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Eastern Alpine glacier activity and climatic records since 1860

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ABSTRACT. We have analyzed records of glacier-front variations, mass-balance reconstructions, temperature and precipitation data of Alpine stations, and found that the difference between summer and winter temperature in connection with winter precipitation is a useful indicator of glacier activity. Application of this parameter to the records of six stations since 1860 indicated the advance around 1920 had been preceded by a decade with frequent positive mass balances, while the period 1928–64 was characterized by increased climatic continentality and strong, uniform glacier retreats.

INTRODUCTION

Besides the impressive advances around 1850 and 1920 which affected the majority of Alpine glaciers, there were a number of minor events of varying intensity in the 1880s and 1890s, around 1900, in 1926 and from 1965 to 1985. Early observations indicated that advances could occur in some regions but not in others, and that within a given region individual glaciers could skip an occasion on which most of their neighbors would advance. In the following investigation we attempt to determine the extent to which the observed fluctuations can be explained by climatic conditions.

In particular, we were intrigued by a table in which Hess (1904, p. 261) depicted a wave of glacier advances going eastwards across the Alps from the Mont Blanc group in 1876 to Hohe Tauern in 1896, and likewise by Finsterwalder and Hess's (1926) report that Vernagtferner had been surging around 1900 but did not react to the favorable climatic conditions of the time before 1920, when about 75% of all observed Austrian glaciers were advancing.

Depending on their length, thickness, surface slope and mass-balance gradient, glaciers react to climatic forcing with different time-scales and reach maximum extent at different times, often reversing their trends before approaching equilibrium length. A convenient time-scale for the adjustment of a glacier to a new climatic condition is the volume time-scale (Jóhannesson and others, 1989) which indicates how long it takes a glacier to reach 67% of its new equilibrium volume. It is determined by the ratio of maximum thickness to net balance at the snout. At the turn of the century most eastern Alpine glaciers had maximum thicknesses of less than 300 m and terminus balances of less than 10 m net ablation, yielding volume time-scales of several decades.

If there had been a single, step-like change in climate or mass balance, say, in the year 1880, the wide spectrum of sizes, slopes and mass balances of the Eastern Alpine glaciers would have resulted in a general advance, with arrival times at the new equilibrium sizes spread over several decades during the 20th century. In reality, however, we observed quite different, short-term events, three of which will be discussed here.

The first kind is the simultaneous advance of many glaciers peaking in nearly simultaneous maximum extent, followed by a retreat period. This is best explained by a succession of negative after positive forcing, as a single, positive step would not produce any sharp peak in the advance statistics. In the Alps the years around 1920 and 1980 are good examples, the emphasis being on the reversal in forcing and a qualitatively uniform reaction of the majority of glaciers.

The second kind is a regionally restricted event in which most of the glaciers of a smaller region advance. Hess's (1904) systematic eastward progression of advances, if real, would belong to this category which ought to be explainable in climatic terms.

The third kind involves a non-linear reaction to the climatic forcing, such as the surge of Vernagtferner in 1900–02 (Finsterwalder and Hess, 1926), the accelerated mode of flow of Hintereisferner in 1920, 1943 and 1979 (Span and others, 1997) or any other case where the dynamic reaction is more than proportional to a change in forcing. This type of reaction will remain restricted to individual glaciers and does not allow a straightforward interpretation of climatic causes.

In the investigation of these events, we emphasized the glaciers of the Eastern Alps and referred to only two relatively small western glaciers, Sarennes and Rhone. In the time domain we chose to exclude the so-called 1850 advance, as it was so strong that it did not leave any easy east/west or regional differentiation. Also, precipitation records, which are crucial for the interpretation, are not available for the central Eastern Alps before 1858, when the monks at Marienberg started their diligent daily duty.

