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From annual glacier mass balances towards a remote monitoring of near real-time mass changes

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Abstract

Traditional annual glacier mass balance measurements on four different glaciers situated in the national parks of Hohe Tauern (Austria) and Northeast Greenland are currently being intensified by a remote monitoring network that delivers mass balance data in an hourly to daily time step. The station network consists of ablation- and accumulations stations, automatic weather stations and automatic cameras. The near real time data shall be assimilated into an operational distributed glacier mass balance model that calculates the actual glacier mass changes. Both the measurements as well as the daily model output will be presented to a broader public within a web-based glacier information system. Here we present main results from traditional mass balance monitoring and selected results from the remote monitoring network.

Keywords

Glacier monitoring, climate change, glacier mass balance, automatic cameras, snow cover monitoring, snow cover model

Introduction

In the last decades Alpine glaciers have been losing mass in an unprecedented speed. However, quantitave information of the actual mass changes of glaciers is not available before the processing of the annual measurements during late summer. The aim of this research is to reduce this deficit of information by installing a widely automatic glacier measurement system, which is able to measure glacier mass changes in near real time on a daily or hourly timescale and to present the results to a broader public.

This remote monitoring network was designed for and installed on four glaciers that are currently monitored by ZAMG. All of the four glaciers are situated within National Parks: Kleinfleißkees and Goldbergkees on Sonnblick and Pasterze on Großglockner in the National Park Hohe Tauern (Austria) and Freya Glacier in the Northeast-Greenland National Park.

Annual glacier mass balance monitoring was initiated on Goldbergkees in 1988, on Kleinfleißkees in 1998 (e.g. Schöner et al., 2009), on Pasterze after a break of 8 years in 2004 and on Freya Glacier in 2007 (e.g. Hynek et al., 2013). Within the last years the glacio-hydrological monitoring at the glaciers near Sonnblick Observatory, Goldbergkees and Kleinfleißkees, has been extended to runoff monitoring, measurements of surface energy balance and chemical analyses of the winter snow pack.

Methods

Glacier mass balance monitoring on the four glaciers consists of annual or seasonal measurements of the spatial distribution of accumulation and ablation on the glacier and their spatial inter- and extrapolation over the whole glacier surface (Østrem & Brugman, 1991). The time series of annual mean surface mass balances are then compared to decadal glacier elevation changes and if necessary homogenized using the methodology of Zemp et al. (2013).

The remote monitoring of glacier mass balance uses mainly two different types of data, which are available online in near real time (delay from 10 minutes on Austrian glaciers to 1 day in Greenland). Glacier mass balance is measured on at least one point on the glacier surface by continuous logging of surface ablation and snow accumulation. To extend that information over the whole glacier surface, the spatial retreat of the seasonal snow line is measured by automatic cameras using the software PRACTISE (Härer et al., 2016). By assimilating all those data into a distributed mass balance model, the surface mass balance of a glacier can be monitored the best possible way in near real time. The model used for this purpose is based on the operational Austrian snow cover model SNOWGRID (Olefs et al., 2013).

Results and Discussion

The glaciers in Hohe Tauern as well as Freya Glacier in NE-Greenland are constantly loosing mass in the current climate. Annual surface mass balance time series of all four glaciers are shown in Fig. 1. While the Austrian glaciers are losing approximately 1 meter of water equivalent every (w.e.) year (which corresponds to 1.1m of mean ice thickness change per year), Freya glacier is currently loosing 0.4 meter w.e./a. Including 2017 there has not been a single positive mass balance year since 2004 in Hohe Tauern. By analysing seasonal mass balance measurements we found that the amount of annual glacier mass balance in Hohe Tauern is determined by weather conditions in summer, while in NE-Greenland it is more determined by winter accumulation.

Results from recent decadal elevation changes confirm the picture of accelerating mass losses during the last decade. In Fig. 2 elevation changes of Pasterze are shown for 3 periods of time. The recent digital elevation model in 2015 covers only the glacier tongue, but still we can see an increase of ice thickness loss with mean values for the glacier tongue reaching from -1.8m/a between 1969 and 1998 to -4.3m/a between 1998 and 2012 and -5.1m/a between 2012 and 2015.

