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Glaciological monitoring in Hohe Tauern National Park

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Keywords: glaciers, climate change, mass balance, glacier inventory

Abstract

Glaciers are important and fast changing landscape elements in Hohe Tauern National Park (HTNP). In 1998, 10% of the HTNP area was covered with ice, less than half of the glaciated area during the Little Ice Age maximum. Glaciological monitoring includes mass balance measurements, glacier inventories, length change records and flow velocity measurements, complemented by climatological, hydrological and dendrochronological observations. All these data evidence the climate and glacier history of HTNP in an outstanding way, comparable to few other sites in the world.

Profile

Protected area

Hohe Tauern National Park

Mountain range

Alps

Country

Austria

Introduction

In 1998, glaciers covered 185.56 km² or 10% of the total HTNP area.[1] During the glacial maximum of the Little Ice Age (LIA), which occurred in the mid-19th century, glaciers were about twice as large as they are today (Groß 1987). Emerging tourism and the foundation of the Austrian and German Alpine Club, plus the expansion of the railway network, facilitated first ascents of the highest peaks as well as scientific research.

The Pasterzen Kees (12° 42' E, 47° 05' N), below Austria's highest peak, the Großglockner (3 798 m), is the largest glacier in Austria (18.36 km² in 1998) and as such was frequently visited by mountaineers, scientists and artists and thus its retreat has been well observed (Lieb & Slupetzky 2011). The map of Carinthia by Holtzwurm dating from 1612 shows Pasterzen Kees as *glacies continua*. The Schlagintweit brothers published the first detailed map of Pasterze in 1850 (Schlagintweit & Schlagintweit 1850). Length and velocity measurements are continuously monitored by the geography department of the University of Graz.

At the nearby peak of Rauriser Sonnblick, Ignaz Rojacher established a meteorological observatory at an elevation of 3 106 m (12° 57' O, 47° 03' N) in 1886 (Böhm et al. 2007). This observatory is very important for the investigation of climate change at high elevations as it is one of the longest operating high elevation stations. The observatory is surrounded by the glaciers Goldberg Kees (12° 57' E, 47° 02' N) and Kleinfleiss Kees (12° 56' E, 47° 03' N), which are also well documented (Böhm et al. 2007). Close to the Sonnblick observatory (3 105 m), at Rudolfshütte-Weißsee in the Stubach valley, a weather station (at 2 305 m, 12° 37' E, 47° 08' N) was established in 1961 (Slupetzky 2004) near Stubacher Sonblick Kees (12° 35' E, 47° 06' N) and Ödenwinkel Kees (12° 38' E, 47° 06' N).

Figure 1 – Stubacher Sonnblick Kees (Granatspitz range) on 7.9.2013. Below the fresh snow in the accumulation area, the underlying ochre Sahara dust from May 2013 is visible. In 2012 / 13 the glacier had a positive mass balance, which is very rare for recent years. © H. Slupetzky

The Austrian Alpine Club established a glacier survey in 1891 (Richter 1894). For several glaciers, like the Pasterzen Kees, much longer observations exist. Apart from length changes, elevation change has been measured from 1928 onwards by Paschinger (1969) and his successors. First ice flow velocity measurements date from 1882 by Seeland (1883).

These data have been complemented by proxy information on the Holocene, for example at the Pasterze forefield, since the first findings in 1990 (Slupetzky 1993). Rich dendrochronological evidence discovered since then allows a detailed interpretation of climate and glacier history for the Holocene (Patzelt 1973; Nicolussi & Patzelt 2001).

[1] In HTNP, *Kees* is the most common word for glacier, the spellings on maps differ: sometimes, the name of the glacier and the word *Kees* are joined into one word, sometimes written in two words.

