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The New Italian Glacier Inventory: a didactic tool for a better knowledge of the natural Alpine environment

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Abstract

A glacier inventory is an important instrument to better know the Alpine glacierized environment. After the glacier inventory realized by the Comitato Glaciologico Italiano (CGI, 1959-1962), only regional and local glacier inventories have been developed. In this work, we briefly present the New Italian Glacier Inventory which has been developed by analyzing high resolution color orthophotos acquired in the 2005-2011 time frame. In the New Italian Glacier Inventory 903 glaciers are listed, covering a total area of 369.90 km^2. The largest part of the glacier area is located in the Aosta Valley Region (36.15% of the total), followed by the Lombardy Region (23.71%) and by the Province of Bolzano (23.01%). The highest number of glaciers is in Lombardy (230), followed by the Province of Bolzano (212), the Region of Aosta Valley (192), the Province of Trento (115). About 84% of the total glacier inventory is given by glaciers under 0.5 km^2 covering only 21% of the total area. Glaciers wider than 1 km^2 are about 9.4% of the inventory, but they cover 67.8% of the total area. In the biggest size class (>10 km^2) three glaciers are found. Only 25 glaciers (2.8% of the census as a whole) were classified as "valley glacier" and the largest part (57.3%) was classified as "mountain glacier" and "glacieret" (40%), confirming that the Italian glacier resource is distributed into many small ice bodies with only a few large glaciers.

Keywords: Alpine Glaciers, Glacier Inventory, Italy

1. Introduction

Glaciers and their evolution can be defined as an important instrument to better know the Alpine environment and the impacts of climate change. Moreover, they are also precious landscape elements and valuable freshwater, energy and tourist resources. A glacier inventory is a widely applied tool to list and collect the main glacier features in a database (both quantitative and qualitative information). The New Italian Glacier Inventory is a project realized at the "Ardito Desio" Earth Science Department of the University of Milan by the Glaciology staff. The project was aimed at giving the most correct, updated and complete information needed to manage the high mountain areas of Italy in the best way and in particular to answer the following crucial questions: How many actual glaciers are there in Italy? What is the present

Italian glacier coverage? How strong and fast has the climate change impact been on the cold and frozen water resource of the Italian Alps?

Elements and data to answer the above listed questions can be given only through a large scale analysis based on the most recent remote sensing and GIS techniques. The analysis was supported by the scientists who have been so keenly studying glaciers over the last decades and the managers and policy makers who have been in charge of the mountain territory and its fresh water resource. Only with the skills and knowledge of all these people has it been possible to produce a reliable, robust and complete picture of the actual Italian glaciation. Our workflow was based on the main outlines and recommendations provided by the WGMS (World Glacier Monitoring Service) to permit worldwide comparisons (Paul et al., 2009).

2. The inventories of the Italian Glaciers

Italy has a long tradition in realizing glacier inventories. After the first glacier database realized by Carlo Porro in 1925, the most important work dealing with this context was the Italian Glacier Inventory, developed by the Comitato Glaciologico Italiano (CGI) in cooperation with the National Research Council (CNR) (1959-1962). This inventory, mainly based on the analysis of maps and field surveys, reported 838 glaciers which covered a total area of about 500 km^2 (CGI-CNR, 1959, 1961a, 1961b, 1962).

At the end of the 70s (XX century) the CGI was involved in the World Glacier Inventory (WGI) (Haeberli et al., 1989; Serandrei-Barbero and Zanon, 1993), which is hosted by the WGI web site (www.wgms.ch/). The total area of the Italian glacier in the WGI was about 600 km^2, and also a numeric increase of glaciers was reported. The Italian data put into the WGI was taken from aerial photos. At the end of the 80s the CGI was appointed by the Environment Ministry of the Italian Government to develop a new glacier inventory. In that database the total area of the Italian glaciers was about 480 km^2, indicating an actual decrease with respect to the CGI inventory and the WGI (Ajassa et al., 1997). This was the last Italian global glacier inventory. Afterwards, only local and regional inventories were published (among the others: Desio, 1967; Zanon, 1990; Servizio Glaciologico Lombardo, 1992; Comitato Glaciologico Trentino, 1994; Bonardi et al., 2012; Diolaiuti et al., 2012a). The project "The New Italian Glacier Inventory" was developed to fill this scientific gap and to produce an actual updated database listing the whole Italian glaciation (Smiraglia and Diolaiuti, 2015) (Figures 1 and 2).

