Spatial Variability of Precipitation and Hydrological Response of a Mountain Catchment

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Räumliche Niederschlagsvariabilität und Abflussreaktion eines alpinen Einzugsgebiets

Introduction

Mountains are important sources of water for the downstream areas. Complex topography affects the variability of many processes which influence the hydrological (runoff) response of mountain catchments. Our previous analyses of the rainfall-runoff events in the Jalovecký creek catchment representing the highest part of the Carpathian Mountains revealed fast runoff response to precipitation (Kostka, 2009). Some events indicated that catchment runoff may be caused by rainfall which occurred only in part of the catchment (Kostka & Holko, 2003). We have established an extended network of rain gauges and stream water level recorders in the warm period of years 2013 and 2014 to study the contribution of subcatchments to the integrated catchment response measured at its outlet. The objectives of this article are to study:

- spatial distribution of precipitation (altitude gradients at various time scales);
- possibility of the overland flow generation;

Zusammenfassung

In einem Einzugsgebiet der West-Karpaten (Jalovecky Creek) wurden für trockene (2013) und feuchte Bedingungen (2014) die Variabilität des Niederschlags und der Abflussbeitrag zweier Teileinzugsgebiete untersucht. Das Einzugsgebiet ist typisch für die hochgelegenen Bereiche der Karpaten. Anhand von 13 Niederschlagsstationen, die zwischen 570 und 1900 m. Sh. lagen, wurde gezeigt, dass die Seehöhe alleine kein geeigneter Indikator für die Niederschlagshöhe ist. Die hydraulische Leitfähigkeit des Bodens war zumeist höher als die gemessene Niederschlagsintensität. Vergleichende Messungen der elektrischen Leitfähigkeit, der Isotopenkonzentration und des gelösten Siliziums an den Teileinzugsgebieten zeigten, dass der Gesamtabfluss stärker vom linken Teileinzugsgebiet dominiert wird, d. h. es lieferte 60 % des Gesamtabflusses.

Schlagwörter: Höhengradient des Niederschlags, Abflussreaktion alpiner Einzugsgebiete.

Summary

Spatial variability of rainfall and contribution of two main subcatchments to catchment runoff in the mountain catchment of the Jalovecký creek (the Western Carpathians) were studied in June–September 2013 (dry summer) and 2014 (wet summer). The catchment is representative for the highest part of the Carpathian Mountains. Thirteen rain gauges located at altitudes 570–1900 m a.s.l. showed that altitude was often not a very good descriptor of precipitation at a particular site. Precipitation causing runoff response at catchment outlet which hit only part of the catchment was not observed. Hydraulic conductivity of the soil surface was in most cases higher than rainfall intensity. Electrical conductivity, stable isotopes and dissolved silica along with discharge and water table data revealed that the stream water at catchment outlet is more similar to the water coming from the left subcatchment. Contribution of that subcatchment to total runoff measured at catchment outlet is about 60 %.

Key words: Altitude gradients of precipitation, mountains, catchment response.

- runoff response and contribution of the two main subcatchments including the frequency of rainfall events that hit only part of the catchment and caused runoff response at catchment outlet.

Study area, data and methods

The study was performed in the Jalovecký creek catchment, northern Slovakia (area 22 km^2, mean altitude 1500 m a.s.l., altitude range 820–2178 m a.s.l., mean slope 30 °) in the warm period of the years 2013 and 2014 (June to September). Precipitation was measured at 13 sites. Twelve of them were in the mountains at altitudes 820–1875 m a.s.l.. One gauge was outside mountains at altitude 570 m a.s.l. (Fig. 1). Three of the gauges were installed at the same site in the forest (site 4 in Fig. 1) to assess the small-scale variability of precipitation in the forest. Regarding construction, 11 gauges were tipping bucket (orifice at height 50 cm), 2 were weighting (orifice 1 m above terrain). Most of the gauges were located at sites protected against wind to minimize the wind-induced errors. The time step of the measurements was 10 minutes. Stream water levels were measured at the same time steps at catchment outlet (820 m a.s.l.) and at the outlets of its two main subcatchments (1050 m a.s.l.). The two main subcatchments have similar area, mean altitude, slope and vegetation. The Jalovecký creek itself comes from the left one (site 3 in Fig. 1).

