Hydrological effects of glacier melt and snowmelt in a high-elevation catchment

D. Penna, L. Mao, F. Comiti, M. Engel, A. Dell'Agnese and G. Bertoldi

Hydrologische Effekte der Gletscher- und Schneeschmelze in einem hochalpinen Einzugsgebiet

1 Introduction

Glaciers play an essential role on hydrological, geomorphic and ecological processes of high elevation catchments and are particularly sensitive to climate change (BENISTON, 2003; VIVIROLI et al., 2011). Understanding the influence of ice and snow melt water on groundwater recharge, runoff and sediment transport dynamics is essential in order to provide conceptual models useful for a correct management of water resources in mountain regions (HUSS, 2011; LEBEDEVA & SEMENOVA, 2011) and long-term projections of the potential hydrologic effects of climate change (JOST et al., 2012). Studies in these areas can benefit from the use of water stable isotopes that have proven to be an effective tool to investigate the origin of runoff and flowpaths also in glacierized environments (CABLE et al., 2011; JEELANI et al., 2011). This study took advantage of isotopic, electrical conductivity and turbidity data to assess the effect of glacier contribution to runoff and suspended sediment transport in a glacierized alpine catchment.

2 Study area and methodology

Experimental data were collected between April and October 2011 in the Saldur catchment, Eastern Italian Alps (area: 62 km^2, elevation range: 1600-3700 m a.s.l., Fig. 1) that hosts a small glacier (2.8 km^2) in its upper portion. Water stage measured by pressure transducers at the catchment outlet and at two locations (LSG: Lower Stream Gauge, at 2150 m a.s.l., drainage area 20 km^2; USG: Upper Stream Gauge, at 2340 m a.s.l., drainage area 11 km^2) was

Zusammenfassung

Der Gletscherrückgang als Ergebnis der globalen Erwärmung berührt die Wassermengenwirtschaft in den betroffenen Gebirgsregionen. In diesem Zusammenhang ist die Kenntnis der Wirkungen von Gletscher- und Schneeschmelze auf die Abflussmengen und den Sedimenttransport wesentlich. Diese Arbeit zeigt experimentelle Ergebnisse aus Untersuchungen mit stabilen Isotopen und Messungen der elektrischen Leitfähigkeit in alpinen Gebieten in Italien. Damit wird auf die Anteile von Grund- und Oberflächenwasser, die Beeinflussung durch Schmelzwasser und die Auswirkung auf die Abflussvariabilität und die Dynamik des gelösten Sedimenttransports geschlossen.

Schlagworte: Gletscherschmelze, Schneeschmelze, Abfluss, Isotope, gelöste Sedimente.

Summary

Over the last decades, the retreat of glaciers as result of global warming has raised issues concerning the water resource management in mountain regions. In this context, it is crucial to understand the effects of glacier and snow meltwater on runoff volumes and on suspended sediment transport in high-elevation catchments. This work presents experimental results derived from the use of turbidity, water stable isotopes and electrical conductivity data collected in an Italian alpine catchment to assess the sources of groundwater and stream water, the role of glacier and snow in groundwater recharge, runoff variability and suspended sediment transport dynamics.

Key words: Glacier melt, snowmelt, runoff, isotopes, suspended sediment concentration.

