Dealing with rare meteorological input data for a water balance assessment

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What is the most appropriate meteorological model input?

Exemplarily this will be demonstrated for precipitation. Comparing the three distinct areal precipitation fields in Fig. 2 significant differences for a specific date (a random example) are recognizable. Are these differences typical for longer periods or accidental? What impact on hydrologic processes do they have? A possibility to decide which input is most appropriate for water balance modeling is to compare measured with modeled runoff. The aim of this work is to minimize the uncertainty that originates from the input data.

The Work is embedded in the BMBF project "IWAS". An IWRM plan has to be developed for a catchment of the river Western Bug in Ukraine (Fig. 1). Water quality is insufficient due to high chemical and biological pollution. The aim of the project is to investigate options to improve the management of the water resources.
As one part of the system analysis, the water balance of the catchment Kamianka-Buzka (2560 km²) has to be assessed. The parameterization of the chosen model SWAT is uncertain due to:

- limited soil information,
- limited land use and management information and
- a meteorological observation network of low density.

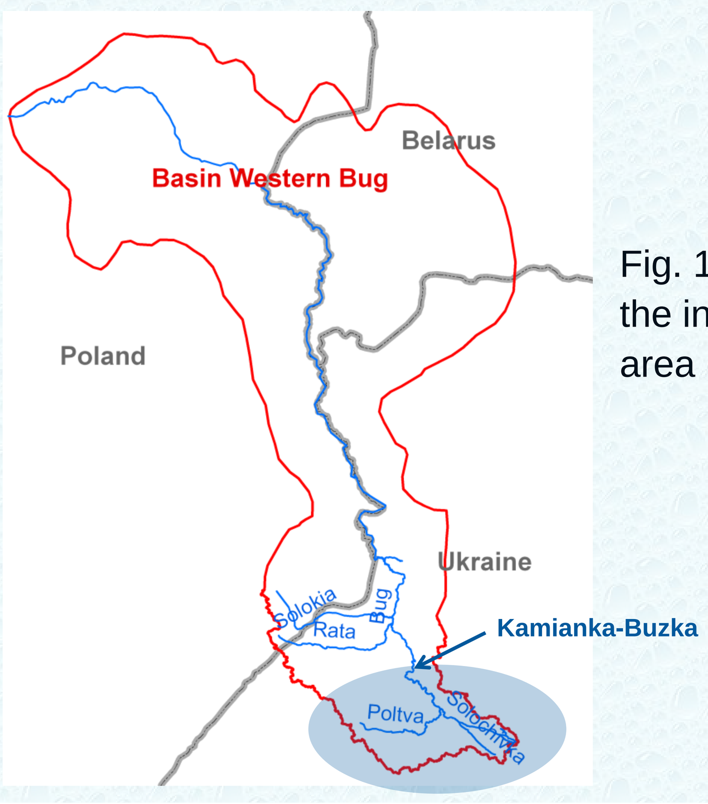

Fig. 1: Location of the investigation area (encircled).