Altitude gradients of precipitation were analysed for several time steps (seasonal, monthly, daily, hourly, 10-minute data). The altitude gradient was considered good when the correlation coefficient between precipitation and altitude was at least 0.6.

10-minutes rainfall intensities were compared with hydraulic conductivities of the soil surface reported by Dóša et al. (2012) to assess the frequency of possible saturated excess overland flow generation. Dóša et al. (2012) measured hydraulic conductivity of soil surface at 17 locations by the minidisc infiltrometer. The locations were distributed along the main valleys and surrounding slopes. Seven measurements were done at each location. We assumed that saturated excess overland flow was not generated if the rainfall intensity was smaller than hydraulic conductivity of soil surface.

Electrical conductivity of water, dissolved silica and stable isotopes (^{18}O and deuterium) were measured once per month at all water level gauges in 2014. They supplemented regular sampling for stable isotopes conducted at catchment outlet only (weekly samples in 2013 and daily samples in 2014). Electrical conductivity, chemical and isotopic composition of water together with discharge/water level measurements were used to infer the role of each subcatchment in contribution to the runoff observed at catchment outlet.

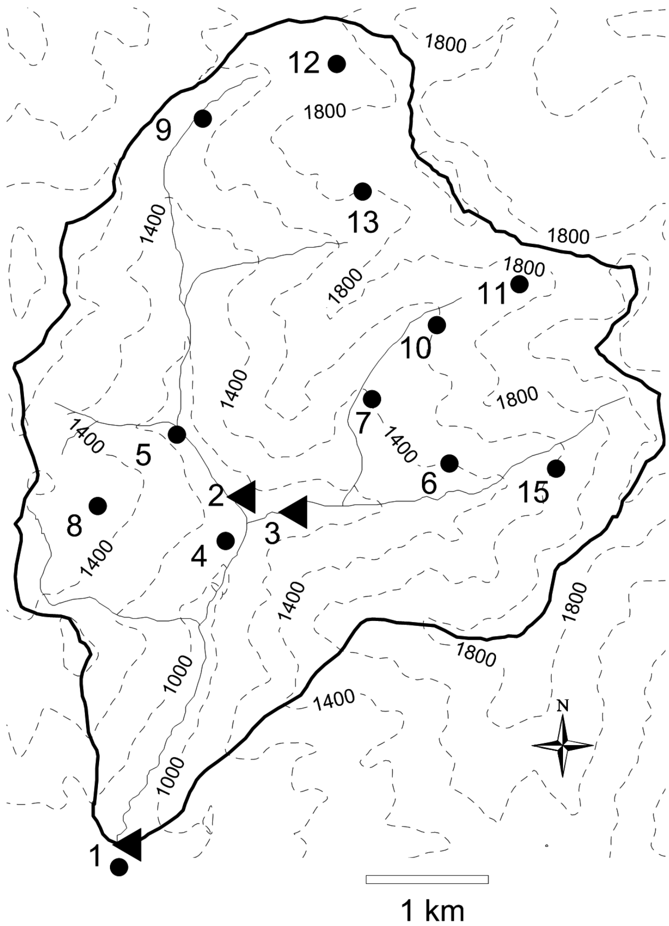

Figure 1: Location of rain gauges (circles) and water level recorders (triangles) in the Jalovecký creek catchment; the rain gauge at the altitude 570 m a.s.l. is located about 8.5 km downstream the catchment outlet; the air masses bringing the precipitation generally come from the west/north-west

Abbildung 1: Lage der Niederschlags- (Kreise) und Pegelstationen (Dreiecke) im Jalovecky Creek Einzugsgebiet. Die Niederschlagsstation auf 570 m Sh. liegt 8.5 km flussab vom Gebietsauslass. Die niederschlagswirksamen Wetterfronten kommen aus west- bis nord-westlicher Richtung

Results and discussion

Total seasonal precipitation in June- September 2013 was almost 40 % smaller than in the same period of 2014. Correlation coefficients between altitude and seasonal precipitation were rather high (0.76 for 2013 and 0.83 for 2014), but precipitation at the same altitudes was often very different. For example, in 2013 we recorded 515 and 637 mm at two sites located at 1500 m a.s.l. or 416 and 665 mm at 1775 m a.s.l. (windward-leeward sites). The differences between three gauges located at the same site in the forest were almost as high as the differences between the gauges located at different elevations in the whole catchment. Significant influence of the local topography was observed for sites 11 and 15 (shading effects of the nearby mountain ridges) and site 5 (wind-blown precipitation through the narrow valley causing higher precipitation amounts).

