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RECENT EVOLUTION OF THE PUNTA SAN MATTEO SERAC (ORTLES-CEVEDALE GROUP, ITALIAN ALPS)

ABSTRACT: RICCARDI A., VASSENA G., SCOTTI R. & SGRENZAROLI M., *Recent evolution of the Punta San Matteo serac (Ortles-Cevedale Group, Italian Alps)*. (IT ISSN 0391-9838, 2010).

This paper summarizes the main results of surveys carried out on the Punta San Matteo serac (Ortles-Cevedale Group, Italy). The monitoring campaigns mainly consisted in surveying the serac with a Total Station (over the period from July 2005 to November 2005) and with a laser scanner. The displacements of the unstable ice mass (about 12 m) and its geometry and volume (about 560,000 m^3) have been calculated. In addition several photographs collected during the field campaigns made it possible to describe the evolution of this unstable ice mass and recorded its partial collapse and gradual breaking into tiny parts. The air temperature trend was also evaluated; the serac displacements resulted not strongly correlated with temperature evolution and the main falling events occurred in the autumn and not in summer when air temperature reached the highest peaks.

KEY WORDS: Serac, Glacial dynamics, Climatic variations, Alps.

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L'articolo sintetizza i principali risultati dei rilievi compiuti sul seracco della Punta San Matteo (Gruppo dell'Ortles-Cevedale). La campagna di monitoraggio è stata realizzata con una Stazione Totale (luglio 2005-novembre 2005) e con un laser scanner. L'elaborazione dei dati ha permesso di quantificare lo spostamento della massa instabile di ghiaccio (circa 12 m) e il suo volume (circa 560.000 m^3). Numerose fotografie raccolte durante le campagne di terreno hanno permesso di evidenziare l'evoluzione del seracco, che è parzialmente crollato con una riduzione di massa di circa il 40%, e si è in parte frammentato in piccoli blocchi. È stata inoltre effettuata un'analisi nel periodo sopra indicato dell'evoluzione della temperatura che non appare fortemente correlata al movimento del seracco; anche la principale fase di crolli si è sviluppata in novembre, non in corrispondenza delle fase più calde.

TERMINI CHIAVE: Seracco, Dinamica glaciale, Variazioni climatiche, Alpi.

INTRODUCTION

Ice fall, avalanching and hanging glaciers (*sensu* Pralong & Funk, 2006) may be affected by periodic or occasional falling ice (due to a dry calving process), which often leads to tragic events (e.g. Allalingletscher, Switzerland, 1965; Huascaran, Peruvian Andes, 1962 and 1970; Grandes Jorasses, Italy, 1993; Dzimarai-Khokh, Caucasus, 2002). These events have aroused growing interest in the study of the dynamics of this kind of ice bodies, with an increasing number of research studies focused on this glaciological phenomenon (Röthlisberger, 1977; Alean, 1985; Haeberli & *alii*, 1989; Margreth & Funk, 1999; Pralong & *alii*, 2005; Le Meur & Vincent, 2006).

The factors responsible for the destabilization of large glacier ice masses are ice fracturing and stresses in the fracture zone. However, the physics of the ice fractures and the feedback mechanisms involved in crevassing, ice deformation and load distribution are complex and represent an area calling for further glaciological investigation. Lack of theory and a lack of measurements make accurate stability assessments difficult (Glen, 1955; Haefeli, 1965; Flotron, 1977; Iken, 1977; Derradji-Aouat & Evgin, 2001; Luthi, 2003; Weiss, 2004; Pralong & Funk, 2005; Pralong & Funk, 2006).

In Italy, the most well-known hanging glacier is Grandes Jorasses, located on the Italian side of the Mont Blanc

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Massif (Western Italian Alps). This glacier has been studied by Margreth & Funk (1999). In the Central Italian Alps studies on the instability of hazardous ice bodies and especially seracs had not been carried out until the episode of Punta San Matteo, in the Ortles-Cevedale Group (Scotti & Cola, 2005; 2006; Riccardi & *alii*, 2009).

Here, in summer 2003, a large fracture was observed on the north-western wall of Punta San Matteo (Lombardy Alps, Italy). Then in the following years, starting from that fracture, a large hanging ice mass or serac developed. This ice mass was clearly detected in May 2005 (Scotti & Cola, 2005). From that period a survey-program was started, with the aim of monitoring such an unstable ice mass and to forecast its evolution with particular regard to the Forni Glacier, the largest valley glacier of the Italian Alps, which is located at the foot of Punta San Matteo and which is visited by several climbers and skiers thus increasing the potential impact of the ice mass falling. The aim of this paper is to present further results from the elaborations of the data collected during the field surveys.

