Project: **1038**

Project title: **Turbulent exchange processes over forests**

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In this project the hydrodynamic flow solver EULAG is used to perform large-eddy simulations (LES) of turbulent flow over forested regions and to study the interaction of this flow with a wind turbine. To generate turbulent upstream conditions in the idealized modelling set-up, a newly developed method with two parallel flow solvers was used. In this method, the upwind domain uses periodic boundary conditions (BC) in flow direction, while the downwind domain including the wind turbine applies open BC and uses the turbulent flow field of the upwind domain as inflow condition (see Fig. 1). The domain size was 4096 m × 384 m × 600 m (x,y,z), the grid resolution was 2 m and the wind turbine had a hub height and rotor diameter of 100 m. The forest height was randomly distributed with heights of 30 m ± 5 m. The forest drag is parameterized by leaf area density profiles according to Shaw and Schumann (1992) and at the surface a drag coefficient of 0.001 is used as surface roughness. All simulations were performed with a neutrally stratified atmosphere and a mean wind speed of 10 m/s and were run for 90 minutes. Altogether 3 different modelling cases were defined:

F0: No forest

F1: Forest only in the downwind domain with a forest edge 500 m upstream of the wind turbine

F2: Forest in the upwind domain with a forest edge 500 m downstream of the wind turbine

The analysis of temporally (over the last 30 minutes) and spatially averaged wind fields in the upwind domain revealed the formation of two vortices rotating in the y-z-plane. These circulations are in the order of 0.2 m s^{-1} and are induced by the lateral periodic BC. Test simulations with doubled y-domain size, with different turbulent forcings and a stable stratified atmosphere could not eliminate these vortices. Due to these weak cross-domain circulations, the locations of averaged minimum and maximum wind speeds were not in the centre of the domain and the wind turbine was not streamed symmetrically. Therefore three different runs were performed for each case (MAX, MIN and MEAN) where the wind turbine was positioned at the maximum, minimum and mean location of the "jet", respectively. Figure 2 shows vertical cross sections of mean u-wind speed of MAX cases. In all cases a wake with reduced wind speeds forms behind the wind turbine. In the F2 case the wake is shortest due to strong mixing in the turbulent boundary layer over the forest. In the F0 and F1 cases winds in the upwind domain are identical, but change in the downwind domain. In the F1 case winds are decelerated in the canopy layer, which leads to stronger jet-like winds above the forest in front of

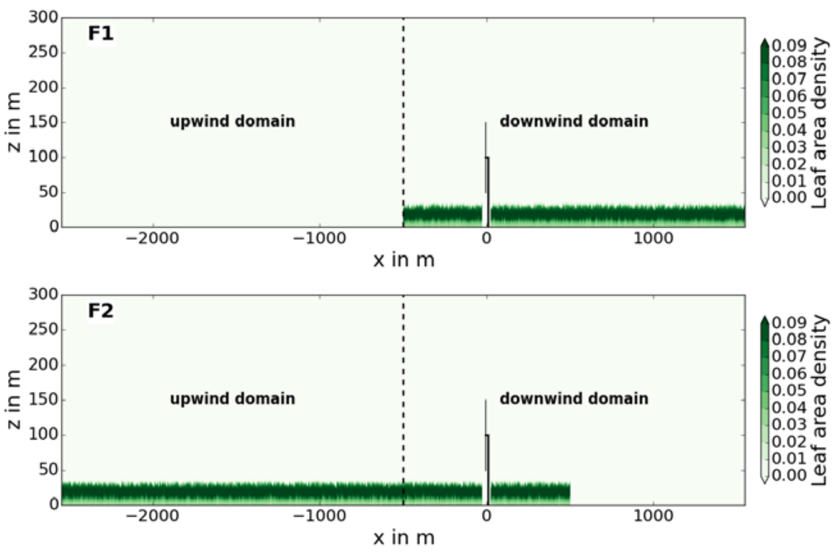

Figure 1 Sketch of the geometry of the case Case F1 (forest edge upstream of the turbine), case F2 (forest edge downstream of the turbine). Coloured contours mark the leaf area density profiles of the forest with tree heights of 30 m ± 5 m. The wind turbine is placed in a 52 m wide forest clearing at x=0 m, y=0 m. The dashed black line schematically separates the upwind and downwind domain.

