Five years of thermal and kinematic monitoring of Alpine permafrost in the Ticino Alps

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Introduction

Rock glaciers are typical landforms related with the presence of permafrost. They are important indicators of the influence of climate change on high mountain environments, especially under current global warming (Barsch, 1996; Kääb et al., 2007). Therefore, their study is very important to understand the Alpine cryosphere evolution. In recent decades, a systematic thermal and kinematics monitoring of active rock glaciers has started throughout the Alps in the framework of several national or transnational programs [e.g. PACE – Permafrost and Climate in Europe (Harris *et al*., 2001), PermaFRANCE (Schoeneich *et al*., 2010), PermaNET – Permafrost Monitoring Network (Mair *et al*., 2011), PERMOS – Permafrost Monitoring in Switzerland (PERMOS, 2013)].
Since 2009, some rock glaciers of the Ticino Alps are also studied to provide data on the permafrost evolution in the Southern alpine morphoclimatic context. Some monitoring sites are belonging to PERMOS.

Methods

Since 2009, nine rock glaciers (fig. 1 and tab. 1) are subjected to annual or multi-annual measurements of the surface displacements by differential GPS (dGPS).
Between these, ground surface temperature (GST) monitoring is performed on five rock glaciers thanks to autonomous mini-loggers (UTL-3; Universal Temperature Logger, Geotest AG), installed at a depth of 10-50 cm in the ground.
The air temperature data of Matro (2171 m a.s.l.) and Robièi (1896 m a.s.l.) meteorological stations (MeteoSwiss data) allowed the quantification of mean annual air temperatures (MAAT) in altitude. MAAT was calculated by a 365 days mobile average of daily temperatures. MAAT data are therefore used to analyze variations in mean annual ground surface temperatures (MAGST), also calculated by a 365 days mobile average.

