# Hydrologic effects of climate change in the Western Bug basin

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## Introduction

Presented work is embedded in the project "International Water Alliance Saxony" (IWAS, http://www.iwas-sachsen.ufz.de/), which aims at solving water management problems in five regions of the world, namely Eastern Europe, Mongolia, Brazil, Vietnam and Oman. For Eastern Europe the river Western Bug (herein after called Bug) in Ukraine, Poland and Belarus was chosen, because of its poor river water quality, insufficient and bad water infrastructure and its location at the border of the European Union. Pollution loads from punctual and diffuse sources are high, due to insufficient water treatment and formerly intensive agriculture. The knowledge of the water balance is an indispensable prerequisite to determine the matter balance of the catchment. A quantification of all diffuse and punctual pollution sources is required to search for the reasons of the poor river quality in most parts of the catchments and to show options to improve the situation. Changes in the natural and anthropogenic conditions - as for instance climate or land use - have to be considered, because they can affect the local water and matter flows negatively but also positively. There are indications that in Ukraine droughts could occur more frequent, for floods no clear signal was found (Lehner et al., 2006). After an evaluation of the past and current state of the system, the second step is the development of model-based future scenarios. We focus on the effect of a climatic change. Exemplarily we used the results of one Global Climate Model (GCM) and one Regional Climate Model (RCM) to show the climate signal and its impacts on the water balance.

This work focuses on the determination of the past and future water balance of the catchment Sasiv of the river Bug. Within the project it is envisioned to determine the water and matter balance of the basin of Kamianka-Buzka (2560 km²). Because of the poor data situation especially regarding the completeness of soil information, the focus was set for this work on the smaller upstream catchment Sasiv (Fig. 1). Here, more profound pedological information was available.

## Data and methods

The catchment of Sasiv (107 km²) is situated in the upstream section of the Bug basin (Fig. 1). Here quantitative and qualitative measurements exist for more than tree decades. The Bug originates in the Voroniaky Hills (part of Podilia Highland, situated north of the Carpathian Mountains) in Galicia at an altitude of 311 m and drains into the river Vistula. The height difference of the catchment ranges between 260 m in the lowland Male Polissia and 450 m in the Podilia Highland. The river valley is formed in the marls of Cretaceous period, in limestones, sandstones and sands of Miocene, in glacial and fluvio-glacial detritus-gravel-clay and sand sediments of lower Pleistocene. The region is situated in the temperate climate zone with a mean temperature of 7.5°C and around 700 mm precipitation (not bias corrected).

