Geogr. Fis. Dinam. Quat.
38 (2015), 79-87, 4 figg., 2 tab.

DOI 10.4461/GFDQ.2015.38.08

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THE EVOLUTION OF THE ITALIAN GLACIERS FROM THE PREVIOUS DATA BASE TO THE NEW ITALIAN INVENTORY. PRELIMINARY CONSIDERATIONS AND RESULTS

Abstract: Smiraglia C., Azzoni R.S., D'agata C., Maragno D., Fugazza D.&. Diolaiuti G.A., *The evolution of the Italian glaciers from the previous data base to the New Italian Inventory. Preliminary considerations and results.* (IT ISSN 0391-9838, 2015).

A glacier inventory is a fundamental tool for describing and managing the Alpine glacierized environment and evaluating the impacts of the ongoing climate change. After the 1959-1962 Italian glacier inventory published by the Italian Glaciological Committee (CGI) in cooperation with the National Research Council (CNR), only regional glacier lists have been developed in Italy, thus giving partial pictures of the evolution of the Italian glaciers. In this work, we summarized the main results from the New Italian Glacier Inventory, a national glacier atlas recently completed and based on the analysis of high resolution color orthophotos which were acquired in the time frame 2005-2011. In the New Italian Glacier Inventory 903 glaciers are described, covering a total area of 369.90 km^2 ± 2%. The largest part of the glacier coverage is located in the Aosta Valley Autonomous Region (36.15 % of the total), followed by the Lombardy Region (23.71 %) and the Autonomous Province of Bolzano (23.01 %). The highest number of glaciers was found in Lombardy (230), then in the Autonomous Province of Bolzano (212), in the Aosta Valley Autonomous Region (192), and in the Autonomous Province of Trento (115). About 84 % of the census is composed by glaciers minor than 0.5 km^2 covering only the 21% of the total area. Glaciers wider than 1 km^2 are 9.4 % of the whole number, but they cover 67.8 % of the total area. In the widest size class (>10 km^2), only three glaciers are found. Only 25 glaciers (2.8 % of the census) were classified as "valley glacier", while the largest part (57.3%) was classified as "mountain glacier" and "glacieret" (40%), thus underlining that the Italian glaciers are spread into several small ice bodies with few larger glaciers. A first comparison between the total area reported in the New Italian Glacier Inventory and the value reported in the CGI –CNR Inventory (1959-1962) suggests an overall reduction of the glacier coverage of about 30% (from 526.88 km^2 in the Sixties to 369.90 km^2 in the present time). A second comparison was performed with the WGI (World Glacier Inventory) dataset which in the Eighties listed 1381 Italian glaciers covering a total area of 608.56 km^2. This comparison suggests a loss of 478 glaciers and an area reduction of 238.66 km^2 (-39 %).

Key Words: Glacier Inventory, Orthophotos, WebGIS, Alpine glaciers, Italian Alps

Riassunto: Smiraglia C., Azzoni R.S., D'agata C., Maragno D., Fugazza D.&. Diolaiuti G.A., *L'evoluzione del glacialismo italiano dalle banche dati del secolo scorso al nuovo Catasto dei Ghiacciai Italiani. Risultati e considerazioni preliminari.* (IT ISSN 0391-9838, 2015).

Un catasto glaciale è uno strumento fondamentale per descrivere e gestire l'ambiente glacializzato di alta quota alpino e per valutare gli effetti del Cambiamento Climatico in atto. Dopo il Catasto dei Ghiacciai Italiani prodotto tra il 1959 e il 1962 a cura del Comitato Glaciologico Italiano (CGI) in collaborazione con il Consiglio Nazionale delle Ricerche (CNR), in Italia sono stati pubblicati solo inventari a scala regionale, utili ad una descrizione parziale del glacialismo nazionale e pertanto non completamente esaustivi di tendenze ed evoluzioni generali. Vengono qui presentati in sintesi i risultati conseguiti dal progetto che ha portato alla compilazione del Nuovo Catasto dei Ghiacciai Italiani, un atlante glaciale nazionale prodotto sulla base dell'analisi di ortofoto a colori ad alta definizione acquisite nel periodo 2005-2011. Nel Nuovo Catasto dei Ghiacciai Italiani vengono descritti 903 ghiacciai estesi complessivamente su un'area di 369.90 km^2 ± 2%. La maggior parte della superficie glaciale è localizzata nella Regione Autonoma Valle d'Aosta (36.15 % del totale), seguita dalla Regione Lombardia (23.71 %) e dalla Provincia Autonoma di Bolzano (23.01 %). Il maggior numero di apparati glaciali è risultato in territorio lombardo (230), nella Provincia Autonoma di Bolzano (212), nella Regione Autonoma Valle d'Aosta (192), e nella Provincia Autonoma di Trento (115). Circa l' 84 % dei ghiacciai (per numero) è rappresentato da apparati di dimensioni minori a 0.5 km^2 che insieme coprono il 21% della superficie totale. Ghiacciai più estesi di 1 km^2 sono solo il 9.4 % del numero complessivo, ma coprono il 67.8 % dell'area glaciale nazionale.

