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Automatic Glacier Monitoring in the Hohe Tauern National Park, Austria

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Keywords

Glacier, remote sensing, SAR, OBIA, classification, Sentinel-1/2, Hohe Tauern National Park

Introduction

Glaciers are amongst the best natural indicators of climate change, with an increase in ablation season temperature often corresponding to a reduction in glacier area (ZEMP et al., 2008). Earth Observation (EO) data are often favoured for monitoring of glaciers due to their large spatial and temporal coverage. Clean ice can be robustly identified from multispectral imagery due to the difference in reflectance values between the visible and shortwave infrared (SWIR) portions of the electromagnetic spectrum. Debris-covered ice is, however, more difficult to identify due to its spectral similarity to paraglacial material and surrounding bedrock, and as such, many investigations use manual image interpretation to map debris-covered ice. Some recent papers have used synthetic aperture radar (SAR) coherence (the persistence in scattering behaviour between two radar images) to identify debris-covered ice based on the assumption that ice will flow between the two acquisitions, resulting in a loss of coherence (FREY et al., 2012, ROBSON et al., 2015). Although a promising method, the costs and technical skills associated with SAR processing mean that classifications have typically used temporally inconsistent datasets. The Copernicus missions provide free access to high-resolution SAR and optical imagery. In this study, we combine Sentinel-1 SAR imagery with Sentinel-2 optical imagery and a LiDAR based digital elevation model (DEM) within object-based image analysis (OBIA) to semi-automatically map clean and debris-covered ice within the Hohe Tauern National Park (HTNP), Austria. This study builds on the work of ROBSON et al. (2015) where we used SAR coherence generated from ALOS PALSAR with Landsat 8 data to map debris-covered glaciers in the Nepali Himalayas, and (ROBSON et al., 2016) where we used Landsat data and a DEM to calculate glacier changes within the HTNP from 1969 to 2013.

Data and Methods

In order to make our method as transferable as possible, we aimed to create a simple and robust method that uses automatically derived thresholds, fuzzy logic, and contextuality. The data used was a Sentinel-2 image from the 26th of August 2016. SNAP 6.0 was used to generate a coherence image from two Sentinel-1 images (2nd and 26th August 2016). Additionally, a DEM (10 m) based on LiDAR data from between 2006 and 2013 was used. All the classification was conducted in eCognition 9.0.

<u>Image segmentation</u>

The segmentation of raw pixels into near-homogenous objects is one of the most important steps in OBIA. It is often found that a hierarchy of multiple object levels, where each level is based on the segmentation of the objects in the level beneath (BLASCHKE et al., 2014). The Sentinel-2 image was segmented twice using a multiresolution segmentation on the Blue, Green, NIR, Red and SWIR-1 bands, as well as the slope, and a ratio between the NIR and SWIR-1 bands. A third segmentation also used the SAR coherence and the Normalized Difference Vegetation Index (NDVI) to help create image objects that resembled the supraglacial debris.

<u>Classification of clean ice and debris-covered ice</u>

The disadvantage of many classifications is that they rely on subjective, user-chosen thresholds. In this study we opt to use an automatic histogram-derived threshold to classify clean ice using a band ratio between the near-infrared and shortwave infrared bands. This makes the classification transferable between different satellite images or different glaciated regions. Following the classification of clean ice, objects were assigned to be debris-covered ice, if they bordered clean ice, had low coherence values, gentle slopes, and contained little vegetation. The classified objects were merged, smoothed, and exported as a shapefile.

Results

138.5 km² of glacier ice was mapped. Note that due to the Sentinel-1 data not covering the entire HTNP, the easternmost portion of the national park was not included in this analysis. We then focused in on the Grossglockner massif which contains an assortment of clean and debris-covered ice. Tab. 1 shows the total ice area of the massif between 2016 and 1969 using data from ROBSON et al. (2016). The fastest melt rates occurred between 1999 and 2003 which coincided with the 2003 European heatwave (PAUL et al., 2005). The presence of seasonal snow at higher elevations on the 2013 satellite image results in an exaggerated rate of glacier loss between 2013 and 2016. Nevertheless, our results indicate an increase in glacier loss rates relative to the second half of the last century. Between 1969 and 2016 the total glacier area reduced by 32.3% (Fig. 1).

