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Evaluation of the Park wake model under different atmospheric stability conditions at the Horns Rev I wind farm

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Abstract

We present the results of the evaluation of the Park wake model against data from a wind turbine row of the Horns Rev I offshore wind farm. The Park wake model here used is similar to that developed in the Wind Atlas Analysis and Application Program (WAsP). The wind farm data are classified into different atmospheric static stability conditions based on measurements of a nearby upstream meteorological mast and the data are filtered to assure that the upstream conditions at the row and mast are nearly the same. The simulations are performed based on the observed wind direction and post-processed to account for the uncertainty in the wind direction. The data and the simulations show good agreement for all atmospheric stability classes; for the first turbines on the row the agreement is better by using the recommended WAsP wake decay coefficient, whereas for the last turbines it is better to use a stability-dependent wake decay coefficient. The power deficits are observed to be higher under stable compared to unstable atmospheric conditions, but attention should be taken as the wind conditions (speed and direction) are different under the different stability classes. Due to the variety of wind directions for each atmospheric stability class (i.e. the winds do not often come parallel to the rows), the limits of the infinite wind farm are not approached, which can be tested by computing the Park wake model for an infinite number of wind turbines.

Modified Park wake model

The modified Park wake model is similar to that described in [1] and implemented in WAsP but taking into account upwind wakes only (sideways or directly). The wake decay coefficient is estimated as [2],

$$k_w = \frac{u_{*free}}{u_{hfree}} = \frac{k}{\ln\left(\frac{h}{z_o}\right) - \varphi_m\left(\frac{h}{L}\right)}$$

where u_{*free} and u_{hfree} are the undisturbed friction velocity and hub-height wind speed, k is the von Kármán constant (0.4), h is the hub height, z_o is the roughness length and $\varphi_m(h/L)$ is the correction due to stability (given by L) at hub height.

