Simulating Flow and Contaminant Transport in Integrated Surface-subsurface Flow Systems: Model Applications at Multiple Catchment Scales

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Abstract: Over the past several years, increasing attention has been directed towards understanding flow and solute transport processes occurring at the interface between surface water and groundwater, and a variety of numerical strategies have been proposed to couple these processes in a holistic, physically-based modelling framework. In this paper, we will examine these coupling strategies in the context of the HydroGeoSphere model, a recently-developed surface/subsurface control-volume finite element model. HydroGeoSphere is a fully-coupled 3D model that can simulate water flow and advective-dispersive solute transport on the 2D land surface and in the 3D subsurface under variably-saturated conditions. Full coupling of the surface and subsurface flow regimes is accomplished implicitly by simultaneously solving one system of non-linear discrete equations describing flow and transport in both flow regimes, as well as the water and solute fluxes between continua. The model capabilities and main features are demonstrated with several high-resolution 3D numerical simulations performed for catchments of various scales, ranging from the scale of an intensively-monitored rainfall-runoff-tracer experiment (~ 2000 m2), to a regional-scale watershed of about 1000 km2, to the continental scale that comprises the entire Canadian land mass. The simulations highlights the difficulties and challenges for representing water flow and solute flux in complex natural systems, and stresses the advantage of using a process-based model such as HydroGeoSphere for prediction of current and future water management scenarios. Among the challenges associated with such simulations is the discrepancy in spatial and temporal resolutions needed for the surface and subsurface flow domains. New algorithms such as sub-timing and sub-gridding have been developed to alleviate these problems and are demonstrated here. Another challenge illustrated by the simulations concerns data acquisition for the model, in particular scaling-up or scaling-down of model parameters depending on the size of the catchment.