SYNOPTIC CLIMATOLOGY OF EASTERN ALPINE GLACIER BEHAVIOUR, 1966-1990

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INTRODUCTION

The mass balance of a glacier is a direct measure of its "state of health". It is governed by the climatic conditions of the balance year, which are in turn a consequence of the weather conditions. The frequency, duration and intensity of synoptic weather conditions determine accumulation during winter and ablation during summer. As a consequence, synoptic climatology can provide some interesting background information about the climatic causes of glacier behaviour (e.g. Hoinkes 1968, Wakonigg 1971, Dreiseitl 1983, Yarnal 1984).

In this paper, the climatic background of years with very positive and very negative mass balances of glaciers in the Eastern Alps (Tab. 1) will be discussed from a synoptic-climatological point of view. More tentatively, some aspects of weather conditions in earlier years will be discussed as well. The basis for the discussion are the mass balance series of Hintereisferner (Ötztal Mountains, Tyrol) and of Stubacher Sonnblickkees (Hohe Tauern, Salzburg). Hintereisferner (Kuhn et al. 1979) is situated at the alpine main ridge in the rather continental central Ötztal Alps, whereas Stubacher Sonnblickkees (Slupetzky 1989, 1991-93) on the northern slope of the Hohe Tauern group is situated in a more oceanic environment.

Table 1: Years with highly positive ("good") and negative mass balance ("bad"), 1966-1990

	good years	bad years
Hintereisferner	1967/68, 76/77, 77/78	1972/73, 81/82, 89/90
Stubacher Sonnblickkees	1973/74, 77/78, 79/80	1972/73, 81/82, 85/86

WEATHER TYPES

The weather classification system used is based on an "Alpenwetterstatistik" approach similar to that used in Switzerland by the Swiss Meteorological Office (Schüepp 1968). Among others, it contains data on surface air flow, 500 hPa airflow and the altitude of the 500 hPa surface. Details of the "calendar" can be found in Kerschner (1989). For the period 1966-1983, it contains also data on the weather character (anticyclonic, mixed, cyclonic) in the Eastern Alps, which is determined from cloudiness and precipitation at 9 selected meterological stations. The classification starts on a daily basis with January 1, 1966 and is presently available for the period 1966-1995.

The weather types used in this paper (Tab. 2) are classified according to surface airflow (db), 500 hPa airflow (dd) and the anomaly of the altitude of the 500 hPa surface (Δ500) relative to the daily normals of the period 1966-1983. Eight directional classes (NE, E, ... , NW, N) and a class for weak pressure gradients (0) describe the airflow at both levels. Well-developed low pressure systems at the surface are classified separately. Advective weather types are first classified according to the surface air flow. If the surface pressure gradient is weak, the 500 hPa airflow is used. If both surface and 500 hPa air flow is weak, the weather type is classified as convective. In the next step, advective and convective weather types are classified according to the anomaly of altitude of the 500 hPa surface. If Δ500 is within the lower quartile of the frequency distribution, the weather type is labelled as "cyclonic" (-), if it is within the upper quartile, as "anticyclonic" (+). All other cases are included in the "mixed" class. For example, a stable anticyclone with weak pressure gradients at both levels is classified as "+H0", a situation with weak surface pressure gradient, westerly air flow at 500 hPa and Δ500 around zero is classified as "w", and northwesterly surface airflow with Δ500 in the lower quartile range as "-NW". In total, 52 different weather types are classified (Tab. 2), which can be combined into a smaller number according to statistical and/or synoptic criteria. For example, classes with surface airflow and 500 hPa airflow can be combined, thus reducing the number of weather types to 28. This weather classification should not be confused with the formally similar "Witterungslagen"-system (Schüepp 1968), which is established in a different way.

Table 2: Weather classification system.

	Δ 500 hPa		
	≥ upper quartile (+)	± 0	≤ lower quartile (-)
db and dd weak	+H0	F0	-L0
surface airflow			
North	+N	N	-N
Northeast	+NE	NE	-NE
etc.			
West	+W	W	-W
Northwest	+NW	NW	-NW
well developed surface low	T		
weak surface pressure gradient:			
North	+n	n	-n
Northeast	+ne	ne	-ne
etc.			
West	+w	w	-w
Northwest	+nw	nw	-nw
well developed 500 hPa low	-L0		