Fig. 2 shows that the biggest differences between the two years occurred in July and August which were unusually dry in 2013 and rather wet in 2014. Altitude gradients of monthly precipitation were generally better in the drier months. Location of the gauge in the wetter months (e.g. local topography causing shading or enhanced precipitation) was more important than its altitude.

The numbers of rainy days in 2013 and 2014 were 74 and 102, respectively (out of 122 days in period 1st June – 30th September). Good altitude gradients (as defined in methodology) of daily precipitation were observed for only 19 days in 2012 and 17 days in 2014. It means that altitude was a good descriptor of local precipitation for only about 17–25 % of all rainy days. Days with higher amounts of precipitation had higher altitude gradients. However, this relationship had a threshold. The trend was visible only in days when the mean daily catchment precipitation calculated as an average of data measured in mountains (i.e. gauges at altitudes 820 m a.s.l. and above) at was up to about 4–5 mm. No relationship was visible for the wetter days (Fig. 3).

Maximum intensities of the 10-minute and hourly rainfalls and maximum daily precipitation at different altitudes are shown in Fig. 4. The altitude gradient at these time scales was not manifested. While maximum daily precipitation in the two studied years was comparable, maximum 10-minute and hourly precipitation in 2014 (observed on

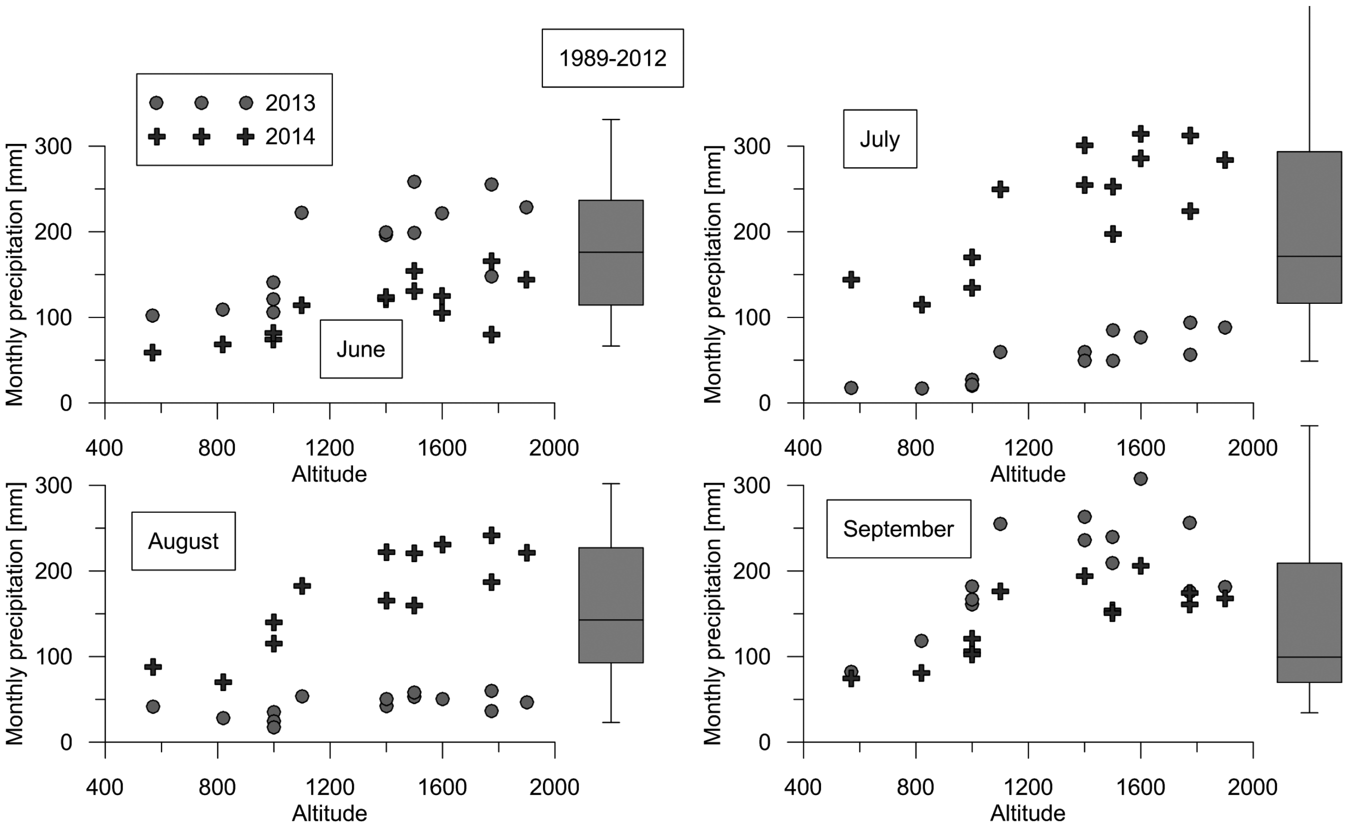

Figure 2: Monthly precipitation in 2013 (circles) and 2014 (crosses) at different altitudes; the box plots show the ranges of precipitation in the particular month in period 1989–2012 (maximum, upper quartile, median, lower quartile, minimum)