converted to discharge by means of salt dilution discharge measurements. Meteorological data were acquired by a weather station at 2000 m a.s.l. Bulk precipitation for isotopic analysis (δ^2H and $\delta^{18}O$) was sampled by three collectors located at 1800 m a.s.l., at LSG, and at USG (Fig. 1). Samples from the rainfall collectors were taken approximately once in 45 days. Grab water samples were collected on a monthly or bimonthly base at 11 locations on the main stream and three locations on tributaries. Samples were also taken at four springs (named Spring 1–3 and Spring USG) in the USG area from July to October with the same sampling frequency (Fig. 1). Two 24-hour samplings were also performed in mid-July and mid-August. On these occasions, isotopic and EC samples were collected approximately every hour from the stream at USG and LSG (no samples were taken at LSG between 22.00 and 8.00). Additionally, concurrent measurements of turbidity at LSG were carried out and isotopic and electrical conductivity (EC) samples from the USG spring were taken once in four hours. Snow, glacier meltwater (water flowing on the glacier surface) and snow meltwater (water dripping from snow patches) samples were collected on three occasions in summer 2012. Additionally, EC at the same sampling locations within the catchment was measured in the field by a portable conductivity meter. Isotope analysis was performed at the Isotope Hydrology Laboratory at the University of Padova, by means of laser absorption spectroscopy, a technology that has proven to be reliable and suitable to hydrological studies (PENNA et al., 2010; 2012). In order to have the highest precision necessary to discriminate the values of samples collected very close in time (and therefore supposed to have similar isotopic compositions), the water samples collected during the two 24-hour field campaigns were analysed for $\delta^{18}O$ by means of mass spectrometry at the Free University of Bozen-Bolzano, following the He-CO_2 equilibration procedure (EPSTEIN & MAYEDA, 1953). Turbidity data were collected occasionally (end of June to end of August) at LSG with a portable turbidity meter. A calibration curve between turbidity (in NTU values) and suspended sediment concentration (in gl^{-1}) was obtained using 21 direct samplings collected at a wide range of discharges and along the whole study period.