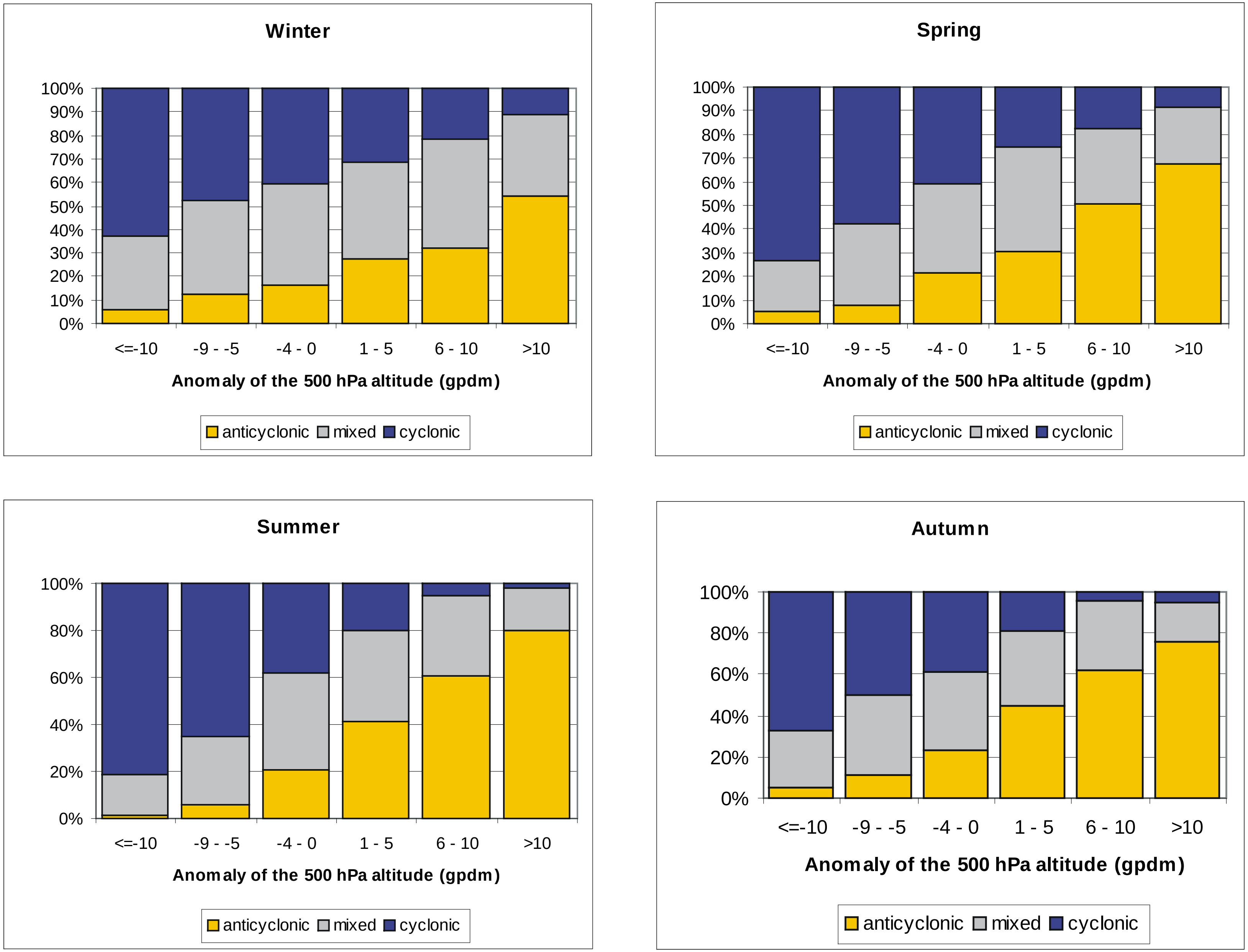


Fig. 1: Weather character and anomaly of the 500 hPa altitude (1966-1983).

ANOMALY OF THE 500 HPA ALTITUDE

The anomaly of the 500 hPa altitude, which is used for the weather classification system, is a good parameter for the general weather character (Fig. 1). Therefore, weather types with an anomaly within the upper quartile of $\Delta 500$ can be labelled as "anticyclonic", those with an anomaly around zero as "mixed", whereas an anomaly within the lower quartile normally indicates "cyclonic" weather character.

With the help of the air pressure and temperature data of the Sonnblick observatory (3106 m) it is possible to reconstruct the altitude of the 500 hPa surface over the Eastern Alps for older periods. During the calibration period 1966-1990, the difference of the monthly means between observed and calculated values is less than 1 gpdm. Then it is possible to estimate the relative frequency of anticyclonic and cyclonic weather back to 1887 (Fig. 2).

Fig. 2 shows a striking agreement between the number of days with cyclonic and anticyclonic weather character and the ELA of Hintereisferner (Kerschner 1997) on the one hand and the percentage of advancing glacier tongues in the Eastern Alps (Patzelt 1979) on the other hand. The extremely high position of the ELA in 1947 seems to have been caused by an unusually high frequency of anticyclonic weather in late spring (April-May). Bad summer weather conditions during the years around World War I led to the marked glacier advance of "1920", which was followed by a long period of glacier recession. In the late 1960s and early 1970s glaciers were small enough to be close to equilibrium. A slight increase in cyclonic weather then caused an advance period (Patzelt 1985), which was terminated by an increase of anticyclonic conditions during the summer months from 1982 onwards.

