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AN EXCEPTIONALLY NEGATIVE MASS-BALANCE OF A SMALL ALPINE GLACIER

ABSTRACT: KASER G., ZINGERLE CH., OBERSCHMIED CH. & MUNARI M., *An exceptionally negative mass-balance of a small Alpine glacier.* (IT ISSN 0391-9838, 2001).

On Weißbrunnferner/Ghiacciaio di Fontana Bianca in the Ortles-Cevedale group, mass balance studies have been made since 1983/84 with a three year interruption. In 1997/98, the mass balance reached its negative record with –1610 kg m^{-2}, being about 1.5 times the former record. Neither the temperature recorded at nearby weather stations, nor particular accumulation deficits can offer an explanation for the exceptional process. Yet, compared to the other years, the vertical mass balance profile was markedly different, indicating distinctly increased ablation in the glaciers' higher zones. This can be explained by the consumption of almost the entire firn body over the last several years when the annual equilibrium line remained above the highest peaks. As a consequence, dust, accumulated over many years, became concentrated on an impermeable layer, changing the surface albedo distinctly. The lack of summer snowfall may be an additional reason for increased ablation. A 0.1 to 0.15 decrease in albedo can explain the increased ablation in the former firn zone of the glacier. Such sudden changes of surface properties can be expected during any period of strong glacier retreat and can lead to markedly wrong conclusions when deducing a previous climate from glacier fluctuations.

KEY WORDS: Glacier mass balance, Climate, Albedo, Alps.

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Dal 1983/84, con un'interruzione di tre anni, viene svolto lo studio del bilancio di massa sul Ghiacciaio di Fontana Bianca, nel gruppo Ortles-Cevedale. Nel 1997/98 il bilancio di massa raggiunge il suo record negativo con –1610 kg m^{-2}, superando di una volta e mezzo il record precedente. Né le temperature rilevate alla stazione meteorologica vicina, né il particolare deficit di accumulo possono offrire una spiegazione sufficiente per questo straordinario andamento. Tuttavia, il profilo verticale del bilancio di massa, comparato con altri anni, è stato decisamente diverso, indicando un marcato aumento dell'ablazione alle quote più elevate del ghiacciaio. Ciò può trovare spiegazione nello scioglimento di quasi tutto lo strato di *firn* nel corso degli ultimi anni, quando la linea annuale di equilibrio (EL) rimase al di sopra della quota massima del ghiacciaio. Come conseguenza, il pulviscolo accumulato per molti anni si è depositato su uno strato impermeabile, modificando sensibilmente l'albedo di superfice. La mancanza di precipitatzioni nevose estive può essere una motivazione aggiuntiva per l'aumento dell'ablazione. Un aumento dello 0.1 fino allo 0.15 nell'albedo può spiegare l'aumentata ablazione nelle zone di *firn* precedenti. Variazioni così repentine nelle caratteristiche della superfice possono avvenire in qualsiasi periodo di forte arretramento glaciale e possono portare a conclusioni molto errate quando dalle fluattuazioni glaciali si vogliono dedurre le condizioni climatiche precedenti.

TERMINI CHIAVE: Bilancio di massa, Clima, Albedo, Alpi.

INTRODUCTION

The Weißbrunnferner / Ghiacciaio di Fontana Bianca (fig. 1) is an East facing, 0,67 km^2 small mountain glacier in the Ortles-Cevedale Group of the Italian Alps (Secchieri & Valentini, 1992). Mass balance has been determined twice per year (winter and annual balance is measured, summer balance calculated as a residual) since 1991/92 by the application of the direct glaciological method. Annual balance values were reported from 1983/84 to 1987/88 (Kaser & *alii*, 1995). The respective mean specific values, averaged over the entire glacier surface, are depicted in fig. 2. In this series, the hydrological year 1997/98 conspicuously shows the most negative mass balance for both the summer period and the entire year with –2470 kg m^{-2} and –1610 kg m^{-2}, respectively. The winter balance was not unusual, with + 860 kg m^{-2}, but nevertheless among the higher ones during the seven years of observation. The summer balance is distinctly more negative then ever before in the series and the annual balance is about 1.5 times as negative as the subsequent negative balances which have thus far been measured. This firstly led to the assumption of a markedly increased sensible heat flux either due to higher air temperatures or