3. Methods and source of data

High resolution orthophotos were the main source of information for data collection, mainly with regard to glacier area. Indeed, to sketch out glacier boundaries and calculate glacier areas, recent color orthophotos have been analyzed, which were kindly made available by regional and local administrations. The orthophotos are derived from high resolution aerial photos mainly acquired at the end of the summer when glaciers show the minimum snow mantle. The orthophotos, surveyed between 2005 and 2011 are purchasable products, with a planimetric resolution specified by 1 pixel (pixel size = 0.5 m); the planimetric accuracy is ±1 m.

The color orthophotos have been used as base layer in a GIS (Geographic Information System) environment to draw and map glacier boundaries and then to calculate glacier areas. These data together with other important information (e.g.: glacier name, identification code, coordinates, etc.) were put into the database of the New Italian Glacier Inventory. To assess the potential error affecting the input data the approach introduced by Vögtle and Schilling (1999) has been followed. Taking into account the high quality and resolution of the orthophotos and the accurate manual mapping, the glacier area data put into the inventory should feature an error of less than ± 2% of the actual value. A check of the glacier data was performed based on existing regional or local inventories, recent maps and by performing field surveys. The last validation of all the New Italian Glacier Inventory data was carried out by a team of experts by the Italian Glaciological Committee and the technical personnel of local administrations.

Figure 1. The cover of the New Italian Glacier Inventory. The New Italian Glacier Inventory is an open access database. The digital copy of the book (text, reporting tables, diagrams and maps) is available on line at http://users.unimi.it/glaciol.

Nome *Glacier name*	Codice *ID Code*	Codice WGI *WGI code*	Coordinate *Coordinates (WGS 84 datum)*	Raggruppamento montuoso: SEZIONE - Sottosezione - Settore di Sottosezione *Mountain Sector: SECTION - Subsection - Sector of subsection*	Bacino Idrografico *Mountain catchment*	Tipologia *Glacier Type*	Area km²	Anno rilievo *Year of survey*	CGI Area km²	WGI Area km²
Monte Rosa										
Rolsetta	291	IT4L01506028	45° 53'09" N 7° 40'47" E	PENNINE - Monte Rosa - Contrafforti valdostani	PO-Dora Baltea - Marmore	Glacionevato *Glacieret*	0.02	2005	0.06	0.06
Ventina-Tzére	295-296	IT4L01504002 IT4L01507296	45° 55'03" N 7° 43'27" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Evancon	Montano (vedi note) *Mountain (See Notes)*	3.56	2009	3.27 + 0.78	–
Verra Grande	297	IT4L01504004	45° 55'34" N 7° 45'33" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Evancon	Vallivo *Valley*	6.60	2009	6.11	7.28
Verra Piccolo-Castore	298 - 299	IT4L01504005	45° 54'56" N 7° 46'53" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Evancon	Montano *Mountain*	2.10	2005	1.41 + 1.09	2.41
Martelli	300	IT4L01504006	45° 54'29" N 7° 46'58" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Evancon	Montano *Mountain*	0.07	2005	0.12	0.13
Perazzi	301	IT4L01504007	45° 54'18" N 7° 47'17" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Evancon	Montano *Mountain*	0.38	2005	0.42	0.63
Felik	303	IT4L01502001	45° 54'30" N 7° 48'02" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Lys	Montano *Mountain*	1.44	2005	1.79	1.86
Lys	304	IT4L01502002	45° 54'31" N 7° 49'58" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Lys	Vallivo *Valley*	9.58	2009	10.78	11.83
Garstelet	305	IT4L01508305	45° 54'03" N 7° 51'12" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Lys	Montano *Mountain*	0.31	2009	0.65	–
Indren	306	IT4L01502003	45° 53'51" N 7° 51'33" E	PENNINE - Monte Rosa - Monte Rosa	PO-Dora Baltea - Lys	Montano *Mountain*	0.92	2005	1.68	1.37
Schkeerpie	307	IT4L01502004	45° 49'37" N 7° 52'08" E	PENNINE - Monte Rosa - Contrafforti valdostani	PO-Dora Baltea - Lys	Glacionevato *Glacieret*	0.04	2009	0.7	0.08
Netscho	308	IT4L01502005	45° 49'23" N 7° 51'49" E	PENNINE - Monte Rosa - Contrafforti valdostani	PO-Dora Baltea - Lys	Montano *Mountain*	0.07	2005	0.19	0.28

Figure 2. An example of database table. The glaciers of Monte Rosa in Aosta Valley. Source: Smiraglia and Diolaiuti, 2015.