Horns Rev I wind farm

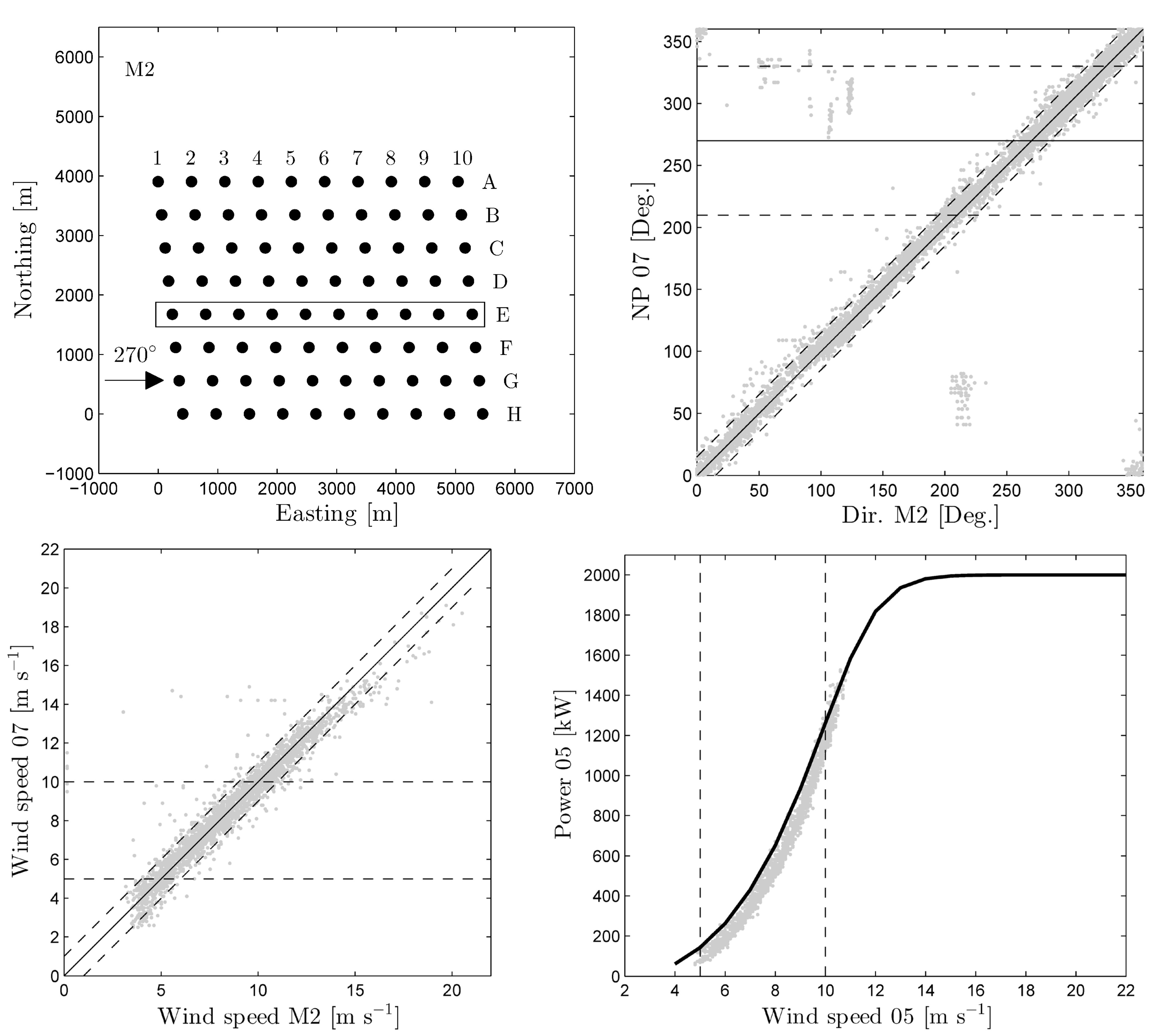

Figure 1. (top left) The Horns Rev I offshore wind farm. (top right) Nacelle position of turbine 07 as function of the direction observed at M2. (bottom left) Wind speeds observed at M2 and at turbine 07. (bottom right) Power performance at turbine 05 based on the nacelle wind

Concurrent 10-min M2 and turbine data are used. Atmospheric stability is inferred from observations at M2 as performed in [3]. Scatter plots for wind direction and speed are performed to filter data assuring similar wind conditions between row E (used for the analysis) and M2 (see Fig. 1). The final dataset is classified in four stability classes: very unstable (magenta), unstable (red), neutral (green) and stable (blue).

Results

Figs. 2 and 3 show the wind conditions of the selected data. The wind speeds are therefore narrowed down to 8.5±0.5 m/s to reduce variability. For each stability class, we run simulations at 0.1 deg. resolution with wake stability dependent wake decays and the WAsP recommended value. Simulations are post-processed to partly account for the wind direction uncertainty as shown in [4], using a normal distribution with a standard deviation of 2.5 deg. The idea is to extract simulations correspondent to the range of wind directions ±3StdDev for each observed direction and stability class and then weight each simulation with the normal distribution. Results are illustrated in Fig. 4 and show a good agreement between the ensemble averages of simulations and observations. For each stability class, the result using the stability dependent wake decay generally fits better the power deficit at the last turbines and that using the WAsP value the deficit at the first turbines.

