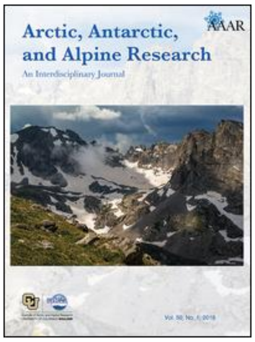

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Retreat of Mediterranean Glaciers since the Little Ice Age: Case Study of Ghiacciaio del Calderone, Central Apennines, Italy

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Abstract

Ghiacciaio del Calderone is the only glacier in the Italian Apennines and the southernmost glacier in Europe. In this paper, the authors present a tentative synthesis of the evolution of the glacier, with a particular focus on evaluating the variations in area and thickness ranging from the end of the Little Ice Age to the present. The analysis was performed in a GIS environment, using available data for georeferation (mainly from recent topographic maps) and for the reconstruction (from historical documents and old topographic maps) of the variations of the glacier in the last two centuries. The resulting values, reconstructed and/or calculated, covering the period since the end of the Little Ice Age, of about 36 m of ice thickness and of about 59,000 m^2 of ice surface area represent the glacier loss by 1990.

Introduction

Ghiacciaio del Calderone is one of Europe's most interesting glaciers. This small (<5 ha) glacier is situated at 42°28′15″N, 12°27 08″E in the Gran Sasso, Abruzzo Regio, Italy, between 2650 and 2850 m a.s.l. (Fig. 1). It is interesting because of isolation in the Apennines and its location within the Mediterranean area, making it the southernmost glacier existing in Europe (Messerli, 1980). We resumed study of Ghiacciaio del Calderone in 1994 after a gap of about 3 yr (Di Filippo et al., 1996; D'Orefice et al., in press). The studies include (1) field surveys of the glaciological, geophysical, and geomorphologic features; (2) data, images, and available cartographic collections; and (3) data processing and printing on GIS.

At present a geo-data base is available on a GIS ARC/INFO Sun work station. In this paper we present additional data from the glacier. Figure 2 presents comparative views of the glacier at the beginning of the 20th century and the present debris cover situation.

Data Sources

Three types of data sources are available to model glacier variations over a significant period of time: (1) historical descriptions, (2) official detailed maps, and (3) maps surveyed with the particular target of Ghiacciaio del Calderone.

HISTORICAL DESCRIPTIONS

(a) A description of the first ascent to the Gran Sasso in August 1573 from the southern slope (De Marchi, 1573), in which a detailed description of the glacier is given from the top of the mountain ("*A great valley of about 1500 m in length where snow and ice lie perpetually*").
(b) A description of the first ascent to the Corno Grande del Gran Sasso through Ghiacciaio del Calderone in July 1794 by Orazio Delfico from the northern slope (Delfico, 1794), in which another detailed description of the glacier is given ("*A plain almost completely surrounded by high peaks, forming a majestic circular depression, and always covered with very solid snow*").

MAPS

Details of the topographic maps which were collected and used in our data processing are summarized in Table 1.

DATA PROCESSING

Delfico's description (1794) and the Istituto Geografico Militare (IGM) map (1884) were used for the reconstruction of the glacier during the Little Ice Age and the last century. Official IGM maps (1954) and the Carta Regione Abruzzo (Map of the Region of Abruzzi, 1982) were used for the 20th century, and supplemented with the most recent maps prepared on larger scales (Tonini, 1963; Gellatly et al., 1994).

The analysis started from the digitization of the entire area of Calderone region with the surrounding peaks and walls from the regional 1:10,000 topographic map of 1982. A further check was performed on this basic document in the glacier area, by overlapping the previously georeferenced topographic map of Ghiacciaio del Calderone prepared at the scale of 1:750 (Gellatly et al., 1994). In this manner, the resulting synthesis map prepared at the scale of 1:10,000 became the "base map" to use as the georeference for other available data, especially the glacier surface variations.

Starting from the data sources mentioned above and their intrinsic features and limits, the following analyses were developed:

(1) A reconstruction of the probable maximum extension and thickness of the glacier during the Little Ice Age, based on the descriptions of De Marchi (1573) and Delfico (1794) and also based on the geomorphological evidence, especially the very visible trim-line and the prominent terminal ice-cored moraine. In particular, following the description of Delfico (1794), the lower part of the glacier was considered as a plane, directly linked and leveled in thickness to the frontal moraine at its maximum level (about 2700 m a.s.l.). For the reconstruction of the