DATA SOURCES

We have mentioned the summaries of Hess (1904) and Finsterwalder and Hess (1926) as sources for the earlier part of the period of our investigations. They report that while Vernagtferner had surged and barred the Rofen valley,

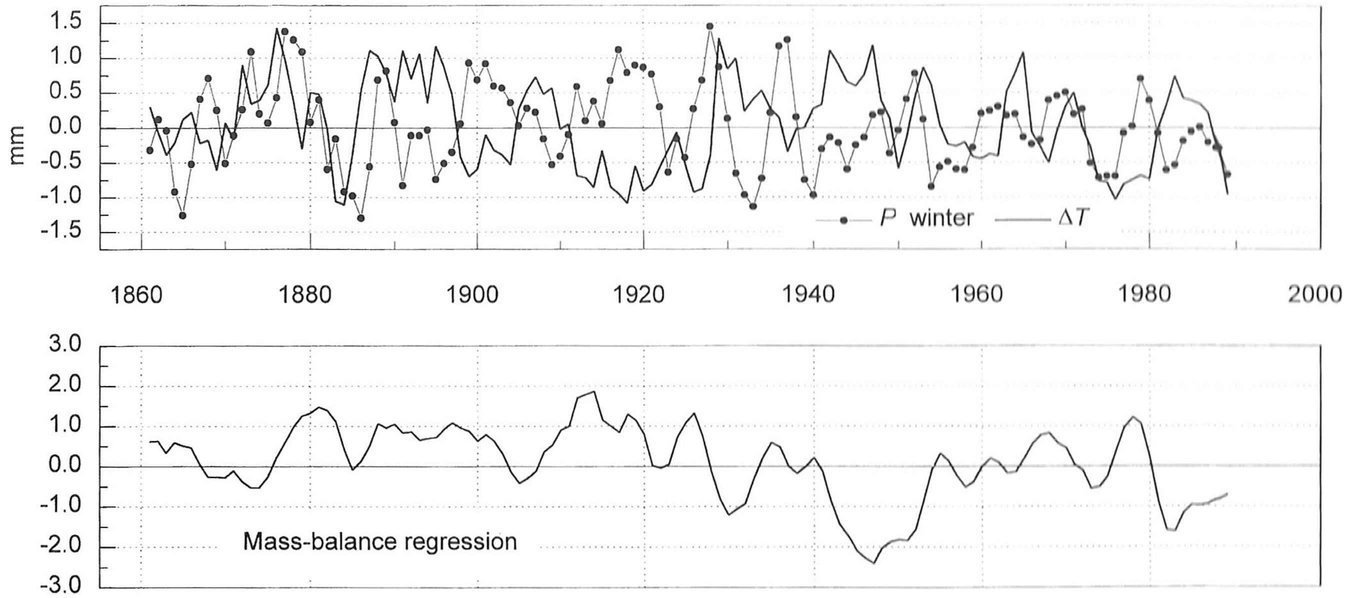

Fig. 1. 3 year running means of summer minus winter temperature at Vent, winter precipitation at Marienberg and a regression of the mass balance of Hintereisferner from records of the same stations. The diagrams show deviations from the 1861–1989 mean divided by the respective standard deviations. Mass-balance values were calculated according to Equation (1).

damming up a lake which catastrophically broke out in 1600–01, 1678–81, 1771–74 and 1845–48, it advanced "without damage" in 1817–20 and 1900–02, reaching its greatest extent in 1902 and its highest terminus velocity of 280 m year^{-1} in 1899. Hintereisferner, which was about 10 km long, had an advance of 60 m from 1917 to 1920, but did not advance around 1928 when it had 3 years of positive mass balance and other glaciers had small advances (Heuberger, 1977; Span and others, 1997).

Hess (1904) states the following periods of advance at the end of the century:

Mont Blanc: 1876–89
Vallais: 1879–93
Bernese Alps: 1880–88
Bernina: 1896 (Rosegg glacier only)
Ortler: 1884–93 (including Suldenferner which may have surged around 1900)
Ötztaler: 1892–1901
Zillertaler: 1892–1896
Hohe Tauern: 1896–1901

This series, which implies a sequence of events, has little support from climate records, however, and deserves critical consideration.

