ABSTRACT: Current climate-scale land-surface models poorly represent many high-latitude processes important for accurate assessment of climate sensitivity. Recent analyses by our group and others have shown that, for example, the CMIP5 suite of models have a very wide range of predictions of high-latitude soil organic matter stocks, soil temperature profiles, and vegetation properties. To address these important shortcomings, the NGEE-Arctic project is working to integrate observations in a permafrost tundra region with several climate-scale model improvements in CLM. First, we have developed an optimization framework to improve representation of coupled plant carbon and nitrogen cycles. This framework seeks to optimize a specific set of plant processes (e.g., productivity, water use efficiency, nutrient use efficiency, transpiration) and reflects a particular competitive strategy a plant employs for survival, growth, defense, or reproduction. A new set of processes integrating multiple pathways of plant nitrogen uptake and associated plant-microbial interactions are incorporated as well as an improved representation of carbon and nitrogen allocation for plant parts and processes (e.g., photosynthesis and respiration). Second, we describe a subsurface reactive transport capability integrated with vertically-resolved C and N biogeochemistry that allows a consistent representation of the interactions between microbial activity, available nutrients, and soil mineral processes under different environmental controls, as well as the ability to directly compare vertically-resolved measurements with predictions. Third, we describe a capability, critical to the spatial scaling methodology being developed for NGEE-Arctic, of simulating lateral subsurface hydrological and tracer flows. CLM currently has a one-dimensional representation of subsurface flow and employs a non-unified treatment of hydrologic process in the vadose and phreatic zones. We implemented in CLM a variably saturated subsurface flow capability with lateral flows. We describe the hydrological and computational approach, present comparisons with analytical solutions, and present simulation results for idealized and actual watersheds.