

ICE/SNOW AVALANCHES FROM THE HANGING SNOUT OF THE PALÒN DE LA MARE GLACIER (CENTRAL ITALIAN ALPS)

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ABSTRACT: In latter years, because of the climate change and the related transition from cold to warm based ice in high elevation glaciers, avalanches due to the collapses of hanging glaciers have raised importance and interest. In this work, we present the case study of Palòn de la Mare, a mountain glacier with a secondary hanging snout, which frequently breaks off producing ice and mixed ice/snow avalanches. We analysed the evolution of this portion of the glacier in the last 30 years also with respect to its mass balance and snow and weather data. Among the recorded nine glacier collapses, we gave a special focus on 5 avalanche events: three pure ice avalanches in 1999, 2002, 2006 and two mixed ice/snow avalanches in 1986 and 2017. For reproducing the ice/snow avalanche events, we used the model RAMMS-Extended. This model allows the simulation of an avalanche from the release to the runout by taking into account: i) potential secondary releases; ii) snow entrainment; iii) snow temperature and density variations along the path. The model simulated the flow dynamics of the events and highlighted the importance of the choice of the release inputs, with particular focus on the ice release temperatures which greatly influenced the runout distances. In this paper we partly present the results and discuss the potentiality of such model, originally born for snow avalanches, in a glaciological context.

KEYWORDS: hanging glacier, ice/snow avalanches, dynamical modeling, ice temperature

1. INTRODUCTION

The air temperature increase is affecting not only the glacier extent but also the glacier temperature conditions resulting in a possible transition from cold to warm based ice in high elevation glaciers. For this reason avalanches due to the collapses of hanging glaciers have raised importance and interest. Some studies have already investigated this topic (e.g. Alean, 1985) but only few of them specifically modelled the mixed flow of ice and snow (e.g. Margreth et al., 2017).

In this work we present the history of the hanging snout of Palòn de la Mare and the avalanche dynamics simulations of some documented events.

2. STUDY AREA

Palòn de la Mare is a mountain glacier located in the municipality of Valfurva (Central Italian Alps) (Fig. 1). It is characterized by a significant hanging snout located at 3200-3350 m asl and around 80-50 m high (depending on the period). Below the hang-

ing snout, a steep 200 m high rock wall stands above a long and sub-flat valley.

The climate in the area is continental. The average annual precipitation is 781 mm and the average annual air temperature is 6.1 °C (data from S. Antonio Valfurva, 1380 m slm, 13 km from the study site, years 1987-2017).

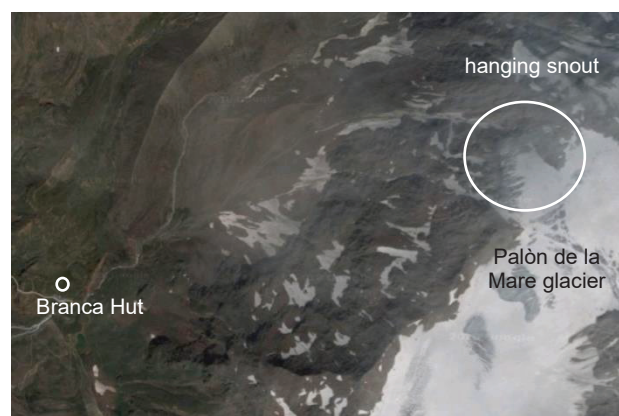


Figure 1: Aerial view of the study area from Google Maps.

3. HISTORICAL DATA

In the last 30 years, nine glacier collapses have been recorded, often after periods of positive glacier mass balance (see Fig. 2 and 3 reported at the end of the paper). They occurred when no seasonal

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snow was on the ground. However, the largest event occurred during wintertime in February 1986. The collapse of a portion of the hanging snout, at about 3250 m asl, triggered a deep dry snow slab at about 2800 m asl, originating a mixed ice/snow avalanche. Despite the pure ice avalanches, which generally stopped on the sub-flat valley, this event reached the mountain hut *Branca*, located at 2493 m asl, causing minor damages. The other mixed snow/ice avalanche occurred in April 2017. Figures 4 and 5 show, as examples, the releases and deposits of some events.

