CLIMATE CHANGE INFORMATION AS DERIVED FROM LONG-TERM MEASUREMENTS OF WINTER AND SUMMER GLACIER MASS BALANCE

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Abstract: Glacier annual mass balance data (b_n) from nearly all regions of the world clearly show the wasting of the ice masses over the last decades and are therefore considered as good indicators of global warming. The separate determination of summer (b_s) and winter (b_w) balances, however, enables a better analysis of the driving climatological factors, i.e. air temperature as a proxy for the energy balance governing the ablation processes, and solid precipitation as the source of accumulation. b_n is or has been determined over longer or shorter periods for close to 300 glaciers worldwide, but b_w and b_s values are only available for approx. 50 glaciers, a majority of them lying in Scandinavia. For alpine glaciers, this data set is provided for just a few glaciers. One of them is Vernagtferner, Oetztal, Austria, where b_n, b_w, and $b_s = b_n - b_w$ are determined with the direct glaciological method annually since 1964/65. Other alpine glaciers with comparable records are, for instance, Glacier de Sarennes (France), Hintereisferner (Oetztal, Austria), Wurtenkees (Sonnblick, Austria), and Fontana Bianca glacier (Weißbrunnferner, Italy), although the latter two comprise much shorter periods than the other glaciers. The standard deviation of the average mass balances show that winter precipitation has not changed much over the last forty to fifty years in the Alps, and thus, the annual net mass balance is dominated by the weather conditions during the ablation seasons. For maritime Scandinavian glaciers like Ålfotbreen, excessive winter accumulation induces positive annual values in spite of excessive summer ablation.

Keywords: *mass balance, glaciers, climate*

1. INTRODUCTION

The retreat of alpine glaciers since the middle of the 19th century is generally considered as a good indicator of global warming. Although this wasting did not run continuously, and several periods with mass gains were observed, these years with positive mass balances did not reverse the general trend. From the end of the little ice age, i.e. around 1850, glaciers have reduced their masses by approx. 50%, their areas by approx. 30% on average.

The change in glacier size is determined by different methods. Most simple and therefore mostly used is the recording of the position of the glacier tongue, although this is a mixed signal, as the variation in glacier length combines glacier mass gains and losses on the one hand, and flow dynamics of the individual glacier, on the other hand. A more direct link between glaciers and climate change is provided by the mass balance determination over many years. For approx. 300 glaciers worldwide, the direct glaciological method is currently or has been applied for some periods. It delivers the change of ice mass at the end of the balance year, i.e. 30 September in the Northern hemisphere, as the difference between mass gains by solid precipitation and mass losses by melting in summer. These annual values do not allow to relate the ice mass changes to the weather conditions during the different seasons (Ohmura, 2004). This goal, however, can be achieved when the winter mass balance b_w is analysed separately at the end of the accumulation period and the summer balance b_s is calculated as the residual between total mass balance b_n and winter balance. This kind of analysis is performed for approx. 50 glaciers all over the world (Dyurgerov and Meier, 1999), but only for just a few ones in the Alps. The longest data set of winter and summer balance for a whole glacier (Glacier de Sarennes, France) starts in 1949 (Vincent et al., 2004) and runs without interruption since then. In the Central Alps, the longest total mass balance series is available for Hintereisferner, starting in 1952/53. The separation between winter and summer balance for this glacier, however, is based on modelling the summer balance with an energy balance approach (Kuhn et al., 1999), so the data are not strictly comparable to those glaciers, where the direct glaciological method is applied.

In this paper, this method is shortly described and the results are discussed with respect to the climatic evolution for the years since 1964/65 for Vernagtferner, the main research glacier of the Commission for Glaciology, Bavarian Academy of Sciences and Humanities (www.glaziologie.de). Then, a statistical comparison is made between several glaciers in the Alps and in Scandinavia in order to detect possible differences between differing climate regimes.

2. MASS BALANCE DETERMINATION FOR VERNAGTFERNER

2.1 Method

For Vernagtferner (Oetztal Alps, Austria, 2800 m a.s.l. – 3630 m a.s.l., area 9.5 km² in 1964, 8.36 km² in 2006), the data collection for the separate determination of winter and summer mass balances has been performed since the very start of the measurements in 1965. The data basis for the accumulation determination, however, varies to some degree. Whereas the total balance is based on roughly the same amount of ablation stakes (approx. 50), only few snow pits were dug and density measurements performed in the early years, and in the worst case the winter mass balance analysis was based on only three pits and a handful of depth soundings. The data set improved in the eighties and nineties, and since 1999, five density profiles and between 100 and 330 snow depth soundings provide a good coverage of the glacier area (Plattner et al., 2003/2004). A reanalysis of the whole data set was performed in 2006, which resulted in some corrections of earlier published data (Moser et al., 1986), and some data gaps could be closed (Escher-Vetter et al., 2005), so the whole series is determined with the same methodology, based on the surveyed altitudinal distribution of the winter snow cover.