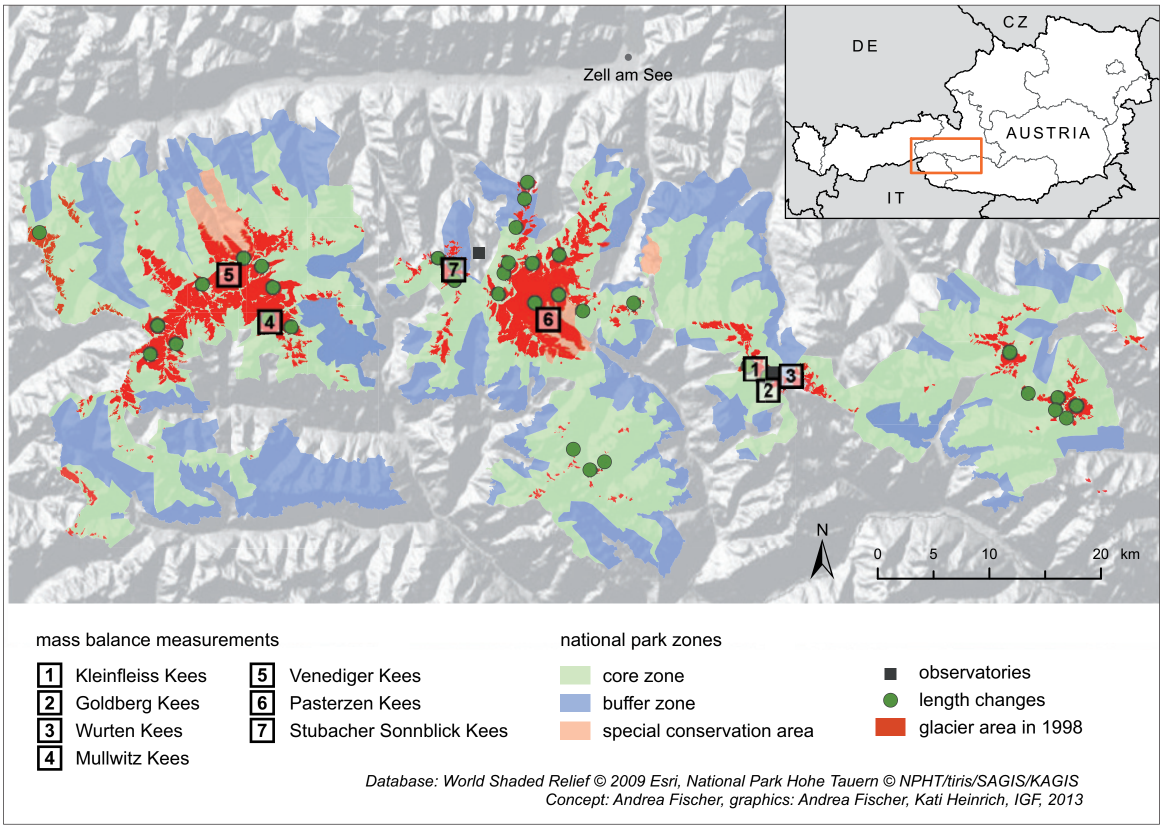

Figure 2 – Map of HTNP with location of specific glaciological measurement sites.

Today the glaciological long-term monitoring includes annual measurements of glacier mass balance at five glaciers, length changes at 36 glaciers and several ice flow velocity measurements at Pasterze, Hochalm Kees and Kälberspitz Kees. The observatory at Hoher Sonnblick and the weather station at Rudolfshütte, as well as runoff observations, e.g. at Obersulzbach Kees, complement the glaciological time series. Together with the three glacier inventories, these data allow numerical modelling of, for instance, glacier runoff. The studies have also resulted in several guidebooks for visitors of HTNP (e.g. Slupetzky & Lieb 2013).

This report provides a glimpse of the rich glaciological data available for HTNP, collected by a number of different scientific institutions.

Methods

Compilation of glacier inventories

The first Austrian glacier inventory was based on airborne orthophotos dating from the year 1969 and contained glacier areas, surface elevations, as well as morphological and glaciological information of all Austrian glaciers (Patzelt 1980). Based on this material, Groß (1987) published area changes between the LIA maximum and 1969, using field mappings as well as orthophoto interpretation of moraine positions. The second Austrian glacier inventory was also based on orthophotos and mapped the glacier extent and surface elevation for the years 1997 to 1998 (Lambrecht & Kuhn 2007). The compilation of a third glacier inventory has been finished for the provinces of Salzburg (Stocker-Waldhuber et al. 2012) and Tyrol (Abermann et al. 2012), but not for Carinthia, as the third inventory is derived from LiDAR DEMs where these data were available.