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The New Italian Glacier Inventory project has been developed in the framework of a cooperation among the Università degli Studi di Milano, Sanpellegrino Spa brand-Levissima and the Association EvK2CNR. This project also took advantage from the precious cooperation of the Comitato Glaciologico Italiano and of several regional and local partners. These latter are both public administrations and private associations of glaciologists, trekkers, climbers and mountain lovers. This work was also performed in the framework of the PRIN project 2010/2011 (2010AYKTAB_006), local leader C. Smiraglia. The project was also accredited and recognized by the World Glacier Monitoring Service, the organization who developed and is managing the World Glacier Inventory. The New Italian Glacier Inventory is an open access data base. The digital copy of the inventory (reporting tables, diagrams and maps) is available on line at http://users.unimi.it/glaciol. The glacier outlines are visible at the open access web-GIS SHARE GEO network ((http://geonetwork.evk2cnr.org/) developed by the EvK2CNR Association which is periodically checked and updated.

Nella classe dimensionale maggiore (>10 km^2) sono risultati tre apparati glaciali. Solo 25 ghiacciai (2.8 % del numero totale) sono stati classificati come "vallivi" e la maggior parte del campione (57.3%) è stato classificato come "montano" mentre il 40% è risultato di tipo "glacionevato", a sottolineare come la risorsa glaciale italiana sia frammentata in un gran numero di piccoli apparati. Un primo confronto tra i dati riportati nel Nuovo Catasto dei Ghiacciai Italiani e quanto pubblicato nel Catasto CGI-CNR (1959-1962) indica una riduzione della superficie glaciale nazionale del 30% (dai 526.88 km^2 degli anni '60 del secolo scorso agli attuali 369.90 km^2). Un secondo confronto effettuato considerando il Catasto Glaciale Mondiale (*World Glacier Inventory* o WGI), pubblicato alla fine degli anni '80 e che descrive 1381 ghiacciai estesi su un'area di 608,56 km^2, suggerisce la perdita di 478 apparati ed una contrazione areale di 238.66 km^2 (-39 %).

TERMINI CHIAVE: Catasto Glaciale, Ortofoto, WebGIS, Ghiacciai alpini, Alpi Italiane

INTRODUCTION

In the recent past glaciers have begun melting at rates that cannot be explained only by natural climate variability (Dyurgerov & Meier, 2000). Glacier shrinkage is particularly severe upon the Alps, and it is likely driven by the important changes occurring in mid-tropospheric conditions, such as the widely acknowledged rapid increase in temperature during the last few decades (IPCC, 2001; 2007; 2013). In the Alps, air warming was estimated to be more than double of the World average over the last half a century (Böhm & *alii*, 2001), with a significant Summer warming since Seventies (Casty & *alii,* 2005). Between 1850 and 1980, glaciers in the European Alps lost approximately 1/3rd of their area and ca. 50% of their mass, and since 1980 another 20 to 30% of the ice has melted (EEA, 2004).

Among possible methods to analyse the ongoing evolution of cryosphere, collection and analysis of glacier inventories (*e.g.* glacier area and geometry features) can be used to investigate mountain glaciation in a changing climate (Paul & *alii*, 2004a), and potential scenarios on the regional Alpine scale (Zemp & *alii,* 2006). In fact, glacier geometry changes are key variables with respect to strategies for early detection of enhanced greenhouse effects on climate (Kuhn, 1980; Hoelzle & *alii,* 2003). Glacier inventories should be carried out at intervals compatible with the characteristic response time of mountain glaciers (a few decades or less in the case of small glaciers), and the currently observed glacier down-wasting calls for frequent updates of inventories (Paul & *alii*, 2007; 2011; Pfeffer & *alii,* 2014).

Also the Italian glaciers are experiencing over the last decades a strong area reduction which is comparable with magnitude and rates of other Alpine glacierized sectors (Diolaiuti & *alii,* 2012a; 2012b, Paul & *alii,* 2004a; 2011; Zemp & *alii,* 2008). Here we summarize data and information reported in the New Italian Glacier Inventory, a recent glacier data base listing all the Italian glaciers and describing their present size, area and geometry. This new record also permits fruitful comparisons with previous national glacier data base, thus giving information on magnitude and rates of glacier shrinkage in the Italian Alps.

PREVIOUS ITALIAN GLACIER INVENTORIES

Italy has a long and valued tradition in developing glacier inventories. After the first glacier data base realized by Carlo Porro in 1925, the most important work dealing into this context and also being a novelty for that time was the Italian Glacier Inventory, developed by the Italian Glaciological Committee (CGI) in cooperation with the National Research Council (CNR) in the time frame 1959-1962. This data base, developed by analyzing maps and through field surveys, reported 838 glaciers (considering both actual glaciers and glacierets) which covered a total area of 526.88 km^2 (CGI-CNR, 1959; 1961a; 1961b; 1962).

