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How to upscale the coupling between hydrology and vegetation at the hillslope scale with an equivalent soil-vegetation column model

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Three-dimensional watershed models coupled with land surface models have demonstrated the control of soil moisture over land energy fluxes, as evaporation and transpiration (Maxwell and Kollet, Nature Geoscience, 2008; Condon et al., Advances in Water Resources, 2013). However, due to computational costs, these fully integrated watershed models cannot be used at larger scales. Upscaling hydrological models can be an alternative to take into account the impact of groundwater hydrology on land energy fluxes at various scales. In this purpose, we propose a two-step upscaling methodology aiming to replace a hillslope model by an equivalent vertical soil column model suitable for land surface modelling.

The hillslope reference model is based on a two-dimensional aquifer model (resolution of Richards' equation) combined with a representation of vegetation and climate forcing as boundary condition. In this system, two main hydrological processes corresponding to different time scales have to be distinguished: the vertical water transfer from roots to the atmosphere through the vegetation, and the longitudinal flow of the aquifer to the stream. In an upscaling approach, two options can be considered: one may accurately model the aquifer longitudinal flow but with a degraded model of vertical transfer, or inversely give a preferential treatment to the vertical flow. As the exchanges between soil, vegetation and atmosphere are strongly dependent on the vertical profile of water (through the distribution of roots), the second option appears to be more adapted to our objective which is the assessment of hillslope hydrology on land surface fluxes.

In the first step of our upscaling methodology, the two-dimensional reference hillslope is modelled as a set of one-dimensional independent vertical soil vegetation columns. In each of them, Richards' equation is solved in the vertical direction, the representation of roots and climate forcing remaining unchanged. Moreover, a sink term is added to Richards' equation at the bottom of the column to model groundwater discharge to streams. Contrary to what has already been proposed (Liang et al., Journal of Geophysical Research, 1994; Yeh and Eltahir, Journal of Climate, 2005; Niu et al., Journal of Geophysical Research, 2007), this sink term is deduced from Darcy's law and Van Genuchten's relationships. Through the approximation of a linear groundwater table profile in two dimensions, a differential equation of the water table depth at a fixed distance from the river has been determined. It depends on topographic and soil parameters, and on the distance between the stream and the modelled column. Different types of soil and climate forcing (especially precipitations) have been tested in the above framework. Comparisons between the 2D reference model and a few 1D columns show good agreement in water table depth and evapotranspiration fluxes. This justifies using an equivalent column to replace the set of independent columns, with respect to evapotranspiration fluxes.