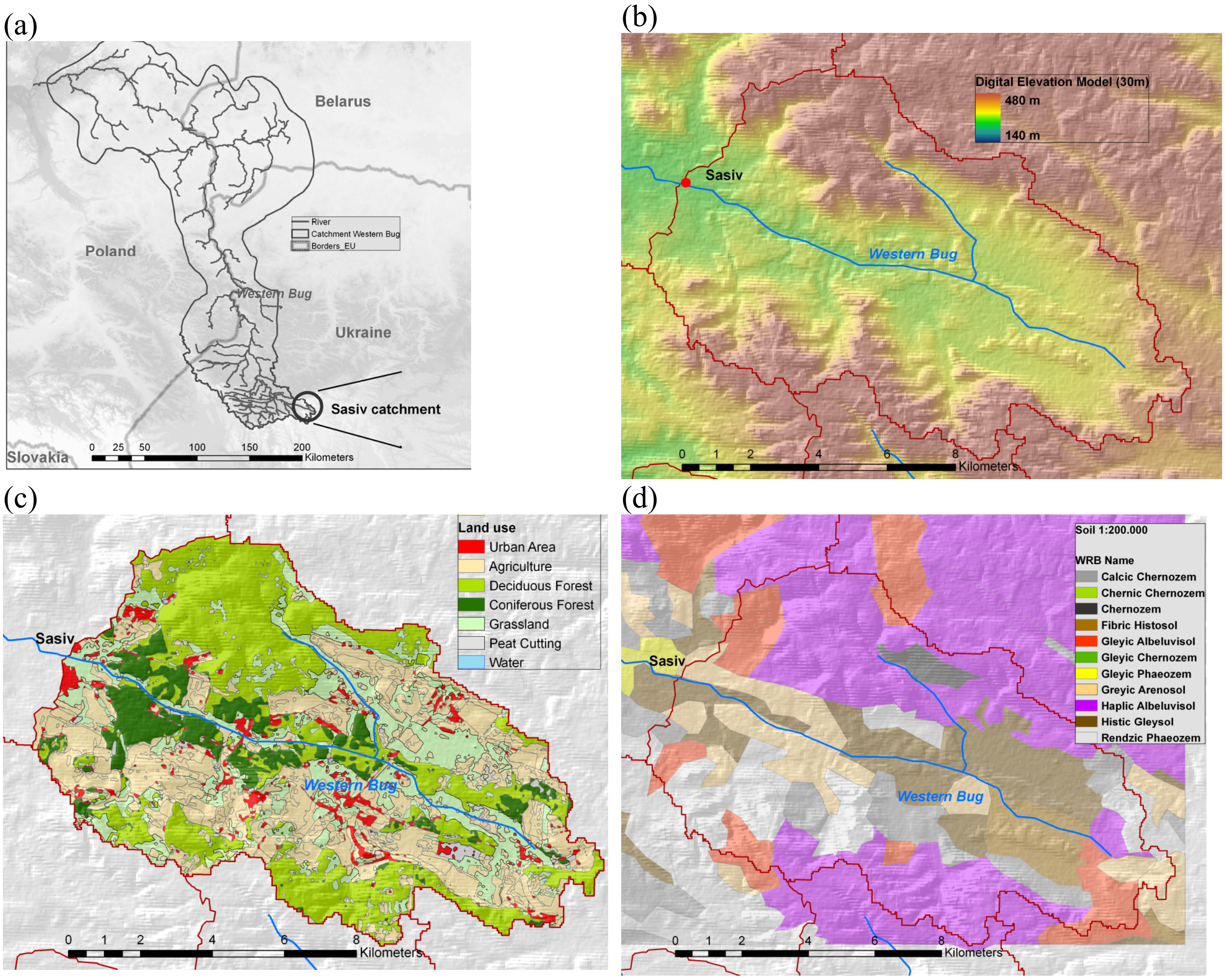

**Figure 1:** Investigation area: a) Overview of whole Western Bug Basin, b) topography based on the 30 m digital elevation model ASTER (https://wist.echo.nasa.gov/), c) land use and d) soils in the Sasiv catchment.

The Soil and Water Assessment Tool (SWAT) was applied, which is a public domain river basin scale model (http://swatmodel.tamu.edu/). It was developed to quantify water and matter fluxes and the impact of land management practices in large, complex watersheds. Daily values of precipitation, global radiation, wind speed, relative humidity and minimum and maximum temperature are needed as meteorological input. Land use and soil data as well as a digital elevation model are used to define hydrological response units and to parameterize them.

Daily meteorological data were downloaded from the internet databases ECA&D and NOAA (http://eca.knmi.nl/, http://www.ncdc.noaa.gov). A further source of meteorological data was the Rostotsky Landscape Geophysical Station in Briuchovychi, which is part of the Ivan Franko University Lviv. The density of climatological stations and rain gauges is low. In Germany, e.g., there exist 50 times more rain gauges. Missing values were added applying multiple regression with neighboring stations. Homogeneity was tested using the Alexandersson test (Alexandersson, 1986) and if necessary data were homogenized. Bias of precipitation measurements due to wind, evaporation and wetting induced errors was corrected according to Adams and Lettenmaier (2002).

To account for future climate conditions the results of the GCM ECHAM5/MPIOM (spatial resolution about 130 km in the investigation area) (Röckner et al., 2003) and of the RCM REMO (spatial resolution about 25 km) (Jacob et al., 2008) were used for the period 2051-2080 and the moderate emission scenario A1B (Nakičenovič and Swart, 2000). These models were chosen to show the differences in the impact of climate models of different resolution and model approaches (GCM vs. RCM). Furthermore, in our working group the RCM "CCLM" was set up for western

Ukraine (Pavlik and Söhl, 2010) that is driven by ECHAM5/MPIOM as well. After an evaluation of the CCLM, the climatological results and hydrological impacts of both RCMs will be compared. The data of the grid cell (GCM and RCM) with the minimal distance to the centre of the catchment were used in order to keep the local variability. Using an areal mean would reduce variability especially of precipitation.

