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Roughness sublayer development in canopy edge flows: streamwise variation in turbulence properties and impact on tree motion

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The presence of a roughness sublayer (RSL) is a ubiquitous feature of flows over plant canopies. Numerous investigations have been performed to describe its properties, and the recognition that turbulence in the RSL shares the character of plane mixing layer rather than boundary layer turbulence has led to substantial improvement in our understanding of RSL flows. However, only horizontally homogeneous canopies have been considered in this body of work, with very few exceptions.

We are interested here in the development of the RSL just after the incoming flow has hit the upstream edge of a canopy. This is a region of interest for many applications (tree stability to wind, particle deposition, ecological environment...). Large-eddy simulation (LES) has been used to provide instantaneous flow fields at fine enough spatial resolution.

A canopy edge generates an inflection point in horizontal velocity, leading to the development of a plane mixing layer. The simulations provide an average picture of the formation of coherent structures in the adjustment region (from the canopy edge to about 10 canopy heights downstream). This region is characterised by the presence of an enhanced gust zone (EGZ) in the upper canopy layers, where the skewness of streamwise velocity exhibits larger values than further downstream. This feature is the consequence of low-level turbulent kinetic energy being advected upwards from the lower canopy, which emphasizes the occasional presence of strong wind gusts coming from aloft. Further downstream, vertical advection vanishes and shear production leads to the development of a region of large turbulent kinetic energy above the canopy. With increasing canopy density the flow adjusts faster and the EGZ gets more marked. A sparse trunk space below the foliated layer tends to increase the length of the EGZ and decrease its intensity, due to the presence of a subcanopy jet.

Such streamwise variation of turbulence properties in the RSL has considerable impact on the aerodynamic sollications exerted on the trees. In order to simulate tree motions induced by instantaneous wind forces, we developed a dynamical model of tree behaviour, based on a detailed description of the architecture and mechanical properties of all roughness elements. Under the forcing of measured turbulent wind, it predicts swaying amplitudes and temporal patterns in good agreement with those measured in the direction of the dominant wind. The biomechanical model has then been coupled with the LES code so that tree motion can be predicted at any location in a virtual canopy. A comparison between a tree at the edge and a tree further downstream shows large differences in the distribution of internal strains, both in space and time, reflecting the streamwise variation in RSL properties.