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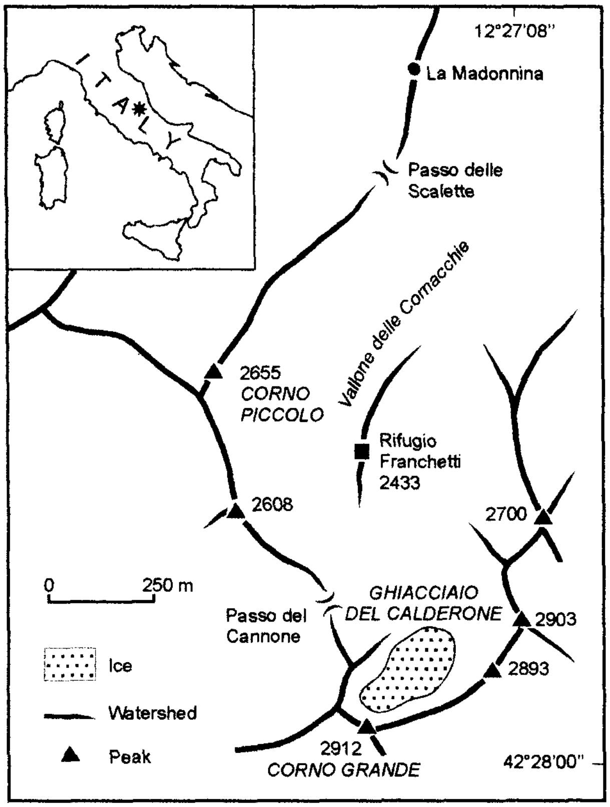


FIGURE 1. Location of Ghiacciaio del Calderone.

upper part of the glacier, the IGM 1884–85 topographic restitution was used with the hypothesis that this area had not changed considerably from one century to the next.

(2) A reconstruction of the surface area (and related thickness variations since the previous reconstruction) in the second half of the 19th century, based on the IGM 1884–85 map. In the reconstruction, considering the distribution of "indicative" contour lines along the glacier, it was also possible to check the extrapolation from historic photographic images, mainly from Rome-CAI (Italian Alpine Club) and private inventories. Truly useful georeferation was not possible, due to the intrinsic error in the surveying methods and the related displacement of the check points in the area, with respect to the original positions.

(3) Georeferation of the perimeter and of the area of the glacier, based on the map of Corno Grande area, IGM 1954–55. The georeferation of the area distribution was also carried out and checked according to the availability of topographic maps (mainly Tonini, 1963) and photographs, which were kindly offered by private collections (mainly by Tonini, 1963, and Graziosi, summers of 1965 and 1966).

(4) Georeferation of the perimeter and the area of Ghiacciaio del Calderone, based on the map of the Region of Abruzzi (1982), 1:10,000, implemented by the map at the scale of 1:750 (Gellatly et al., 1994).

A direct comparison between the large-scale detailed maps of the 20th century (as previously made by Tonini, [1963], for the 1934–1960 period) was not carried out as the data obtained were not comparable with those obtained from the other, older sources.

For each one of the four maps chosen, a Digital Terrain Model (DTM) was prepared from the "base map" 1:10,000), using the ARC/INFO GRID and TIN module. Figure 3 shows a 3-D view of the area from the northeast, including Calderone and showing its characteristic location at the head of a deep valley. The view was prepared starting from ground data of the Abruzzi Region (1982). It should be emphasized that a definition of the exact area of the glacier in recent decades involved considerable problems because debris has almost entirely covered the lower and middle sector of the glacier since 1985.

A further step in the same GIS environment consists in the choice of one common and significant profile broken-line for the four DTMs, from the top of Calderone to the current lower concave part of the glacier. Using georeferenced data, in Win Grapher environment, the four profiles resulting are shown in Figure 4, along with the related variations in thickness over time.