Measurement of length changes

The monitoring of glacier length changes is done annually by members of the glacier survey of the Austrian Alpine Club following the instructions of Richter (1894). As the time series of glacier length changes in HTNP is one of the longest observed glaciological parameters anywhere, the method has been continued unchanged to avoid discontinuities. For measuring length changes, several fixed points, usually rocks, are marked in the glacier forefield. The distance from these fixed points to the glacier tongue is measured year by year in a specific direction as closely as possible to the ice flow line. The difference between these distances averaged for all fixed points close to a specific glacier tongue is the annual glacier length change. As glaciers do not retreat steadily, influenced not only by climatic, but also topographic and dynamic conditions, a larger sample of glaciers within a mountain range is usually surveyed to obtain representative averages.

Measurement of glacier mass balance

The mass change of a glacier can be calculated by comparing mass gain, in the form of snow, with mass loss by melt of snow and ice for a specific time period.

Various indirect methods can be used, such as hydrological or geodetic methods, as well as the direct glaciological method, as used in the studies presented here, to determine the glacier mass balance (Paterson 1994).

The defined time period for the annual mass balance of the glaciers mentioned above is the hydrological year, which starts on October 1st. In addition, the year is divided into accumulation and ablation periods, when mass gain is expected during winter and mass loss during the summer months. Winter and summer mass balances are determined with the help of ablation stakes, snow depth soundings, snow pits and density measurements.

Results

Glacier inventories

The glacier inventories show a glacier retreat since the LIA maximum. In the glacier inventory of 1998, the 351 glaciers in HTNP covered a total area of 185.56 km². In the glacier inventory of 1969, the glaciated area was 207.25 km². The ice cover thus decreased by 11% between 1969 and 1998, which is less than the 17% average for all Austrian glaciers. Although the third glacier inventory (2006) has not yet been fully completed for Carinthia, the average decrease of 8% for the glacier area in Tyrol (Abermann et al. 2012) may be taken as an indicator for glacier changes in this period. For the glacier decrease in Salzburg between 1998 and 2009, Stocker-Waldhuber et al. (2012) found a high variability in area changes for different regions, ranging from area losses of 15% in the Venediger Group to −43% in the Ankogel Group.

Time series of glacier length changes

Observation of glacier *oscillations*, for example in the Glockner Group, were carried out as early as 1847–1849 by the Schlagintweit brothers (Schlagintweit & Schlagintweit 1850). Seeland took such measurements at Pasterzen Kees from 1879 until 1899. Richter, the initiator of the glacier survey of the Austrian Alpine Club, which has been operating since 1891, included Obersulzbach Kees and Karlinger Kees in his network. Today the length of 36 glaciers in HTNP is recorded annually (Patzelt 1970; Patzelt 1977; Fischer et al. 2013). The comparison of length changes recorded at Pasterzen Kees and Schlaten Kees shows that specific glaciers show individual reaction despite being exposed to fairly similar climatic conditions (Figure 3).

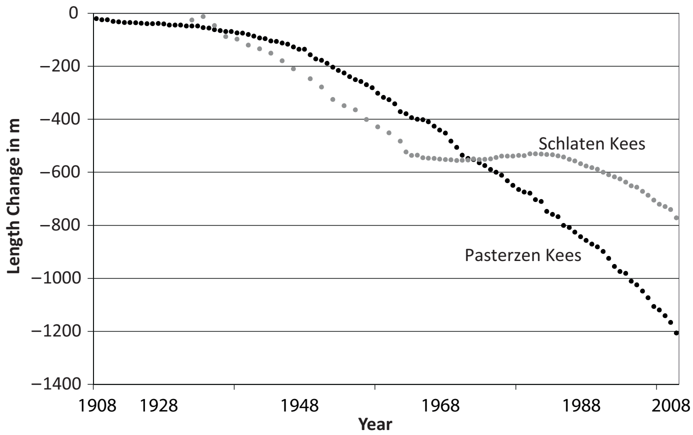

Figure 3 – Length changes of Pasterzen Kees and Schlaten Kees reveal a general retreat, but the faster reacting Schlaten Kees advanced during the 1980s / 1990s, whereas Pasterzen Kees retreated almost continuously.

