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**.

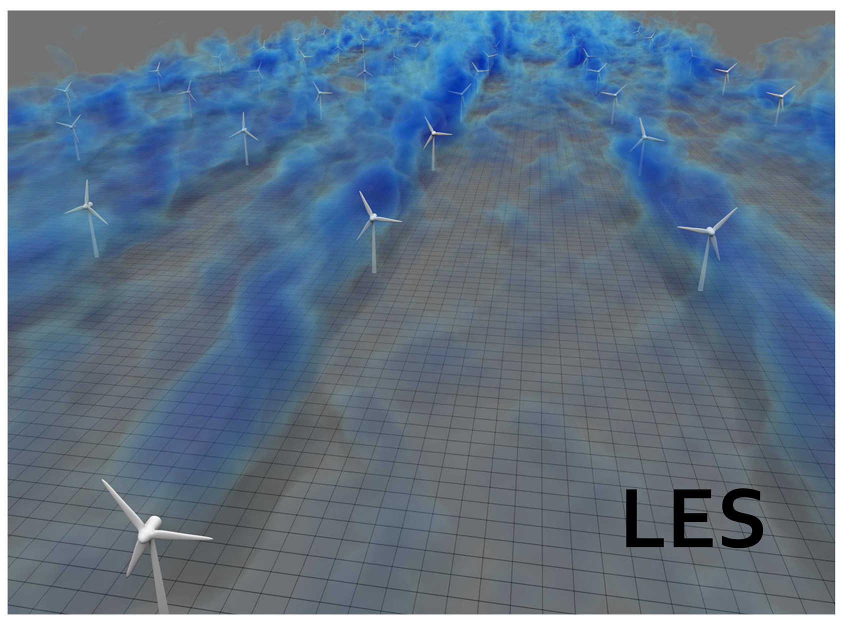
LES equations

$$\partial_i \tilde{u}_i = 0$$

$$\partial_t \tilde{u}_i + \partial_j \left(\tilde{u}_i \tilde{u}_j \right) = -\partial_i \tilde{p}^* - \partial_j \tau_{ij} + g\beta\delta_{i3} \left(\tilde{\theta} - \left\langle \tilde{\theta} \right\rangle \right) + \epsilon_{ij3} f_c \left(\tilde{u}_j - G_j \right) + f_i$$

$$\partial_t \tilde{\theta} + \tilde{u}_i \partial_i \tilde{\theta} = -\partial_i q_i$$

Method



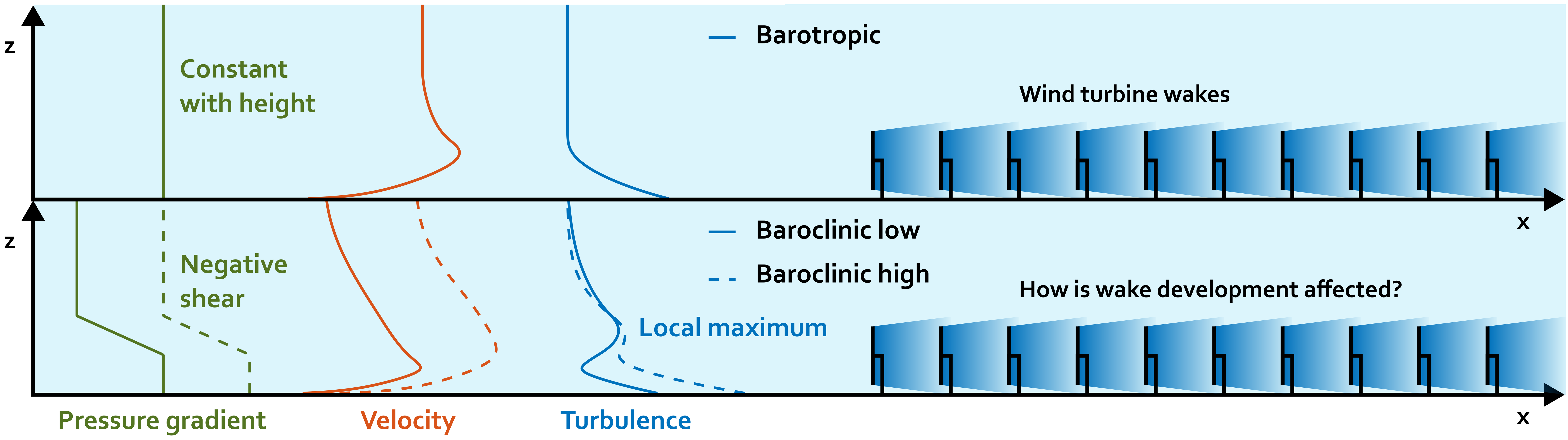
We employ **Large Eddy Simulations (LES)** to simulate wind farms of 10x5 turbines in neutrally and stably stratified atmospheres.