Results and Conclusions

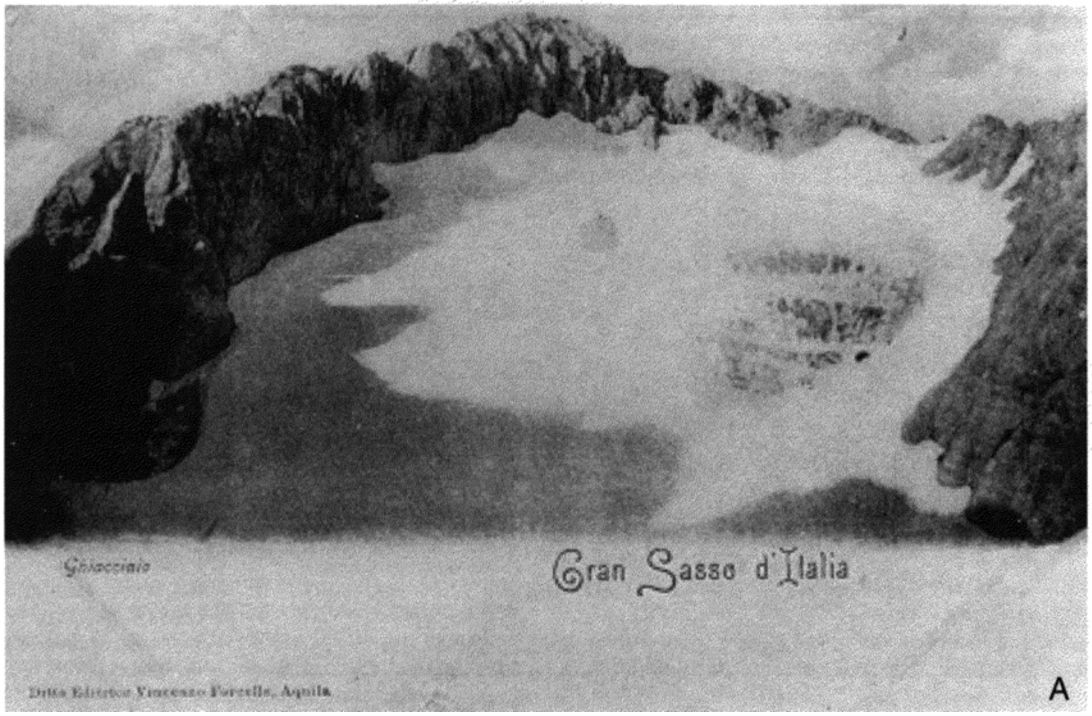
Following the steps of the described methodology, it was possible to evaluate the variations in area and in ice thickness along the chosen profile outlined in Table 2 and shown in the diagram of Figure 5. In addition to the glacier area data calculated using the four sources listed previously, the same table presents the data for the surface area surveyed and calculated for 1916 by Marinelli and Ricci (1916), for 1934 and 1960 by Tonini (1963), and for 1990 by Smiraglia and Veggetti (1992) and by Gellatly et al. (1994). The 1990 values are highly variable in that in one case (Smiraglia and Veggetti, 1992) the total ex-

TABLE 1

Details of the available and used maps of Ghiacciaio del Calderone

Year	Scale	Authors	Co-ordinate system	Title	Survey method	Contour interval (m)
1884–85	1:50,000	IGM[a]	Flamsteed Projection	Gran Sasso d'Italia	Ground topography	10
1916	1:5,000	Marinelli and Ricci	local	—	Field topography	5
1934	1:1,000	Sforzini, Tonini and Tonini	UTM—Fuse 33	—	Ground topography	5
1954–55	1:25,000	IGM	UTM—Fuse 33	Gran Sasso d'Italia	Aerial + ground control	25
1958	1:1,000	Caloi, Zuccarini, and Vaccanti	UTM—Fuse 33	—	Ground topography	5
1960	1:1,000	Balducci, Pesavento, Di Fazio, and Tiberio	UTM— Fuse 33	—	Aerial	5
1966	1:1,000	Tonini	UTM—Fuse 33	—	Ground topography	5
1981–82	1:10,000	Abruzzi Region	ED 50—Fuse 33	Corno Grande	Aerial + ground control	10
1990	1:750	Gellatly, Tomkin, Parkinson, and Latham	local	—	Ground topography	10

[a] IGM—Istituto Geografico Militare.



