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VARIATIONS OF ITALIAN GLACIERS BETWEEN 1980 AND 1999 INFERRED BY THE DATA SUPPLIED BY THE ITALIAN GLACIOLOGICAL COMMITTEE

ABSTRACT: SANTILLI M., OROMBELLI G. & PELFINI M., *Variations of Italian glaciers between 1980 and 1999 inferred by the data supplied by the Italian Glaciological Committee.* (IT ISSN 0391-9838, 2002).

The study synthesises the analysis of those data relevant to the variation registered in the Italian glaciers during glaciological surveys carried out by the Italian Glaciological Committee between 1980 and 1999. The last twenty years of the 20th century were characterized by a phase of general retreat of the glaciers, that followed an advancement phase that took place in the 70s and in the early 80s. The data matrix, which is largely incomplete, includes 335 glaciers. The percentages of advancing, stationary and retreating glaciers have been reckoned on the entire sample and on the single geographic sectors, mountain groups and glaciers having comparable aspects and size. Cumulative and yearly values of the front variations and of the terminus elevation changes have been quantified for those glaciers with at least 10 data out of 20. The percentage of advancing glaciers decreased from 66% in 1980 to 4% in 1999, while that of the retreating ones increased from 12% to 89%. These values changed quickly during the first decade, and then stabilized during the following one. The decrease in the number of advancing glaciers took place first in the Eastern Alps (Trentino-Alto Adige, Veneto and Friuli-Venezia Giulia: Triveneto Regions) and later in the Central (Lombardy) and Western (Piedmont-Aosta Valley) sectors. A similar trend has been also observed in the bigger glaciers and in those having a northern or southern exposure, while the smaller glaciers and those facing east and west have shown more irregular variations. The average annual variation per glacier was of −4.8 m/year, for an average total variation per glacier of −95.4 m, during the twenty years considered. However, marked differences have been observed over the two decades, with stronger variations during the period between 1990 and 1999. The retreat phase was more marked in the Central sector (Lombardy), where the average total retreat of the fronts was of nearly 150 m. Modest variations (−44 m) occurred instead in the Western sector (Piedmont-Aosta Valley). The small glaciers had little annual average variations compared to the bigger ones, but greater, in proportion. The magnitude of the retreat was greater for those having an eastern and western exposure compared to the others. The minimum altitude of the glacier fronts raised 18 m on average. Marked variations (+38 m) were recorded in the Central (Lombardy) sector, while those in the Eastern sector were smaller (+12 m) and those in the Western one marginal (+3 m).

KEY WORDS: Glacier variations, Italian glaciers, Italian Glaciological Committee.

RIASSUNTO: SANTILLI M., OROMBELLI G. & PELFINI M., *Variazioni dei ghiacciai italiani fra il 1980 e il 1999 sulla base dei dati del Comitato Glaciologico Italiano.* (IT ISSN 0391-9838, 2002).

Il lavoro sintetizza l'analisi dei dati relativi alle variazioni rilevate per i ghiacciai italiani durante le campagne glaciologiche svolte dagli operatori del Comitato Glaciologico Italiano nel periodo 1980-1999. L'ultimo ventennio del XX secolo è stato caratterizzato da una fase di generale ritiro dei ghiacciai, che ha fatto seguito ad una fase di avanzata negli anni '70 e nei primi anni '80. La matrice di dati, molto incompleta, è composta da 335 ghiacciai. Sono state calcolate le percentuali di ghiacciai in avanzata, stazionari e in ritiro per l'intero campione e per singoli settori geografici, gruppi montuosi e insiemi di ghiacciai con caratteristiche stazionali e dimensionali comparabili. Per i ghiacciai con almeno 10 dati su 20 sono stati quantificati i valori medi annui e cumulati delle variazioni frontali e delle quote delle fronti. La percentuale di ghiacciai in avanzata è scesa dal 66% nel 1980 al 4% nel 1999, mentre quella dei ritiri è salita dal 12% all'89%. Tali valori si sono modificati rapidamente durante il primo decennio per poi stabilizzarsi in quello successivo. La diminuzione del numero di ghiacciai in avanzata si è manifestata dapprima nel settore Triveneto e successivamente in quelli Lombardo e Piemontese-Valdostano. Andamenti simili sono stati osservati anche per i raggruppamenti di ghiacciai di dimensioni maggiori e con esposizioni N e S, mentre sono più irregolari, invece, le fluttuazioni dei ghiacciai di dimensioni minori e di quelli con esposizioni E e O. La variazione media per ghiacciaio è valutata in −4,8 m/anno, per complessivi −95,4 m nell'arco del ventennio considerato. Differenze marcate sono state osservate comunque a livello dei due decenni, con variazioni più consistenti nel periodo 1990-1999. La fase di regresso è stata più marcata nel settore Lombardo, dove il ritiro medio cumulato delle fronti è stato di quasi 150 m. Variazioni modeste (−44 m) sono invece avvenute nel settore Piemontese-Valdostano. I ghiacciai di piccole dimensioni hanno subito variazioni medie annue ridotte rispetto a quelli grandi, ma, in proporzione, superiori. L'entità del ritiro è stata maggiore per le esposizioni E e O

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rispetto alle altre. Le quote minime delle fronti hanno subito un innalzamento medio di 18 m. Le variazioni sono state accentuate nel settore Lombardo (+38 m), intermedie nel Triveneto (+12 m) e minime nel settore Piemontese (+3 m).

TERMINI CHIAVE: Variazioni glaciali, Ghiacciai italiani, Comitato Glaciologico Italiano.

INTRODUCTION

During the 20th century Italian glaciers were subject to several phases of advancement and retreat (Zanon, 1991) (fig. 1). A phase of general retreat, which lasted until 1960, followed the period of remarkable progress between 1910 and 1925. Since then, the number of advancing glaciers increased until it reached a maximum level in 1980 (*Cold phase posterior to 1950*; Pinna, 1991). The phenomenon has had remarkable importance, synchrony and extension, as it is documented wherever in the Alps (e.g. Aellen, 1985; Patzelt, 1985; Maisch, 2000) and in other mountain regions of the Earth, too (e.g. Haeberli, 1985; Haeberli & Müller, 1988; Wood, 1988). The advancing phase occurred in different ways and times on the Italian Alps, according to the environmental and climatic characters of the different geographic areas (Cerutti, 1985) and to the physiographic characteristics of every single glacier (Zanon, 1985). Finally, the last two decades were characterized by a remarkable retreat of nearly all the mountain glaciers, causing concern that this is in some way related to the climatic changes caused, at least in part, by man (Haeberli & *alii*, 1989; Jones, 1994; Pinna M., 1996; Pelfini & Smiraglia, 1997).

The growing interest in the study and monitoring of the glaciers is connected to their sensitivity to climate changes (e.g. Belloni & Pelfini, 1995; Haeberli & *alii*, 2000), which modify their dynamics and size. Since 1895 the Italian Glaciological Committee (CGI) has been coordinating the researches in the glaciology field in Italy. Every year, at the end of the ablation summer season, members of the Committee, together with other groups and associations, carry out glaciological surveys by means of direct measurements, photographs from permanent points, observations of the residual snow cover and of the front morphology.

The present study analyses the data relevant to variations recorded in the Italian glaciers during the annual glaciological surveys carried out between 1980 and 1999. It synthesises the data recorded in all the Italian Alps and compares single geographic sectors, various mountain groups and groupings of glaciers having comparable aspects and size characteristics.

MATERIALS AND METHODS

The annual reports published by the Italian Glaciological Committee in the journal «Geografia Fisica e Dinamica Quaternaria», supply measures of front variations and front altitudes for a variable number of glaciers for the period between 1980 and 1999. The available data includes both numeric values actually measured, positive, negative or null ones, and acronyms or symbols indicating stationary conditions (ST) and uncertain variations due to the snow cover on the fronts (SN) and to other causes (–x, +x, ?). Moreover, the geographic sector they belong to, the mountain group, the drainage basins, the highest altitudes reached by the glaciers, the lowest altitudes of the fronts, the length, the area and the aspect of each glacier have also been quoted, according to what is published in the volumes of the *Catasto dei Ghiacciai italiani* (CGI-CNR, 1959, 1961a-b, 1962).

Data has been processed in two main ways, first evaluating the percentage of advancing, stationary and retreating glaciers, then quantifying the entity of the front variations and of the front altitude ones.

