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Climate variations in a high altitude Alpine basin and their effects on a glacial environment (Italian Western Alps)

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RESUMEN

El principal objetivo de este estudio es evaluar la variación de los parámetros climáticos (temperatura, lluvia y nieve) medidos en dos estaciones meteorológicas (Formazza y Sabbione) que nunca antes se habían analizado, ubicadas en un ambiente glaciar (la cuenca del Sabbione en los Alpes occidentales italianos). El estudio se centra en la evolución climática de la cuenca alpina durante los últimos 60 años (1950-2012): el cambio climático ha causado una declinación glaciar pronunciada cuyo origen es el aumento de la ablación debido principalmente al incremento de la temperatura del aire y la reducción de la alimentación, a su vez ocasionada por la disminución de nieve fresca. La prueba de correlación cruzada muestra que la temperatura influye sobre la dinámica de la retracción glaciar más que la precipitación de la nieve. Se han identificado formas periglaciares y ligadas al permafrost (p. ej., suelos estructurados y glaciares de roca) en depósitos de glaciares provenientes de la Pequeña Edad de Hielo (PEH), lo cual evidencia la transición de un ambiente glaciar/proglaciar a un ambiente periglaciar aún en curso. Además, para identificar mejor el dominio periglaciar de la cuenca, se ha elaborado un mapa de la temperatura media anual del aire a partir de los análisis climáticos.

ABSTRACT

The main objective of this study is to evaluate the variations of climatic parameters (temperature, rain and snow) measured by two weather stations (Formazza and Sabbione) that have never been analyzed before, located in a high glacial catchment (the Sabbione basin in the Italian Western Alps). The study highlights the climatic evolution of the Alpine basin during the last 60 years (1950-2012): climate change has caused a pronounced glacial decline originated by ablation augmentation, due mainly to increasing air temperatures and to reduced alimentation caused by a fresh snow decrease. The cross-correlation test shows that temperatures affect the glacial retreat dynamics more than snowfall. Periglacial and permafrost landforms (e.g., patterned grounds, rock glaciers) have been identified within the Little Ice Age (LIA) glacial deposits, which indicate the ongoing transition from glacial/proglacial to periglacial environments. Furthermore, in order to better identify the periglacial domain in the basin, a map of mean annual air temperature (MAAT) was produced based on climatic analysis.

Keywords: Climate change, glacial decline, permafrost, Italian Western Alps.

1. Introduction

In the last years, several studies have demonstrated the existence of accelerated climate modifications that have affected the whole Earth, in particular the most vulnerable ecosystems such as mountainous regions. In the last 100 years (1906-2005), the global mean air temperature has increased 0.74 ± 0.18 ºC, while in the Alps the increase in temperature is almost the double (Auer *et al.*, 2007; IPCC, 2007). Minimum air temperatures in the Alps have increased more than maximum air temperatures, which have shown a limited rise (Böhm *et al.*, 2001; Beniston, 2005; EEA, 2009). Moreover, there have been changes in precipitation amounts, especially in fresh snow, although they are not geographically homogeneous due to the heterogeneous morphology of the alpine region and the high complexity of alpine climate (Fratianni *et al.*, 2009; Terzago *et al.*, 2010, 2012; Acquaotta and Fratianni, 2013). In particular, in the Western Italian Alps a decrease in the fresh snow amount and snow cover permanence has been observed, which is closely related to the temperature rising as highlighted by the studies of Terzago *et al.* (2013), Acquaotta *et al.* (2014) and Fratianni *et al.* (2015).

At high altitudes, climatic variations interact with glacial processes and influence the dynamics of alpine ecosystems. Mountain glaciers are the major fresh water source for people living in or nearby the adjacent lowlands of mountain ranges (Barnett *et al.*, 2005). The observed worldwide glacier retreat is thus an important concern for the availability of fresh water. For example, in 1850 the total area covered by Alpine glaciers was about 4500 km^2, while in 2000 it reduced to about 2270 km^2 (around –50%) (Cat Berro *et al.*, 2008). Italian alpine glaciers have also suffered a general retreat since the end of the Little Ice Age (LIA) and this regression has been accelerating in recent years due to the effects of climate warming. This trend has also been observed in the study area (Sabbione basin), where glaciers have been retreating since the second half of the 19th century.

The regression of glaciers allows the formation of periglacial environmental conditions in deglaciated areas with a range of cold/non-glacial processes (French, 2007). The periglacial environment is characterized by the presence of frost action and cryotic morphogenetic processes (Tricart, 1968; Péwé, 1969), and of permafrost, defined as "soil and/or rock that has remained below 0 ºC for more than two consecutive years" (Brown and Péwé, 1973).

In the present work, the data extracted from two high altitude meteorological stations (named "Formazza" and "Sabbione") located in the Sabbione basin (Ossola Valley, North Piedmont, Italy) were analyzed for the first time in order to: (1) characterize the climate of the study area; (2) identify the trends of the main climatic parameters; (3) verify the existence of climatic conditions for the development of cryotic processes, using also the data recorded in other stations situated in the Ossola Valley (Agaro, Alpe Devero, Toggia and Vannino), and (4) investigate the morpho-climatic evolution of the basin, considering in particular the glacial/proglacial/periglacial transition. In this area several cryotic geomorphological occurrences have been highlighted during field surveys within deglaciated areas since the 1950s (Colombo *et al.*, 2013). Moreover, other meteorological stations (Canevarolo *et al.*, 2011) close to the study area, have been considered to estimate the basin areas included into the periglacial domain through mean annual air temperature (MAAT).

Indeed, according to the empirical definition proposed by French (2007), the MAAT < 3 ºC is considered for the definition of periglacial domain. Guglielmin (2004) divides this domain, called "sensu lato" periglacial environment, in: (1) "sensu stricto" periglacial environment (MAAT between + 3 and 0 ºC), and (2) permafrost environment (MAAT < 0 ºC). Rainfall is less than 2000 mm/year (André, 2003; Boelhouwers, 2003).

Changes in glaciers are related to climatic variables through their energy and mass balance. Negative changes in the mass balance of a glacier result either from increased ablation or decreased accumulation, which are mainly determined by precipitation and air temperature (Leonelli *et al.*, 2011; Senese *et al.*, 2012). Thus, to understand the effects of climate evolution on glacial dynamics, two climatic parameters (summer air temperature and fresh snow) have been correlated with the frontal glacier regression of the northern Sabbione glacier for the time span 1978-2005.

2. Study area

The Sabbione basin is located in the Formazza Valley (Ossola Valley, Lepontine Alps, Italy, 46º 41' N, 8º 34' E), forming the upper basin of the Toce river and the Swiss border (Fig. 1). The major peaks of the