Abbildung 2: Monatlicher Niederschlag von 2013 (Kreise) und 2014 (Kreuze) in verschiedener Seehöhe. Die Box Plots zeigen die Schwankungsbreite des Niederschlags im Zeitraum 1989–2012 (Maximum, obere Quartile, Median, untere Quartile, Minimum)

11 August and 21 July, respectively) were much higher than in 2013. Very intensive rainfall hit the higher part of the catchment on the two days. Intensities at altitudes below 1000 m a.l. were much smaller. Rains with similarly high intensities were reported in the studied mountains as extraordinary (e.g. PACL, 1960).

Comparison of maximum 10-minute rainfall intensities with hydraulic conductivity of the soil surface showed that maximum rainfall intensities in 2013 were smaller than the first (lower) quartile of measured values of hydraulic conductivities. Rainfall intensities in 2014 were much higher than in 2013, but still, about one half of soil hydraulic conductivities were higher than the most intensive rainfall. These results suggest that saturated excess overland flow is not very frequent in the catchment.

Measured precipitation data revealed that significant rainfalls that hit only part of the catchment and caused runoff response at catchment outlet are probably rare in the studied

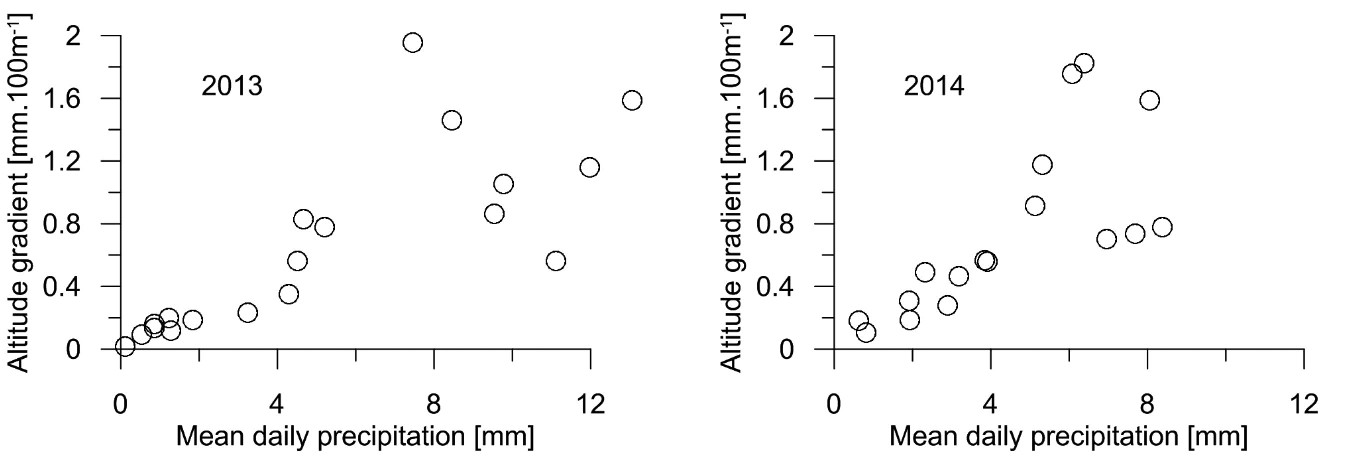

Figure 3: Relationship of altitude gradients of daily precipitation on days when correlation coefficient between precipitation and altitude was at least 0.6 and precipitation amount on that particular day (calculated as an average of readings of the gauges located in mountains)
Abbildung 3: Beziehung zwischen Höhengradient des Tagesniederschlags und der Niederschlagssumme

