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RESPONSE TIME OF GHIACCIAIO DEL NORDEND (VALLE ANZASCA, WESTERN ALPS) TO THE CLIMATIC FLUCTUATIONS

ABSTRACT: MAZZA A., *Response time of Ghiacciaio del Nordend (Valle Anzasca, Western Alps) to the climatic fluctuations.* (IT ISSN 0391-9838, 2001).

The geographic position of Ghiacciaio del Nordend and the history of its name are shortly reviewed.

Then the map and picture sources concerning this glacier are carefully examined. They enable the reconstruction, at least qualitative, of the evolution of Ghiacciaio del Nordend, synchronous with that of Ghiacciaio del Belvedere, in which, at given time intervals, the investigated glacier was used to conflue. The available documentation, mainly by Monterin and Sacco, as well as the measurements carried out at the terminus by Demaria and others, during the yearly glacier surveying organized by the Comitato Glaciologico Italiano, starting from 1925, are later discussed. The researches carried out by VAW/ETH on Belvedere and Nordend glaciers are also reviewed, as strongly documenting the recent fluctuations of Ghiacciaio del Nordend.

The climatic data available for this Alps area are quite poor, so that the glacier response to climate can just be guessed as order of magnitude.

The estimated glacier response time to the climatic fluctuations is then checked on the base of a simple empiric formula, the result of which is in substantial agreement. Eventually a comparison of the response time of Nordend, Belvedere and Nord delle Locce glaciers is attempted; it clearly results the response time dependance on the physical parameters which characterize each of the three glaciers, under the same climatic conditions.

KEY WORDS: Climatic fluctuations, Terminus fluctuations, Glacier response time, Monte Rosa (Alps).

RIASSUNTO: MAZZA A, *Il Ghiacciaio del Nordend (Valle Anzasca, Alpi Occidentali): tempo di risposta alle variazioni climatiche.* (IT ISSN 0391-9838, 2001).

Viene presentata la posizione geografica del Ghiacciaio del Nordend e l'evoluzione della relativa toponomastica.

Sono illustrate le fonti cartografiche ed iconografiche che consentono la ricostruzione, almeno qualitativa, dell'evoluzione del Ghiacciaio del Nordend, in sincronismo con quella del Ghiacciaio del Belvedere nel quale, a più riprese, confluì. Segue la descrizione della documentazione disponibile, soprattutto del Monterin e del Sacco, delle misure eseguite dal Demaria e di successive valutazioni effettuate nel quadro delle Campagne Glaciologiche organizzate, a partire dal 1925, dal Comitato Glaciologico Italiano. Sono ricordati anche i rilevamenti del VAW/ETH sul Ghiacciaio del Belvedere, che hanno contribuito a definire l'evoluzione recente del Ghiacciaio del Nordend.

Pochi sono i dati climatici disponibili per la zona; pertanto la relazione tra fluttuazioni climatiche ed evoluzione del ghiacciaio può essere stimata solo per l'ultimo ventennio. L'evoluzione del ghiacciaio e la sua risposta al clima vengono confrontate con una formula empirica, che fornisce un buon accordo con la stima su base climatica. A completamento della ricerca, si confronta il tempo di risposta del ghiacciaio in studio con quello dei ghiacciai vicini, Nord delle Locce e Belvedere: ne risulta chiara la dipendenza del tempo di risposta dai parametri fisici che caratterizzano i ghiacciai, nelle stesse condizioni di evoluzione del clima.

TERMINI CHIAVE: Fluttuazioni climatiche, Variazioni frontali, Tempo di risposta, Monte Rosa.

GEOGRAPHIC POSITION

The Ghiacciaio del Nordend is located at an mean latitude of 45° 56' and at a mean longitude of 4° 34' West from Monte Mario, that is about 7° 53' East from Greenwich, corresponding to UTM coordinates TMR41405090. The maximum glacier elevation is 3550 m; the terminus elevation is 2115 m (electronic altimeter and GPS surveying).

The glacier flows in a steep gully (about 33°) on a length, reduced to the horizon, of 2200 m, with an elevation difference of 1435 m; the glacier width oscillates between 300 and 400 m: these values are approximate because, as we will see later, all maps concerning this glacier are inaccurate; presently there is no single map – either official or private – which shows its actual size, shape and elevation, specially in the glacier terminal area.

The *Catasto dei Ghiacciai Italiani*, volume 2, Piemonte (CGI/CNR, 1961) gives the glacier the entry number 324 and lists the following data: length, 1800 m; width, 700 m; surface area 63 ha; inclination, 40°. All these values do

(*) *Via Parini 98, 20043 Arcore (MI).*

not correspond to those derived from the IGM map 29 I N.E., Monte Rosa, 1934, a section of which is reported in the inventory.

