8. The changing Italian glaciers

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8.1 State of Italian glaciers in 1988-89, 2006-07, 2014-15

Glaciers are among the most impressive elements of the Alpine landscape, providing a precious renewable freshwater resource. They are among the most sensitive climatic indicators, and mountain glacier variations are considered one of the best natural proxies to investigate climate changes and to predict future scenarios (Zemp et al., 2006; IPCC 2007, 2013; Haeberli et al., 2007; Winkler et al., 2010).

Knowledge of the entity of spatial and volumetric glacial changes represents one of the most important tools for investigating environmental and climate changes. Ongoing climatic warming has been particularly significant in the Alps since the late Little Ice Age (ca. 1850 AD) and it dramatically accelerated after the end of the 20th century (IPCC, 2007, 2013; Brunetti et al., 2009; Büntgen et al., 2011). Monitoring the changing alpine cryosphere is a key instrument to better understand the evolution of Italian glacial resources under a warming climate. With this aim, we realized a multitemporal inventory of the glaciers hosted in the Italian Alps and in the central Apennine chain (Gran Sasso d'Italia Group) for 1988-1989, 2006-2007 and 2014-2015 hydrological periods (Figure 1).

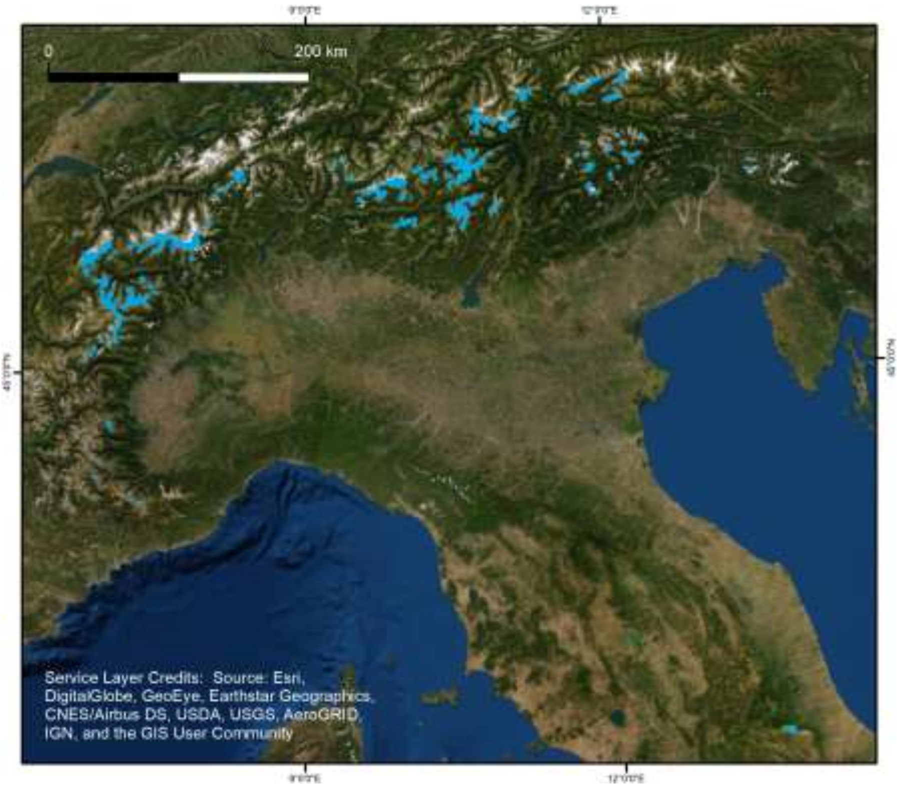

Figura 1. Distribution of Italian glaciers on the Alps and on the Central Appennine chain (Gran Sasso d'Italia)

Glacier boundaries at different time steps were detected by using orthorectified aerial photos at high geometric resolution provided by the National Geoportal of the Ministry of Environment and Protection of Land and Sea (available through the Web Map Service http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/raster/ortofoto_colore_06.map), or provided by the Regional cartographic server via WMS. In some cases, the Regional administration supported digital orthophotos in DVD (Valle d'Aosta for the 2014-2015 period).

All glacier body outlines were manually digitized by an open source Geographic Information System (Q-GIs®), which allowed to map glacier limits as polygons in the vector domain (shape files), and to create an alphanumeric attribute table (dBase) associated with the glacier outlines.

The criteria adopted to create the multi-temporal inventory dBase took into account the guidelines for compilation of glacier inventory data from digital sources suggested by the World Glacier Monitoring Service (WGMS), as previously adopted by Salvatore et al. (2015).

The database provides the main morphometric parameters for each glacial body (area, maximum length, width, slope, max and min elevation, aspect, latitude and longitude of the glacier centroid) as well as the glacier identification WGI code (ID), as suggested by WGMS (1989). The dBase contains additional fields, which supply codes and names of glacial bodies according to the previous Inventory of Italian Glaciers (CGI-CNR, 1959, 1961a, 1961b, 1962), as well as the geographic location, according to the International Standardized Mountain Subdivision of the Alps - ISMSA (SOIUSA, Marazzi, 2005; Figure 2).

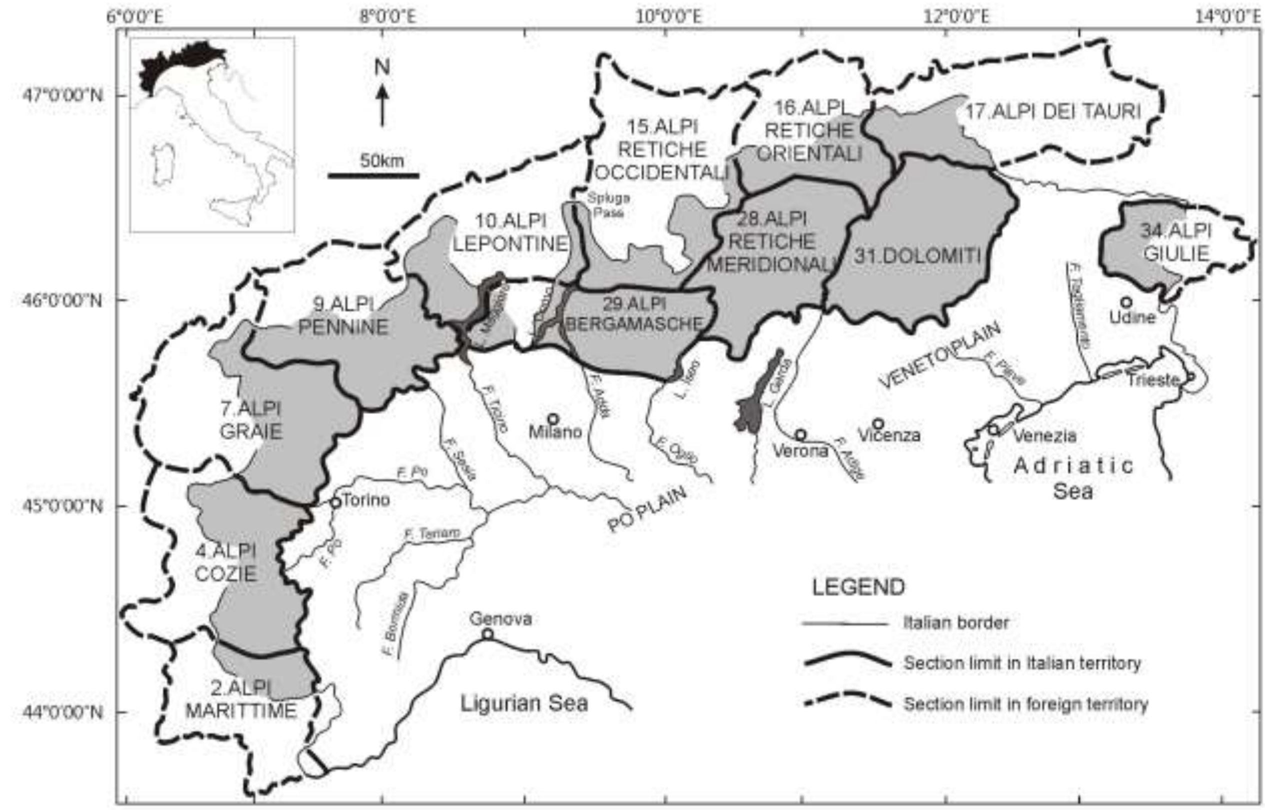

Figure 2. *Geographical setting of the Alps according to the International Standardized Mountain Subdivision of the Alps (ISMSA) according to the section level. The figure shows only the sections containing glaciers (from Salvatore et al., 2015).*

The geographic reference system adopted for all the time intervals was WGS84 UTM32, while the metadata followed the INSPIRE standard and are available at the Nextdata Project website (http://geonetwork.igg.cnr.it/geonetwork/srv/eng/catalog.search#/metadata/c82e995a-226c-4643-8ac5-7d57e7aff0fa).