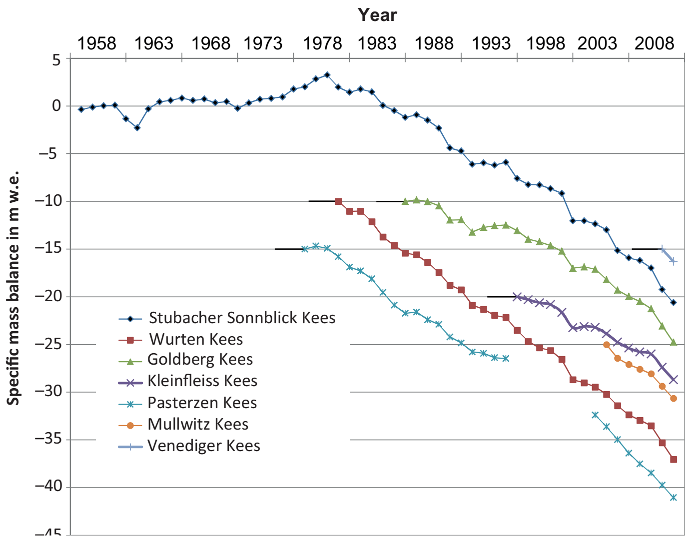

Figure 4 – Cumulated values of specific mass balances for the surveyed glaciers in HTNP. The graphs start arbitrarily at the x-axis (Pasterzen Kees: –10 m), although mass changes of course also happened before measurements began and during survey breaks. Starting points of the mass balance curves are marked with a thick line. Stubacher Sonnblick Kees has the longest time series, Pasterzen Kees the most significant mass loss during the last decade.

Time series of glacier mass balance

Stubacher Sonnblick Kees and Ödenwinkel Kees

Stubacher Sonnblick Kees and Ödenwinkel Kees are located close to the climate station Rudolfshütte in the Granatspitz Group. While the Stubacher Sonnblick Kees is a slope glacier, Ödenwinkel Kees is a valley glacier in a north-facing cirque with a debris covered tongue. Since 1963 / 64 glacier mass balance has been measured at Stubacher Sonnblick Kees by Slupetzky (1989), which makes it the first and longest mass balance series in HTNP. For the years 1959 to 1963, the mass balance has been reconstructed. On Ödenwinkel Kees, ice flow velocities have been recorded from 1962 onwards, using stone lines until 1965 and stakes thereafter (Slupetzky 1969). The specific mass balance of Stubacher Sonnblick Kees is the longest times series in the region (Figure 4).

Kleinfleiss Kees, Wurten Kees, Goldberg Kees

Wurten Kees (WUK, 13° 00’ E, 47° 02’ N), Goldberg Kees (GOK) and Kleinfleiss Kees (FLK) are small glaciers in direct vicinity of the Sonnblick observatory at 3 105 m. (Figure 5). Measurements on WUK started in 1982, on GOK in 1986 and on FLK in 1999, and the direct measurements of mass balance are ac-

