# Climate patterns in the long-term hydrometeorological data series of the Rietholzbach catchment

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## Hydro-meteorologische Zeitreihendaten des Testgebiets Rietholzbach

## Introduction

In 1975 measurements were initiated in the Rietholzbach catchment in Switzerland to determine and understand the water balance and related processes in this small, pre-alpine basin. Measurements were started with the installation of a grass covered, weighing lysimeter with a surface area of 3.14 $m^2$ and a depth of 2.5 m at the main measurement site "Büel" located almost in the centre of the catchment and the main gauge "Mosnang" at the outlet of the basin (operated by the Federal Office for the Environment, Hydrology Division, Bern, Switzerland). As a follow-up to several short-term projects, additional measurements were recently undertaken. The current dataset includes long-term data series of common hydrological and meteorological parameters such as air temperature, humidity, pressure, wind, radiation, precipitation and runoff, as well as groundwater, soil moisture, soil temperature, and water isotope data. The measurements continue and were enhanced in 2009 by eddy covariance measurements for momentum, sensible, latent, and $CO_2$ flux densities. In addition, the soil moisture observations have been intensified within the framework of the Swiss Soil Moisture EXperiment (SwissSMEX, http://www.iac.ethz.ch/url/SwissSMEX). Further information on the catchment can be found in Seneviratne et al. (submitted), and on the following web pages: http://www.iac.ethz.ch/url/rietholzbach and http://www. hydrodaten.admin.ch/d/2414.htm.

In this study long-term time series of precipitation, runoff, and air temperature are analysed to detect diurnal


### Zusammenfassung

In der vorgestellten Studie wurden Langzeitbeobachtungen am schweizerischen Rietholzbach analysiert. Außer bei der Temperatur (+0.09 K/a) wurde bei den Messgrößen Wind, Niederschlag, Evapotranspiration und Abfluss kein signifikanter linearer Trend festgestellt. Eine Analyse von Temperatur, Niederschlag und Abfluss mittels Wavelet Verfahren, welches die Erfassung des Einflusses von Schneeschmelze und Evapotranspiration ermöglicht, zeigte während der Sommermonate eine verdunstungsbedingte Abnahme des Abflusses bis zu 5%. Schneeschmelze erhöht den Abfluss während der Monate November bis Mai mit maximaler Erhöhung um ca. 8% im März. Für den Beobachtungszeitraum 1976 bis 2006 wurden für die Analyse hinreichend viele Ereignisse zur Dokumentation des Abflussbeitrages erfasst.


**Schlagwörter:** Rietholzbach, Klimaänderung, Wavelet Transformation.


### Summary

Long-term time series of the Swiss Rietholzbach catchment are analysed in this study. Except for temperature (+0.09 K/yr) no significant linear trend was found in wind, precipitation, evapotranspiration or discharge. A wavelet analysis of temperature, precipitation, and runoff, which allows snowmelt and evapotranspiration events to be identified, showed evapotranspiration events peak in August and contribute < 5% to the decrease in runoff during the summer months. Snowmelt events add to runoff from November to May, with the highest contribution in March (~8%). Overall, we find considerable variability in both the number of diurnal events and the contribution from these events to runoff in the catchment over the 1976–2006 period.


**Key words:** Pre-alpine catchment; climate trends; snowmelt; evapotranspiration; diurnal cycles.

cycles in streamflow and evapotranspiration and to examine the characteristics and the long-term trend of these events.