The multitemporal Inventory dBase allowed us to obtain snapshots of the total number and extent of Italian glaciers in four different hydrological periods, to be compared to the previous inventory of CGI (1957-1958).

Considering the most recent time step, our data evidence that during the 2014-2015 periods the Italian Alps hosted about 857 glacial bodies, which covered a surface of ca. 344 km^2 ± 2% (also including two glacierets on the Gran Sasso d'Italia).

Since 1957, Italian glaciers have experienced a strong progressive reduction in their areal extension. The number of glacial bodies increased progressively from 1957-1958 to 2006-2007 owing to the enduring withdrawal of glaciers and their consequent fragmentation into minor glacial bodies. Between 2006-2007 and 2015 the persistent areal contraction induced a considerable decline in the number of glacial bodies but a relevant increase in the number of extinct glaciers (Figure 3).

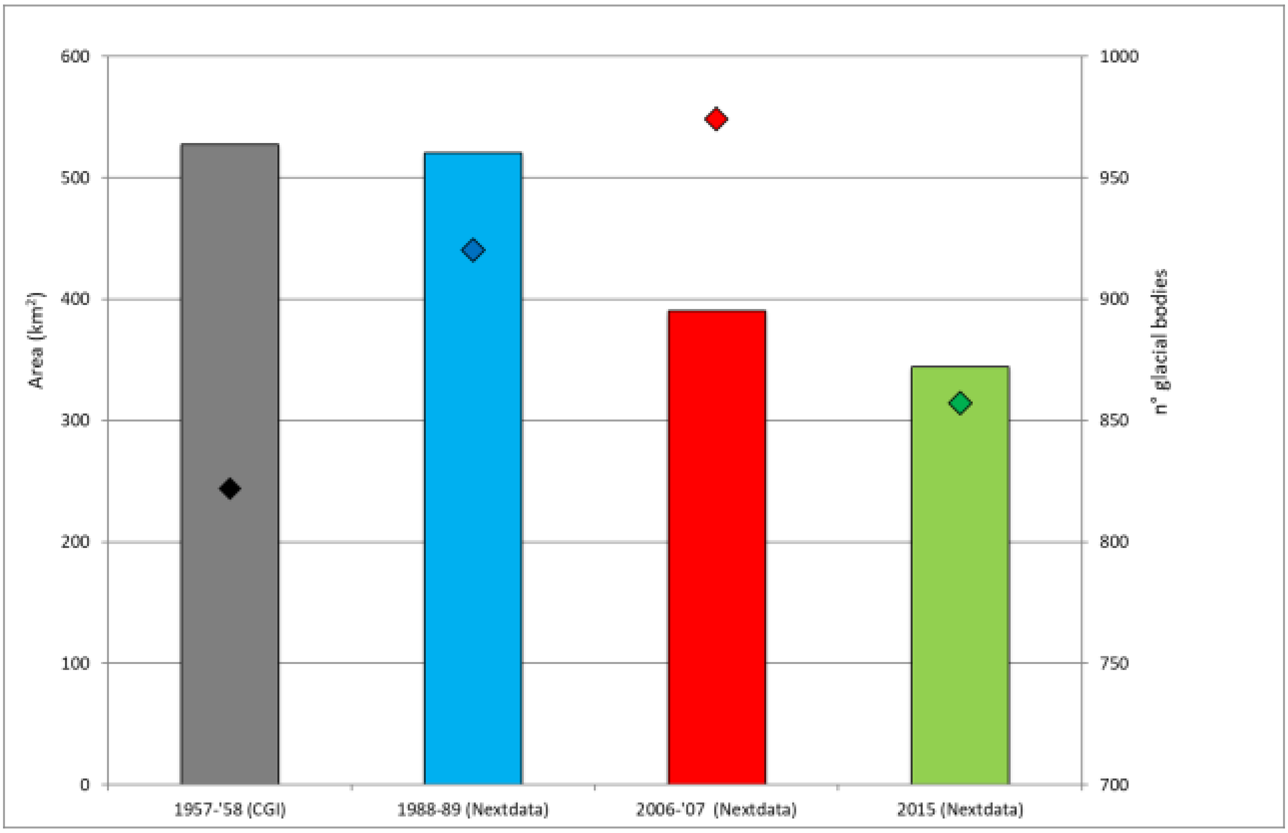

Figure 3. *Areal extent (km^2) and number of glaciers (diamonds) during the different time steps.*

The most glaciated mountain massifs are located in the Southern Rhaetian Alps, in particular in the Ortles Cevedale (ca. 66 km^2) and in the Adamello massif (ca. 39 km^2), which host respectively 125 and 73 glaciers. The Pennine Alps and the Graie Alps are followed by Mount Rosa (ca. 37 km^2) and Mount Bianco (ca. 36 km^2) in terms of glacial coverage (Figure 4).

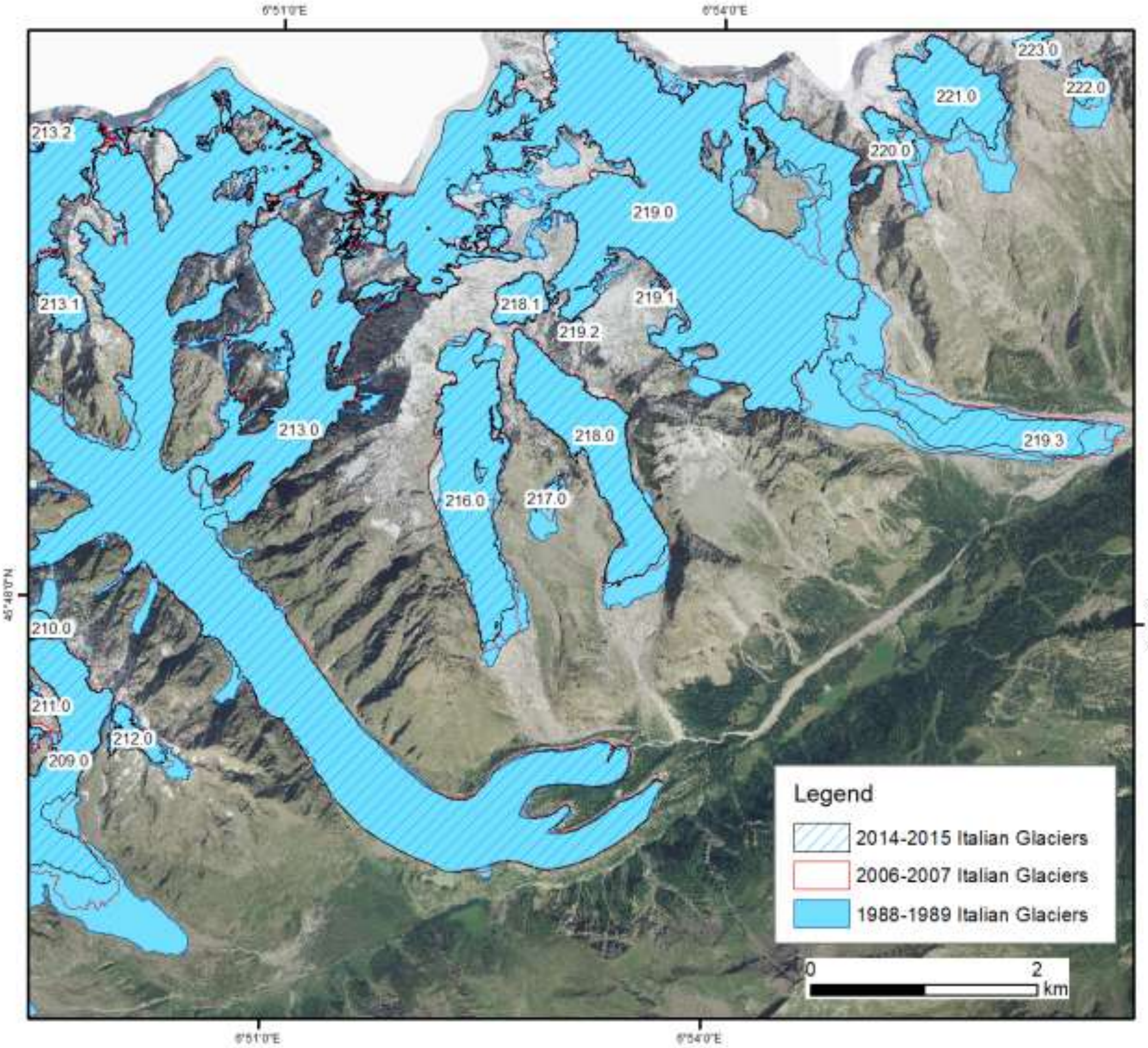

Figure 4. *Glaciers of Val Veny, Mount Bianco Group in different time steps.*

The three widest glaciers of the Italian Alps were the Adamello ice plateau (15.7 km^2) and the Forni Glacier (10.7 km^2) in the Southern Rhaetian Alps together with the Miage Glacier (10.5 km^2) in the Pennine Alps. Altogether, these three ice bodies covered approximately 37 km^2, representing approximately 10% of the total area.