In order to make it possible to compare the annual data relevant to groups of glaciers with different characteristics and different in number, the first analysis took into account only the positive, negative (including the qualitative

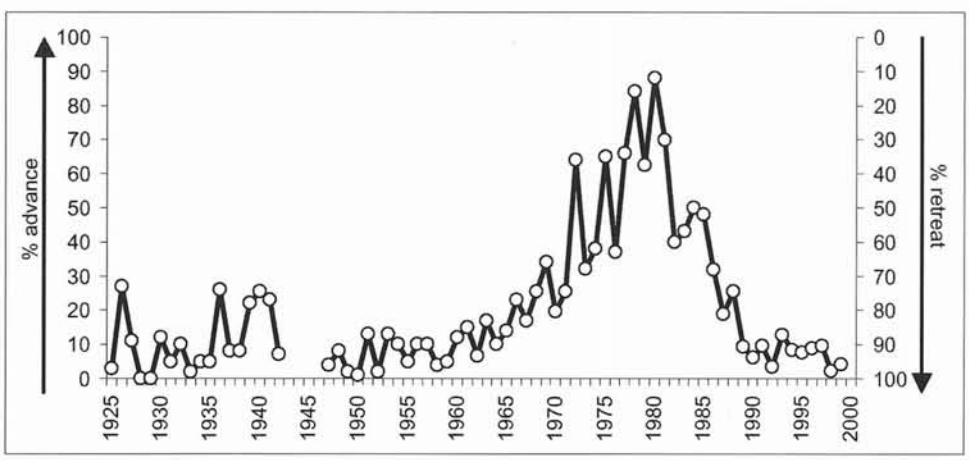


FIG. 1 - Percentage of advancing and retreating glaciers in the Italian Alps from 1925 to 1999. A phase of prevailing retreat, accentuated in the 40s and 50s, was followed by a short advancing phase, culminated in the early 80s, and then by a fast return to the current conditions of general retreat (processing by Zanon, 1985, redrawn).

ones «–x» and «+x») or null («ST» and «0») variations, expressed as a percentage. The uncertain variations indicated with «SN» and «?» were instead excluded. In any case the real number of the considered glaciers has been reported under the diagrams. Both the entire data set and the subdivision into geographic sectors, main mountain groups and classes, according to their size and aspects, have been considered. The classes based on the length and surface area have been formed in order to have groups with a significant and comparable number of glaciers.

In the second analysis, glaciers with at least 10 out of 20 available data (50%) have been considered in order to quantify the amount of the front variations. Where it was possible, the data lacking has been reconstructed dividing the amount of the variations relevant to several years into average annual values. Hence the central part of the matrix created is complete, while some data lacks on the extremities. The magnitude of the front variations for every single glacier has been calculated both as annual average and as a cumulative value. The sample of glaciers has also been divided into geographic sectors and into classes according to their size (length and surface area) and exposure. The cumulative variation has been subsequently compared to the glacier length.

An analogous method has been applied to calculate the front altitude variations, but in this case a complete matrix, also on the extremities, has been obtained.

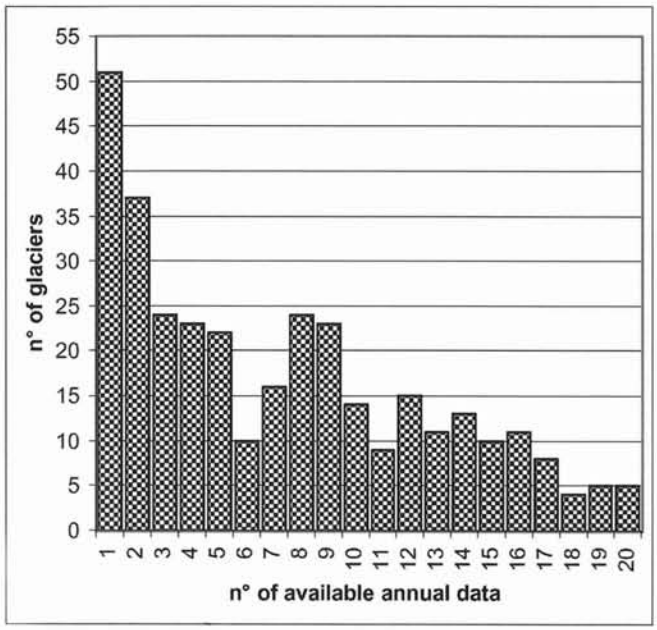


FIG. 2 - Number of available annual data for each glacier in the period between 1980 and 1999. The sample analysed is made up of 335 glaciers.

RESULTS

The number of recorded annual data ranged from a minimum of 48 in 1982, to a maximum of 188 in 1980, on a total of 405 glaciers observed (some data refers to different portions of a same glacier) and each annual sample can be only partially overlapped to the others. Various discordant or contrasting values have been observed (e.g. front altitude variations not relative to the variation in their position), probably due to different types of error, different surveyors or observations carried out from different measure points (such problems are cited also in Zanon, 1985).

The elaboration of the original matrix has reduced the total number of glaciers to 335. 51 glaciers (15%, to which the 70 disregarded glaciers must be added) supplied only one datum, 180 glaciers (54%) 2 to 9 data, while the remaining 104 glaciers (31%) supplied at least 10 data; only 5 of them (1.5%) supplied a complete annual set of data spanning the entire period between 1980 and 1999 (*Ventina* e *Forni* for the Lombardy sector; *Pré de Bar*, *Lys* and *Rutor* for the Piedmont- Aosta Valley sector) (fig. 2). Altogether 2443 data out of 6700 possible ones is available.

Figure 3 shows the distribution of some characteristics on the analysed glacier sample, according to the cadastral data in 1958. Since this is not recent data, and considering the current retreat phase, the surface and length values were certainly overestimated compared to the present ones. In 1958 the maximum elevation reached by the glaciers (329 data available; fig. 3a) ranged between 2010 m and 4810 m, with an average value of 3217 m; most of the values (74%) were included between 2800 and 3500 m. The minimum front altitudes (330 data; fig. 3b) were between 1550 and 3200 m with an average of 2672 m; in the Piedmont-Aosta Valley sector the values were concentrated between 2500 and 3100 m altitude (79%); in Lombardy between 2500 and 3000 m (84%) and in the Eastern sector of the Alps (Triveneto) between 2400 and 2800 m (73%). The length of the glaciers (331 data; fig. 3c) was between 130 m and 10-km (1468 m average), but most of them were between 300 and 2500 m long (78%). Their surface area (327 data; fig. 3d) was between 0.9 and 2000 hectares (115 ha average), for a total of approximately 377 km^2, with the majority of values between 10 and 500 ha (84%); only 4 glaciers exceeded 1000 ha surface. The number of glaciers (331 data; fig. 3e) having a northern exposure is decidedly higher (26%), followed by glaciers facing north-west (16%) and north-east (14%) while the number of those having Eastern, Southern and Western aspects is much lower (6-12%).

Most of the glaciers examined in the three alpine sectors are located the Piedmont-Aosta Valley one (176 glaciers, 53 glaciers monitored every year on average) followed by the Lombardy sector (101 glaciers, 39 monitored per year on average) and by the Eastern sector (58, 30 monitored per year on average). Figure 4 shows the annual percentages of glaciers with positive, negative and null variations of the whole-analysed sample and of its single alpine sectors. In any case the progressive and drastic decrease in the number of advancing glaciers to the advantage of those retreating is evident; on the contrary the number of the stationary ones is generally of little influ-