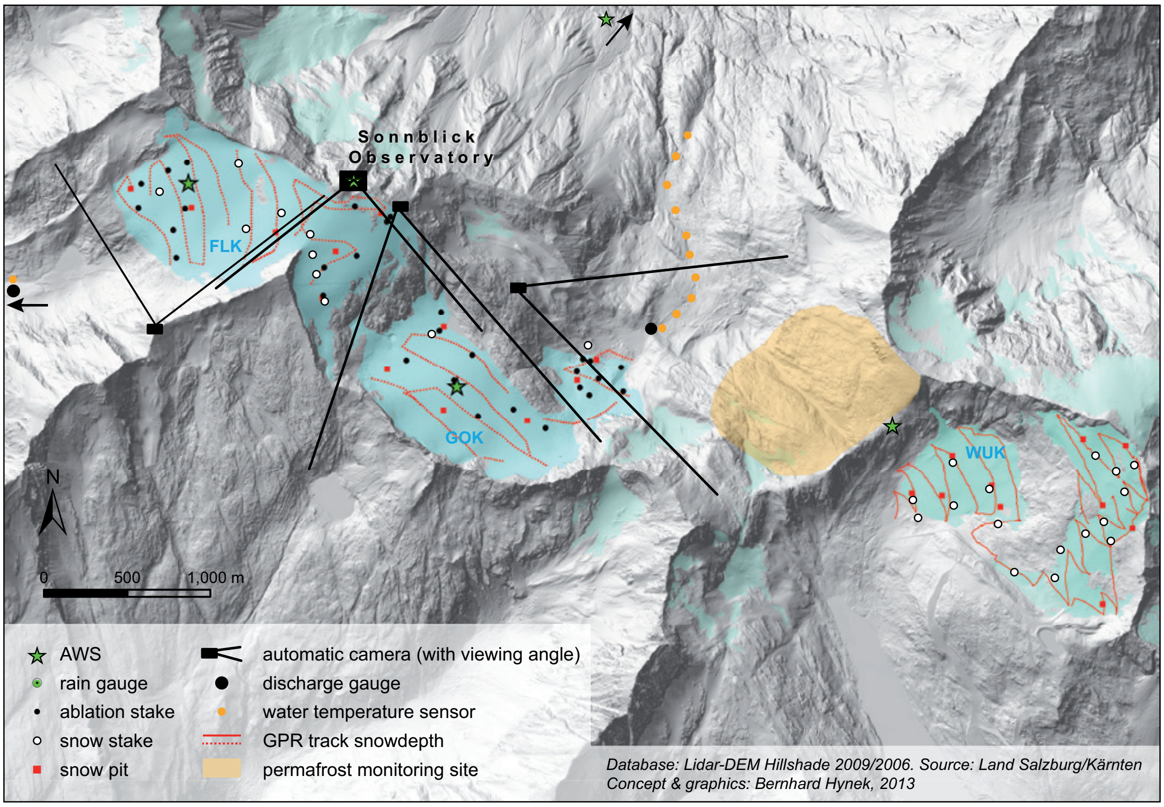

Figure 5 – Typical distribution of cryospheric measurement sites near the Sonnblick observatory, including mass balance glaciers Kleinfleiss Kees (FLK), Goldberg Kees (GOK) and Wurten Kees (WUK).

companied by dense monitoring of meteorological and glacio-hydrological parameters. Overall the mass balance of the three glaciers was negative in the last two decades, with an average mean ice thickness loss of about 0.8 m / year. The glacier areas are currently shrinking (2009: WUK 0.7 km², FLK 0.8 km², GOK 1.3 km²) and disintegrating. In 2010 Goldberg Kees broke up into three parts, while Wurten Kees consists of two separated glacier parts.

Mass balance measurement density is typically high, with up to 100 points / km² for winter balance and 10–20 points / km² for annual balance. Since July 2011, two automatic weather stations are operating on FLK and GOK to measure the glacier surface energy budget. In addition to glacial runoff, monthly snow depth and water temperatures are measured in these two glacial catchments. In recent years the use of automatic cameras for snowline detection has enhanced measurement accuracy and facilitated the areal extrapolation of mass balance as well as glacio-hydrological model evaluation. While mass balance monitoring on Kleinfleiss Kees and Goldberg Kees is currently intensified by the use of automatic systems on the glaciers, monitoring on the upper Wurten Kees was stopped in 2012 because of the large anthropogenic influence from the Mölltaler Gletscher ski resort, which increasingly impaired the determination of a natural (i.e. climate induced) glacier mass change signal. Annual mass balance reports are published in the *Sonnblick-verein Jahresberichte* and submitted to the World Glacier Monitoring Service (Böhm et al. 2007).