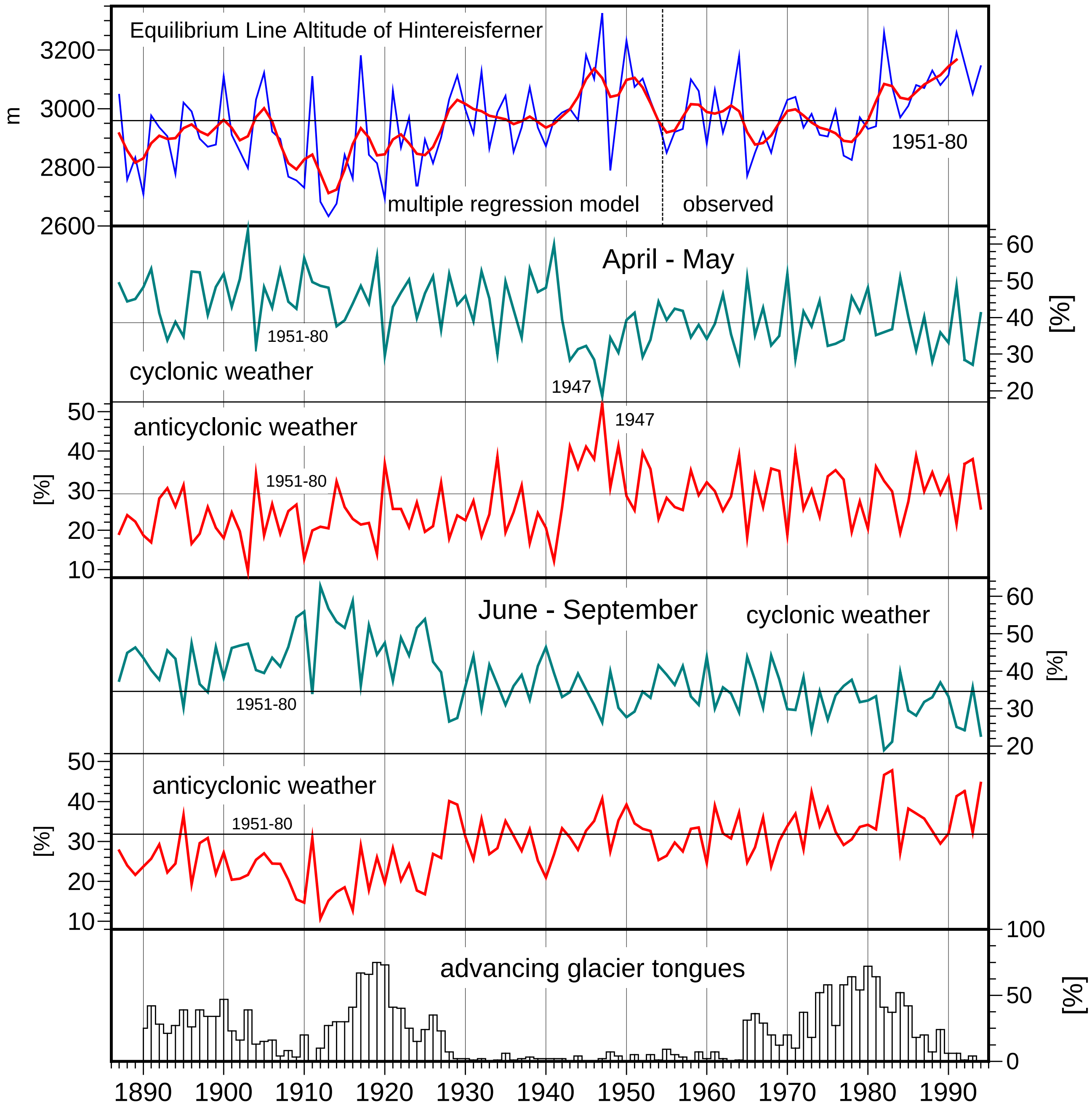


Fig. 2:

Frequency of cyclonic and anticyclonic weather, equilibrium line of Hintereisferner and percentage of advancing glacier tongues.