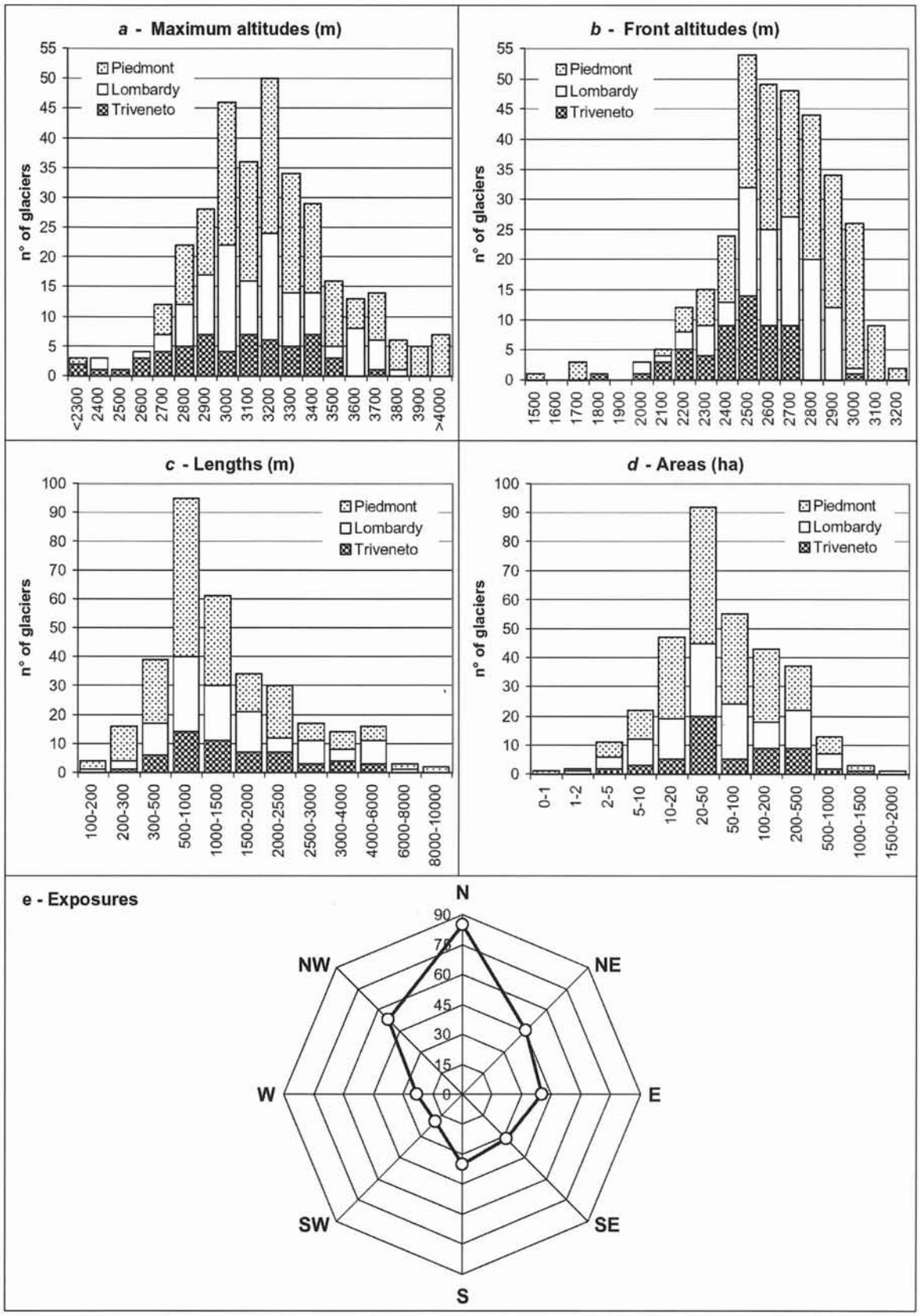


FIG. 3 - Distribution of some glacier parameters of the analysed sample, according to the cadastral data recorded in 1958.

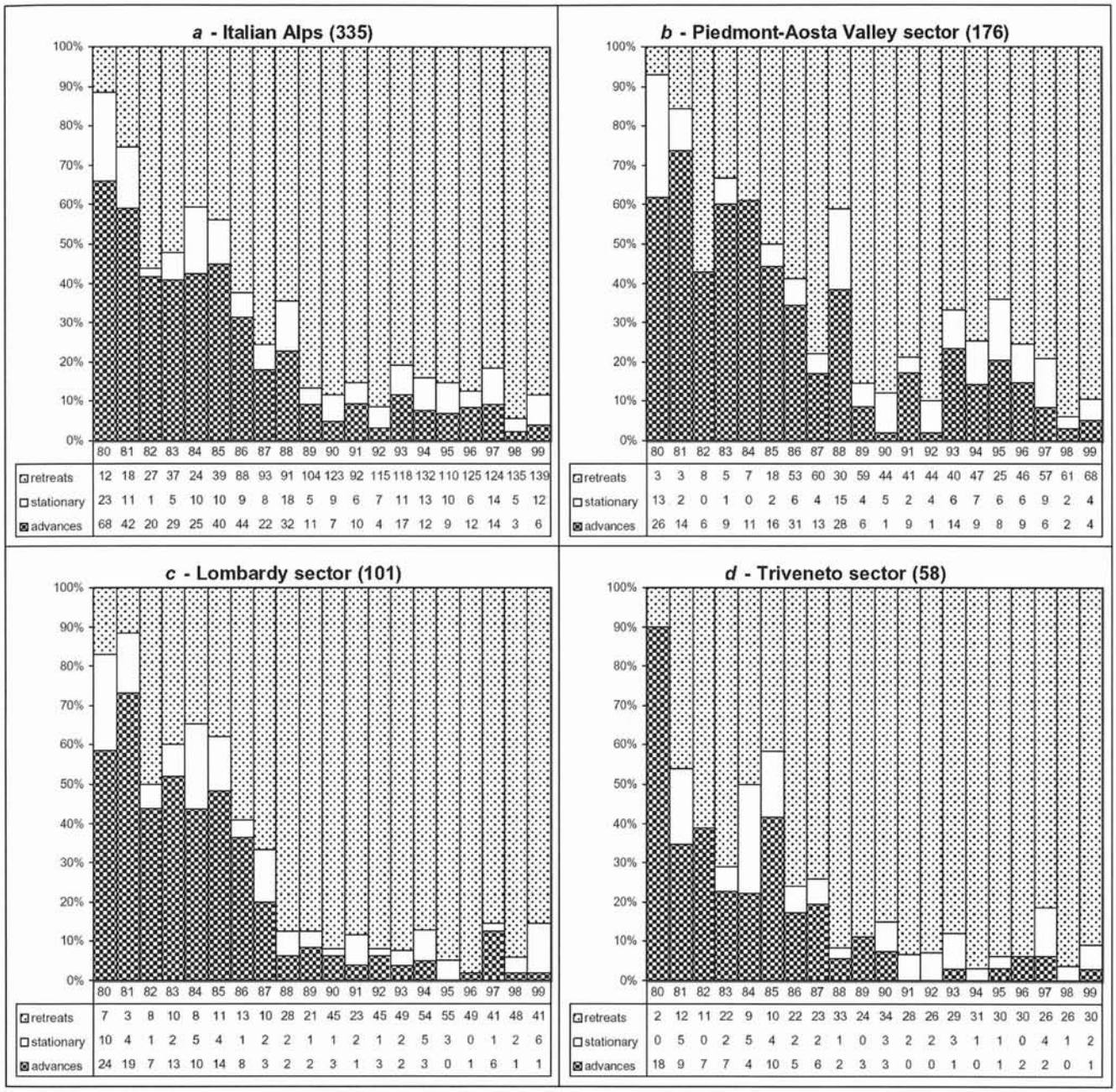


FIG. 4 - Percentage of advancing, stationary and retreating glaciers in the Italian Alps (4a) and in the three sectors into which they are divided (4b, 4c, 4d), in the period between 1980 and 1999 (the number of glaciers representing the sample is reported in brackets).

ence. For the whole sample (122 glaciers monitored every year on average, for a total of 2366 measures; fig. 4a), the percentage of advancing glaciers decreased from 66% in 1980 to 4% in 1999, while that relevant to the retreating ones increased from 12% to 89%. Such values modified quite quickly during the first decade and then stabilized in the following one, during which the percentage of retreating glaciers settled around 80-90%. At the level of every single sector, despite their parallel course, it has been noted that the number of advancing glaciers started to decrease first in the Eastern sector (fig. 4d) and subsequently in the Lombardy (fig. 4c) and in the Piedmont- Aosta Valley ones (fig. 4b). During the early 80s the advancing phase of the latter maintained for a longer time, furthermore showing a modest resumption (10-20% of the monitored glaciers) in the mid 90s. Moreover, the same sector,