STUDY AREA

The hanging ice mass on the northwestern wall of Punta S. Matteo is located in the north-west sector of the mountain wall which constitutes one of the southern margins of the Forni Glacier (Ortles-Cevedale Group, Alta Valtellina) (fig. 1). The Forni glacier (c. 12 km^2 of surface area in the Stelvio National Park, Lombardy Alps), which presents a north aspect and an elevation ranging between 2600 and 3670 m a.s.l., is a composite valley glacier formed by three ice streams, the confluence of which forms a tongue that extends over 2 km. Moreover it is a popular destination for tourists, skiers and trekkers during both winter and summer seasons. The base of the unstable ice mass is located at an elevation of about 3350 m asl. In May 2005, the situation appeared particularly dangerous. Ice falling from the unstable ice mass, if any, would have involved the west sector of Forni Glacier, thus representing an actual hazard for climbers, tourists, skiers and trekkers visiting the glacier.

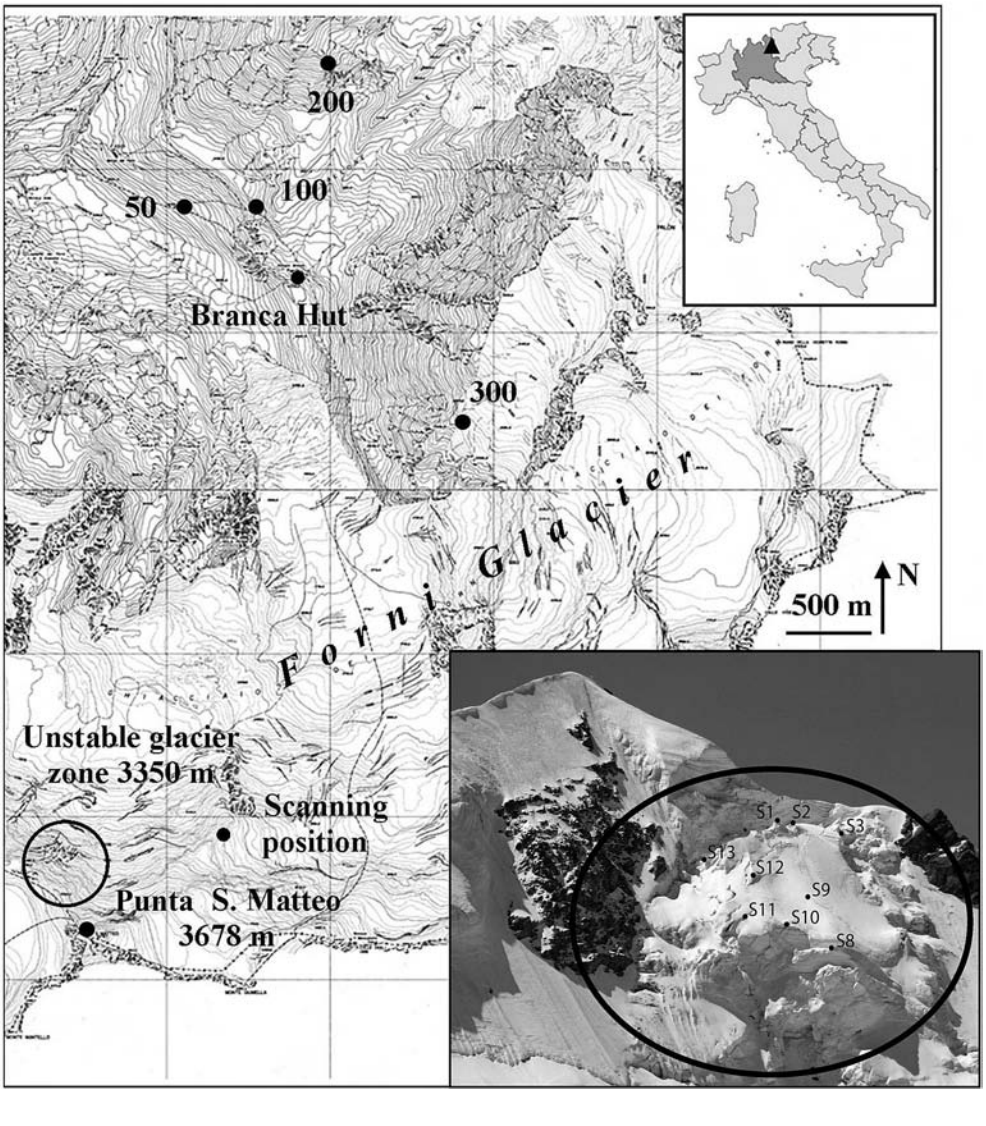


FIG. 1 - Study area. Position of the survey points used to acquire the photographs (points 50, 100, 200, 300); displacement points on the serac surface (photo by R. Scotti) and location of laser scanner are mapped. The base layer is the Lombardy Region Technical Regional Map at the scale 1:10,000.

METHODS AND DATA COLLECTION

The monitoring campaigns were carried out in 2005 and 2006. They consisted of several surveys of the ice mass using a Total Station and laser scanner data acquisition. In addition, local air temperature data from an Automatic Weather Station (AWS) located on Monte Vioz (2950 m, not far from the Punta S. Matteo) were collected to evaluate the role of air temperature in the evolution of the serac. Moreover several photographs were taken during the field surveys. The photographs (acquired from May 2005 to March 2007) made it possible to outline the evolution of the unstable ice zone.

The Total Station data (from July 2005 to November 2005) were processed to calculate unstable ice mass displacements and velocities, whereas the laser scanner data processing (May 2005) enabled quantification of serac volume and geometry.