CLIMATE ELEMENTS AND WEATHER TYPES AT THE SONNBLICK OBSERVATORY

Ablation during the summer months is governed by the energy supplied by the radiation balance (short wave and long wave) and by the turbulent fluxes of sensible and latent heat (Kuhn 1981, 1989). For the purpose of this paper, global radiation can be expressed as a function of cloudiness and the long wave radiation balance can be regarded as a function of air temperature and hence the altitude of the zero degree level. The sensible heat flux is also a function of air temperature, whereas the latent heat flux depends on the vapour pressure difference between the glacier surface and the surrounding atmosphere. Assuming a constant glacier surface temperature of 0°C, condensation and hence a transfer of latent heat towards the glacier occurs, if the vapour pressure (e) is higher than 6.11 hPa, whereas sublimation takes place, if e is below 6.11 hPa. In that case, energy is transferred from the glacier to the atmosphere and the glacier surface is effectively cooled. At an air pressure of 700 hPa (ca. 3100 m a.s.l.), a vapour pressure difference of 1 hPa is equivalent to about 2 K. Fig. 3 and 4 show the daily means of the altitude of the zero degree level, of vapour pressure and of cloudiness for the different weather types (cf. Fliri 1965). Data of the Sonnblick observatory (3106 m) were used for the calculations.

During the early part of the ablation period (May - June), vapour pressure is rather low. For almost all weather types, the vapour pressure difference is negative, thus counteracting the effect of already positive temperatures and the radiation balance. This should be taken into account, when degree day models for ablation are calibrated (e.g. most recently Braithwaite and Zhang 2000). It should, however, be noted that the daily normals of e rise steeply from the beginning of May to the end of June. Therefore, Fig. 3 probably represents best the conditions at the end of May / beginning of June.

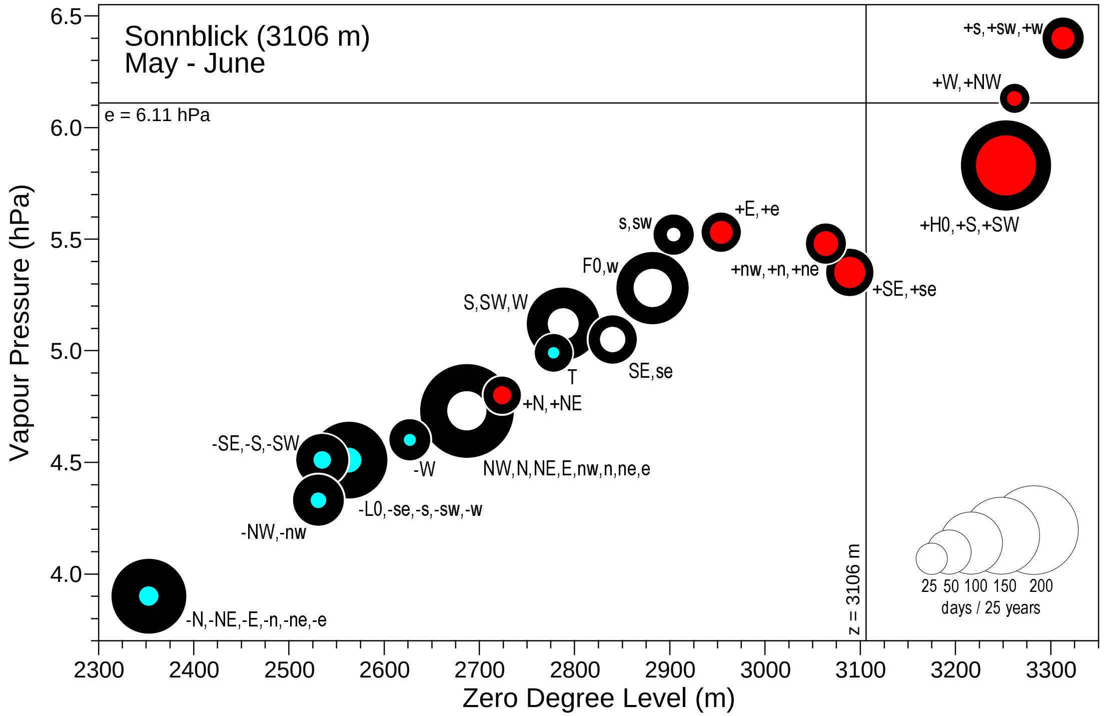


Fig. 3:

Synoptic-climatological diagram of zero-degree-level, vapour pressure and cloudiness, May - June.

Inner circles indicate sunshine duration (100-cloudiness,%).

Red: Anticyclonic weather types, blue: cyclonic weather types.

