*Geogr. Fis. Dinam. Quat.*,
*5 (1982), 75-81, 6 ff.*

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# RECENT GLACIOLOGICAL RESEARCH IN THE ORTLES-CEVEDALE REGION (Italian Alps) (**)

ABSTRACT: ZANON G., *Recent glaciological research in the Ortles-Cevedale region* (*Italian Alps*) (IT ISSN 0084-8948, 1982).

The Caresèr Glacier (surface area 4.8290 km$^2$, snout height 2 857 m) is situated in the Ortles Cevedale Massif (Central Alps), the most strongly glaciated region of the southern slope of the Alpine chain. Under observation since the end of the last century, since 1925 the glacier has been subjected to various types of research, including hydroelectrical use of its waters, currently dammed at 2 600 m. Moreover, various large-scale photogrammetric surveys have been carried out during the last 50 years. In 1966 a research programme was begun on the glacier's mass balance, established by means of the separate evaluation of gross accumulation and ablation over its entire surface. This report presents the results obtained for the period 1966-67 ÷ 1977-78.

Although net balance is moderately negative for the period in question (−140 mm of water equivalent/year, equal to a total loss of mass of about $8 \times 10^6$ m$^3$), and although the equilibrium line shows a rise of only 28 m with respect to its position under steady-state conditions, the ratio accumulation area/ablation area now turns out to be greatly modified with respect to steady-state condition (1 : 1.6 against 1 : 1). This capacity of the glacier to amplify the variations of its net balance and thus the effect of climatic parameters, maintains it in a state of unbalance although to a lesser extent than in the past; this continues to cause evident modifications in the ablation area and persistent snout retreat, in contrast with the current prevailing tendency of Italian glaciers to advance.

RIASSUNTO: ZANON G., *Recenti ricerche glaciologiche nella regione dell'Ortles-Cevedale* (*Alpi italiane*) (IT ISSN 0084-8948, 1982).

Il Ghiacciaio del Caresèr (superficie 4,8290 km$^2$; quota della fronte 2 857 m) è situato nel Massiccio dell'Ortles-Cevedale (Alpi Centrali), la regione più fortemente glacializzata del versante Sud della catena alpina. Il ghiacciaio, già oggetto di osservazione sino dalla fine del secolo scorso, dal 1925 è stato più volte il campo di ricerche di vario genere, anche nel quadro dei progetti di utilizzazione idroelettrica delle sue acque, attualmente sbarrate da una diga a 2 600 m di altitudine. Per gli ultimi cinquant'anni, inoltre, sono disponibili vari rilievi fotogrammetrici a grande scala. Dal 1966 ha avuto inizio un programma di ricerche sul bilancio di massa glaciale, stabilito mediante la separata valutazione dell'accumulo e dell'ablazione lorde su tutta la superficie del ghiacciaio. Nella presente nota si riferisce sui risultati ottenuti nel periodo 1966-67 ÷ 1977-78.

Nonostante che per il periodo in esame il bilancio netto risulti moderatamente negativo (−140 mm di equivalente in acqua/anno, pari ad una perdita di massa complessiva di circa $8 \times 10^6$ m$^3$ d'acqua) e che la *linea di equilibrio* registri un innalzamento di soli 28 m rispetto alla sua posizione con un bilancio di parità, risulta ora notevolmente alterato il rapporto area di accumulo - area di ablazione rispetto alla situazione a bilancio in parità (1 : 1.6 contro 1 : 1). Tale attitudine del Ghiacciaio del Caresèr ad amplificare le variazioni di bilancio netto e quindi l'effetto dei parametri climatici mantiene pertanto condizioni di squilibrio; esse continuano a provocare, sia pure in forma attenuata rispetto al passato, sensibili modificazioni nel bacino ablatore e un persistente ritiro frontale, in contrasto con una prevalente tendenza al progresso che si va evidenziando per molti ghiacciai delle Alpi italiane e dello stesso Gruppo Ortles-Cevedale.

TERMINI-CHIAVE: Climatologia; Glaciologia; bilancio.

The Caresèr Glacier is situated in the Ortles-Cevedale Massif, the most glaciated region of the southern slope of the Alpine chain, holding in effect 130 of the 838 glaciers listed in the 1958 Italian Glacier Inventory. They cover a surface area of about 100 km$^2$, slightly less than a fifth of the total. The Ortles-Cevedale Group also contains the largest Italian glacier, the Vedretta dei Forni.