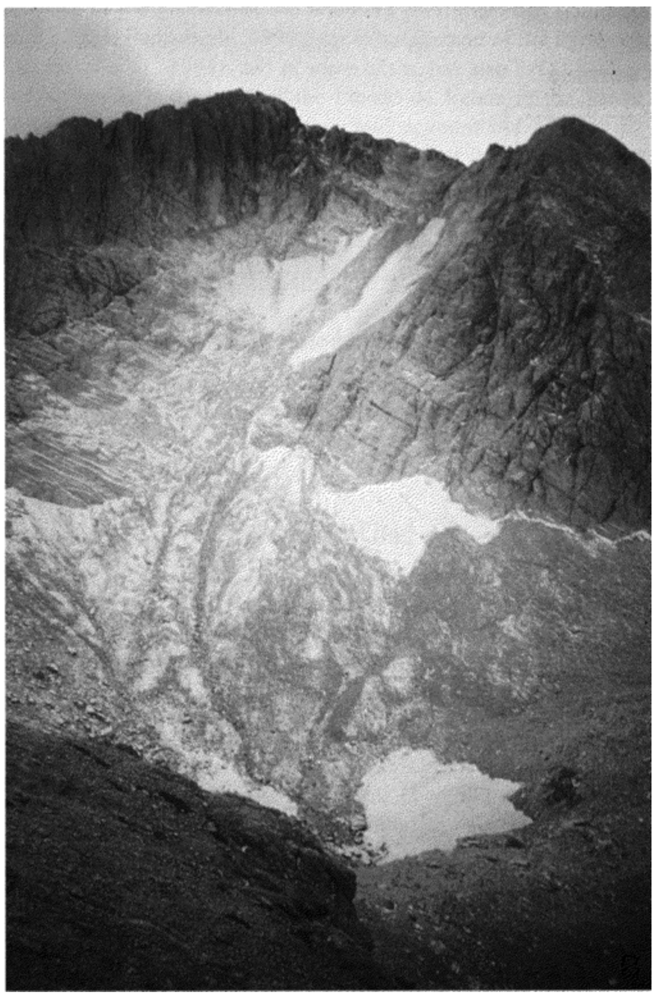


FIGURE 2. Ghiacciaio del Calderone in the (A) early 20th century (July) (F. Capaldi collection) and (B) in 1995 (October) from about the same view point.

tension of the glacier was considered, including the lower sector covered with debris and the boundaries of which are still uncertain. In the other case (Gellatly et al., 1994), only the ice surface that was free of debris was taken into consideration.

The trend emerging from Figure 5 is directly related to the almost progressive loss in area, and it well demonstrates the reduction of Ghiacciaio del Calderone (almost equal to the half of the starting surface area) over the course of the last two centuries. In particular, calculating each difference between the past and present situations, since Delfico (1794) up to 1990, the av-

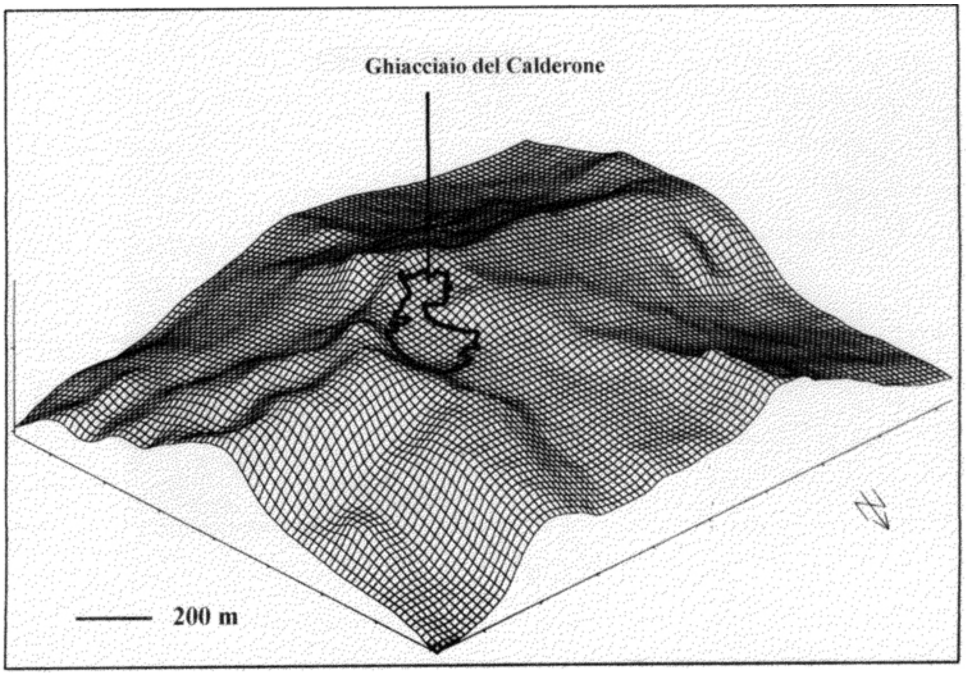


FIGURE 3. Three-dimensional view from the NE (elevation of 45°) of the top area of the Gran Sasso d'Italia (Corno Grande), computed starting from the topographic contour lines and spot heights of the orthophotographic map of Abruzzi Region (scale: 1:10,000) (1982); the thicker line represents the present perimeter of the glacier.