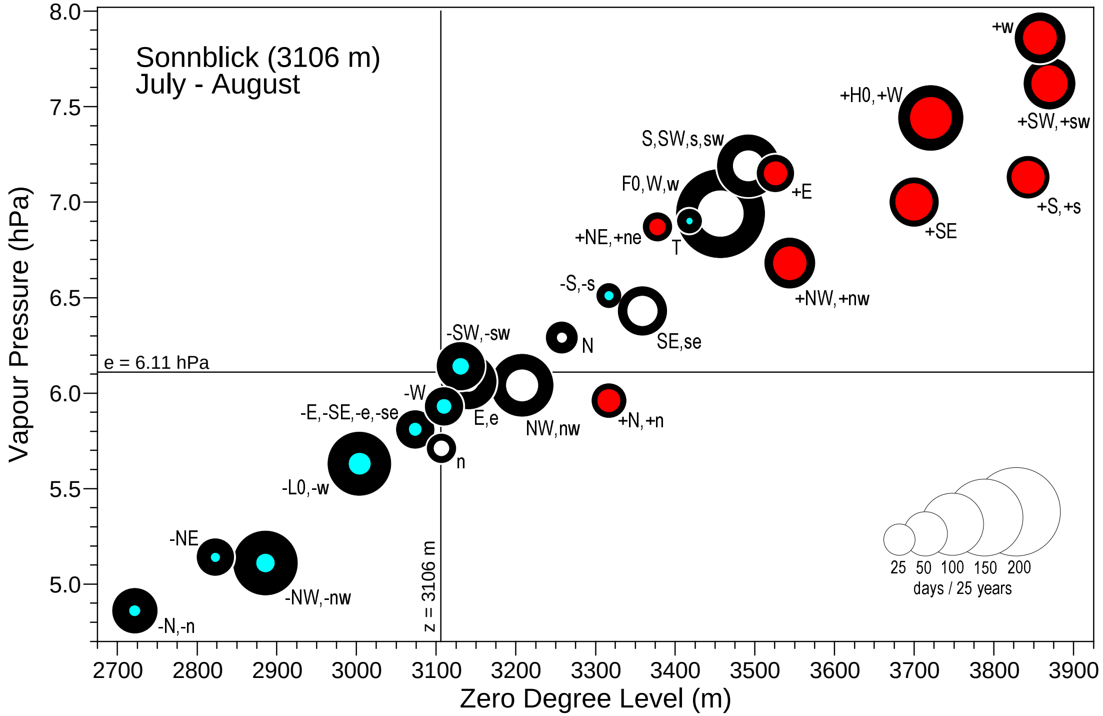


Fig. 4:

Synoptic-climatological diagram of zero-degree-level, vapour pressure and cloudiness, July-August.

Inner circles indicate sunshine duration (100-cloudiness,%).

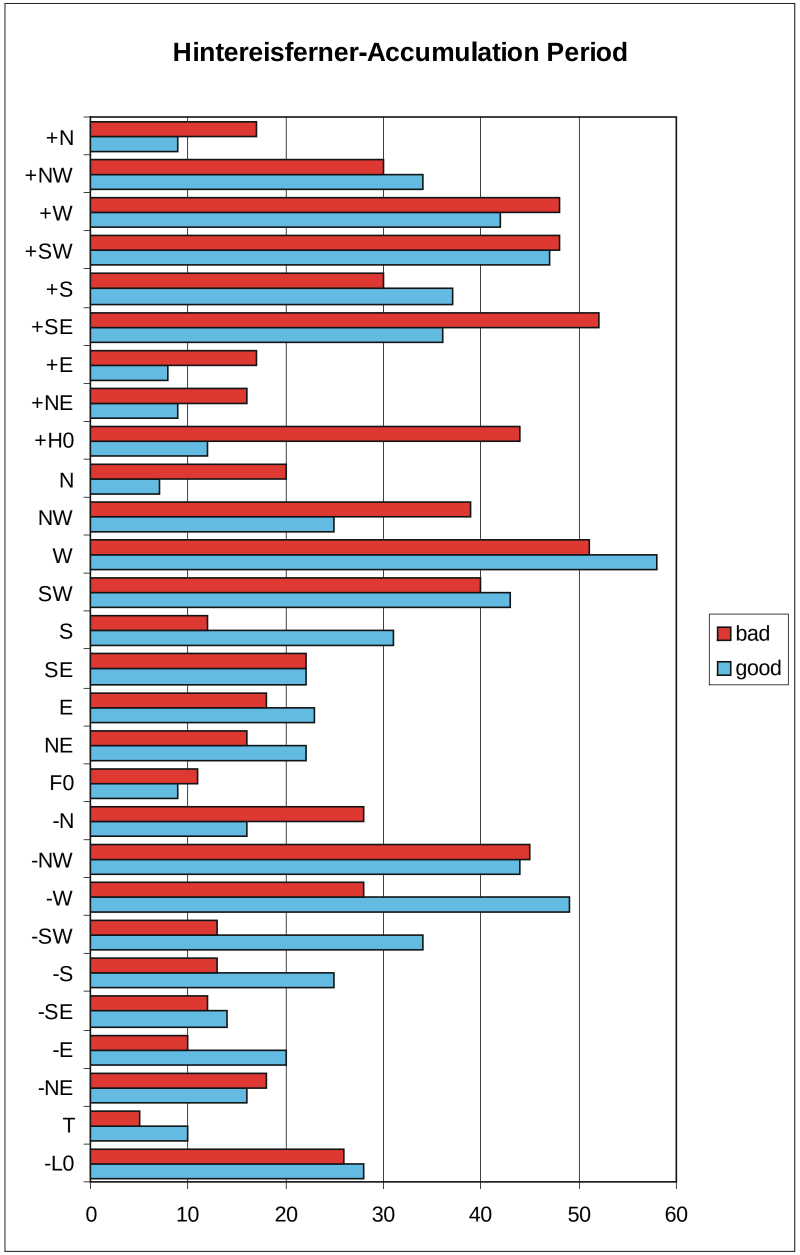
Red: Anticyclonic weather types, blue: cyclonic weather types.