Heuberger (1977) evaluates the morphology of part of the Zillertaler Group and finds maximum extents at

Hornkees: "1890", 1901, 1923, 1928
Waxegg: "1890", 1902, 1923, 1928.

While a study by Hoinkes and others (1975) that relies on annual measurements of glacier length in that area does not confirm the 1928 data, it corroborates Hornkees as the fastest-reacting glacier in that area.

Further summaries of Eastern Alpine glacier extents are given by, among others, Patzelt (1970, 1973) and the annual reports of the Comitato Glaciologico Italiano, the Swiss Glacier Commission (e.g. Aellen and Herren, 1992) and the Austrian Alpine Club, all contained in *Fluctuations of Glaciers* (e.g. Haeberli and Hoelzle, 1993).

A CLIMATIC INDEX FOR GLACIER ACTIVITY

In order to establish the climatic conditions favorable to enhanced glacier activity, a suitable combination of simple climate data needs to be selected that is insensitive to errors in old records and to long-term drifts of local measuring situations or instrument properties. We argue that the difference between summer and winter temperature fulfills that condition and serves the climatological purpose, in that it expresses continental or maritime influence: small differences between summer (June–August) and winter (December–February) temperatures imply mild winters and cool summers, both of which are favorable to glacier mass balance, while large temperature differences imply hot summers and cold winters with negative influence on mass balance.

In the Alps, mild winters often have more snowfall than cold winters; for example, the 3 year running means of winter temperature and winter precipitation at Vent station during the years 1917–56 have a correlation coefficient of 0.58. We checked the validity of the temperature difference as mass-balance index by adding the relative values of winter (November–April) precipitation of Marienberg to Figure 1. In many cases, notably in the period 1890–1925, maxima of winter precipitation coincide with minima in the summer/winter temperature differences.

The third curve in Figure 1 is a regression of annual mean specific mass balance (b) of Hintereisferner with the winter precipitation of Marienberg (P_{wi}) and the summer temperatures of Vent (T_{su}), calibrated with data of 1952–92 according to Schlosser (1996) in rounded figures:

$$b = 4060 - 600T_{\mathrm{su}} + 2.0N_{\mathrm{wi}} \,. \qquad (1)$$

Marienberg is situated 20 km southeast of Hintereisferner at 1400 m elevation. Vent is situated 10 km to the northeast at 1900 m elevation.

The correlation between the variables of Figure 1 is time dependent and reflects changes in the Alpine climate on a scale of several decades, as indicated by Table 1. All three had large excursions in the period 1876–96, but correlation coefficients remained low. From 1890 to 1920, when mass balance was predominantly positive, the high correlation of winter precipitation with the summer/winter temperature differences is striking, as is the insignificance of winter precipitation for the mass balance. The latter seems to be more important in the most recent advance period, 1965–85, which also has the highest correlation of the summer/winter temperature differences with mass balance.

ARE THERE ANY REGIONAL DIFFERENCES?

Since Hess's table seemed to imply a regional differentiation of advances, we checked the continentality of six Alpine stations from Basel to Vienna by comparing their summer/winter temperature differences.

The altitude and location of the six stations are as follows:

Basel	47°36′ N,	7°30′ E,	270 m a.s.l.
St Bernard	45°52′ N,	7°10′ E,	2460 m a.s.l.
Vent	46°52′ N,	10°56′ E,	1900 m a.s.l.
Innsbruck	47°16′ N,	11°24′ E,	580 m a.s.l.
Sonnblick	47°03′ N,	12°57′ E,	3106 m a.s.l.
Vienna	48°15′ N,	16°22′ E,	203 m a.s.l.

