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Water resources under global change: Process-based hydrological modelling for the lower catchment of the Jordan River

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Abstract

Downstream of Lake Kinneret the climatic regime of the Jordan river catchment changes to semiarid or even arid conditions. Hence specific tools are required to cope with enhanced spatial and temporal variability of rainfall and adequate modelling of generated overland flow by saturation or infiltration excess. To simulate climatological variability, historical extremes (dry and wet seasons) are modelled using C-band rainfall radar data as model input. A parsimonious model concept (the ZIN-model) was successfully tested in a neighbouring 680 km^2 catchment. It was run both in a single event and continuous mode using a constant set of field derived parameters. When model runs were started at high antecedent moisture conditions, single event simulations were promising, while longer term continuous simulations were less accurate both under- and overestimating the catchment scale runoff response. For the Jordan River it is envisaged to couple this process-based approach with the hydrological model TRAIN. This model focuses on the continuous simulation of processes at the interface between soil, vegetation and atmosphere and thus helps to identify e.g. water use from vegetated surfaces and related water stress conditions. The model combination leads to improved simulations of longer term components (evapotranspiration, soil moisture, ground water recharge) of the water cycle. As such, detailed patterns of available water resources for historical extremes are expected. These will be correlated to climatic change scenarios to arrive at sound estimates of induced changes in water availability all across the lower Jordan River.

Introduction

Similar to other dry regions in the Middle East, runoff generation in the Lower Jordan River catchment (downstream of Lake Kinneret) is limited to a few hours only, follows single rainstorms and is highly variable in space and time. Dominating runoff processes are saturation excess in Mediterranean areas, e.g. Lange *et al.* (2003) and infiltration excess in arid parts e.g. Lavee *et al.* (1998). This means indirect runoff components, which are important in the upper Jordan River, (e.g. interflow, snowmelt, groundwater components) only play a minor role. Hence runoff generation is directly linked to rainfall making a correct assessment of catchment rainfall an important prerequisite to dependently estimate generated surface runoff. Once a dependable rainfall input is available for modelling, adequate, process-based approaches are needed to translate rainfall to volumes of surface water. This will help to manage the water resources of the region, since to date no systematic, regional estimates of naturally available surface water resources in the Lower Jordan River catchment exist.

Assessing rainfall variability by volume scanning rainfall radar

Rainfall in the area is characterized by accentuated spatial and temporal variability with the majority of large floods generated by high intensity rainstorms of a limited spatial extent which are difficult to measure. Conventional ground measurements may be effective in very small catchments in which a reasonable gauge density may be achieved. In larger catchments the number of gauges needed to evaluate the spatial variability exceeds reasonable numbers. Here the use of volume scanning rainfall radar is an appropriate solution. In the region existing C-band volume scanning radar data is loaded with ground clutter (misleading radar echoes from the ground rather than from raindrops) originating from the unfavourable location of the radar antenna: Since the terrain rises up in very short distances from the antenna, only large vertical beam angles guarantee clutter free radar echoes. However, a minimum angle is necessary to prevent cloud overtopping and non-realistic results. Therefore various steps to improve radar echoes (e.g. vertical reflectivity analysis, GIS-based clutter correction) must be carried out before adjusting radar measurements to ground rainfall. Only then historical extremes (dry and wet seasons) are can be modelled using rainfall radar data as model input.

Hydrological model concepts

For the Jordan River it is envisaged to couple two different modelling concepts: the SVAT model TRAIN and the hydrological model ZIN. TRAIN is a physically-based, spatially distributed model which includes information from comprehensive field studies of the water and energy balance (Menzel, 1999). It has been designed to simulate the spatial pattern of the individual water budget components at different spatial and temporal resolutions. Special focus is on processes at the soil-vegetation-atmosphere interface, with evapotranspiration as one of the principal mechanisms. TRAIN has successfully been applied and validated at selected sites (including both agricultural and natural vegetation) in the Jordan region, where continuous climate data series and information on soils, land-cover and individual water balance components were available. This work served to further develop the model for an improved consideration of hydrological processes of semi-arid and arid environments and helped to evaluate the interactions between water fluxes, vegetation and landuse under the given climatic and physiographic conditions.

The ZIN model has originally been developed for high magnitude floods in arid rocky desert catchments (Lange *et al.* 1999). It is spatially distributed, concentrates on dominating processes of arid and semi arid zone flood response and can be parameterized including only field-based parameters with rainfall radar as input. On runoff producing slopes runoff generation can be described by infiltration-, saturation excess or by a combination of both. Infiltration excess is parameterized by a concept of initial losses and a temporal variable infiltration rate. The infiltrated amount is filling a volume of soil storage which is emptied by evapotranspiration or deep infiltration. When soil storage is filled, saturation excess is the dominant process of runoff generation. From small tributary catchments overland flow is delivered to adjoining channels where runoff is routed using the Muskingum-Cunge routing scheme. Up to now the model has been applied to urban environments and different scale arid and semi arid catchments.

