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Large Scale Terrestrial Modeling: A Discussion of Technical and Conceptual Challenges and Solution Approaches

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A number of simulation platforms have been developed to study the spatiotemporal variability of hydrologic responses to global change. Sophisticated terrestrial models demand large data sets and considerable computing resources as they attempt to include detailed physics for all relevant processes involving the feedbacks between subsurface, land surface and atmospheric processes. Access to required data scarcity, error and uncertainty; allocation of computing resources; and post processing/analysis are some of the well-known challenges. And have been discussed in previous studies dealing with catchments ranging from plot scale research (10^2m^2), to small experimental catchments (0.1-10km^2), and occasionally medium-sized catchments (10^2-10^3km^2). However, there is still a lack of knowledge about large-scale simulations of the coupled terrestrial mass and energy balance over long time scales (years to decades). In this study, the interaction between subsurface, land surface, and the atmosphere are simulated in two large scale ($>10^4$km^2) river catchments that are the Luanhe catchment in the North Plain, China and the Rur catchment, Germany. As a simulation platform, a fully coupled model (ParFlow.CLM) that links a three-dimensional variably-saturated groundwater flow model (ParFlow) with a land surface model (CLM) is used. The Luanhe and the Rur catchments have areas of 54,000 and 28,224km^2 respectively and are being simulated using spatial resolutions on the order of 10^2 to 10^3m in the horizontal and 10^{-2} to 10^{-1}m in the vertical direction. ParFlow.CLM was configured over computational domains well beyond the actual watershed boundaries to account for cross-watershed flow. The resulting catchment models consist of up to 10^8 cells which were implemented over more than 1000 processors each with 512MB memory on JUGENE hosted by the Juelich Supercomputing Centre, Germany. Consequently, large numbers of input and output files were produced for each parameter such as; soil hydraulic characteristics, land cover, geology, hydraulic conductivity, and atmospheric parameters. For example, to simulate the Luanhe catchment for one year at one hour time step, the number of input and output files approach 10^8 files based on the most simple implementation of parallel I/O. Storage requirements quickly approach terabytes in production simulations, while single data files often exceed available memory. Handling these large data sets in terms of pre-/post-processing and visualization demands considerable computing resources and new data analysis tools. The difficulties will increase considerably at even finer lateral spatial resolution and longer simulation times, which will be required in the discussed studies and are planned at 100m and 10^1 years. In this article we present in detail the main challenges and technical issues inherent in simulating the interaction between land surface, subsurface and climate parameters of catchments at the basin scale. We also suggest approaches to overcome some of the discussed difficulties.