The Caresèr Glacier, in its turn the third glacier of the group and the largest on the southern side, is found on the SE branch of the massif, peripheric with respect to the main glaciation centre of Mt. Cevedale (3 778 m). Hydrographically it is part of the Adige basin, through its tributary the Noce Bianco. However, the glacial stream quickly changes its natural course; about 2 km downstream it has been dammed to form a reservoir at an altitude of 2 600 m, the water feeding two hydroelectric power stations before flowing finally into the Noce network.

The glacier mass is currently contained in a subelliptical hollow, opening southwards and defined by an almost continual ridge, the highest point of which reaches 3 386 m. Although the glacier had quite a long tongue until a few decades ago, it was not, even in the past, considered a valley glacier of Alpine type. DESIO (1968) considers it of the cirque type, and the 1958

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(**) *Research carried out with the financial support of ENEL (National Electricity Board) and the coordination of Comitato Glaciologico Italiano.*

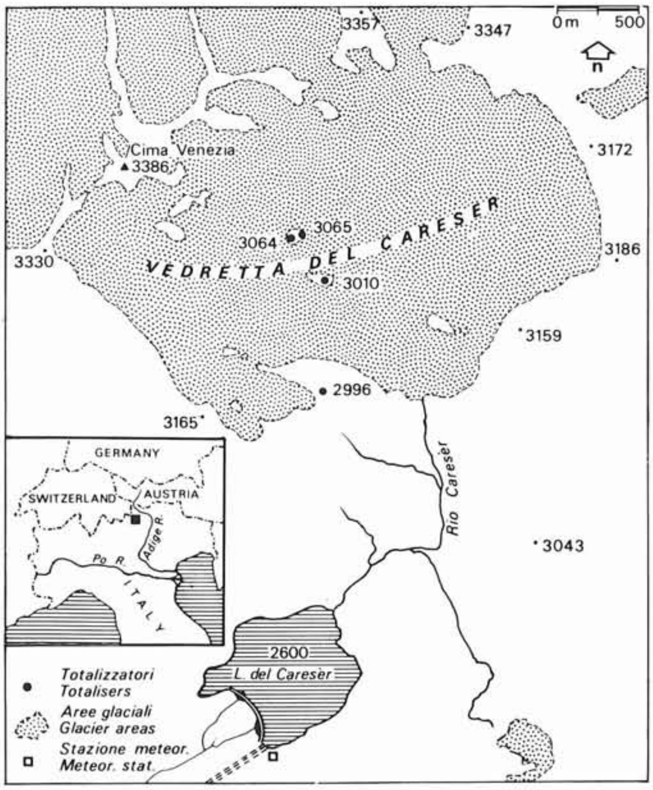


FIG. 1 - Sketch map of the Caresèr Glacier (Central Alps).

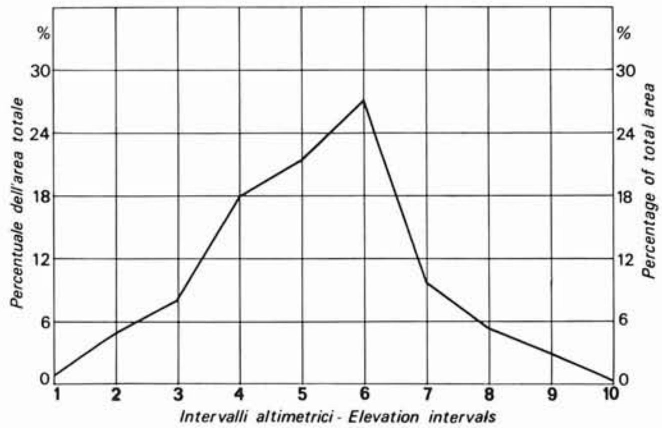


FIG. 2 - Area distribution curve on the Caresèr Glacier according to AHLMANN (1948). Partial surfaces are expressed as percentage of glacier total area; each elevation interval corresponds to 1/10 of total height differences on the glacier.

Glacier Inventory classifies it as a kind of plateau glacier. The actual compilation instructions of the World Glacier Inventory (MÜLLER & *alii*, 1977) would classify it as a « mountain glacier » with a simple basin. Apart from considerations regarding size, the very definition of a « mountain glacier » ([1]) is not really in contrast with the area distribution curve of the Caresèr Glacier, constructed according to AHLMANN (1948) (fig. 2), with which it shows more similarities with certain valley glaciers (I type) than with the cirque type.

The Caresèr Glacier was first described by PAYER (1868) and RICHTER (1888), and first mapped by PAYER himself. Snout fluctuations have been described from 1897 onwards. DESIO continued surveys from 1923 onwards and, with some interruptions, these have continued until today by various research workers (DESIO, 1968).