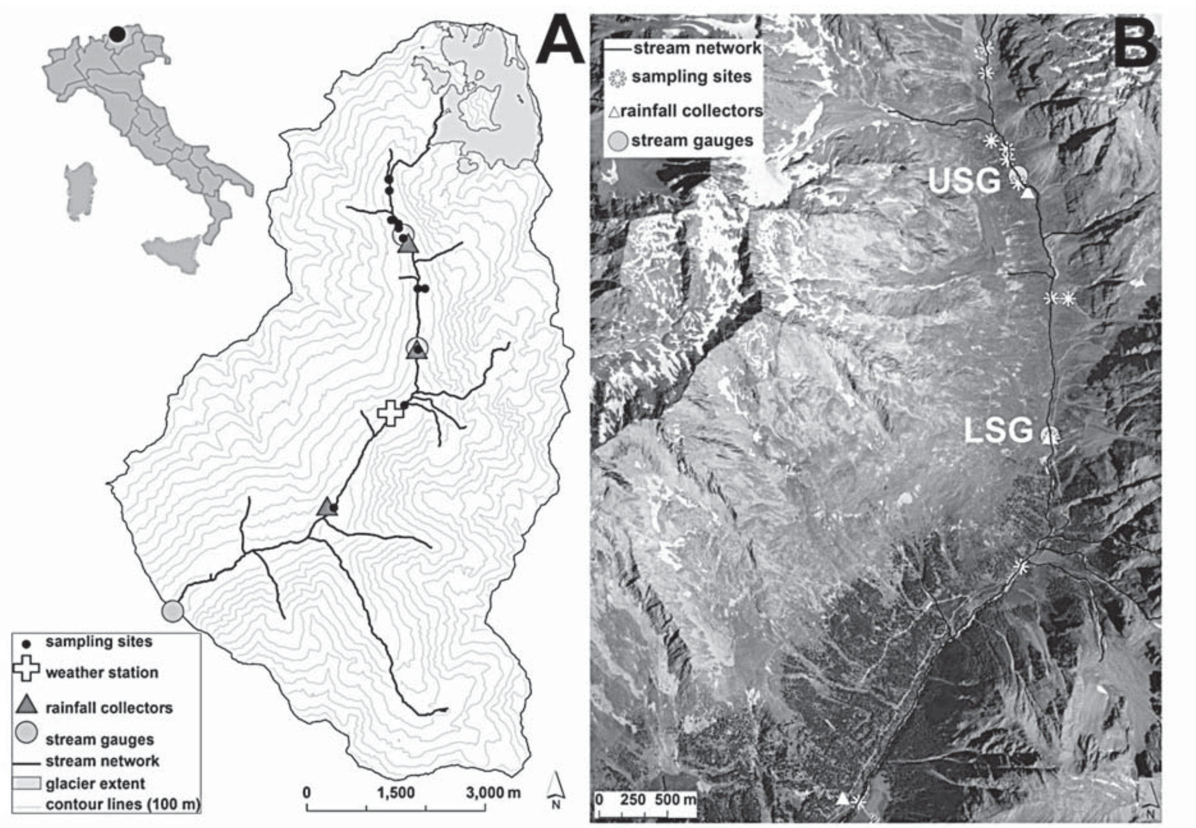

Figure 1: Study area, field instruments and sampling points (A). Orthophoto showing the sampling area for isotopic and EC analysis (B)
Abbildung 1: Untersuchungsgebiet, Feldinstrumentierung und Probenentnahmepunkte (A). Das Orthophoto zeigt die Standorte der Isotopen- und der EC-Messungen (B)

3 Results

Samples collected in the Saldur catchment showed different isotopic composition according to the water source they were taken from (Fig. 2). First of all, rainfall data plotted extremely close to the Global Meteoric Water Line (GMWL) and showed a very similar slope and intercept of the regression line, suggesting a prevalent Atlantic origin of air masses determining the precipitation on the study area. Stream water and groundwater showed an isotopic signal (approximately between –90 ‰ and –120 ‰ in δ^2H, between –16 ‰ and –12.5 ‰ in δ^{18}O) markedly different from summer precipitation (approximately between –40 ‰ and –80 ‰ in δ^2H, between –11 ‰ and –5 ‰ in δ^{18}O, Fig. 2 inset). Indeed, the former reflected more closely the autumnal precipitation and, most of all, the glacier melt and partially the snowmelt isotopic composition. Tributaries (draining from unglacierized subcatchments) and groundwater were characterized by a regression slope lower than that of GMWL (6.0 and 6.7, respectively) suggesting secondary evaporation processes during groundwater recharge. Conversely, samples collected at different cross-sections along the main stream showed a slope (7.9) similar to that of glacier melt samples (7.5) that, in turn, reflected the precipitation signal. This suggests that tributaries were mainly fed by groundwater, originated from rainfall and partially from snowmelt, whereas runoff in Saldur stream was significantly influenced by glacier melt dynamics.

Daily runoff variability, as observed in other glacierized sites (HUSS et al., 2011; JOST et al., 2012) was mainly dependent on temperature oscillations that determined snowmelt and ice melt. Runoff response was less influenced by precipitation, except for the storm event on September 4th that generated the highest peak discharge of the study period (Fig. 3, panels A–D). Also, suspended sediment concentration was clearly influenced by glacier melt, showing a positive correlation with streamflow and reaching the highest values during the warmest days in July and August (Fig. 3B, where, due to the daily variability, only data taken at the same time in the afternoon are shown). As expected, the isotopic composition of precipitation reflected air temperature during the storms, with enriched delta values during the warmest periods and relatively depleted values at the end of the season (Fig. 3A). Isotopic composition and EC values of stream water at LSG and USG (Fig. 3C–D) were directly correlated with streamflow and showed an overall seasonal trend, with most negative isotopic and lowest EC values associated to high flow conditions due to meltwater from the glacier and the snow (isotopically depleted and little conductive). Groundwater also showed a trend towards enriched isotopic values (Fig. 3F) and, analogously, EC values exhibited an increasing pattern for all three sites (Fig. 3E). This suggests a decrease in the intensity of snowmelt and glacier melt contribution over the season, with a tendency to return to background composition during no melting periods.

During the runoff event occurred on July 12–13 (Fig. 4), the decrease of δ^{18}O (up to –15.4 ‰) and EC (up to 70 µScm^{-1}) values at USG mirrored the increase in streamflow. The average δ^{18}O and EC values of glacier melt sam-