In the period July 2005 - November 2005, the positions of several points (located on the surface of the serac, on the surface of the Forni Glacier and on mountain peaks outside the glaciers) were repeatedly collected using a Total Station (Leica WILD T 1000). The points located on mountain peaks and ridges (i.e., fixed points) were used as control points. By acquiring the positions of the fixed points, it was possible to quantify systematic errors affecting the measurements. A topographical network was developed to calculate the horizontal distances between the base point and the various points surveyed. The distance between the point where the Total Station was located (i.e., base point) and the points to be surveyed was about 4 km. Using trigonometry, vertical and horizontal components of displacement vector were computed.

Vertical component of displacement vector was computed as follows (fig. 2):

$$S_V = (\Delta_{300-A})_t - (\Delta_{300-A})_{t+1}$$

where $\Delta_{300\text{-}A}$ is the difference between the elevation of the base point and the elevation of the surveyed points, calculated according to:

$$\Delta_{300-A} = h_{instr} + d_0 \text{cotg}\phi + \frac{1-k}{2R} d_0{}^2$$

where:

- h_{instr} = instrument height
- d_o = horizontal distance between the base point and the surveyed points
- ϕ = zenith angle
- k = atmospheric refraction coefficient = 0.17
- R = earth radius = 6,379,319 m

The horizontal component of displacement vector was computed as follows:

$$S_0 = \sqrt{2d_0{}^2(1-\cos\omega^*)}$$

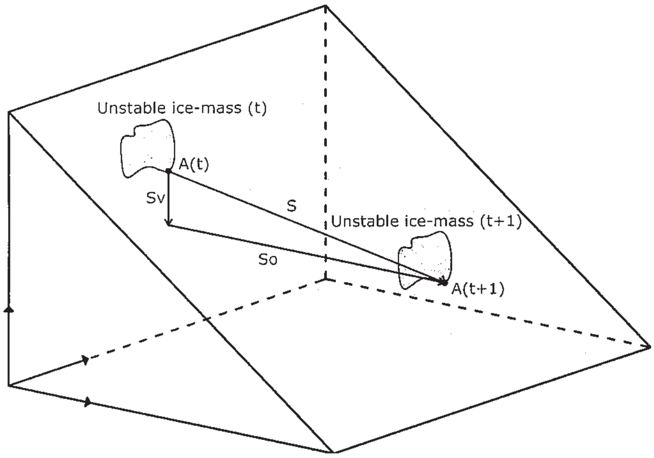


FIG. 2 - Vertical and horizontal components of displacement vector. S_v indicates the vertical component of displacement vector, S_0 indicates the horizontal component of displacement vector and S indicates the modulus of displacement vector.

where:

$$\omega^* = \omega(t+1) - \omega(t)$$

These data were used to calculate displacements, velocities and flow direction of the unstable ice mass.

On the 25th of May 2005, a laser scanner survey was performed (using a RIEGL LMS-Z420 instrument). The scanning base point was located at an elevation of c. 3200 m asl and at a distance of about 800 m from the unstable ice mass (fig. 1).

