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Benefits and optimal design of vertically staggering wind farms

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Strategic wind farm design and development is becoming an absolute necessity as the growing population places increased stress on both energy resources and available land. Optimizing the power output of wind farms requires understanding the wake effects following each turbine. Alternating tall and short turbines (vertical staggering) in the streamwise direction could be advantageous by circumventing negative wake effects while capitalizing on the undisturbed atmospheric flow. However, in contrast to horizontal staggering, the use of vertical staggering is still relatively unexplored. Could vertically staggering a new wind farm or retro-actively fitting a current wind farm with smaller turbines increase productivity?

To investigate this, we have improved upon a top-down, analytical model [3], which is applied to vertically staggered wind farms. Important turbine features such as rotor diameter, hub height, and turbine spacing can be readily adjusted in the domain of this periodic model. The model theory is based on the self-similar solution for the mean velocity parallel to a surface with the boundary layer decomposed into six layers. Each layer is characterized by different parameters, such as the roughness length scale, eddy viscosity, and friction velocity (Figure 1). The resulting horizontally-averaged streamwise velocity profile is used to calculate the average power output of the both big and small turbines.

The power production is analysed for different vertically staggered layouts and turbine design characteristics and is compared to the case in which no short turbines are present. We consider the case in which small turbines are incorporated retro-actively, though other scenarios are also of interest. With this model, we find that the design of the wind turbines is an important consideration. For instance, decreasing the height of the small turbines should decrease the adverse wake effects but this benefit is eclipsed by the low energy available for extraction near the surface. The model can be used to explore multiple turbine heights and rotor sizes to find a balance between these two effects.

More importantly, the costs associated with including smaller turbines must be considered when optimizing power production. In this case, the power output of different layouts is compared to a simplified, dimensionless cost parameter which includes the cost of the land and turbines. The spacing of the small turbines can be optimized subject to this dimensionless cost parameter. For a simplified example with assigned values, the model shows that a vertically staggered wind farm can be more profitable than the case of having the big turbines alone.

This simple model provides exciting insight into vertically staggered wind farms but can be enhanced by considering downstream development and thermal aspects of the atmospheric boundary layer. Further, we are currently using large eddy simulations to corroborate the analytical model results.

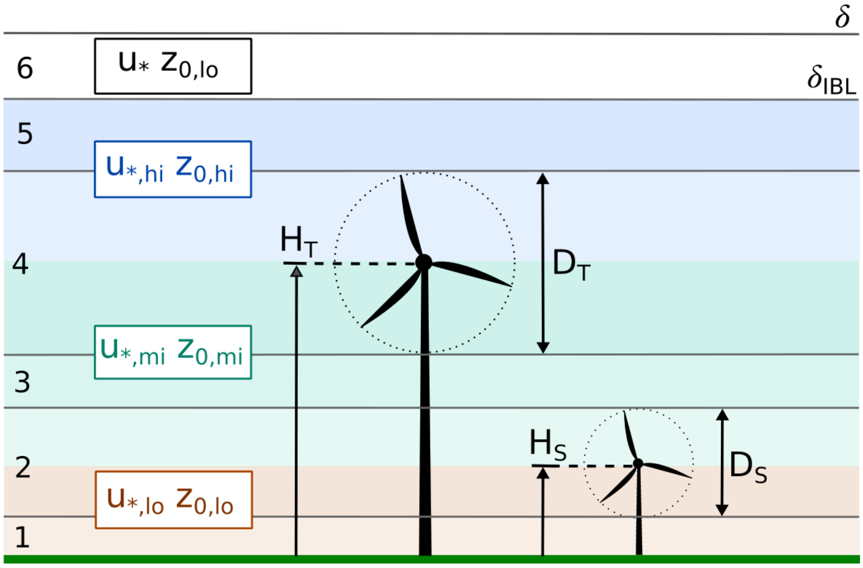

Figure 1 Schematic of top-down model applied to a vertically staggered wind farm depicting six layers that are characterized by different parameters and velocity profiles.

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