%, from 2115.48 km^2 in 1973–2086.62 km^2 in 2014. The most significant reduction in ice coverage occurred between 1992 and 1998, when glaciers retreated on average at a rate of −2.97 km^2/yr (0.85% of the total coverage measured in the 1970s). In contrast, many glaciers advanced from 2008 to 2014 and glacial coverage increased by 0.19 ± 0.00 km^2. In comparison to fast retreating glaciers in the Hindukush and the Trans-Himalayan regions, the glaciers in the Hunza Basin are relatively stable. The topographical characteristics and the size of the glaciers have direct impacts on glacial changes in the Hunza Basin. Specifically, significant changes occurred mainly below 5500 m above sea level, glaciers retreated more extensively on steep slopes than on gentle slopes, and small glaciers retreated relatively faster than large glaciers. The overall pattern of glacial retreat is related to the warming trend in summer temperature, whereas the relative stability of glaciers in the Hunza Basin, as well as their recent advance (2008–2014), is likely driven by increasing autumn and winter precipitation.

1. Introduction

Global climate change, along with its consequent impact on water resources, has become a concern throughout the world. Glaciers are a major source of fresh water, especially in high alpine regions. They are sensitive to climate change and are one of the major indicators of local and regional climate change. Combined temperature records from both land and ocean surfaces show a warming of 0.85 °C globally from 1880 to 2012 (IPCC 2013). The majority of glaciers worldwide have been retreating since the middle of the 19th Century in response to global warming (Bolch et al., 2012; IPCC, 2013; Bajracharya et al., 2015). Since the recent decades, decreasing glacial coverage has exerted a direct impact on sea level rises and this impact is likely continuing in this century (Zhao et al., 2014; Huss and Hock, 2015). In addition, this phenomenon is also affecting regional water cycles and the availability of water resources (Immerzeel et al., 2010; IPCC, 2013).

The Karakoram is located on the southwestern margin of the Tibetan Plateau, a continental region commonly referred to as the "Third Pole" (TP) because of the enormous amounts of perennial snow and ice stored in its high altitudes (Yao et al., 2012b). Glacial retreat in this region not only has a potential impact on atmospheric circulation patterns, but also affects millions of people in South Asia who rely on glacier meltwater for agricultural irrigation, power generation, and drinking water sources. Glacial retreat has also induced a rise in lake and reservoir levels, and subsequently increased the risk of flooding downstream. Over the recent years, the majority of glaciers on the Tibetan Plateau and its surrounding mountains have been retreating (Yao et al., 2012a; Sarıkaya et al.,

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2013; Neckel et al., 2014), whereas glaciers in the Karakoram have either been stabilized, or re-advanced (Hewitt, 2005; Bishop et al., 2008; Bolch et al., 2012; Gardelle et al., 2012, 2013). Glacial advances and/or surges in the Karakoram have been attributed to its diverse climatic processes, complex topography, and debris cover, causing a positive mass balance anomaly (Hewitt, 2005; Quincey et al., 2011; Bocchiola and Diolaiuti, 2013). However, mechanisms behind this unusual behavior are still poorly understood. Investigating glacial changes in the Karakoram is therefore of critical importance in understanding how glaciers respond to climate change in different climate and topographic settings, and aiding implement a more competent, efficient, and effective management of water resources in downstream areas (Qureshi, 2011).

The Hunza Basin is one of the areas in the Karakoram where glacier changes have been rarely studied. In this paper, we investigate changes in glacier length, coverage, and surface elevation over the past four decades, and attempt to identify the climatic and topographical controls on these changes.

