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Angelou, Nikolas; Dellwik, Ebba; Mann, Jakob

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Characterization of a tree wake using three short-range WindScanners

N. Angelou¹, E. Dellwik¹, J. Mann¹
(1) Department of Wind Energy, Technical University of Denmark, Frederiksborgvej 399, Roskilde, Denmark

The presence of solitary trees in a flat terrain introduce heterogeneities, which modify the characteristics of the wind. Trees act like obstacles that extract energy from the mean flow and increase the turbulence of the wind. This has an impact on the momentum flux and thus is of particular interest in climate related studies. Furthermore, the wind-trees interaction is a topic of study also in applied research areas, like wind energy, where the estimation of wind resources and associated turbulence levels is necessary to describe accurately the wind conditions over an area. In the case of rough landscapes typical uncertainties in the estimation of the terrain roughness can result to 10% uncertainty in the annual energy production estimate [1].

In order to contribute to the understanding of the aforementioned topics a project called Single Tree was initiated in the Wind Energy Department of the Technical University of Denmark (DTU), with the objective to characterize the flow around a solitary tree. For the needs of this study a European Oak tree (Quercus robur), located on the shore of the Roskilde fjord in Denmark, was selected. Such a tree is commonly found in forests or solitarily in urban and rural environments in temperate regions. Using a commercial terrestrial laser scanner, the dimensions and the detailed geometry of the tree were measured (see Figure 1 and Figure 2, left) and two meteorological masts equipped with multiple in-situ sonic anemometers were used to provide reference measurements of the wind conditions.

A phenomenon that describes the wind-trees interaction is the wake of a tree, since it is the result of the momentum extracted from the wind due to the presence of the tree, which acts as a porous obstacle with a complex geometry. This complex geometry creates challenges in the numerical prediction of wind-trees interaction and thus the generation of high quality experimental flow data is paramount. Such an investigation is feasible using three short-range WindScanners, which are mobile remote sensing instruments developed in the Wind Energy Department of DTU [2].

A short-range WindScanner consists of a Doppler wind lidar and an optical scanner head. The lidar is a continuous-wave, monostatic, in-phase/quadrature, infrared Doppler lidar, capable to measure both the amplitude and sign of the projection of the wind vector to its line-of-sight [3]. The transmitted light is steered in the atmosphere using a scanner head that deflects the lidar’s line-of-sight using two independently rotating wedge-shaped prisms, each with a deflection angle of 30°. Through the implementation of the aforementioned configuration the short-range WindScanner can scan a volume defined within a cone with an aperture angle of 120°.

Figure 1 Drawing of the experimental setup where the tree (blue dots), the three short-range WindScanners (black dots and the scanning plane (opaque blue lines) are presented.
A thorough study of a tree wake requires information on all the components of the wind. This is possible using three short-range WindScanners to acquire synchronous measurements in the same air volume. Such a configuration has been proven capable to successfully measure both the mean and the high frequency fluctuations of the wind [4].

In this experiment, the short-range WindScanners were placed on the ground and programmed to scan synchronously a 2D vertical plane, with an area of 16 m x 16 m. The scanning plane was located 4 m from the tree in the downwind direction and it consisted of vertical lines, which were separated by a distance of 0.5 m.

In Figure 2 an example of a 5-min mean wake of the tree is presented, based on the radial wind speed measurements acquired from one of the short-range WindScanners. The wake has been measured during a period when the wind was flowing from a direction that had an offset of 25 degrees from the normal axis to the scanning plane (y-axis in Figure 1). Due to this offset the centre of the wake is displaced to the right part of the scanning pattern (see Figure 2, right). Additionally, the wake appears to be slightly higher than the tree, which either indicates a slight vertical component in the wind vector or a diffusion of the momentum deficit.

The acquired data reveal the details of the wake dimensions, quantify the corresponding wind deficit and provide an insight on the characteristics of the flow around the tree. These observations contribute to the understanding of the wind-trees interaction and furthermore shall be used for the validation of fluid dynamics numerical models.

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References