Toponomastic Remark: In Catasto dei Ghiacciai Italiani (CGI/CNR, 1959-1962) the glacier No. 324 is entered under the name «Ghiacciaio della Nordend», depending on the habit of calling «la Nordend» the North Peak (4609 m IGM) of the summit Monte Rosa ridge. As we will show later, describing the single glacier maps, in the past the name «Ghiacciaio del Nordend» has been used, which, for the Italian reader, looks like to be more correct as consisting of the substantives «Nord» (German) and «end» (English), both neutral. Names such as «Jäger» and «Riegel» (Sacco, 1930) have been also used in the past. On the IGM map, sheet 29 I, Monte Rosa, surveyed in 1884 and revised in 1906, the name «Gh. Jägerrücken» is quoted; on the 1925 release of the same map, the glacier name becames «Nordendgletscher».

AVAILABLE MAPS AND PICTURES

We have already written that the maps of this glacier are quite inaccurate; but, to investigate the past extent of the glacier and of its glacial deposits, we need to use maps and pictures. The relationship between the glacier past extent and climatic fluctuations, can but be guessed, as any past data of the local Valle Anzasca climate are missing. Hence, we list first the maps and pictures found.

1821 - In this year the famous painter Gabriel Lory visited Macugnaga and painted a very nice panorama of the NE wall of Monte Rosa (Valsesia, 2000); at the last maximum of the Little Ice Age (LIA), Ghiacciaio del Nordend was fully confluent into Ghiacciaio del Belvedere.

1856 - S. W. King (in AA.VV., 1991) publishes his work «The Italian Valleys of the Pennine Alps» to which a map including also the glacier of the NE slope of Monte Rosa is enclosed. Ghiacciaio del Nordend was still wholly confluent into Ghiacciaio del Belvedere; the drawing is approximate, but the side moraines can be clearly identified. The map, with the only scale bar in miles (the scale should be about 1:100 000), is coloured and, hence, easy to read, but the details are missing.

1857 - The *Carta degli Stati Sardi in Terraferma*, sheet XXIII, Monte Rosa, in scale 1:50 000, surveyed in 1854 and published in 1957, is not easy to read but the confluence of Ghiacciaio del Nordend into the Ghiacciaio del Belvedere is clearly shown; no possibility of deriving the elevation at which the confluence took place, as no contours are drawn.

1878 - The national Swiss map (*Landeskarte der Schweiz*, in the following quoted LK), in scale 1:50 000, called *Topographischer Atlas der Schweiz* or *Siegfried-Karte*, is the first quite correct map of Ghiacciaio del Nordend; the glacier length is about 2400 m and the terminal glacial deposits are shown quite clearly; there is a gap towards the left glacier bank, due to the run-out waters. The surface confluence of the glacier into Ghiacciaio del Belvedere is no longer present, in accordance with the general glacier retreat phase in the Alps after about 1855. The former releases of the same map did not show the Italian side of Monte Rosa.

1884 - The *Carta d'Italia*, sheet 29 I, in scale 1:50 000, surveyed by IGM in 1884, shows a glacier extent close to that of the Swiss «Siegfried» map; same drawing of the Swiss map for the glacier terminal reach, but less clear. Also this map seems to exclude the confluence of Ghiacciaio del Nordend into Ghiacciaio del Belvedere, at least on surface.

1895 - A picture by V. Sella (in Sacco, 1930), which shows the NE wall of Monte Rosa and its glaciers, taken from Monte Moro (the elevation of the photographic station is not quoted) confirms that both the Swiss (1878) and Italian (1884) maps are correct; the terminal moraines with the gap are clearly seen.

1906 - In this year a partial revision of the IGM 1884 map, 29 I - Monte Rosa - has been carried out; no variation is entered concerning the glaciers, but Ghiacciaio del Nordend gets now the name «Gh. Jägerücken».

1916 - A picture by Somigliana (in Sacco, 1930), taken *some 200 m above Alpe Jazzi* in August 1916, shows Ghiacciaio del Nordend wholly confluent into Ghiacciaio del Belvedere. Of course it is impossible to assess when the glacier started to advance, at least in 1914 (Monterin, 1922). In any case this picture records the glacier evolution in the time span 1895-1916.

1917 - A picture by Porro (in Sacco, 1930), taken in September 1917, neatly confirms that Ghiacciaio del Nordend is wholly confluent into Ghiacciaio del Belvedere; no terminal moraine can be longer seen as pushed away or overridden by the advancing glacier. Of course no elevation data can be derived from the picture.