In the 1920s, projects for using the glacial stream for hydroelectricity gave rise to detailed glaciological, hydrological, meteorological, topographical and geophysical studies (DESIO, 1968), also accompanied by a series of large-scale aerial surveys which clearly show the evolution of the glacier over the last 50 years.

Alfter PAYER's initial (1869) surface area calculation of 5.64 km², the first terrestrial photogrammetric survey of 1933 showed the glacier as having a surface area of 5.4415 km². After its continual reduction, which continued until 1970 (as shown by later surveys, the last being the 1980 aerial survey, scale 1:5 000), the glacier now covers 4.8290 km², being slightly larger than in the past (GIADA & ZANON, in preparation, a).

As already mentioned, the glacier has recently varied its general shape too; its tongue progressively diminished until it disappeared completely in 1961. Data and observations are lacking on its positions of maximum advance in the first half of the 19th century, partly because of the submersion of the proglacial area for hydroelectrical purposes. Since 1897, when the first measurements were carried out on the snout, the glacier has been retreating. Retreat was particularly fast in the 50-year period between 1923 and 1970, causing a linear retreat of the snout of 1,3 km and an increase in height of more than 200 m (SECCHIERI, 1975). Now at an altitude of 2 858 m (1980), the snout still appears to be retreating.

Climatically, the Caresèr basin is in a transition zone. The main Alpine divide, which passes North of the Ortles-Cevedale Group from the Resia Pass to the Brenner Pass, along the highest ridge of the chain of the Venoste Alps (Oetztaler Alpen), does not—particularly as regards precipitation distribution—act as a climatic boundary between the continental regime of Central Europe and the North Mediterranean zone, characteristic of the Po Plain and the Prealpine belt. This transition begins on the SE slope of the massif, autumn and spring precipitation assuming more and more importance over that of the continental-type summer (HÖLLERMANN, 1964). The orographic factors also sometimes greatly influence the importance and efficiency of cyclones. Precipitation is moderate from this viewpoint too, the area considered here being transitional between the slope regime of the southern Alpine zone and the semi-arid conditions of the Val Venosta to the North (ALBERTINI, 1951).

([1]) « Any shape, sometimes similar to a valley glacier but much smaller; frequently located in cirque or niche ». (MÜLLER & *al.*, 1977).

The Caresèr basin is served by a meteorological station located near the dam, at an altitude of 2 600 m [2]. Functioning since 1930, it is equipped with maximum-minimum thermometer, thermograph, hygrograph, pluviometer, pluviograph, heliophanograph. Snow thickness and density are also measured regularly. A totaliser of the UIMA type has been working near the glacier since 1956. In 1970, three more UIMA and EDF (Electricité de France) totalisers were set up on rocks emerging from the centre of the glacier, in order to verify the working of the different models of instruments and to compare snow accumulation on the glacier with the data supplied by the instruments themselves (fig. 3) (Rossi & Zanon, 1974; Giada & Zanon, in preparation, b).

## Research on the glacial mass balance

Since 1966, following an initiative of the Italian Glaciological Committee and with the financial support of ENEL (National Electricity Board), the Caresèr Glacier has been the subject of a long-term programme of research on its mass balance. This particular glacier was chosen for its physical characteristics, which are specially suitable for this type of research; it is also accessible throughout the year for measurement purposes (Zanon, 1973). The preliminary results of this research have been published in various places (Zanon, 1970, 1973, 1976); annual data are contained in periodical reports of the Study and Research Department (DSR) of ENEL (not published).

The research method adopted is based on surface measurements carried out over the whole surface of the glacier. The methodology and instrumentation used are those proven by long experience abroad, particularly in Scandinavia. Detailed information on this is shown in the bibliography (Zanon, 1965; 1967; Østrem & Stanley, 1969). However, some fundamental definitions are recalled here, since they will be frequently referred to later on.

Surveys on the glacier are carried out over a balance year, coinciding with the hydrological year October 1 - September 30, and deal in particular with:

*a*) determination of the *accumulation* (water stock corresponding to the snow cover existing on the glacier before the beginning of the ablation season, formed since the beginning of the balance year;

*b*) study and evaluation of the melting processes (*ablation*) of the year's snow cover, ice and firn of tre previous years;

*c*) calculation of the *net balance* of the glacier for the current year (quantitative comparison of the two preceding terms).

