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An introduction to the hydrological modelling system PREVAH and its pre- and post-processing-tools

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ABSTRACT

Spatially distributed modelling is an important instrument for studying the hydrological cycle, both concerning its present state as well as possible future changes in climate and land use. Results of such simulations are particularly relevant for the fields of water resources, natural hazards and hydropower. The semi-distributed hydrological modelling system PREVAH (PREecipitation-Runoff-EVApotranspiration HRU Model) implements a conceptual process-oriented approach and has been developed especially to suit conditions in mountainous environments with their highly variable environmental and climatic conditions.

This article presents an overview of the actual model core of PREVAH and introduces the various tools which have been developed for obtaining a comprehensive, user-friendly modelling system: DATAWIZARD for importing and managing hydrometeorological data, WINMET for pre-processing meteorological data, GRIDMATH for carrying out elementary raster data operations, FAOSOIL for processing FAO World Soil Map information, WINHRU for pre-processing spatial data and aggregating hydrological response units (HRU), WINPREVAH for operating the model, HYDROGRAPH for visualising hydrograph data and VIEWOPTIM for visualising the calibration procedure. The PREVAH components introduced here support a modelling task from pre-processing the data over the actual model calibration and validation to visualising and interpreting the results (post-processing). A brief overview of current PREVAH applications demonstrates the flexibility of the modelling system with examples that range from water balance modelling over flood estimation and flood forecasting to drought analysis in Switzerland, Austria, China, Russia and Sweden.

Software availability

Software name: PREVAH hydrological modelling system
Contact: prevah@giub.unibe.ch
Hardware requirements: Personal Computer
Software requirements: Windows 98/ME/NT/2000/XP/Vista
Coding language: Compaq Visual Fortran 6.6C
Availability: Sample project and extensive documentation at http://www.hydrologie.unibe.ch/PREVAH; for full version, contact authors via e-mail (see above)
Cost: Free for non-commercial academic research. Training courses are provided upon request

1. Introduction

In the past decade, spatially distributed modelling became an established tool for studying both components and possible changes of environmental systems. The hydrological cycle has great significance in these systems since it connects geology, ecology, atmosphere and society and involves basic sciences such as physics, chemistry and biology (Savenije, 2009). Furthermore, all of these aspects are integrated into a single response through runoff at the catchment's outlet. When the hydrological cycle is brought into focus, important fields for models are water resources in individual basins (e.g. Singh and Bengtsson, 2005; Christensen and Lettenmaier, 2007) and at global scale (e.g. Barnett et al., 2005; Viviroli et al., 2007a), natural hazards and extremes such as floods (e.g. Cameron et al., 2000; Lamb and Kay, 2004) and droughts (e.g. Zappa and Kan, 2007; García et al., 2008), hydropower (e.g. Bergström et al., 2001; Schaefli et al., 2007), and ecology (e.g. Zierl, 2001; Randin et al., 2006;

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Hannah et al., 2007). In order to understand the effects of changes in the system (e.g. climate, land use, population dynamics), it is of paramount importance to have models at hand which, through adequate representation of key processes, give the right answers for the right reasons under present conditions (Kirchner, 2006) and therefore provide reliable estimates for potential future conditions.

When we concentrate on hydrological processes at catchment scale, aforementioned adequacy calls for physically congruous hydrological models, including their careful parameterisation, calibration and evaluation (Gurtz et al., 2003; Refsgaard, 1997; Uhlenbrook and Leibundgut, 2002). Especially for mountainous catchments, simulation is a challenging task since the environment is characterised by highly variable morphology, soil and vegetation types as well as by pronounced temporal and spatial variations of the climatic elements (Klemeš, 1990; Gurtz et al., 1999; Weingartner et al., 2007). Depending on the location and elevation of a watershed, mountain discharge regimes are influenced by glacial melt, snowmelt, rainfall and their spatial and temporal superposition (Weingartner and Aschwanden, 1992). The quality of a hydrological simulation depends on the ability of the underlying model to describe and accurately represent the heterogeneity of such hydrological systems at the different spatial and temporal scales.

The semi-distributed hydrological catchment modelling system PREVAH (Precipitation-Runoff-Evapotranspiration HRU Model) has been developed to suit these conditions. Its main purpose is to describe the hydrological processes in mountain environments in their high spatial and temporal variability. With a view to keeping computational cost and complexity of process descriptions within reasonable bounds, PREVAH implements a conceptual, process-oriented approach.