Year	Glacier Area (km²)	Mean Annual Change (%/yr)
2016	39.4	-0.67
2013	41.4	0.02
2003	41.2	-3.00
1999	53.2	-0.15
1985	55.3	-0.18
1969	58.2	

Table 1: The total glacier area of the Grossglockner massif between 1969 and 2016.

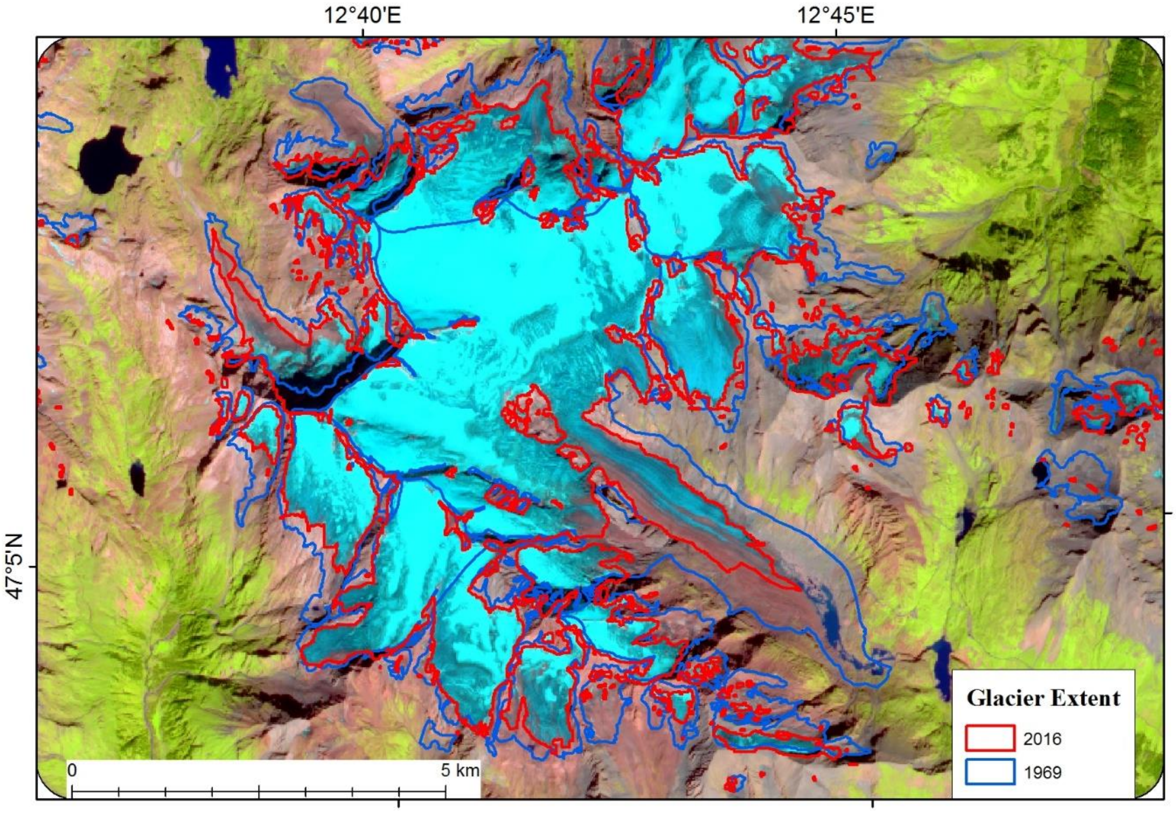

Figure 1: Glacier area change between 1969 and 2016.

Discussion and Conclusion

There are considerable advantages to using Sentinel-1 and 2 data to delineate glaciers. Firstly, the use of Sentinel data allows creating temporally consistent glacier inventories. Additionally, the higher spatial and temporal resolutions of the Sentinel-2 mission as opposed to the Landsat missions offer new possibilities for investigating glaciers. Unlike previous classification methods, we believe that our method is transferrable and can be used effectively in other glaciated regions to robustly map clean and debris-covered ice.

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