2.2 Results

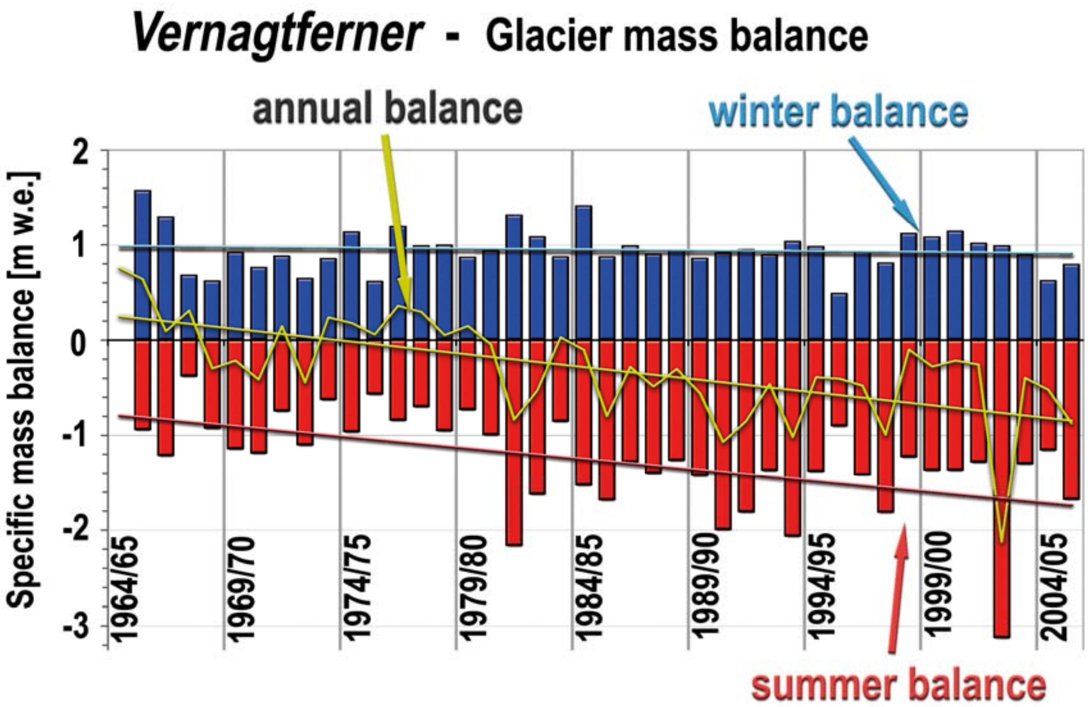

Figure 1: Time series of annual (yellow line), winter (blue columns) and summer (red columns) mass balance data and corresponding linear trends of Vernagtferner for the period 1964/65 to 2005/06, as determined with the direct glaciological method.

Over the whole period, the significant trend of the total mass balance results from the increase in summer ablation values, as the winter accumulation does not show a significant trend. The correlation coefficient between summer and total mass balance for the whole series is 0.82, between winter and total mass balance 0.04, i.e. no correlation at all. This is also documented by the averages and the standard deviations of the three time series, as given in the first line of Table 1: the standard deviation for the annual mass balances (501 mm water equivalent) is nearly the same as that for the summer balances (506 mm w.e.).

Tab.1 : Averages and standard deviations of annual <b_n>, σ_n, winter <b_w>, σ_w, and summer <b_s>, σ_s mass balance values, given in mm w.e., for five alpine and two Scandinavian glaciers. Data sources: * : Kuhn et al., 1999; #: Dyurgerov, 2002; ^ : pers. Comm. World Glacier Monitoring Service (www.wgms.ch); $: Munari et al., 2006.

	<b_n>	<b_w>	<b_s>	σ_n	σ_w	σ_s	Period of observation
Vernagtferner	- 330	950	- 1280	501	218	506	1964/65-2005/06
Hintereisferner*	- 416	909	- 1325	534	334	534	1952/53-1996/97
Sarennes #	- 668	1662	- 2266	909	565	756	1948/49-1994/95
Wurtenkees ^	- 790	1370	- 2170	475	300	530	1982/83-2000/01
Fontana Bianca $	- 940	976	- 1916	757	407	753	1991/92-2004/05
Storglaciären #	- 246	1452	- 1698	730	423	508	1945/46-1996/97
Ålfotbreen #	353	3795	- 3401	1268	1042	652	1964/65-1998/99