Land-use information was derived from the satellites Landsat-TM5 and SPOT-1. Combining three different images of each satellite between July 1989 and August 1990 a multi temporal classification with a resolution 15 m was conducted. Data were classified according to the CORINE Land Cover classification scheme (http://www.corine.dfd.dlr.de/intro_en.html), a European approach for recording land cover and land use. Up to now 7 classes were detected (Fig. 1), namely: water (0.04% of the Sasiv catchment), natural grassland (19.5%), agricultural land (34.6%), deciduous forest (31.1%), coniferous forest (9.3%), peat cutting (1.2%) and artificial surface (4.3%). Coniferous forests consist mainly of pines (*Pinus*) and deciduous forests of beeches (*Fagus sylvatica),* hornbeams (*Carpinus betulus*) and limes (*Tilia europaea*). Industrial farming and subsitence farming were practiced in the region until the eighties. Later on industrial farming was abandoned. The main agricultural crops were and are winter wheat, barley, potato, cabbage, corn, cabbage etc., whereby only barley, potato and corn were modeled. Changes in crop composition or crop rotations were disregarded up to now, because of lack of detailed knowledge. Plant characteristics were mainly taken from the SWAT database but were adapted to East European conditions (biomass, leaf area index, potential heat units, minimal and optimal temperatures etc.).

A soil map in the scale of 1:200.000 was available for the Oblast Lviv from 1969. Soils were classified according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007) (Fig. 1). Soil and hydraulic parameters (texture, water content at field capacity and at wilting point, porosity, bulk density and saturated hydraulic conductivity) were derived using local expert knowledge and field and laboratory measurements (Tavares Wahren et al., 2010). The floodplains of the river Bug were drained since the sixties but since the nineties not maintained anymore. Apart from information from topographical maps and some visual impressions no detailed knowledge was available. Therefore, it was decided that the soils Fibric Histosol and Histic Gleysol are drained and parameters that describe drainage in the model are free for calibration.

Monthly runoff data of the gauge Sasiv (period: 1963-1998) were checked on homogeneity using the gauge Kamianka Buzka situated further downstream. No grave inhomogeneities were detected. No station metadata were available for a detailed analysis.

## Results and discussion

The period 1968-1980 was chosen for model calibration and 1981-1990 for validation. The years 1966-1967 were simulated for adaptation of the model conditions without using the results. Observed and modeled runoff as well as precipitation of the calibration period is shown in Fig. 2. According to Arnold and Allen (1999) base flow was estimated as 88-92% of total runoff in the catchment. This information, long-term means of river flow and plausible evapotranspiration rates of different land uses were used during calibration process. Congruence between modeled and observed runoff is not high. Runoff was overestimated in the first half of the period and underestimated in the second half. Most probably, modeled evapotranspiration rates are too low in the first half. Radiation observations were incomplete before 1976 and were substituted by a mean daily value that was calculated from observations. Averaged values do not have strong variations such as observations from single years. The missing of days with high radiation probably caused an underestimation of evapotranspiration. At the beginning of the year 1974 there is a strong difference between modeled and observed runoff. Precipitation was very low in the period winter 1974, similar as in the surrounding stations. A further strong deviation is observable in winter 1976, were strong precipitations occurred. The simulated flood was too fast and strong. The assumption that falling and melting of snow were not properly reproduced by the model was enervated by trying different parameter settings. Influence of these parameter variations proved to have little influence on the hydrograph in both periods. The reason for the sometimes large differences in the hydrograph could be the insufficient representativeness of the meteorological station used (Brody), especially for precipitation.

There is a negative trend of precipitation, but a positive trend of the observed runoff. These for now inconsistent facts can be caused by improper description of the meteorological conditions in the catchment, by erroneous runoff data and/or by land use changes, drainage activities etc. Further gathering of information and calibration efforts are needed and planned. Mean values of the water balance are summed in Tab. 1.