## Accumulation

The accumulation season on the Caresèr Glacier generally begins between the end of September and the beginning of October. The moment of maximum accumulation varies in relation to the altitude of the various parts of the glacier, normally in May. This means that measurements are carried out at different times and supplementary measurements must quite frequently be carried out if the accumulation season is prolonged, sometimes even into June.

The accumulation surveys are composed of thickness soundings at intervals of 50-100 m along profiles directed on the stakes in the glacier and on fixed points of the rocky surround. The thickness values are then transformed into water equivalents through measurements on the average density of the snow cover, carried out in pits at different altitudes. Maps of annual accumulation are constructed from the measurement data, thus allowing later calculations.

For the period 1966-67/1977-78, the observed average annual accumulation was 1 030 mm of water equivalent, corresponding to $4.8225 \times 10^6$ m$^3$. However, the variability of this parameter in the various balance years in considerable, ranging between 58.3 % and 183.5 % of the average of the period in question, although it should be remembered that the latter value refers to one year (1976-77) in which precipitation, both as annual total and for the single accumulation seasons, was without precedent in the whole 50-year life of the Caresèr station. If this particular year is not taken into consideration, the annual maximum value falls to 116.5 % of the average.

As regards snow accumulation measured at high altitude on the glacier, it is important to observe how this is insufficiently evaluated, both by the meteorological station near the dam and by the very network of totalisers installed on the glacier (Rossi & Zanon, 1973; Zanon & Giada, in preparation, b), in spite of the good correspondence of measurement data obtained from the various instruments (fig. 3).

For the period 1966-67/1977-78, the ratio between precipitation measured at the dam and the water equivalent evaluated on the glacier for the zone between 3 050 and 3 100 m (on which this type of survey is concentrated) is 0.53. Even lower is the ratio between the totalisers on the glacier and the water equivalent (from 0.328 and 0.307), as weighted averages of the annual ratios between totalisers and water equivalents (Zanon & Giada, in preparation, b).

According to an examination of the yearly maps, the distribution of the snow cover on the glacier does not follow exact or constantly valid laws. Considering the small differences in altitude on the glacier and its relatively small size, the combination of the microscale factors exerts an influence which very often prevails over that of general factors (altitude and orography).

Among the local factors which influence the pattern of annual distribution of the snow cover on the glacier, the most important is undoubtedly wind action. This takes place not only during precipitation (prevailing winds being westerly and southerly) but also and mainly as regard the snow cover (prevailing winds being northerly). The effects of wind are sometimes particularly evident, considering the relatively thin snow thicknesses

(2) The most significant climatological data of the Caresèr station are: *Precipitation*: annual total: 899 mm; rainy days: 106; nivometric coefficient: 60 %; *Temperature*: annual mean: —1.4° C; annual range: 15,2° C; lapse rate: 0.55° C/100 m; altitude of 0° C isotherm: 2 300 m.

