ORIGIN OF SURFACE AND SUBSURFACE WATERS IN A PERIGLACIAL CATCHMENT ANALYSED BY MEANS OF ENVIRONMENTAL TRACERS

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INTRODUCTION AND OBJECTIVES

The hydrological response of high elevation catchments is strongly influenced by snowmelt processes. Moreover, in alpine periglacial environments, the presence of permafrost (generally discontinuous and frequently associated to landforms such as rock glaciers) makes even more difficult to identify the origin of surface and subsurface waters and the main contributors to stream runoff. Based on the use of isotopic (deuterium and 18-oxygen), electrical conductivity (EC) and water temperature data, this study aims to:

1. Identify the environmental tracer(s) that could be used as best indicator(s) of the possible influence of permafrost on groundwater and stream water.
2. Investigate the role of snowmelt and rainfall on seasonal runoff response in a periglacial catchment.

STUDY AREA AND METHODOLOGY

Field surveys were carried out during summer and early autumn of 2010 and 2011 in the Upper Val de La Mare basin (36 km^2, Ortles-Cevedale massif, Eastern Italian Alps, Fig. 1). In 2010, grab samples were taken from 54 springs in the entire area in order to capture the spatial variability of the tracer composition of groundwater (Fig. 2a, Table 1). In 2011, the analysis focused on the temporal variability of groundwater by sampling two springs (one of these flowing from a rock glacier, SPR-44) and a small stream in the 0.8 km^2 Noce Nero subcatchment (Fig. 2b, Table 2). Precipitation, air temperature and stream water stage were recorded continuously. The isotopic content of water samples was determined by laser absorption spectroscopy (Penna et al., 2010). Water temperature and electrical conductivity were measured in the field by a portable conductivity meter.

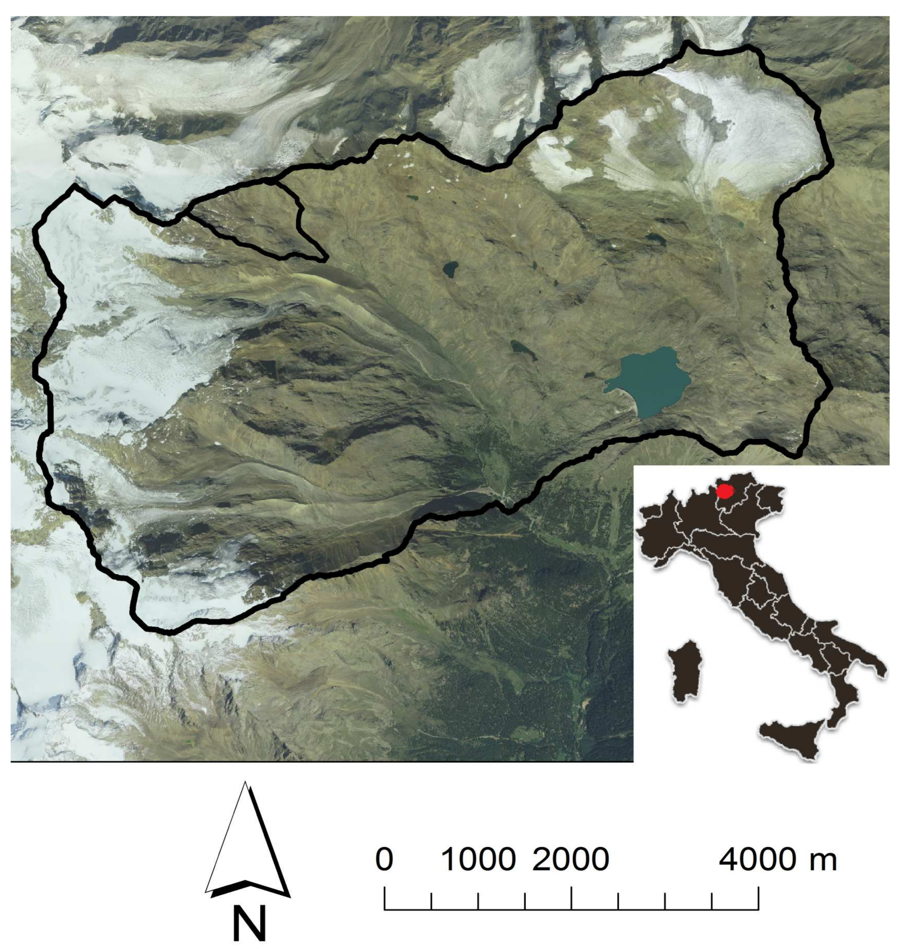

Fig. 1. Val de La Mare catchment.