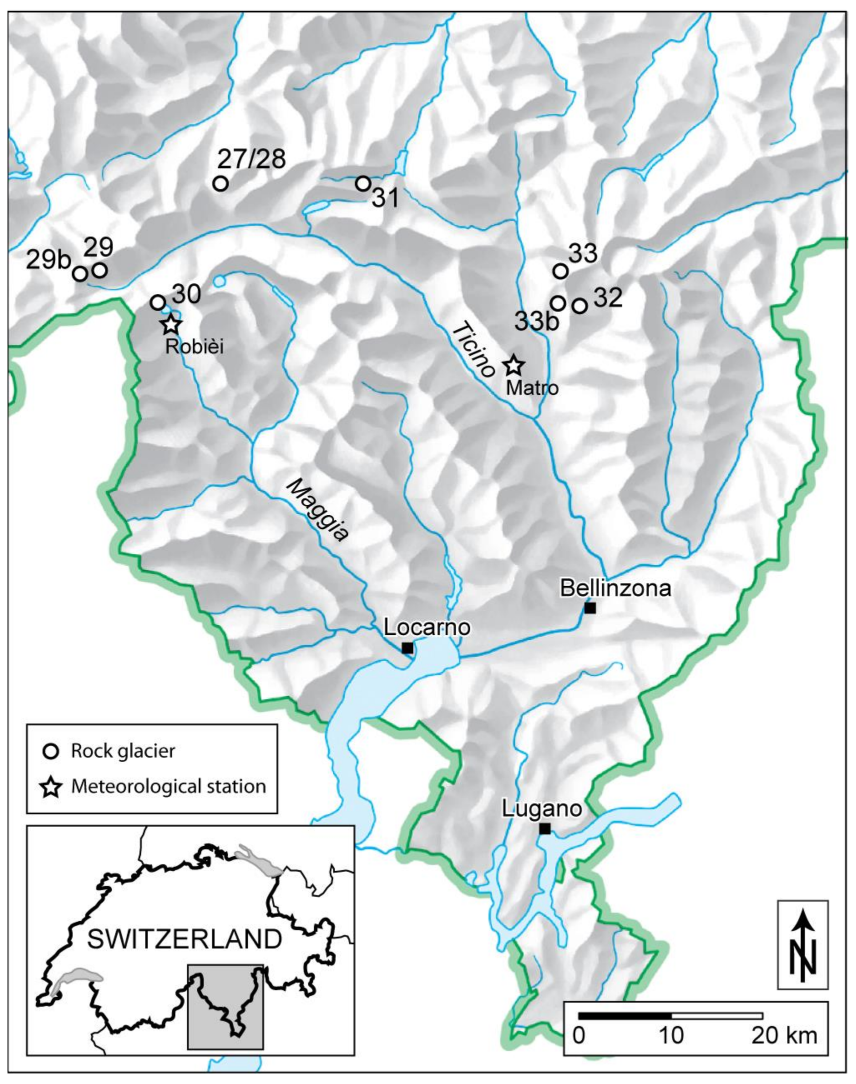

Figure 1. Distribution of studied rock glaciers and meteorological stations. Name and characteristics of rock glaciers are in table 1.

Site	Region	Elevation (m a.s.l.)	Aspect	GSTM No. logger	DGPS No. measures	Institution	PERMOS
27 Monte Prosa A	Gotthard	2430-2600	N	-	Yearly	UniFR	x
28 Monte Prosa B	Gotthard	2450-2520	WNW	-	Yearly	UniFR	x
29 Pizzo Nero	Val Bedretto	2600-2700	S	-	Every five years	SUPSI	
29b Pizzo Gallina	Val Bedretto	2660-2760	SE	4	Yearly	SUPSI	
30 Passo di Grandinagia	Val Bavona	2560-2800	NE	4	Biennial	SUPSI	
31 Ganoni di Schenadüi	Val Cadlimo	2480-2640	N	4	Yearly	SUPSI	
32 Piancabella	Val Malvaglia	2440-2550	NE	10	Yearly	SUPSI	x
33 Stabbio di Largario	Val Soi	2240-2550	N	4	Yearly	SUPSI	x
33b Alpe Pièi	Valle di Blenio	2340-2500	S	-	Three yearly	SUPSI	

Table 1. List and characteristics of the monitored rock glaciers in the Ticino Alps.

Results

The collected data of velocity and GST in nine rock glaciers of the Ticino Alps concerning period 2009-2014 are illustrated in fig. 2 and 3.
Every rock glaciers presents different surface horizontal velocities depending on morphostructural and topographical factors (fig. 2a). The values are comprised from a minimum of 0.02 m/a at Alpe Pièi to a maximum of 0.56 m/a at Stabbio di Largario.
Instead, the annual mean, normalized to 2009-2010 hydrological year, increase in 2010-2013 period and decreases slightly in 2013-2014 (fig. 2b). The slowest rock glacier is Ganoni di Schenadüi, whereas the fastest is Monta Prosa A.
The GST have a trend similar in all sites but they do not show any good correlation with the MAAT (fig. 2c). Indeed, the GST depends also on other factors such snow cover (depth and duration), ground properties (albedo, debris size, and permeability), altitude and aspect.