We compare results between **three stable cases**:

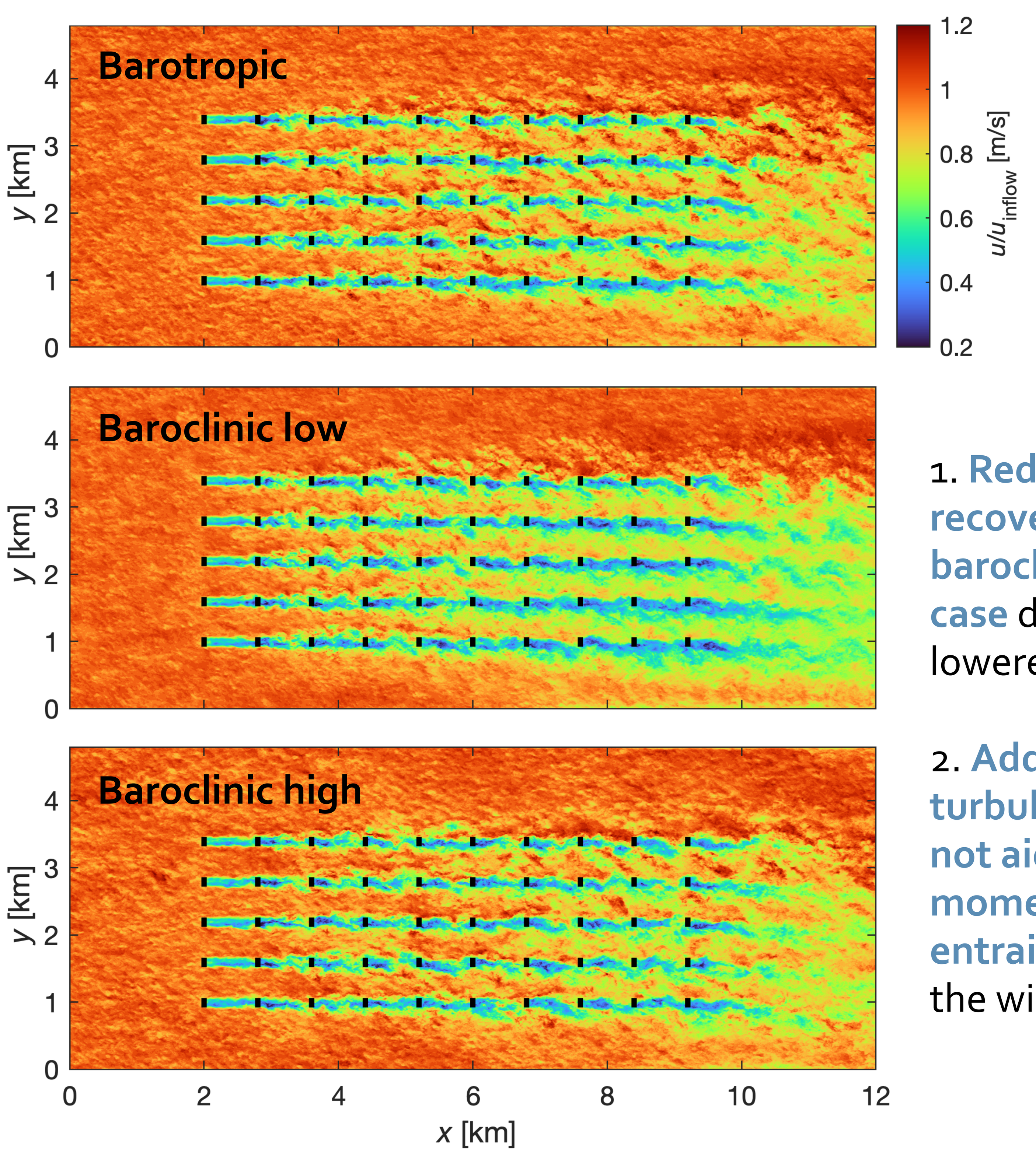
1. Barotropic
2. Baroclinic low
3. Baroclinic high