To better describe the current behaviour of the Italian glaciers, we considered seven classes of glacier extension (Figure 5), which allowed for a comparison between our data and those provided by other national and international inventories (Paul et al., 2004).

As regards the 2014-2015 hydrological period, glacier size spanned from <0.1 km^2 to 15.7 km^2. Smaller size classes retained most of the Italian glaciers in 2014-2015, representing ca. 55% of the total number (474 vs. 857) but covering less than 6% of the total area. The southernmost glacier in the Italian Peninsula, the Calderone glacier in the Gran Sasso d'Italia, splitted into two small debris-covered glacial bodies extending for about 0.04 km^2.

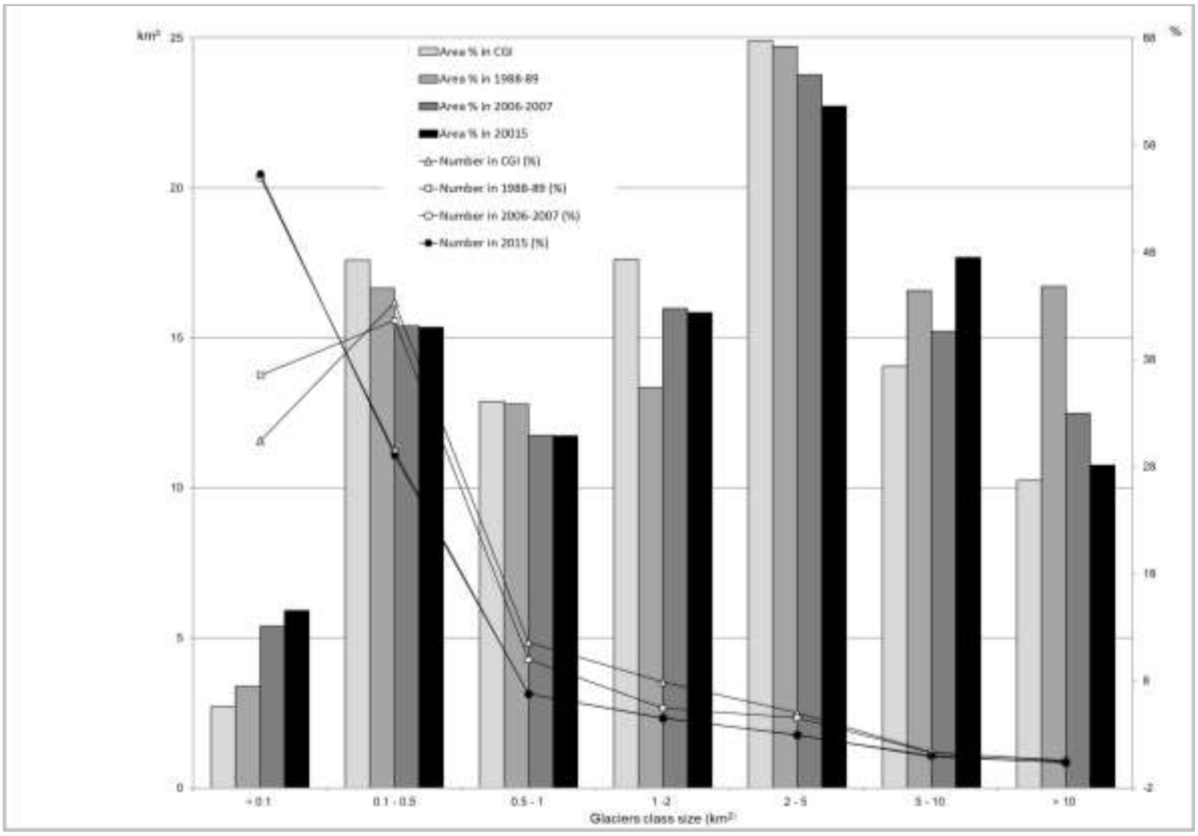

Figure 5. *Areal frequency distribution and percentage of Italian glaciers considering different size classes, during the different time steps.*

The state of the glacier units over the entire Italian Alpine chain shows the widest glacierized area and highest number of glaciers mainly found on the slopes facing the northern quadrants (NW, N and NE; Figure 6).

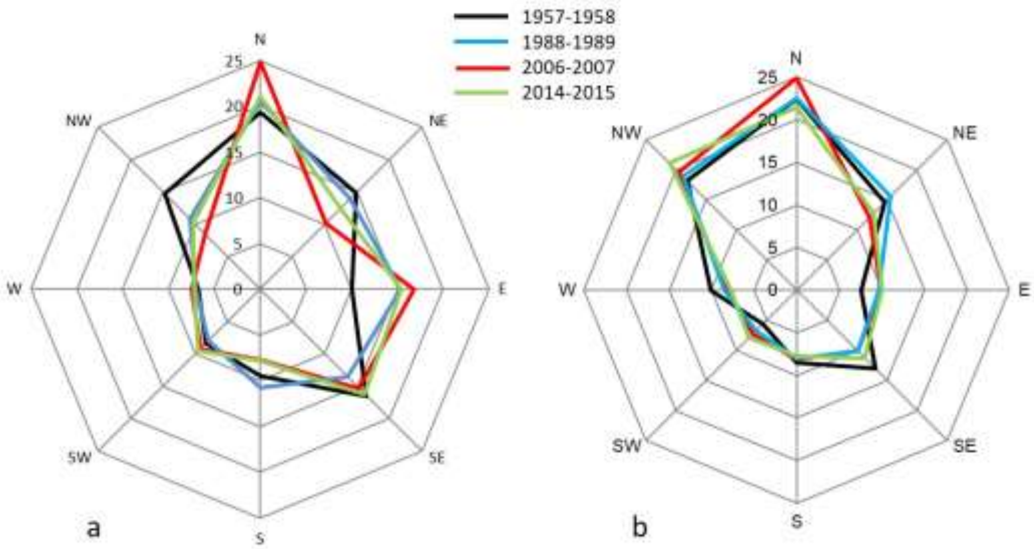

Figure 6. *Frequency distribution of glacier areal extension (a) and number (b) in percentages with respect to aspect in the Italian Alps.*

Mean glacier altitude and minimum elevation of frontal margin change moving from west to east (Figure 7). The trend shows slight fluctuations of mean elevations from the highest values in the western sector (>3000 m), fluctuations in the central sector (8°-11.5° E, ranging from 2700 to ca. 3200 m) and minimum elevations in the eastern sector (from 2700 m to ca. 2200 m). The Julian Alps host the glaciers with the lowest mean and frontal elevation, showing substantial stability despite the warming climate in recent years (Salvatore et al., 2015; Colucci and Guglielmin, 2015).