## Basin Characteristics

The watershed is situated in the north-eastern part of Switzerland in the basin of the Thur, a tributary of the Rhine. Its area is 3.31 km$^2$ and covers elevations ranging between 682 and 950 m a.s.l. A hydrological peculiarity is the congruence of surface and sub-surface catchment areas. Together with the pronounced topography, the parent rock types – mainly lime and dolomite coarse gravels – have produced a large variety of soil types. They can be summarized as a group of gley soils (42% of the area, mainly in the lower catchment parts) and a group of regosols and cambisols (58% of the area, mainly on the slopes). The basin is predominantly used as pasture land (73%) and about a quarter is covered by wooden vegetation (mostly coniferous forest). Despite artificial drainage systems mainly installed in the 1950s, a wetland without stagnant water exists next to the uppermost part of the creek. The area is only sparsely populated with single farmsteads. Since the beginning of the measurements no major interventions such as building activities or clear-cuts have occured. Consequently the land use has been almost constant over time and changing signals in the long-term data series can be clearly attributed to climate change.

## Mean climatology and hydrology

The Rietholzbach catchment site is characterized by a temperate humid climate with a clear seasonal cycle. Mean annual temperature is 7.1 °C with temperatures slightly below zero during winter and about 15 °C during summer. Precipitation shows highest values in late spring and summer with mean monthly values of > 140 mm and sums up to 1459 mm on a yearly average. Discharge is strongly related to precipitation input and shows higher values during winter and a peak in March due to snow melt. The discharge regime is pluvial and highly variable with a mean annual value of 106 l/s, corresponding to 1016 mm. Evapotranspiration derived from the lysimeter data shows highest monthly values (> 80 mm) from June to August, low values during winter months (< 10 mm), and sums up to 560 mm per year. Evapotranspiration and discharge show a complementary seasonal behaviour in conjunction with ample precipitation, indicating both the absence of severe long-term water shortages and evapotranspiration that is limited by radiation and not by water.

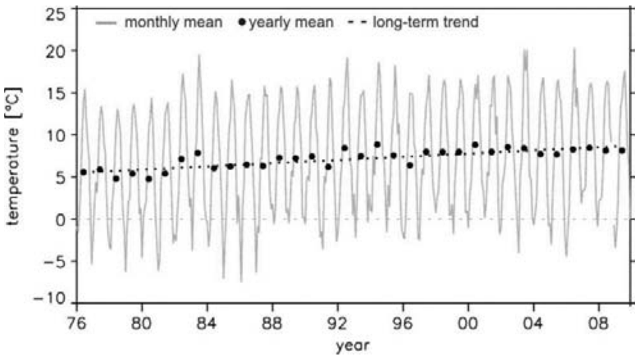


Figure 1: Mean monthly and yearly values as well as the long-term linear trend of 2 m air temperature at "Büel"
Abbildung 1: Monatsmittel, Jahresmittelwerte und linearer Trend der Lufttemperatur (2 m) am Standort "Büel"

Linear analysis of the long-term data series of temperature, wind, precipitation, evapotranspiration and discharge showed no significant trends except for temperature. Measurements over the 1976–2009 period show a temperature increase of 0.9 K per decade (Figure 1) which is consistent with other studies of temperature trends in Switzerland (OcCC, 2007).

## Wavelet statistics to identify diurnal cycles

In unregulated rivers, characteristic 24-h diurnal cycles in streamflow occur due to daily variations in solar radiation that ultimately regulate water fluxes (Lundquist and Cayan, 2002). Several processes are responsible for the signature of diurnal cycles in streamflow including evapotranspiration and infiltration of the streambed (decrease runoff) and processes that increase runoff (i.e. precipitation and snowmelt). The characteristics of diurnal events (amplitude, shape, and timing) are influenced by catchments features, including topography, soils, vegetation, snowpack and meteorology. As diurnal events differ between wet and dry years, an analysis of the variability of these cycles over longer periods could provide an insight into dominant-catchment processes, catchment responses to drought/wet periods and how these responses might have changed over time.