4. Some results from the New Italian Glacier Inventory

On the Italian side of the Alps about 1/5th of the Alpine glaciarized area is found with a total area of 369.90 km^2, a considerable value if compared to the Alps as a whole (2050 km^2, Paul et al., 2011). The total number of Italian glaciers is 903, a large value with respect to the Alpine census (3370 glaciers, Paul et al., 2011); they show an ample distribution, from the Maritime to the Julian Alps (Figure 3). The glacier size and type covers a wide range as well: from the largest Italian glacier, the Adamello ice plateau, to the large valley glaciers the Lys and Forni, to the small mountain glaciers and glacierets (also on the Apennine chain two small glacierets were found).

The largest part of the Italian glaciation was seen to be located in the Aosta Valley Region (36.15% of the total area), followed by the Lombardy Region (23.71%) and the Province of Bolzano (23.01%). In the other regions minor values of glacier area (the minima in the Region of Friuli-Venezia Giulia, 0.05%, and in the Abruzzo Region, 0.01%) were found.

With regard to the glacier number, the highest one is found in Lombardy (230), then in the Province of Bolzano (South Tyrol) (212), in the Aosta Valley (192), in the Province of Trento (Trentino) (115) and Piedmont (107). The smallest number of glaciers was found in Veneto, in the Friuli-Venezia Giulia and in Abruzzo (38, 7 and 2 respectively) (Table 1).

The mean area value featured by each glacier Region clearly indicates that in the Italian glaciation the small ice bodies are predominant: the average value is 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).

As regards the 903 Italian glaciers, the largest part of their area shows a predominant North aspect (NW, N and NE) (Figure 4A). 61% of the glacierized area and 54% of the glaciers show a North, North-West and North East aspect.

To better know the size distribution of Italian glaciers, the surfaces were sorted into seven classes, already used in previous glacier 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 et al., 2004) (Figure 2). The size distribution of the Italian glaciation it is not too different from the one found in other sectors of the Alps and other glacierized mountain chains (Paul et al., 2004; Racoviteanu et al., 2008; Diolaiuti et al., 2012a, 2012b) with a prevalence of a wide number of small ice bodies (i.e.: <1 km^2) and only a few large glaciers (i.e.: >10 km^2). From this size classification, the number of ice bodies less than 0.5 km^2 constitutes about 84% of the Italian glacier number, but covers only 21% of the total area. Glaciers wider than 1 km^2 collect about 9.4% of the total number, but cover 67.8% of the total area. In the largest size class (>10 km^2) only three glaciers were found: the Forni Glacier (11.36 km^2) in Lombardy, the Adamello Glacier (16.44 km^2) in both Lombardy and the Province of Trento, and the Miage Glacier (10.47 km^2) in the Aosta Valley.

Moreover the type classification offers a similar picture of the Italian glaciers. Indeed, only 25 glaciers (2.8% of the total number) were classified as "valley glacier", while most of the glaciers was classified as "mountain glacier" (i.e. 517 glaciers corresponding to 57.3%) and "glacieret" (i.e. 361 ice bodies corresponding to 40%), thus further underlining the fact that the Italian glaciers are distributed in many small ice bodies with only a few large glaciers (Figure 4B).

Moreover the New Italian Glacier inventory also includes an updated bibliography on Italian glaciers. In fact, an updated reference list is a fundamental scientific and didactic tool which supports any development in scientific research, including glaciology.

In conclusion the development of a new Italian Glacier Inventory database will hopefully produce favorable effects, according to Müller and Scherler, 1977, 1) to improve the knowledge of water budget and hydrological cycle at a local, regional and global scale; 2) to make valuable data available to technicians and scientists for the management of the freshwater resource (civil use, irrigation and hydropower) and to develop actual risk management strategies; 3) to contribute to the analysis of environmental processes and natural phenomena linked to climate and its variations.

The New Italian Glacier Inventory is an open access database. The digital copy of the book (reporting tables, diagrams and maps) is available online at http://users.unimi.it/glaciol. The glacier outlines are visible on the web-GIS SHARE GEO network developed by the EvK2CNR Association which is periodically checked and updated (http://geonetwork.evk2cnr.org/).