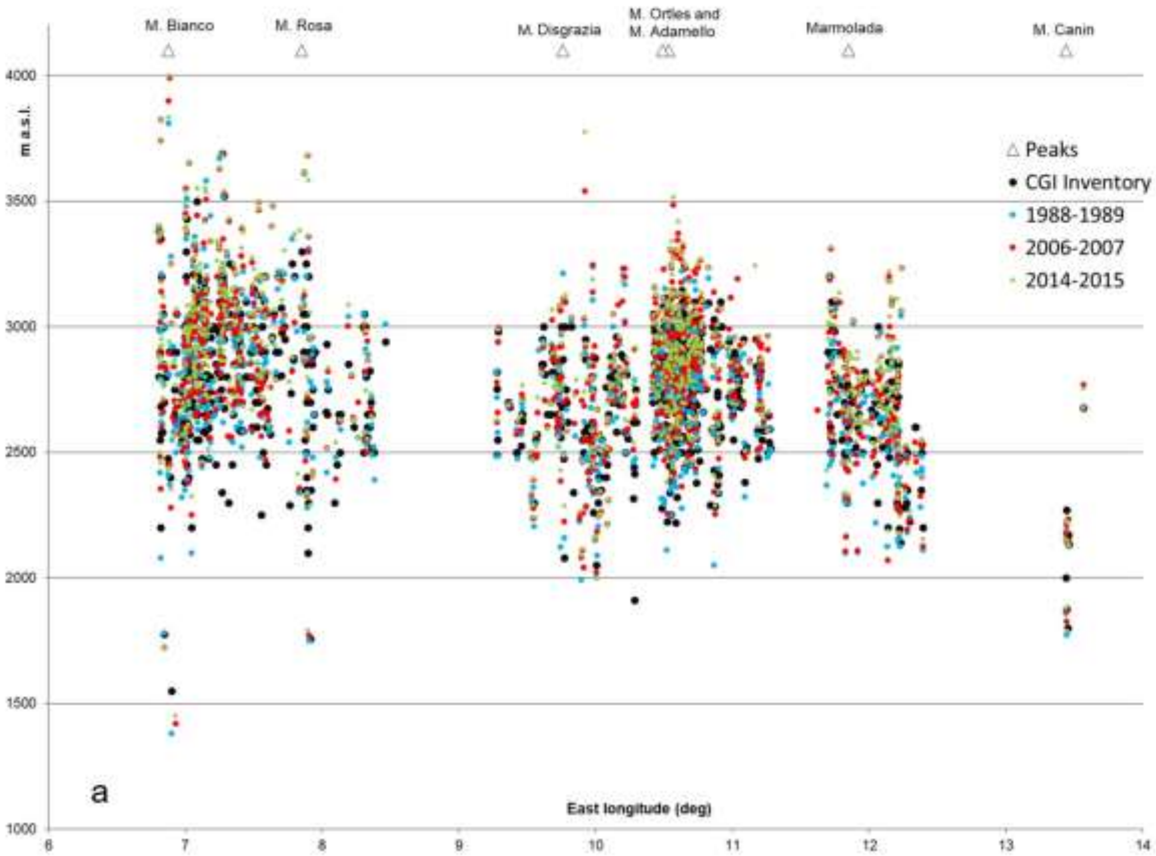

Figure 7. *a) altimetric distribution of Italian glacier fronts with respect to longitude in different time steps; b) altimetric distribution of mean elevation of Italian glaciers with respect to longitude in different time steps. Triangles indicate the geographical position of the main peaks of the Italian Alps.*

8.2 Glacier snout fluctuations

Long-term glacier observation series represent the basis for reconstructing secular trends and for investigating the physical processes driving the response of glaciers to ongoing climatic changes. Since its origins, the Italian Glaciological Committee (CGI) has recognized the relevance of systematic monitoring of Italian glaciers and, in particular, it has started the measurement of frontal variations. Annual glaciological surveys have been conducted regularly since the end of the 19th century with the only exception of the war periods, supplying one of the longest observation series of glacial front variations in the world. Precious photographic documentation has been collected since the beginning of the annual glaciological surveys. The photographic archive of CGI holds thousands of images related to Italian glaciers imprinted on various media (negatives, black and white, colour print, slides, DVDs, and precious and delicate glass plates). The results obtained in the framework of the glaciological campaigns have been regularly published since 1927 in a dedicated section of the CGI Bulletin (published today as Geografia Fisica e Dinamica Quaternaria) and freely downloadable from the CGI website (http://gfdq.glaciologia.it/issues/; http://www.glaciologia.it/i-ghiacciai-italiani/le-campagne-glaciologiche/).

About 130 glaciers are presently monitored every year by many surveyors, also belonging to different volunteer associations. The national correspondent of the Italian Glaciological Committee sends annually to the WGMS frontal variation data that are available on the WGMS website (at the link: https://wgms.ch/data_databaseversions/).

Within the framework of the NextData Project, we have collected all the existing data related to frontal variation surveyed by the CGI during the last 100 years in order to build a standardized database of glacial snout variations.

The database related to the frontal variations of Italian glaciers collects a complete set of validated frontal variation measurements aimed at reconstructing time-distance curves of the Italian monitored glaciers (1895 to 2017, to be updated).

The database is organized in tabular form within a spreadsheet to allow an easier check and update of the glaciological dataset as well as the construction of time-distance curves. All data were validated and verified for each individual monitored glacier in order to build reliable and complete time-distance curves.

Glacier name and inventory ID according to CGI and according to WGI and WGMS are also provided for each monitored glacier. The database shows the geographic location of each glacier through latitude and longitude coordinates (WGS 84) as well as the SOIUSA subdivision of the Alps to aggregate glaciers of the same mountain group and/or belonging to different alpine sections and subsections.

Thanks to its internal structure, the T-D database (TDDB) is linked to the multi-temporal database of Italian glaciers produced within the framework of WP1.6 task 1, to the World Glaciers Inventory (WGI), and to the World Glaciers Monitoring Service database.

The Metadata related to the time-distance database are available at http://nextdata.igg.cnr.it:8080/geonetwork/srv/eng/catalog.search#/home.

The collected data are referred to 408 Italian Glaciers, 137 of which have no validated measurements or real data consistency (less than 10 measurements), 238 of the monitored Italian glaciers have 10 or more measurements of front variation, while only 116 glaciers have more than 30 measurements of front variations.

The largest number of monitored glaciers (considering only glaciers with 10 or more than 10 measurements) are in the Southern Rhaetian Alps – the Ortles Southern Rhaetian Alps, the Graian Alps – the Gran Paradiso Alps and the Southern Rhaetian Alps – the Adamello Alps and the Presanella Alps with respectively more than 35, 25, 13 measured glaciers (Figure 8).

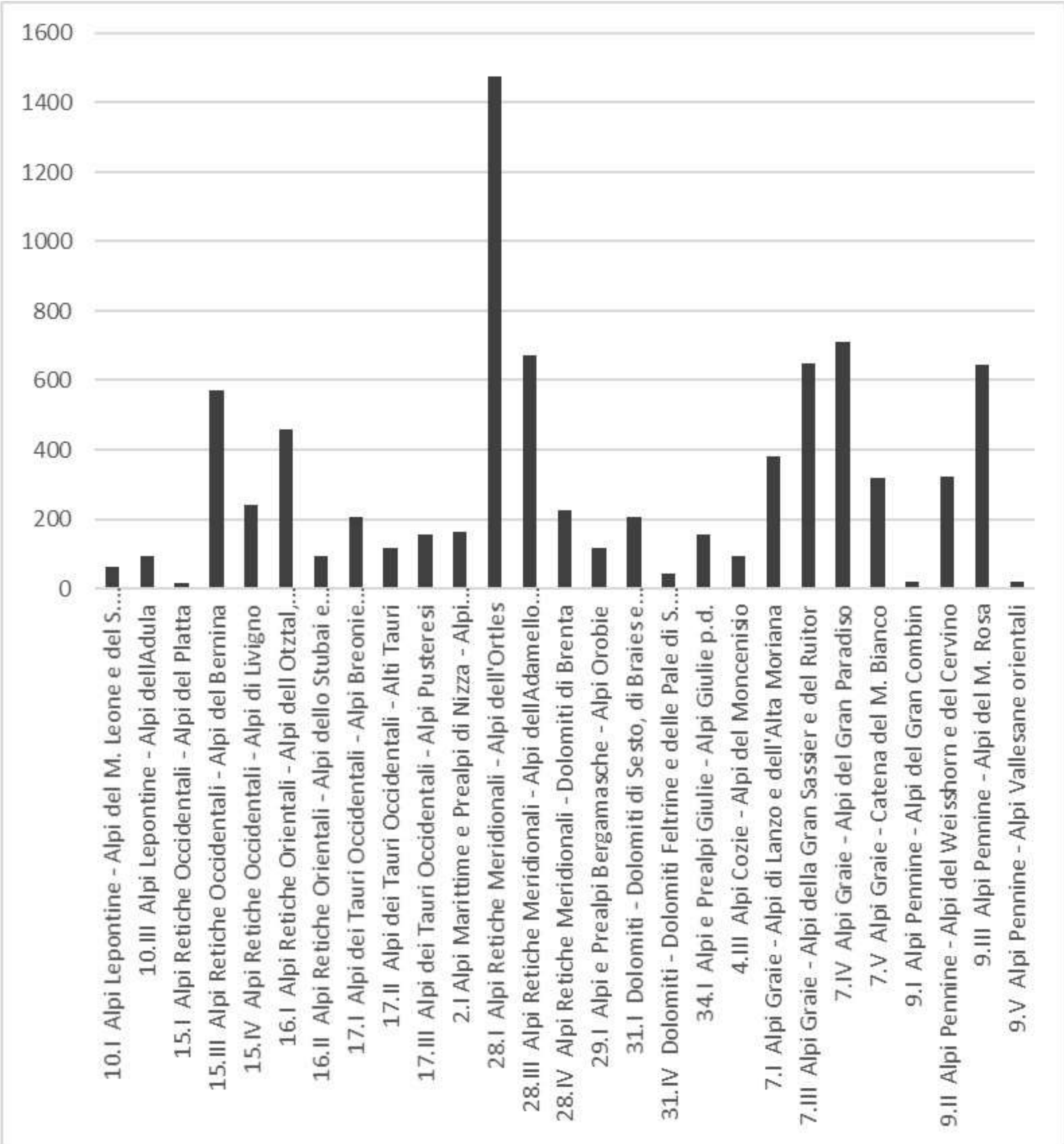

Figure 8. *Number of validated data on frontal variation for each SOIUSA Alpine section-subsection, considering glaciers with 10 or more measurements.*

Time-distance curves underline a strong retreat of glacial bodies, interrupted by periods of stasis or by short re-advance phases, the most vigorous of which occurred during the late '70s and early '80s, as recorded by many alpine glaciers.

