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Research papers

Influence of hydro-meteorological data spatial aggregation on streamflow modelling

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ABSTRACT

Data availability is important for virtually any purpose in hydrology. While some parts of the world continue to be under-monitored, other areas are experiencing an increased availability of high-resolution data. The use of the highest available resolution has always been preferred and many efforts have been made to maximize the information content of data and thus improve its predictive power and reduce the costs of maintenance of hydrometric sensor networks. In the light of ever-increasing data resolution, however, it is important to assess the added value of using the highest resolution available.

In this study we present an assessment of the relative importance of hydro-meteorological data resolution for hydrological modelling. We used a case study with high-resolution data availability to investigate the influence of using models calibrated with different levels of spatially aggregated meteorological input data to estimate streamflow for different periods and at different locations. We found site specific variations, but model parameterizations calibrated using sub-catchment specific meteorological input data tended to produce better streamflow estimates, with model efficiency values being up to 0.35 efficiency units higher than those calibrated with catchment averaged meteorological data. We also found that basin characteristics other than catchment area have little effect on the performance of model parameterizations applied in different locations than the calibration site. Finally, we found that using an increased number of discharge data locations has a larger impact on model calibration efficiency than using spatially specific meteorological data. The results of this study contribute to improve the knowledge on assessing data needs for water management in terms of adequate data type and level of spatial aggregation.

1. Introduction

High resolution hydrometrical data is becoming increasingly available in many places (Isotta et al., 2014; Ivanov et al., 2004), enhancing the development of new approaches, such as data mining, that rely on large amounts of data to make predictions (Hall et al., 2002). For modelling purposes the general perception in the hydrological community is that it is always useful to use the best available resolution (Rauthe et al., 2013). However, with the increasing resolution of the available data this might not be so clear and the added value of using the most detailed data might be negligible. For instance, density limits in precipitation sensor networks have been found beyond which prediction skills are not improved (Girons Lopez et al., 2015; Xu et al., 2013). The issue of data-resolution requirements has also been investigated for discharge estimation in large scale basins. Findings suggest that the sensitivity to data resolution is dependent on the basin size (Bergström and Graham, 1998; Shrestha et al., 2006). At a global scale, though, data might not always be available at the desired resolution or accuracy for a specific application (Berne et al., 2004) or it might even be non-existent for the required location, which becomes a large issue due to the large geographical and scale-dependent variability and complexity of hydrological processes (Beven, 2000).

Either way hydrological data is crucial for improving societal resilience. Urban planning and fresh water supply as well as flood and drought management policies depend to a large extent on hydrological data availability (Lézine et al., 2011) and reducing the number of hydrometric stations can produce a negative impact

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on the accuracy of hydrological predictions on which such actions depend (Spence et al., 2007).

It is thus important to clearly define and quantify the data needs for different purposes including data resolution and density. Different approaches have been taken to address this issue, mainly by exploring ways to rationalize the design of hydrometric networks in order to maximize their information content and therefore their cost-benefit ratio (Beven et al., 2008). Relevant examples include findings on the value of hydrometric data (Hunger and Döll, 2008; Perrin et al., 2007), the effect of measurement location on prediction efficiency (Carrera et al., 1984), the importance of data resolution (Boyle et al., 2001; Faurès et al., 1995; Schuurmans and Bierkens, 2007), the use of remote sensing data and soft data sources to complement or replace hard data (Seibert and McDonnell, 2002; Smith et al., 2012; Wood et al., 2000), or even the use of poor quality data under certain circumstances (Boughton, 2006).

Even if there has been significant progress in the rationale behind the design of hydrometric networks much work is still needed. Mishra and Coulibaly (2009) identified several pressing issues that need to be addressed such as data processing and dissemination, increased spatial and temporal data resolution for improved sustainable water resource management under changing climatic conditions, including climatic extremes in the network design process, or the integration of different measurement approaches and techniques.

With this paper we aim to improve the knowledge on hydrometrical data needs for water management purposes by presenting an assessment of the importance of spatial resolution of meteorological data – precipitation and temperature – for streamflow simulation as well as its relative importance vis a vis other data types. More specifically we addressed the following questions:

i. Does using sub-catchment-specific meteorological time series instead of one series for the entire catchment give better model performance in the sub-catchments, if the model is calibrated for each sub-catchment?
ii. Does using sub-catchment-specific meteorological time series, instead of one series for the entire catchment, produce better model performance in the sub-catchments, if the model is calibrated for the outlet of the entire catchment only?
iii. Which modelling approach results in better model performances for sub-catchment runoff: (1) using one meteorological time series for the entire catchment, but considering sub-catchment discharge series for the calibration, or (2) using sub-catchment-specific meteorological time series, but considering only runoff at the catchment outlet for the calibration?