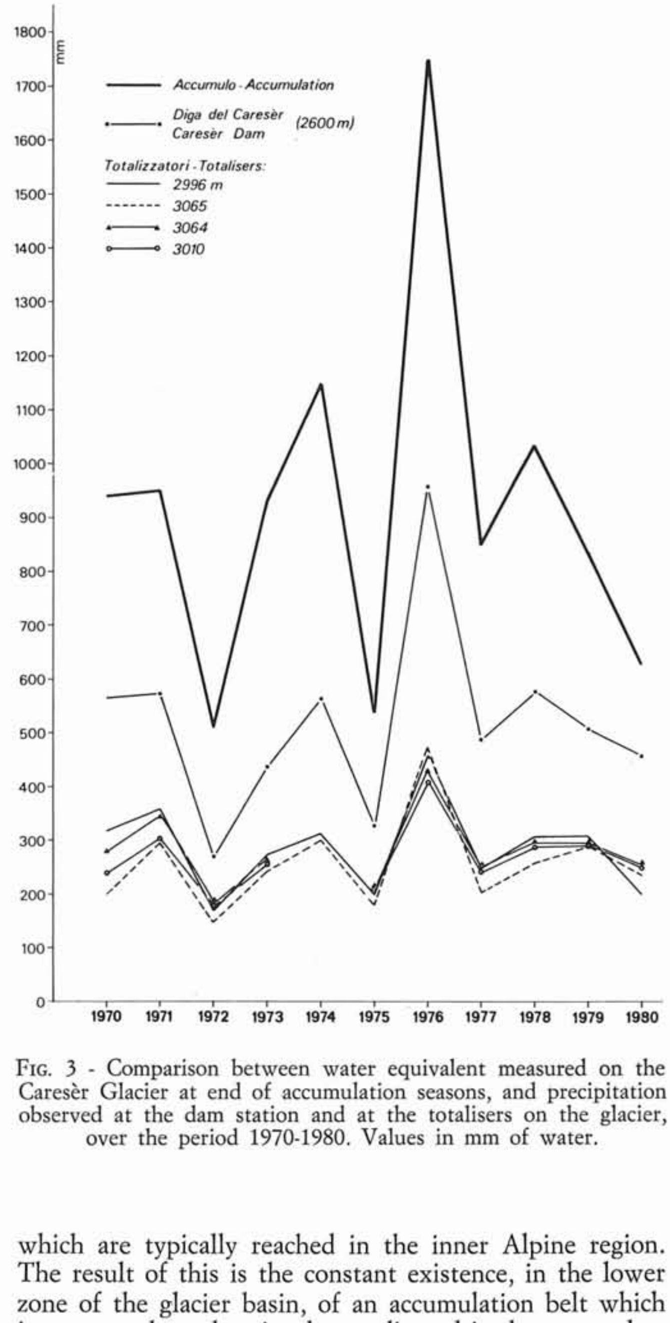


FIG. 3 - Comparison between water equivalent measured on the Caresèr Glacier at end of accumulation seasons, and precipitation observed at the dam station and at the totalisers on the glacier, over the period 1970-1980. Values in mm of water.

which are typically reached in the inner Alpine region. The result of this is the constant existence, in the lower zone of the glacier basin, of an accumulation belt which is greater than that in the medium-altitude areas, thus apparently in contrast with the normal increase due to altitude, which may indeed be observed only towards the upper half of the glacier. This tendency is clearly shown in the diagram of the trend of specific accumulation versus altitude (fig. 4), which reflects the characteristics encoutered in the single years.

Above the terminal zone (2 855-2 900 m) values diminish up to the 3 050-3 100 m interval. There is then a further increase reaching its maximum in the small summit areas, where data are partly the result of extrapolation, since direct measurements are almost impossible. Instead, it should be observed how the zone of maximum extent (fig. 4) does not coincide with the zone of maximum snow cover.

## ABLATION

Taking into account the various parts of the glacier, ablation — as we have said — includes all or part of the snow already evaluated as accumulation, as well as the ice and firn of the previous years. Measurement of the melting of the different materials composing the glacier mass requires the use of different methods: ice melting is measured on the basis of the lowering of the surface of the glacier near the light alloy stakes, fixed into the glacier in specially bored holes. Snow and firn melting is derived from the difference between the water equivalent measured respectively at the beginning and end of the ablation season, determined using thickness soundings and density measurements, all referring to the closing of the balance year.

On the Caresèr Glacier winter snow melting commences about the beginning of May on the lower part and progressively extends to higher areas. Its disappearance from the glacier surface has generally never begun before July is advanced. This moment thus identifies a temporary snow line progressively rising along the glacier; at the end of the balance year, it is transformed into the *equilibrium line* (see later). The maximum quantity of ice and firn melting (*net ablation*) occurs from mid-July to September. Finally, the results of the melting processes are variously elaborated and the data used for balance computations.

Very great differences in ablation are encountered at the different measurement points. Again due to the small differences in altitude and to the prevalences of very large, gently undulating surfaces, the importance of local factors comes to the fore, including heat emanating from nearby rocks, differences in albedo of the various types of surface (including the effect of summer snowfalls in the middle and upper parts) and the effect of denudation due to frequent *slush avalanches*.

Instead, no particular problem is posed due to the formation, in spring, of *superimposed ice*, the product of melt-water from snow freezing on contact with the glacier surface. This process may give rise the formation of new ice which accumulates to thicknesses of 10-20 cm, temporarily altering the results of ablation measurements and sometimes causing errors of interpretation, regarding the effective amount of ablation. On the whole, however, a clearly defined dependence of gross ablation with altitude may be observed.

For the period 1966-67/1977-78, gross ablation reached an average water thickness of 1 170 mm, corresponding to 5.4780 $\times$ $10^6$ $m^3$/year. However, this parameter too has shown great variability over the balance years. Extreme values range from 45.3 % to 161 % of the average, but considerable differences are also observed in the remaining years. The diagram of mean specific ablation (fig. 4) falls into the field of negative values. In effect, in all years and at all altitudes some form of ablation took place, the only exception being 1967-68, during which summer snowfall above 3 200 m exceeded annual melting, causing a "positive" ablation of 100 mm. However, this phenomenon is completely anomalous for the Caresèr Glacier.

