Coupled Surface–Subsurface Modeling across a Range of Temporal and Spatial Scales

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A blueprint for modeling fully integrated surface, subsurface, and land-surface processes that was originally put forth 40 years ago (Freeze and Harlan, 1969) is now becoming a reality. Although truly coupled models have only recently appeared in the literature (VanderKwaak and Loague, 2001; Panday and Huyakorn, 2004; Jones et al., 2006; Kollet and Maxwell, 2006; Qu and Duffy, 2007; Kollet and Maxwell, 2008), there is now a growing library of models and community of modelers that contribute considerably to our understanding of the coupled terrestrial hydrologic and energy cycles. Updated numerical and computational technologies have, in part, enabled new approaches for modeling these coupled interactions. While these models all take different numerical, discretization, and even coupling approaches, they all share the common goal to rigorously, mathematically model the terrestrial hydrologic and energy cycle as an integrated system. Research addressing these issues encompasses a range of scales and includes a variety of processes. Papers in this special section present theoretical, numerical, and process-description advancements to address some of the current research questions in coupled modeling.

This special section of Vadose Zone Journal is composed of five invited contributions, which were originally presented at the 17th Computational Methods in Water Resources 2008 Meeting held in San Francisco, CA (6–10 July 2008). The suite of papers highlights hydrologic modeling approaches and their use to understand interactions and feedbacks of coupled processes across the land-surface interface. The contributions provide a representative cross-section of state-of-the-art physics-based modeling and include numerical studies that address components of the water and energy cycles in an integrated fashion over a wide range of time scales (diurnal to decadal) and spatial scales (column to basin). Papers cover a range of subtopics, including watershed dynamics, impacts of land-use on water quality, feedbacks to evapotranspiration, thermodynamics of soil moisture, infiltration and runoff, and interactions with the atmosphere.

These papers each address current challenges in coupled modeling: the disparate timescales between the surface and subsurface systems, how to better integrate models and observations, inclusion of broader-reaching coupled phenomena such as energy transport or human–water interactions, and expanding traditional physics coupling approaches to be more mathematically accurate.

To better understand and represent the disparate timescales inherent in the surface–subsurface systems, Park et al. (2009) present an implicit, adaptive, time-integration scheme for a fully integrated model (HydroGeoSphere). They use this scheme to decouple the time steps of the surface and subsurface components with a significant improvement in efficiency and minor loss of accuracy. To better couple model and observations Camporese et al. (2009) embed a fully integrated hydrologic model (CATHY) into a data-assimilation framework. They compare an ensemble Kalman filter (EnKF) to a Newtonian nudging (NN) technique for a small catchment in Belgium, demonstrating that the EnKF method outperforms the more straightforward NN approach.

Two articles expand the types of physics normally included in coupled modeling. Kollet et al. (2009) present a model of fully coupled water and energy balance (ParFlowE) that includes conductive and convective heat transport coupled to radiation balance at the land surface, something previously unexplored in integrated modeling. They compared their model simulations to observations collected from a field site in the Netherlands. This paper demonstrates, among other things, the importance of precipitation temperature on the land-energy budget. Panday et al. (2009) apply the fully integrated hydrologic model (MODHMS) to the upper Santa Clara Watershed on the West Coast of the United States. They also incorporate new, coupled physical processes and extend this model to include land-use and associated surface water discharges due to irrigation and other practices. They then use this model to predict the chlorine total maximum daily load (TMDL), a surface-water regulation in the United States.

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Finally, Kumar et al. (2009) advance the accuracy of integrated surface–subsurface systems and present a second-order, finite volume model of coupled surface–subsurface flow (FIHM). They develop the theoretical basis for this model, discuss the coupling approach, and apply it to a number of test cases.

These papers all highlight different theoretical model developments and advancements, pointing to the exciting new developments that fully coupled models portend. Integrated hydrological models are now poised to answer challenging water quality and quantity questions such as the role in hydrologic cycling in water quality for ubiquitous contaminants such as nitrate; how anthropogenic changes affect the hydrologic cycle; and fundamental questions of connections between surface and subsurface flow, land-surface processes, and the atmosphere. The vision put forth 40 years ago (Freeze and Harlan, 1969) is now realized: models of coupled surface–subsurface processes have come of age.

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References