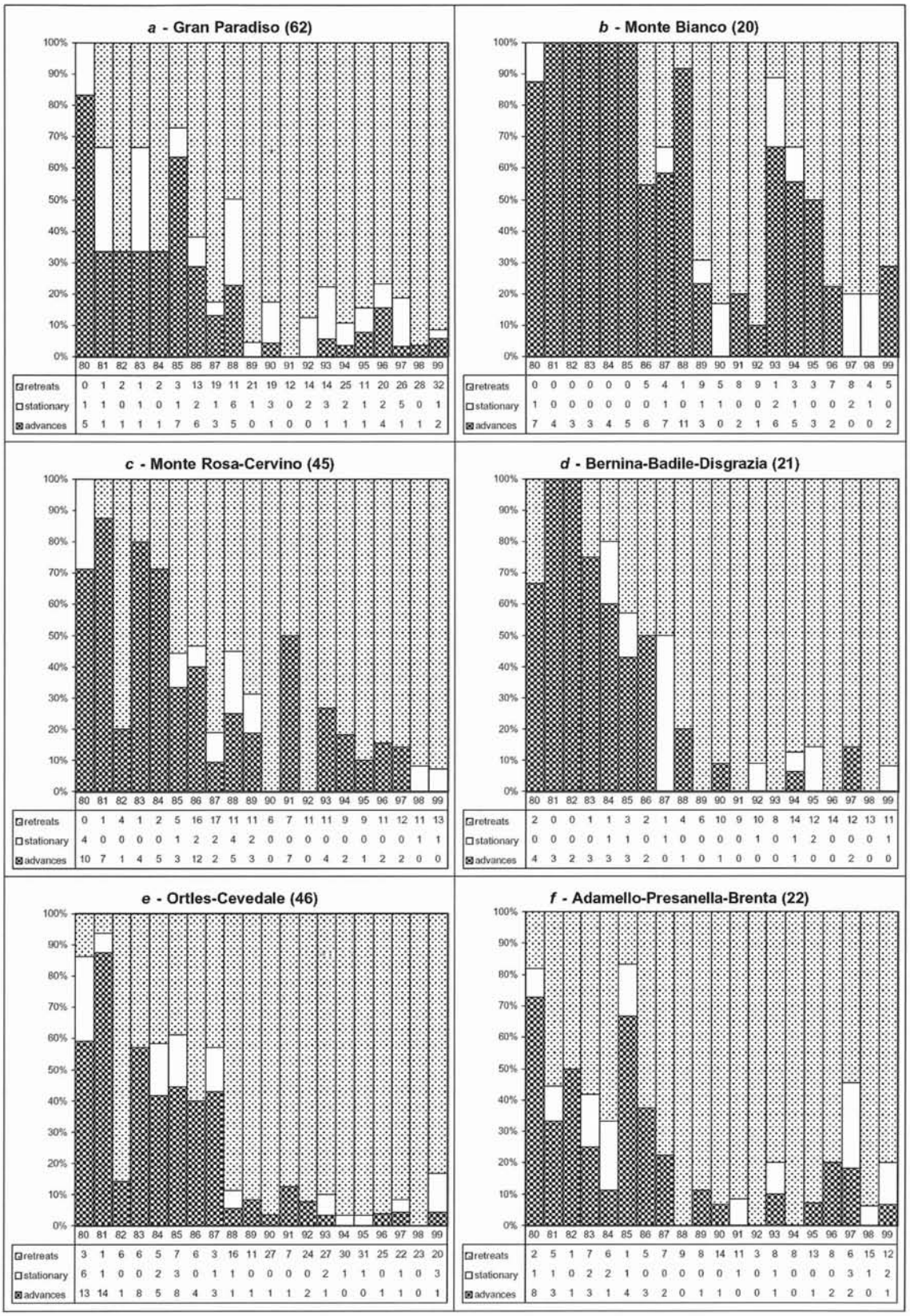


FIG. 5 - Percentage of advancing, stationary and retreating glaciers in the main mountain groups of the Italian Alps (the number of glaciers representing the sample is reported in brackets).

in particular the Monte Bianco Group, was the first to show the Cold Phase (Cerutti, 1971, 1992; Vivian, 1975; Zanon, 1985).

Analogous processing performed on mountain groups with a sufficient number of glaciers (fig. 5) show trends similar to the one already described, despite a greater annual variability related to the lower number of data. The Gran Paradiso Group (fig. 5a) has been supplying a good number of measures since 1986, and most of its glaciers are retreating. The Monte Bianco Group (fig. 5b) supplied scanty data, but the short advancing phase which occurred in the mid 90s, also visible in the Monte Rosa-Cervino Group (fig. 5c) and to a lesser extent in the Adamello-Presanella-Brenta Group (fig. 5f), seemed to be significant. Remarkably prevailing retreats characterized the Bernina-Badile-Disgrazia (fig. 5d) and Ortles-Cevedale Groups (fig. 5e) in the late 80s and in the 90s. Figures 6 and 7 show the percentage of advancing and retreating glaciers of the entire sample, respectively according to their length and surface. In both cases, the trend of the first two classes (fig. 6-7a-b), including the smaller glaciers (< 0,7-km long; < 30-ha wide), show an irregular pattern of variations, partly due also to the lower number of measures. On the contrary the other four classes (fig. 6-7c-d-e-f), particularly those including the bigger glaciers, show the same trend as the one of the entire sample of Italian glaciers (fig. 4a). Some intermediate classes (fig. 6c-7b-7c) supplied a sufficient number of data only from 1986 to 1999, which however confirmed the predominance of retreats. The bigger glaciers (fig. 6-7e-f) continued to advance in the 80s consequently delaying the next phase of prevailing retreat a few years.

Figure 8 shows the data according to the glacier aspect. The general trend is the same as above and is more marked in the classes of glaciers with a northern and southern aspect; on the contrary glaciers facing east and west show more irregular variations.

Glaciers, which supplied at least 10 annual data for the twenty years considered, are 104. Figures 9, 10 and 11 and table 1 show the average annual (a) and cumulative (b) variations of the different sectors and classes formed according to their dimensions and aspect, and those relevant to the entire sample of 104 glaciers considered.

For the latter positive variations (approximately +5 m) were observed in 1980 and 1981, almost null values were recorded for the period between 1982 and 1985, and variations from –4 m to –13 m (absolute maximum value in 1998) during the following years. The yearly average variation per glacier for the whole period was –4.8 m. The curve of the cumulative variations is positive until 1987, and then becomes negative until it reaches an average total value per glacier of –95.4 m during the twenty years considered.

Figure 9 shows the variations calculated for the three alpine sectors. The retreating phase was more marked in the Lombardy sector, with above-average negative variations, especially after 1990 (average annual retreat > 10 m), and with an average cumulative retreat of the fronts of nearly 150 m. Variations below the average were instead observed in the Piedmont-Aosta Valley sector, characterized by a general advancing phase which lasted a few more years, followed by a total retreat of 44 m only. On the contrary, glaciers of the Eastern sector follow the average trend. Figure 10 reports the data divided according to the length and the area. The smaller glaciers show more modest positive or negative average annual variations (until 8 m) compared to the bigger ones (up to 17 m). Therefore the latter, which advanced much more in the first decade, also showed a much greater retreat compared to the first ones in the succeeding period (approximately 110-120 m against 70-80 m).

In figure 11 data is reported according to the glacier aspect. Glaciers with an eastern and western exposure show a greater retreat, with an average annual retreat of nearly 6-7 m and a cumulative value of 120-130 m per glacier (with a curve always below the average). Glaciers facing north and south had instead more moderate variations, approximately –4 m retreat/year and a total retreat of nearly 85 m. The first group shows a marked advancing phase in the cumulative curve, culminated in 1985 (more than 30 m). The second group reflects the average values well, also because it represents the bigger group. The relation between front variations and exposure proceeding counterclockwise from North to North-East (Belloni & *alii*, 1985) is not highlighted.

Figures 9, 10 and 11 also show the regression line relevant to the average annual variations of the entire glacier set revealing a statistical tendency to increase of the average glacier front retreat of 0.73 m/yr (cf. tab. 1).

Data above mentioned is reported in detail in table 1, supplying both the average variations for the period between 1980 and 1999 and those relevant to every single decade for every grouping above analysed. Data confirms that the greater variations are those relevant to the Lombardy sector, to the glaciers having an eastern and western aspect, and to the bigger ones, while the other glacier groups, among which, in particular, the Piedmont-Aosta Valley glaciers, had smaller variations. Moreover, marked differences between the two decades have been observed. In the period between 1980 and 1989 the average variation per glacier was –1.2 m/year, including also the positive values recorded in the Piedmont-Aosta Valley sector and in the glaciers facing south. In this decade the greatest variation occurred in the glaciers facing East. In the next decade, 1990-1999, the average variation per glacier was –8.4 m/year; in this second period of time glaciers of the Lombardy sector underwent a retreat nearly double compared to the others. The same thing occurred for the bigger glaciers with regard to the smaller ones. On the contrary the exposure seemed to have less influence since the four groups were subject to retreats of nearly the same entity. The cumulative average variation per glacier was –83.8 m. The bigger glaciers and those belonging to the Lombardy sector were well above the average.

The cumulative variation calculated for each glacier in the twenty years considered, takes very variable proportions when compared with their length; as regards the