During July and August, the zero degree level and vapour pressure are generally high. The most favourable ablation conditions are caused by westerly and southwesterly anticyclonic weather types (+w,+sw,+SW,+W) and by stable anticyclones (+H0). Similar altitudes of the zero degree level, but slightly dryer conditions are typical for anticyclonic southerly (+s,+S) and southeasterly weather types (+SE,+se). Mixed southerly, southwesterly and westerly weather types are also warm and humid. Cold weather with low values of vapour pressure is typically associated with cyclonic northerly and northwesterly airflow and with those weather types, which are normally connected with cyclonic activity in the Mediterranean (-NE - -SE).

WEATHER TYPE FREQUENCY

A comparison of the weather type frequency between "good" and "bad" years at Hintereisferner and Stubacher Sonnblickkees shows clear differences in the weather type frequency and between the two glaciers (Fig. 5). At Hintereisferner, the accumulation period of bad years are characterised by a high frequency of anticyclonic weather types, in particular +H0 and +SE, which cause dry, sunny and sometimes also rather warm weather. The accumulation period of good years is characterised by a relatively large number of days with mixed or cyclonic southerly to westerly airflow (S,SW,W,-S,-SW,-W). This reflects the fact that accumulation in the central Ötztal Alps is largely influenced by air masses coming from the South. During the ablation period of bad years, anticyclonic weather types are also more frequent. In particular, stable anticyclones (+H0) and anticyclonic southwesterly air flow (+SW) are more frequent. To a lesser degree, mixed westerly and northwesterly types and situations with weak gradient occur more often. Positive years show a much higher frequency of cyclonic weather types, most of all -W, -SW and easterly airflow (-NE,-E,-SE), which is associated with cyclonic activity in the Mediterranean.

At Stubacher Sonnblickkees, the accumulation period of bad years shows roughly the same picture as at Hintereisferner with a higher frequency of anticyclonic southwesterlies. Good years show a higher frequency of S, SE, -W and -SW. However, the difference between good and bad years during the accumulation period is not so clear as for Hintereisferner. The ablation period of bad years is dominated by a generally higher number of anticyclonic weather types. During good years, there is a clear dominance of -NW, -W and -SW, showing the typical pattern of bad summer weather at the northern slope of the Hohe Tauern mountains.



