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An analytical 1-D model for vertical momentum and energy flux through a fully developed wind farm

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Wind farms capture momentum from the atmospheric boundary layer (ABL) both at the leading edge and from the atmosphere above. Momentum is advected into the wind farm and wake turbulence draws excess momentum in from between turbines until momentum is only available from above the wind farm. This distance can be described by the so-called drag development length scale, which arises from the canopy drag force term in the momentum equation. At this point the flow can be considered fully developed. The horizontally-averaged velocity profile for a fully developed wind farm flow exhibits a characteristic inflection point near the top of the wind farm, similar to that of sparse canopy-type flows (Markfort et al., JoT, 2012). The inflected vertical velocity profile is associated with the presence of a dominant characteristic turbulence scale, which may be responsible for a significant portion of the vertical momentum flux. We evaluate an analytical canopy-type flow model for wind farm-atmosphere interaction by testing it against wind-tunnel experimental data of flow through a model wind farm. The model is adapted to predict the mean flow, vertical momentum flux, and the mean kinetic energy flux as well as kinetic energy dissipation within the wind farm. This model is particularly useful for wind farm configuration optimization, considering wind turbine spacing and surface roughness and can also be useful to represent wind farms in regional scale atmospheric simulations.