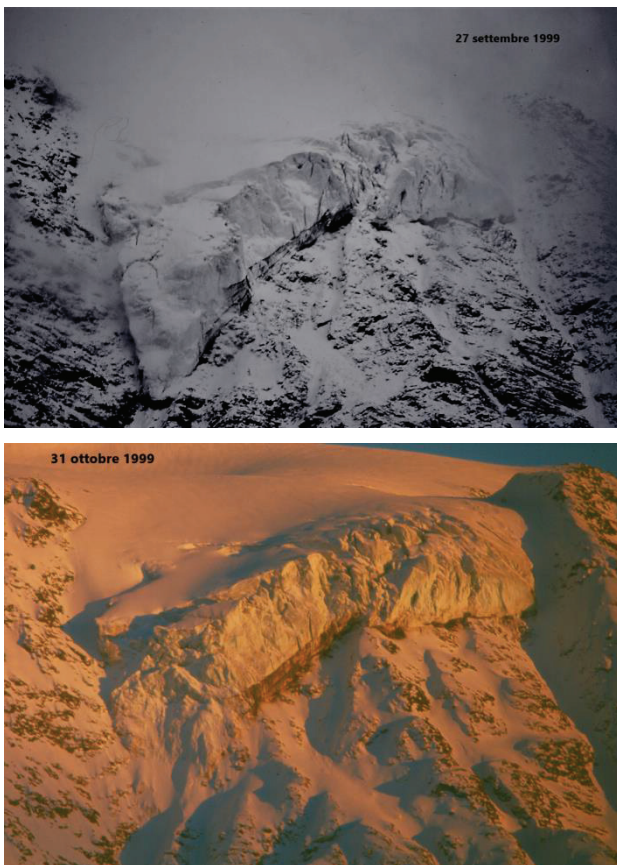


Figure 4: View of the hanging snout before (above) and after (below) the event in 1999.

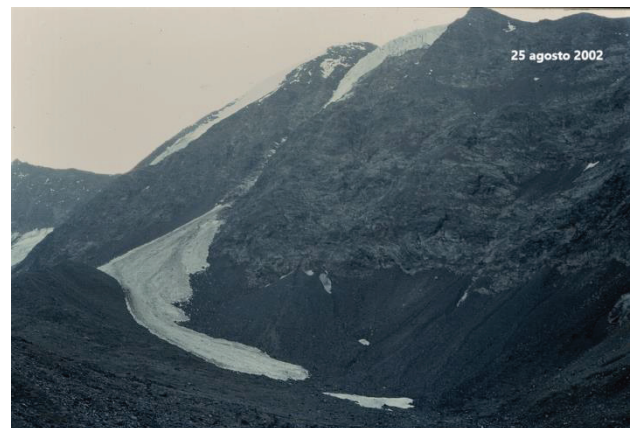
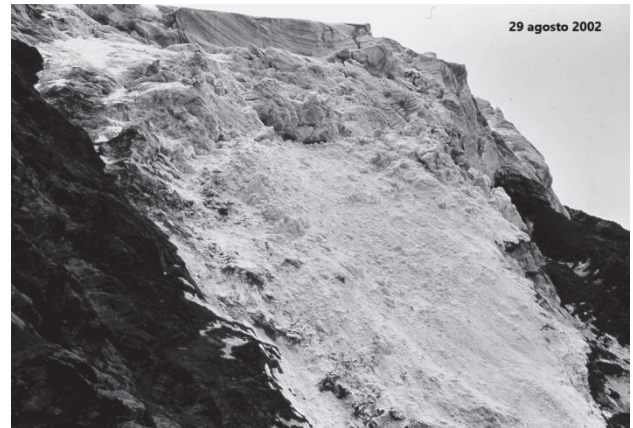
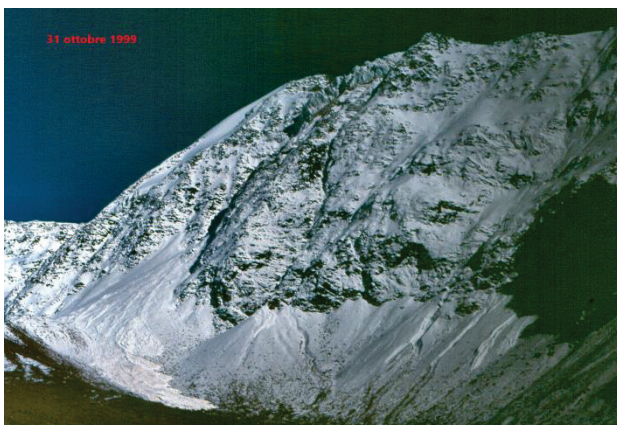


Figure 5: Photos of the events occurred in 1999, 2002, 2006, 2017.

