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Analysis of coherent structures in canopy flows

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Since the introduction of the concept of coherent structures in turbulence, many studies have started in order to assess their existence and their contribution to the instantaneous momentum transfer and mixing. Their characterization is however a complex task especially when dealing with atmospheric flows, where the uncertainty of the measurements (and of the boundary conditions) limits the physical interpretation of the data set as well as the possibility to determine correct scaling laws. A typical example is the flow over forests where the presence of the trees adds further complexities in the analysis as an unknown roughness with a non-uniform spatial distribution.
The atmospheric boundary layer over a forest canopy is an important flow case due to relevant applications in micrometeorology and has also gained a renewed interest due to the exploitation of wind energy in forested terrain. Field campaigns using tower measurements have been able to determine some statistical properties of the flow field, but a description of the involved structures is subjected to severe limitations due to many uncertainties and approximations. Thus, both numerical simulations (NS) and wind tunnel experiments (EXP), with their pro and cons, are needed in order to obtain more qualitative data. (i) NS provide full information of the flow field but are nevertheless limited to low Reynolds numbers (Re) and by the accuracy of the actual closure models. (ii) EXP offer the possibility to perform accurate measurements in a well controlled environment, but cannot meet the true atmospheric Reynolds number, which is typically two orders of magnitude higher, and hence are limited to moderate Re.
With the aim to provide further evidences and to characterize some scaling properties of coherent structures over forests, hot-wire anemometry and Particle Image Velocimetry (PIV) measurements over a forest model have been performed in the MTL wind tunnel at KTH in Stockholm. The canopy has been modelled by means of pin fin plates where the fins absorb momentum trough their aerodynamic drag and therefore act in a similar way on the atmospheric flow as real trees. The thick atmospheric boundary layer has been generated by means of triangular spires located at the inlet of the test section followed by a rough grid to establish the boundary layer.
The experimental results have also been compared to large-eddy simulations of turbulent boundary layers at moderate Reynolds numbers, where body forces were introduced close to the wall in order to simulate the presence of the canopy. The ADM-RT (Approximate Deconvolution Model with a Relaxation Term) model has been used in order to close the sub-grid stress terms. Despite the smaller Reynolds numbers as compared to the experiments, single point statistics show reasonable agreement with the experiments.
Conditional sampling methods have been applied to both measurement techniques in order to assess some characteristics of the structures generated by the canopy boundary condition. The new experimental results have been compared with real forest data and numerical simulations and the comparison will be discussed in detail in the paper.