1918 - Monterin (1918) in an accurate review of the glaciers of Monte Rosa, including the Ghiacciaio del Nordend, gives the following information: «Between the Eastern buttress of the Nord Ende (m. 4610) and of the Jägerhorn, the very steep but fairly regular and crevassed Jäger glacier flows down. From the base of these ridges ... two side-terminal moraines begin; they converge towards the confluence (of Nordend glacier) into the Macugnaga glacier (today called Ghiacciaio del Belvedere) and encircle quite completely the lower (Nordend) glacier area. This is initially separated from that of Macugnaga (glacier) along a section of the right terminal moraine but, further, as the confluence is becoming closer and closer, the side moraine turns into a surface-one, uniformly distributed on the glacier. On the left glacier bank, either owing to the glacier thrust or owing to the (ice) mass increase, the side-terminal moraine is now too low to contain the whole glacier. The glacier in fact flows higher that the morainic ridge, with walls protruding some meters, continuously ejecting morainic debris of different size, i.e. boulders, cobbles, sand and glacial silt». The strong expansion of Ghiacciaio del Nordend is confirmed in 1917 (year of Monterin's visit), but, unfortunately no elevation data had been taken or, at least, communicated.

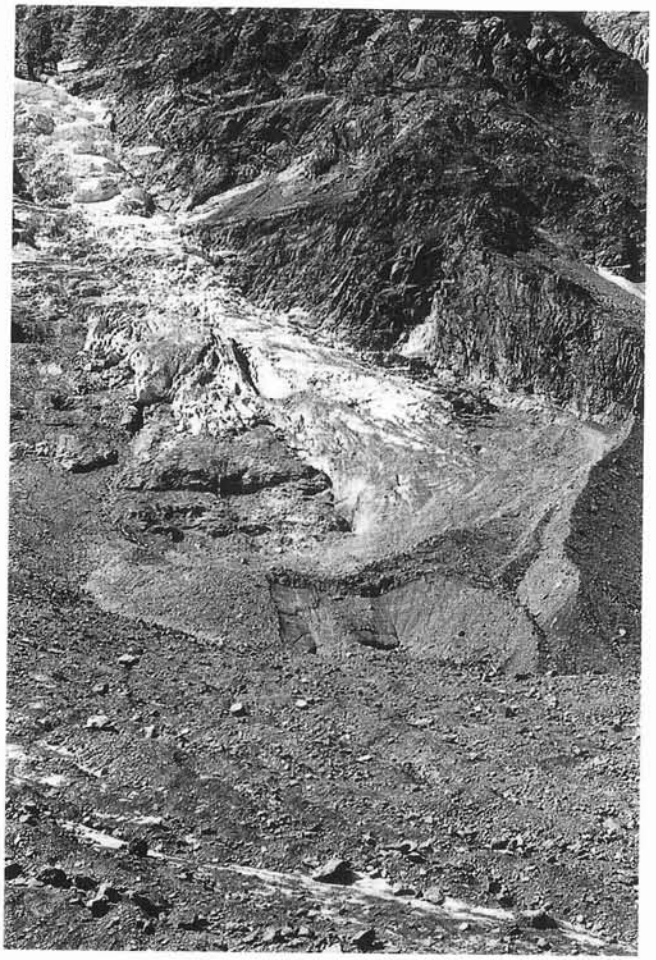

FIG. 1 - View of Ghiacciaio del Nordend.

1919 - Sacco (1930), in a section of the IGM map (29 I, Monte Rosa), surveyed in 1884 and revised in 1906, enclosed to his paper (1930), and dated 1919 (date of Sacco's visit to the glaciers of Valle Anzasca), states that the terminal area of Ghiacciaio del Nordend is in steady state, but the drawing of the terminal moraine is in contrast with the above quoted pictures of 1916 and 1917, as the IGM map of 1884 have been updated in 1906 with the extension of all Valle Anzasca glaciers unaltered.

Examining the glaciers of Valle Anzasca, Sacco (1930) gives the following description of Ghiacciaio del Nordend:

«... The Ghiacciaio del Nordend (quoted also as Jägerrücken, Jäger o Riegel), separated from the glacier (Belvedere) by the Marinelli ridge... presents in its lower reach a terminus quite polluted by morainic debris... broken at its central section and similarly held in position by a morainic arch... broken at its center; hence, the glacier terminus, crevassed and close to vertical, converges in its left side into the left bank of the under-flowing Ghiacciaio del Monte Rosa (now Belvedere) of which it (the Nordend glacier) is a secondary tributary».