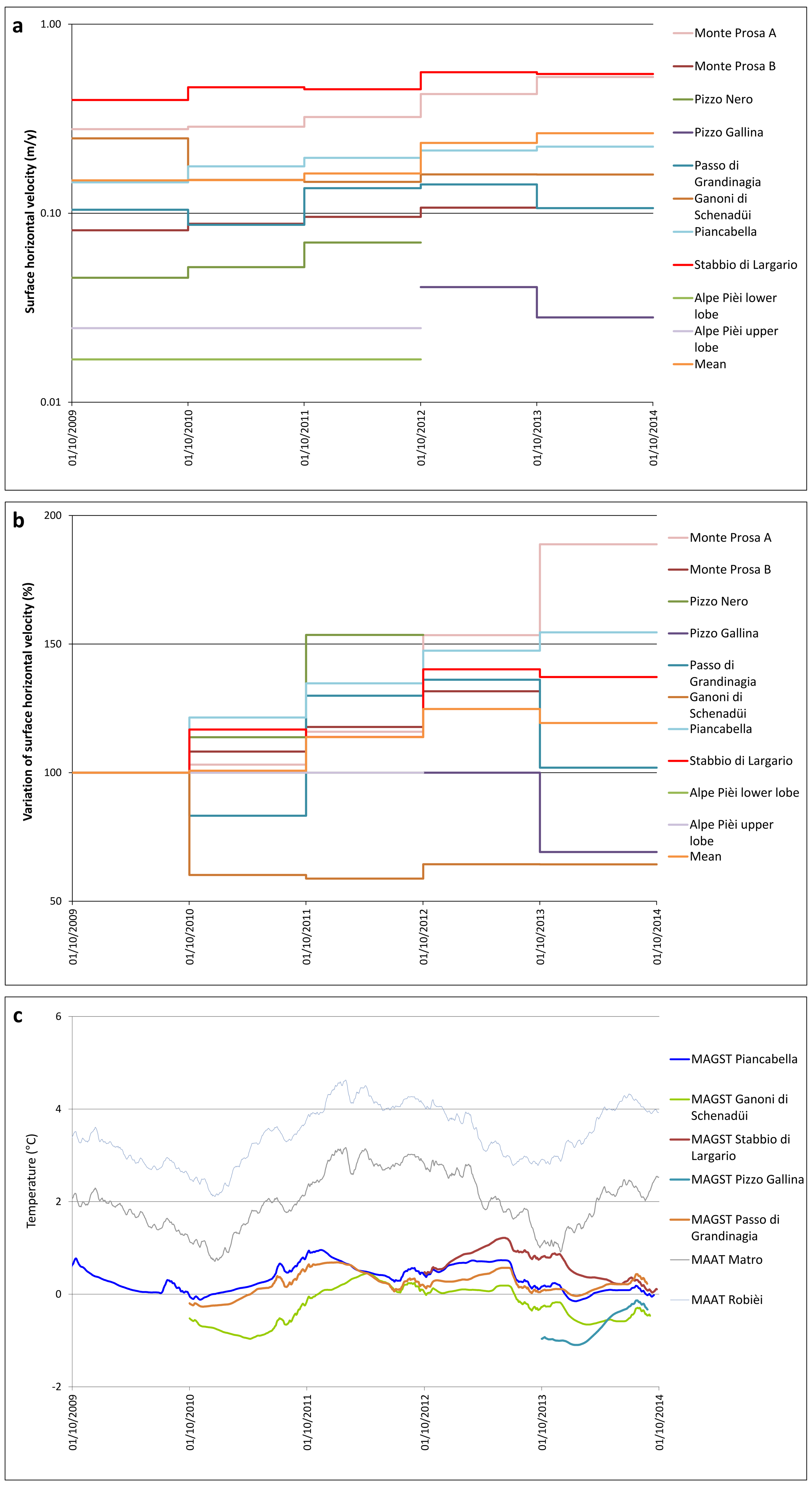

Figure 2. Comparison between rock glacier kinematics and evolution of Mean Annual Ground Surface Temperature (MAGST).
a. Mean horizontal annual velocity of nine rock glaciers monitored in the Ticino Alps. At Alpe Pièi site the rock glacier is composed by two lobes, upper and lower, with different horizontal movements and age; for this reason we have considered the two lobes separately as two distinct rock glaciers.
b. Variation of surface horizontal velocity compared to 2009/2010 hydrological year (2012/2013 for Pizzo Gallina rock glacier because the dGPS measures started in 2012.)
c. Comparison between Mean Annual Air Temperature (MAAT) of Matro and Robièi meteorological stations and Mean Annual Ground Surface Temperature (MAGST) of five rock glaciers in the Ticino Alps.