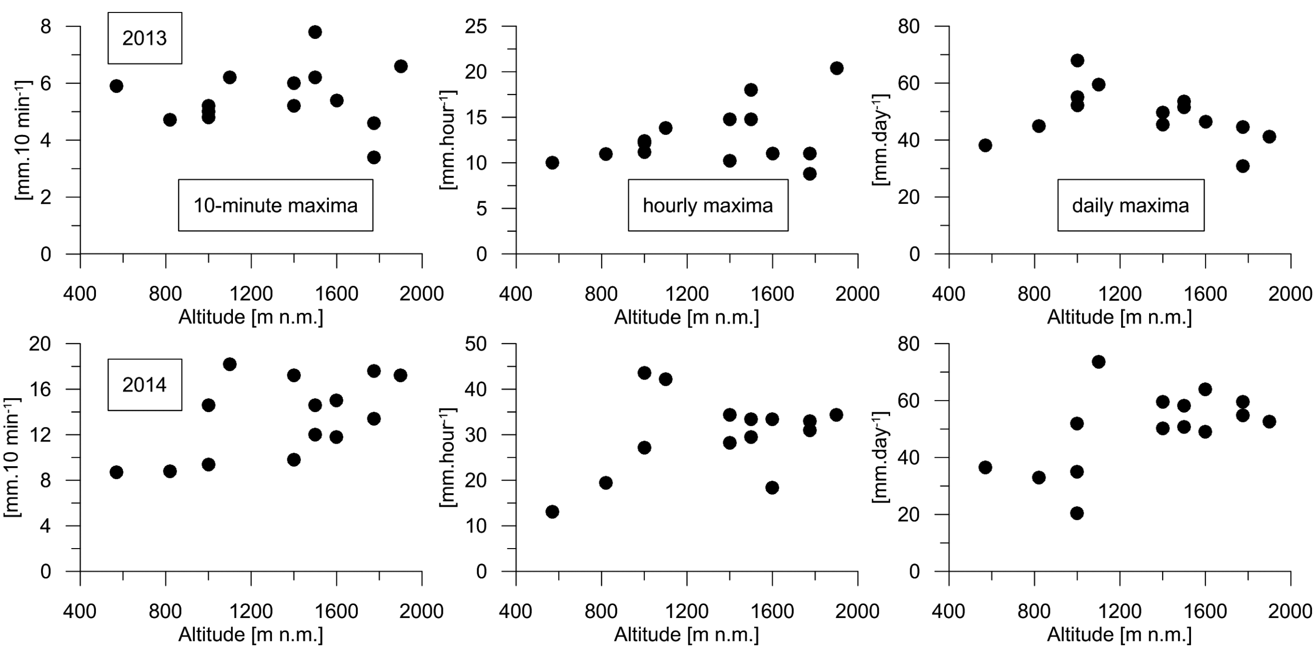

Figure 4: Maximum 10-minute, hourly and daily rainfalls at different altitudes in 2013 and 2014
Abbildung 4: Maximale Niederschlagshöhen verschiedener Dauerstufen (10 Minuten, 1 Stunde, 1 Tag) in unterschiedlichen Höhenlagen für die Jahre 2013 und 2014