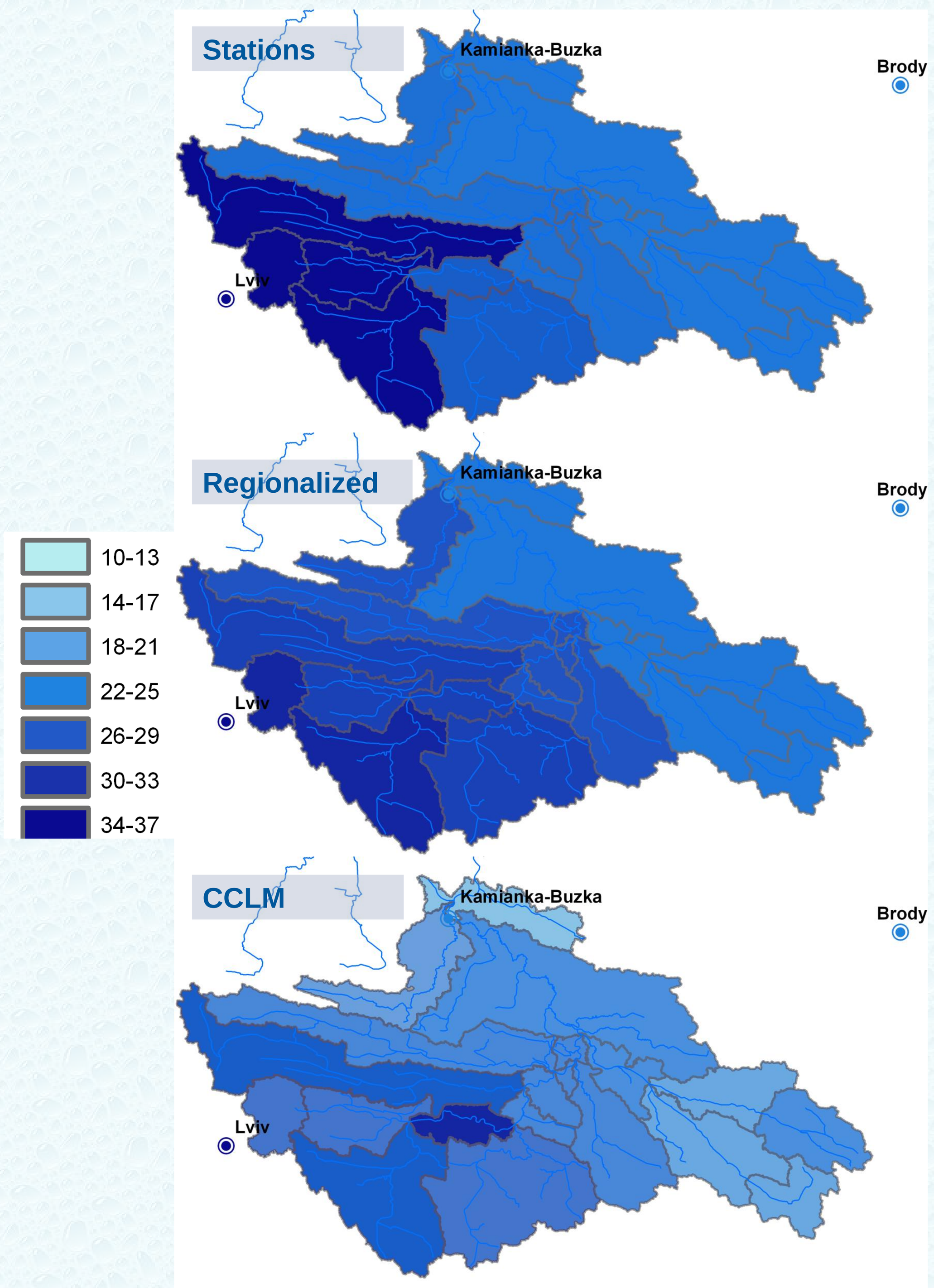

Fig. 2: Three different areal precipitation inputs (mm) for Sept., 27th 1987. For details see Chapter Data and Methods.

Data and Methods

The hydrological model SWAT (http://swatmodel.tamu.edu/) was used. Parameterization features:

- Land-use information was derived using images of the satellites Landsat-TM5 and SPOT-1 (Schanze et al. 2011).
- On the basis of a soil map in the scale of 1:200.000, soil and hydraulic parameters were derived using expert knowledge, and measurements (Tavares Wahren et al. 2011).

- Three meteorological stations in and nearby the basin had sufficient precipitation data (1971-1990). Due to high spatial variability of precipitation (especially during convective events), the spatial representativeness of the existing stations is often low. This is a major source of uncertainty in hydrological modeling.

Three approaches to assimilate precipitation data were tested:

- ***Stations:*** By default, SWAT incorporates meteorological observations into the model using station data that are nearest to the centroid of each sub catchment.

- ***Regionalized***: Data of 20 stations were regionalized applying kriging methods onto a 3 x 3 km grid.

- ***CCLM***: The regional climate model CCLM (resolution approx. 7 km) was set up for the target area (Pavlik et al., 2011). Resulting daily time series were bias corrected.

Grid cells within each of the 20 sub-basins were arithmetically averaged to obtain 20 fictive precipitation stations.
Mean differences in the three precipitation inputs are low (Tab.1), most noteworthy is the known fact that ***CCLM*** produces too much days with rain. ***Regionalized*** and ***CCLM*** data are more balanced than ***Station*** data, that means they show less extremes.

Before applying alternative precipitation inputs, SWAT was pre-calibrated step by step (1981-1990) in a mix of manual and automatic calibration using meteorological data ***Stations*** as well as monthly runoff data of two sub-basins and of Kamianka-Buzka. The model was validated (1971-1980) using runoff of Kamianka-Buzka.
Finally, three models with different precipitation inputs were calibrated independently using the auto-calibration procedure Sequential Uncertainty Fitting (SUFI2) that is integrated in the SWAT interface SWAT-CUP (Abbaspour et al., 2004).