Considering the mean value of the cumulative length change values (m) of the monitored glaciers (with more than 10 observations), the weighted average is equal to -454.5 m. Glaciers that experienced the highest mean value of retreat are located in the Bernina Alps (about -935 m); in the Eastern Rhaetian Alps, (with a mean calculated on the 13 monitored glaciers with more than 10 observations); in the Adamello Alps and in the Presanella Alps (about -812 m); in the Southern Rhaetian Alps (with a mean calculated on the 13 monitored glaciers with more than 10 observations); and in the Ortles Alps (about -663 m); in the Southern Rhaetian Alps (with a mean calculated on the 38 monitored glaciers with more than 10 observations).

Figures 9 and 10 show the distribution of the cumulative frontal variation of the glaciers with more than 10 observations. In general, the graph shows that the glaciers experienced the strongest cumulative frontal retreat between 10°-11° East Longitude.

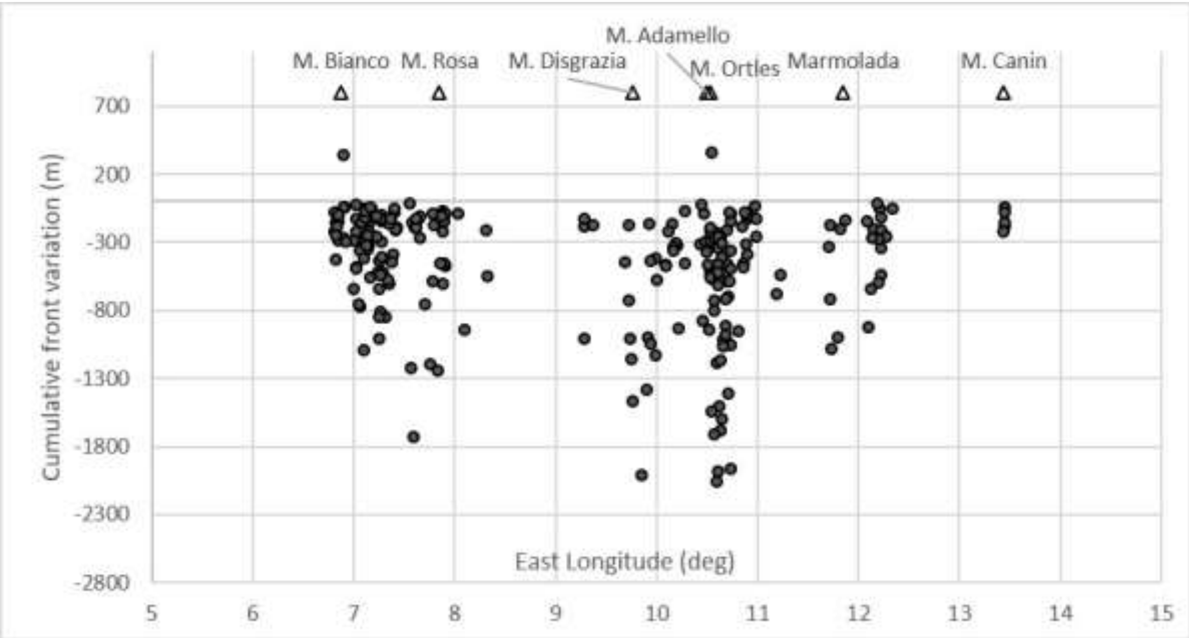

Figure 9. *Distribution of cumulative frontal retreat (m) of the monitored glaciers (with more than 10 observations) vs. East Longitude.*

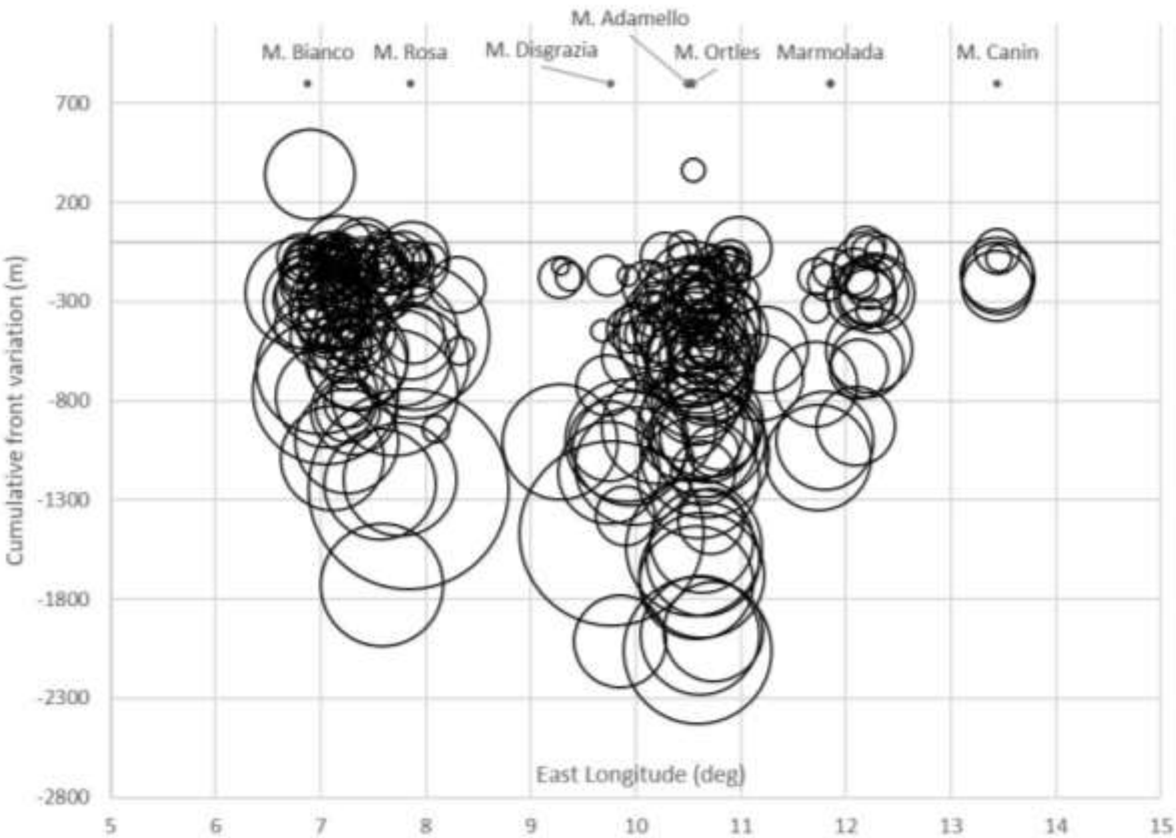

Figure 10. *Distribution of cumulative length variation values (m) of the monitored glaciers (with more than 10 observations) vs. East Longitude. Circle dimensions are proportional to the number of validated measurements collected in the database.*