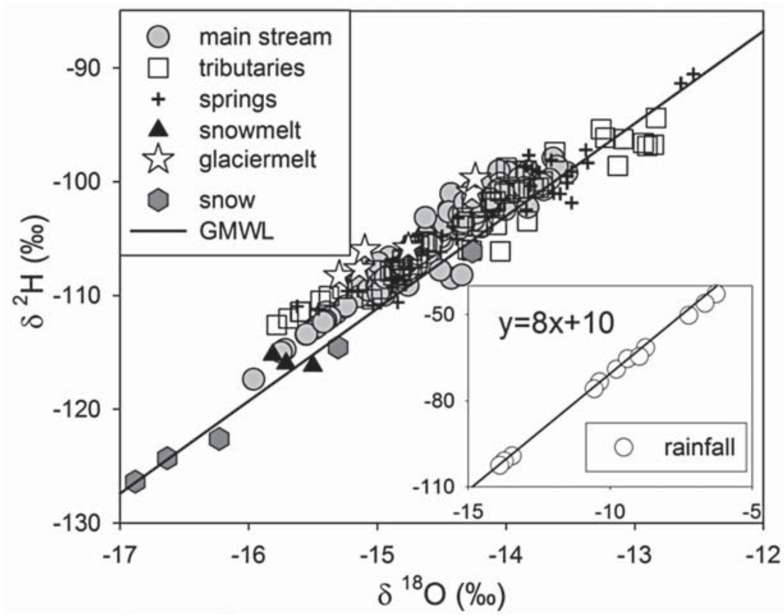

Figure 2: Plot of δ^2H vs. δ^{18}O of the collected water samples. The GMWL is also plotted as reference. In the inset graph, the δ^2H vs. δ^{18}O plot of rainfall samples with the GMWL is reported. The regression line for the rainfall samples has the following equation: y = 7.8x+6.7 (R2 = 0.999)

Abbildung 2: Diagramm der δ^2H- und δ^{18}O-Zusammensetzung der Wasserproben. Als Referenz ist die GMWL dargestellt. Die eingefügte Grafik zeigt die Zusammensetzung der Regenwasserprobe mit folgender Regressionsgerade: y = 7.8x+6.7 (R2 = 0.999)