Sacco (1930) adds the following consideration: «However the topographic map (M. Rosa) of the former «Stati Sardi», and that of Schlaginweit (1851), and much more that of Adams-Reilly, show that this Ghiacciaio del Nordend, specially before the half of the 19th century, was largely confluent into Ghiacciaio di Macugnaga (now Belvedere). In the years of maximum advance, the left bank of the glacier (Nordend), pushing on the close moraine, was flowing a little more downstream».

Sacco's description (1930), but not the IGM maps, allow us to reconstruct the evolution of Ghiacciaio del Nordend, but, once again, only qualitatively; as usually in the literature of those times, data on coordinates and elevations, as well as on surveying methods are missing, so that a comparison of the former glacier size with the present-one cannot be made.

1925 - In this year a revision of the IGM map 29 I, Monte Rosa, had been released; now the glacier name is «Nordend gletscher», but the drawing is absolutely the same of the 1884 map. The revised map carries the geographic network (longitudes with respect to Monte Mario) and this makes easier the reference to the following IGM map (1934). This map could be extremely interesting for the local glaciology, if the last maximum glacier expansion in Valle Anzasca had been entered.

1934 - Within the program of the new «Carta d'Italia» in scale 1:25 000, the sheet 29 I N.E., Monte Rosa, was surveyed by photogrammetry. For the time being, the map is very good, but the drawing of the terminal area of Ghiacciaio del Nordend is somewhat uncertain; on the right glacier bank the side moraines are not clearly drawn. No geodetic data are given, to allow a comparison with the following release (1970).

1941 - The first release of the new Swiss map (LK), sheet 284, Mischabel, is published in scale 1:50 000; the 1965 release shows Ghiacciaio del Nordend with its terminus at about 2195 m; of course the drawing of the glacier terminal area is taken from the Italian map, 1934; even if the side moraines are better recognized; they look like to be gently sloping towards the level of Ghiacciaio del Belvedere, at an elevation of about 2140 m. The map is based on a cylindric oblique projection and referred to the Bessel ellipsoid; the squaring is according to the kilometric Swiss grid, and the datum too is Swiss-specific.

1957 - Within the activities of the Italian Glaciological Committee during the International Geophysical Year (IGY, 1957-1958), the tongue of Ghiacciaio del Belvedere is surveyed from the toe of the NE Monte Rosa wall to the terminus by terrestrial stereophotogrammetry (EIRA, 1963); the derived map, in scale 1:5000, shows a wide confluence of Ghiacciaio del Nordend into the Belvedere at an elevation between 2125 (right glacier bank) and 2100 m (left bank). But Demaria's comments in 1957 - see later, yearly glacier survey - force us to doubt that there was still a confluence, at least on the glacier surface; the

confluence should have existed between 1917 and about 1950 (?). The glacier thickness in its terminal area, according to the geophysical survey, was about 75 m (De Visentini, 1963).

1967 - The new release of the sheet 1348 of the LK map, Zermatt, in scale 1:25 000 is published; the terminal area of Ghiacciaio del Nordend is still confluent into Ghiacciaio del Belvedere, on a width of at least 150 m; of course the drawing is practically the same of the Italian map of 1934; this is in contrast with the survey and pictures made by Demaria during the yearly glacier surveying by care of Comitato Glaciologico Italiano, the results of which are later discussed. The geodetic frame of the map are the same of the map in scale 1:50 000.

1970 - A revised release of the Italian map sheet Monte Rosa - 29 I N.E. - by IGM, based on aerial photogrammetric up-dating of 1968, is published. The drawing of the terminal area of Ghiacciaio del Nordend is unaltered with respect to the 1934 edition. The new map is somewhat worse than the former release (1934) and, concerning the glaciers, only «Belvedere» and «Nord delle Locce» glacier terminal areas have been updated. The UTM metric grid is referred to the Hayford ellipsoid (oriented on Monte Mario, Rome); the geographic coordinates are still referred to the Bessel ellipsoid. The map datum is the ED50 (European Datum 1950).

1981 - The 1981 release of the map «Il Cervino e il Monte Rosa», in scale 1:50 000, published by the Touring Club Italiano (TCI), cannot be taken in consideration to reconstruct the Monte Rosa glacier history, because it shows the glaciers (without contours) as of the last maximum of 1922 (Monterin, 1922). It is quite curious that this is the only map recording the last glacial advance, disregarded by the official IGM map (1925 revision of the sheet 29 I, Monte Rosa, see above).