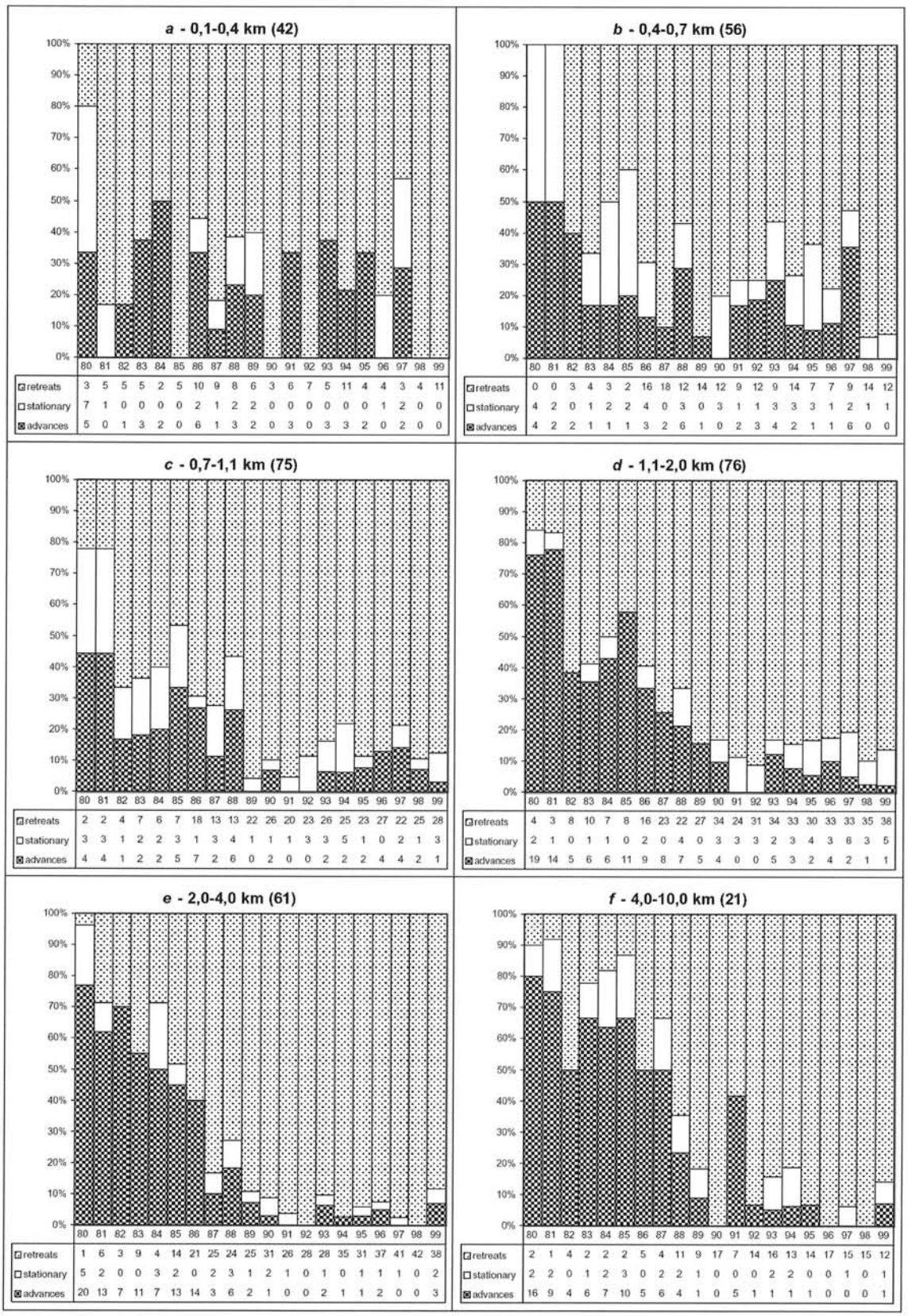


FIG. 6 - Percentage of advancing, stationary and retreating glaciers of the Italian Alps according to the length (the number of glaciers representing the sample is reported in brackets).

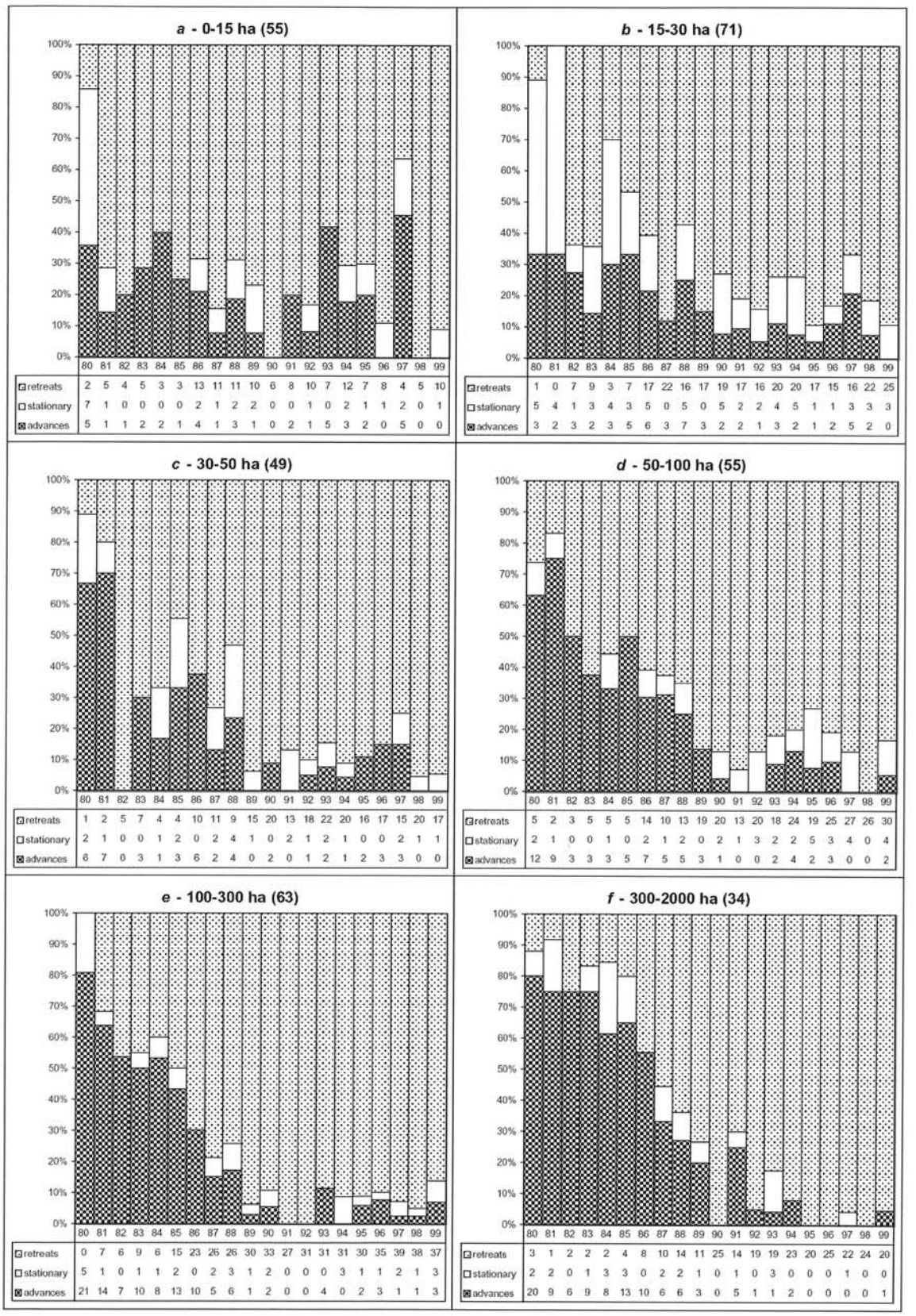


FIG. 7 - Percentage of advancing, stationary and retreating glaciers of the Italian Alps according to the surface area (the number of glaciers representing the sample is reported in brackets).