Mullwitz Kees

Mullwitz Kees is situated in the core zone of HTNP and can be divided into the inner Mullwitz Kees, also known as Rainer Kees, and the outer Mullwitz Kees, including the glacier tongue area known as Zettalunitz Kees. The mass balance measures were only conducted on the outer Mullwitz Kees (Figure 6). The glacier is mainly exposed to the south, has a great plateau without a surrounding mountain ridge. The accumulation area has therefore shifted to lower elevations zones as a result of wind drift. The highest point of the glacier is at an elevation of 3450 m, the tongue reaches down to an elevation of 2900 m and in 2009 the glacier covered an area of about 3 km² (Stocker-Waldhuber et al. 2013).

Venediger Kees

Venediger Kees (47° 12’ N, 12° 33’ E) is located in the core zone of HTNP. The original name of this glacier system was Obersulzbach Kees. Due to area loss since 1850, the connection between individual parts of Obersulzbach Kees was lost and the resulting individual glaciers were renamed. In 2009 Venediger Kees covered an area of about 2.17 km². The glacier extends up to an altitude of 3400 m, just below the Großvenediger summit, the lowest part of the glacier tongue reached down to 2480 m in 2009. The Venediger Kees is a typical valley glacier. Such glaciers are constrained by underlying topography and gravity, with an accumulation area in a firn basin and an ablation area mostly congruent with the glacier tongue.

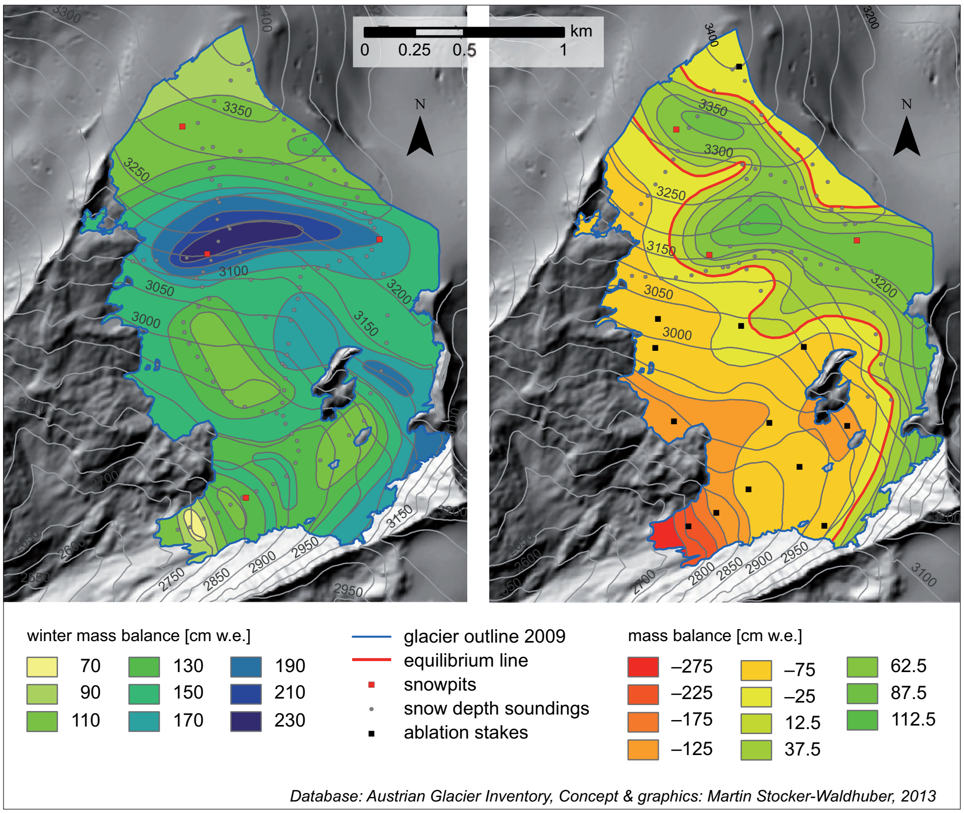

Figure 6 – Observation network and mass balance map of Mullwitz Kees for the year 2013.

Glacier monitoring was launched in May 2012 as a supplement to the runoff gauge maintained by the Hydrographic Office of the Land Salzburg at an altitude of 2202 m, in front of a peri-glacial lake. The monitoring programme includes direct mass balance measurements and three time lapse cameras for recording changes in the snow cover.

