Development of a soil-plant-atmosphere continuum model with support for heterogenous computing architectures

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Abstract

Vegetation plays a significant role in land-atmosphere interactions by controlling the surface energy balance and planetary boundary layer. Furthermore, transport of water through the soil-plant-atmosphere continuum (SPAC) regulates transpiration and photosynthesis. DOE's E3SM Land Model (ELM) – v1.0 uses a big-leaf scheme to simulate vegetation processes but does not include a plant hydraulics (PL) model and multi-layer canopy (MLC) model. Thus, ELM is unable to mechanistically simulate transport of water through the SPAC and vertical transport of water vapor and energy within the canopy air space. Inclusion of models for PL and MLC in ELM will require robust numerical methods with a flexible coupling framework to solve tightly coupled multi-physics problems. The Exascale class of DOE supercomputers will have accelerators along with multi-core CPUs, thus the new model developments must include support for heterogenous computing architectures.

In this work, we extend the open-source Multi-Physics Problems (MPP) library to include models for PL and MLC. The MPP library uses PETSc, a numerical library that provides scalable solvers for non-linear and linear system of equations, as well as abstractions for "composition" of optimal, problem-specific solvers from these building blocks. The PL model is used to study the response of stomata to stem water potential in regulating transpiration. The PL model is validated against observations of soil moisture, sap flow, and latent heat flux at the US-UMB study site. We show that the PL model is able to accurately capture the transport of water across the SPAC. The MLC model includes: (i) a vertically resolved shortwave and longwave radiation scheme; (ii) a roughness sublayer model to account for turbulence within canopies; and (iii) models for conservation of water, momentum, and energy within canopies. The MLC model has been benchmarked against the CLM-ml model. Using PETSc's support for heterogenous computing architectures, the MLC model has been successfully run using the GPU accelerators that power DOE's Summit supercomputer. The integration of the new models in the future version of ELM will improve the representation of terrestrial biophysics processes within E3SM.