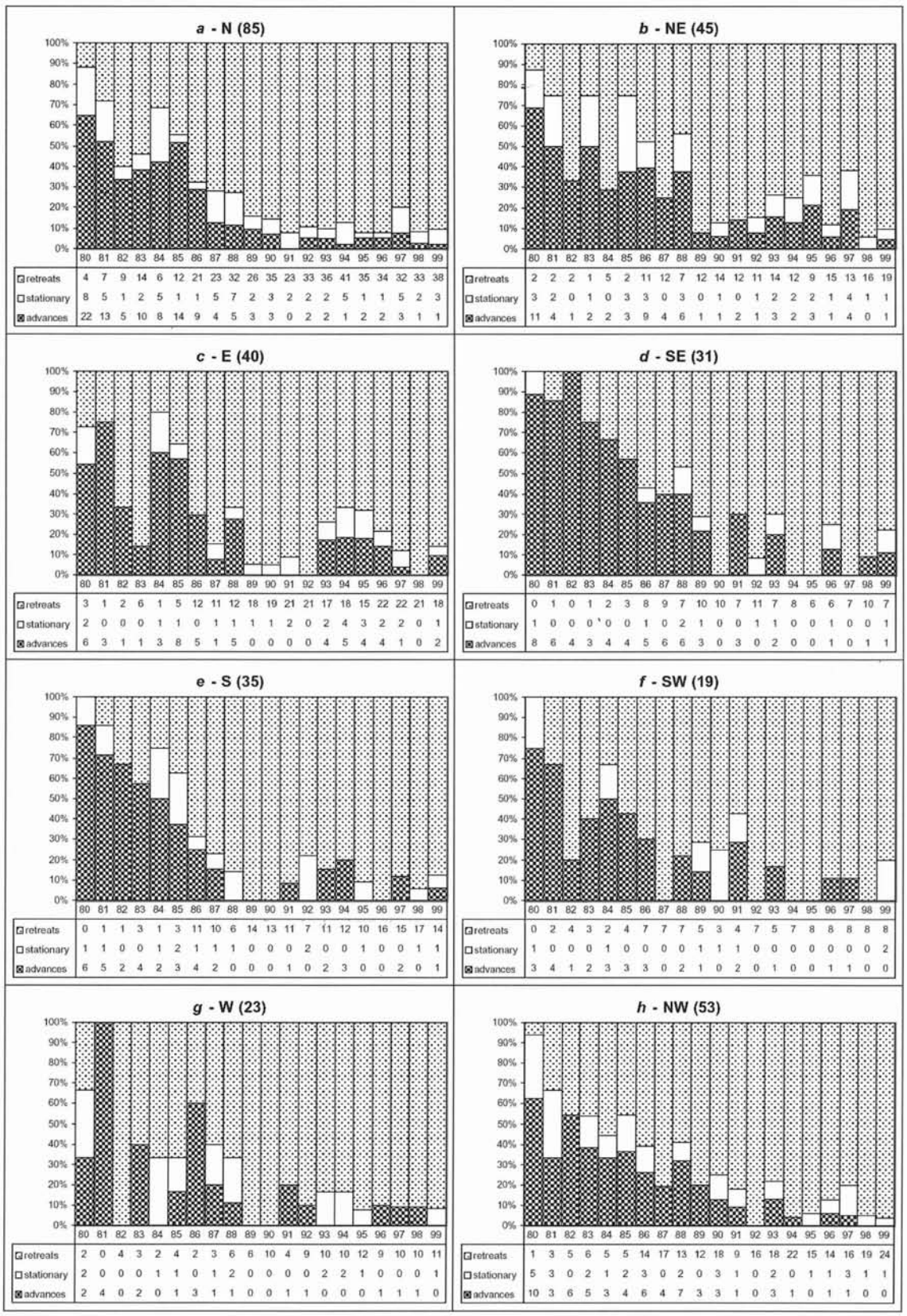


FIG. 8 - Percentage of advancing, stationary and retreating glaciers of the Italian Alps according to their aspect (the number of glaciers representing the sample is reported in brackets).

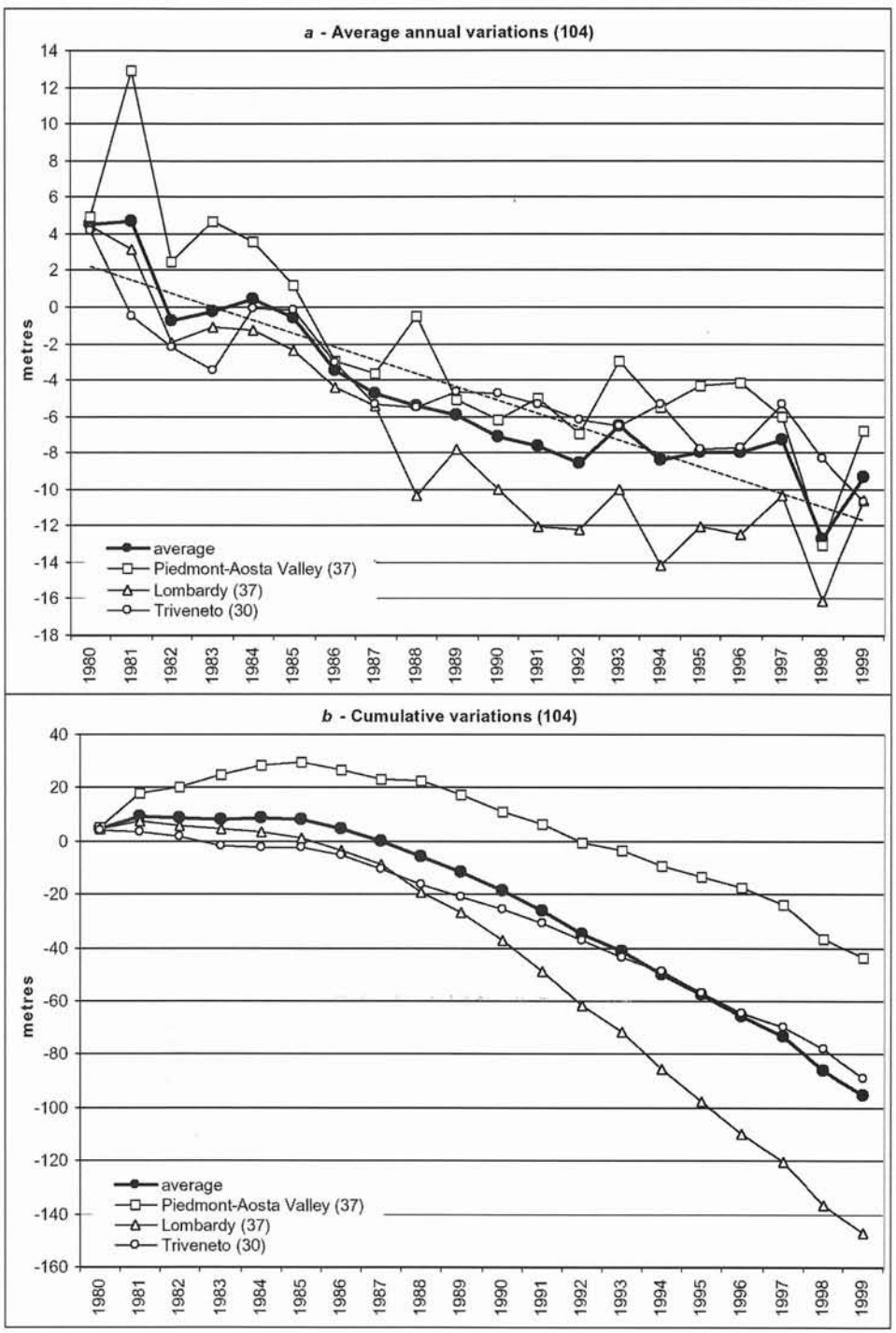


FIG. 9 - Annual (9a) and cumulative (9b) average variation on a sample of 104 glaciers supplying at least 10 annual data out of 20 (50%). The total average is compared to that of every single sector.

smaller glaciers (< 1600-m long) the average retreat is between 5% and 32%; with regard to the bigger ones (> 1600-m long) the percentage variation is between 1% and 7%. Therefore, although the first were subject to variations of smaller entity, they underwent, in proportion, a much greater loss compared to the latter. In an analogous way, the proportion based on the annual average retreat of the fronts shows variations lower than 0.4% as regards the greater glaciers, and up to 1.6% as regards the smaller ones.

The percentages of advancing, stationary and retreating glaciers (fig. 12) reflect very well the trend previously observed (fig. 4a), although they are based on a subsample (less than 1/3) of the entire data set.

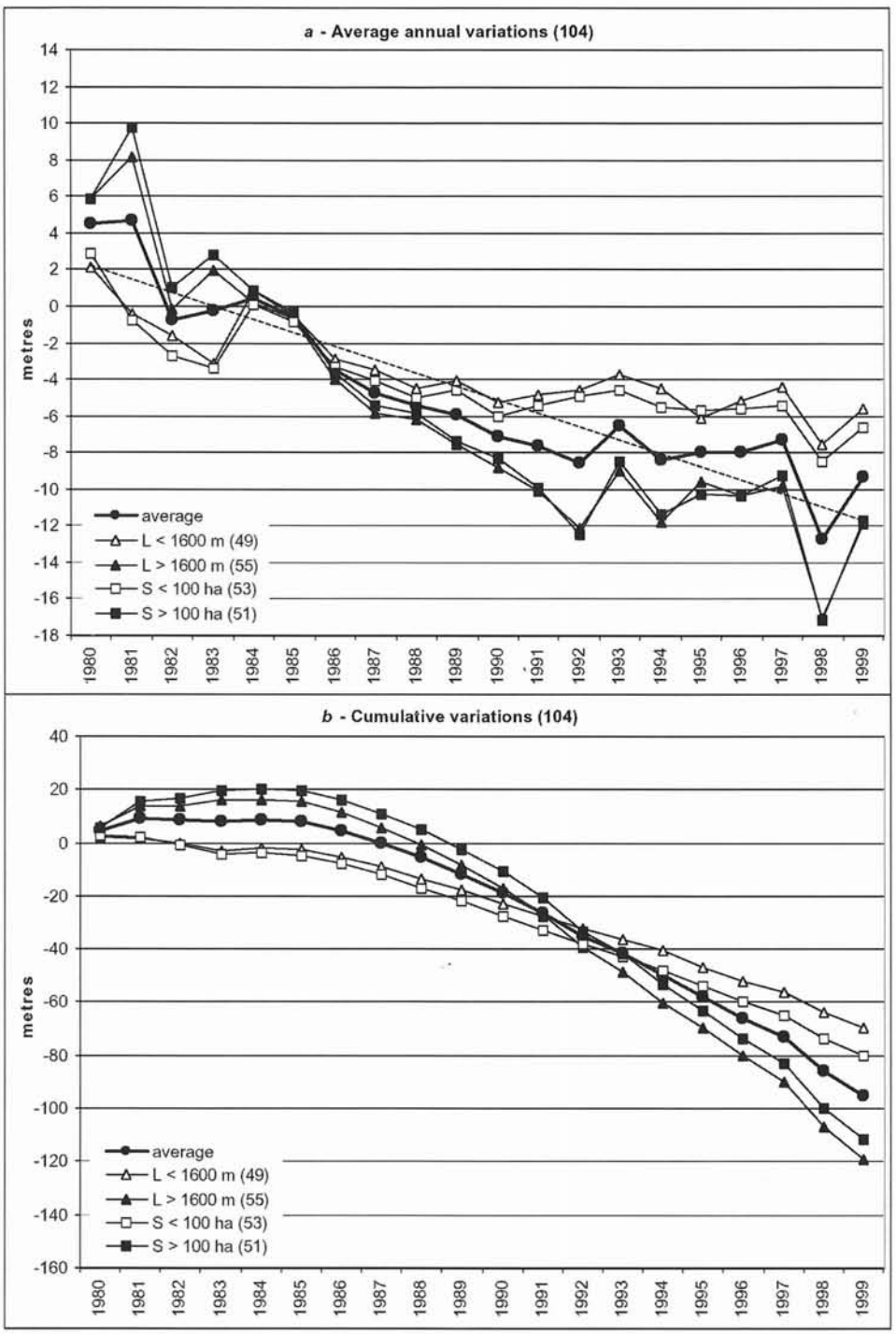


FIG. 10 - Annual (10a) and cumulative (10b) average variation on a sample of 104 glaciers supplying at least 10 annual data out of 20 (50%). The total average is compared to the one relevant to the groupings formed according to the glacier length and surface.