To georeference the laser scanning, three reflecting targets were placed near the scanning point. GPS antennas were mounted on the targets to enable calculation of their coordinates. Close to the Branca Hut (fig. 1) a master GPS station was located for *real-time* correction of the data acquired by the antennas mounted on the targets. To insert the Branca Hut master station data into the WGS84 system and to evaluate its coordinates, a GPS network was developed. The laser scanner data were then processed to obtain a 3D image of the unstable ice mass and to evaluate and quantify its geometry and volume.

The air temperature data were processed to detect the occurrence of any trend in the period July 2005 - November 2005 and to evaluate the role of weather conditions in the evolution of the unstable glacier zone. The temperature data were acquired by the Monte Vioz Automatic Weather Station (AWS, 2950 m asl) and then adjusted according to the general temperature lapse rate (–0.0065 °C/m) in order to evaluate the mean air temperature at the elevation of the unstable ice mass.

Several photographs were taken regularly from May 2005 to March 2007. As it was difficult and dangerous to reach the unstable ice mass, the survey points for the photos were placed outside the serac (the distances between the survey points for the photographs and the points on the unstable ice zone to be surveyed were about 4 km - fig. 1). The photographs were compared in order to describe the evolution of the serac.

RESULTS

The Total Station survey enabled quantification of displacements, velocities and flow direction of the serac during the study period. The average displacement between the 20th of July and the 8th of November 2005 proved to be 12.4 m. The average velocity between the 20th of July and the 8th of November 2005 was 0.112 m/day. The central sector of the unstable ice mass showed faster movement. On the 8th of November 2005 (when the last topographic survey was performed), an acceleration occurred at the points located in eastern lower sector of the unstable ice mass, preceding the fall of this part, which occurred shortly thereafter (it disappeared on the 22nd of November 2005).

The ice flow direction was assumed to be that indicated by the horizontal components of the displacement vectors: if $S_0<0$ ($\omega^*<0$), the flow direction was eastward; if $S_0>0$ ($\omega^*>0$), the flow direction was westward. As all the monitored points showed positive values of S_0 (except point S8), the flow direction proved to be westward (fig. 3).

To evaluate the precision of the horizontal distances and displacements, the law of propagation of variances was applied. The precision of the displacement (S) calculation proved to be 0.53 m.

The laser scanner survey enabled the acquisition of a large number of points to calculate a 3D model representing the unstable ice mass geometry. This 3D model was analysed to obtain information about the serac shape, size and volume. On the 25th of May 2005, when the laser scanner survey was performed, the maximum length of the unstable ice mass was 80 m, the maximum width was 100 m and the frontal height was 55-70 m (minimum value in the western part and maximum value in the eastern part). The most recent data-processing permitted to estimate an ice mass volume of about 560,000 m^3; this value resulted larger than the one previously calculated (Riccardi & *alii*, 2009) and is mainly due to the complex shape and morphology of the serac. To evaluate changes in volume, another laser scanner survey was planned two months later, but due to adverse meteorological conditions the scanning could not be performed.

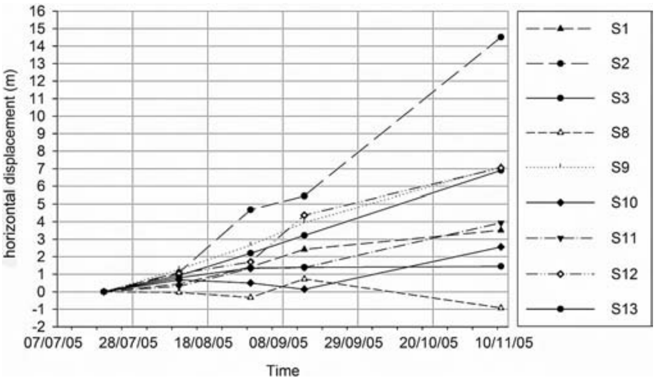


FIG. 3 - Horizontal component of displacement vector of points on serac over time. All the monitored points showed positive S_0 values (sole exception: point S8). Flow direction proved to be westward.

As regards the air temperature, the trend between July 2005 and November 2005 was evaluated. The analysis showed that during the ablation season (July-September), the daily average air temperature values were almost always positive.