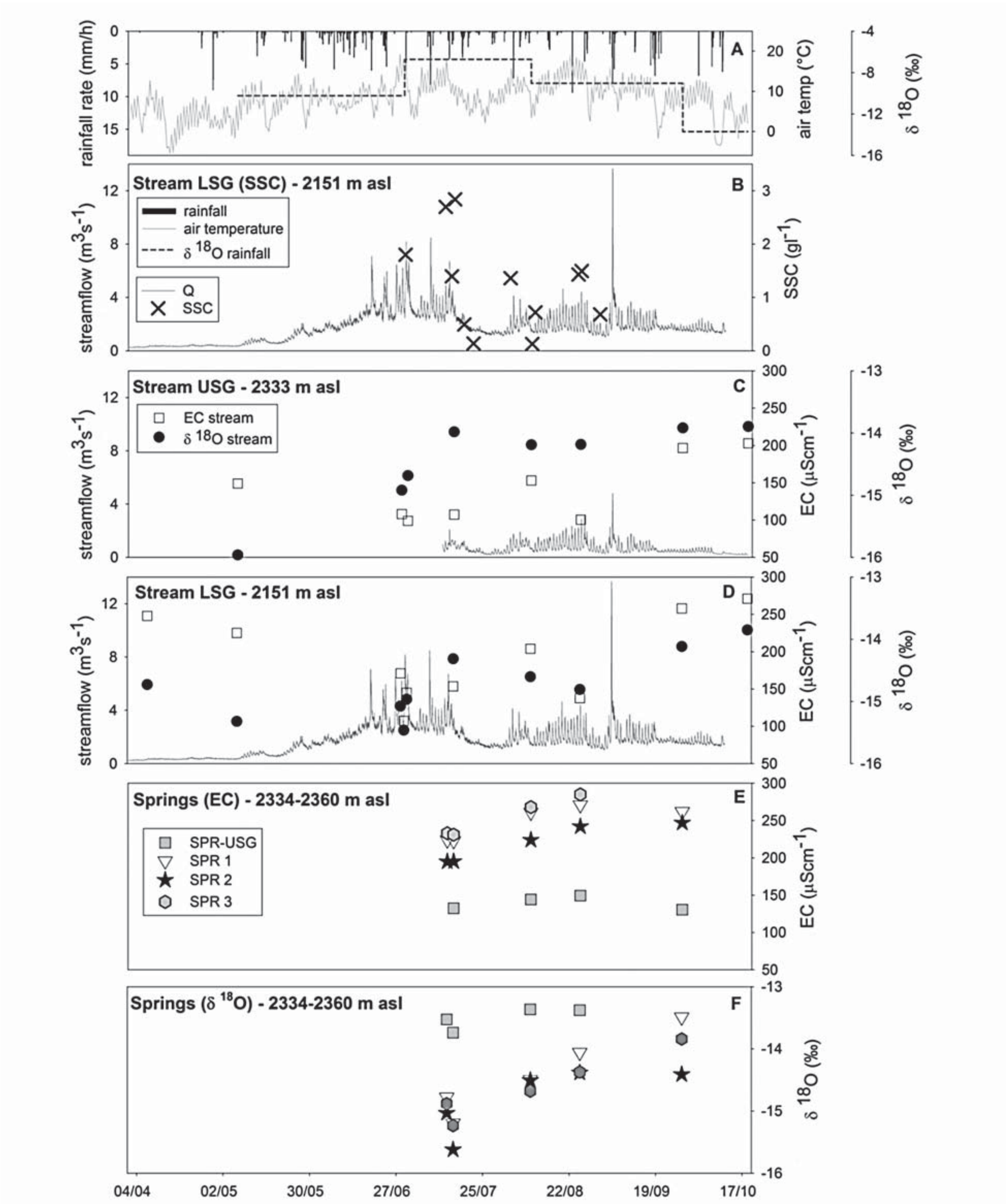

Figure 3: Time series of precipitation, air temperature, streamflow and isotopic composition of stream water at two sections (USG and LSG), suspended sediment concentration data (SSC) at LSG, isotopic composition of rainfall (average of three collectors), isotopic composition and EC of the four springs

Abbildung 3: Zeitreihen des Niederschlags, der Lufttemperatur, des Gerinneabflusses und der Isotopenzusammensetzung des Flusswassers an den Standorten USG und LSG, der gelösten Sedimentkonzentration bei LSG, der Isotopenzusammensetzung des Niederschlags (Mittelwerte) und an vier Quellen ples were –14.80 ‰ and 1.9 µScm^{-1}, respectively, whereas the average $\delta^{18}O$ and EC values of snowmelt samples were –15.81 ‰ and 61 µScm^{-1}, respectively. Therefore, we hypothesize that the main contribution to runoff for the July event came from snowmelt water. Conversely, during the runoff event occurred on August 10–11 (data not shown here) the less negative $\delta^{18}O$ values in stream water (up to –14.80 ‰) would suggest a significant contribution by glacier melt. However, the isotopic pattern in the stream on August 10–11 was not consistent with the one on July 12–13, highlighting the need of further analyses to better discriminate the role of glacier and snow meltwater at the runoff event scale. During the July event, the spring at USG did not exhibit significant variations in EC but showed a lagged isotopic depletion, likely due to a delayed snowmelt contribution through subsurface flow. Isotopic values at LSG did not present a clear pattern, probably due to the contribution of groundwater-fed tributaries draining small lateral subcatchments without snow cover. However, the influence of the glacier and/or snowmelt appeared to be relevant in terms of suspended sediment transport at LSG, which followed the streamflow pattern and reached values up to 2.8 gl^{-1}.

4 Conclusions

Preliminary water discharge, tracer and turbidity data acquired from April to October 2011 in streams and springs in the glacierized Saldur catchment (Northern Italy) revealed the strong influence of glacier and snow on runoff and suspended sediment transport dynamics. The highest values of turbidity and the lowest δ^2H, $\delta^{18}O$ and EC data were associated to intense glacier melt-induced runoff events, very close to bankfull conditions, occurring during warm summer days. Tracer data also allowed to assess the role of snowmelt and precipitation on groundwater recharge and to evaluate the water sources for the main stream and the lateral tributaries. Next field activities and further anal-

