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Numerical modelling of the wind over forests: roughness vs. canopy drag

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Due to rapid technological improvement in airborne lidar scanning (ALS), data on land surface and vegetation characteristics have become available, with increasing detail and quality. Methods have been developed to allow calculation of highly heterogeneous and realistic Plant Area Density (PAD) using raw ALS data (Lefsky et al., 1999; Richardson et al., 2009; Boudreault et al., 2015). To facilitate usage of ALS forest data in flow models with different types or levels of canopy drag-force prescription (e.g. linearized, RANS, and mesoscale models), Sogachev et al. (2017) recently suggested an objective method to translate PAD into spatially varying values of effective roughness. This parameter, which connects the surface friction velocity and geostrophic wind speed in a way satisfying the geostrophic drag law (Blackadar and Tennekes, 1968), allows prediction of wind flow over vegetation using typical numerical models, without needing to incorporate local drag forces in each grid volume of a three-dimensional model domain.

In the present study we explore the effect of different canopy representations on flow modelling over two forested sites: one located on a flat coastal plain (Østerild, Denmark) and the other in a hilly region (Rödeser Berg, Germany). The PAD for each site was derived from ALS data using the method of Boudreault et al. (2015), and the method of Sogachev et al. (2017) was applied to the PAD datasets to get roughness.

The RANS solver EllipSys3D, which uses a k-epsilon turbulence model, was applied for numerical simulation of the wind field over the two sites; this was done both with a full description of canopy drag forces, and with forest replaced by the effective roughness. Results of the simulations show that for the Østerild site, the major difference between the two CFD descriptions is observed in the near-surface layer (∼twice canopy height). Above the surface layer, wind profiles predicted by the different methods converge. Local friction velocities are also identical, except inside the canopy layer. Simulation results for the Rödeser Berg site show that the two CFD canopy implementations give similar airflow only upwind of the hill; on the summit and downwind, the modelled airflow structures are different.

As a whole, results of numerical experiments and their comparison with observations show that a CFD approach based on a roughness representation of forest can estimate wind speed and turbulence levels over forested areas, at heights potentially interesting for wind energy applications (∼60 m and higher) — but only above the flat terrain. Advanced CFD models capable of incorporating (distributed) local drag forces are recommended for complex terrain covered by forest.