The impact of negative geostrophic wind shear on wind farm performance

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Baroclinicity, which leads to height-dependent driving pressure gradients, occurs in various situations, such as the flow transition between land and sea and sloping terrain. It has been shown that baroclinicity modifies the structure of the atmospheric boundary layer (ABL).[1] Negative shear baroclinicity creates additional turbulence at higher elevations, which might influence the energy entrainment into large wind farms. We use large-eddy simulations to study the effect of baroclinicity-induced negative shear on wind farm power production and energy entrainment into the farm. Our simulations show that negative geostrophic wind shear significantly modifies the mean wind velocity in the ABL.[2] Specifically, for the cases considered in the study, the negative geostrophic shear causes a change in the mean velocity up to 2.3 m/s at hub height, which greatly alters wind farm power production. Figure 1(a) shows the vertical wind profile for three cases. Figure 1(b) shows that the power production normalized by the power production of its first row of the barotropic reference case strongly depends on baroclinicity. This figure highlights that baroclinicity alters the mean wind profile in the ABL and thereby affects the wind energy available for extraction by the turbines. Additionally, we demonstrate with an energy budget analysis that a wind farm does not necessarily benefit from the additional turbulence created by the negative geostrophic wind shear. This is because the baroclinicity-induced negative shear alters the height and strength of the low-level jet and creates an upward flux above the jet, limiting the energy entrainment into the wind farm. Our results show that wind resources are altered in the boundary layer due to negative geostrophic wind shear and should be considered in wind farm modeling and power forecasts. Consequently, including baroclinicity effects in numerical and analytical models used to design wind farms is crucial to obtaining accurate performance predictions.

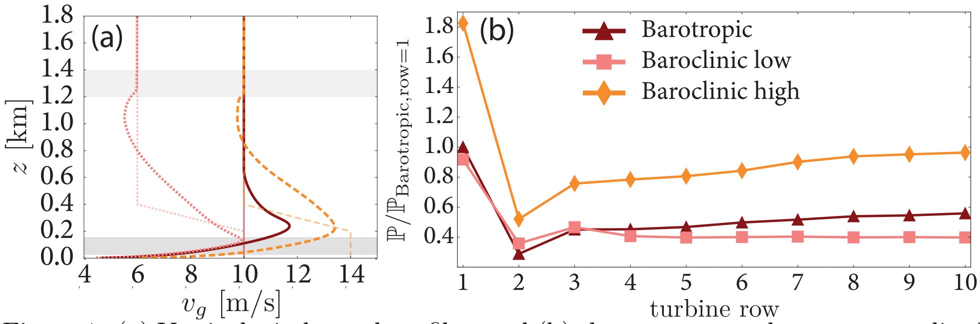

Figure 1: (a) Vertical wind speed profiles, and (b) the row-averaged power normalized with the barotropic case.

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[1] M. Momen, E. Bou-Zeid, M.B. Parlange, M. Giometto, J. Atmos. Sci. 75, 3797 (2018)

[2] A. Stieren, J.H. Kasper, S.N. Gadde, and R.J.A.M. Stevens, PRX Energy 1, 023007 (2022).