Impact of negative geostrophic shear on wind farm performance

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Motivation

In simulations and analytical models of wind farms the atmosphere is typically assumed barotropic, i.e. the driving pressure gradient is assumed constant with height.

However, in various situations, such as the flow transition between land and sea, the atmosphere is baroclinic and pressure gradients are height-dependent.

Negative shear baroclinicity significantly alters wind velocity and turbulence in the atmospheric boundary layer [1,2]. Here, we study how this affects wind farm wake development and power production.

LES equations

\[
\begin{align*}
\partial_t \bar{u}_i &= 0 \\
\partial_t \bar{\theta} + \partial_j (\bar{u}_i \bar{\theta}) &= -\partial_i p^* - \partial_j \tau_{ij} + g/\alpha \Delta \left( \bar{\theta} - \bar{\theta}_L \right) + \epsilon_{ij} \beta \left( \bar{u}_j - G_j \right) + f_i \\
\partial_t \bar{\theta} + \bar{u}_i \partial_i \bar{\theta} &= -\partial_i q_i
\end{align*}
\]

Method

We employ Large Eddy Simulations (LES) to simulate wind farms of 10x5 turbines in neutrally and stably stratified atmospheres.

We compare results between three stable cases:
1. Barotropic
2. Baroclinic low
3. Baroclinic high

*Three neutral cases were also simulated, for which the results can be found in our full (soon to be published) research paper!

Case overview

Pressure gradient velocity turbulence

Wake development

1. Reduced wake recovery in baroclinic low case due to lowered jet height.
2. Additional turbulence does not aid momentum entrainment into the wind farm.

Power production

1. Relative power production of downstream turbines is reduced under negative shear.
2. Given the velocity aloft is unaltered, negative shear can significantly increase the absolute power output of a wind farm.

References