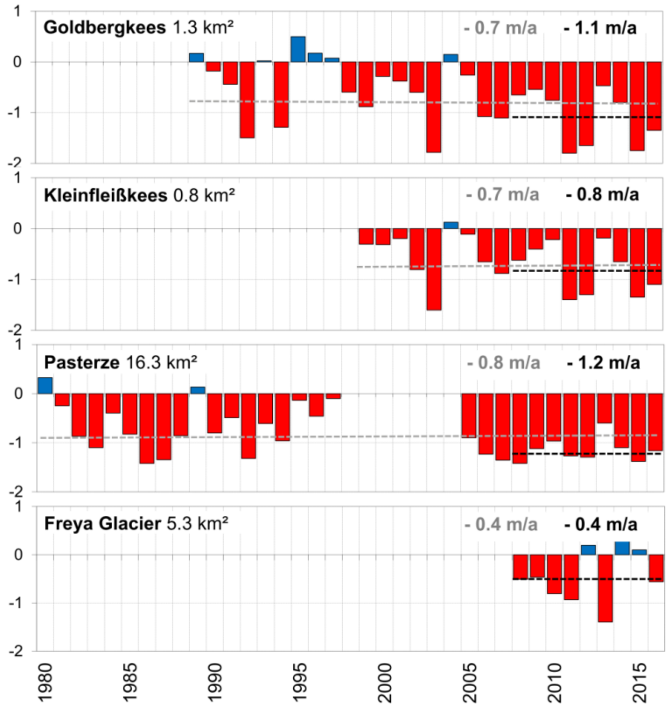

Figure 1: Time series of annual glacier mass balance of all ZAMG-monitored glaciers in Hohe Tauern (Austria) and on Clavering Island (Northeast Greenland). Plotted is the aerial average surface mass balance in meters water equivalent. Mean values are given for the total measurement period (grey) and for the last 9 years (black).

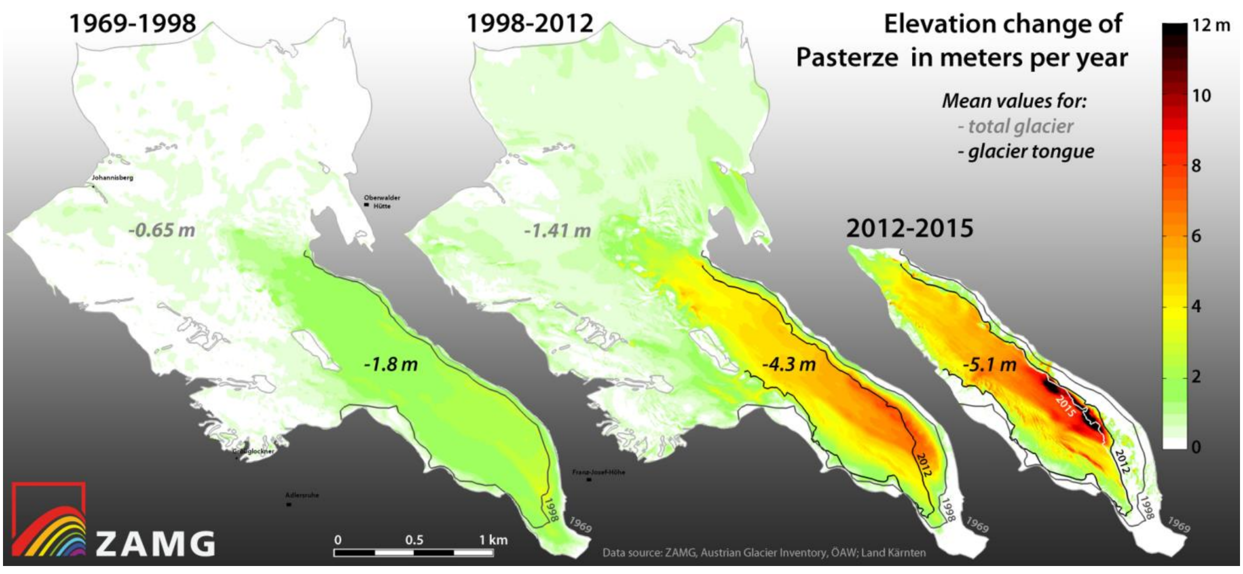

Figure 2: Elevation changes of Pasterze within the last decades show the recent acceleration of mass loss. Calculated using data from KUHN et al.,2009, Land Kärnten and ZAMG. **Please check the digital conference volume for the true colour version of this figure!**

