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Effects of trees on momentum exchange within and above a real urban environment

Marc B. Parlange (1), Marco G. Giometto (2), Andreas Christen (3), Pascal E. Egli (4), Manuel F. Schmid (5), Rory T. Tooke (6), and Nicholas C. Coops (6)

(1) Department of Civil Engineering, Monash University, Clayton, Australia, (2) Columbia University, Civil Engineering and Engineering Mechanics, United States (marco.giometto@columbia.edu), (3) Environmental Meteorology, Faculty of Environment and Natural Resources, University of Freiburg, Freiburg, Germany, (4) Institute of Earth Surface Dynamics, University of Lausanne, Lausanne, Switzerland, (5) Department of Civil Engineering, Faculty of Applied Science, University of British Columbia, Vancouver, BC, Canada, (6) Department of Forestry, University of British Columbia, Vancouver, BC, Canada

Large-eddy simulations (LES) and tower measurements are used to gain insight into the effects of trees on momentum transfer rates characterizing the atmosphere within and above a real urban canopy. Several areas that are part of a neighbourhood in the city of Vancouver, BC, Canada are considered. These areas are representative of the majority of Vancouver's neighborhoods and North American cities. An immersed-boundary method is used to account for buildings in the LES, whereas trees and bushes are modeled via a location-specific leaf area density. Both buildings and vegetation geometries are obtained from airborne light detection and ranging data. A suite of LES are performed, varying systematically wind direction and leaf area densities. Long term wind and turbulence measurements are also available in such area from a 30 m meteorological tower, and are used to validate the numerical simulations and to provide additional insight into the flow system. Surface roughness lengths (z_0) from both LES and tower measurements are fund to be sensitive to the $0 \leq \mathrm{LAI}/\lambda < 3$ parameter, where LAI is the leaf area index and λ is the frontal area fraction of buildings characterizing a given canopy. Both tower measurements and LES predict a non-negligible seasonal increase in z_0, up to 27% for the most representative LES canopy characterized by λ=0.15, leaves-off LAI = 0.116, and leaves-on LAI = 0.35. Removing vegetation from such a canopy would cause a dramatic drop of approximately 50% in z_0 when compared to the reference summer value. The momentum zero-plane displacement height from LES is also strongly dependent on the LAI/λ parameter, due to the disproportionate amount of drag that the (few) relatively taller trees exert on the flow. Within the urban canopy, trees mainly reduce downward turbulent transport of high-momentum fluid, significantly reducing the wind intensity at the heights where people live and buildings consume energy.