All these materials represent a precious tool to develop didactic activities aimed at showing students and young people the actual Italian glaciers and at evaluating its changes over time mainly due to climate variations. The students could develop maps and perform data analysis for assessing magnitude and rates of glacier retreat, describing regional and local glacier coverage in their search for relationships, if any, with other environmental variables.

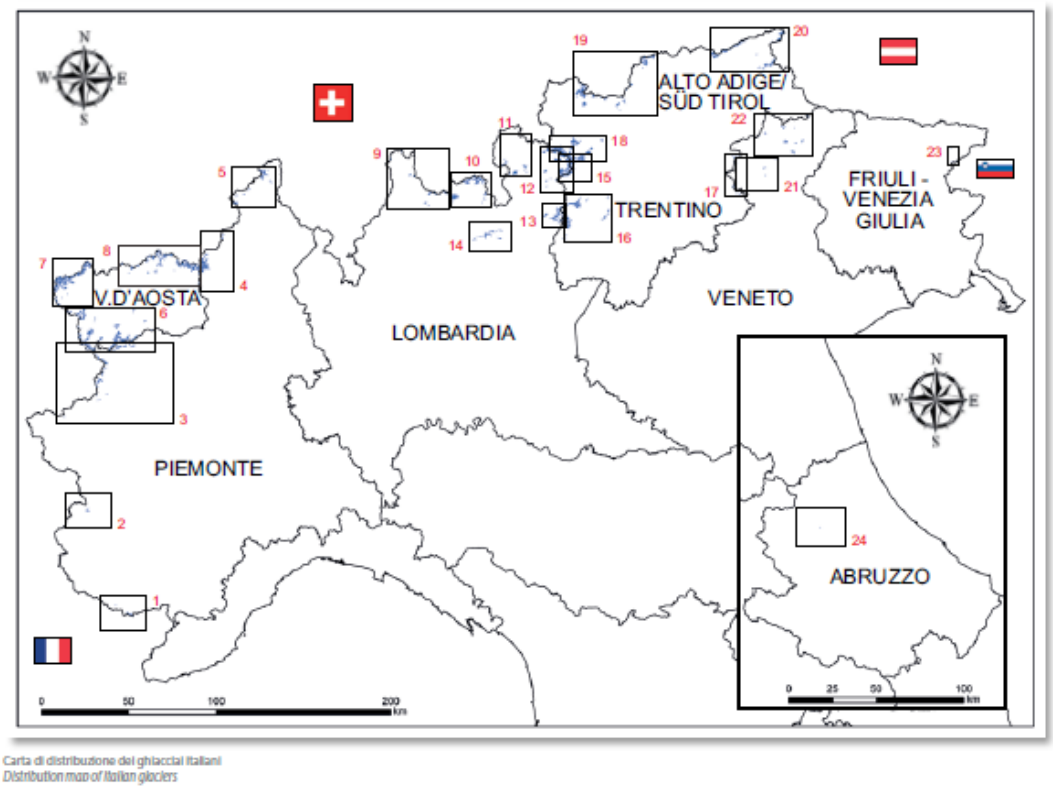

Figure 3. Map distribution of the Italian glaciers. Source: Smiraglia and Diolaiuti, 2015.

Region	Number of glaciers	Cumulative area (km^2)	Percentage Region contribution to the total area	Percentage Region contribution to the total number of glaciers
Piedmont	107	28.92	8%	12%
Aosta Valley	192	133.73	36%	21%
Lombardy	230	87.71	24%	25%
Trento	115	30.96	8%	13%
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%*

Table 1. Surface area and number of the Italian glaciers according to the Region or Province where they are located.