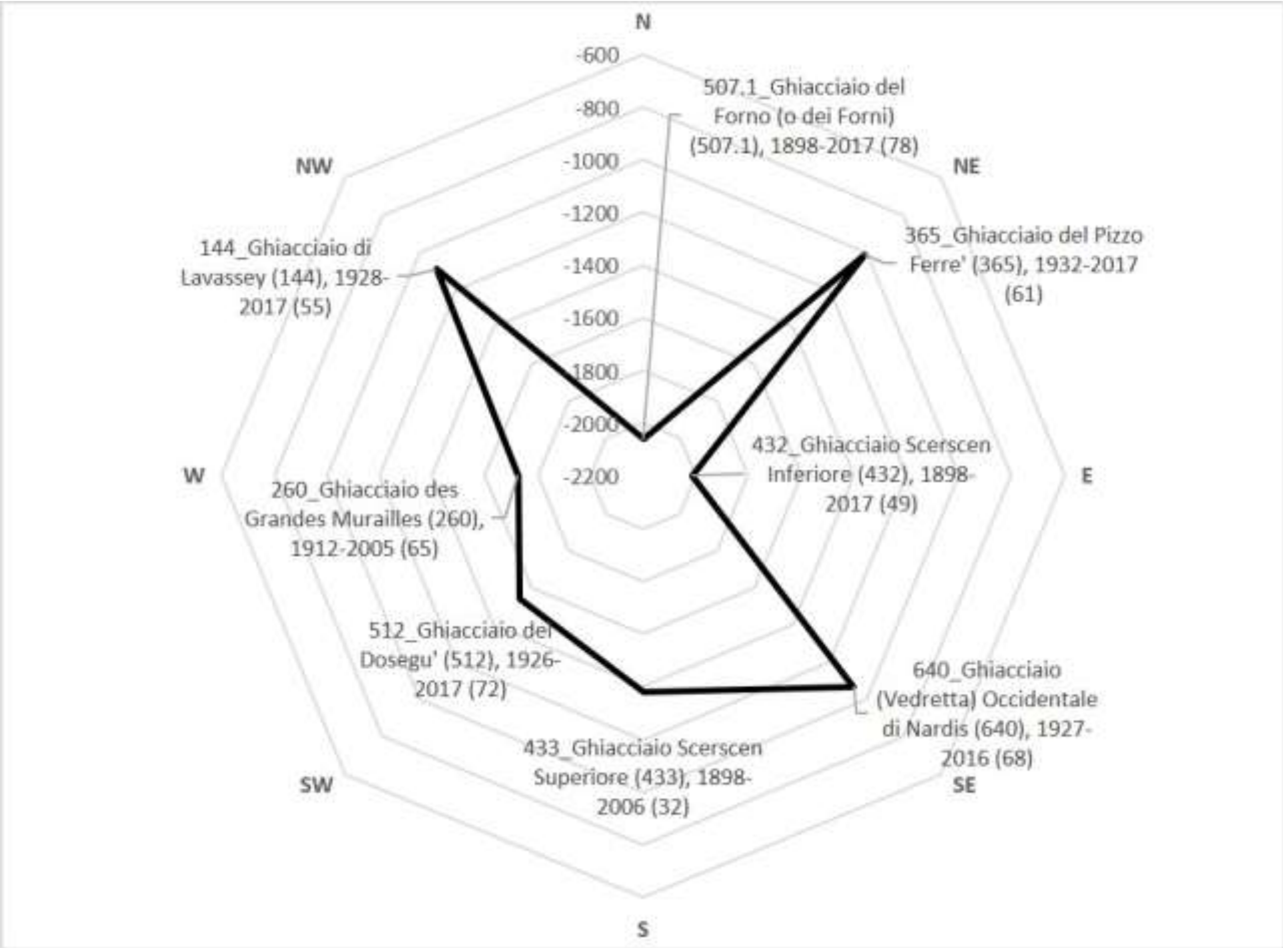

Figure 11. *Maximum value of retreat respect mean orientation of selected Italian glaciers. The graph labels show the code and the name of the glacier and, after the comma, the period of observation (FIRST YEAR - LAST YEAR) and the number of validated measurements (in brackets).*

Among all the monitored Italian glaciers (Figure 11), the Forni Glacier experienced the most important cumulative frontal retreat (m), recording more than -2050 m from 1898 to 2017 (and 78 validated measurements).

The glacier with the highest number of validated observations (more than 105 observations) is the Lys-Garstelet Glacier (code 304-305 of the CGI-CNR Glacier Inventory) with measurement coverage of 114 years (1902-2016).

The five longest time-distance curves (Figure 12) are from the Pre de Bar (or Mont Dolent) Glacier (code 235 of the CGI-CNR Glacier Inventory), which covers the 1930-2014 time-period;, the Lys Glacier-Garstelet Glacier (code 304 - Lys of the CGI-CNR Glacier Inventory; 1902-2017); the Belvedere Glacier (code 325 of the CGI-CNR Glacier Inventory, 1915-2017); the Ventina Glacier (code 416 of the CGI-CNR Glacier Inventory, 1896-2017); the Forno (or Forni) Glacier (code 507.1 of the CGI-CNR Glacier Inventory, 1898-2017). Considering these five glaciers, the time-distance curves evidence a general retreat interrupted by some positive length changes; only two of these show a less "important" cumulative length change and - in particular - they are two glaciers characterized by the presence of supraglacial debris.

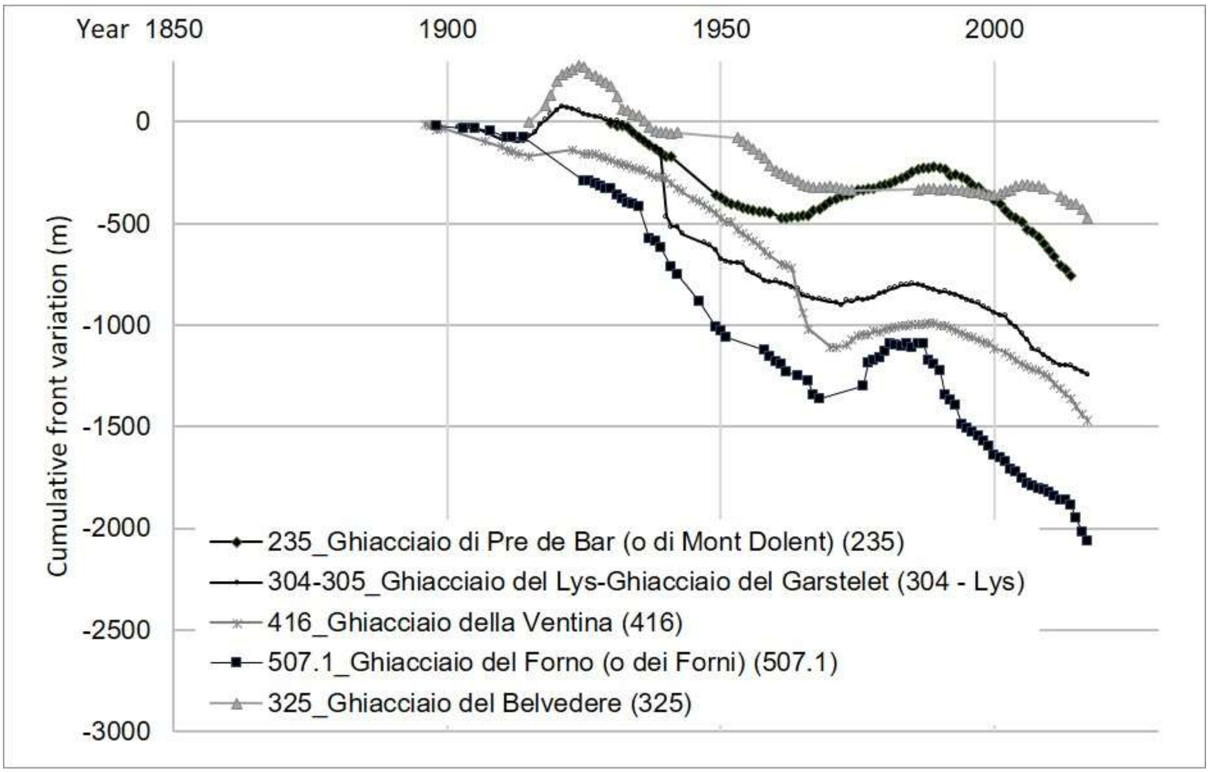

Figure 12. *The five longest time-distance curves of the Database with the validated front variation measurements.*

From the validated front variation measurements collected in the database it is clear that almost all the monitored Italian glaciers show a general retreat trend, interrupted only by a brief glacier readvance in the 1920s and 1980s, although not always so clearly visible. It is instead difficult to see how this general retreat has become particularly marked since the 21st century (Figure 12) (Salvatore et al., 2015; Zemp et al., 2015).

8.3. Database of annual mass balance measurements

The dataset contains the time series of annual and multi-annual mass balance measurements of the Italian Glaciers monitored by the Italian Glaciological Committee (CGI; Figure 13). The monitored glaciers are located in the Alpine chain (18 in total: 4 in the Western Alps and 14 in the Eastern Alps including the Lombardy sector) and in the Central Apennines (1). Net and cumulative mass balance data and, when available, the summer and winter mass balance are also included in the dataset. Name and number according to the Inventory of Italian Glaciers (CGI-CNR, 1959, 1961a, 1961b, 1962) are provided for each glacier, as well as the identification number (ID) according to the hydrological coding suggested by the WGMS (1989) and the ID number following the WGI, Elevation of the Equilibrium Line Altitude (ELA), Ablation Area Ratio (AAR). The geographic location is also indicated following the International Standardized Mountain Subdivision of the Alps (ISMSA), better known with the acronym SOIUSA (Marazzi, 2005), which better allows to connect groups along the entire Alpine chain. The mass balance database can be linked to the T-D database and to the multi-temporal database of the Italian glaciers.