1991 - The Carta Tecnica Regionale del Piemonte (CTR) is surveyed by aerial photogrammetry. Ghiacciaio del Nordend is shown on the sheets No. 071070, Monte Rosa, and No. 071030 Cima di Jazzi. This large-scale map, 1:10 000, represents a great improvement with respect to the IGM national map; the scale could make it highly interesting for the local glaciology, but the dashed contours on glaciers, and, frequently, with interval of only 50 m instead of 10 m, makes it difficult to read; of course this impairs its value for glaciological purposes. In any case, the CTR is one of the two reliable documents (the other is LK map) today available and showing the correct size of the present glaciers in Ossola valleys. Some elevation figures have been duly corrected, with reference to the IGM maps, and are in good agreement with those surveyed and calculated by us. The apparent (bare ice) glacier terminus is shown at about 2230 m, against the actual value, downstream the stagnant ice, of 2115 m. The grid is in accordance with the Italian Gauss-Boaga projection, but the ticks of the UTM grid are also shown at the map margins. The geographic grid is referred to the ED50.

RECORDS OF MEASUREMENTS WITHIN THE YEARLY SURVEYS BY CARE OF COMITATO GLACIOLOGICO ITALIANO

From 1929 (Sacco, 1930) to 1952, the year in which the observations of Gatti & Demaria (1953) begin, there is no information about the evolution of Ghiacciaio del Nordend.

1952 - Gatti & Demaria (1953) propose two alternatives for the glacier terminus:

1) Either «The Ghiacciaio della Nordend extends, through a narrow tongue, irregularly inclined, with steps, as down as to reach Ghiacciaio del Belvedere»;
2) or «The terminus ends in correspondence with one of the above steps and the ice, seen here and there at lower elevation, is nothing but dead ice».

1953 - Gatti & Demaria (1954) state that Ghiacciaio del Nordend is in steady state.

Later there is no longer information until the glacier survey of 1957. Starting from 1958 the survey of the terminus fluctuation of Ghiacciaio del Nordend is carried out only by Demaria (1959-1974).

1957 - After the 1957 glacier survey, Demaria (1959) writes: «The Ghiacciaio del Nordend is now completely separated from Ghiacciaio del Belvedere». The surveyor set the mark DD 57 at 37 m from the glacier terminus the minimum elevation of which is given in 2100 m. This assessment is clearly in contrast with the EIRA map in scale 1:5 000, surveyed in 1957. The terminal elevation quoted is lower than present value (2115 m).

1963 - Demaria & Zeuli (1966) publish a sketch of terminus of the investigated glacier; but, missing any topographic reference, it is not possible to relate the sketch, otherwise very good, to the present situation (2000). The terminus altitude is confirmed in about 2100 m.

1964 - Demaria (1967) publishes a picture of the glacier terminus; the photographic station is not given and, therefore, no comparison with the present terminus morphology is possible.

1965 - Demaria (1969) visits again the glacier terminus and publishes a topographic sketch which shows the terminus positions in the summers 1963, 1964 and 1965; no reference to the official map (IGM) is made.

1969 - Demaria (1970) publishes once again his sketch of the glacier terminus, with the variations taken place between 1963 and 1969; no reference, also in this case, to the IGM or other maps. The terminus elevation is confirmed at about 2100 m.

Starting from 1978, CGI's operator Tettamanti (1980-1988), carries out some qualitative observations without making measurements; in the following his remarks are quoted between inverted commas.

1978 - «The fan-shaped terminus has clearly advanced, even if in small amount ...». The statement is undetermined; no reference to any mark.

1980 - «The terminus has already advanced, in a fan shape ... it lies at the elevation of 2250 m and its thickness has also increased; the glacier is highly crevassed». The

quoted elevation is unreliable, as higher than the elevation of the left historic moraine.

1981 - The further expansion of the glacier terminus is confirmed; the elevation is given as of 2240 m.

1982 - The glacier, according to Tettamanti, is in steady state. «Debris cover from 2240 m (map) to the terminus». Probably the elevation values previouly quoted were referred to bare glacier ice. Even if these information is only qualitative, it confirms a quite short response time of this glacier to the climatic fluctuations (exceptional snow accumulation in 1977 and 1988), as we will see later.