At the end of the Seventies (XX century) the CGI was part of the international team leading the World Glacier Inventory (WGI), which was published later as a synthesis (Haeberli & *alii*, 1989; Serandrei-Barbero & Zanon, 1993) and with full details at the dedicated web page hosted by the WGI web site (www.wgms.ch/). The WGI listed 1381 Italian glaciers covering a total area of 608.56 km^2 (Belloni & *alii,* 1985). The Italian data inserted in the WGI derived from aerial photos, in several cases affected by a non negligible snow coverage. At the end of the Eighties the CGI was charged by the Environment Ministry of the Italian Government of developing a new updated glacier inventory. In the obtained data base the Italian glaciers resulted covering an area of about 480 km^2, indicating an actual decrease with respect to both the CGI inventory and the WGI (Ajassa & *alii,* 1994; 1997). This was the last Italian general inventory, no other studies to develop a national glacier data base were performed. Afterwards, only local (mainly regional) inventories were published (among the others: Desio, 1967; Zanon, 1990; Servizio Glaciologico Lombardo, 1992; Comitato Glaciologico Trentino, 1994; Federici & Pappalardo, 1995, 2009; Citterio & *alii,* 2007; Bonardi & *alii,* 2012; Diolaiuti & *alii,* 2012a; 2012b; Secchieri, 2012; Cerutti, 2013). Then the project named "The New Italian Glacier Inventory" was ideated and developed to fill this scientific gap and in a quite short time frame it has produced an actual updated data base describing the whole Italian glaciation (Smiraglia & Diolaiuti, Eds., 2015).

APPLIED METHODS AND SOURCE OF DATA

The main source of information for data collecting (in particular glacier area data) are high resolution orthophotos. In fact, to mark glacier boundaries and to calculate glacier areas, recent color orthophotos have been analyzed, which were made kindly available for this research project by regional and local administrations. The orthophotos are derived from high resolution aerial photos featuring low or absent cloud coverage and mainly acquired at the end of the summer when glaciers show the minimum snow mantle and then their limits result clearer and better detectable. The analyzed orthophotos have been surveyed in 2005 (Valle D'Aosta, RAVA Flight); 2007 (Lombardia, digital color orthophoto BLOM-CGR S.p.A.-IIT2000/VERS.2007); 2008 (Provincia Autonoma di Bolzano Alto

Adige, PAB Flight); 2009 (Veneto: LIDAR survey performed by Regione Veneto-ARPAV Centro Valanghe di Arabba); 2009-2011 (Regione Piemonte, ICE Flight); 2011 (Provincia Autonoma di Trento, PAT Flight). The orthophotos are purchasable products, with a planimetric resolution specified by 1 pixel (pixel size = 0.5 m). The planimetric accuracy stated by the manufacturers is ±1 m. In few cases satellite imagines have been used to improve the glacier mapping (Valle d'Aosta, 2009 SPOT imagines featuring a resolution of 6 m) and field and literature data as well (Friuli -Venezia Giulia and Abruzzo). The color orthophotos have been used as base layer in a GIS (Geographic Information System) environment to detect and map glacier boundaries. These latter permitted the calculation of glacier areas. The area data together with other crucial information (e.g.: glacier name, identification code, coordinates, catchments, etc.) were inserted in a data base which constitutes the New Italian Glacier Inventory. A cross check of the obtained glacier data was performed considering already existent regional or local inventories, recent published maps and cartography and performing dedicated field surveys. The final validation of all the New Italian Glacier Inventory data was performed by a team of experts selected from the Italian Glaciological Committee and /or from technical personnel of local administrations (Smiraglia & Diolaiuti, Eds., 2015).

To assess the potential error affecting data inserted in the new inventory the approach introduced by Vögtle & Schilling (1999) has been followed. This method, largely applied in the recent past to evaluate the glacier area error in some Italian regions (Diolaiuti & *alii,* 2012a, Diolaiuti & *alii,* 2012b), is based on the calculation for each mapped glacier of the surface area buffer. The final precision of the whole glacier coverage was determined by taking the root of the squared sum of all the buffer areas. Thanks to the high quality and resolution of the orthophotos and to the accurate manual mapping, the obtained glacier area data featured an error minor than ± 2% of the actual value. Exceptions occur in the case of supraglacial debris presence (i.e.: debris covered glaciers, Kirkbride, 2011; Smiraglia & Diolaiuti, 2011). These conditions are becoming more frequent on the last years (Diolaiuti & Smiraglia, 2010) and make more difficult and uncertain to detect and map glacier outlines. In such conditions the mapped glacier area can be underestimated up to 10% of the actual value. To reduce the error, whenever debris occurs at the glacier surface, we also considered particular glacier morphological features (ice cliffs and ice pinnacles, bediérès and epiglacial streams, supraglacial lakes and water ponds, glacier moulins and surface roughness, dark areas due to higher water content or areas showing clear changes of elevation, meltwater streams originating from heavily debris covered areas) indicating the occurrence of buried ice (Paul & *alii*, 2004b; 2009). From the orthophotos analysis we also derived information on glacier aspect and type (following the recommendations listed by Paul & *alii,* 2010; Cogley & *alii*, 2011; Pfeffer & *alii*, 2014); these data were inserted in the New Italian Glacier inventory, as well (Smiraglia & Diolaiuti, Eds., 2015).