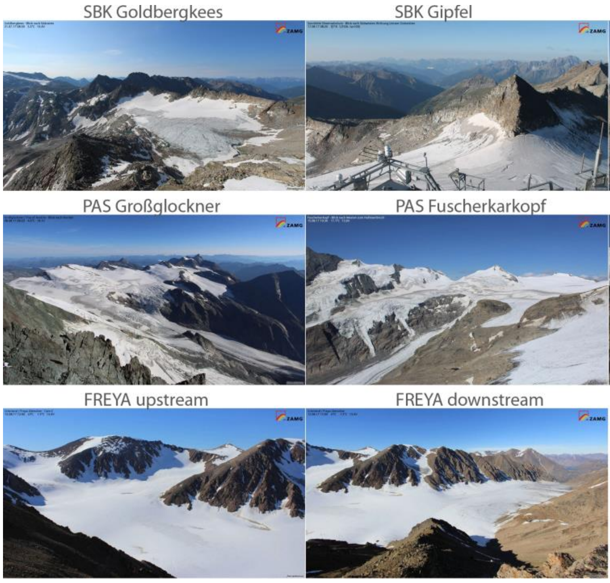

Figure 3: 10 webcams operated by ZAMG and University of Graz to measure snow cover, surface velocity and glacier retreat at the Goldbergkees, Kleinfleißkees on Sonnblick (SBK), Pasterze and Freya. The webcam pictures are freely accessible (photo-webcam.eu), except the 4 cameras on Pasterze (second row) that are located on the property of the Austrian Alpine Club (ÖAV).

Remote mass balance monitoring is based on three energy and mass balance stations (Freya, Lower Pasterze and Kleinfleißkees), two mass balance stations (Goldbergkees and upper Pasterze) and ten automatic cameras, that cover more than 95% of the total glacier area of the four glaciers. The glacier cams in Hohe Tauern are working all year round and deliver a picture every 10 minutes. The two cameras in the Arctic make pictures every hour and deliver one picture per day via Iridium.

The pictures are orthorectified and then the surface is classified into the categories ice, firn and snow to calculate the daily snow covered area fraction of the glacier, which is a good proxy for the mass balance state and a useful validation or calibration source for a distributed mass balance model. Examples of classification results for Kleinfleißkees during the ablation season 2015 are shown in Fig. 4. Until now the distinction between ice and brighter surfaces works automatically, but some manual interference in setting the right threshold is still needed to distinguish between snow and firn (snow that is older than one year).

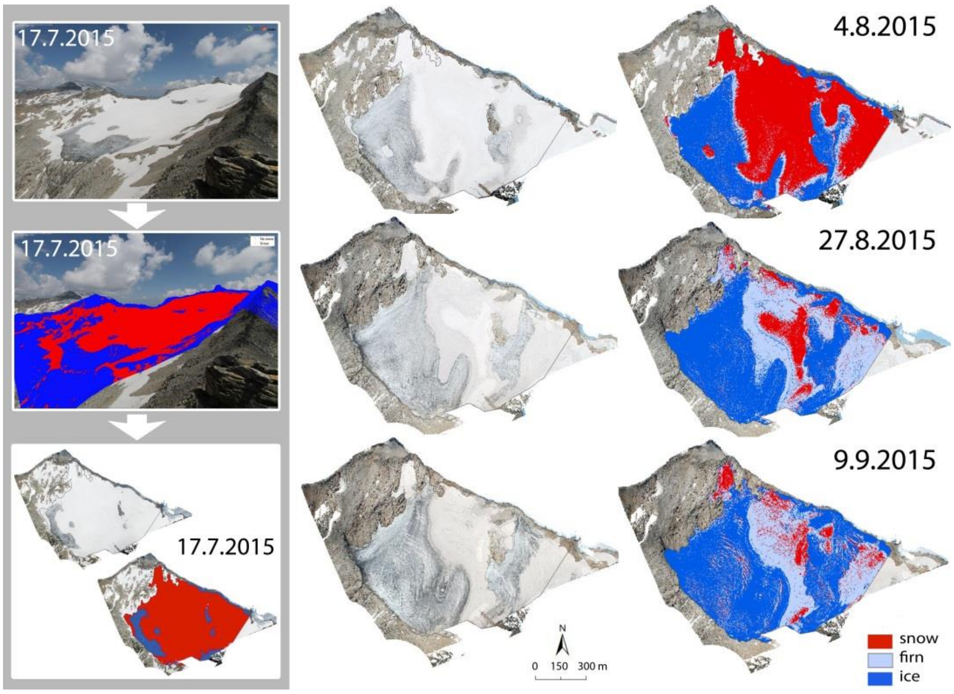

Figure 4: Webcam Kleinfleißkees: Results from Rojs (2016): Daily orthofoto production and surface classification (ice/firn/snow) using the photo rectification and classification software Practise (Härer et al., 2016)

Outlook

After completing the installation of an appropriate station network for a remote mass balance monitoring of all four glaciers we currently work on the assimilation of all data into an operational glacier mass balance model and on the visualisation of near real time data and model output via glacio-live.at and zamg.ac.at. In a next step it is planned to extend the operational glacier mass balance model to all glaciers of Austria.

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