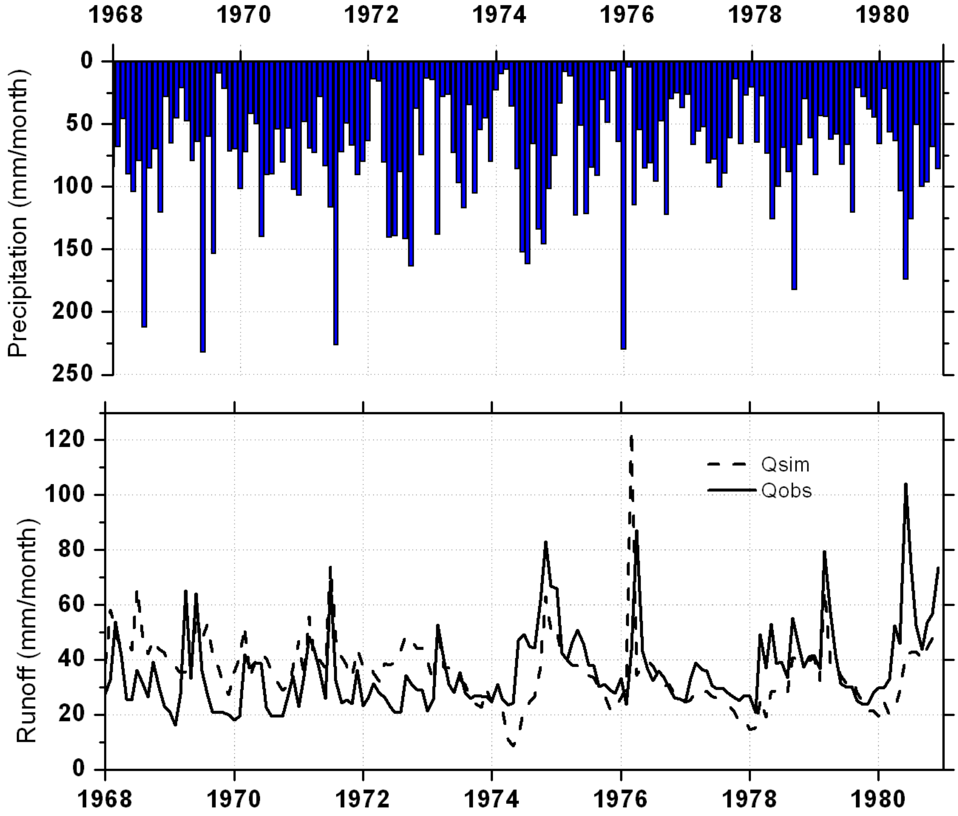

Figure 2: Monthly values of observed precipitation, modeled and observed runoff for the calibration period.

Runoff was modeled too high (9%) in the validation period (not shown) in comparison to observations (Tab. 1). Meteorological conditions were different, higher temperatures led to a decreased percentage of snow and an increased percentage of potential evapotranspiration. The same uncertainties as in the calibration period apply.

Before hydrographs of the future scenario A1B of the GCM (ECHAM) and the RCM (REMO) are analyzed, some remarks to the climate signal that is observable in the data (Fig. 3). The climate signal is understood as the difference of the scenarios to the control period (1961-1990). Precipitation is remarkably reduced (yearly mean: -8 until -20%), especially between May and September. Global radiation is increasing in both models in the summer month and decreasing minimal in the rest of the year (+2.9%). Minimal and maximal temperatures are increasing during the whole year, being more remarkable in the winter month (Tmax: +1.8°C, Tmin: +3.6°C). Wind strongly increases in both models, especially in summer (+12.7%). A significant positive signal in relative humidity is modeled only by ECHAM (+7.6%), having higher values especially in winter. REMO shows a stronger climate signal in global radiation, temperature and wind, but ECHAM in precipitation and relative humidity.