2010	No RG	RG
30 July	9	4
19 August	13	3
20 August	7	6
22 August	1	1
26 August	2	0
10 September	2	2
11 September	3	1

Table 1. Number of samples collected from springs in 2010.

No RG = springs not emerging at the front of rock glaciers; RG = springs emerging at the front of rock glaciers.

2011	Stream	SPR-44	SPR-a
26 June	17	0	0
13 July	14	6	2
29 July	12	3	11
19 August	8	4	8
6 September	8	4	8
4 October	4	4	4

Table 2. Number of samples collected in 2011 from Noce Nero catchment at the stream gauge, SPR-44 (a spring emerging at the front of a rock glacier) and SPR-a (a spring not emerging at the front of a rock glacier).

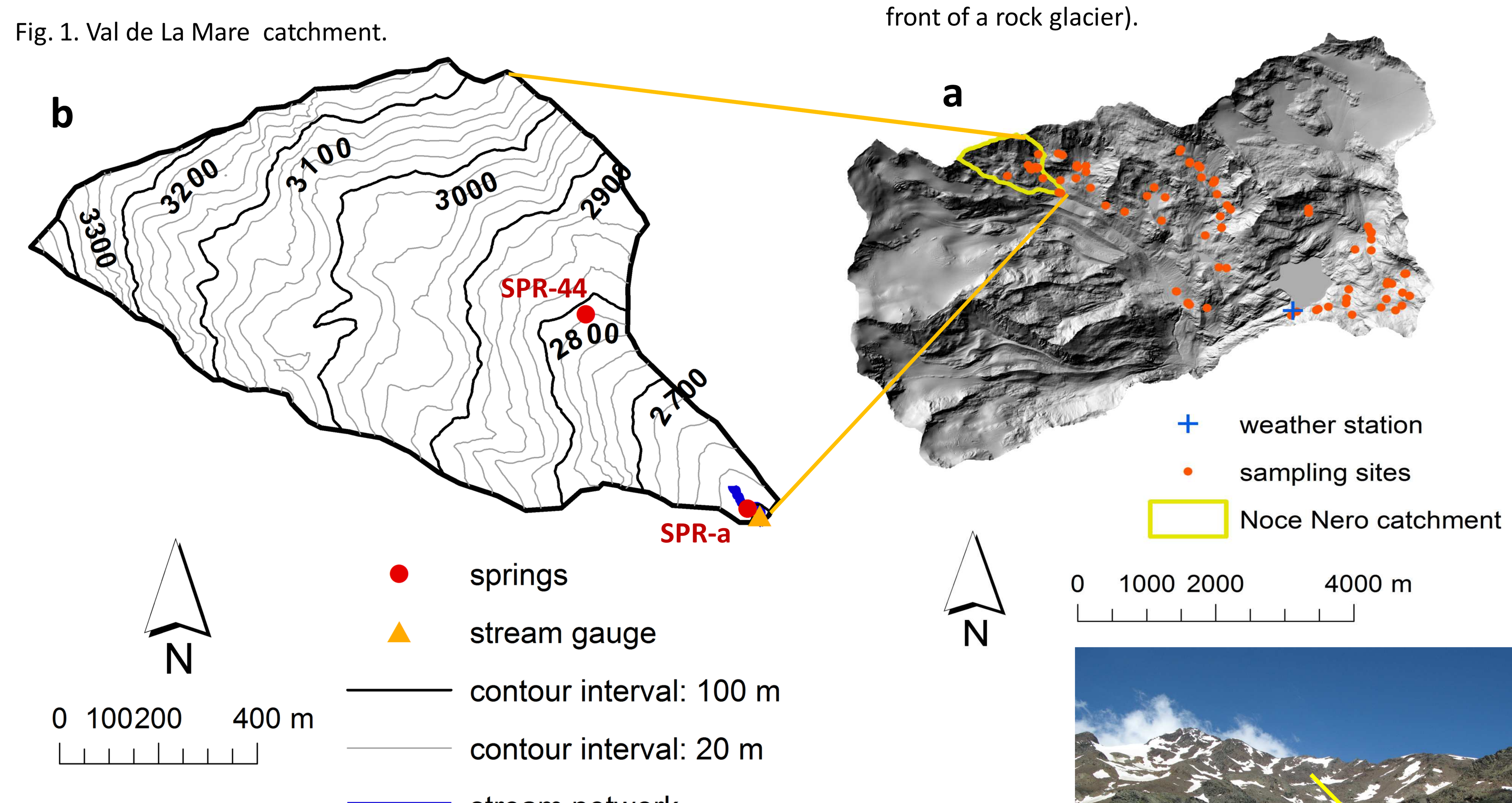

Fig. 2. Map of Val de La Mare catchment (a) with the location of sampling sites and map of Noce Nero subcatchment (b). In additon to springs, samples from lakes, small streams, snow patches and ephemeral spring were also collected (results not reported here) .

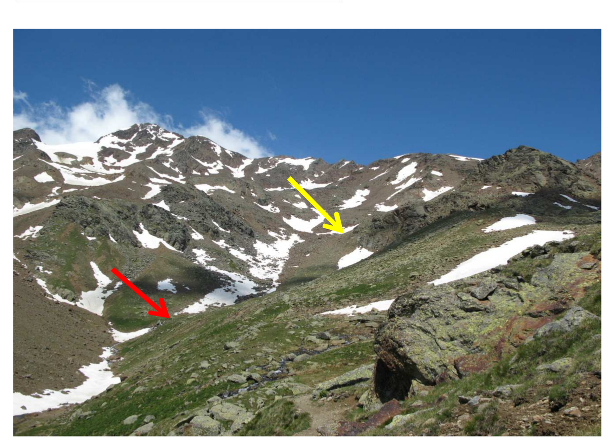

Fig. 3. Noce Nero catchment. The red arrow refers to stream gauge and SPR-a, the yellow arrow to SPR-44.

1. WATER TEMPERATURE AS INDICATOR OF THE POSSIBLE INFLUENCE OF PERMAFROST

Analysis of data collected in 2010 in the entire study area shows that water temperature of springs emerging at the front of rock glaciers is statistically lower than water temperature of other springs (Fig. 4a and Table 3), revealing the influence of permafrost on temperature, and possibly, origin of groundwater in these areas. This also suggests that water temperature can be used as an effective indicator of permafrost-related springs. On the contrary, electrical conductivity and the isotopic composition of spring water do not yield significant information about the origin from different water sources (Fig. 4b,c,d and Table 3), likely due to the effect of other interacting processes (lithology for electrical conductivity, evaporation and mixing with other waters for the isotopic content).