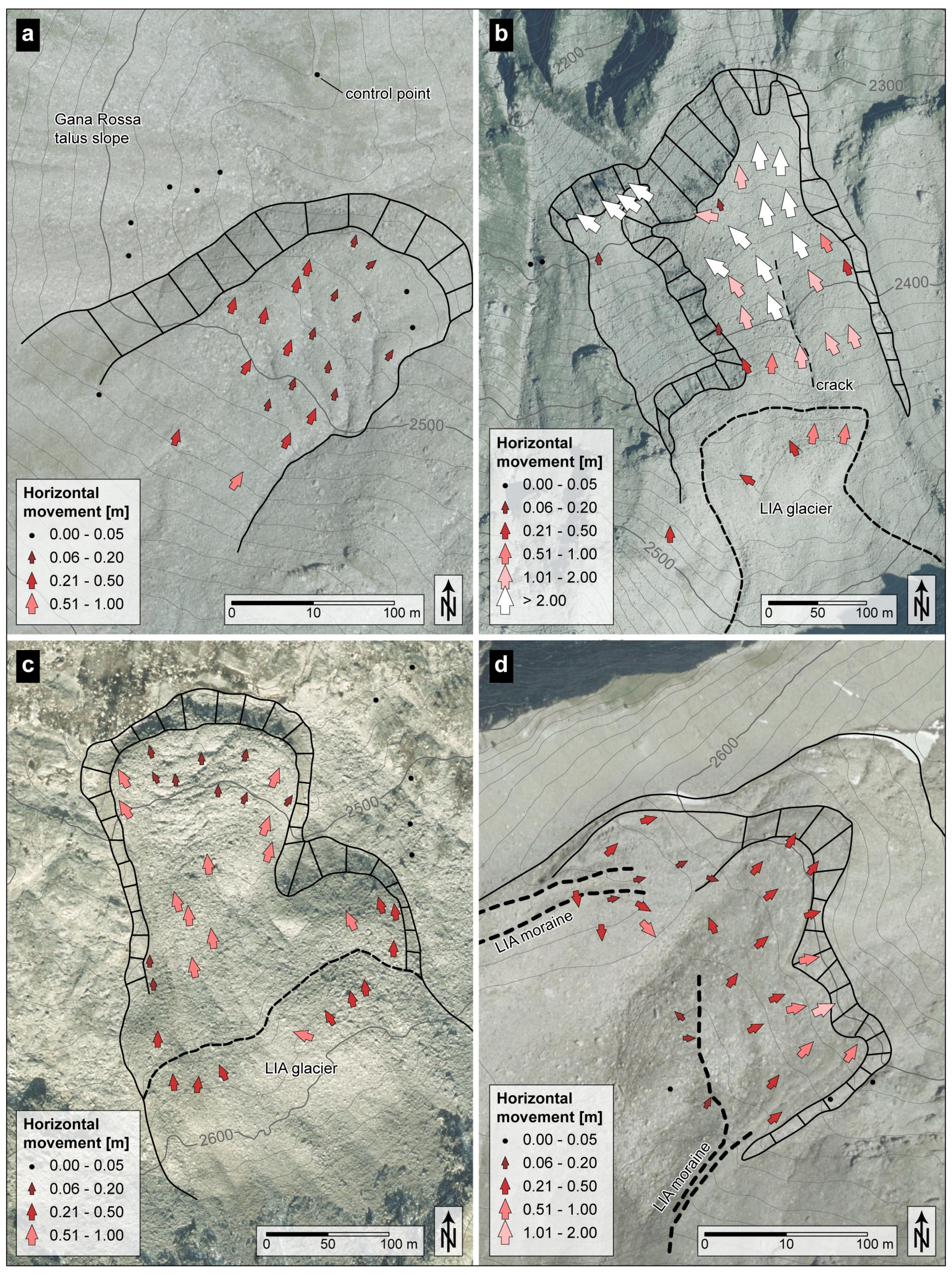

Figure 3. Surface horizontal movements of four rock glaciers in the Ticino Alps in period 2009-2013.
a. Piancabella;
b. Stabbio di Largario;
c. Ganoni di Schenadüi;
d. Passo di Grandinagia.
LIA = Little Ice Age. Equidistance of contour lines: 10 m. Map bottom: Swissimage © swisstopo.

Discussion

From the comparison between rock glacier kinematics and MAGST, it result that annual variations in horizontal surface velocity of the measured rock glacier are significantly correlated with MAGST variations, with a delay of some month. In turn, MAGST is not apparently correlated with MAAT because it is influenced not only by air temperature variations but also by other factors (snow, ground properties, …).
The significant link between changes in temperature and rock glacier behavior highlighted in the Southern Swiss Alps was also evidenced in several other regions of the Alps.
Despite local and regional differences in climate and topography within the Alps, this may indicate that the rock glacier kinematics is probably influenced principally by the first order climatic variation at the continental or global scale.

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