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The evolution of debris mantling glaciers in the Stelvio Park (Italian Alps) over the time window 2003-2012 from high resolution remote-sensing data

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Abstract

Debris cover is a key parameter influencing glacier energy budget, and over the last decades, its expansion on mountain glaciers worldwide has been reported. Nevertheless, works dealing with the detection and mapping of quite continuous supraglacial debris and deep analyses aimed at identifying the temporal and spatial trends affecting glacier debris cover are still limited. In this study, we present a high-resolution detection and mapping of debris mantling glaciers in the Ortles-Cevedale Group in Stelvio National Park, Italy, based on high resolution aerial and UAV orthophotos.

Keywords

Glacier, debris cover, Stelvio Park, remote-sensing.

Introduction

One of the most evident effects of the ongoing climate change, and in particular of the global air temperature warming, is the intense area decrease of glaciers observed worldwide (IPCC 2013). Moreover, the glacier surface undergoes important physical changes, which have significant effects on high-elevation landscapes (OERLEMANS 2009): in particular, several authors have reported the areal expansion of supraglacial debris cover over the last decades in the major mountain ranges, including the Alps (KELLERER-PIRKLBAUER 2008). Glacier darkening is favored by the increased availability of debris in the area surrounding glaciers (REID et al., 2012). High-resolution mapping and analysis of the spatial and temporal evolution of supraglacial debris are complicated, but its knowledge of is relevant for the glacier mass and energy budgets and evolution (DIOLAIUTI et al. 2009). In fact, on the one hand fine and sparse debris is one of the main forcing factors of supraglacial albedo, increasing the ice melt rates (AZZONI et al. 2016). On the other hand, if supraglacial debris thickness is higher than a threshold value it may reduce ice melt rates (MATTSON & GARDNER, 1989). Different techniques, such as semi-automatic approaches based on medium-resolution remote sensing data, were developed to assess the occurrence and distribution of continuous supraglacial debris covers, however, the accuracy of these methods decreases analyzing small ice bodies such as the largest part of Alpine glaciers.

In this work, we propose a method to map and describe the supraglacial debris cover on glaciers in the Ortles-Cevedale Group through multi-temporal and high-resolution remote sensing data (aerial and UAV color orthophotos). These methods permitted us to analyze the evolution of supraglacial debris over the last decade, thus offering a novel approach to describe climatic-triggered surface processes affecting the evolution of high mountain environments. The focus of this research is the Lombardy Sector of the Stelvio Park, which includes the 51 glaciers, covering ca. 29.27 km² (SMIRAGLIA et al. 2015). These glaciers have significantly retreated over the past decades, losing about 40% of their area between 1954 and 2007.

Materials and Methods

We analyzed aerial color orthophotos (0.5 m resolution) acquired in 2003, 2007 and 2012. Glacier outlines were already available (SMIRAGLIA et al. 2015). The evaluation of supraglacial debris cover was performed by means of a supervised classification using the software ArcMap. In particular, we used the maximum likelihood classification to discriminate four different classes and form a signature file: debris, ice, snow, and shadow. Shadows were removed from subsequent analysis because it is not possible to investigate efficiently the surface below them.

We create different signature file for each orthophoto to avoid some classification problems caused by the different illumination conditions and we used a different classification scheme in relation to the two different lithologies outcropping in this area (micaschist and carbonates). To assess the accuracy of the supervised classification, we defined separate sets of random points and we manually checked the conformity between the values predicted by the supervised classification (i.e. debris, ice, snow, and shadow) and the ones observed in the orthophotos.

Results and Discussion

The analysis of the 2003, 2007 and 2012 orthophotos permit us to describe the characteristics of the debris cover for each year. In particular in 2003 debris covered 16.7% of the total glacier area, in 2007 22.5%, whereas in 2012 debris covered 30.1% of the total glacier area. These data highlighted a clear increase in debris cover on glaciers located in the Ortles-Cevedale Group in only 10 years (Tab.1).

	2003	2007	2012
TOTAL DEBRIS- COVERED AREA (km²)	5.28	6.59	8.15
AREA OF ALL GLACIERS (km²)	31.58	29.24	27.08
DEBRIS COVER (%)	16.72	22.54	30.10

Table 1: Surface features of all the glaciers located in the Ortles-Cevedale Group in the time frame 2003-2012.

On the Forni Glacier ablation tongue, where we extended our analysis also to 2014 and 2015, the debris cover was 26.7% in 2003, 32.4% in 2007, 51.1% in 2012, 48.2% in 2014, and 48.1% in 2015.

The accuracy of these data are confirmed by the error assessment: the overall precision of this supervised classification resulted in 0.87, but the precision of debris classification (the ability of the classification to detect the differences between debris and other surfaces) was higher, up to 0.95.

Debris does not homogeneously cover the glacier surfaces: in fact, some sectors of glaciers are totally covered (the medial or lateral moraine ridges) and it is more common on small glaciers, compared to the large ones. In particular, on glaciers with a surface smaller than 0.10 km^2, the debris cover is 70.9%; conversely, the largest ones exhibit a debris cover of about 17% of their entire surface. We can explain the larger debris cover on the smallest ice bodies considering their geomorphological settings; in fact, these glaciers are predominantly located in small cirques or in narrow valleys, often at the foot of steep rock walls where the debris availability is large. Moreover, their dynamics are limited and the rate of debris transport along the glacier is very low. Conversely, the larger glaciers are characterized by wide accumulation basins, where the presence of debris is scarce and the dynamics of the ice allows carrying debris towards the glacier snout.

Moreover, the large increase in debris cover can be mainly related to the slowing-down of glacier flows occurred in the last decade that prevents the transport of supraglacial debris along the glacier tongue and the discharge of material in the proglacial area. In summary, we detected:

1. a general widening of medial moraine ridges and debris cover in the frontal area
2. the formation of new lateral supraglacial moraine ridges caused by the higher availability of debris from surrounding steep rock walls
3. the development of new debris cones, caused by the emergence of englacial debris.

Conclusion

The analysis of high resolution remote sensing data permitted to detect an appreciable increase in area of debris cover on glaciers in the Ortles-Cevedale Group between 2003 and 2012. In fact, in this period the glacier area covered by rock debris went from 16.7% of the total in 2003, to 22.5% in 2007, to 30.1% in 2012. Debris was found not homogeneously covering the glacier surfaces: in fact, some sectors of glaciers were totally covered (the medial or lateral moraine ridges) and it was found to be more common on small glaciers, compared to the large one.

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