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

Case overview



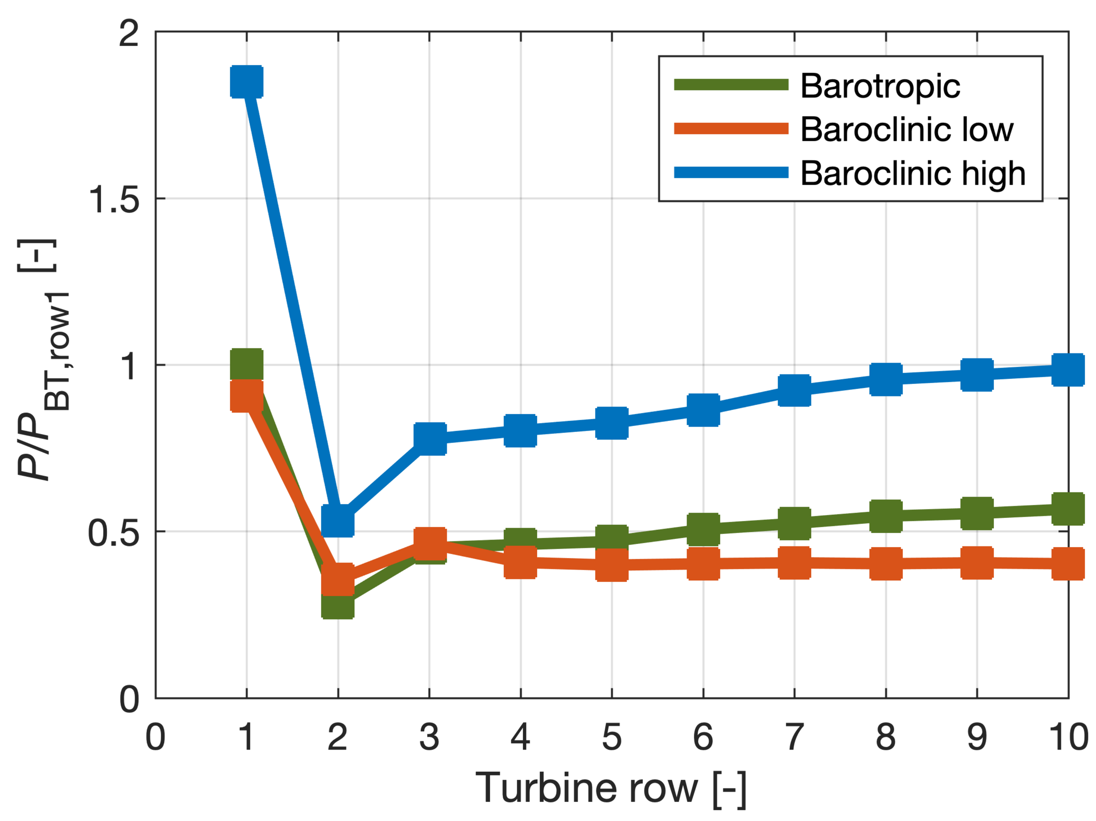
Wake development



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

[1] M. Momen, E. Bou-Zeid, M.B. Parlange, M. Giometto. Modulation of Mean Wind and Turbulence in the Atmospheric Boundary Layer by Baroclinicity. *Journal of the Atmospheric Sciences*, 75(11), 3797-3821, 2018.

[2] L. Conangla, J. Cuxart. On the Turbulence in the Upper Part of the Low-Level Jet: An Experimental and Numerical Study. *Boundary-Layer Meteorology*, 118(2), 379-400, 2006

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