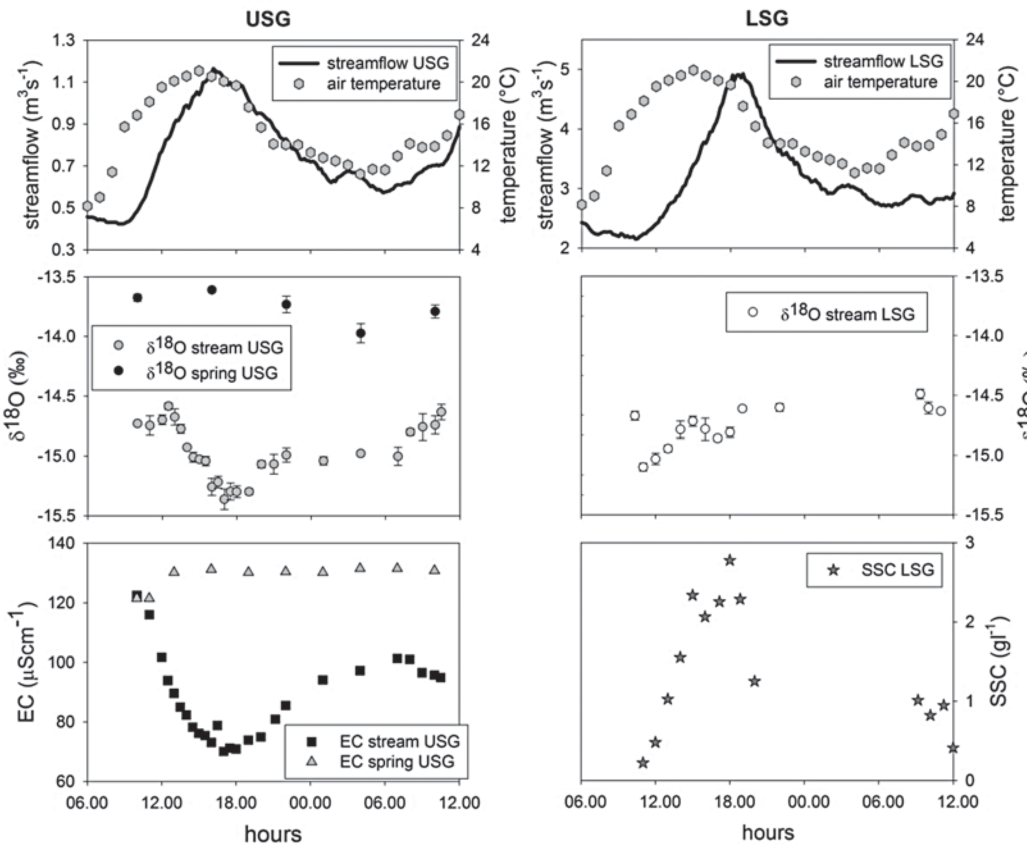

Figure 4: Time series of streamflow, $\delta^{18}O$ and EC composition of stream and groundwater and suspended sediment concentration (SSC) for the runoff event on July 12–13. Left panel: USG; right panel: LSG

Abbildung 4: Zeitreihendarstellung des Abflusses, der $\delta^{18}O$- und EC-Werte von Fluss- und Grundwasser sowie der gelösten Sedimentkonzentration (SSC) des Abflussereignisses vom12.–13.Juli. Links: USG; rechts: LSG yses will be performed, coupling experimental results with hydrological and end-member mixing models and remote sensing data, in order to better distinguish the role of glacier melt and snowmelt at the seasonal and flood event scale.

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Address of authors

D. Penna, Department of Land, Environments, Agriculture and Forestry, University of Padova, viale dell'Università 16, 35020 Legnaro (PD), Italy, and Faculty of Science and Technology, Free University of Bozen-Bolzano, piazza Università 1, 39100, Bolzano, Italy daniele.penna@unipd.it

L. Mao, Department of Ecosystems and Environment, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Casilla 306-22, Santiago, Chile.

F. Comiti and A. Dell'Agnese, Faculty of Science and Technology, Free University of Bozen-Bolzano, piazza Università 1, 39100, Bolzano, Italy.

M. Engel and G. Bertoldi, Institute for Alpine Environments, EURAC, via Esperanto 3, Bozen-Bolzano, Italy.