Tab.1: Comparison of three precipitation inputs (1981-1990)

Precipitation input	P (mm/a)	Days/year with P > 0 mm/d	P>10 mm/d	Mean bias to *Stations* (mm/a)
Stations	665	178	17	-
Regionalized	651	188	14	-1.2
CCLM	676	246	14	+0.9

Results

Observed and simulated runoffs are displayed in Fig.3. Best performance shows the model with the precipitation input ***Stations*** having R^2 and a Nash-Sutcliffe model efficiency coefficient (NSE) of 0.66/ 0.61, respectively (***CCLM***: 0.54/ 0.54, ***Regionalized***: 0.57/ 0.53). The arithmetic mean of all simulated runoffs results in R^2=0.67 and NSE=0.67, which meets the expectation that ensemble means perform better than single models. Mostly, all modeled hydrographs are within a narrow band (enveloping curve). Larger deviations are caused sometimes by ***CCLM***, because differences in precipitation are high in comparison to observations (e.g. June 1983).
The parameter 95PPU is the 95 Percentage Prediction Uncertainty, which results when the uncertainty of the calibration parameters is modeled by a multitude of runs and the hydrographs between 2.5th and 97.5th percentile are chosen. The wide range of 95PPU illustrates that uncertainty of the parameters, but also of driving variables, model, and measured data is high. In some cases none of the models is able to reproduce the observed runoff (95PPU dos not bracket the observation). The authors see the reasons mainly in an erroneous modeling of snowfall and snowmelt processes (e.g. 1986) and the missing representativeness of observations (e.g. May, 1989).

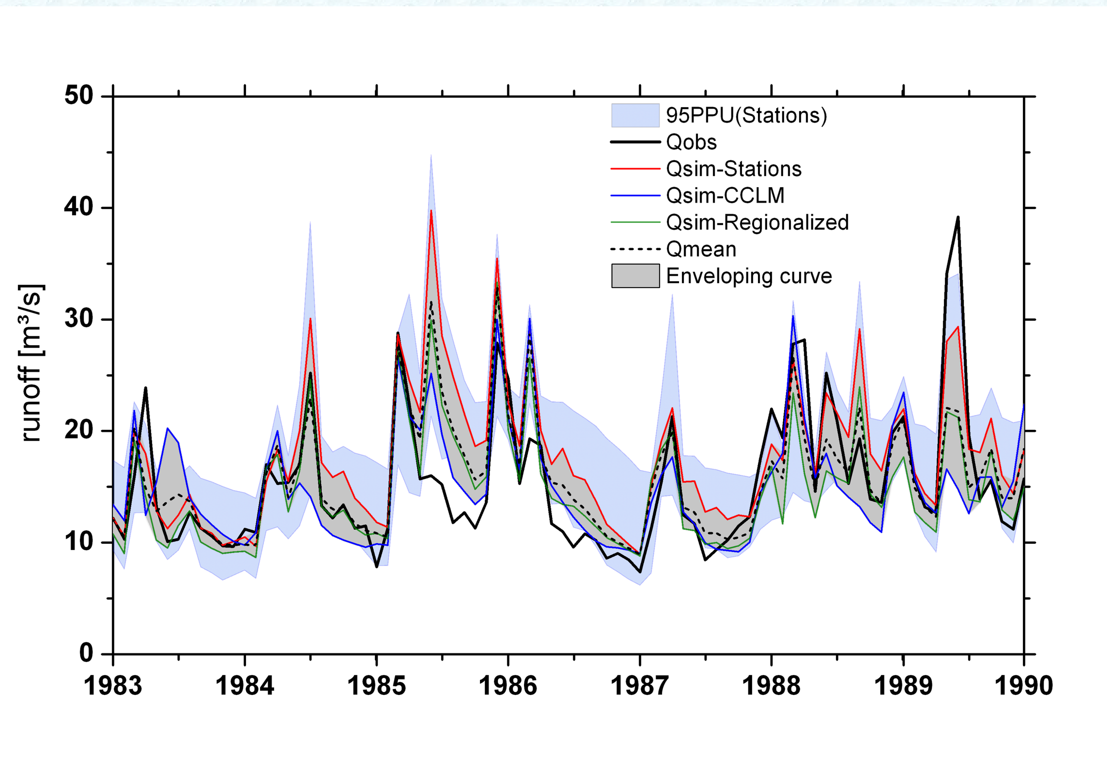

Fig. 3: Observed and modeled hydrographs of three models, their mean, their enveloping curve and the uncertainty band of the model ***Stations*** (95PPU) for the calibration period.

Conclusion

- ***Regionalization*** of station data should produce a more realistic areal distribution of precipitation than the direct use of stations, because it uses additional information (more stations and topographical and areal gradients).
- ***CCLM*** is applicable as alternative precipitation input.
- Results are not as straightforward as expected: The simplest approach ***Stations*** had the best model performance, probably because the model was extensively pre-calibrated with ***Stations*** data. This was necessary because hydro-geological conditions in the area are difficult (e.g. Karst).
- A simple averaging of the best hydrographs of the three models produced an even better performance → Uncertainty of input data could be reduced.
- Generally, the uncertainty is high. This includes especially the representativeness of precipitation, the model parameters, the boundary conditions, the model concept, but very probable also the observed runoff.
- Further calibration effort – including alternative optimization procedures – as well as more advanced averaging methods can probably improve the simulations and the final result.

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