3. MASS BALANCE SERIES FOR OTHER GLACIERS

3.1 Alpine glaciers

The mass balance series of Hintereisferner (10.5 km² in 1953, 8.7 km² in 1997) was started in 1952/53, and Kuhn et al. (1999) give annual values of annual, winter and summer mass balances for the period 1952/53 to 1996/97. The averages and standard deviations (Table 1) depict the same feature as for Vernagtferner ($\sigma_n \approx \sigma_s$), although the components were determined by modelling the summer mass balance and calculating winter data as the residuals, and not by surveying winter accumulation as was done in the case of Vernagtferner. Futhermore, in the years since 1992/93, Bortenschlager (2006) took over the measurement programme of the Hintereisferner series up to 2004/05, and for this period, winter balances were measured directly, and summer balances could be determined as in the Vernagtferner case. For this period, the respective values amount to <b_n> = - 819 mm w.e., <b_w> = 1106 mm w.e., and <b_s> = - 1925 mm w.e., σ_n = 413 mm w.e., σ_w = 204 mm w.e., and σ_s = 443 mm w.e.. While the modelled averages are larger both for annual and seasonal data, the standard deviations are smaller than for the modelled period.

The longest mass balance record of an entire alpine glacier is available for the Glacier de Sarennes (0.5 km²) in the French Alps, starting in 1949, and even longer are the stake measurements on Claridenfirn, Switzerland, starting in 1914 at two representative points of the glacier. Vincent et al. (2004) give the standard variations of 440 mm w.e. (winter), 750 mm w.e. (summer) and 900 mm w.e. (annual value) for the 50 years of Sarennes data, which slightly differ from the Dyurgerov data in Table 1.

Auer et al. (2002) report the mass balance data of Wurtenkees (Sonnblick region, Austria), having a glacier size of 3.59 km² in 1850, and of 1.13 km² in 1998. The mass balance records start in 1982/83, and the separate analysis results in a correlation coefficient between winter and annual mass balances of 0.03, and 0.85 for the coefficient of summer to annual balance. This confirms the dominance of summer weather conditions on annual mass balance, as also analysed for Vernagtferner.

For a small glacier in South Tyrol, Ghiacciaio di Fontana Bianca (0.6 km²), winter and summer balance data have been determined since 1991/92. They also confirm the importance of the increasing summer ablation, although small winter accumulations like in 1994/95 also play their part in the continued negative mass balance values (Munari et al., 2006).

3.2 Scandinavian glaciers

Most of the available time series of winter and summer mass balances were analysed for glaciers in Scandinavia, and Storglaciären data from Sweden date back to 1945/46, those from Ålfotbreen in Norway to 1964/65 (Østrem and Haakensen, 1999). The comparison of σ_w, σ_s and σ_n for Ålfotbreen (Table 1, last line) reveals the different patterns of accumulation and ablation for this coastal region in southern Norway, as the extremely high σ_w of 1042 mm w.e. dominates the σ_n-value, whereas the σ-values for Storglaciären in northern Sweden are more like those from alpine glaciers, as it is situated on the lee side of the coastal mountains.

4. DISCUSSION AND CONCLUSIONS

For all but one glacier (Norwegian case), the small standard deviation of the winter mass balance series as given in Table 1 is a clear signal that winter precipitation did not vary considerably over the periods of investigation. This is not only valid for the glaciers from different parts of the Alps, but also for Storglaciären in northern Sweden. In spite of some single winters like e.g. 1966/67 and 1995/96, where accumulation dropped to values as low as 620 mm w.e. and 490 mm w.e. on Vernagtferner, or, for Fontana Bianca in 1995/96, with a value as low as 540 mm w.e. (Munari et al., 2006), we can state that since the 1980's the mass losses for most of the glaciers result from negative summer balances, i.e. large ablation rates caused by the rising energy absorption at the glacier surface. When we use air temperature as a proxy for the energy balance, we see a linear rise of 2.3 K in the summer averages (June-July-August) for the Pegelstation Vernagtbach site (2640 m a.s.l.) from 1974 to 2006. The average temperature rise for the months April to September for the period 1975 to 1999 amounts to 1.1 K for the Pegelstation, and this is in good agreement with the records from Sonnblick for the same seasons (Auer et al., 2002). Winter precipitation amounts for Sonnblick, on the other hand, even show a slight increase since the middle of the 1970, which is not detected in the Vernagtferner records. The absolute amounts of b_w in Table 1 are not strictly comparable, as the record lengths differ substantially between the glaciers, but even for the most westerly one, Sarennes, the average winter mass balance (1662 mm w.e.) is less than half of the Norwegian Ålfotbreen amount (3795 mm w.e.). And it is this high winter mass balance, which leads to an average total mass balance of 353 mm w.e., as the average summer mass losses of some – 3400 mm w.e. over more than thirty years would be devastating for any alpine glacier. This last comparison shows the importance of the separation of winter and summer mass balance of glaciers in order to detect the climatic signal more clearly.

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