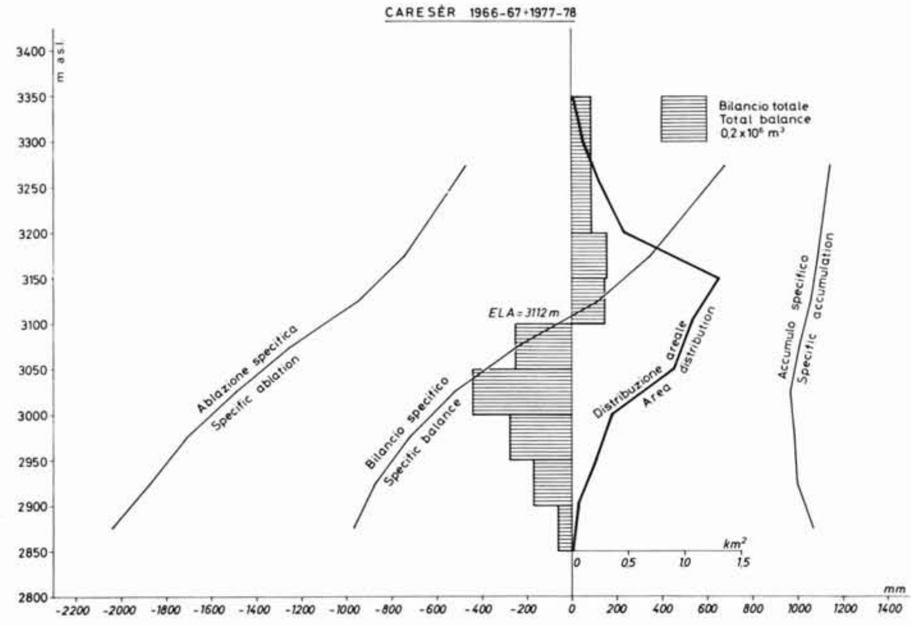


FIG. 4 - Caresèr Glacier, 1966-67 ÷ 1977-78. Accumulation, ablation, net balance (specific and total) and area distribution as a function of altitude, for elevation intervals of 50 m. Equilibrium line (ELA) at 3 112 m. The balance quantities are expressed in water equivalents.

