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Comparison of four regionalisation methods for a distributed hydrological model

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Summary This study presents a grid-based modification of the HBV model concept and four regionalisation approaches using widely available catchment characteristics in the meso-scale Neckar catchment. The HBV model was adapted to allow for the simulation of catchment runoff and daily groundwater recharge in a high spatial discretisation. The resulting large number of model parameters requires the use of a regionalisation method which also ensures consistent parameter estimation. Therefore, in the first approach, functional relationships between catchment characteristics and model parameters have been defined a priori. These established relationships were used to calibrate the model by modifying the parameters of the transfer functions instead of the model parameters themselves. The results are compared to relationships derived from simultaneously calibrated model parameters constrained to form a function of catchment characteristics by a modification of the Lipschitz condition, a monotony condition and a combination of both constraints. Through this reduction of the available parameter space for optimisation, the problem of equifinality is avoided which often results in weak regression relationships between model parameters and catchment characteristics. The methodology is demonstrated using six subcatchments of the Neckar basin to set up the relationships and 51 other subcatchments to evaluate its performance. All four methods were able to produce reasonable parameter sets for most of the regionalisation catchments. As expected, all four methods failed to reproduce the observed discharge in karstic areas and in heavily modified or regulated river basins, which indicates their sensitivity to catchment characteristics. The modified Lipschitz condition produced the most efficient simulations of observed discharges in the regionalisation at the cost of some inconsistencies in the physical interpretation of the resulting relationships. The monotony condition preserved the assumed trends in the functions between cell properties and model parameters but produced sharp jumps which are not considered plausible. The combination of both methods seems to be the most promising because it produced equally good regionalisation results with much more consistent regression relationships.

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The approach can reproduce derived trends and the resulting relationships match our understanding of how the underlying processes are represented in the model.

Introduction

Relationships between catchment characteristics and model parameters are important prerequisites for the parameterisation of distributed hydrological models, assessment of land use changes and predictions in ungauged basins Sivapalan et al., 2003. As distributed information is used more and more in water resources management and planning, there is a continuing need for improved parameterisation strategies of distributed models. As the effect of land use changes can not always be assessed with experimental data, distributed models are currently the most promising way to solve this problem (Hundecha and Bárdossy, 2004).

Vogel (2005) provides a comprehensive overview of regionalisation studies and approaches. Besides bi- and multivariate regression, clustering, kriging, neural networks and hydrologically homogeneous regions have been used but so far with only limited success. The biggest problem in most of these studies has been the existence of multiple optimal parameter sets which results in weak regression relationships when the regionalisation is carried out after individual calibration.

Parajka et al. (2005) found that a kriging approach and a similarity approach performed best when they tested 17 methods of the types arithmetic mean, spatial proximity, regression and similarity on the HBV model parameters of 320 Austrian catchments. Lee et al. (2005) attempted to find relationships between suitable conceptual rainfall-runoff model structures and catchment types to improve the reliability of model regionalisation to ungauged catchments. They investigated 28 UK catchments and 12 potential model structures but did not find strong correlations to area, baseflow index or annual average rainfall. Maréchal and Holman (2005) developed a catchment-scale rainfall-runoff model parameterised by the UK Hydrology of Soil Types classification. They calibrated the model to three distinct catchments and found promising results for the regionalisation of the parameters throughout the UK.

However, scale-differences between the variables the relationships were developed for and those they are applied on require additional attention. Xu (2003) found that the parameters of a monthly water balance model could be transferred by regression from 22 meso-scale subcatchments in the NOPEX area to the 30 times larger Lake Mäaren basin in Sweden.

Nevertheless, for distributed water balance models, regionalisation of the parameters is often the only possibility to reduce the uncertainty from overparameterisation, effective grid scale parameters and the model structure or sometimes to find appropriate parameter values at all (Beven, 2001). Engeland et al. (2001) therefore used a Bayesian approach to parameterise the 2 km^2 gridded ECOMAG model for nine catchments of the NOPEX region in Sweden, based on six soil and five land use classes. A limit in the identifiability was reached for three snow related parameters after data from seven catchments was included. On the other hand two retention related parameters (depression storage and vertical conductivity) could not be defined appropriately with information from all nine catchments.

Beldring et al. (2003) calibrated six parameters for five land use classes in their 1 km^2 distributed HBV model of Norway. They ran the model with a daily time step but used monthly mean runoff for calibration in 141 catchments. Although they used 31 parameters to describe the altitude gradients, they found that the major problem was the spatial interpolation of the meteorological input data.

In this study, five parameters of a 1 km^2 gridded version of the HBV model are estimated based on soil properties, topography and six land use classes. Four regionalisation methods are compared: The first approach estimates the relationships between catchment characteristics and model parameters directly. Following the ideas of Hundecha and Bárdossy (2004), transfer functions are defined and the parameters of the transfer functions are calibrated instead of the model parameters themselves. The other three more general approaches use prior knowledge about the form of these functions. By imposing conditions on the relationships between model parameters and catchment characteristics the available parameter space for calibration is significantly reduced. This is demonstrated with a modified Lipschitz condition as a measure of similarity, a monotony condition and a combination of both constraints. The model is calibrated to the central European Neckar basin.

Data

The Neckar basin, located in south-western Germany, covers an area of about 14,000 km^2 (Fig. 1). The elevation in the catchment varies from 91 m a.s.l at the catchment outlet to about 1030 m a.s.l in the Swabian Alb in the south of the catchment. The climate can be characterised as humid with a long-term average annual precipitation of 950 mm, ranging from 750 mm in the lower part to over 1200 mm in the Black Forest.

Land use (Landsat 1993, resolution 30 m), soil (Bodenübersichtskarte 200, scale 1:200,000) and topographic data (resolution 50 m) were aggregated to a common resolution (1 km). Precipitation and temperature data for model input was interpolated from observation station data using external drift kriging (Ahmed and de Marsily, 1987). Daily discharge data from 57 gauging stations was used for model evaluation. All data was provided by the State Institute for Environmental Protection Baden-Württemberg.

The distributed HBV model

The HBV model concept was developed by the Swedish Meteorological and Hydrological Institute in the early 1970s. It has conceptual routines for calculating snow accumulation and melt, soil moisture and runoff generation,