For measuring the ablation, 13 ablation stakes were installed at the beginning of monitoring, 11 on Venediger Kees and 2 on Sulzbacher Kees (see Figure 7). Two further ablation stakes were installed on Sulzbacher Kees to secure the measurement series. Accumulation is measured in three snow pits and a number of snow depth probings.

Pasterzen Kees

In 2004 the Central Institute of Meteorology and Geodynamics (ZAMG) restarted measuring the annual mass balance on Pasterzen Kees, Austria's biggest glacier, which had been monitored by hydropower generator Tauernkraft AG from 1980 to 1997. To extract the typical mass balance distribution on the glacier, a very dense network of point measurements (Figure 8) with more than 60 stakes has been established in the ablation area as well as accumulation measurements with snow pits, snow probings and snow depth measurements by ground penetrating radar (GPR).

Alongside glacier mass balance observations, various other measurements are carried out on Pasterzen

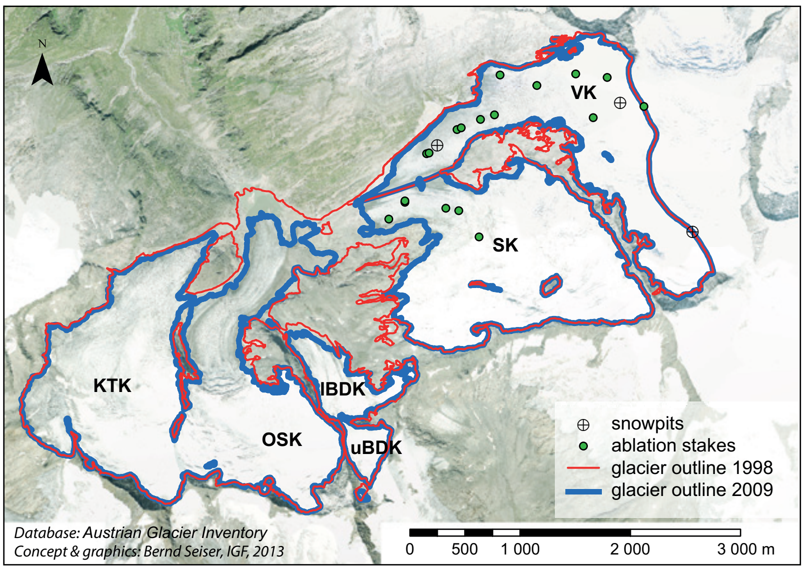

Figure 7 – Overview of the catchment of Venediger Kees (VK), Sulzbacher Kees (SK), lower Bleidächer Kees (lBDK), upper Bleidächer Kees (uBDK), Obersulzbach Kees (OSK) and Krimmlertörl Kees (KTK) with measuring points.