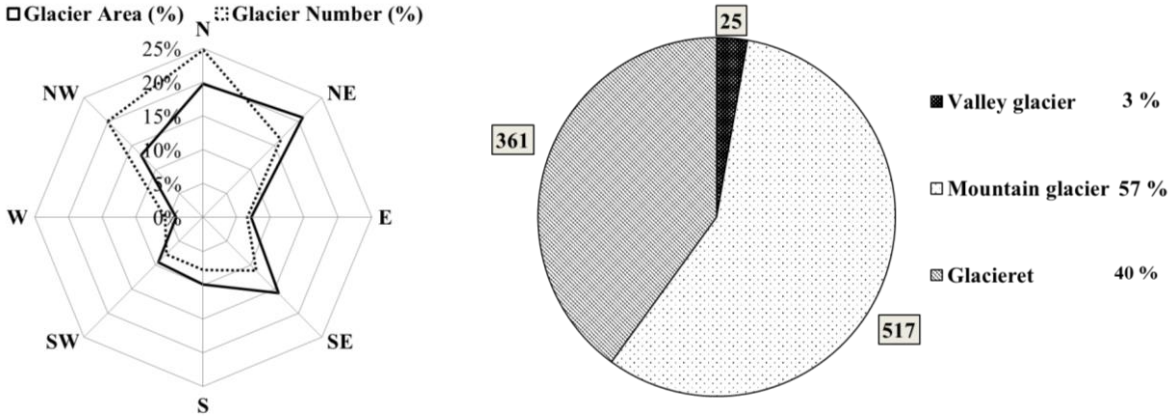

Figure 4. A) Aspect frequency distribution. The percentage of glacier area (black line) and glacier number (black dotted line) in 45° aspect bins are reported. North is the preferred aspect. B) Type frequency of the Italian glaciers. In the legend the percentage value (%) with respect to the total number of glaciers. The labels on the graph are the number of glaciers belonging to each type class.

Figure 5. The glaciers of Piedmont. The Coolidge Glacier in the Monviso mountain group. Source: M. Palomba – CGI Archive, 2005.

Figure 6. The glaciers of Piedmont. The Sabbione Meridionale Glacier in the Monte Leone-San Gottardo mountain group. Source: D. Cat Berro, 2011.

Figure 7. The glaciers of the Aosta Valley. The Tribolazione Glacier in the Gran Paradiso mountain group. Source: Fondazione Montagna Sicura – RAVA, 2014.

Figure 8. The glaciers of the Aosta Valley. The Miage Glacier in the Mont Blanc mountain group, the largest Italian debris covered glacier. Source: C. Smiraglia, 2012.

Figure 9. The glaciers of Lombardy. The Forni Glacier in the Ortles-Cevedale mountain group, the largest Italian valley glacier. Source: C. Smiraglia, 2013.

Figure 10. The glaciers of Lombardy. The plateau of the Adamello Glacier in the homonymous mountain group, the widest Italian glacier. Source: C. Casarotto, 2009.

Figure 11. The glaciers of Trentino. The Lares Glacier in the Adamello mountain group. Source: C. Casarotto, 2010.

Figure 12. The glaciers of Trentino. The Agola Glacier in the Brenta mountain group. Source: C. Casarotto, 2007.

Figure 13. The glaciers of South Tyrol. The Cevedale Glacier in the Ortles-Cevedale mountain group. Source: P. Bruschi, 2009.

Figure 14. The glaciers of South Tyrol. The Malavalle Glacier in the Breonie Occidentali mountain group. Source: L. Franchi, 2008.

Figure 15. The glaciers of Veneto. The Antelao Superiore Glacier in the Antelao-Marmarole mountain group. Source: Regione Veneto – ARPAV, 2007.

Figure 16. The glaciers of Friuli-Venezia Giulia. The Montasio Ovest Glacier in the Montasio-Canin mountain group. Source: R.R. Colucci, 2009.

Figure 17. The glaciers of Abruzzi. The Calderone Glacier in the Gran Sasso Massif, the unique ice body of the Apennines. Source: R. Tonelli, 2011.