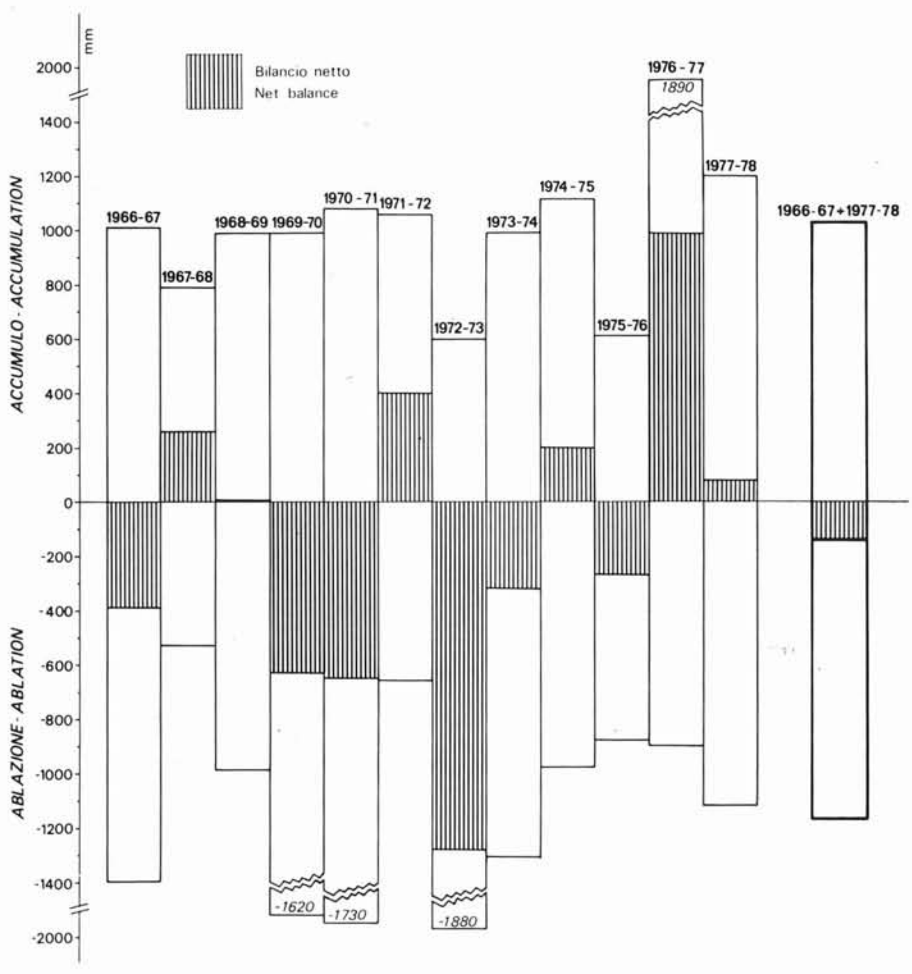


FIG. 5 - Accumulation, ablation and net balance on the Caresèr Glacier for balance years from 1966-67 to 1977-78, in mm of water equivalents.

NET BALANCE

In the period 1966-67/1977-78, the Caresèr Glacier underwent 6 years of negative balance, 5 of positive balance and 1 of zero balance (fig. 5). The method of evaluating the net balance on the basis of comparing values of gross accumulation and ablation allows an analysis of the quantities involved in the various years and thus of understanding their significance in the determination of each single balance.

Of the 6 *negative* balance years, 5 were characterized by ablation ranging between 112 % and 161 % of the average for the period in question. Instead, accumulation remained around average values in 4 years, ranging between 96 % and 104 %. In the year with the maximum negative balance (−1 280 mm) (1972-73), the effects of ablation of 161 % of the average and accumulation of 58 % were combined. It is therefore probable that the very strong ablation of that year was not only the result of temperature conditions, but also due to the anticipated melting of the thin winter snow cover, consequently reducing the surface albedo (see ∅STREM & *alii*, 1976). In 1975-76, with an equally scarce accumulation (59 % of the average), the balance was only slightly negative, since summer temperatures and an unusual anticipation of the stable snow cover on September 12 limited ablation to 75 % of the average.

It may thus be pointed out how the negative balances observed up till today are primarily the consequence of greater ablation than normal and only subordinately of scarce accumulation.

As regards the 5 *positive* balance years, they all showed ablation values of less than average (from 45 % to 96 %). Instead, accumulation was lower or only slightly greater than the average (from 77 % to 116 %). The 1976-77 was a particular case, being the year with the largest positive balance observed (+ 990 mm): a normal ablation was accompanied by an exceptional accumulation (183 % of the average). The positive balances thus took place almost exclusively in conditions of reduced ablation.

The average balance for the period considered turns out to be slightly in deficit: −140 mm water equivalent/year. The net reduction in mass for the whole period was thus 1 680 mm, for a total water volume of just under 8 million $m^3$. Observing the trend of the partial balances for elevation intervals (diagram of fig. 4), their differentiation is very evident, due to the prevailing effect of ablation. The specific values are negative – from 7 to 2 times lower than the average – up to the 3 050-3 100 m interval. Transition to positive values occurs in the 3 100-3 150 m interval (equilibrium line at 3 112 m, see later), reaching a maximum of 680 mm in the highest areas above 3 200 m.

Next to the diagram showing the trend of the specific balance versus altitude, fig. 4 shows a histogram of the trend of the total balance (in millions of $m^3$ water equivalent) for the same elevation intervals. This parameter allows us to pass from the concept of balance as water thickness to volumes of water per elevation zones, in obvious relation to the area distribution of the latter. In effect, the strong deficit as water thickness encountered in the lower part of the glacier (in the 100 m between the snout and 2 950 m) shows a value which is only 19 % of the average net losses of the whole ablation area. In turn, the moderately negative balance in the 3 000-3 100 m interval is much more important for the economy of the glacier, since it is in this 100 m interval that the maximum net reduction of the mass in the ablation area occurs (58 % of the total). For the opposite reason, the strong positive balance of the areas above 3 200 m only represents 45.5 % of the total mass gain in the accumulation area.

Analysing the glacier balance from the viewpoint of the modifications occurring between 1966-67 and 1977-78, the strong deficit observed in the lower parts led to reductions in thickness which, in terms of ice, may be calculated between 10.7 and 7.9 m for the elevation interval between the snout and 3 000 m. This gave rise to progressive and sometimes very evident modifications in the physiognomy of the ablation basin, with continual snout retreat, snout flattening, emergence of rocky areas, increase in ablation moraine, etc.

