NGEE-Artic

Development of reduced order models to capture subgrid-scale soil moisture dynamics in a polygonal tundra landscape

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Microtopographic features, such as polygonal ground, are characteristic sources of landscape heterogeneity in the Alaskan Arctic coastal plain. In a future warmer climate, the spatial distribution of soil moisture is expected to be a key environmental factor controlling the rate and products of microbial decomposition of thawed soil organic carbon. Existing land surface models (LSMs) describe physical and biological processes that occur over a wide range of spatial and temporal scales. Methane production and soil moisture dynamics are nonlinearly coupled, thus accurate prediction of mean soil moisture at coarse-resolution alone is insufficient for accurate prediction. Techniques to estimate subgrid soil moisture distribution are required; in this work we present two Reduced Order Model (ROM) methods: (i) A traditional downscaling approach that uses local coarse-resolution solutions to estimate local fine-resolution solution and (ii) a Proper Orthogonal Decomposition (POD) mapping method that reconstructs temporally-resolved fine-resolution solutions based on global coarse-resolution solutions.

We performed multi-year surface-subsurface isothermal flow simulations using the PFLOTRAN model for summer months at six spatial resolutions (0.25 m - 8 m, in increments of a factor of 2). Simulations were performed for four study sites near Barrow, Alaska. Results indicated a non-linear scaling relationship for statistical moments of soil moisture. Coarser resolution simulations were able to accurately capture mean soil moisture for all study sites, but soil moisture variance was significantly under-estimated in coarser resolution simulations. The traditional ROM was able to accurately capture spatial patterns of soil moisture at fine resolution when compared to true fine-resolution simulations (mean error for all study sites was < 1%).

We built the POD-ROMs of the 4-D soil moisture field using simulation results from three summer seasons (1998-2000) for the four study sites individually (single-site) and aggregated (multi-site). The results indicate that the POD-ROM produced a significant computational speedup with very small relative approximation error (< 0.1%) for two validation years not used in training the ROM. We also demonstrated that the POD-ROM approach: (1) efficiently corrects for coarse-resolution model bias and (2) can be used for polygonal tundra sites not included in the training dataset with relatively good accuracy (< 1.5% relative error), thereby allowing for the possibility of applying these ROMs across a much larger landscape. This method has the potential to efficiently increase the resolution of land models for coupled climate simulations, allowing LSMs to be used at spatial scales consistent with mechanistic physical process representation.