As far as the variation of the minimum altitudes of the fronts during the considered period (fig. 13) is concerned, on a sample composed of 90 glaciers supplying at least 10 data, an average elevation of 18 m per glacier (from 2546 m to 2564 m) has been calculated. The trend shows a light lowering of the altitudes culminated in 1986, followed by a gradual raising. However, as regards every single sector, very marked variations (+ 38 m) occurred in the Lombardy sector, where the initial lowering is not even visible, while smaller ones took place in the Triveneto Eastern sector (+ 12 m); very marginal were those in the Piedmont-Aosta Valley

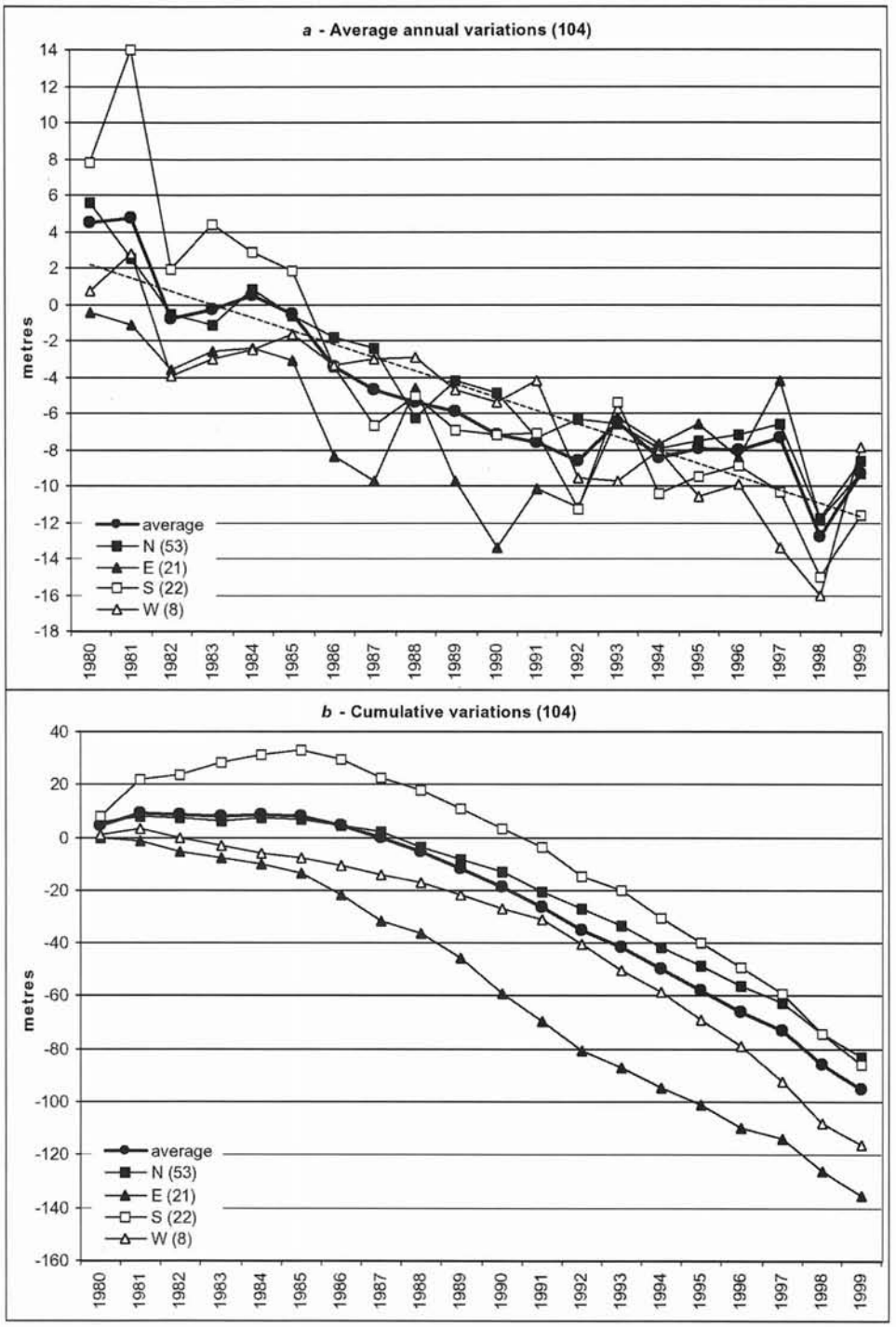


FIG. 11 - Annual (11a) and cumulative (11b) average variation on a sample of 104 glaciers supplying at least 10 annual data out of 20 (50%). The total average is compared to the one relevant to the four aspects.

one (only + 3 m). All the glaciers in Lombardy faced a remarkable elevation of the fronts, above the average, and no cases of altitude reduction have been recorded (fig. 14). Both positive and negative variations have been instead calculated for the glaciers of the other sectors.

DISCUSSION

The lack of a homogeneous and complete data set on the glacier variations in the Italian Alps makes a precise analysis and the comparison of results rather difficult. Moreover, the anomalous behaviour of some glaciers can

TABLE 1 - Annual and cumulative average variations of 104 glaciers supplying at least 10 annual data out of 20 (50%) and of all the groupings analysed in the text, both in the period between 1980 and 1999 and in the two decades composing it (the average standard deviation is also reported). The linear regression equation relevant to the average annual variations and the respective coefficient of determination (R2) are also reported. In the period between 1980 and 1999, a tendency to an increase of 0.73 m/yr of the average annual retreat is shown by the regression line reported in figures 9, 10 and 11

	Linear regression		Average variation (m)			Cumulative variation (m)		
	$y = mx+q$	R^2	'80 - '99	'80 - '89	'90 - '99	'80 - '99	'80 - '89	'90 - '99
Ali glaciers (104)	y = – 0.73 x + 2.89	0.85 (± 11.0)	– 4.8 (± 11.3)	– 1.2 (± 10.7)	– 8.4	– 95.4	– 11.6	– 83.8
Piedmont-Aosta Valley sector (37)	y = – 0.81 x + 6.36	0.71	– 2.2	*1.7*	– 6.1	– 43.7	*17.3*	– 61.0
Lombardy sector (37)	y = – 0.90 x + 2.05	0.82	– 7.4	– 2.7	– 12.0	– 147.2	– 27.1	– 120.1
Triveneto sector (30)	y = – 0.51 x + 0.89	0.77	– 4.5	– 2.1	– 6.8	– 89.0	– 20.9	– 68.1
Length < 1600 m (49)	y = – 0.35 x + 0.17	0.71	– 3.5	– 1.8	– 5.2	– 69.5	– 17.8	– 51.8
Length > 1600 m (55)	y = – 1.02 x + 4.77	0.84	– 5.9	– 0.8	– 11.1	– 118.9	– 8.3	– 110.6
Area < 100 ha (53)	y = – 0.38 x – 0.03	0.72	– 4.0	– 2.2	– 5.8	– 80.1	– 21.7	– 58.4
Area > 100 ha (51)	y = – 1.07 x + 5.60	0.84	– 5.6	– 0.3	– 10.9	– 111.8	– 2.5	– 109.3
Exposure N (53)	y = – 0.67 x + 2.92	0.86	– 4.2	– 0.8	– 7.5	– 83.1	– 8.2	74.9
Exposure E (21)	y = – 0.40 x – 2.53	0.39	– 6.8	– 4.6	– 8.9	– 135.3	– 46.0	– 89.3
Exposure, S (22)	y = – 1.13 x + 7.61	0.81	– 4.3	*1.1*	– 9.7	– 86.0	*10.8*	– 96.7
Exposure W (8)	y = – 0.71 x + 1.63	0.79	– 5.8	– 2.2	– 9.5	– 116.2	– 21.6	– 94.6

sometimes alter the result of some analysis (e.g.: in 1981 the Brenva glacier, Valle d'Aosta, advanced as much as 160 m). Nevertheless, the tendency to a progressive retreat to which most of the glaciers are subject is clearly evident; it manifested in a generalized way, with only minor deviations, independently of the groups of glaciers considered.