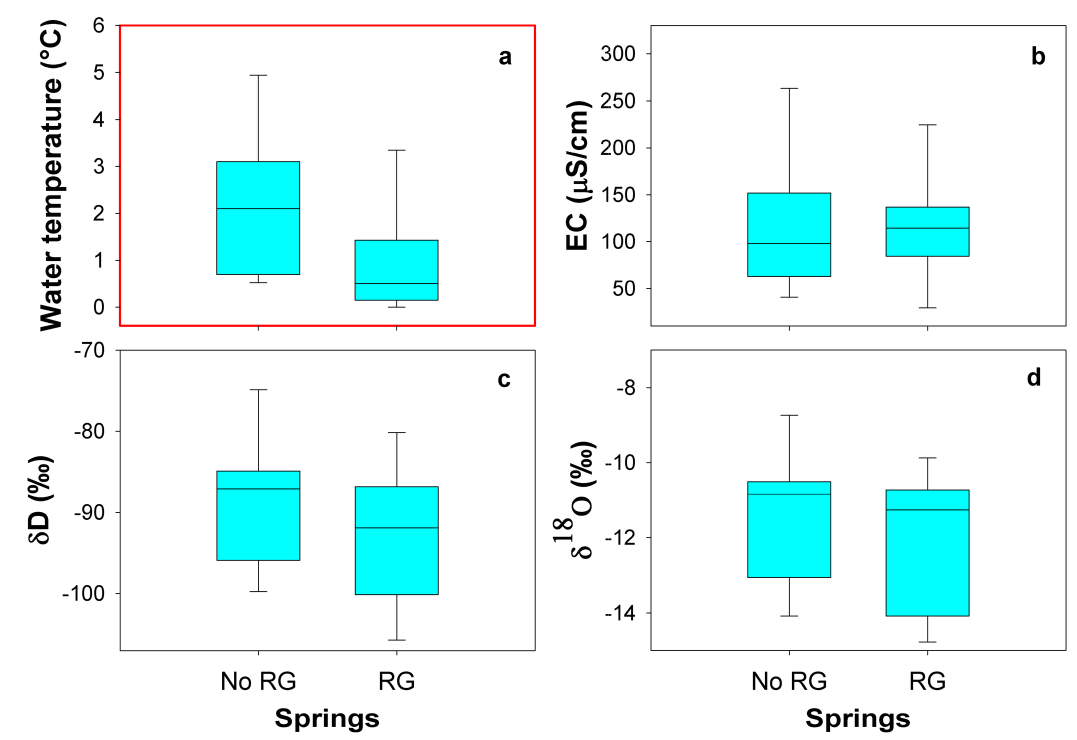

Fig. 4. Boxplots of water temperature (a), EC (b) and isotopic composition (c and d) of the springs sampled between 30 July and 26 August 2010. The boxes indicate the 25th and 75th percentile, the whiskers indicate the 10th and 90th percentile, the horizontal line within the box marks the median.

	Mann-Whitney U test (p-value)
Water temperature	0.00
EC	0.74
δD	0.07
δ18O	0.12

Table 3. Results of the Mann-Whitney U test for each environmental tracer to assess whether the two groups (No RG springs and RG springs) come from the same population. Groups significantly different (p-value<0.05) are highlighted in red.

CONCLUDING REMARKS

Temperature, EC and stable isotopic data from stream and spring water in Val de La Mare catchment show that:

1. Temperature is the most reliable indicator of permafrost-related spring waters.
2. Snowmelt noticeably influences the runoff response and the groundwater tracer composition at the seasonal scale.
3. Different potential groundwater sources exist, even at the small catchment scale.

2. SNOWMELT AND RAINFALL AS THE DOMINANT CONTROLS ON SEASONAL RUNOFF RESPONSE

At the seasonal scale (from June to October), the stream discharge in the Noce Nero catchment tends to decrease (Fig. 5). At the same time, stream water and groundwater become more conductive and enriched in heavy isotopes (Figs. 6 and 7), reflecting the decreasing contribution of snowmelt (Krainer et al., 2007). In addition, stable isotopes point out that stream water samples collected in June and mid-July are statistically similar (Table 4) likely due to the snowmelt contribution. They are also statistically different from samples collected later in the season (Table 4), less influenced by snow. Once the snowmelt contribution drops, the runoff response appears to be mainly dependent on rainfall events. This is particularly evident for the rainfall event occurred on 5-6 Sept. 2011 that led to a decrease of electrical conductivity and to a marked isotopic enrichment of stream water (red circle in Figs. 6 and 7).