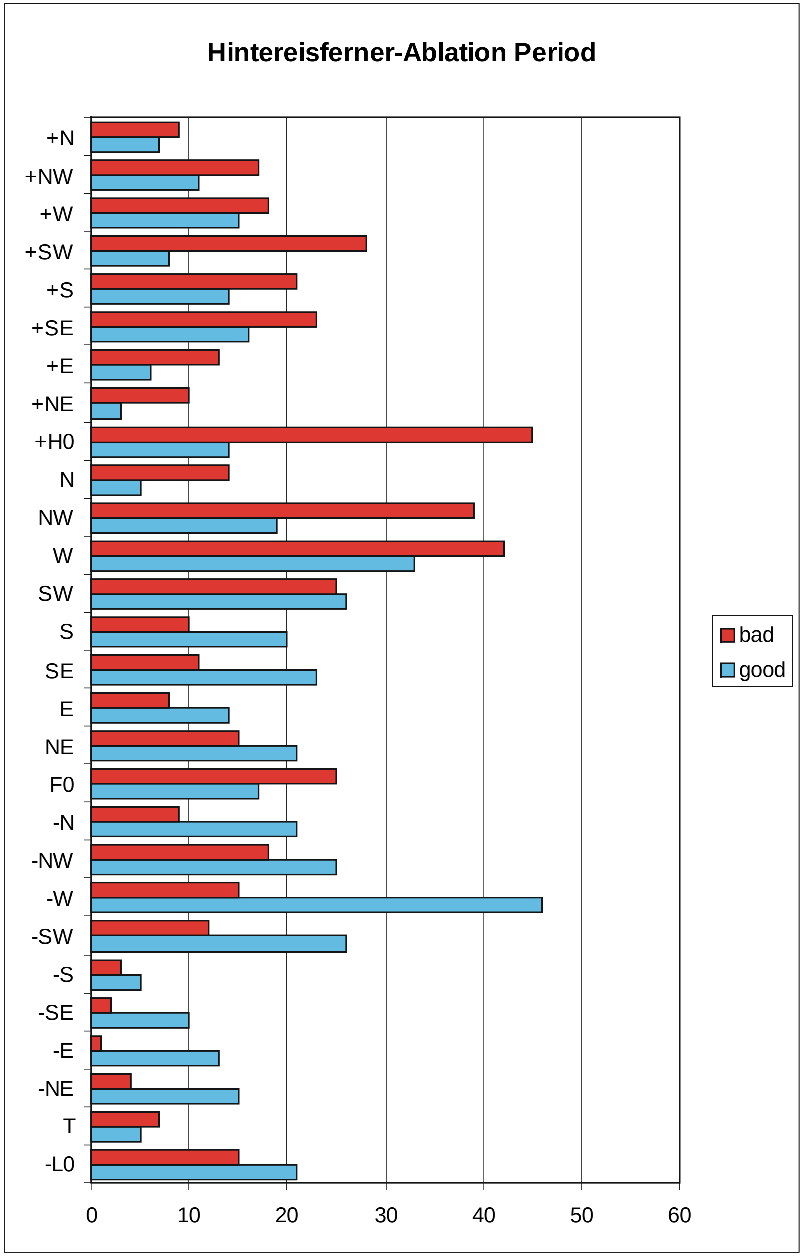
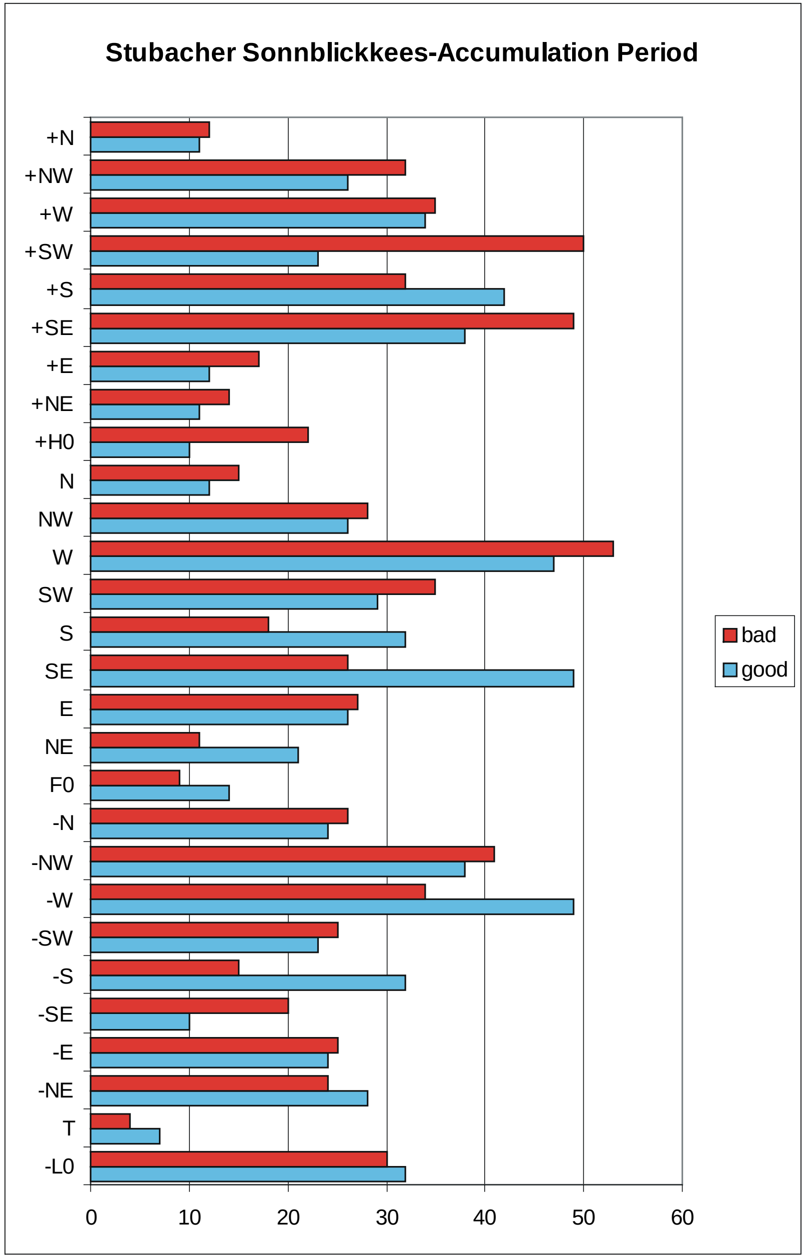


Fig. 5:

Weather type frequency during the accumulation period (10-5) and ablation period (6-9) of good and bad years at Hintereisferner and Stubacher Sonnblickkees.