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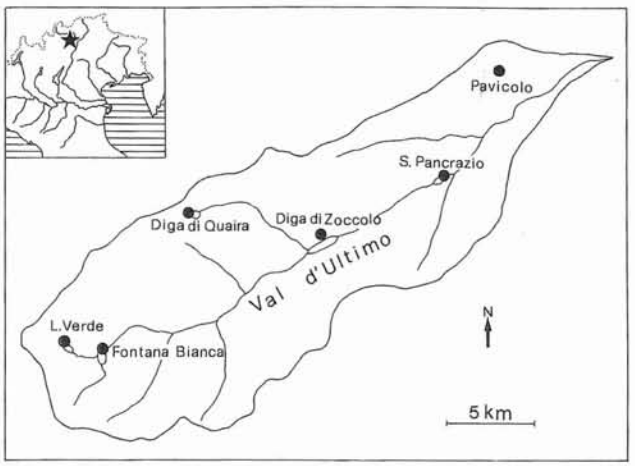

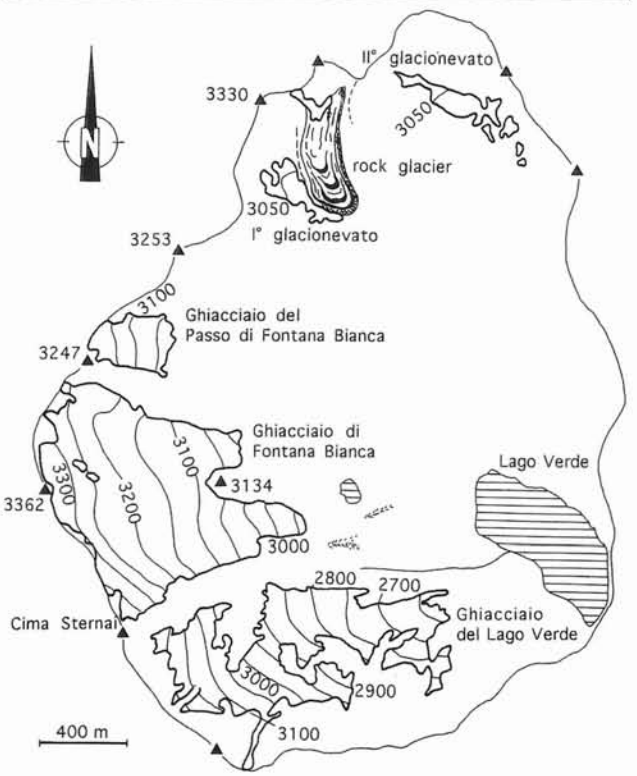

FIG. 1 - The setting of Weißbrunnferner / Ghiacciaio di Fontana Bianca in the upper Ulten / Ultimo Valley, Ortles-Cevedale group (from Secchieri & Valentini, 1992).

due to an extended ablation period. Yet, looking at the records of the nearby Weißbrunn / Fontana Bianca (1900 m a.s.l.) weather stations (fig. 1), this was not confirmed.

It has to be mentioned that all figures show fix date values, which are fairly close to the stratigraphic mass balance values (unpublished analysis) in most cases. In the 1997/98 hydrological year, between 50 kg m^{-2} in the upper areas and 150 kg m^{-2} on the tongues ablated in late autumn 1997, when the warm and sunny weather extended far into the month of October. Still, the remaining –2370 kg m^{-2} for the summer balance and -1510 kg m^{-2} of the entire mass balance are exceptionally high values.

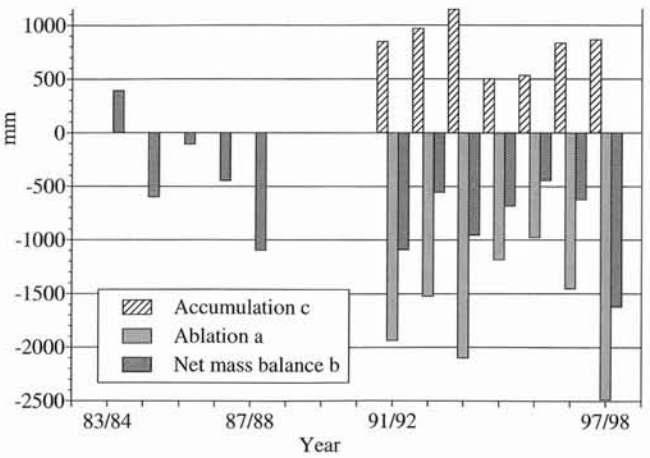

FIG. 2 - The series of annual and seasonal mass balance values for the respective hydrological seasons, obtained from applying the direct glaciological method. Winter and net balance are measured separately, and the summer balance is calculated as a residual.

DISCUSSION

In order to explain the high mass loss in 1997/98, an initial consideration is that increased air temperatures during the ablation period caused an increased sensible heat flux. From a great number of stations mounted by the Hydrographic Service of South Tyrol (Ufficio Idrografico della Provincia Autonoma di Bolzano), two were chosen for a closer investigation into the climatological features of the 1997/98 mass balance year. A corrected and homogenized temperature series has been available for Marienberg / Monte Maria since 1967, and Weißbrunn / Fontana Bianca recordings have been documented since 1983. The latter shows an especially short series for climatological studies, but has the advantage of being close to the glacier.