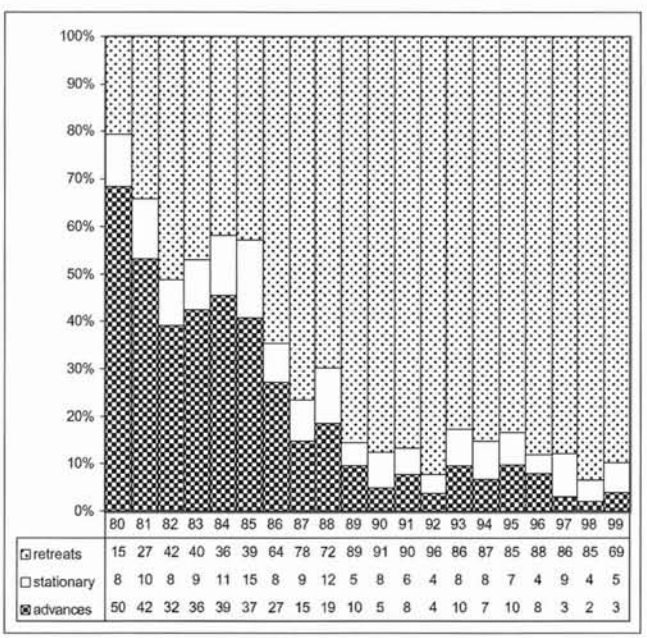


FIG. 12 - Percentage of advancing, stationary and retreating glaciers on a sample of 104 glaciers supplying at least 10 annual data out of 20 (50%).

The number of retreating glaciers progressively increased during the first of the two decades considered - in 1989 Ajassa & *alii* (1997) already recorded a reduction in the glaciated areas by over 2000 hectares compared to the cadastral data in 1958 - and continued for all the following decade, during which the greater variations were observed. The retreat phase mostly affected the Lombardy sector, where front variations and an uplift of the front altitudes well above the average value were recorded.

There is a significant relationship between the glacier dimension (length and area) and the front variations: the small glaciers show irregular variations due to their greater sensitivity to the annual climatic conditions, while the biggest ones follow the multiyear climatic trend, because of the greater inertia and of the longer response time. Nevertheless, the biggest glaciers undergo, according to their length and surface, smaller variations compared to the smallest ones. This inverse relation between the variations and the initial dimensions of the glaciers has already been stressed, for example, by Belloni & *alii* (1985) and Maisch (2000).

The present study constitutes a schematic and synthetic evaluation of the Italian glacier behaviour in the last twenty years, based uniquely on the field observation conducted by the Italian Glaciological Committee. The results give an idea of the magnitude of the variations, but they also represent average values from which the single glaciers can remarkably diverge. Considering the non-homogeneity of the available data and the corrections brought, all the values calculated and considered must be interpreted as rough estimates. However, they are significantly indicative of the general trends. The alarming situation of general glacier retreat makes the follow up of their monitoring desirable, in order to prolong into the future a continuous sequence of annual measurements and observations which on the Italian Alps started in 1925.

FIG. 13 - Variation of the front minimum altitudes on a sample of 90 glaciers supplying at least 10 annual data out of 20 (50%). The total average is compared to the one relevant to every single sector.

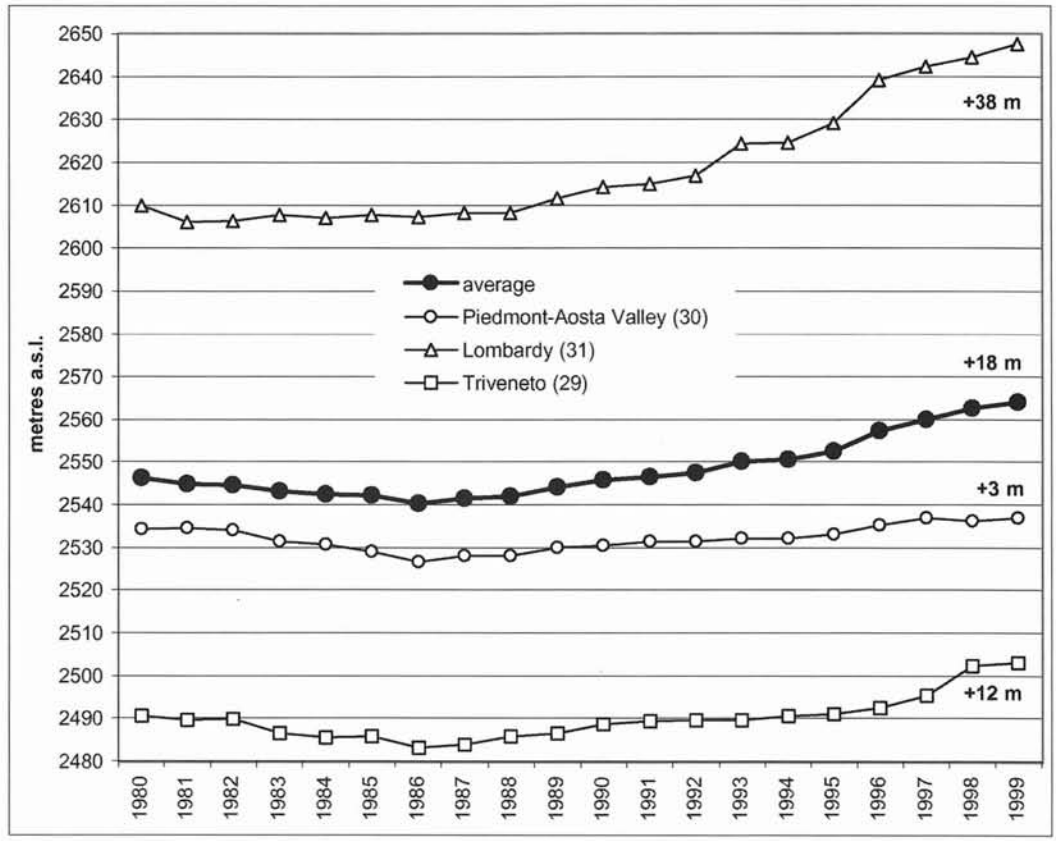
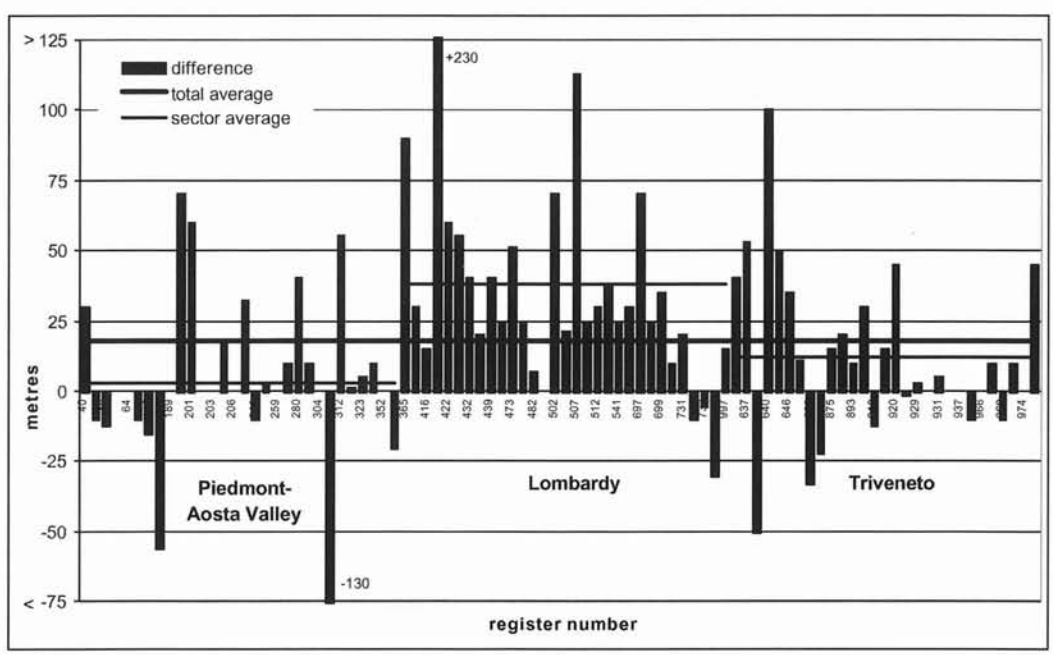


FIG. 14 - Difference between the front minimum altitudes recorded in 1999 and in 1980 on a sample of 90 glaciers supplying at least 10 annual data out of 20 (50%). Each histogram represents a glacier (the register number of which is shown in the abscissa). The total average is compared to the one relevant to every single sector.



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