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An Analysis of the Importance of a Fully-Coupled Atmosphere and Land-Surface When Considering the Impact of Multi-Scale Land Spatial Heterogeneity on Cloud Development

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Land-surface heterogeneity is known to play an important role in land-surface hydrology, which drives the bottom boundary condition for atmospheric models in numerical weather prediction (NWP) applications. However, the ultimate impact of land-surface heterogeneity on atmospheric boundary layer (ABL) development is still an open problem with implications for sub-grid scale (SGS) parameterizations for both NWP and climate modeling. Large-eddy simulation (LES) is often used to study the effects of land-surface heterogeneity on ABL development, most typically via specified surface fields which are not influenced by the atmosphere (i.e. semi-coupled). Heterogeneous land surfaces have been seen in previous studies to have a significant influence on ABL dynamics, particularly cloud production, in certain cases when semi-coupled to the atmosphere.

Here we use the Weather Research and Forecasting (WRF) model as an LES with both semi-coupled and fully-coupled land surfaces to investigate the impact of two-way coupling on the interaction between heterogeneous land surfaces and daytime ABLs. For semi-coupled simulations, the HydroBlocks land-surface model is run offline, driven by 4-km NLDAS-2 meteorology with Stage-IV radar rainfall data, and then used to specify the bottom boundary in WRF. The WRF-Hydro model is used for cases where the land surface is fully coupled to the WRF model. Both land-surface models use the Noah-MP model as their underlying physics package and add both subsurface and overland flow routing. The WRF model uses a 100-m horizontal resolution, and the land-surface models use high resolution (30 m) datasets that were upscaled to match the LES resolution for elevation, landcover, and soil type using NED, NLCD, and POLARIS respectively. These LES experiments are performed over the ARM Southern Great Plains Site atmospheric observatory in Oklahoma during the Summer of 2017 with a grid size of 100 km x 100 km to imitate a single cell in a modern climate model. The impact of land-surface heterogeneity on the atmosphere is evaluated by comparing simulations using the fully heterogeneous land surfaces with simulations where the land surface is homogenized at each timestep, taking a domain-wide spatial mean value at every grid cell. Results are evaluated primarily by the differences in the development of clouds and evolution of turbulent kinetic energy in the ABL.