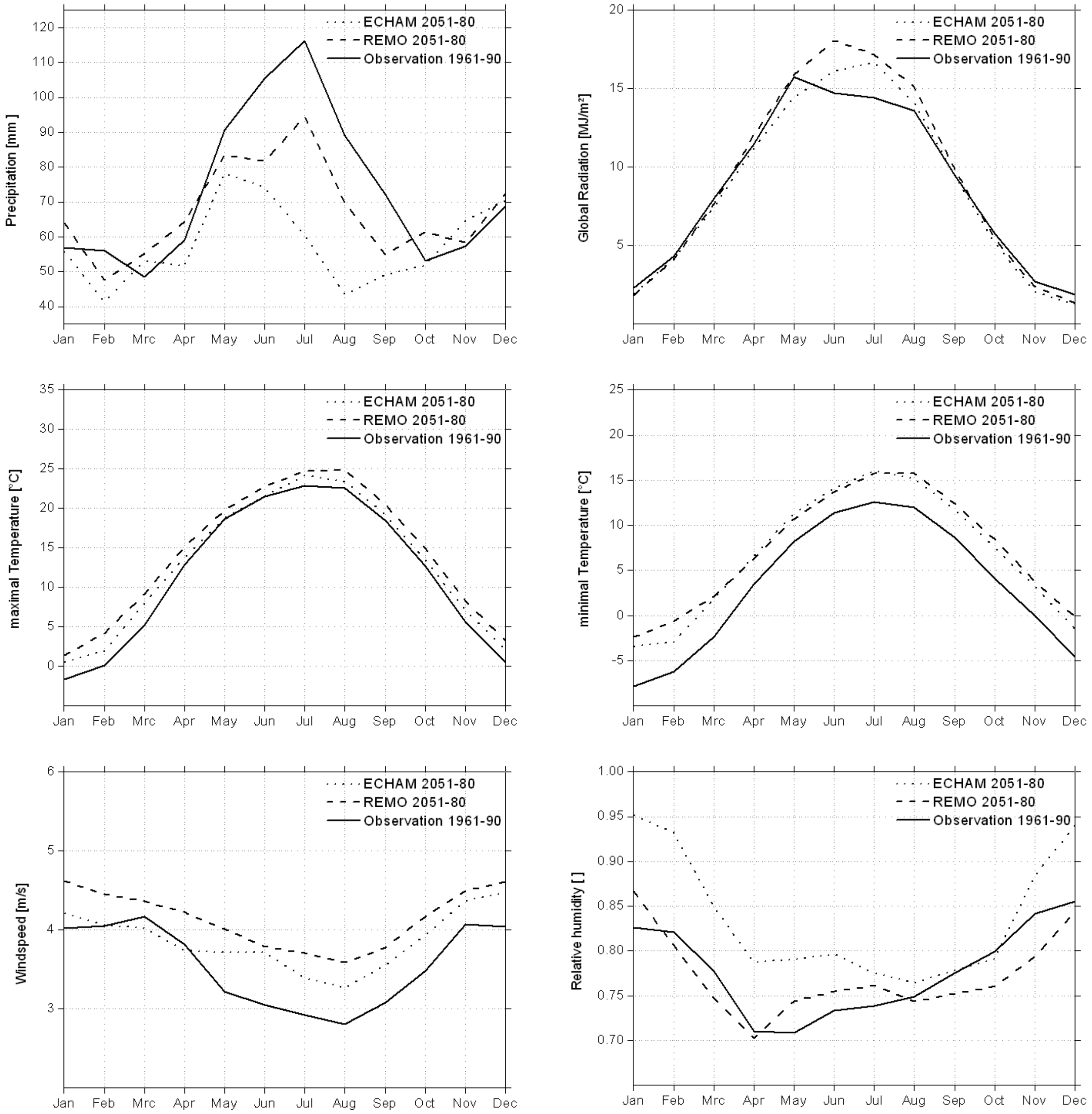

Figure 3: Climate signal of the GCM (ECHAM) and the RCM (REMO) in comparison to the observed values of the period 1961-1990.

Increasing temperatures in the future lead to a reduced percentage of snow (Tab. 1 and Fig. 4). Together with higher wind speeds and a higher solar irradiation the RCM REMO simulates a higher potential evapotranspiration throughout the entire year, whereas the GCM ECHAM simulates an increase in summer and autumn only (Tab. 1 and Fig. 4). Using SWAT - under consideration of land use, soil etc. - the actual evapotranspiration rates were simulated. For REMO a considerable rise in evapotranspiration was modeled, especially during the winter half year. The low water availability (precipitation) projected by ECHAM caused decreasing actual evapotranspiration rates. There are large differences between evapotranspiration and potential evapotranspiration in summer, what means that plants will suffer from water stress.