In the elevation interval of the median altitude of the glacier (3) (situation in the 1970 survey), the loss of thickness in terms of ice was about 2.5 m. However, this evaluation is slightly generous, since during the 12-year observation period this has been a transition zone from accumulation to ablation area, thus involving less dense materials. For areas higher than the current equilibrium line (3 112 m, see later), determination of the variations in surface level (since this is in accumulation area) implies greater approximations in the evaluation of the density of the various materials—specially firn—whose values range between 0.6 and 0.8 g/$cm^3$. The increase in surface level about 3 100 m should therefore oscillate between a minimum of 1 m and a maximum of 5.7 m. These values, which have been calculated for elevation intervals, do not take into account variations from place to place, but are approximately confirmed by a preliminary comparison of the aerial surveys of 1967 and 1980.

In passing from negative to positive values, the diagram of the net specific balance for elevation intervals establishes the *equilibrium line altitude* (ELA) or net balance line equal to zero, separating accumulation area from ablation area (4). The value of 3 112 m (the average for the period 1966-67/1977-78) represents a rise

(3) *Median altitude* means here the contour line which divides the glacier surface in half.

(4) Fig. 6 shows the relationship between ELA and specific net balance for the balance years from 1966-67 to 1977-78, similarly to that for the Nigard Glacier (Norway) in ØSTREM & *alii*, 1976. This relationship is expressed by the regression line: y = 16.36788 − 0.00533, where y is specific balance in m of water equivalent (r = 0.943).

of 28 m with respect to the ELA established by steady-state conditions (3 084 m) (ZANON, 1973). Moreover, it implies a ratio between accumulation and ablation areas of 1 : 1.6 as against a ratio of 1 : 1, again for steady-state conditions. This rise in ELA and thus the reduced ratio accumulation/ablation areas, is however only partially compensated by a rise in the median altitude of the glacier, which now reaches (1980 survey) 3 092 m.

From the trend of the area distribution of the glacier, with almost 50 % of the total surface concentrated in the 3 050-3 150 m interval (within which limit the ELA varied between 1967 and 1978), it may be seen that, in terms of total balance, the Caresèr Glacier is extremely sensitive to even small variations in ELA. The current situation of an overall although moderate negative balance, together with the glacier's scarce activity, thus agrees well with the negative evolution which continues to involve the body of the glacier, particularly in its lower areas, in contrast to the prevailing tendency towards advance noted in many glaciers of the Italian Alps and in the Ortles Cevedale Group itself.

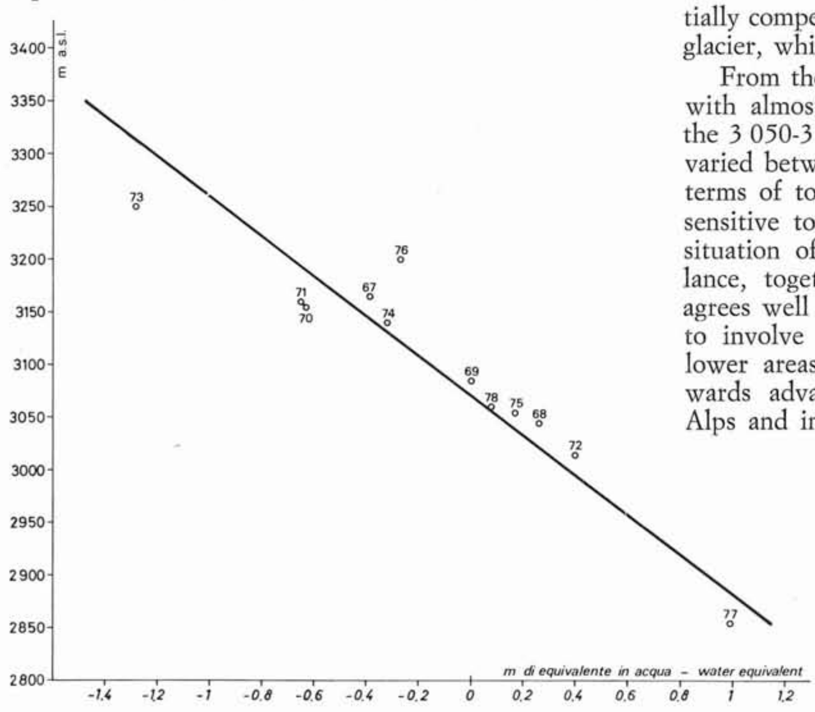


FIG. 6 - The relationship between equilibrium line and specific balances at the end of each balance year from 1966-67 to 1977-78 is expressed by means of a regression line.

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