Compared to the summer temperatures of the 1991 to 1997 period (fig. 3), the period of mass balance measurements under discussion, monthly averages (May to September) at Marienberg / Monte Maria deviate by only –0.5 to +0,8°C. The mean deviation during the whole 1998 ablation period is +0.3°C, taking the third position in the series of seven years. The other station also shows deviations only between –0.4 and +1.0°C. However, temperature deviations cannot explain the amount of the 1998 summer ablation. At both stations, the 1997/98 annual precipitation is close to the long term mean values, but there is a clear lack of winter precipitation, particularly from January to March (fig. 4). Small amounts of winter precipitation are, however, characteristic for all seven years of mass balance observations.

Over the years, the ablation stake at site 10 (fig. 1), on the orographically left tongue, has become an index stake for our considerations basically because of its easy accessibility. A high number of readings were made at this stake

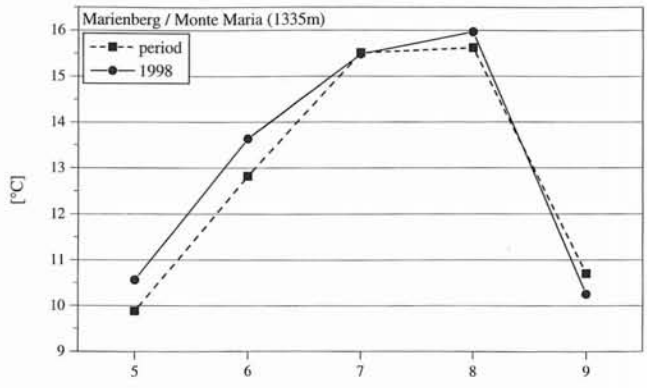

FIG. 3 - Monthly mean summer temperatures at Marienberg / Monte Maria (1335 m a.s.l.).

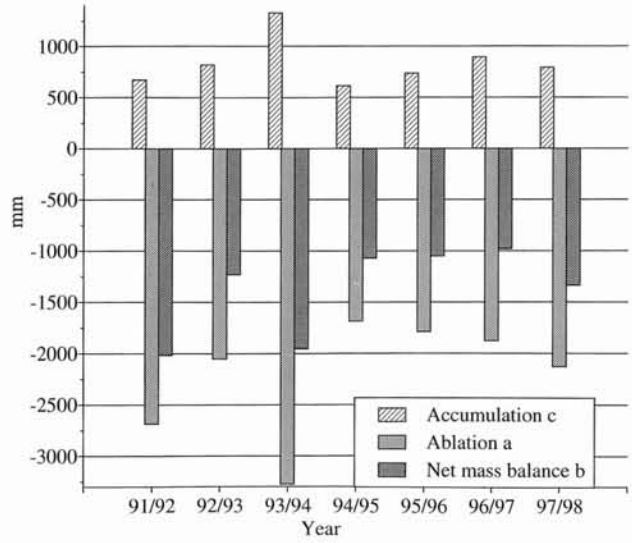

FIG. 5 - Seasonal mass balance values at stake 10 on Weißbrunnferner / Ghiacciaio di Fontana Bianca.

and snow pits were dug at this site each spring. There, the 1997/98 ice ablation makes up only the third highest value in the series, but (and) the annual net balance is the most negative by only a slight amount (fig. 5). After all, the position of this year's values within the series corresponds to the respective climate conditions and gives no indication as to the exceptionally negative balance for the entire glacier.

Much more information can be gained if one looks at the balance altitude distribution (fig. 6). Generously speaking, interannual mass balance differences of the years from 1991/92 to 1996/97 were quite constant with altitude and thus, the mass-balance-altitude-profiles are almost parallel. Digressions can be explained by local peculiarities of the small glacier, e.g. the avalanche activity

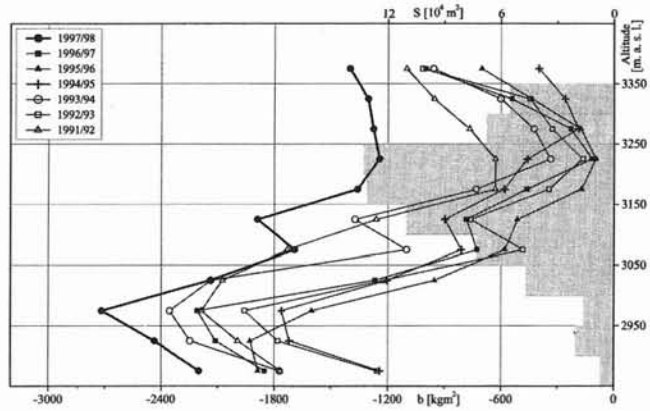

FIG. 6 - The altitudinal distributions of annual specific mass balances (b) and of the surface area of Weißbrunferner / Ghiacciaio di Fontana Bianca (S).