RESULTS

The actual picture of the Italian glaciation

On the Italian side of the Alps about 1/5th of the whole Alpine glaciation is located with a total glacierized area of 369.90 km^2 ± 2%, a non-negligible value if compared to the Alps as a whole (2050 km^2, Paul & *alii*, 2011). The total number of Italian glaciers results 903 (also consider-

Table 1 - Area and number of the Italian glaciers sorted according to the Region or Province where they are located

Region or Province	Number of glaciers	Cumulative area value (km^2)	Region contribution to the total area (percentage with respect to the whole Italian coverage)	Region contribution to the total census (percentage with respect to the total number of Italian glaciers)
PIEDMONT	107	28.92	8%	12%
AOSTA VALLEY Autonomous Region	192	133.73	36%	21%
LOMBARDY	230	87.71	24%	25%
TRENTINO (Autonomous Province of Trento)	115	30.96	8%	13%
SOUTH TYROL (Autonomous Province of Bolzano)	212	85.12	23%	23%
VENETO	38	3.23	1%	4%
FRIULI-VENEZIA GIULIA	7	0.19	0%	1%
ABRUZZO	2	0.04	0%	0%
ITALY	903	369.90	100%	100%

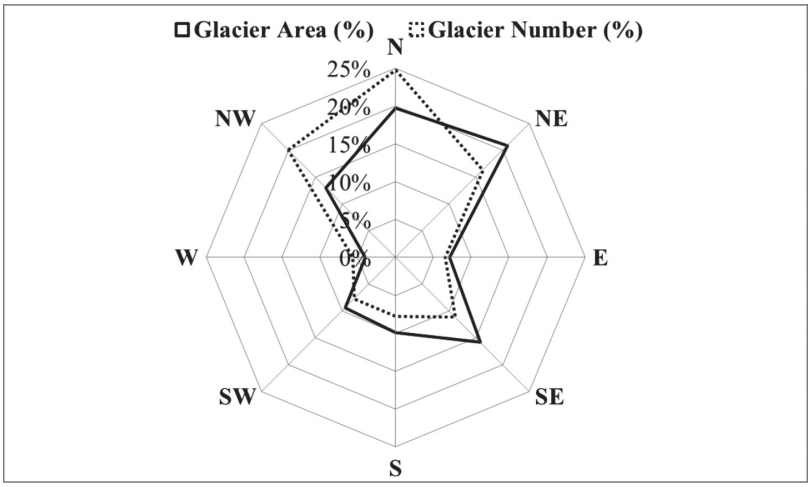

FIG. 1 - Aspect frequency distribution. The percent of glacier area (black) and glacier number (black dotted line line) in 45° aspect bins are reported.

ing two small ice bodies on the Apennines which form the Calderone Glacier), a large value with respect to the Alpine census (3370 glaciers, Paul & *alii*, 2011); they feature an ample distribution, from the Maritime to the Julian Alps. The glacier size and type covers a wide range as well: from the largest Italian glacier, the Adamello ice plateau, to Lys and Forni, large compound basin valley glaciers, to the small mountain glaciers and glacierets.

According to the regional distribution applied in the New Italian Glacier Inventory, the largest part of the glacierized area of Italy resulted to be located in the Aosta Valley Autonomous Region (36.15 % of the total), followed by the Lombardy Region (23.71 %) and the Autonomous Province of Bolzano (23.01 %). The other regions host minor values of glacier area (the minima were found in the Autonomous Region of Friuli-Venezia Giulia, 0.05 %, and in the Abruzzo Region, 0.01 %).

With regards to the glacier number, the highest one is ranked in Lombardy (230), then in the Autonomous Province of Bolzano (212), in the Autonomous Region of Aosta Valley (192), in the Autonomous Province of Trento (115) and in Piedmont Region (107). A very small number of glaciers is located in Veneto Region, in the Autonomous Region of Friuli-Venezia Giulia and in Abruzzo (38, 7 and 2 respectively) (tab. 1).

The mean area value featured by each glacier Region clearly indicates that in the Italian glaciers the small ice bodies dominate: the average value was found 0,41 km^2 and at regional level the range of the mean values goes from 0.70 km^2 (Aosta Valley) to 0.09 km^2 (Veneto).

With regard to the 903 inventoried Italian glaciers, the largest part of their area shows a prevalent North aspect (NW, N and NE) (fig. 1). The 61% of the glacierized area and the 54% of the glaciers feature a North, North-West and North East aspect.

For a better description of the size distribution of Italian glaciers, the surfaces were sorted according to seven size classes, already used in previous regional and international Alpine inventories (i.e.: <0.1 km^2; 0.1-0.5 km^2; 0.5-1 km^2; 1-2 km^2; 2-5 km^2; 5-10 km^2 and >10 km^2; Paul & *alii*, 2004) (fig. 2).