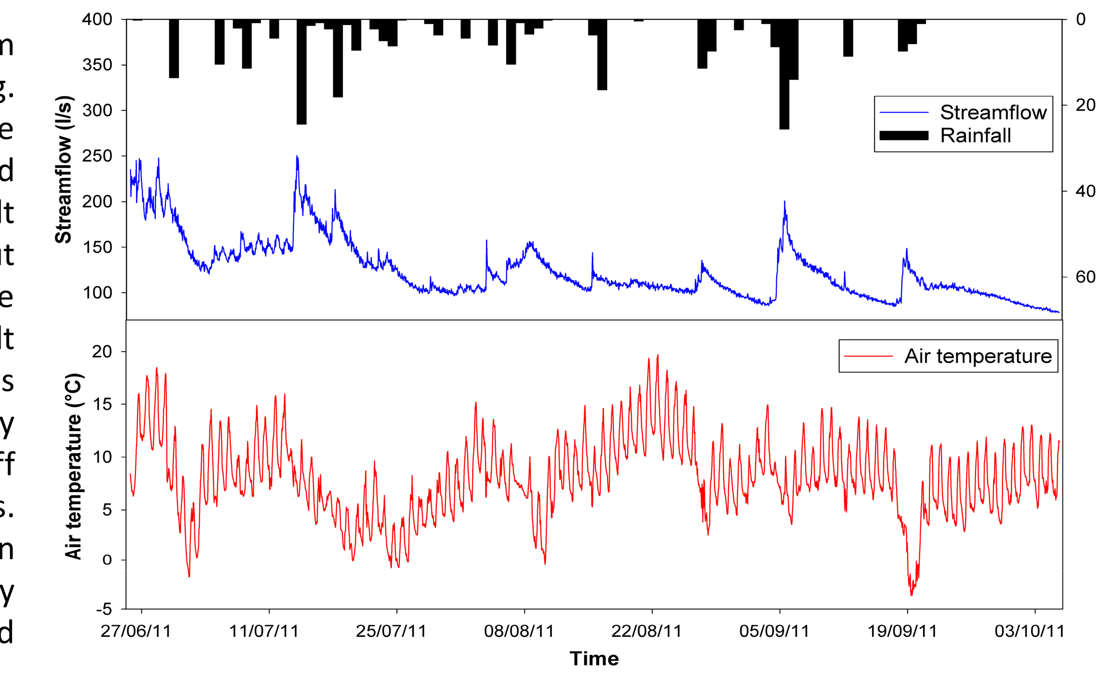

Fig. 5. Time series of rainfall, air temperature and Noce Nero streamflow.

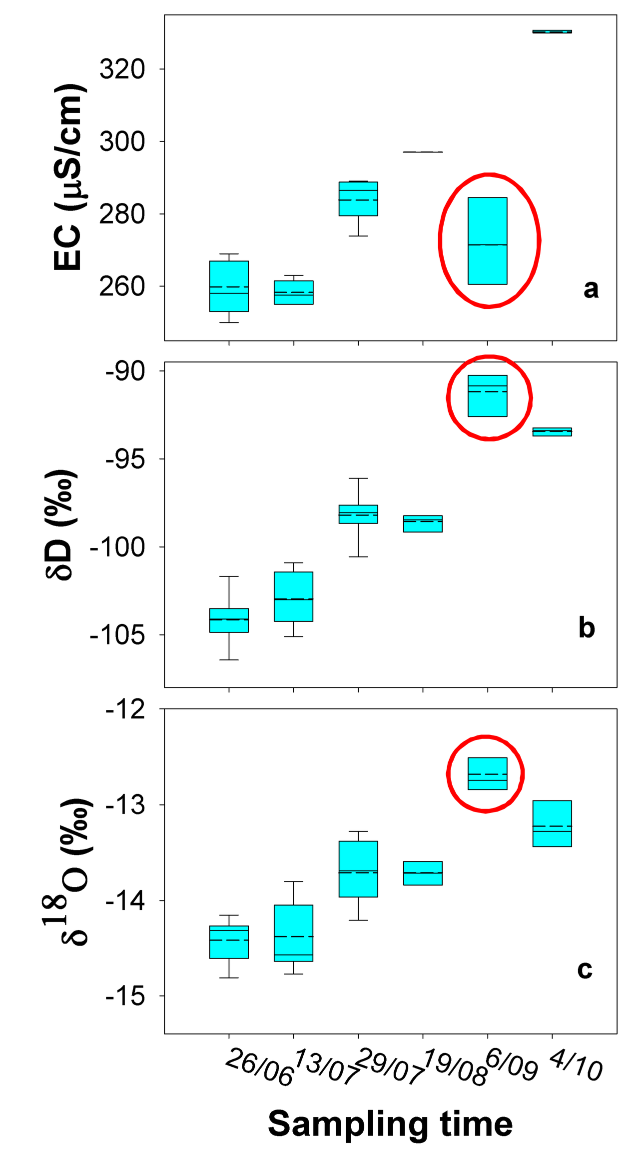

Fig. 6. Boxplots of EC (a) and isotopic composition (b and c) of streamflow samples collected in 2011 at Noce Nero stream gauge. The boxes indicate the 25th and 75th percentile, the whiskers indicate the 10th and 90th percentile, the horizontal line within the box marks the median and the dash line marks the mean.

	26 Jun.	13 Jul.	29 Jul.	19 Aug.	6 Sep.	4 Oct.
26 Jun.						
13 Jul.						
29 Jul.						
19 Aug.						
6 Sep.						
4 Oct.						

Table 4. Results of the multiple comparison test for the isotopic composition (δD and δ18O) of stream water associated to Kruskal-Wallis test. Pairs significantly different (p-value<0.05) are highlighted in red.

SPR-44, located at the front of a rock glacier, is characterized by temperature constantly around 0.6-0.7°C, an indication that, within the rock glacier, the water flows in direct contact with ice (Krainer and Mostler, 2002; Berger et al., 2004). The three tracers used here reveal a high degree of similarity between SPR-44 and stream water (Fig. 7), suggesting the same origin. However, we lack robust experimental evidence (e.g., isotopic analysis of direct permafrost melt) to assess the permafrost contribution to stream runoff. SPR-a, not related to permafrost landforms and always showing temperatures greater than 3°C, is characterized by a different tracer signature (less conductive and isotopically more depleted, especially evident from mid-summer, when most of snow has disappeared from the catchment, Fig. 7). This reveals the possible co-existence of different groundwater sources in the same area.