Runoff will decrease absolutely, but also relatively for both climate models (Tab. 1 and Fig. 4). The changes in the runoff distribution are caused by different amounts of precipitation, altered conditions of snow falling and melting and a higher evaporative demand. Very concise is the runoff recession in summer and autumn, which is due water depletion in the soil.

**Table 1.** Past and future water budget

| | Precipitation (mm) | Snow fall (%) *1 | Runoff (%) *1 | Evapotranspiration (%) *1 | Potential Evapotranspiration (%) *1 |
|---|---|---|---|---|---|
| 1968 – 1980 | | | | | |
| Observation | 895 | | 48 | | |
| Calibration | | 19 | 48 | 48 | 77 |
| 1981 - 1990 | | | | | |
| Observation | 862 | | 45 | | |
| Validation | | 15 | 49 | 49 | 81 |
| 2051 - 2080 | | | | | |
| REMO | 812 | 14 | 37 | 59 | 114 |
| 2051 - 2080 | | | | | |
| ECHAM | 700 | 12 | 44 | 51 | 103 |

*1 in % from precipitation

## Conclusion

The water balance of the small catchment Sasiv/ Western Bug was modeled for a period in the past (1968-1990) and in the future (2053-2080). For latter one, the results of the GCM ECHAM and of the RCM REMO were used for the emission scenario A1B. Simulation of the past period made the high uncertainty of the input data clear. Deficits lay in the representativeness of meteorological data as well as in insufficient information regarding soil, drainage and land use change. Therefore, simulation of water balance in the catchment has to be regarded as preliminary and further investigations are needed.

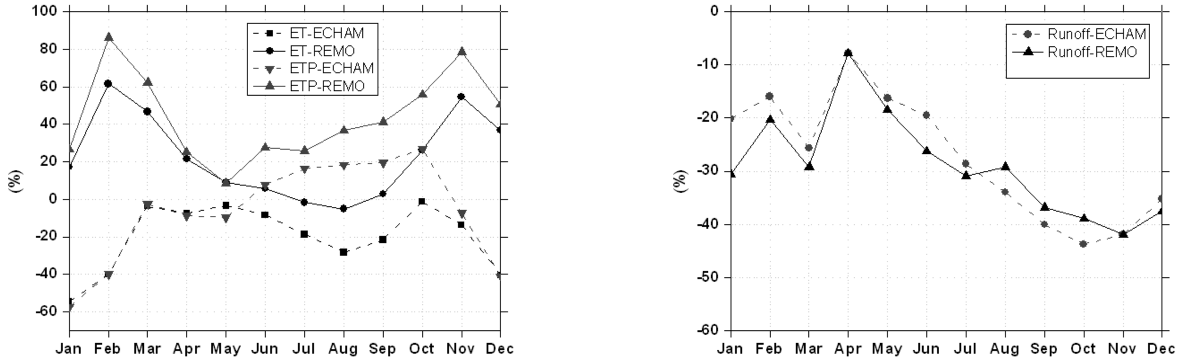

Figure 4: Relative differences (%) of the projected (2053-2080) runoff and (potential) evapotranspiration in comparison to observed (1968-1990) values.

The climate signals between the two used climate models differ in magnitude and sometimes in directions. But in general a decrease in precipitation and an increase in temperature, wind speed, relative humidity and global radiation are projected for the period 2053-2080. This has severe implications on the water balance of the region. There will be less snowfall, an earlier snow melt, and a higher potential evapotranspiration. In their impact on the - all processes integrating - runoff the meteorological elements and processes compensate each other so that the usage of both climate model data results in a similar hydrograph (Fig. 4). Assuming that RCM better resolve topography, soil, processes etc., they are supposed to deliver more realistic values in the future. That would mean higher evapotranspiration rates, but also water stress for plants. Still a lot of uncertainties exist within the climate models, e.g. bias to observed climatological elements that were not accounted for up to now. For future works this will be considered.

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