Using wavelet analysis, a spectral analysis technique that allows us to expand a time series into the frequency-time domain, we can identify diurnal (24-hr) cycles in time series of runoff, precipitation and temperature in order to better understand snowmelt and evapotranspiration events for the Rietholzbach catchment. Unlike other spectral techniques including using the Fourier transform, wavelet analysis allows us to keep information about when certain events occur in the time domain, allowing specific diurnal events to be identified and studied in-depth. The wavelet analysis was performed for the time period 1976 to 2006. As an example the year 2004 with a snowy winter is discussed in more detail. Figure 2 shows the raw time series (6-hourly) of precipitation, runoff and temperature for 2004 and one can imagine the difficulty in identifying these cycles in this raw dataset. The continuous wavelet power spectrum is shown in Figure 3 (top) for the individual time series. The Morlet wavelet was used since it is the preferred wavelet for extracting features and provides a good balance between frequency and time localization (GRINSTEAD et al., 2004). The wavelet power spectrum for precipitation shows strong variability at all scales (period in hours), most notably in May and June for 2004, which also corresponds to a strong variability in runoff. Diurnal variability for temperature is significant (above the 5% significance level, shown as black contour) for most of the year and strongest from March to September. The cone of influence is also shown, indicated with a lighter shade outside, as edge effects might distort the power spectrum since the wavelet is not completely localized in time.

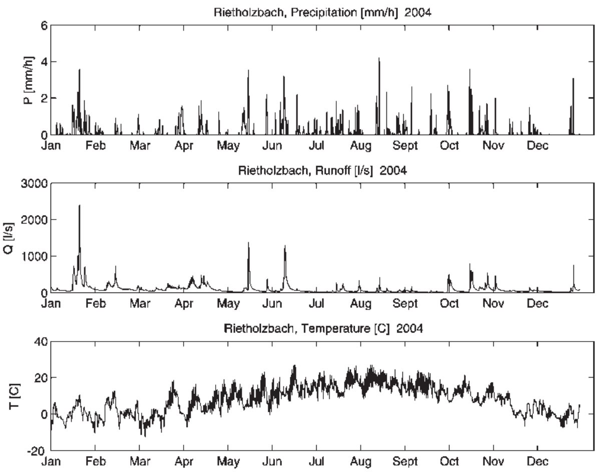


Figure 2: Hourly time series of precipitation (P), runoff (Q) and temperature (T) for 2004

Abbildung 2: Stundenwerte des Niederschlags (P), des Abflusses (Q) und der Lufttemperatur (T) für das Jahr 2004