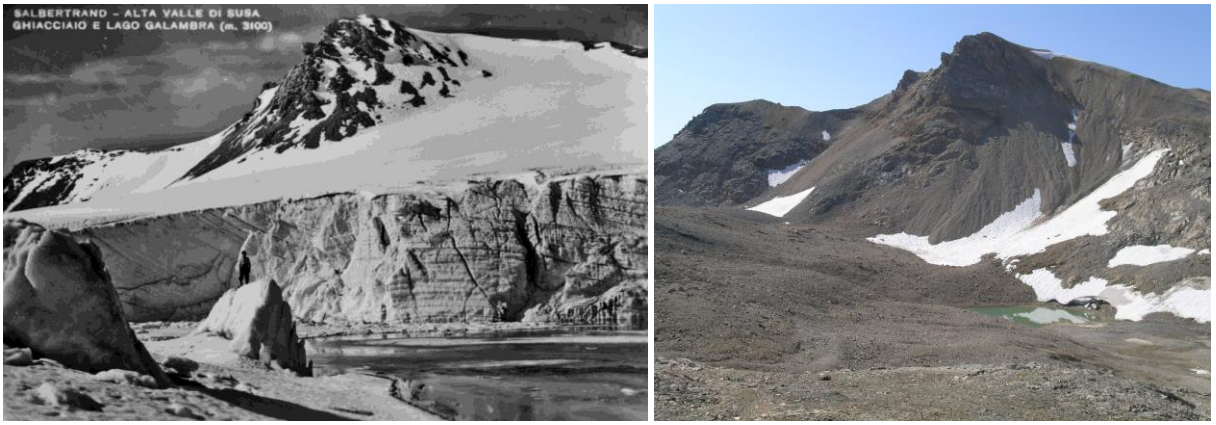

Figure 18. The extinction of the Italian glaciers. The Galambra Glacier in the Moncenisio mountain group (Piedmont): on the left, a 1954 postcard; on the right, 2009, extinct. Source: Bogliaccino – SMI archive and M. Tron.

Figure 19. The reduction of the small cirque glaciers. The Sforzellina Glacier in the Ortles-Cevedale mountain group (Lombardy), on the left 1929 (Source: A. Mentasti, Archive P. Casati); on the right 2014 (Source: C. Smiraglia).

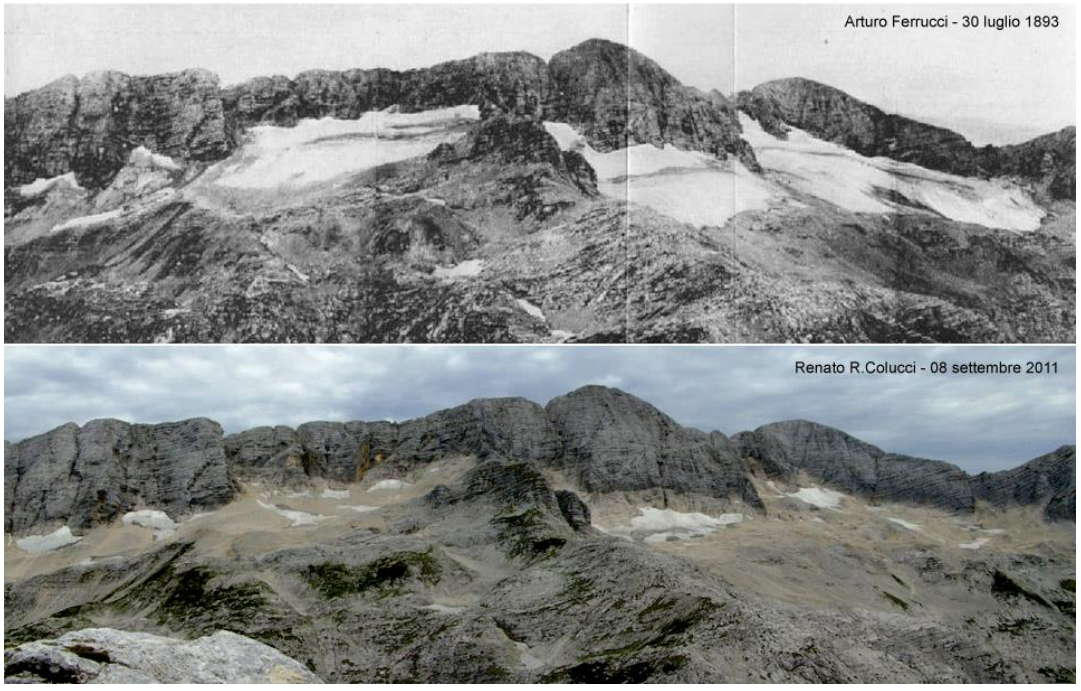

Figure 20. The shrinkage of the small Eastern glaciers. The Canin Glaciers in the Montasio-Canin mountain group (Friuli-Venezia Giulia) 1893 and 2011. Source: A. Ferrucci and R.R. Colucci.

