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Effect of porosity on ABL evolution over a canopy patch in a stable atmosphere: a wind tunnel study

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Landscape heterogeneity, complex topography, and atmospheric stability present significant challenges for measuring and predicting fluxes of momentum, heat, moisture, and climate-controlling trace gases in the atmospheric boundary layer (ABL) because similarity solutions break down. Canopies and small-scale topography can have a significant affect on land-atmospheric fluxes especially in the wake region. Understanding the impact of atmospheric stability on complex boundary layer flows is also of great interest as stability presents significant challenges for subgrid-scale models in large-eddy simulations. The resulting complex wake flows are particularly challenging to study because ideal field cases are difficult to find and uncertainty in numerical approaches hinders accurate simulation of high Reynolds number separated flows within the ABL.

Alternatively wind tunnel experiments allow observation of a stationary, stable boundary layer and careful measurement of the flow development over complex terrain. We conducted controlled wind tunnel experiments in the St. Anthony Falls Laboratory atmospheric boundary layer wind tunnel to investigate the evolution of a thick and stably stratified boundary layer over a porous canopy patch and a solid block. The study was designed to improve our understanding of canopy porosity effects on the flow structure and evolution of the ABL compared to the flow over a solid block. The block and canopy patch are similar in dimension (2h x 1v), and the canopy patch has a uniform density. Both were immersed deep within the boundary layer, $h/\delta \sim 13\%$. Using high-resolution Particle Image Velocimetry (PIV) we obtained details of the flow including the onset of separation, the recirculation zone and flow reattachment. Turbulent momentum and heat fluxes were characterized using a combined x-wire and cold wire at selected stream-wise locations. The results highlight the importance of considering canopy porosity in parameterizations of canopy wakes in ABL models, and has important implications for modeling the ABL over deforested lands, areas with shelterbelts/windbreaks, sheltered lakes, and also for biogeochemical flux measurements in the proximity of trees or other tall structures on the landscape.