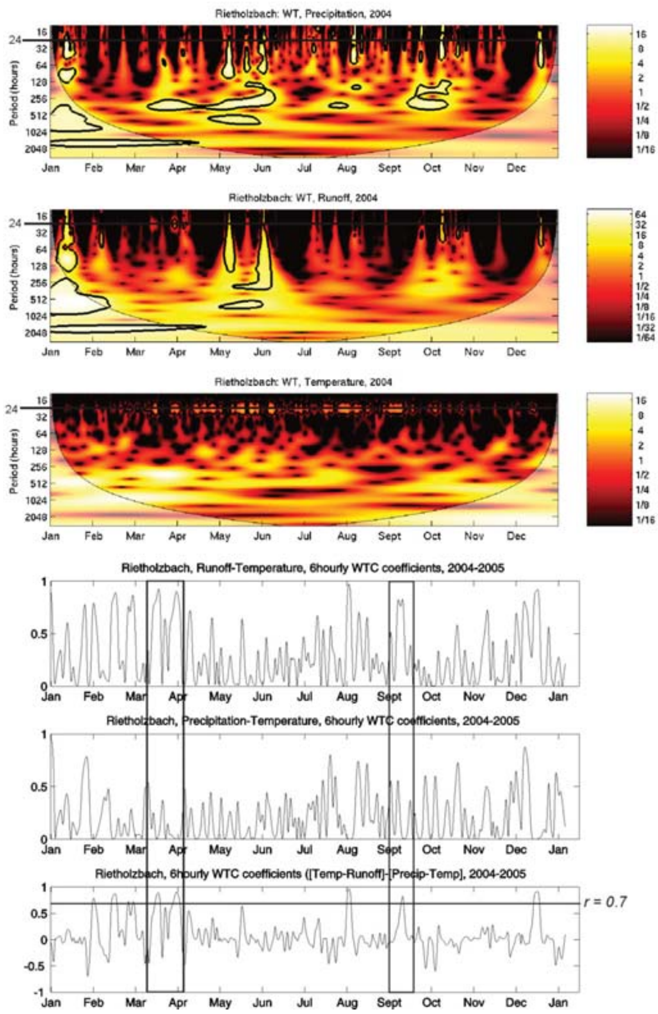


Figure 3: (top) Wavelet transform for P, Q, and T for 2004. The scales show the wavelet power for a given time and period, which is plotted and normalized by the time-series variance. Regions of significance are shown as a black contour. The cone of influence where edge effects become important is a lighter shade. The 24-hour period has been highlighted and the individual wavelet coherence coefficients for the 24-hour period are shown below
(bottom): Wavelet coherence coefficients between P, Q, and T show strong correlations with diurnal (period = 24 hrs) variations. Diurnal events are identified where r > 0.7, shown as a black line. Two snowmelt events (Mar) and an evapotranspiration event (Sept) are indicated with a box and highlighted in Figure 4.

Abbildung 3: (Oben): Wavelet Transformation für P, Q und T für das Jahr 2004
(Unten): Wavelet Kohärenz Koeffizient zwischen P, Q und T

In order to identify specific snowmelt and evapotranspiration events in runoff, we use the wavelet coherence coefficients (TORRENCE and WEBSTER, 1998) for the diurnal events which allow us to identify local temporal correlations between two variables in the frequency-time domain. Wavelet coherence coefficients between the variables are shown in Figure 3 (bottom) for the diurnal period. Runoff-temperature coefficients (top panel) show several diurnal events, however evapotranspiration, and even snowmelt events may be influenced by convective precipitation throughout the year. During the summer months, convective precipitation events can be quite frequent and are responsible for some diurnal variability in the runoff in the Rietholzbach catchment. We identify these convective events with the wavelet coherence coefficients in precipitation-temperature variables. We thus subtract the precipitation-temperature coefficients from the temperature-runoff coefficients in order to remove the convective signal and identify purely evapotranspiration or snowmelt events. Coefficients close to 1 indicate strong diurnal correlations and the bottom panel shows that strong events are found throughout the year. We identify diurnal events where $r > 0.7$, shown as a black line. Two snowmelt events (March) and an evapotranspiration event (September) are indicated with a box and highlighted in Figure 4. A strong evapotranspiration event also occurs from 30 July to 5 August which shows similar diurnal cycles in the runoff to the September event (and temperature), but is slightly shorter in duration, so is not shown.

## Results

### Characteristics of individual events

Figure 4 (left) shows the raw time series for precipitation, runoff and temperature for the two snowmelt events in March 2004. This is shown as 2004 had a particularly snowy winter and has several snowmelt events. The diurnal variations in runoff from snowmelt are characterized by a sharp rise followed by a gradual decline over the daily cycle. For Event 1, an increase in temperature with a strong diurnal cycle triggers the snowmelt runoff cycles which have a mean amplitude of 200 l/s over the 5 day period. Before Event 2, which starts 29 March 2004, the air temperature drops below zero, there is a contribution of snowfall to precipitation and accumulates to the snowpack. The event lasts until 03 April 2004 and the runoff has a mean amplitude of 280 l/s, much larger than the amplitudes found for evapotranspiration events. For the pre-alpine catchment of Rietholzbach, the snowmelt in the 1976 to 2006 period leads to a maximum in runoff 3–4 hours after the maximum daily temperatures for January, February and March events (cross-correlation for the lag is 0.75). For lower magnitude snowmelt events later in the season (April, May), the maximum runoff is often shifted to early next morning (between 6:00–10:00, lag > 12 hours). Since travel times are related to snowpack properties and the location of snowmelt, this increase in travel time later in the season may reflect changes in the snow cover in our catchment. Some studies have reported that as the snowpack thins in snow dominated

