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The water and energy balance at basin scale: a distributed modeling approach

Abstract

In recent years, the hydrologic research has evolved towards an overall theory describing the mass, energy and motion quantity exchanges between surface and atmosphere at several scales. At the same time, several inflow-runoff models have been developed and, independently, Soil-Vegetation-Atmosphere-Transfer (SVATs) schemes. Inflow-runoff models, based on the unitary instantaneous geomorphological hydrograph are successful in flood events modeling, but they are generally unable to follow flow-rate evolution afterwards.

In this work the surface energy and water balance coupled system, ranging from the local scale (a one-dimensional solution of the water and energy balance), the hillslope scale (a quasi-three dimensional solution of the vertical and lateral water redistribution), to the catchment scale, in small mountain basins and medium-size floodplains basins, is analyzed.

A new distributed hydrological model, called *GEOTop,* bas been developed. It can be seen both as an inflow-runoff model able to simulate hydrological cycle with continuity in the time and as an attempt to incorporate in SVATs an adequate treatment on hydrological variability at small scales (in particular the effects due to different uses of soil, complex topography and channel network).

GEOTop is a terrain-based model, i.e. it is based on the employment or DEMs (digital elevation models); it is a distributed model, since all the simulated variables are returned for each pixel in the basin; it is a model of the hydrological cycles, in the sense that it simulates all the elements of the hydrological cycle, and not only the mass balance but also the energy balance. As to the soil-atmosphere interaction, *GEOTop* follows the treatment implemented in SVATs, but emphasis is put on the description of the topographic effects on the energy balance. *GEOTop* implements a suitable solution of Richards equations, which makes it possible to describe also the flow and infiltration transients generated by the dynamics of the suction potential gradient and not only the flows moved by the topographic gradient (like TOPMODEL). Discharge calculation is done using the GIUH approach.

The diagnostic and prognostic effectiveness of the model is analyzed in several study cases of increasing complexity. At local scale the energy balance has been validated against eddy correlation measurements collected at Bolzano airport (Italy) and snow melt processes are analyzed at the Tonale Pass (TN, Italy). At basin scale, the model has been validated with field data collected in Lake Serraia basin (TN, Italy) and Little Washita basin (OK, USA), during the Southern Great Plains 97 experiment. Moreover, on the last data-set , a comparison to the Variable Infiltration Capacity (VIC) model has been performed.

At the local scale, the model works as a single-column LSM, capable of predicting with sufficient accuracy the soil moisture profile and the energy balance components at the surface. At basin scale, the model is able to simulate stream-flow with not more calibration than a typical rainfall-runoff model, but it is also capable of capturing the spatial distribution or the surface soil moisture, and it can be used as a tool to understand what the major controls on soil moisture patters are.
The model has been applied to the Solstice (CA, USA) experimental basin, to understand the runoff production mechanism in small headwater catchments. Model results confirm the importance of considering the flow inside the bedrock to reproduce the basins response. Moreover, the model shows that a significant contribution to the saturated area is given by the potential suction gradient, which forms at the interface between unsaturated hillslopes and saturated hollows, whose modeling can be neglected, as in most of the currently available hydrological models.
Finally, the *GEOTop* model has been used to analyse the short-term effects on the topography variation on surface and subsurface lateral water flows and on evapotranspiration. Moreover, the effects of the variations in the hydrographic network extent and in the soil thickness have been analyzed individually, so as to consider its effects separately. The results of this investigation show that the presence of topography and the degree of detail with which the hydraulic network is presented, influence the hydrologic balance and that a parametrization of these processes in models at greater scale is necessary.