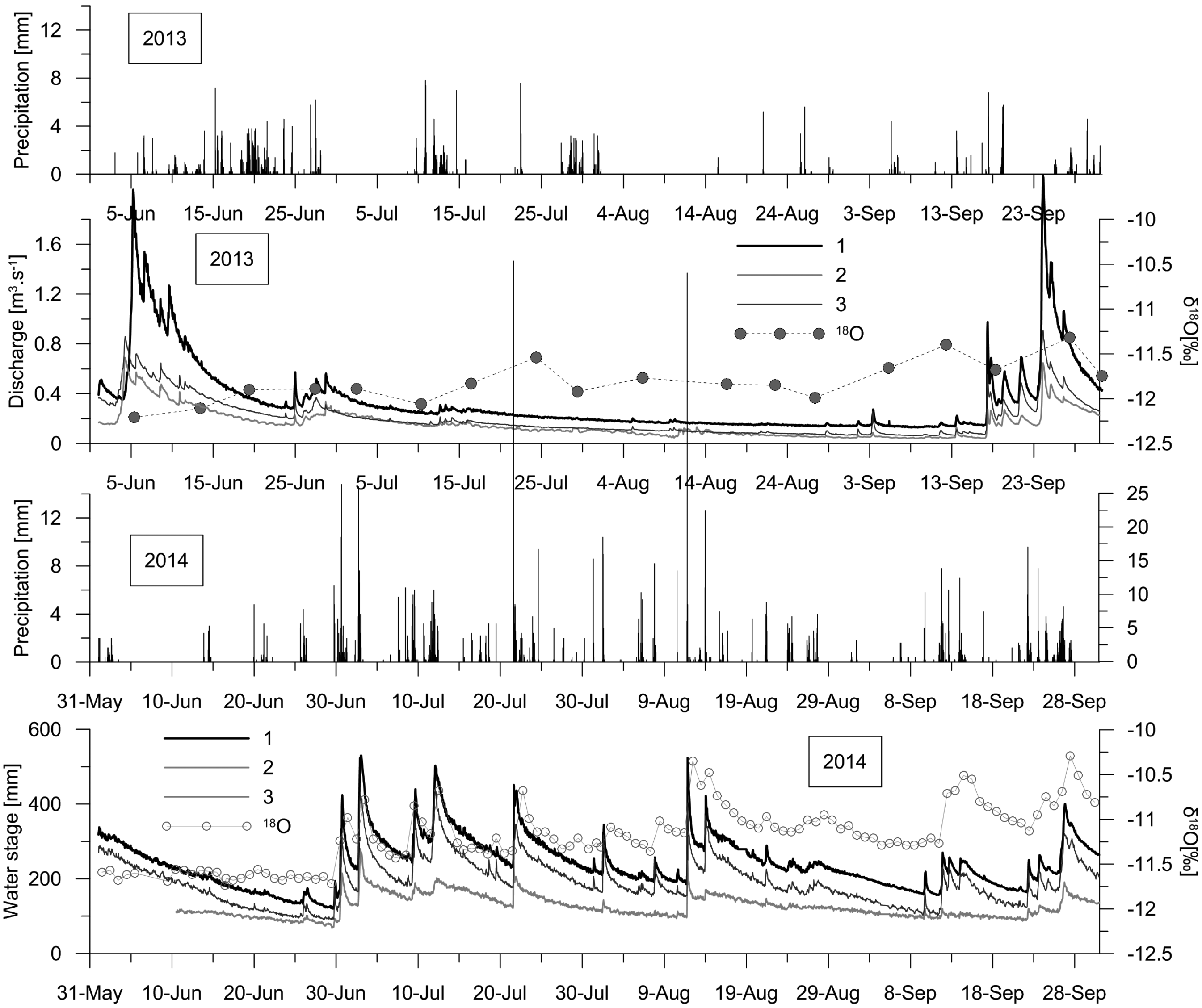

Figure 5: Hourly rainfall (site 7 in Fig. 1) and runoff in June-September 2013 and 2014; $\delta^{18}O$ of samples collected once per week (2013) and once per day (2014); water stage is shown in 2014 instead of discharge, because the profiles were changed by a big flood in May 2014 and the new rating curves were not yet constructed

Abbildung 5: Stündlicher Niederschlag und Abfluss (Standort 7 aus Abb. 1) von Juni bis September 2013 und 2014. δ18O wurde 2013 wöchentlich und 2014 täglich beprobt. Für 2014 sind die Wasserstände anstelle der Durchflüsse dargestellt (fehlender Pegelschlüssel aufgrund Hochwasser)

catchment. Despite size and topographic variability of the catchment the rainfall covers almost always all catchment area.