During the observation period, the evolution of the unstable ice mass seemed to be slightly influenced by the air temperature trend. In fact, in some cases disaggregation and some falling events coincided with temperature increases (fig. 4, grey boxes were used to mark the largest falling events). Nevertheless the displacements resulted not correlated with air temperature values and the main and larger falling events occurred in the autumn (second part of November) and not in summer when air temperature reaches the highest peaks. Then probably air temperature may help ice disaggregation but is not the unique driving factor of such phenomenon.

The photographs collected were used to reconstruct the evolution of the serac. In the entire observation period (May 2005 - March 2007), substantial disaggregation (i.e., the separation of the unstable ice mass into smaller ice parts due to subprocesses of fracture; Pralong & Funk, 2006) occurred in the serac lower sector and along its lateral side.

Due to disaggregation, there was substantial mass reduction (c. 40%) and therefore a lower level of hazard. The development of large crevasses was observed, occurring before the disaggregation events.

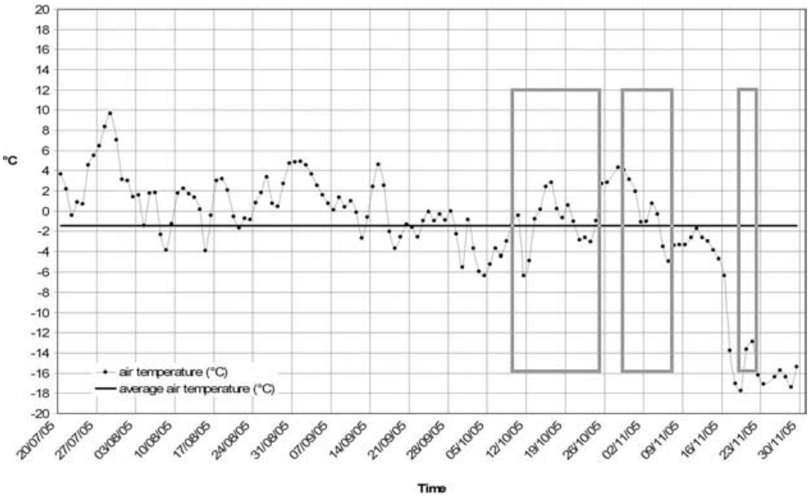
CONCLUSIONS

The fracture process affecting the S. Matteo serac could be defined (using the avalanching glacier fracture classification by Pralong & Funk, 2006) as slab fracture. This fracture process occurs differently in cold ice and in temperate ice. In the case of the Punta S. Matteo serac, it was not possible to measure the ice temperature (as it was difficult and risky to reach the unstable ice mass). However, it can be reasonably assumed that the glacier is made up at least partially of cold ice and should have a frozen base (due to the steep slope). Thus, the fracture has probably developed near the ice mass bed when shear stress exceeds the stress threshold for damage initiation. At present, the main fracture is not totally developed; on the other hand, the disaggregation that has occurred in the lower sector and on the lateral side of the unstable ice mass is substantial, reducing the size of the unstable ice mass and thus the hazard level.

The Total Station surveys enabled calculation of the displacements and velocity of the unstable ice mass: during the survey period, the average displacement was 12.4 ±0.5 m, equal to 0.112±0.005 m/day.

The laser scanner survey enabled evaluation of the size, shape, morphology and volume of the unstable ice mass (about 560,000m^3).

FIG. 4 - Air temperature trend at the elevation of the serac between July 2005 and November 2005. The grey boxes indicate the falling events occurred during the 2005 survey period (i.e.: 9th-25th October, 4th-7th November, 18th-22nd November).



Air temperature affects cold glaciers and temperate glaciers differently. In the case of cold glaciers, air temperature is not the main parameter driving velocity variation (Lliboutry, 1968; Pralong & Funk, 2006). In fact, in our study, air temperature resulted not strongly related with displacement data, on the other hand it seemed to affect slightly the disaggregation of the unstable ice mass and in a few cases, higher temperatures were found to be correlated with the occurrence of falling events. Then we can consider the Punta San Matteo serac an ice mass partially made of cold ice which has a dynamics and an evolution only partially influenced by air temperature values.

The monitoring of the serac on Punta San Matteo will continue, using both high-resolution photographs and Total Station surveys. An additional laser scanner survey will be carried out to quantify volume changes over the last five years and to evaluate the present morphology and size of this unstable ice mass. Meteorological data acquired directly on the Forni Glacier surface by the first Italian glacier AWS (Citterio & *alii*, 2007) will be useful for further investigations of the role played by meteorological conditions in the evolution of the unstable ice zone.

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