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Massively Parallel Multiscale Simulations of the Feedback of Urban Canopies

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Urban canopies consist of buildings and trees that are aligned along a street in the horizontal direction. These canopies in cities and forests modulate the local climate considerably in a complex way. Canopies constitute very fine subgrid features that actually have a significant impact on other components of earth system models but their feedbacks on larger scales are by now represented in rather heuristic ways. The problem in simulating their impact is twofold: First, their local modeling is delicate and, secondly, the numerical modeling of the scale interaction between fine and large scales is complicated since the fine scale structure is global. We will mostly focus on the second aspect.

Multiscale finite element methods (MsFEM) in their classical form have been applied to various porous media problems but the situation in climate, and hence flow-dominated regimes is different from porous media applications. In order to study the effect of various parameters like the concentration of pollutants, or the dynamics of the background velocity and of the temperature in the atmospheric boundary layer, a semi-Lagrangian reconstruction based multiscale finite element framework (SLMsR) developed by [1, 2] for passive tracer transport modeled by an advection-diffusion equation with high-contrast oscillatory diffusion is applied.

These methods are composed of two parts: a local-in-time semi-Lagrangian offline phase that pre-computes basis functions and an online phase that uses these basis functions to compute the solution on a coarse Eulerian simulation mesh. The overhead of pre-computing the basis functions in each coarse block can further be reduced by parallelization. The online phase is approximately as fast as a low resolution standard FEM but using the modified basis that carries subgrid information still allows to reveal the fine scale features of a highly resolved solution and is therefore accurate. This approach is studied in order to reveal the feedback of processes in the canopy layer on different scales present in climate simulation models and in particular on the atmospheric boundary layer.

We will show the results of massively parallel simulations for passive tracer transport in an urban region using the new multiscale approach and compare them to classical approaches.

References :

[1] Simon, Konrad, and Jörn Behrens. "*Semi-Lagrangian Subgrid Reconstruction for Advection-Dominant Multiscale Problems.*", Springer Journal of Scientific Computing (JOMP) (provisionally accepted), 2019

[2] Simon, Konrad, and Jo□rn Behrens. "*Multiscale Finite Elements for Transient Advection-Diffusion Equations through Advection-Induced Coordinates.*", Multiscale Modeling & Simulation 18.2 (2020): 543-571.