The time series in Figures 2 and 3 are very similar to each other, especially in the time of occurrence of extremes. Translated into glaciology this implies a regionally homogeneous field of advances and retreats in the past 130 years when interpreting climatic data. Real mass-balance data analyzed by Letréguilly and Reynaud (1990) indicate that since 1952 simultaneous mass-balance changes have prevailed in the Alps if longer-term trends are subtracted.

From Figures 2 and 3 it appears that major changes have occurred simultaneously all over the Alps, while minor changes may display local or regional peculiarities (Kuhn and others, 1985). The high-altitude stations of Figure 3 have a lower mean temperature difference, as would be expected, and a lower variance which may be due to a lower incidence of winter inversions; by all means they are more representative for glaciers than the low-level stations of Figure 2.

Table 1. Correlation coefficients between annual mass balance of Hintereisferner, b (Equation (1)), summer/winter temperature difference at Vent, ΔT, and winter precipitation at Marienberg P_{wi}, for selected periods

	1876–96	*1890–1920*	*1965–85*	*1861–1989*
P_{wi}/b	0.41	0.09	0.53	0.20
$\Delta T/b$	−0.10	−0.40	−0.51	−0.33
$P_{\mathrm{wi}}/\Delta T$	0.17	−0.80	0.05	−0.15

Possible regional differences were further investigated by comparing the time series of annual precipitation of four central Alpine stations, Marienberg and Vent in the East and Reckingen and Andermatt (Müller-Lemans and others, 1995) in the vicinity of Rhone glacier, in Figure 4. As well as significantly different mean values, the two groups had different amplitudes and sometimes opposite extremes.

In particular, we found confirmation of regional differences in the precipitation records around 1890 and 1900. These were in agreement with the statistics of front positions given by Aellen and Herren (1992) for the Swiss Alps and by Patzelt (1970) for the Austrian Alps. While both sources indicate about 75% of all observed glaciers were advancing around 1920 and 1980, only about 25% of the Austrian but 50% of the Swiss glaciers were advancing in the 1880s.

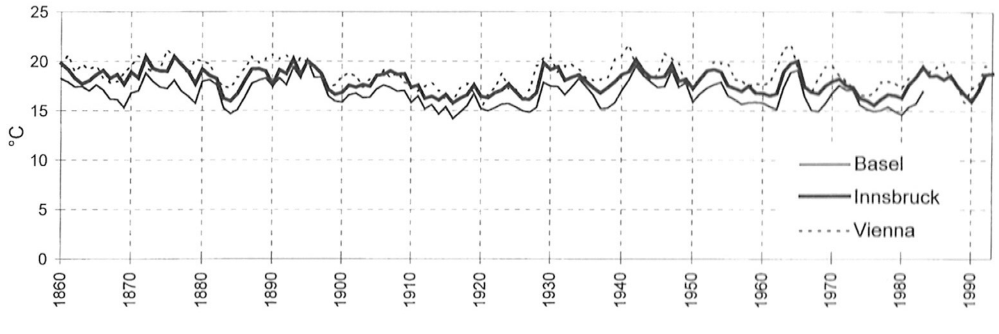

Fig. 2. 3 year running means of summer minus winter mean temperature at Basel, Innsbruck and Vienna.

Fig. 3. 3 year running means of summer minus winter temperature at St Bernard, Vent and Sonnblick.