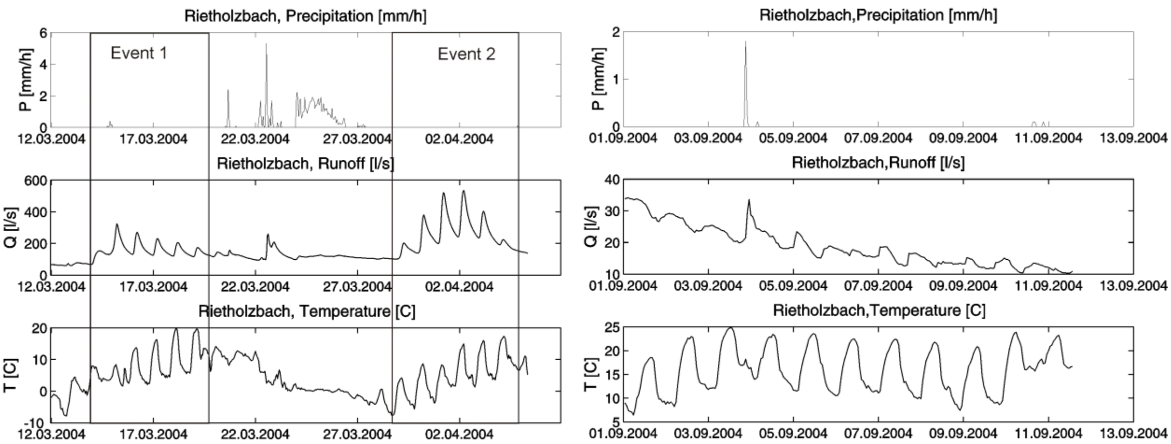


Figure 4: Precipitation, runoff and air temperature for two snowmelt events in March 2004 (left) and an evapotranspiration event in September 2004 (right)

Abbildung 4: Niederschlag, Abfluss und Lufttemperatur an zwei Schmelzereignissen im März 2004 (links) und einem Verdunstungsereignis im September 2004 (rechts) catchments and the mean discharge increases, travel times are shorter due to the reduced time needed for meltwater to percolate through the snowpack to the ground (LUNDQUIST and CAYAN, 2002; DEWALLE and RANGO, 2008). Since Rietholzbach is not a snow dominated catchment, the increased travel time later in the season could be due to the large variability in the snow cover within the catchment. A future research question will address this variability using historical snow height data collected at Rietholzbach.

Figure 4 (right) shows time series for precipitation, temperature and runoff for an evapotranspiration event in September 2004. An analysis of the evapotranspiration events at Rietholzbach for the 1976–2006 period shows a lag of 3 to 6 hours between daily maximum temperature and minimum runoff, which is consistent with other studies in similar catchments (BARNARD et al., 2010). Although experimental evidence suggests that lag times are highly correlated with soil moisture status (BARNARD et al., 2010) we do not find any change in this lag time over the course of the summer. The fact that no significant time lag shifts are found may be caused by the intermittent rainfall during summer months which may keep the soil relatively moist.

## Runoff contribution due to diurnal events

Strong variability in the number of diurnal events during one season is found over the 1976–2006 period. Figure 5 (left) shows the annual fraction of snowmelt events (March, April, May), showing considerable year to year variability. Similarly, the variability in evapotranspiration events (Figure 5, right) shows large fluctuations, with the largest number of events occurring in recent years, notably in 2006 and 2003. An analysis of the contribution of evapotranspiration and snowmelt events to runoff (Figure 6) also shows large month to month variability for the 1976–2006 period. The contribution for snowmelt events add to the total runoff and are indicated with a plus, "+" and evapotranspiration events with a negative, "-". The overall contribution is calculated as the ratio of the mean amplitude over all events for a month to monthly mean runoff (shown as a percentage). The mean contribution for each month over the period

