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Development of a transient, lumped hydrologic model for geomorphologic units in a geomorphology based rainfall-runoff modelling framework

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We propose a modelling framework for distributed hydrological modelling of 10^3-10^5 km^2 catchments by discretizing the catchment in geomorphologic units. Each of these units is modelled using a lumped model representative for the processes in the unit. Here, we focus on the development and parameterization of this lumped model as a component of our framework.

The development of the lumped model requires rainfall-runoff data for an extensive set of geomorphological units. Because such large observational data sets do not exist, we create artificial data. With a high-resolution, physically-based, rainfall-runoff model, we create artificial rainfall events and resulting hydrographs for an extensive set of different geomorphological units. This data set is used to identify the lumped model of geomorphologic units. The advantage of this approach is that it results in a lumped model with a physical basis, with representative parameters that can be derived from point-scale measurable physical parameters.

The approach starts with the development of the high-resolution rainfall-runoff model that generates an artificial discharge dataset from rainfall inputs as a surrogate of a real-world dataset. The model is run for approximately 10^5 scenarios that describe different characteristics of rainfall, properties of the geomorphologic units (i.e. slope gradient, unit length and regolith properties), antecedent moisture conditions and flow patterns. For each scenario-run, the results of the high-resolution model (i.e. runoff and state variables) at selected simulation time steps are stored in a database.

The second step is to develop the lumped model of a geomorphological unit. This forward model consists of a set of simple equations that calculate Hortonian runoff and state variables of the geomorphologic unit over time. The lumped model contains only three parameters: a ponding factor, a linear reservoir parameter, and a lag time. The model is capable of giving an appropriate representation of the transient rainfall-runoff relations that exist in the artificial data set generated with the high-resolution model.

The third step is to find the values of empirical parameters in the lumped forward model using the artificial dataset. For each scenario of the high-resolution model run, a set of lumped model parameters is determined with a fitting method using the corresponding time series of state variables and outputs retrieved from the database. Thus, the parameters in the lumped model can be estimated by using the artificial data set.

The fourth step is to develop an approach to assign lumped model parameters based upon the properties of the geomorphological unit. This is done by finding relationships between the measurable physical properties of geomorphologic units (i.e. slope gradient, unit length, and regolith properties) and the lumped forward model parameters using multiple regression techniques. In this way, a set of lumped forward model parameters can be estimated as a function of morphology and physical properties of the geomorphologic units. The lumped forward model can then be applied to different geomorphologic units.

Finally, the performance of the lumped forward model is evaluated; the outputs of the lumped forward model are compared with the results of the high-resolution model.

Our results show that the lumped forward model gives the best estimates of total discharge volumes and peak discharges when rain intensities are not significantly larger than the infiltration capacities of the units and when the units are small with a flat gradient. Hydrograph shapes are fairly well reproduced for most cases except for flat and elongated units with large runoff volumes. The results of this study provide a first step towards developing low-dimensional models for large ungauged basins.