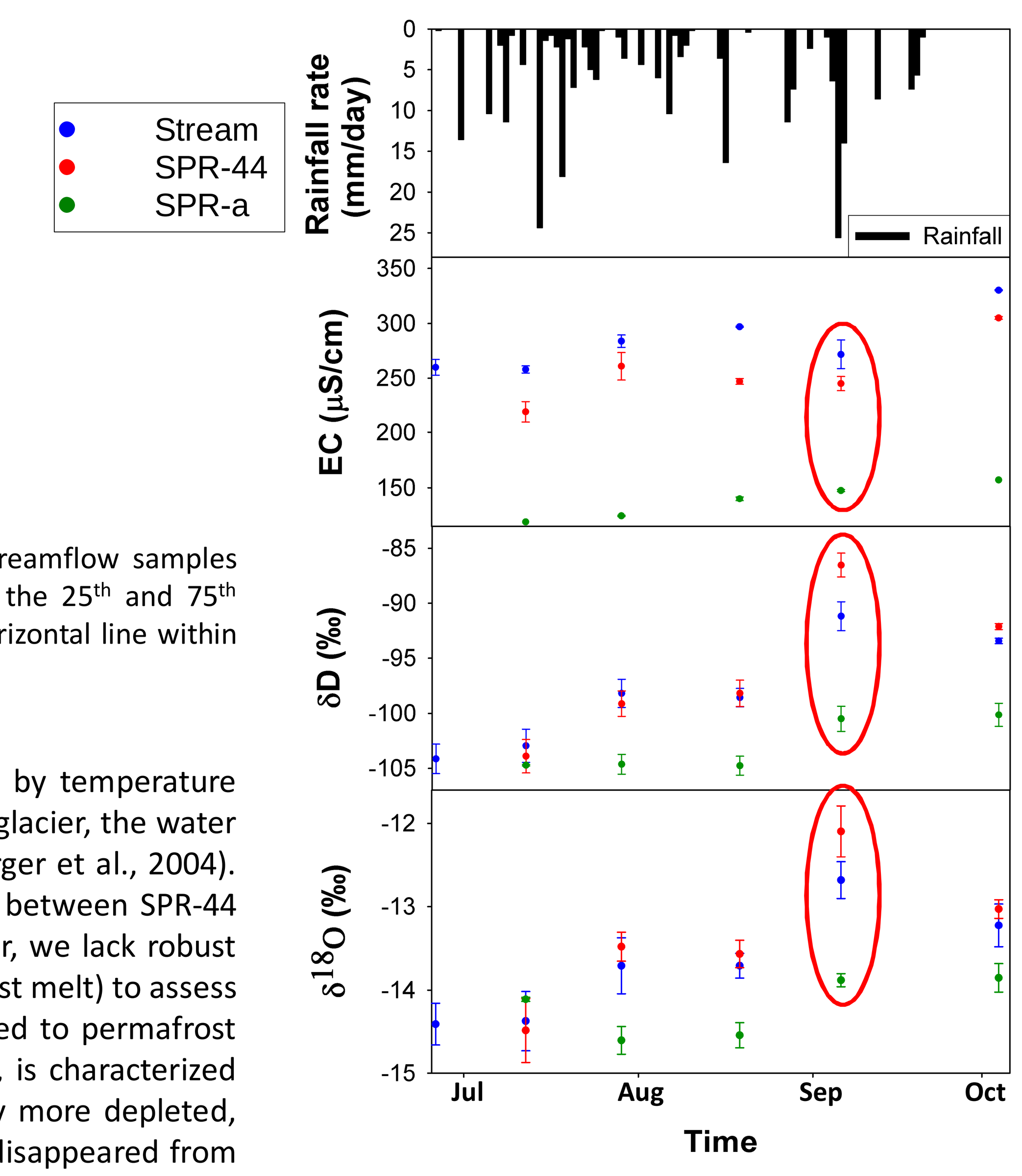

Fig. 7. Daily-averaged values of EC and isotopic composition of stream, SPR-44 and SPR-a sampled in 2011. Error bars represent the standard deviation.

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