2. Study area

The Hunza Basin (36°31′N, 74°52′), located in the western Karakoram, is one of the important sub-basins of the Upper Indus Basin (UIB) (Fig. 1). It is the southern part of the Eurasian tectonic plate, sandwiched between the Eurasian Plate and the Indian Plate. To the south is the Kohistan Arc, with its northern margins sutured to respective plates by the Main Karakoram Thrust (MKT) zone and the Main Mantle Thrust (MMT) zone (Searle et al., 1989; Kazmi and Jan, 1997). Our study area dissects the NW–SE trending Karakoram in a NE–SW direction. Steep cliffs and narrow valleys are typical characteristics in this region with comparably great vertical height difference over a short horizontal distance (Goudie et al., 1984). The elevation gradually increases from south to north from 1391 m to 7850 m above sea level (a.s.l.). The region is influenced by the Indian Summer Monsoon (ISM) and the Westerlies (Owen and Elias, 2007). The basin covers an area of 13,718 km^2 and includes the Hunza, Naltar, Nagar, Shimshal, and Chapursan valleys, and several high peaks, such as Mt. DistaghilSar (7885 m a.s.l.), Mt. BaturaSar (7795 m a.s.l.), and Mt. PassuSar (7476 m a.s.l.). The high peaks are distributed in the southeast to northwest direction surrounded by large glaciers, including the Hispar Glacier (with an area of 349 km^2), and the Batura Glacier (with an area of 226 km^2). Most glaciers are valley glaciers. These glaciers are generally classified as continental climatic type, but some have maritime features (Hewitt, 2014). The equilibrium line altitude (ELA) in the Hunza Basin has been estimated to fall between 4500 m and 5500 m a.s.l. (Hewitt, 2011, 2014; Scherler et al., 2011; Kaab et al., 2012; Gardelle et al., 2013). The Hunza Basin is located in subtropical climatic zone with mean annual temperature of 2.8° C– 6.5° C in the valleys between 2810 m and 3669 m a.s.l. The precipitation is mainly controlled by the Indian monsoon and the westerlies, with a mean annual precipitation between 180 mm and 690 mm in the valleys.

3. Data and methods

3.1. Data selection

The data we used in this study include Landsat MSS/TM/OLI imagery, CORONA imagery, Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM), and Google Earth imagery (Table 1). Most data, except Google Earth imagery, were collected from the United States Geological Survey (USGS; http://earthexplorer.usgs.gov) and the Global Land Cover Facility (GLCF) at the University of Maryland (http://glcfapp.glcf.umd.edu). SRTM DEM data were initially acquired in February, 2000 and a 30 m resolution of this dataset in our study area was recently available from the USGS. The Landsat scenes with minimum cloud cover (<10%) and minimum snow cover during the ablation season from

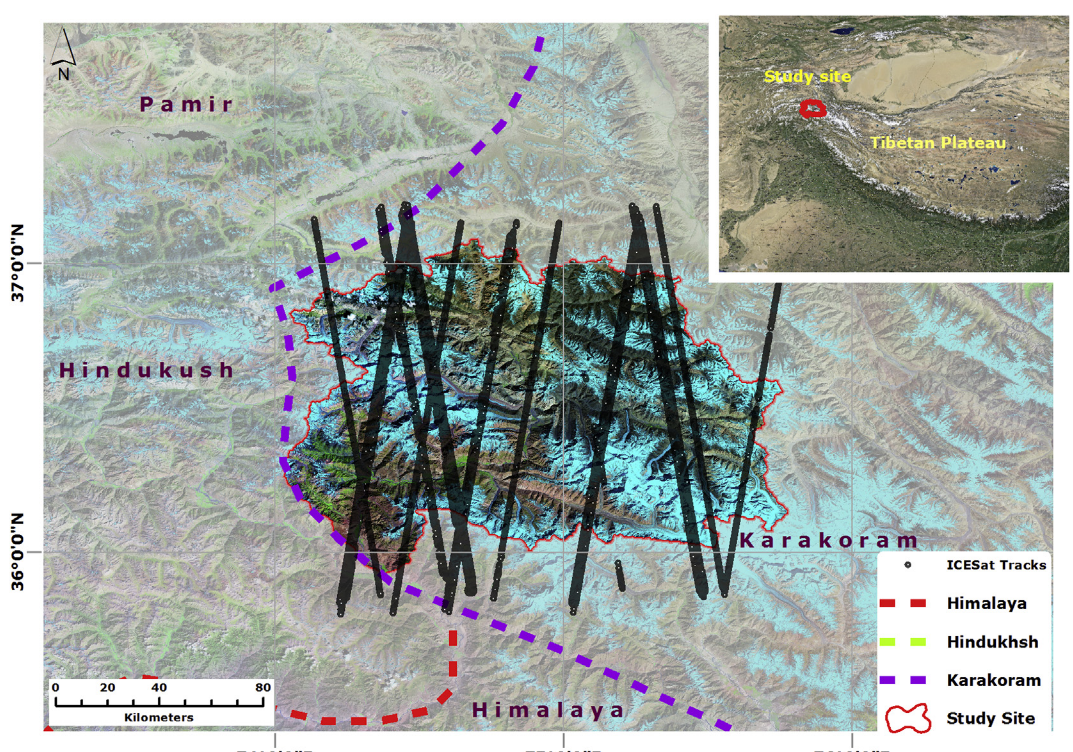

Fig. 1. Geographical location of the study area. Black lines represent ICESat coverage over the study area.