The size distribution of the Italian glaciation agrees with the ones found on other sectors of the Alps and other glacierized mountain chains of the Earth (Paul & *alii*, 2004a, Racoviteanu & *alii*, 2008; Diolaiuti & *alii,* 2012a; 2012b) with a predominance of a large number of small ice bodies (i.e.: < 1 km^2) and only few large glaciers (i.e.: > 10 km^2). Applying this size classification it results that about 84 % of the total glacier number is composed by glaciers minor than 0.5 km^2, but covering only the 21% of the total area. Glaciers wider than 1 km^2 are about 9.4 % of the total number, but they cover 67.8 % of the total area. In the biggest size class (>10 km^2) only three glaciers are found: the Forni Glacier (11.36 km^2) in Lombardy Region, the Adamello Glacier (16.44 km^2) in both Lombardy Region and in the Autonomous Province of Trento, and the Miage Glacier (10.47 km^2) in the Autonomous Region of Aosta Valley. Altogether, these three ice bodies cover about 10.3 % of the Italian glaciation area. A similar picture of the Italian glaciation derives from the type classification. In fact, only 25 glaciers (2.8 % of the total census) were classified as "valley glacier" and the largest part of the sample was labeled as "mountain glacier" (i.e. 517 glaciers corresponding to 57.3%) and "glacieret" (i.e. 361 ice bodies corresponding to 40%), thus further underling a glacier resource spread into several small ice bodies with only few larger glaciers.

Moreover the New Italian Glacier inventory also includes an updated bibliography on Italian glaciers. In fact, an updated reference list is a fundamental tool which supports any development of the scientific research, including glaciology. To accomplish this crucial issue, in the New Italian Glacier Inventory a reference list reporting all the scientific papers dealing with Italian glaciers and published in the time window 1962-2014 was included. In the first volume of the CGI Inventory (1959) the list of the scientific publications, which were focusing on the Italian glaciation and were published up to 1961, was reported. After this date some interesting publications reporting a more recent reference list were published as well, among the others the one by Pantaleo (1973) which has updated by Mortara & *alii* (1995). The main limits of all these works is they only

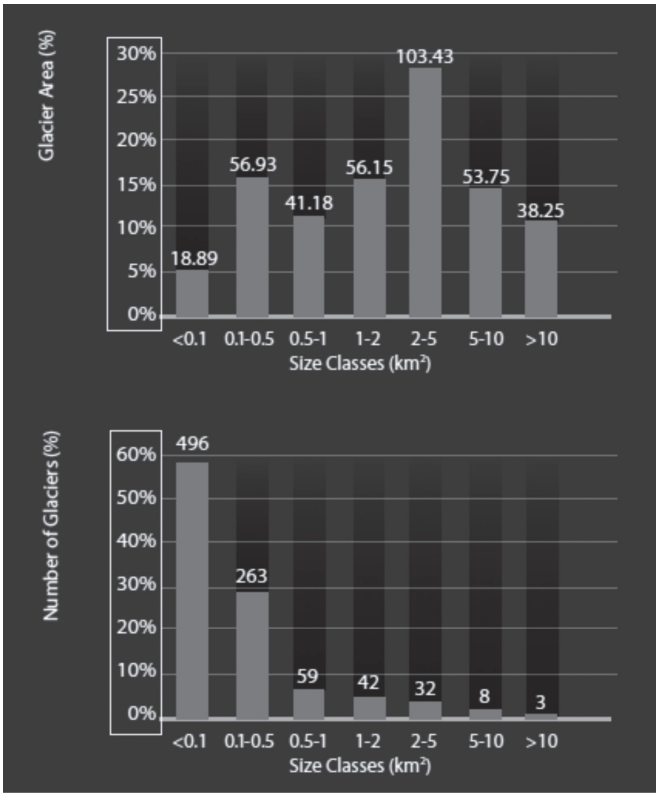

FIG. 2 - Upper panel) Area frequency distribution of the Italian glaciers (on the left, data are percentage values (%) with respect to the total coverage). Area were sorted according to 7 size classes. The labels show the area value of each size class. Lower panel) Number frequency distribution of the Italian glaciers (on the right, data are percentage values (%) with respect to the total glacier number). Number were sorted according to 7 size classes. The labels show the number of glaciers of each size class (from Smiraglia and Diolaiuti, Eds. 2015).

reported papers and monographs edited by the Italian Glaciological Committee (CGI) and then published on the CGI official journal (i.e.: up to 1977 on the "Bollettino del Comitato Glaciologico Italiano", this latter in 1978 became "Geografia Fisica e Dinamica Quaternaria"). To give a more exhaustive picture of the actual Italian Glaciation in the New Italian Glacier Inventory were listed all the papers dealing on Italian glaciers and published in the time window 1962-2014 on national and international journals, books and monographs.