As TRAIN simulates rather long term fluxes between soils, vegetation and atmosphere it is an ideal supplement to ZIN, which concentrates on short term runoff generation processes. The coupling layer of both models is the soil storage. Here a "dynamic" coupling will be performed with a flexible time step of modelling adapted to periods of rain and no-rain. During times of rain the field-based runoff generation routine of the ZIN model is active describing the filling of the soil storage (field derived infiltration functions) and overland flow generation by Hortonian or saturation excess runoff. Certain modules of TRAIN will be de-activated (e.g. evapotranspiration, which is negligible during rainfall). The generated surface runoff will be concentrated, and routed through the channel network by ZIN accounting for surface reservoirs and channel transmission losses. During times of no-rain the soil module of TRAIN is active emptying the soil storage by evapotranspiration. These calculations are important for modelling the next event, as they describe initial filling of the soil storage. As such TRAIN provides the missing long term soil moisture reduction terms to ZIN. This changes the single event model ZIN to a combined model that can be run on a continuous mode. On the other hand the runoff generation, concentration and routing routines of ZIN provide hydrological components additionally to TRAIN making the combined model two-dimensional accounting for lateral fluxes and spatial concentration of water resources important for water management.

Model application in a neighbouring catchment

The ZIN-model was successfully tested in a neighbouring 680 km^2 Wadi (Nahal) Ayalon located in the western Judean (West Bank) Mountains. There hydrological process knowledge was incorporated into the model to analyse a series of large floods in the historic rainfall season 1991/92 with C-band rainfall radar data serving as model input. Using a simple concept of a soil storage emptied by infiltration during rainfall, long term percolation and constant evaporation, the model concentrated on the dominating process of flood generation at high moisture states: saturation excess runoff. It was run both in a single event and continuous mode using a constant set of field derived parameters. When model runs were started at high antecedent moisture conditions, single event simulations were promising, while longer term continuous simulations were less accurate both under- and overestimating the catchment scale runoff response (Fig. 1).

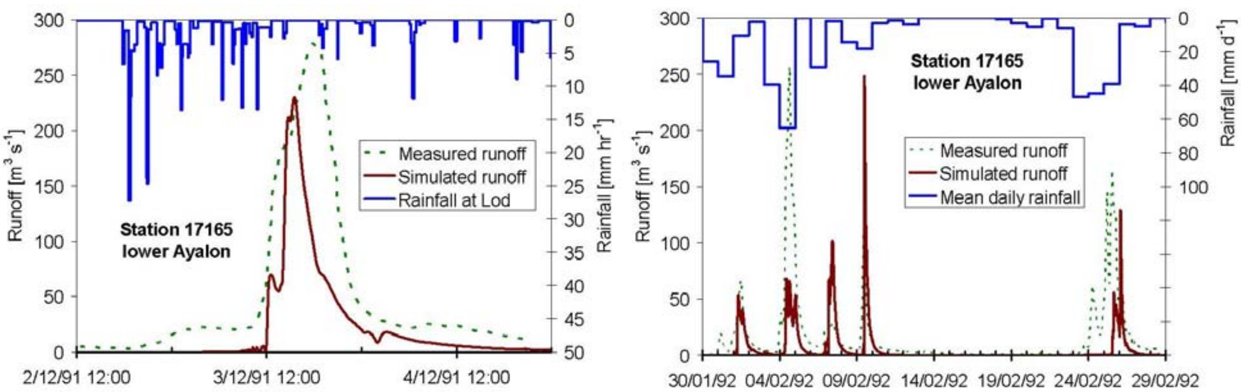

Figure 1. Results of the ZIN-model application in Wadi Ayalon; left: single event modelling, right: continuous modelling.

Still the model application suggested that at the 680 km^2 catchment scale large floods were generated by saturation excess runoff on limited parts of the catchment. Runoff generating zones seemed to be mainly restricted to slopes with southern exposition characterized by higher water deficits than their north facing counterparts resulting in sparser vegetation and thinner soil covers.

This was in line with the results from field experiments, where overland flow on a rocky slope was traced and measured, while an opposite vegetated slope did not produce any runoff. Although the available radar data were heavily loaded with ground clutter and only limited ground information for calibration existed, the model provided non-biased, reliable estimates of catchment rainfall in adequate temporal and spatial resolution. This was finally checked comparing model simulations and gauged streamflow data.

Outlook

We expect that the planned model coupling will lead to improved simulations of both short term runoff generation and longer term water balance components (evapotranspiration, soil moisture, groundwater recharge). As such, detailed patterns of available water resources for historical extremes (extremely dry and wet seasons) can be determined. These will be correlated to climatic change scenarios to arrive at sound estimates of induced changes in water availability all across the lower Jordan River. In a first step, we will apply the newly coupled models in focus regions on both sides of the river. In a second step, obtained results will be regionalized to the entire catchment.

References

Lange, J., Leibundgut, Ch., Greenbaum, N. & Schick, A. P. (1999) A noncalibrated rainfall-runoff model for large, arid catchments. Water Resources Research 35 (7), 2161-2172.

Lange, J., Greenbaum N. , Husary S., Ghanem M. , Leibundgut C. & Schick AP (2003 a): Runoff generation from successive simulated rainfalls on a rocky, semi-arid, Mediterranean hillslope. Hydrological Processes 17, 279–296.

Lavee, H., Imeson, A. C. & Sarah, P. (1998) The impact of climate change on geomorphology and desertification along a mediterranean-arid transect, Land Degradation and Development 9, 407-422.

Menzel, L. (1999) Flächenhafte Modellierung der Evapotranspiration mit TRAIN, PIK-Report No.54, Potsdam-Institut für Klimafolgenforschung (PIK), Potsdam.