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The mass balance series of Stubacher Sonnblickkees 1946–2016 and the semi-direct calculation of the mass balance of glaciers. A contribution to LTER Austria

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Abstract

This poster presents the results of the semi-direct calculation of the annual mass balances of Stubacher Sonnblick Glacier in the heart of NP Hohe Tauern for the periods 1946–1963 and 1981–2016. They are based on annual measurements of the mass balance by the direct glaciological method carried out between 1964 and 1980. Together they make up a mass balance series of 70 years. The small east-facing glacier is situated north of and close to the main crest of the Hohe Tauern range (Eastern Alps). In 2016 it covered an area of 1 km² and terminated at an elevation of 2,650 m. The results and observations of the 17-year series allow the inference of several systematic relations between glaciological parameters and the annual mass balance.

Keywords

glacier monitoring; long term ecological research (LTER); mass balance; semi-direct calculation, NP Hohe Tauern; climate change

Introduction

The LTER Master Site Oberes Stubachtal | Sonnblickkees is a long term research site with a main focus on measurement of glacier parameters, going along with hydrological budget estimations within the catchment area of the lake Weißsee. Stubacher Sonnblickkees (SSK) is located in the Hohe Tauern Range (Eastern Alps) in the south of Salzburg Province. From 1964 to 1981, the yearly mass balance was calculated by direct measurements. Based on these records of 17 years, a semi-direct method was used since then. From the beginning in 1964 until 2016 Heinz Slupetzky, University of Salzburg, carried out the mass balance and related glaciologycal measurements as the principal investigator and as a senior adviser since then. The usual and necessary link to the climate and climate change is given by the weather station at the Rudolfshütte (ZAMG and HDS).

The glacier type of SSK can be classified as a slope glacier, i.e. the relief is covered by a relatively thin ice sheet and there is no regular glacier tongue. The rough subglacial topography makes for a complex shape in the surface topography, with various concave and convex patterns.

The main reason for selecting this glacier for mass balance observations (as early as 1963) was to verify on a complex glacier how the mass balance methods and the conclusions - derived during the more or less pioneer phase of glaciological investigations in the 1950s and 1960s - could be applied to the SSK glacier. In terms of regional climatic differences between the Central Alps in Tyrol and those of the Hohe Tauern, the latter experienced significantly higher precipitation, so one could expect new insights in the different response of the two glaciers SSK and Hintereisferner (Ötztal Alps) - where a mass balance series went back to 1952 (FISCHER et al. 2014).

The usual and necessary link to climate and climate change was given by a newly founded weather station (by Heinz and Werner Slupetzky) at the Rudolfshütte in 1961, which ran until 1967. Along with an extension and enlargement to the so-called Alpine Center Rudolfshütte of the OeAV, a climate observatory has been operating without interruption since 1980 under the responsibility of ZAMG and the Hydrological Service of Salzburg, providing long-term met observations.

Methods

Direct yearly mass balance measurements were started in 1963, first for 3 years as part of a thesis project. In 1965 the project was incorporated into the Austrian glacier measurement sites within the International Hydrological Decade (IHD) 1965 - 1974 and was afterwards extended via the International Hydrological Program (IHP) 1975 - 1981. During both periods the main financial support came from the Hydrological Survey of Austria. After 1981 funds were provided by the Hydrological Service of the Federal Government of Salzburg. The research was conducted from 1965 onwards by Heinz Slupetzky from the (former) Department of Geography of the University of Salzburg.

These activities received better recognition when the High Alpine Research Station of the University of Salzburg was founded in 1982 and brought in additional funding from the University. With recent changes concerning Rudolfshütte, however, it became unfeasible to keep the research station going. Fortunately, at least the ZAMG weather station at Rudolfshütte is still operating.

In the pioneer years of the mass balance recordings at SSK, the main goal was to understand the influence of the complicated topography on the ablation and accumulation processes. With frequent strong southerly winds on the one hand, and precipitation coming in with storms from the north to northwest, the snow drift is an important factor on the undulating glacier surface. This results in less snow cover in convex zones and in more or a maximum accumulation in concave or flat areas. As a consequence of the accentuated topography, certain characteristic ablation and accumulation patterns can be observed during the summer season every year, which have been regularly observed for many decades. The process of snow depletion runs through a series of stages (described by the AAR) every year. The sequence of stages until the end of the ablation season depends on the weather conditions in a balance year. One needs a strong negative mass balance year at the beginning of glacier measurements to find out the regularities; 1965, the second year of observation resulted in a very positive mass balance with very little ablation but heavy accumulation. To date it is the year with the absolute maximum positive balance in the entire mass balance series since 1959, probably since 1950.