THE RECENT CHANGES OF ITALIAN GLACIERS

A first comparison between the total glacier area we reported in the New Glacier Inventory and the glacier coverage value from the CGI Inventory (1959-1962) suggests an overall reduction of the glacier extent of about 30% (from 526.88 km^2 in the Sixties to 369.90 km^2 in the present time). Considering the glacier regions we have introduced to analyze the Italian glaciation, it resulted an area loss ranging from the stronger reduction experienced by glaciers in Friuli, Piedmont and Veneto to the smaller decrease of Lombardy glaciers (tab. 2). The glacier number resulted increased and 68 new ice bodies were found: in fact, 835 glaciers were listed in the CGI Inventory (this latter reported 838 glaciers but three of them were located in France and then not suitable to be inserted in a national record of data), instead the new inventory described 903 ice bodies. The number increase of glaciers is manly due to both fragmentation phenomena (which are particularly frequent during a glacier retreating phase) and identification of glaciers without any previous mention in the past inventory (generally due to abundant supraglacial rock debris coverage which may have suggested in the past to consider extinct the glacier, now the high resolution source of data we analyzed permitted to detect evidence of glacier activity and then to analyze the ice body and insert its data and features in the new inventory).

Then to better analyze the area changes occurred over a time frame of half a century, we compared only the glaciers listed in both the records of data (CGI Inventory and the New Italian Glacier Inventory) (fig. 3); in case of fragment-

TABLE 2 - Changes of area and number of the Italian glaciers sorted according the Regions where they are located

Region	Glacier number in the New Glacier Inventory	Glacier number in the CGI Inventory	Change of glacier number	Area change (%)
PIEDMONT	107	115	-8	-48%
AOSTA VALLEY	192	204	-12	-26%
LOMBARDY	230	185	45	-24%
TRENTINO	115	91	24	-33%
SOUTH TYROL	212	206	6	-30%
VENETO	38	26	12	-43%
FRIULI	7	7	0	-50%
ABRUZZO	2	1	1	-33%
TOTAL	903	835	68	-30%

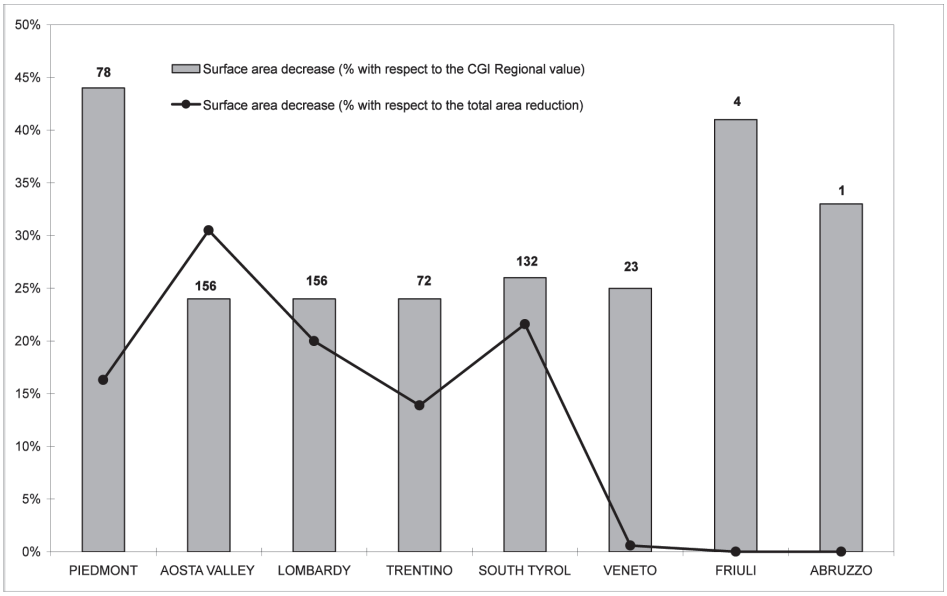

FIG. 3 - Area changes of a subset of Italian Glaciers (we compared the ones reported in both the records of data) in the time window 1959/62 and 2005/11. On the X axis the glacier Regions are reported, on the Y axis the area decrease (%) is indicated. The values in bold at the top of each columns are the number of glaciers compared for each glacier Region.

ed glaciers we compared the CGI area value with the one obtained by crediting the area data of all the glacier fragments listed in the New Italian Glacier Inventory. The subset of glaciers common to both the inventories is composed by 622 ice bodies.

They were covering 500.96 km^2 in the Sixties and 363.76 km^2 in the present time thus giving a total area loss of 137.20 km^2, about -27 % of the total glacier coverage in the CGI inventory. Considering the area changes occurred in each glacier region we found the stronger decreases in Piedmont and Friuli which had lost more than 40% of their previous coverage even if they contributed only to 17% of the total area change (fig. 3). Minor diminishments resulted in Lombardy and Trentino (both have experienced a decrease of ca. 24% of their previous area but together they contributed to about 34% of the total glacier loss) and South Tyrol (26% or area reduction with respect to the past regional extent equal to 21.60% of the total area change). Aosta Valley has lost 24% of its previous area giving the largest contribution to the national glacier loss (30.50%).