In order to encourage its application, the actual model core of PREVAH (Gurtz et al., 1999, 2003) has been supplemented over the past few years by a large number of tools. These tools facilitate handling the large amounts of data involved in pre-processing and post-processing tasks, model parameterisation, calibration and evaluation as well as visualisation of results. This user-friendliness constitutes an important prerequisite for thorough and extensive modelling studies which are, for example, necessary for regionalisation, i.e. application of models in regions where calibration data are not available (Beven, 2007). Paired with the flexible modular structure, the easy applicability furthermore facilitates the incorporation of uncertainty and sensitivity frameworks (Beven and Freer, 2001; Campolongo et al., 2007; Refsgaard et al., 2007), identification of models or model components (Wagener and McIntyre, 2005; Bai et al., 2009), application of ensemble methodologies (Atger, 2004; Ahrens and Jaun, 2007; Roulin, 2007) as well as assimilation of novel data products such as soil moisture estimates from remote sensing (Vischel et al., 2008; Immerzeel and Droogers, 2008; Parajka et al., 2009) or radar-based precipitation estimates (Borga, 2002; Zhang et al., 2004; Kim et al., 2008; Germann et al., 2009).

After a short review of hydrological models and the position of PREVAH (Chapter 2), this article presents an overview of PREVAH's most important key features (Chapters 3 and 4) and describes the tools accompanying it (Chapter 5), altogether constituting a complete hydrological modelling system. An overview of selected applications demonstrates the abilities of PREVAH and the flexibility of its tools (Chapter 6). The presentation is completed with a discussion of PREVAH's strengths and limitations (Chapter 7) and an outlook (Chapter 8).

2. Development of hydrological modelling and position of PREVAH

Hydrological models are important tools for simulating the behaviour of catchments in space and time and provide important information to both scientists and policy makers. By means of mathematical equations, such models attempt to represent – in varying degree of detail – the complex interactions of water, energy and vegetation.

With the digital revolution which started in the 1960s it became possible to simulate different components of the hydrologic cycle and integrate them in a single model (Singh and Woolhiser, 2002). The first attempt in that direction was the pioneering Stanford Watershed model (Crawford and Linsley, 1966). Being a 'lumped' and process-oriented model, it represents entire landscape units as interconnected reservoirs for which hydrological fluxes and storage levels are computed and the mass balance is solved. Representatives of this model type are, among many others, the Sacramento Soil Moisture Accounting (SAC-SMA) model (Burnash et al., 1973; Burnash, 1995), the Hydrologiska Byråns Vattenbalansavdelning (HBV) model (Bergström, 1976; Lindström et al., 1997), the Tank model (Sugawara, 1967) or the Xinanjiang model (Zhao, 1977; Zhao and Liu, 1995). Spatially refined application of lumped models is achieved by sub-dividing a catchment into smaller landscape units or even raster grid cells. In spite of their strong conceptualisation, lumped models have proven to be robust and are therefore still very popular, particularly for flood forecasting and water resources planning and management. Moreover, they can cope with reasonable quantities of meteorological and physiogeographical input data and are therefore applicable in a wide range of environments.

A large number of more physically based and distributed modelling tools were devised since. An ambitious approach was pursued in the widely known Système Hydrologique Européen (SHE) (Abbott et al., 1986a,b) which follows the so-called Freeze–Harlan blueprint (Freeze and Harlan, 1969), thus departing from non-linear partial differential equations for different surface and subsurface processes. Another interesting concept is found in the popular TOPMODEL distributed simulation tool (Beven and Kirkby, 1979) which considers saturation excess to compute runoff formation; it is based on a topographic index which is calculated for each pixel. Interesting examples of recent developments of distributed models are the Water balance Simulation Model-ETH (WaSiM-ETH), a fully distributed model with a highly physical description of hydrological processes (Klok et al., 2001), the TOPographic Kinematic APproximation and Integration (TOPKAPI) model, a fully distributed and physically based hydrologic model (Liu and Todini, 2002), and the Gridded Surface/Subsurface Hydrologic Analysis (GSSHA) model, an enhanced version of the two-dimensional, physically based model CASC2D which considers streamflow generation by both infiltration excess and saturation excess mechanisms, as well as exfiltration and groundwater discharge to streams (Downer et al., 2004). It would however be beyond the scope of this paper to deal in more depth with the large number of models available today. For a more comprehensive review, the reader is referred to Singh and Woolhiser (2002), Reggiani and Schellekens (2005), Singh and Frevert (2006) and Todini (2007).

PREVAH, in general, follows the HBV model structure and is process-oriented. The lumped formulation of the original HBV was however changed to semi-distributed by implementing hydrological response units (HRUs), which is a cost-efficient way of achieving spatially distributed results. Furthermore, PREVAH contains a number of improvements and extensions which concern the soil moisture accounting and evapotranspiration scheme, the interception module, the combined temperature-radiation modules for snow- and icemelt, distinct glacier storage modules for firn-, snow- and icemelt as well as a three-department groundwater module. These components are discussed in more detail in the following Chapter 3. A comparison against the fully distributed and more physically formulated WaSiM-ETH showed that PREVAH