The highly complex ablation patterns required a high number of ablation stakes at the beginning of the research and it took several years to develop a clearer idea of the necessary density of measurement points to ensure high accuracy. A great number of snow pits and probing profiles (and additional measurements at crevasses) were necessary to map the accumulation area/patterns. Mapping the snow depletion, especially at the end of the ablation season, which coincides with the equilibrium line, is one of the main basic data for drawing contour lines of mass balance and to calculate the total mass balance (on a regular-shaped valley glacier there might be an equilibrium line following a contour line of elevation separating the accumulation area and the ablation area, but not at SSK). - An example: in 1969/70, 54 ablation stakes and 22 snow pits were used on the 1.77 km² glacier surface. In the course of the study the consistency of the accumulation and ablation patterns could be used to reduce the number of measurement points. - At the SSK the stratigraphic system, i.e. the natural balance year, is used instead the usual hydrological year.

From 1964 to 1981, the yearly mass balance was calculated by direct measurements. Based on these records of 17 years, a regression analysis between the specific net mass balance and the ratio of ablation area to total area (AAR) has been used since then (SLUPETZKY 2014). The basic requirement was mapping the maximum snow depletion at the end of each balance year. Verifications took place as often as possible by means of independent geodetic methods, i.e. monoplotting, aerial and terrestrial photogrammetry, more recently also the application of PHOTOMODELLER and laser scans. The semi-direct mass balance determinations used at SSK were tentatively compared with data from periods of mass/volume change, resulting in promising first results on the reliability of the method. In recent years re-analyses of the mass balance series have been conducted by the World Glacier Monitoring Service and will be done at SSK too. The methods developed at SSK also add to another objective, much discussed in the 1960s within the community, namely to achieve time- and labour-saving methods to ensure continuation of long-term mass balance series.

The regression relations were used to extrapolate the mass balance series back to 1959, the maximum depletion could be reconstructed by means of photographs for those years. R. GÜNTHER (1982) calculated the mass balance series of SSK back to 1950 by analysing the correlation between meteorological data and the mass balance; he found a high statistical relation between measured and determined mass balance figures for SSK.

Results

In spite of the complex glacier topography, interesting empirical experiences were gained from the mass balance data sets, giving a better understanding of the characteristics of the glacier type, mass balance and mass exchange. It turned out that there are distinct relations between the specific net balance, net accumulation (defined as Bc/S) and net ablation (Ba/S) to the AAR, resulting in characteristic so-called 'turnover curves'. The diagram of SSK represents the type of a glacier without a glacier tongue. Between 1964 and 1966, a basic method was developed, starting from the idea that instead of measuring years to cover the range between extreme positive and extreme negative yearly balances one could record the AAR/snow depletion during one or two summers. The new method was applied on Cathedral Massif Glacier, a cirque glacier with the same area as the Stubacher Sonnblickkees, in British Columbia, Canada. During the summers of 1977 and 1978. It returned exactly the expected relations, e.g. mass turnover curves, as found on SSK.

Between 1965 and 1981, there was a mass gain of 10 million cubic metres. With a time lag of 10 years, this resulted in an advance until the mid-1980s. Since 1982 there has been a distinct mass loss of 35 million cubic metres by 2013. In recent years, the glacier has disintegrated faster, forced by the formation of a periglacial lake at the glacier terminus and also by the outcrops of rocks (typical for the slope glacier type), which have accelerated the meltdown. The formation of this lake is well documented. The glacier has retreated by some 600 m since 1981. - Since August 2002, a runoff gauge installed by the Hydrographical Service of Salzburg has recorded the discharge of the main part of SSK at the outlet of the new Unterer Eisboden See.

Discussion

The annual reports - submitted from 1982 on as a contractual obligation to the Hydrological Service of Salzburg - document the ongoing processes on the one hand, and emphasize the mass balance of SSK and outline the climatological reasons, mainly based on the met-data of the observatory Rudolfshütte, on the other. There is an additional focus on estimating the annual water balance in the catchment area of the lake. There are certain preconditions for the water balance equation in the area. Runoff is recorded by the ÖBB power stations, the mass balance of the now approx. 20% glaciated area (mainly the Sonnblickkees) is measured and the change of the snow and firn patches/the water content is estimated as well as possible. (Nowadays laserscanning and ground radar are available to measure the snow pack). There is a net of three precipitation gauges plus the recordings at Rudolfshütte. The evaporation is of minor importance. The long-term annual mean runoff depth in the catchment area is around 3.000 mm/year.

The precipitation gauges have measured deficits between 10% and 35%, on average probably 25% to 30%. That means that the real precipitation in the catchment area Weißsee (at elevations between 2,250 and 3,000 m) is in an order of 3,200 to 3,400 mm a year. The mass balance record of SSK was the first one established in the Hohe Tauern region (and now since the Hohe Tauern National Park was founded in 1983 in Salzburg) and is one of the longest measurement series worldwide. Great efforts are under way to continue the series, to safeguard against interruption and to guarantee a long-term monitoring of the mass balance and volume change of SSK (until the glacier is completely gone, which seems to be realistic in the near future as a result of the ongoing global warming).

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