A second comparison was performed with the WGI dataset which in the Eighties listed 1381 Italian glaciers covering a total area of 608.56 km^2. This comparison suggest a loss of 478 glaciers and an area reduction of 238.66 km^2 (39 % of the total). The largest decreases area found in Friuli (73 %), Piedmont (57 %) and Trentino (56 %).

DISCUSSION AND CONCLUSIONS

Firstly we compare the area changes we have evaluated for the Italian glaciers with respect to the ones occurred on the second half of the XX century in other glacierized areas of Europe.

As regards of glaciers in the Svalbard, Nuth & *alii* (2013) developed a multi-temporal digital inventory of Svalbard glaciers with the most recent from the late 2000s containing 33 775 km^2 of ice covering 57 % of the total land area of the archipelago. The glacierized area has decreased by an average of 80 km^2 a $^{-1}$ over the past 30 years, representing a reduction of 7 %. Andreassen & *alii* (2008) have analyzed glaciers in the Jotunheimen and Breheimen region (Norway) in the time frame 1930-2003 and the glaciers they investigated shrank since the 1930s with an overall area reduction of about 23% for 38 glaciers. As regards Iceland, this is a glaciated country. Approximately 11% of Iceland's total area of roughly 100.000 km^2 is covered by glaciers. The estimated coverage loss per year is about 0.2% overall, which amounts to 20-30 km^2 becoming ice free every year (data from University of Iceland). In the European Alps, Maisch (2000) evaluated an overall decrease of 27% from the mid-nineteenth century to the mid-1970s, and losses were even greater in some areas. Even more striking was the recession in the Berne-Valais area during 1973-98 (Kääb & *alii,* 2002). The strongest area reduction is affecting small glaciers (i.e. glaciers with area < 1 km^2), that cover roughly 80% of the census in the Alps and make an important contribution to water resources (Citterio & *alii,* 2007a; Federici & Pappalardo, 2010; Bocchiola & *alii*, 2010; Diolaiuti & *alii ,* 2012a, b; D'Agata & *alii,* 2014). Paul & *alii* (2004a) estimated that 44% of the glacier area decrease during 1973-1998/1999 was charged to glaciers smaller than 1 km^2, encompassing 18% of the total area in 1973. From the new Swiss Glacier Inventory SGI2010 (Fischer *et alii*, 2014), the total glacierized area resulted 944.3 ±24.1 km^2 and the area changes are -362.6 km^2 (-27.7%, or -0.75% a^{-1}) between 1973 and 2010. Lambrecht & Kuhn (2007) estimated that the Austrian glaciation experienced an area decrease of about 17% during 1969-1998. French glaciers recent changes are analyzed by Gardent & *alii* (2014), who realized the first multitemporal French Glacier Inventory. They found an extent decrease by 25% between 1967–71 and 2006–09. Glaciers in the French