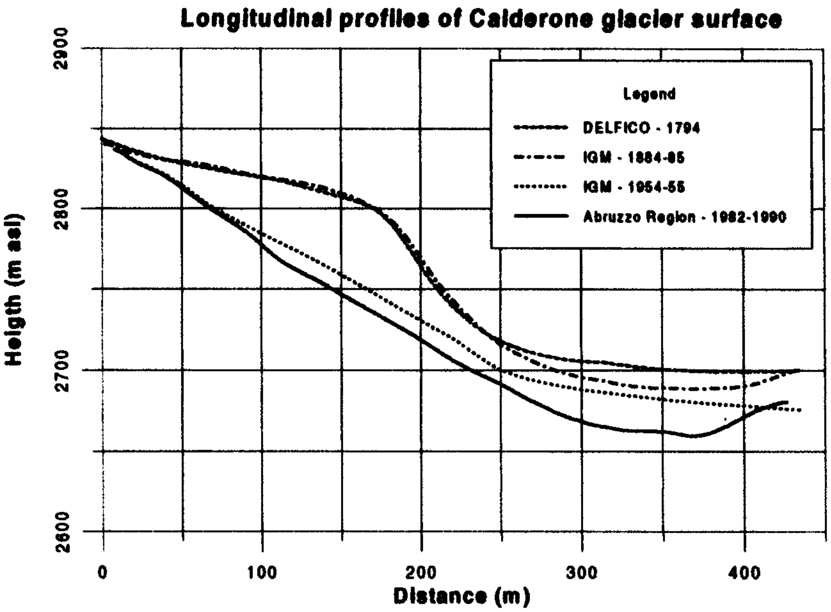


FIGURE 4. Variation of reconstructed longitudinal profiles of Ghiacciaio del Calderone surface during the period considered.

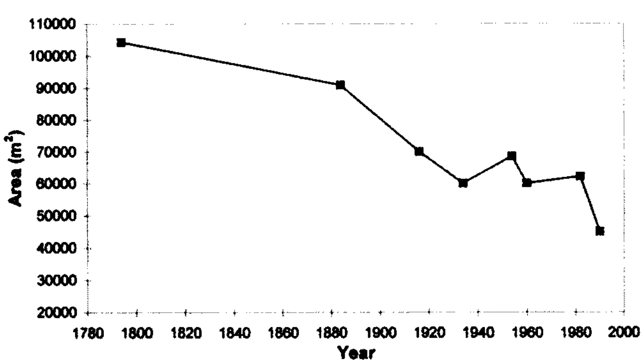


FIGURE 5. Variation in surface area of Ghiacciaio del Calderone since 1780.

erage loss in area is about 59,000 m^2 (more than half of the Little Ice Age surface area), while the average loss in thickness of about 36 m (Table 2) should be equal to about one and half times the present maximum thickness of the ice (about 20 m, according to Fiucci et al., 1997). The reduction in thickness between 1954 and 1982, calculated as a mean along a longitudinal profile, proves to be 11.28 m (0.40 m yr^{-1}), whereas the mean calculated by Tonini (1963) for the entire glacier since 1934 up to 1960 is about 7 m (reduction rate of about 0.27 m yr^{-1}).

The area reduction figures seem to indicate that after a rapid reduction that continued up to the early decades of the 20th century, the glacier, due to the thick debris cover, reached an "equilibrium" surface area of about 6 ha at least until the start of the 1980s. There was another, additional area loss in the next decade.

Ghiacciaio del Calderone is thus in keeping with the ten-

TABLE 2

Data concerning Ghiacciaio del Calderone features and variations over time—1990 being the reference year; figures with asterisks (*) represent reconstructed data; (a): Smiraglia and Veggetti (1992); (b): Gellatly et al. (1994)

Year	Area (m^2)	Loss in area up to 1990 (m^2)	Mean loss in thickness up to 1990 (mm)
1794	104,257*	59,257	35.940
1884	90,886*	45,886	33.020
1916	70,000	—	—
1934	60,000	—	—
1954	68,501	23,501	11.280
1960	60,000	—	—
1982	62,151	—	—
1990	45,000 (a) 20,000 (b)	0	0

dency of Mediterranean glaciers in general, experiencing a constant rise in altitude of the snowline since the 1850s, as well as an almost continuous sequence of negative balances. The result has been the reduction of the surface area and thickness, as is the case of the glaciers of the Southern Maritime Alps (Gellatly et al., 1994; Pappalardo, 1999), for example, and of the Pyrenees (Arenillas et al., 1991), and in some cases, has also led to glacier extinction, as is the case of the Picado de Veleta in the Sierra Nevada (Messerli, 1980). Taking into account the present dimensions of Ghiacciaio del Calderone, unless there is a marked change in the present climatic trend, the glacier could be extinct in the course of a few decades, despite the reduction in ablation brought about by the considerable thickness of the debris covering the entire lower sector of the glacier.

Acknowledgments

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