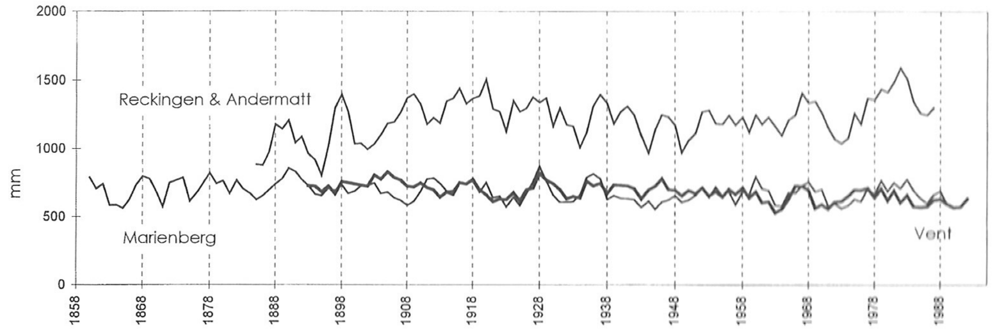

Fig. 4. 3 year running means of annual precipitation at Marienberg, at Vent and at Reckingen and Andermatt in central Switzerland (Müller-Lemans and others, 1995; Schlosser, 1996).

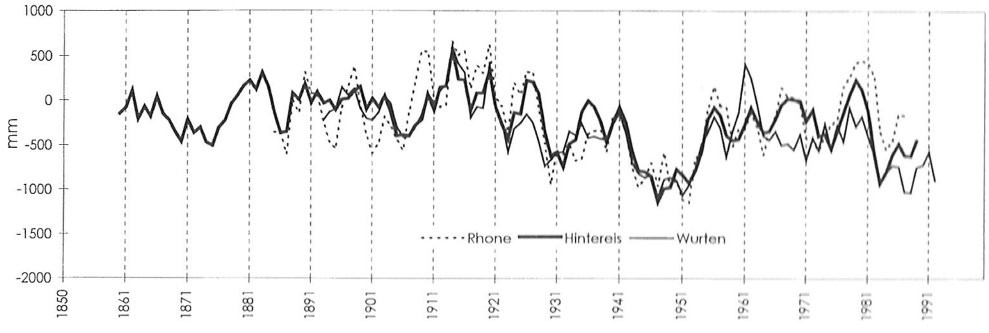

Fig. 5. Reconstructed mass-balance series of Rhone, Hintereis and Wurten glaciers (Hammer, 1994; Müller-Lemans and others, 1995; Schlosser, 1996).

COMPARISON WITH MASS-BALANCE RECONSTRUCTIONS

In recent years a growing number of mass-balance series have been reconstructed using climatic records in P, T models or in linear regressions. Their ability to reproduce extreme positive values is somewhat limited, as these were missing during the calibration periods, but in general they give useful additional climate information.

We used such series of Glacier de Sarennes (Martin, 1978), Rhone glacier (Müller-Lemans and others, 1995), Hintereisferner (Schlosser, 1996) and Wurtenkees (Hammer, 1994) to apply a final check on the mass-balance situation at the end of the 19th century. Rhone, Hintereis and Wurten glaciers are entered in Figure 5.

As in the temperature data of Figures 2 and 3, the years around 1885 stand out clearly in the mass-balance series of Hintereis and Rhone glaciers. In subsequent decades, however, Rhone glacier has larger amplitudes than Hintereis and Wurten, while Rhone and Hintereis correlate very well from about 1920 to 1975.

CONCLUSIONS

From the records of glacier-front variations, from mass-balance reconstructions, temperature and precipitation data, we conclude that glacier activity since 1860 has been generally homogeneous throughout the Alps. There is, however, a short period at the end of 19th century when regional variability of precipitation may have translated into regionally differing accumulation, although a systematic progression from west to east was not found. Hess's data in that respect may have suffered from averaging over sparse observations and may be considered an artifact.

By the last two decades of the 19th century, glaciers had nearly reached equilibrium size after a rapid decrease following their mid-century maxima. In that healthy state, local topography and local climate may have prompted individual glaciers to advance, spending their reserves in one advance so that they were not able to react to the next favorable phase, as is well documented for Vernagtferner which advanced in 1900 but not in 1920.

Following the 1920 advance period, Alpine glaciers were not so close to equilibrium as before or as they were from 1965 to 1985. Judged by the large differences between summer and winter temperature, the period 1930–64 was dominated by higher continentality, strong retreat and rather uniform reaction of all Alpine glaciers.

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