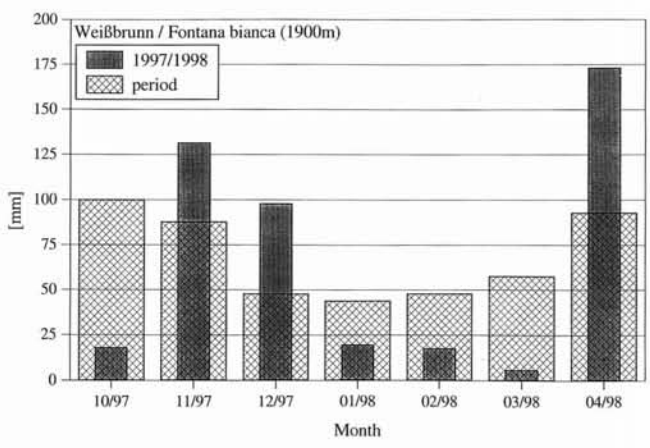

FIG. 4 - Monthly mean summer temperatures at Weißbrunn / Fontana Bianca station (1900 m a.s.l.).

on the relatively steep orographically right branch varies, ranging from depositions in certain areas in one year to erosion in another. But, the 1997/98 profile is remarkably different from the other profiles. Whereas it only shows slightly more negative values on the tongues, it clearly deviates from the other profiles above 3050 m a.s.l. If subtracting the October 1997 ablation values, this pattern becomes even more apparent. The upper portion of the glacier suffered from a much more dramatic mass loss than in the previous years. Regular observations during each ablation period and comparisons of photographs from

each summer lead to the following explanation for the observed mass-balance-profiles. If it ever appeared in the seven years, net accumulation was reduced to very small concave areas of the glacier to a degree that, as a mean over the various altitude steps, positive mass balance was never calculated. Thus, the firn pack was continuously reduced. The distinctly negative mass balances, which have been measured since the mid 1980s on other glaciers, create the assumption that the destruction of the firn body has already lasted more than ten years.

In the Summer of 1998 the entire firn had finally disappeared and a surface appeared, which had a density close to that of ice and was widely impermeable for percolating water. As a consequence, all dust being distributed within the firn was suddenly concentrated on the surface and when the winter snow had disappeared in June, the entire glacier became considerably dark. This more or less sudden change toward a low albedo changed the radiation balance in a way that the mass balance became exceptionally negative despite a «normal» climate. The energy budget was influced by the change of the glacier surface, being the glacier's long term «memory» of unfavorable climate.

The lack of any major snowfall during the Summer of 1998 may be an additional reason for increased ablation values. At an altitude of 3250 m a.s.l., the 1997/98 ablation was approximately 600 to 900 kg m^2 higher than in other years with markedly negative mass balances. The corresponding difference in albedo would need to be 0,10 to 0,15, respectively, if the duration of the ablation period is assumed to be 100 days and the mean short wave incidental radiation to be 20 MJ m^{-2} d^{-1} and if this energy is entirely consumed by melting.

CONCLUSIONS

One has to expect that a glacier does not only react to annual mass balances but accumulates «memory» of long lasting continuous conditions. Especially a number of strongly negative balances consume firn year after year. If the firn is then consumed entirely and glacier ice appears, surface properties can change suddenly over more or less vast areas of the former accumulation zone. On Weissbrunnferner / Ghiacciaio di Fontana Bianca, this probably happened in the Autumn of 1997 and, when the scarce winter snow from 1997/98 melted away by June 1998, a comparably dark surface became exposed to the sun and made the irradiation much more effective.

From field experience, we assume that this effect affected most glaciers in the Summer of 1998, at least on the southern side of the Alps. Small glaciers experienced such conditions, destroying the firn entirely, and also on larger glaciers only small portions with firn were left. Now it depends very much on the next couple of years whether abundant accumulation can return the regime back to its former conditions or whether the summer ablation remains accelerated.

It has to be further assumed that the effect of changing albedo occurs whenever glaciers retreat continuously from any formerly bigger extent. This has to be taken into consideration when deriving former climate conditions from different glacier extents, especially when modeling glacier retreat. However, concern is superfluous when steady state glacier extents are compared to each other.

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