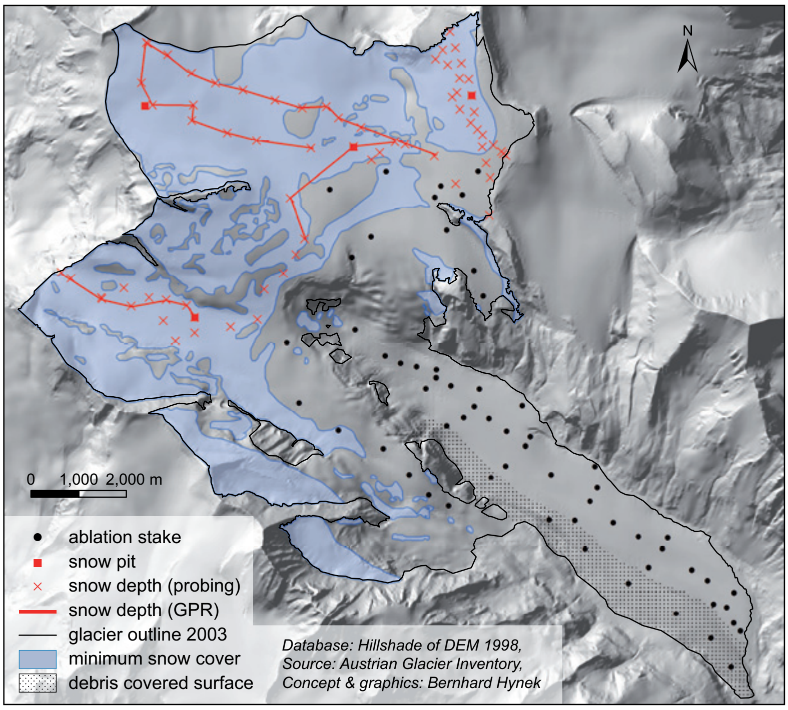

Figure 8 – Mass balance monitoring network on Pasterzen Kees glacier 2006 / 2007.

Kees: ice thickness measurements with GPR and reflection seismic, ice surface velocity measurements by GPS stations and meteorological measurements on automatic weather stations on the glacier. Monitoring will be continued in the coming years and further enhanced by the use of automatic cameras and automatic surface melt sensors.

Historical maps and documents: Case study Mullwitz Kees

Mullwitz Kees has been subject to several investigations since the mid-19th century, when the glaciers around the Großvenediger (3664 m) were described for the first time (Kürsinger & Spitaler 1843). The first detailed map of Mullwitz Kees was created as early as 1866 (Keil 1866). The extent of the glaciated area on Mullwitz Kees has been recorded since the end of the LIA around 1850 by means of moraine mapping and in the years 1930, 1969, 1998 and 2009 (Figure 9, Table 1; Stocker-Waldhuber 2010).

Discussion and conclusions

Glacier monitoring in HTNP has a long history and tradition. As one of the few areas in the world where earliest glacier maps date back to the early 17th century and a wealth of dendrochronological evidence exists, the Hohe Tauern area has great potential for detailed studies on the Holocene and LIA climate history. These data are supplemented by excellent climate data from high elevation observatories. The ongoing mass balance programmes are geographically well distributed and provide a good data basis for numerical modelling. For the next decade these programmes should not only be kept in operation but more closely linked with ongoing ecological research. Moreover, the high visibility of glacier changes in the landscape can be put to good use for impressing on visitors of HTNP the variability of landscape changes within the Holocene, especially the rapid changes in recent times. Increasing efforts to visualize glacier changes from historical sources could be another attractive educational feature of HTNP.

Acknowledgements

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Table 1 – Area change of Mullwitz Kees between 1850 and 2009.

year	1850	1930	1969	1998	2009
area [km²]	5.49	4.52	3.52	3.24	3.03
% of the area 1850	100	82	64	59	55
period 1850–1930	1930–1969	1969–1998	1998–2009	1850–2009	
area change [km²]	−0.97	−1.00	0.28	−0.22	−2.47

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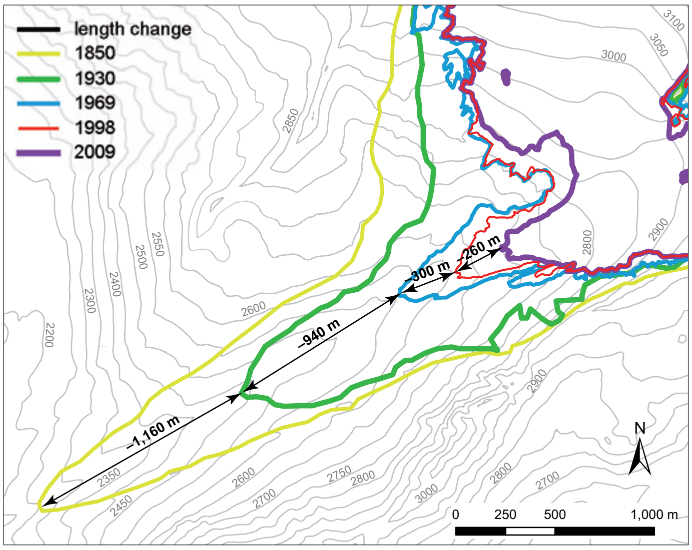

Figure 9 – Area change of the tongue of Mullwitz Kees between 1850 and 2009.

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