4. AVALANCHE SIMULATIONS

For reproducing the ice/snow avalanche events, the model RAMMS-Extended was used (Bartelt et al., 2006 and 2012; Buser and Bartelt, 2015). This model allows the simulation of an avalanche from the release to the runout by taking into account: i) potential secondary releases; ii) snow entrainment; iii) snow temperature and density variations along the path.

The release areas and snow cover parameters were reconstructed from historical data; model inputs were chosen according to historical data and specific expert-based assumptions about the physics of the considered events. In particular, release mass (volume and density) was determined only from observation and field survey, no specific measurements were made. Volumes ranged between 30'000 m³ and 50'000 m³ (Fig. 6). The event in 1999 was particularly well documented also in the release zone before and after the collapse; Cola and Galluccio (2000) estimated the released ice volume as reported in figure 7.

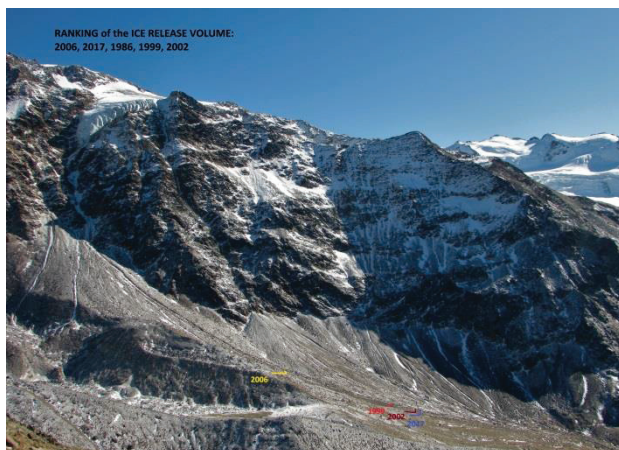


Figure 6: Runout distances of the simulated avalanches. In February 1986 the avalanche stopped further down (2450 m asl) right of the picture.

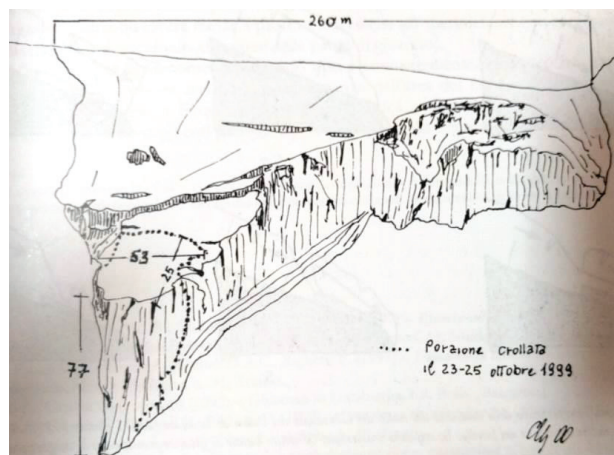


Figure 7: Drawing of the hanging snout concerning the event of 1999 (Cola and Galluccio, 2000).

In case of only ice breaking, we used a release density of 850 kg/m³ but also a value of 600 kg/m³, to consider ice fragmentation down the steep rock wall before the ice collapse became an avalanche flow.

Temperatures of the falling ice were not known, therefore different values between -1 and -10 °C were used as inputs to the model, according to recent literature (Gabrieli et al. 2016; Hoelzle et al., 2011; Margreth et al., 2017) which measured temperatures in different glaciers in the Alps. Therefore these last input parameters (release mass and in particular temperature) were affected by large uncertainties.