the wind turbine compared to the F0 case. The drag of the wind turbine induces local wind speed maxima at the upper tip of the rotor plane at 150 m height in all simulations. In cases without forest (F0) a surface jet is generated below the wind turbine at altitudes below 50 m. This low-level jet is missing in the F1 and F2 cases due to forest friction. Time averages of the u-wind component at hub height are scaled with the corresponding upstream u-wind speed U_0 (first point in x-direction) and shown in Fig. 3. In all cases the influence of the wind turbine on the flow is visible at x=0 m where the flow is strongly slowed down. The strongest deceleration of the flow in relation to the upstream winds occurs in the F0 case where wind speeds are reduced to 51.6% of the upstream winds. In the F2 case the flow is decelerated to 55.4% and adjusts faster to the upwind conditions than in the F0 case due to strong turbulent mixing over the forest. In the F1 case winds increase in front of the wind turbine and are decelerated to 60.1% of the upstream flow. In this case the wind speed behind the wind turbine increases very slowly and stays at about 70% of the upstream wind due to the influence of the forest. In the future, the produced turbulent flow fields are further analysed and will be used to study sound propagation over forested terrain, which is induced by wind turbines.

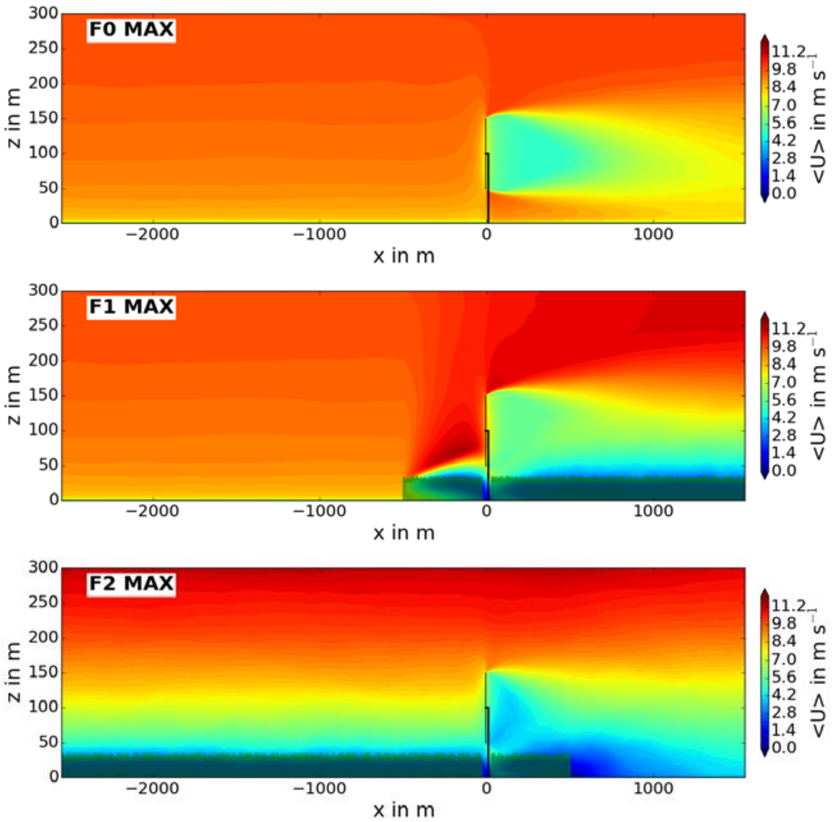

Figure 2 Vertical cross sections at y=0 m of 30 minute averages of the u-wind component for the F0 to F2 cases with the wind turbine located at the MAX position. The wind turbine is marked with black lines and the forest is indicated with green areas.

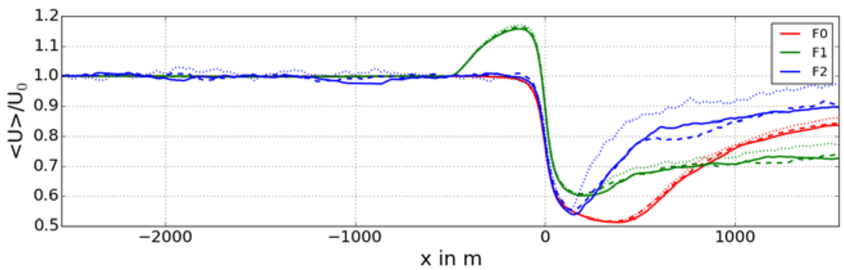

Figure 3 Scaled u-wind component at hub height (z=100 m) and at y=0 m for the three different cases F0 to F2. Solid, dotted and dashed lines mark corresponding simulations with the wind turbine in MAX, MIN and MEAN position, respectively.

References

Shaw R. H., Schumann U. 1992: Large-eddy simulation of turbulent flow above and within a forest. Bound.-Layer Meteor., 61, 47-64.