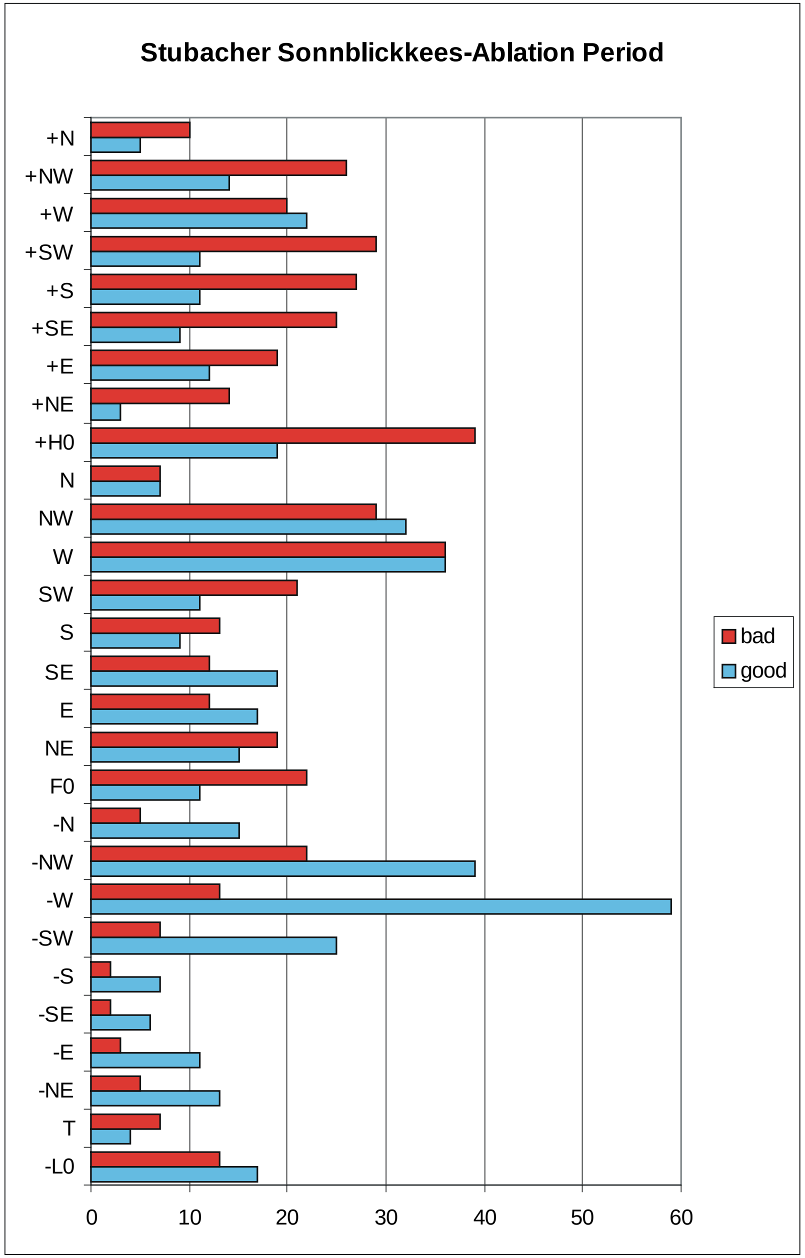


Fig. 5 continued

CONCLUSIONS

Some conclusions can be drawn as follows:

- A weather type classification, which is based on surface airflow, 500 hPa airflow and the anomaly of the 500 hPa altitude on a regional scale seems to be a useful tool to describe the synoptic background of mass balance fluctuations in the Eastern Alps.
- The 500 hPa anomaly can be used to reconstruct the frequency of anticyclonic and cyclonic weather character back in historical times.
- Weather types, which are highly ablation effective are not only characterised by high temperatures, but also by a highly positive vapour pressure difference during July and August. This should be taken into account for the calibration of degree day models.
- Generally, bad years with highly negative mass balance values are caused by a higher than normal frequency of anticyclonic, warm and humid weather types during the ablation period, whereas good years come along with a higher frequency of cyclonic and cold weather with negative vapour pressure differences.
- The well known fact that years with positive mass balance in the central Ötztal Alps are associated with a higher frequency of cyclonic southerly to westerly airflow can be supported. The abundance of anticyclonic weather during the accumulation period of bad years at Hintereisferner also suggests that highly negative mass balance values are caused by a significant lack of accumulation.
- Good years at Stubacher Sonnblickkees are mainly caused by a predominance of cyclonic westerly to northerly airflow during the ablation period, whereas bad years are caused by a general dominance of anticyclonic conditions during the ablation period. Weather conditions of the accumulation period seem to be of lesser importance.

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