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CFD modelling of nocturnal low-level jet effects on wind energy related variables

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The development of a wind speed maximum in the nocturnal boundary layer, referred to as a low-level jet (LLJ), is a common feature of the vertical structure of the atmospheric boundary layer (ABL). Characterizing and understanding LLJ streams is growing in importance as wind turbines are being built larger and taller to take advantage of higher wind speeds at increased heights. We used a computational fluid dynamics (CFD) model to explore LLJs effect on wind speed, wind directional and speed shear inside the surface layer 40 – 130 m, where their physical measurements are not trivial and still rare today.

We used the one-dimensional version of the ABL model SCADIS (Sogachev et al. 2002: Tellus 54:784-819). The unique feature of the model, based on a two-equation closure approach, is the treatment of buoyancy effects in a universal way, which overcomes the uncertainties with model coefficients for non-shear source/sink terms (Sogachev, 2009: Boundary Layer Meteor. 130:423-435). From a variety of mechanisms suggested for formation of LLJs, such as inertial oscillations, baroclinicity over sloping terrain, and land-sea breeze effects, the one-dimensional ABL model is capable of simulating only the first one. However, that mechanism, which is caused by the diurnal oscillation of eddy viscosity, is often responsible for jet formation. Sensitivity tests carried out showed that SCADIS captures the most prominent features of the LLJ, including its vertical structure as well as its diurnal phase and amplitude.

We simulated ABL pattern under conditions typical for LLJ formation (a fair day on July 1, a flat low-roughness underlying surface) at 30 and 50o latitudes. Diurnal variability of wind speed and turbulence intensity at four levels of 40, 70, 100 and 130 m above ground and of wind and directional shear between those levels were analysed. Despite of small differences in LLJ structure the properties of LLJ important for wind energy production are still common for two latitudes. Along with the wind speed increase in night time the turbulence intensity decreases and, as it was confirmed by many experiments, are insignificant in comparison with midday values (both factors are favourable for wind production). However, wind and directional shear across the entire layer occupied by hypothetical wind turbine rotors (between 40 – 130 m) provide different wind conditions above and below the turbine hub. For example, the shear exponent was higher than 0.65 during most part of night (below 0.08 at midday) and direction shear was sometimes higher than 0.3 degree per meter (about 0 at midday). Most extreme values of both parameters occurred at dawn when turbulence starts to develop. This creates large amounts of stress on the turbines, causing difficulties in their operation and fatigue issues over time.

The model will have to be coupled to an aeroelastic model to be able to predict quantatively the consequences for power production and dynamic loads on wind turbines.