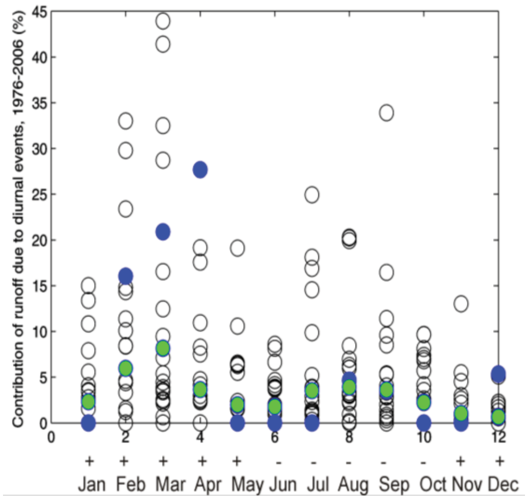


Figure 6: Contribution to runoff (snowmelt "+", evapotranspiration "-") due to diurnal events (%, calculated as the ratio of the mean amplitude over all events for a specific month to monthly mean runoff). Green circles show the mean for each month, blue circles show values for 2004

Abbildung 6: Monatliche Abflussbeeinflussung durch Schneeschmelze ("+") und Verdunstung ("-") für den Zeitraum 1976–2006

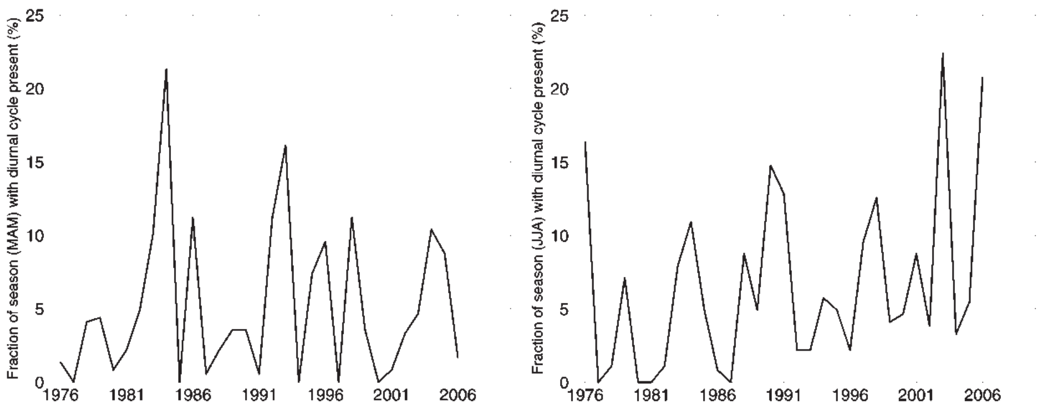


Figure 5: Fraction of year with diurnal cycle present (%). Both snowmelt events (MAM, left) and evapotranspiration events (JJA, right) show considerable year to year variability

Abbildung 5: Anteil der Tage (in %) mit Schneeschmelzeinfluss (links) und Verdunstungseinfluss (rechts) (shown as green circles), shows that evapotranspiration events peak in August and contribute < 5% to the decrease in runoff during June, July and August. Very low reductions in runoff are found between June and October. Snowmelt events add to runoff from November to May, with the highest contribution in March (~8%). Individual years however show significantly higher values, for example in 2004 (shown as blue circles), April shows large contributions from snowmelt of 27%. Overall, we find considerable variability in both the number of diurnal events and the contribution from these events to runoff in the catchment.

## Conclusion

This study shows the potential of wavelet analysis to better understand processes in the catchment and changes in catchment behavior that are not caught with simple linear analysis. Consequently we are currently validating the most recent data and will carry out an analysis of the full dataset for 1976–2010 to determine whether any significant change in the contribution of snowmelt and evapotranspiration events has occurred over this period. In addition we will expand the analysis to precipitation patterns.

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