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References

1. Ajassa R., Biancotti A., Biasini A., Brancucci G., Carton A. and Salvatore M.C., "Changes in the number and area of Italian Alpine glaciers between 1958 and 1989", *Geografia Fisica e Dinamica Quaternaria*, 20, 1997, pp. 293-297.
2. Bonardi L., Rovelli E., Scotti R., Toffaletti A., Urso M. and Villa F., *I ghiacciai della Lombardia, evoluzione ed attualità*, Milan, Hoepli, 2012.
3. Comitato Glaciologico Italiano – Consiglio Nazionale delle Ricerche, *Catasto dei Ghiacciai Italiani, Anno Geofisico Internazionale 1957-1958. Elenco generale e bibliografia dei ghiacciai italiani*, Turin, Comitato Glaciologico Italiano, vol. 1, 1959.
4. Comitato Glaciologico Italiano – Consiglio Nazionale delle Ricerche, *Catasto dei Ghiacciai Italiani, Anno Geofisico Internazionale 1957-1958. Ghiacciai del Piemonte*, Turin, Comitato Glaciologico Italiano, vol. 2, 1961a.
5. Comitato Glaciologico Italiano – Consiglio Nazionale delle Ricerche, *Catasto dei Ghiacciai Italiani, Anno Geofisico Internazionale 1957-1958. Ghiacciai della Lombardia e dell'Ortles-Cevedale*, Turin, Comitato Glaciologico Italiano, vol. 3, 1961b.
6. Comitato Glaciologico Italiano – Consiglio Nazionale delle Ricerche, *Catasto dei Ghiacciai Italiani, Anno Geofisico Internazionale 1957-1958. Ghiacciai delle Tre Venezie (escluso Ortles-Cevedale) e dell'Appennino*, Turin, Comitato Glaciologico Italiano, vol. 4, 1962.
7. Comitato Glaciologico Trentino, *I ghiacciai del Parco Naturale Adamello-Brenta*, Trento, Nuova Stampa Rapida, 1994.
8. Desio A., *I ghiacciai dell'Ortles Cevedale*, Turin, Comitato Glaciologico Italiano, 1967.
9. Diolaiuti G., Bocchiola D., D'Agata C. and Smiraglia C., "Evidence of climate change impact upon glaciers' recession within the Italian alps: the case of Lombardy glaciers", *Theoretical and Applied Climatology*, 109, 3-4, 2012a, pp. 429-445.
10. Diolaiuti G., Bocchiola D., Vagliasindi M., D'Agata C. and Smiraglia C., "The 1975-2005 glacier changes in Aosta Valley (Italy) and the relations with climate evolution", *Progress in Physical Geography*, 36, 6, 2012b, pp. 764-785.
11. Haeberli W., Bösch H., Scherler K., Østrem G. and Wallèn C.C. (Eds.), *World Glacier Inventory – Status 1988*, AHS-UNEP-UNESCO, 1989.
12. Müller and Scherler (1977) – *Instructions for the compilation and assemblage of data for a world glacier inventory*, Zurich, Temporary Technical Secretariat for World Glacier Inventory, Swiss Federal Institute of Technology.
13. Paul F., Kääb A., Maisch M., Kellenberger T. and Haeberli W., "Rapid disintegration of Alpine glaciers observed with satellite data", *Geophysical Research Letters*, 31, 21, 2004.
14. Paul F., Barry R.G., Cogley J.G., Frey H., Haeberli W., Ohmura A., Ommanney C.S.L., Raup B., Rivera A. and Zemp M., "Recommendations for the compilation of glacier inventory data from digital sources", *Annals of Glaciology*, 50, 53, 2009, pp. 119-126.
15. Paul F., Frey H. and Le Bris R., "A new glacier inventory for the European Alps from Landsat TM scenes of 2003: challenges and results", *Annals of Glaciology*, 52, 59, 2011, pp. 144-152.
16. Racoviteanu A.E., Arnaud Y., Williams M.W. and Ordonez J., "Decadal changes in glacier parameters in the Cordillera Blanca, Peru, derived from remote sensing", *Journal of Glaciology*, 54, 186, 2008, pp. 499-510.
17. Serandrei-Barbero R. and Zanon G., "The Italian Alps", in Williams R.S. and Ferrigno J.G. (Eds.), *Satellite Image Atlas of Glaciers of the World – Europe*, USGS Professional Paper 1386-E, Washington D.C., 1993.
18. Servizio Glaciologico Lombardo, *Ghiacciai in Lombardia*, Bergamo, Bolis, 1992.
19. Smiraglia C. and Diolaiuti G. (Eds.), *The New Italian Glacier Inventory*, Bergamo, Ev-K2-CNR, 2015.
20. Vögtle T and Schilling K., "Digitizing Maps", in Bähr H.P. and Vögtle T. (Eds.), *GIS for Environmental Monitoring*, Stuttgart, Schweizerbart, 1999, pp. 201-216.
21. Zanon G., *I Ghiacciai del Veneto*, Treviso, Canova, 1990.