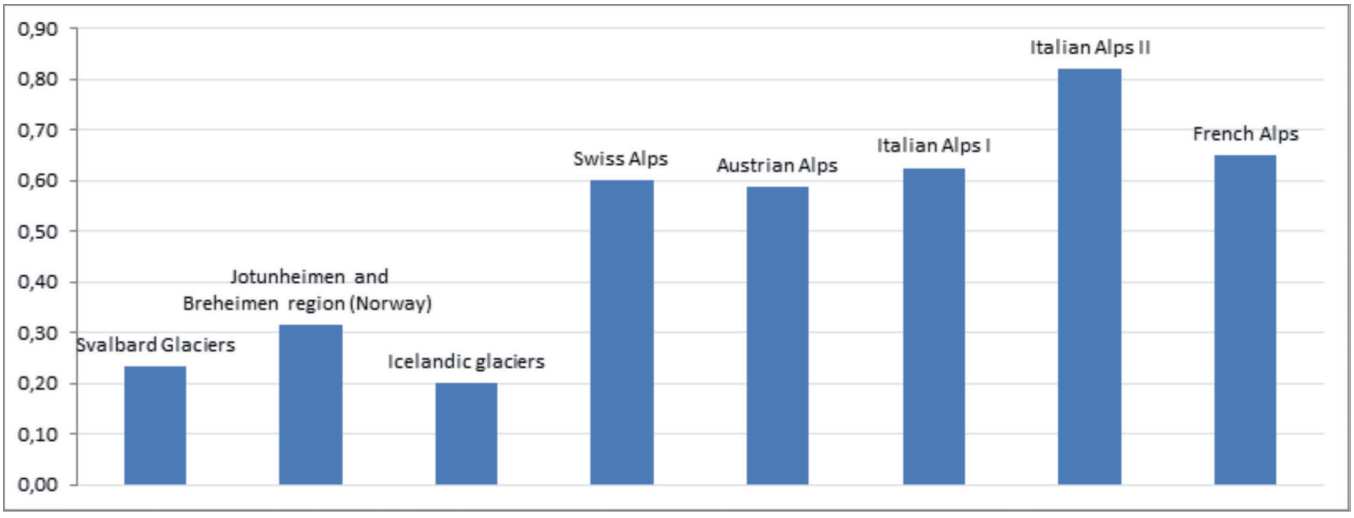

FIG. 4 - Glacier area changes (reported as percentage (%) of area lost per year) of a selection of European glaciers. The input data are derived from the literature cited in the text. For the Italian glaciers two bars are plotted. Italian glaciers I is the area change computed by comparing the CGI data to the values reported in the New Inventory. Italian Glaciers II is evaluated by comparing the WGI data describing Italian glaciers with the New Italian Inventory record. This second yearly area change resulted highest thus suggesting stronger retreat over the last decades. The diagram underlines that glacier size is the most important factor which modulates magnitude and rates of glacier shrinkage. Glaciers in the North of Europe are wider and are retreating slower, glaciers in the central and southern sector are smaller and are experiencing faster changes.

Alps covered 369 km^2 in 1967/71 and 275 km^2 in 2006/09 (fig. 4).

Secondly we discuss our results to understand the meaning of our findings and their reliability. As regards the evaluation of the overall error affecting our comparisons we cannot state an actual value since no information on data accuracy were provided by the CGI surveyors; differently the New Glacier Inventory resulted featuring a mean error always minor than ± 2% of the computed area value. Then a different strategy has to be applied to obtain an estimation of the reliability of CGI Inventory data and on the potential error affecting such data base (Smiraglia & Diolaiuti, Eds., 2015). A suitable occasion to evaluate the accuracy of CGI data is offered by regional glacier database developed in the recent years by analysing aerial photographs acquired in the Fifties. Among the others, the glacier records by Diolaiuti *& alii* (2011) and D'Agata *& alii* (2014), who described two representative sub samples of Lombardy glaciers in the time frames 1954-2003 and 1954-2007 respectively, give the possibility of a comparison with CGI Inventory area data.

Diolaiuti *& alii* (2011) estimated an area change of 28 glaciers in the Dosdè Piazzi group (Lombardy Alps) during 1954–2003 of –3.97 km^2 (–51% of the area coverage in 1954). D'Agata *& alii* (2014) studied the recent evolution of 43 glaciers located in the Ortles-Cevedale group (Stelvio National Park, Italy) by analysing surface area changes from 1954 to 2007; these subset of glaciers chosen for the analysis are among the best known and studied of Italy, also comprising the widest Italian valley glacier (namely Forni). The analysis provided area surface changes as -19.43 km^2 ± 1.2 %, approximately -40 %, from 1954 to 2007. Since these authors published detailed tables reporting all the data (stating an error minor than ± 5% of the calculated area), it was possible for 55 ice bodies a deeper analysis by comparing the 1954 area value with the one reported in the CGI Inventory (and dating back to 1957-1958 time frame). Then for each glacier of the subset we evaluated the departure between 1954 value and CGI inventory one. The absolute values resulted ranging from a minimum of 0.02 km^2 to a maximum of 5.92 km^2, with an average of 0.38 km^2. Adding all the absolute departure values, it resulted a misunderestimated area of 18.12 km^2 and of 2.67 km^2 for the Ortles-Cevedale and the Dosdè-Piazzi group respectively. These values correspond to an error of about 37% and 35% of the actual area featured by the two analysed mountain groups. The largest error resulted affecting the widest Italian valley glacier (i.e. Forni, 20 km^2 in the CGI Inventory and 14.08 km^{2}in D'Agata *& alii*, 2014). In spite of this large overestimation experienced by the Forni glacier, the largest part of glaciers in the subset resulted affected by underestimations (from 5% to 80%).

Surely this is a comparison of a small subset with respect to the whole Italian glaciation (903 glaciers in the new inventory) and the date of acquisition of the compared datasets is not perfectly overlapping (1954 vs 1957-1958), nevertheless it can give some elements for further discussion.

From the one hand our results suggested that the CGI Inventory values are affected by a non-negligible error mainly due to the source of data applied, thus limiting the reliability of the area changes derived from the comparison with the New Italian Glacier Inventory (which instead is based on high resolution imagery). The error we have evaluated for the glacier subset suggests a underestimated area of the whole Italian glaciation in the CGI inventory of about 30%, thus suggesting larger area losses over the last half a century in stronger agreement with the other Alpine litera-

ture (Maisch 2000, Kaab *& alii*, 2002; Knoll & Kerschner 2009; Diolaiuti & *alii,* 2011; D'Agata & *alii,* 2014). From the other hand, in spite of the wide errors probably affecting the whole CGI Inventory sample, a general regression trend is found and this is a truthful environmental impact of climate change which suggests to perform further investigations on the Italian glacier resource based on high resolution imagery describing the past coverage thus allowing better estimations of glacier variations.

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(Ms received 1 March 2015; accepted 1 June 2015)