Variability of runoff at catchment outlet and in the two main tributaries is shown in Fig. 5. Only two larger events occurred in the dry year 2013 while there were many events in the wet year 2014. Isotopic data indicate that the influence of snowmelt season, i.e. isotopically lighter water is still visible in June. Frequent summer rainfalls in 2014 shifted the isotopic composition of the creek towards heavier values. Comparison of measured discharge, isotopic and chemical composition of water (Fig. 6) at sites 1–3 indicated that contribution of the right subcatchment to total catchment runoff was smaller than that of the left subcatchment. Comparison of discharges and application of the common two-component mixing formula with stable isotopes showed that on average 60 % of total catchment runoff comes from the left subcatchment and 40 % comes from

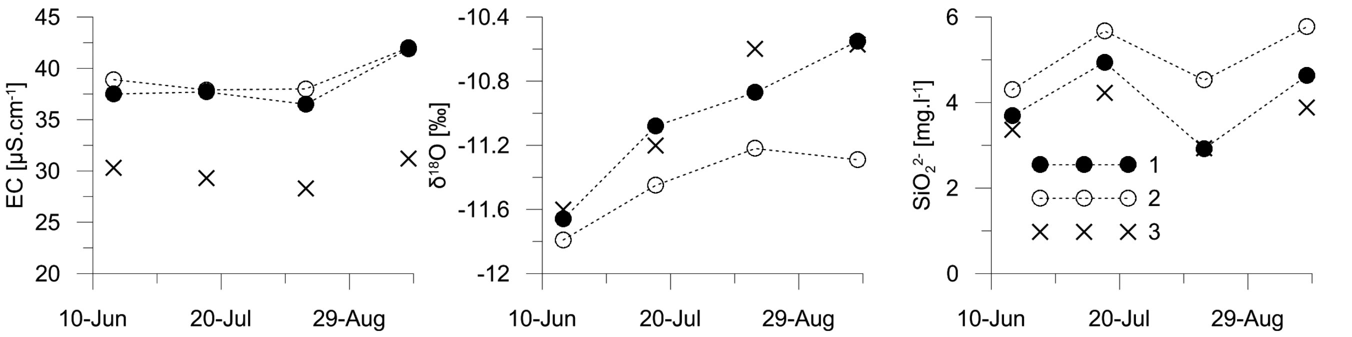

Figure 6: Electrical conductivity, $\delta^{18}O$ and dissolved silica in monthly samples collected in June to September 2014 at the stream gauges 1–3 shown in Fig. 1

Abbildung 6: Elektrische Leitfähigkeit, δ18O und gelöstes Silizium in monatlichen Proben von Juni bis September 2014 für die Messstationen 1 –3

the right one. More significant contribution of the part of the catchment downstream from sites 2 and 3 is restricted only to larger runoff events.

Higher concentrations of silica in the right subcatchment (Fig. 6) might indicate longer water residence. However, it should not be forgotten that although dissolved silica has been commonly used as a conservative tracer, its concentrations may be independent on the contact time of water with minerals (Asano et al., 2003). The information from the isotopes and water chemistry obtained in 2014 is in the agreement with the discharge measurements in 2013. Response of the right subcatchment in drier periods is smaller compared to the response of the left subcatchment (some runoff events are not visible). It might confirm the longer water storage indicated by silica. Extraordinary flood in May 2014 destroyed or moved all water level recorders except the one at site 3. Although the water level measurements were restored in a few weeks, the rating curves to obtain discharges from measured water levels could not have been constructed so quickly. Therefore, was not possible to compare the discharge data at different sections of the creek for 2014. However, the water level measurements confirmed the behaviour observed in 2013. Variability of water levels at catchment outlet was almost identical to the one at site 3 (outlet of the left tributary). Water levels at site 2 (the right subcatchment) again did not respond to small events. Isotopic composition of stream water at catchment outlet measured in 2014 responded to water level changes. Hydrograph separations using more detailed isotopic data measured every 6 hours will be presented in another paper.

Conclusions

The study showed that altitude gradients of precipitation which are often utilized in hydrological studies of mountain catchments are rarely good. Comparison of rainfall intensity with hydraulic conductivity of the soils indicated that saturated excess overland flow was not very frequent. Contribution of two main subcatchments to catchment runoff measured at its outlet was similar, but not equal. One subcatchment did not respond to small events which may indicate larger storage.

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