TABLE 1 - Terminus fluctuations of Ghiacciaio del Nordend from 1957 to 1974 (surveyor Demaria, 1958-1974). The terminus elevation had been constantly indicated as of 2100 m

1957-1958	– 5,5 m
1958-1959	– 3,5
1959-1960	no measurement
1960-1961	– 2
1961-1962	– 2
1962-1963	no measurement; new reference mark (*)
1963-1964	– 5 (from the new mark (*)
1964-1965	– 10
1965-1966	– 10
1966-1967	+ 2
1967-1968	+ 3
1968-1969	+ 5 (**)
1969-1970	– 8 (the terminus elevation is given in 2100 m)
1970-1974	the terminus is hidden by morainic debris (no measurement further possible)

(*) As no coordinates (either geographic or cartesian) have been quoted, it is impossible the relate Demaria's reference marks to our present mark (1998). Azimuth and distance between the two Demaria's marks are also missing.

(**) Starting from the 1969 surveying report, the glacier is called «Ghiacciaio della Nordend».

1983 - No terminus variation; the elevation is now indicated in 2150 m, which is possible; but no data are given concerning the measurement procedure used to assess the new elevation value. «The left tongue, which is directed towards Ghiacciaio del Belvedere, is always covered by debris». The details concerning the terminus shape are interesting, but not confirmed by any sketch or picture.

1983 - Investigations and surveys were carried out by VAW/ETH (Laboratory for Hydraulic, Hydrological and Glaciological Researches of the Federal Polytechnic University of Zuerich, Switzerland) at Ghiacciaio del Belvedere, following the outburst of Lago delle Locce, on July 19, 1979; the terminal area of Ghiacciaio del Nordend was included in the investigations. Tettamanti's statement «The Ghiacciaio del Nordend is advancing», is in agreement with the assessments of the Swiss researchers.

This research program concerned also Ghiacciaio del Nordend, where measurement of the Bottom Temperature of Winter Snow cover (BTS), was carried out to establish the presence of ice under the thick debris cover. The ice and, hence, the confluence of Ghiacciaio del Nordend into the Belvedere, according to the Swiss researches, took place, at the time of the investigations (1983) at a depth of 6-7 m under the terminal moraine. A sketch of the terminal area was made, printed in scale of about 1:3700, in a local coordinate system: this does not allow a comparison with the present situation (CTR 1991 map and our surveying).

Assessing the elevation (hence, thickness) increments of Ghiacciaio del Belvedere, also the terminal area of Ghiacciaio del Nordend has been surveyed. Elevation (thickness) increments as high as 25 m, with respect to the values of the EIRA 1957 map (1961) in scale 1:5000, have been measured, but the Swiss researchers pointed out that the values obtained by their photogrammetric survey, were in average higher of some 12.5 ± 1.5 m, with respect to those of the EIRA map surveyed in 1957.

Also a sketch in scale 1:10 000, without absolute elevations and drawn in a local coordinate system, cannot be referred to the present (1991) CTR map. The elevation and coordinates of the bench mark used for the Swiss levelling are also unknown, so that we are not able to explain the strong difference in elevations with respect to the official Italian (IGM) and also Swiss (LK) maps.

Again according to the Swiss investigations, the elevation (thickness) increment from 1977 (LK) and 1983, should have been of 35 m, and this could be ascribed to a strong kinematic wave reaching the terminal area of Ghiacciaio del Nordend; but, at the very terminus, some reduction of the elevation (thickness) was already (1984) taking place. And this again confirms the short reponse time of the subject glacier.

But, once again, some considerations of geodetic and topographic nature, do not allow us to make a comparison between the Swiss maps and the situation according to the CTR map (1991). No measurement of terminus fluctuations had been made or, at least, communicated by the Swiss researchers.

1986 - Tettamanti writes: «The glacier is slightly advancing in its right side which is close to the left and central sides, both covered by abundant debris». No picture, mesurement and sketch support this statement.

1988 - An increase in thickness is quoted. The terminus elevation is given as of 2100 m. In 1988 Tettamanti's remarks end; they had been only qualitative, but useful to characterize the advance phase of some of Monte Rosa glaciers, which took place in the early 80's, in accordance with the investigations of the Swiss researchers.

1993 - For the first time there is a short run-out river flowing out from the thick debris cover; this would exclude the confluence of Ghiacciaio del Nordend into the Belvedere.

1994 - In 1994 Mazza (1991-2000) starts surveying the altitude of some glaciers, specially if difficult or dangerous to reach, by trigonometric leveling; the bare ice on Ghiacciaio del Nordend is at 2200 m; the run-out river cannot be seen any longer. A strong retreat of the glacier in its right bank is also assessed on the base of picture comparison.

FIG. 2 - Terminus of Ghiacciaio del Nordend in 1998.