Such uncertainties were reflected in the model outputs, especially in the runout distances, which depended strongly from release temperatures. Longer runout distances were computed for higher temperatures. For example, the simulation of the event of 1999 calculated a runout distance at 2660 m asl (closer to the observed one) with a release ice temperature $T = -10$ °C, otherwise with $T = -3$ °C the calculated runout was down to 2555 m asl (Fig. 8). The same trend occurred also for the other events.

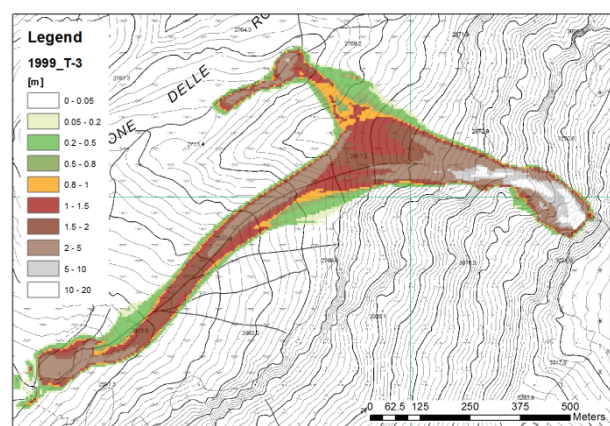
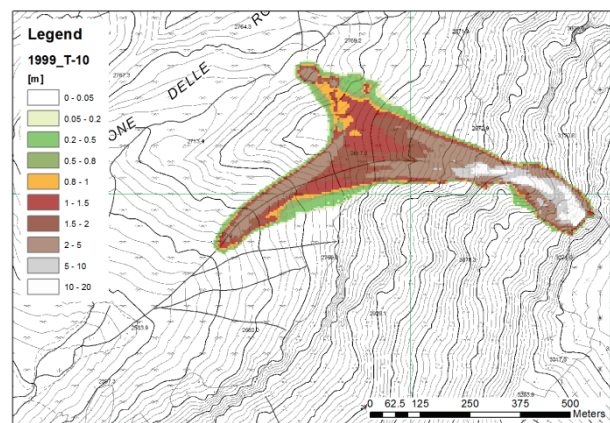


Figure 8: Maximum flow-height for the event in 1999 in case of release ice temperature of -10 °C (above) and -3 °C (below).

Flow temperature influences the amount of liquid water which is produced during the motion: more water in the flow -> more lubrication -> lower friction -> longer runout distances. If the release temperature was already close to the ice melting point, the production of liquid water occurred earlier in the flow. Actually, in the simulation with $T = -10\text{ }^{\circ}\text{C}$, the flow warmed up along the path but never reached a temperature higher than $-7\text{ }^{\circ}\text{C}$, without liquid water production. In case of a release temperature of $-3\text{ }^{\circ}\text{C}$, the production of liquid water started at about 2800 m asl, causing a fluidization of the flow, a lowering in the friction coefficient and a consequent longer runout distance.

In case of simulations with release ice densities of 850 or 600 kg/m^3 the runout distances did not differ much, while impact pressures a little.

An important difference between simulations and real events was the main direction of the flow. In real events the flow below the rock wall turned left, while in the simulation a portion of the mass flew straight towards NW (Fig. 8). We might explain these differences with the accuracy of the Digital Elevation Model (at 5 m resolution) which cannot represent specific small scale features existing along the path. In general, the accuracy of a DEM on steep terrain is low (Bühler et al., 2012). In our case study the DEM cannot reproduce a rock bank on the right hand side of the flow, which in reality might deflect it towards left. Another reason might be that the simulated flow-height at the beginning of the path is not realistic but higher than in reality. In fact, the starting ice volume fragmented in more parts just below the release, while the model simulated a flow-height starting from the release fracture depth, which is about 13-20 m. Such thick modelled flow could not feel small topographic feature along the rock wall.

5. DISCUSSION AND CONCLUSIONS

In this work we briefly present the history of the hanging snout of the glacier Palòn de la Mare. The available data in terms of frequency and photographic material is unique, as for 30 years the glacier has been being monitored.