The third question evaluates the relative importance of hydrological and meteorological data for hydrological model calibration. These are relevant questions that can contribute to improving decisions on hydrometric measurement network deployment and management, especially in data-scarce areas.

2. Study area and dataset

The study was carried out in the Thur river basin, which is located in north-eastern Switzerland (Fig. 1). River Thur is a tributary of the Rhine and it is currently the largest non-regulated river in Switzerland. The river has a history of human intervention, mainly through the building of levees for flood defence purposes, but river restoration measures have been carried out in recent years to improve flood management as well as the ecological status of the river and its riparian zone (Woosley et al., 2007).

The drainage basin of river Thur has an area of 1696 km^2 and covers the front ranges of the Swiss Limestone Alps. The elevation of the basin ranges between 356 to 2503 m a.s.l. with an average elevation of 770 m a.s.l. The catchment headwaters are dominated by alpine limestone whereas the lowlands are mainly composed of Molasse-sandstones and Pleistocene unconsolidated sediments (PEER, 2010). Agriculture is the main type of land use in the lowlands while the highlands are dominated by pastures. Overall, approximately a quarter of the catchment area is covered by forest. Population is mainly composed of scattered settlements and some larger agglomerations, the largest of which are St. Gallen (72,000 inhabitants) and Frauenfeld (23,000 inhabitants).

The climate of the basin is classified as alpine and pre-alpine (Yang et al., 2007) and the flow regime of the river Thur is dominated by snowmelt (nivo-pluvial). The average flow at the outlet for the period 1904–2008 is 47 $m^3\,s^{-1}$, the 100-year high flow is 1071 $m^3\,s^{-1}$, and the low flow for the same return period is 3.16 $m^3\,s^{-1}$ (FOEN, http://www.hydrodaten.admin.ch/de/2044.html, 22 January, 2016). The average annual rainfall is 1350 mm and is distributed over the year with a peak during the summer months and a positive elevation gradient. Large precipitation events in the headwaters might cause a rapid discharge build-up in the basin due to the steep terrain and short concentration times.

Several data sources were used in this study. First, hourly gridded precipitation data was obtained from the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss). This is a high-resolution experimental dataset with a resolution of 1 km^2, called RdisaggH, which is the result of aggregating rain gauge and radar data (Wüest et al., 2010), and which is available for the period 2003–2010. A total of 29 rain gauges within the Thur basin were used for the precipitation correction procedure of RdisaggH (Fig. 1). The high temporal resolution provided by this product was important to capture the short concentration times in the smaller sub-basins and the combination of data sources ensured a good representation of the spatial variability of the precipitation.

Temperature data was also obtained from MeteoSwiss. The data consisted of daily gridded mean, minimum, and maximum temperature (named TmeanD, TminD, and TmaxD, respectively) based on an interpolation procedure between meteorological stations (Frei, 2014). Annual average values of potential evaporation for the Thur river catchment were obtained from the Hydrological Atlas of Switzerland (HADES) and distributed over the 12 months using a sine curve. A digital elevation model at a resolution of 25 m provided by the Swiss Federal Office of Topography (swisstopo) was used together with the gridded precipitation and temperature data to calculate elevation precipitation and temperature lapse rates respectively. The DEM was further used to compute the elevation range areas for each of the (sub) basins in the analysis as required by the hydrological model (see Section 3).

Discharge data from the Swiss Federal Office for the Environment (FOEN) were used for validating the results of this study. FOEN currently has nine operational stream discharge monitoring stations within the Thur River Basin providing hourly cumulative discharge information (Table 1). Among the different sub-basins, Rietholzbach – Mosnang (S9) is a research catchment that has been used for about 40 years as it is representative of pre-alpine countryside (Gurtz et al., 1999). The contributing areas as well as elevation range and land cover differ significantly from one station to another. All the sub-catchments have the annual peak flow during the spring months, but varying from March to June depending on their respective elevation. Despite differences in the annual mean runoff, flow duration curves for the different sub-catchments have a similar shape. This is supported by a two-sample Kolmogorov-Smirnov test among all the possible sub-catchment pairs. The test