1996 - A snow fall, on Semptember 24, melting on the debris but not on the ice, even if debris-covered, enhances the glacier terminus which is becoming free from debris. This consideration is based on the same procedure used by the Swiss researchers to assess the buried ice (BTS, see above) extension.

1998/2000 - It is eventually possible to start again the measurement at the terminus, now at spots free from morainic debris, of Ghiacciaio del Nordend. The terminus elevation is 2115 m, assessed by electronic altimeter and by GPS measurements; some water pools lie at the base of the steep ice wall; the measurements in 1999 and 2000, with respect to 1998, show that the glacier terminus is close to the steady-state; but the terminus is being again increasingly covered by debris. The problem of the confluence of Ghiacciaio del Nordend into the Belvedere is still open as it cannot be solved on the base of methods and instruments currently used during the yearly glacier surveying by CGI's operators. The existence of water pools in the proglacial area, consisting of large-sized debris, would suggest that there is ice below the surface, impeding water to percolate underground. The elevation difference between the surface of Ghiacciaio del Belvedere (about 2085 m, ± 10 m owing to the extremely rough glacier surface, covered by debris) and the proglacial area of Ghiacciaio del Nordend, is now (2000) 20 to 30 m.

Considering the information we have collected examining maps, pictures and reports of different surveyors, as well as the investigations of VAW/ETH, for Ghiacciaio del Nordend the following fluctuation phases, can be sketched:

a) possible maximum glacier extension between 1820 and 1855 (end of the Little Ice Age);

b) following retreat phase, probably ended in 1910;

c) advance phase started towards 1914 (?) and lasted untill 1921-1922, as assessed for Ghiacciaio del Belvedere (Monterin, 1922), documented by pictures but not by the official Italian maps (IGM);

d) retreat phase followed after 1922 and probably lasted until 1975, partially assessed by Demaria (1959-1974);

e) new advance phase, probably started in 1978 and qualitatively decribed by Tettamanti, and quantitatively assessed by the Swiss researches (VAW/ETH, 1984), but only concerning the ice surface increase in elevation, synchronous with the advance of Ghiacciaio Nord delle Locce (Mazza, 1998); it is not possible to ascertain when the last advance phase ended;

f) measurement at the terminus started again in 1998, without any possibility of relating the new reference mark to the past ones.

CLIMATIC DATA

As already stated by Mazza (1998; 2000) we must confirm that there are no climatic data concerning the upper Valle Anzasca. Some data concerning Valle Formazza (Mazza & Mercalli, 1992) may be used just for guidance, as precipitations values are in ratio 1 in 2 (Anzasca versus Formazza), but the trend is very similar.

Some precipitation data collected at the Camposecco and Cingino ENEL dams in the neighbouring Valle Antrona, with similar climatic conditions, have been already published (Mazza, 1998); we reprint them here for reader's commodity. They show that from the winter 1974/75 to 1977/78 (except 1975/76) a strong increase in winter and spring precipitations took place; it can be used as starting point to attemp to assess the response time of Ghiacciaio del Nordend to the climatic fluctuations. No data on temperature and its evolution have been found; but, as well known, the temperature fluctuations, specially if given in Kelvin, are quite smaller than those of precipitation.

THE RESPONSE TIME OF GHIACCIAIO DEL NORDEND TO CLIMATIC FLUCTUATIONS

«The response time is the time a glacier takes to adjust to a change in mass balance» (Paterson, 1994: p. 319).

Basically, the response time of a glacier may be determined as follows:

a) measuring and recording the terminus fluctuations of a glacier, and establishing the dependance from climatic data, if available. In the case of Ghiacciaio del Nordend the ice mass increase (surface elevation close to the terminus) has been clearly assessed (but only partially recorded metrically), mainly due to the strong precipitation increments between 1974/75 and 1977/78 winters. The response was the increase of elevation in the terminal area of Ghiacciaio del Nordend, probably in the order of magnitude of 25 to 35 m, according to VAW/ETH (1984), measured in 1983; on this base and considering the peak in precipitations of 1977 in the neighbouring Valle Antrona, we can guess a response time of about 5/6 years for the investigated glacier.

b) making recourse to the glacier mechanics; citing again Paterson (1994: p. 53) we read: «The climate, along with the physical properties of ice, determines the extent and behaviour of glaciers».

Hence, to establish a glacier model, we need to know:
- ice rheology, depending on temperature, grain size and grain boundaries;
- glacier velocity (vector) and its variations along the ice stream (strain rate tensor);
- stress condition: different response of ice depending on stretching or compression at the glacier surface; creep in the glacier body, and shear stress at the glacier base;
- basal sliding and basal till strain, if any; and
- glacier mass, geometry, orientation and elevation (hence ice and air temperature).