We tried to simulate the better-documented events with the scientific version of RAMMS, which, to our knowledge, is one of the few models able to simulate such mixed snow/ice or pure ice avalanches. From our results, which we could not present completely due to limitation of space, it seems crucial the correct choice of the initial release mass and temperature. Such parameters are the most influencing the avalanche dynamics.

In conclusion, we think the use of RAMMS-Extended for risk assessment of mixed snow/ice or pure ice avalanches is possible but limited to the knowledge of the ice temperature, as it was recently

done by Margreth et al. (2017) for the hanging glacier on the Eiger west face. Indeed our simulations further highlighted the significant role of the ice temperatures in the resulting ice avalanche dynamics suggesting the ice temperatures are a fundamental parameter to forecast the effects of hanging glacier collapses.

To improve our results and valorize the available data of Palòn de la Mare, future works should be done in order to monitor glacier temperatures and eventually motion with a time-lapse camera installed at the opposite site of the valley. Information on release ice temperature might strongly improve the avalanche dynamics simulations, while a time-lapse camera should give insight in the release process, which also deserves attention when thinking at risk assessment. In particular, the analysis of the ice collapses with respect to the glacier mass balance and the snow and weather data could be improved, and eventually made also with respect to possible future climate scenarios.

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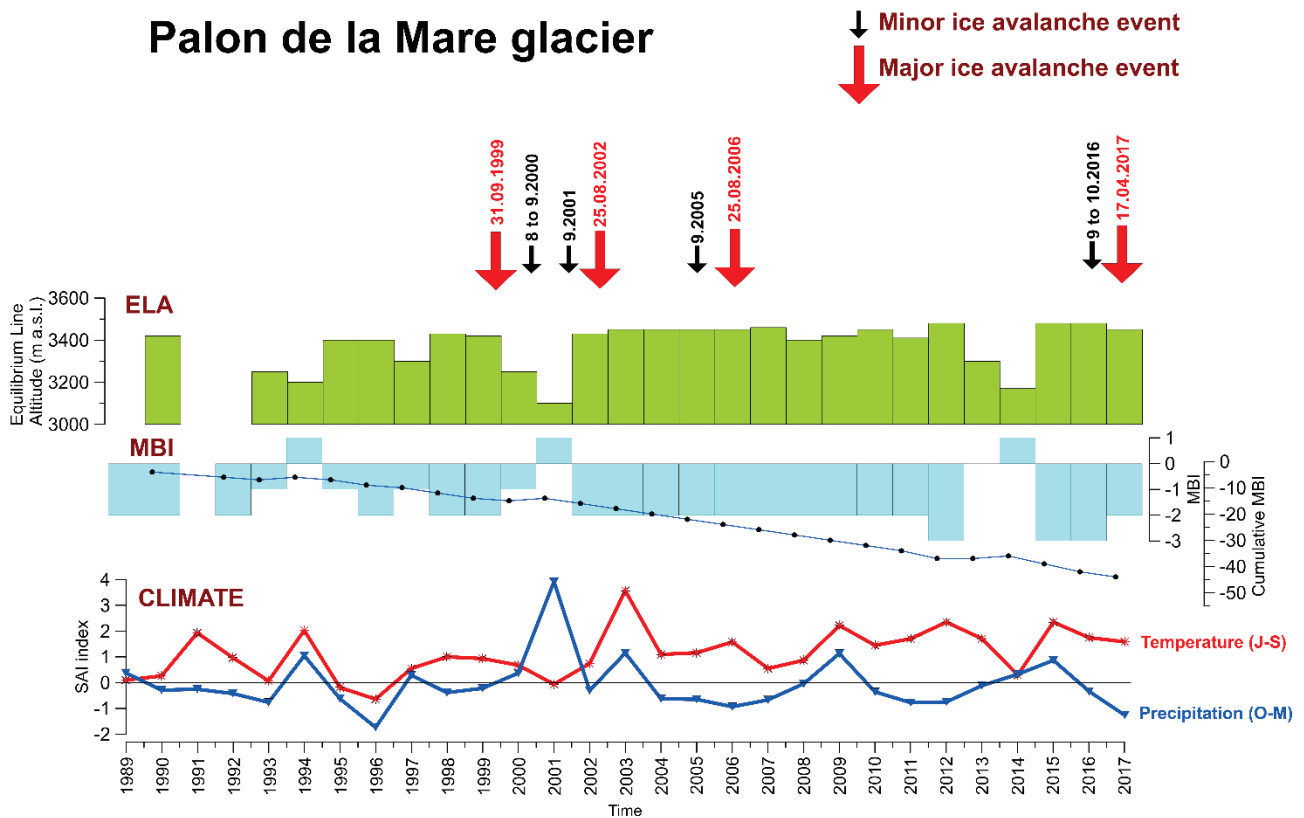