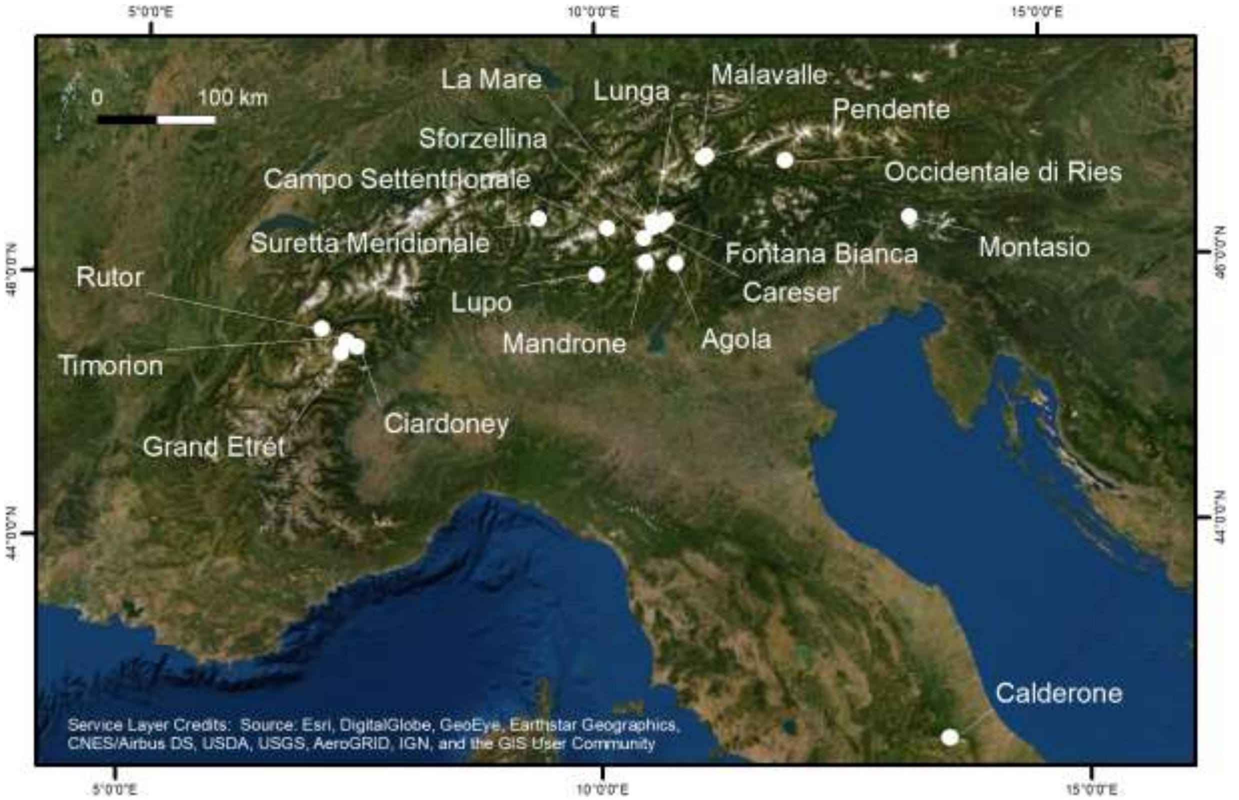

Figure 13. *Geographic location of the Italian glaciers monitored for mass balance measurements (see Table 7.3.1 for the monitoring period of each glacier).*

The data source on mass balances is based primarily on glaciological surveys coordinated by CGI and transmitted to the World Glacier Monitoring Service, published in peer-reviewed journals or in WGMS publications (e.g., CGI, 1914-1977 and 1978-2011; Baroni et al., 2012, 2013; 2014; 2015; 2016; 2017; 2018; Cannone et al., 2008; Carturan et al., 2016; WGMS 2014; 2015; 2017; 2018 and earlier issues). In few cases data sources come from glacier reports of local authorities or regional volunteer associations.

The analysis of Italian glacier mass balance is published in Carturan et al. (2016) and Baroni et al. (2018) and references therein.

The glaciers monitored and the people involved in mass balance measurements are listed in Tables 1 and 2.

Glacier code	Glacier name	Glaciological operators / affiliation
81	Ghiacciaio di Ciardoney	Mercalli Luca, Cat Berro Daniele, Fornengo Fulvio (SMI)
126	Ghiacciaio del Timorion	Arpa Valle d'Aosta
134	Ghiacciaio del Grand Etrèt	Bertoglio Valerio (Parco Nazionale Gran Paradiso)
189	Ghiacciaio del Rutor	Arpa Valle d'Aosta
371	Ghiacciaio Meridionale di Suretta (Suretta Sud)	Scotti Riccardo (SGL, CGI), Villa Fabio, Gallo Paolo (SGL)
516	Ghiacciaio della Sforzellina	Smiraglia Claudio (Università di Milano, CGI)
543	Ghiacciaio del Lupo	Scotti Riccardo (SGL, CGI), Manni Marco, Porta Roberto (SGL)

639	Ghiacciaio del Mandrone	Trenti Alberto (Meteotrentino, CGI), Casarotto Christian (MUSE, CGI), Tognoni Gianluca (Meteotrentino)
657	Ghiacciaio dell'Agola	Trenti Alberto (Meteotrentino, CGI), Casarotto Christian (MUSE, CGI), Tognoni Gianluca (Meteotrentino)
699	Ghiacciaio de La Mare	Carturan Luca (Università di Padova, CGI)
701	Ghiacciaio del Careser	Carturan Luca (Università di Padova, CGI), Trenti Alberto (Meteotrentino, CGI), Casarotto Christian (MUSE, CGI), Tognoni Gianluca (Meteotrentino)
713	Ghiacciaio Fontana Bianca (Weissbrunnferner)	Dinale Roberto, Di Lullo Andrea (Agenzia per la Protezione civile, Provincia autonoma di Bolzano, CGI)
733	Vedretta Lunga (Langenferner)	Galos Stephan P. (ACINN, Innsbruck), Dinale Roberto (Agenzia per la Protezione civile, Provincia autonoma di Bolzano, CGI)
875	Vedretta di Malavalle (Uebeltal Ferner)	Franchi Gianluigi, Dinale Roberto (Provincia Autonoma di Bolzano, CGI)
876	Vedretta Pendente (Hangender Ferner)	Franchi Gianluigi, Dinale Roberto (Provincia Autonoma di Bolzano, CGI)
930	Ghiacciaio Occidentale di Ries (Vedretta Gigante Occidentale/Westl. Rieser Kees)	Dinale Roberto, Di Lullo Andrea (Agenzia per la Protezione civile, Provincia autonoma di Bolzano, CGI)
981	Ghiacciaio Occidentale di Montasio	Cazorzi Federico (Università di Udine, CGI), Cucchiaro Sara (Università di Udine), Moro Daniele (Regione autonoma Friuli Venezia Giulia), Carturan Luca (Università di Padova, CGI)
997	Ghiacciaio Settentrionale di Campo (Campo Nord)	Scotti Riccardo (SGL, CGI), Colombarolli Davide, Bera Andreina (SGL)
1006	Ghiacciaio del Calderone	Pecci Massimo (Presidenza del Consiglio dei Ministri – Dip. Affari Regionali e Autonomie, CGI), D'Aquila Pinuccio (CNSAS, Chieti), Cappelletti David (Università di Perugia, CGI), Esposito Giulio (CNR – IIA, Monterotondo, Roma), Pecci Mattia (CAI, Roma)

Table 1. *List of monitored Italian glaciers, operators and their affiliations (after Baroni et al., 2018).*

Basin and n. of inventory (CGI)	*Glacier*	*Measurement method**	*Initial date*	*Last date*
Orco - Po				
81	Ciardoney	GLAC (DA)	1991/92	2016/17
Dora Baltea - Po				
126	Timorion	GLAC (DA)	2000/01	2016/17
134	Grand Etrèt	GLAC (DA)	1999/00	2016/17
189	Rutor	GLAC (DA)	2004/05	2016/17
Adda - Po				
371	Mer. di Suretta (Suretta Sud)	GLAC (AUTO)	2008/09	2016/17
Inn - Danubio				
997	Settentrionale di Campo	GLAC (MAN)	2009/10	2016/17