TABLE 2 - Precipitation values at the ENEL Cingino (2255 m) and Camposecco (2327 m) dams (Valle Antrona)

average	CINGINO 1025 mm (12 years) (mm)	CAMPOSECCO 1049 mm (13 years) (mm)
1972/73	1198 (+173)	1055 (+6)
1973/74	1352 (+227)	1049 (=)
1974/75	1401 (+376)	1396 (+347)
1975/76	1149 (+124)	834 (–215)
1976/77	**2341 (+1316)**	**1890 (+841)**
1977/78	1272 (+247)	1249 (+200)
1978/79	826 (–199)	874 (–175)
1979/80	1302 (+277)	1115 (+66)
1980/81	1507 (+482)	1339 (+290)
1981/82	889 (–136)	1173 (+124)
1982/83	—	1213 (+164)
1983/84	—	—
1984/85	498 (–527)	632 (–417)
1985/86	621 (–404)	870 (–179)

After establishing the glacier model, if the mass balance variation is known, there is eventually a reasonable possibility of calculating the response time of a glacier, with some reserve concerning the Summer temperatures, which cannot be anticipated.

Missing the above data for Ghiacciaio del Nordend, we try to check its reponse time using an empiric formula proposed by Johannesson (in Paterson, 1994: p. 320), based on glacier average thickness (h) and ablation rate (da/dt) at the terminus:

$$t = h/a_0 \qquad (1)$$

where:
- t = response time of the glacier;
- h = mean glacier thickness, estimated from the glacier thickness at the terminus;
- a_0 = ablation rate at the terminus, as taken from the literature (4-5 m a^{-1} for alpine glaciers).

The calculation gives the possible response times of investigated glacier, shown in table 3, depending on the input data. The results of this formula would confirm the response time derived from the elevation increase at the glacier terminus, assessed by the Swiss researchers.

Both methods (measurements and the empiric formula) are in substantial agreement, for the positive (advance) response of the three main glaciers of the NE wall

of Monte Rosa: Belvedere, Locce Nord and Nordend to the better snow feed of the winters 1976/77 to 1979/80. Of course the response time depends on their different features:

– Ghiacciaio Nord delle Locce: as partially calving and, hence, with higher velocity at the terminus, before sinking the level of Lago delle Locce (Mazza, 1998), its response time was quite short, about 4-5 years;

– Ghiacciaio del Belvedere: its larger mass, elevation difference, geometry and stress/strain condition, receving a mass contribution for Ghiacciaio Nord delle Locce, and, probably, even if it is still to be ascertained, from Ghiacciaio del Nordend, give a response time of about 8-10 years, in agreement with a Lliboutry's statement (Lliboutry, 1995) that the reponse time of an alpine valley glacier is about 10 years.

TABLE 3 - Response time of Ghiacciaio del Nordend depending on glacier mean thickness and ablation rate at the terminus

thickness m	ablation m a^{-1} year	response years	ablation m a^{-1} year	response years
30	5	6	4	7.5
35	5	7	4	8.75
40	5	8	4	10
45	5	9	4	11.25
50	5	10	4	12.5
60	5	12	4	15

– Ghiacciaio del Nordend: fully crevassed, and hence, with a block flow exceeding the creep, it is likely that its response time, on the base of the above data, be about 5-6 years. This value however is subject to improvement, as the measurement at the terminus have been started again only in 1998, without any possibility of connection with the older-ones.

CONCLUSIONS

The reconstruction of the glacier evolution on the base of maps is difficult and uncertain owing to the different map sources, generally with undefined or unknown geodetic frame, and different surveying and mapping technique.

Examining the available maps covering the investigated glacier, as well as other glaciers in the Ossola valleys, the conclusion must be derived that scarce attention has been devoted by the Surveying Agencies to this phenomenon of Nature which, in some cases, specially in this long retreat time span, can constitute a hazard for human life and activities (see the tragedy of the Allalingletscher, in Wallis, Switzerland; Tufnell, 1984).

Even if the relation between climatic evolution and terminus fluctuations of Ghiacciaio del Nordend is poorly understood, the derivation of a response time can be tried on the base of semiempirical calculations, but, in any case, the reponse of a glacier to climatic variations depends also on the Summer temperatures, a forecast of which cannot be reasonably made. The problem of the possible confluence of Ghiacciaio del Nordend into Ghiacciaio del Belvedere is still open and cannot be solved by the means of a single surveyor in the frame of the yearly glaciological survey organized by the Comitato Glaciologico Italiano.

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