Fig. 2. Overview of the ice collapses at Palòn de la Mare together with other significant data: Equilibrium Line Altitude (ELA) and Mass Balance Index (MBI) for the glacier, taken from annual reports by *Servizio Glaciologico Lombardo*; SAI index - with respect to the long-term average values (1864-2017) – for temperature (June-September) and precipitation (October-May) from the automatic weather station Sils Maria (Engadina, CH), 64 km from the site At 1799 m asl.

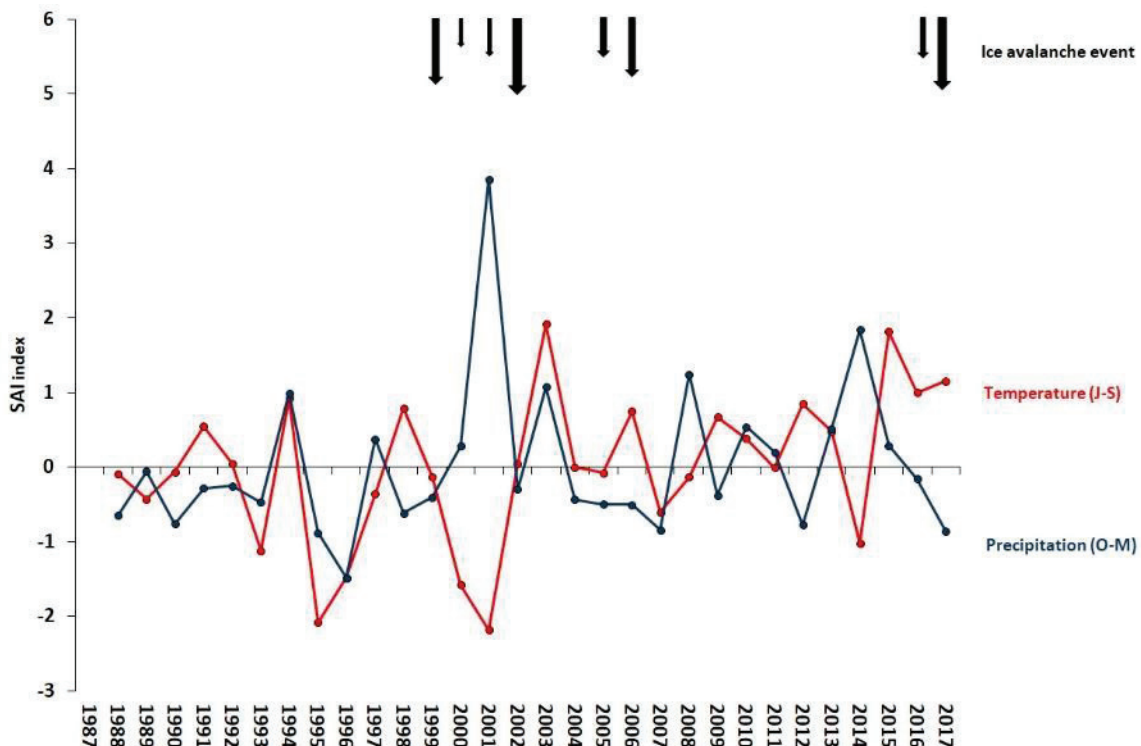


Fig. 3. Overview of the ice collapses at Palòn de la Mare (indicated with arrows with dimensions proportional to the release volumes) plotted together with temperature (red) and precipitation (blue) data from the weather station Sant'Antonio Valfurva (1380 m asl) 15 km away from the study site.