EGU21-14039, updated on 19 Jun 2021
https://doi.org/10.5194/egusphere-egu21-14039
EGU General Assembly 2021

Leveraging clustering and geostatistics to improve the modeling of sub-grid land-atmosphere interactions in Earth system models

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Multi-scale spatial heterogeneity over the land surface (meter to km scales) can play a pivotal role in the development of clouds and precipitation. To model this process within Earth system models (ESMs; ~100 km spatial resolution), sub-grid reduced-order modeling approaches are used. More specifically, state-of-the-art ESMs sub-divide the land surface of each grid cell into representative clusters (e.g., forest, lakes, and grasslands) that are learned a-priori from available high-resolution satellite remote sensing data (e.g., STRM, Landsat and Sentinel-2) via clustering. However, until recently, these clusters have remained spatially agnostic making it infeasible to infer spatial statistics of the modeled sub-grid heterogeneity over land that are required by the atmospheric model to ensure proper development of simulated convection (e.g., spatial correlation length of surface evaporation). This presentation will introduce an approach that leverages the precomputed cluster positions in space to construct an effective and efficient approach to assemble the experimental semivariogram from the sub-grid clusters within ESMs. As a proof of concept, we will show results by applying the novel method on sub-grid model output from the HydroBlocks land surface model over a 100 km domain centered at the Southern Great Plains site in Oklahoma, United States. Furthermore, to illustrate the added-value that the experimental semivariograms will have towards improving the modeling of land-atmosphere interactions, we will illustrate the results from large-eddy simulations over the domain that show how differences in correlation length of surface fluxes can have, at times, a dramatic impact on the development of clouds and convection in the atmosphere. When implemented in ESMs, this new approach will make it possible to infer the modeled sub-grid spatial organization of the surface fluxes (e.g., sensible heat flux) per time step with negligible increases in computation expense.