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Invited review article

Glacier variations in the Northern Caucasus compared to climatic reconstructions over the past millennium

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ABSTRACT

In the Northern Caucasus, glacier and climatic variations over the past centuries remain insufficiently documented. In this review, we summarized the high-resolution information on glacier and climate fluctuations in the region for the past millennium and provided a synthesis of these two lines of evidence with respect to regional climate change. The key areas considered in the paper are the Elbrus area, the Teberda and Arkhyz valleys in the Western Caucasus and the Cherek Bezengiisky and Tsey valleys in the Eastern Caucasus, where the most paleoclimatic evidence has been retrieved.

We focused on the fluctuation records of the ten glaciers that are best documented. To reconstruct changes in glacier length in the past, we used aerial photos, optical space images, repeated photographs and old maps. The ages of moraines were defined with the help of instrumental records, historical images, old maps, and tree-ring dating. Lichenometry was used as a supplementary tool to determine the relative ages of glacial landforms. We reviewed the collection of control points used for the lichenometric curves and determined the time limit of potential use of this method in the Caucasus to be up to one millennium.

High-resolution tree-ring-based hydroclimatic reconstructions in the Northern Caucasus are presented based on the reconstruction of June–September temperature (1595–2012 CE), the mass balance reconstruction of the Garabashi Glacier (1800–2008 CE) and the runoff of the Teberda River (low-frequency variations) for May, July and August for 1850–2005 CE.

The synthesis of all the available paleoclimatic records revealed several distinct climatic periods. Evidence of a warm interval (traditionally referred to as the "Arkhyz break in glaciation") preceding the Little Ice Age (LIA) in the Caucasus is based on archeological, palynological, geochemical and pedological data. However, the conclusions concerning the duration and magnitude of this warming are still vague due to the low resolution of the data available and ambiguous interpretation of the evidence. The first LIA maximum glacier extent in the past millennium is poorly constrained. According to our data, it occurred prior to the year 1598 CE (tree-ring-based minimum age). Two other major phases of advances occurred in the second half of the 17th century CE and the first half of 19th century CE. General glacier retreat in the Northern Caucasus started in the late 1840s CE, with four to five minor readvances in the 1860s–1880s CE and three readvances or steady states in the 20th century CE (1910s, 1920s and 1970s–1980s). Since the last LIA maximum in the middle of the 19th century CE, most glaciers have decreased in length by more than 1000 m, and the rise in the elevation of the glacier fronts has exceeded 200 m. The glacier advances correspond to summer temperature minima and are generally coherent with the reconstructed mass balance of the Garabashi Glacier. A comparison of a tree-ring-based summer temperature reconstruction in the Northern Caucasus with detailed reconstructions of summer temperature and glacier fluctuations in the Alps shows a pronounced agreement between the records and supports the similarity between the patterns of climatic and glacier variations in the two regions.

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1. Introduction

The glacier and climate variations in the Northern Caucasus over the past centuries are still poorly known and documented in comparison with many other mountain regions around the world (e.g., Solomina et al., 2015). Recently, some progress has been achieved in the field of mapping and dating the glacial moraines using remote sensing techniques, tree rings and, to some extent, ^{14}C dating (Zolotarev, 2009; Zolotarev and Kharkovets, 2012; Baume and Marcinek, 1998; Laverov, 2004; Solomina et al., 2012a,b, 2013; Bushueva, 2013), as well as tree-ring-based quantitative reconstructions of hydrometeorological conditions (Dolgova and Solomina, 2010; Matskovsky et al., 2010; Dolgova, 2016). These results are mostly published in Russian and are therefore not easily accessible to the broad international community. In this review, we aimed to summarize the high-resolution information on glacier and climate fluctuations in the Northern Caucasus for the past few centuries, to provide a synthesis of these two lines of evidence of regional climate change and to consider these changes in the broader chronological context of the past millennium.

In accordance with this goal, we divided the review into three parts: 1. Glacier variations over the past 500 years; 2. Tree-ring-based hydroclimatic reconstructions for the same period; and 3. Synthesis of both lines of evidence with the addition of available low-resolution records, such as lake and peat sediments, buried soils, and sea level variations, in a longer temporal context.

In this paper we use the following approximate boundaries: ~950 to 1250 CE for the Medieval Warm Period (the same as Medieval Climatic Anomaly, or MCA) and ~1350 to ~1850 CE for the Little Ice Age (LIA) (IPCC AR5, 2013). However, when possible, we use the dates of events rather than these definitions.

2. Study area

The Caucasus Mountains are a vast elevated area south of the East European Plain and consist of two separate mountain systems — the Greater Caucasus and the Lesser Caucasus. This research focuses on the glacier and climate variations on the northern slope of the Greater Caucasus (within the territory of the Russian Federation) (Fig. 1).

The Caucasus Mountains are a high mountain chain located at the edge of the temperate and subtropical zones between the Black and Caspian seas. The Ancient Greeks included the Caucasus in "Skiphia Land" and were more interested in ethnology rather than the climate of the region. The Greek colonization of the Black Sea coasts in the 6th century BCE and the later campaigns of Alexander the Great (334–323 BCE) extended their knowledge of these regions. However, their descriptions of Skiphia remained sporadic and are not useful for paleoclimatic assessments. During the Medieval period, the coastal area of the Caucasus was under the influence of Byzantium (4th–late 8th centuries CE) and Genoa (from 13th century CE). The merchants and Christian missionaries penetrated inland and reached the valleys in the Northern Caucasus; however, their descriptions of this land remained very scarce. Historical records that contain some information on glaciers and climate and regular meteorological observations date back to 19th century, when the Caucasus were conquered by the Russian Empire (Lomakin et al., 2015).

The Greater Caucasus is the most elevated and extensive part of the Caucasus. This range is traditionally divided into Western, Central and Eastern parts with the mountains Elbrus (5642 m) and Kazbek (5047 m) as the demarcation points. At the same time, the terms Northern and Southern Caucasus are frequently used to refer to the corresponding macroslopes of the Greater Caucasus range. The Greater Caucasus range extends for 1100 km from west-northwest to east-southeast with a width varying from 30 km in the marginal parts to 180 km near Mount Elbrus.

The Greater Caucasus is a part of the Alpine geosynclinal belt. The mountain system of the Greater Caucasus is a complex mega-anticlinorium elevated structure divided my multiple linear and transversal faults. The oldest Precambrian and Lower Paleozoic bedrock is found in a relatively short segment of the middle part of the Greater and the Lateral ranges. The majority of the region is built up by Jurassic and Cretaceous rocks. Tertiary rocks are found on the foothills and within intermontane synclinal zone. Effusive rocks primarily build up volcanic cones of Elbrus and Kazbek.

The Greater range is continuous for its almost entire length, it includes several peaks above 5000 m (Shkhara — 5193 m) and in the central part goes down to 3000 m only in the ridge passes. The Greater range serves as a primary watershed of the river basins of north and south direction in the Western and Central Caucasus. The southern macroslope of the Greater Caucasus is generally shorter and steeper than the northern one and consists of a variety of separate minor ridges.

The relief of the Greater, the Lateral and the South ranges is substantially alpine with a variety of glacial landforms — cirques, trough valleys, karlings, and hanging valleys. Most of the cirques in the Central Caucasus are occupied by glaciers, while in the lower western and eastern parts glaciers are found only in separate cirques with favorable orientation.