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Control of mass balance error in a detailed model of surface–subsurface flow interaction

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Several process-based catchment-scale hydrologic models have been developed in recent years to describe the interactions and feedbacks between different components of the water cycle, but few studies have considered the sources of coupling error in these models. In this work we analyze the sequential iterative coupling scheme of the distributed model CATHY (CATchment HYdrology) in order to identify the different sources of mass balance error and to examine how these are influenced by topography, hydraulic properties, and atmospheric forcing. A pair of adimensional indices that quantify the degree of coupling and of flux partitioning is presented. Our analysis shows that mass balance errors increase during the flood recession limb because of the exchange of information between surface and subsurface water flow. Surface water propagation is cell centered, while the subsurface flow equation is solved on the vertices of surface cells. Evaluation of surface pressure heads and exchange fluxes is critical on this staggered surface–subsurface mesh, especially during transitions from unsaturated to saturated conditions and vice versa. A modified version of the flux exchange algorithm is introduced that considers the effective availability of water on surface cells. The performance of the model is also improved by introducing a heuristic procedure to control and adapt the time step interval. Starting from numerical stability and convergence constraints, this procedure varies the computational interval as a function of the rate of change of surface saturation via the coupling degree index. A final improvement made to the sequential coupling scheme in CATHY is to solve the surface routing equation after rather than before the subsurface module. We find that the modified version improves the water balance by more than 50% in most of the tests considered for a simple v-shaped catchment. The results so far obtained for the synthetic v-catchment indicate the need for a more comprehensive analysis including real catchments.