	(Campo Nord)			
Adda - Po				
516	Sforzellina	GLAC (MAN	1986/87	2016/17
543	Lupo	GLAC (AUTO)	2008/09	2016/17
Sarca-Mincio-Po				
639	Mandrone	GLAC (COM)	20161012	2016/17
657	Agola **	GLAC (COM)	2001/02	2016/17
Noce - Adige				
699	La Mare	GLAC (COM)	2002/03	2016/17
701	Careser	GLAC (AUTO)	1966/67	2016/17
Valsura - Adige				
713	Fontana Bianca	GLAC (MAN)	1983/84	2016/17
Plima - Adige				
733	Langenferner - Vedretta Lunga	GLAC (MAN)	2003/04	2016/17
Isarco - Adige				
875	Malavalle	GLAC (COM)	2001/02	2016/17
876	Pendente	GLAC (MAN)	1995/96	2016/17
930	Occidentale di Ries (Vedretta Gigante Occidentale)	GLAC (MAN)	2008/09	2016/17
Fella - Tagliamento				
981	Montasio	GEOD (FT)	2009/10	2017/18
Mavone - Vomano				
1006	Calderone	GEOD (FT)	1994/95	2016/17

Table 2. *Italian glaciers monitored for mass balance (modified after Baroni et al., 2018).*

** Measurement method: GLAC = glaciological (direct); GEOD = geodetic (Baroni et al., 2018).*
In brackets: the interpolation and calculation method is reported for the glaciological method (AUTO = automatic by means of GIS software; RL = linear regression of mass balance vs elevation; MAN = manual drawing of mass balance isolines; DA = glacier divided into areas with uniform mass balance; COM = combination of other methods). The survey technique is reported for the geodetic method (GPS = GPS survey; FT = terrestrial photogrammetry; FA = aerial photogrammetry; TLS = ground-based LiDAR; ALS = aerial LiDAR).
*** discontinuous measurements*

The observation period of the entire set of monitored glaciers ranges between 50 and 10 years (Table 1). The Careser Glacier, in the Ortles Cevedale Group, furnishes the longest series of annual measurements in the Italian Alps (50), being monitored since 1966/67 (Zanon, 1992; Carturan et al., 2013). Figure 7.3.2 the cumulative curves of annual mass balances of the monitored Italian glaciers (data modified after Carturan et al., 2016; Baroni et al., 2018 and reference therein).

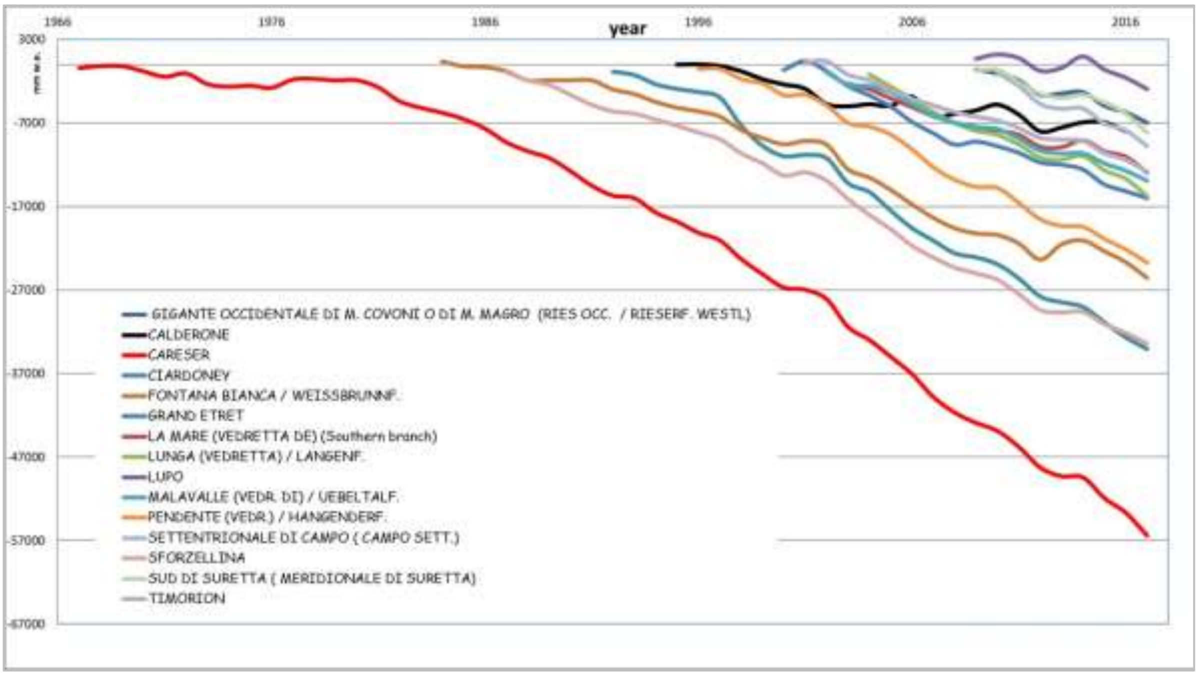

Figure 14. *Cumulative curves of annual mass balances of the monitored Italian glaciers.*

All glaciers experienced mass loss in the observation period and are clearly experiencing imbalanced conditions. The longest series sustain enduring negative trends of annual balance and one or two change points, as Carturan et al. (2016) recognized using the “Changepoint” R package (Killick and Eckley, 2014). In particular, the longest series of mass balance measurement from the Careser Glacier shows three phases: 1) 1967-1980: the glacier was close to near-equilibrium conditions (mean B_a = -132 mm w.e. yr^{-1}, SD = 540 mm w.e.); 2) 1981-2002: the glacier sustained imbalanced conditions (mean B_a = -1192 mm w.e. yr^{-1}, SD = 517 mm w.e.); 3) the period after 2002: the glacier underwent stronger imbalance (mean B_a = -1926 mm w.e. yr^{-1}, SD = 725 mm w.e.).

The Fontana Bianca, Sforzellina and Pendente glaciers, whose measurements started in the 1980s and 1990s, also bear a transition in 2002-2003, while this transition is less evident in the Ciardoney Glacier that experienced negative mass balance already in 1998 and 1999 (Carturan et al., 2016). Increased ablation, due to warmer temperature and related feedbacks (including the lengthening of the ablation season) is responsible for the measured negative mass balances. The combination of the October-May precipitations and the June-September temperatures is responsible for enduring negative annual mass balance. Total precipitation does not show any significant trend in the study area, but solid precipitation decreased as a consequence of the warmer temperature (Carturan et al., 2016).

Low altitude glaciers and, overall, those glaciers with low range of elevation are more out of balance than those extending with wide accumulation basins at the highest elevation, although eventually reaching a lower elevation with their fronts. Emblematic is the case of the Careser Glacier: mass loss occurs at very high rates with respect not only to other glaciers of the region, but also to the entire European Alps. In fact, according to Carturan et al. (2013), the very high climatic sensitivity of the Careser Glacier is further enhanced by its hypsometry, which causes large variations in the AAR also in response to reduced changes in the ELA.

In synthesis, accumulation areas of many monitored glaciers are progressively shrinking and most monitored glaciers are close to extinction, even without considering the additional problem of climate warming. Therefore, they will soon need to be replaced with larger and higher glaciers retaining accumulation areas, as suggested by Carturan (2016).

Conclusions

Since the end of the Little Ice Age (LIA), climate warming has been particularly significant in the Alps, and has dramatically accelerated in the last two decades (IPCC, 2013; Brunetti et al, 2009). Mountain regions like the Alps suffer paucity and discontinuous distribution of data. Longer and improved datasets of measurements of changes in glacier extension and their spatial distribution through time will certainly increase our confidence in understanding the impact of ongoing deglaciation in a changing climate. The recovery of existing data in an updatable dynamic glacier inventory and the costruction of an *in fieri* dataset on the current state of Italian glaciers is therefore essential to monitor and characterize the ongoing degradation process of the Alpine cryosphere. The new dynamic glacier inventory and the updatable dataset represent a key tool for improving our understanding of observed variability, timescale of responses, trends, and climate feedbacks, also to offer a contribution to projected future changes in the cryosphere.

Acknowledgements

This work conducted in the framework of the project of strategic interest NextData (PNR National Research Programme 2011–2013; project coordinator A. Provenzale CNR-IGG, WP 1.6, leader C. Baroni UNIPI and CNR-IGG). Authors wish to thank Dr. L. Cignoni for improving the english text.

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