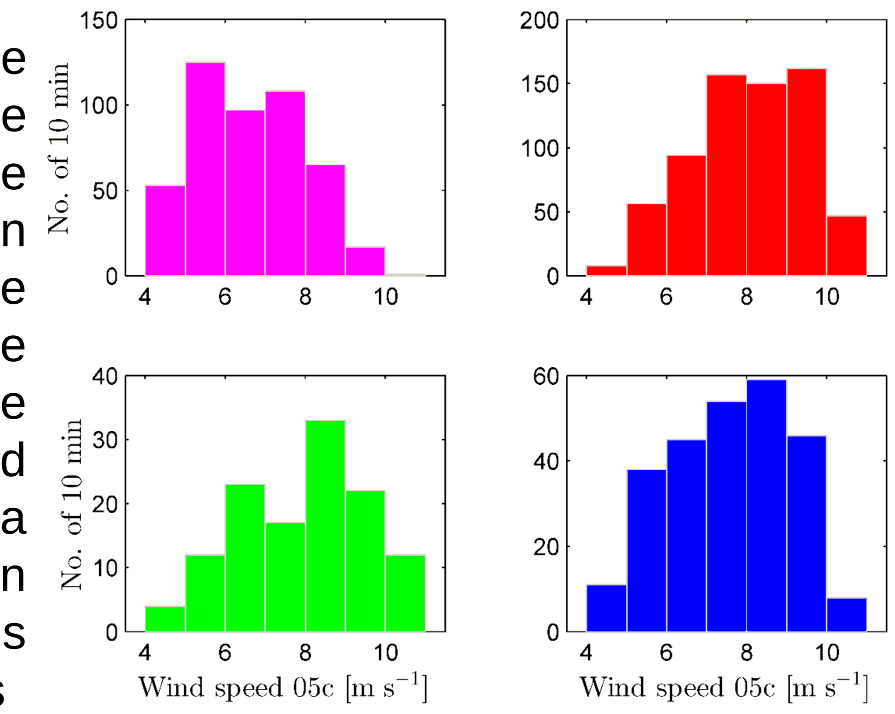

Figure 2. Wind speed histograms for each stability class

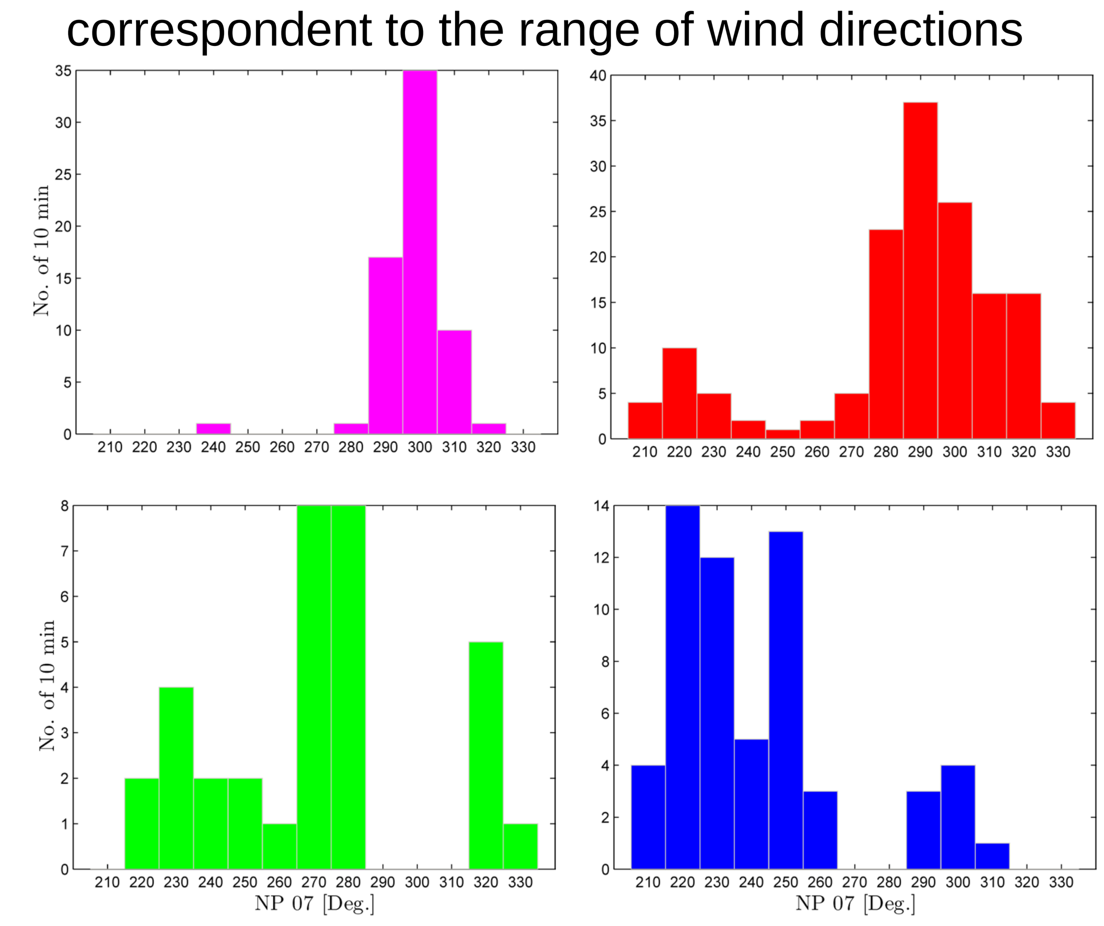

Figure 3. Wind direction histograms for each stability class

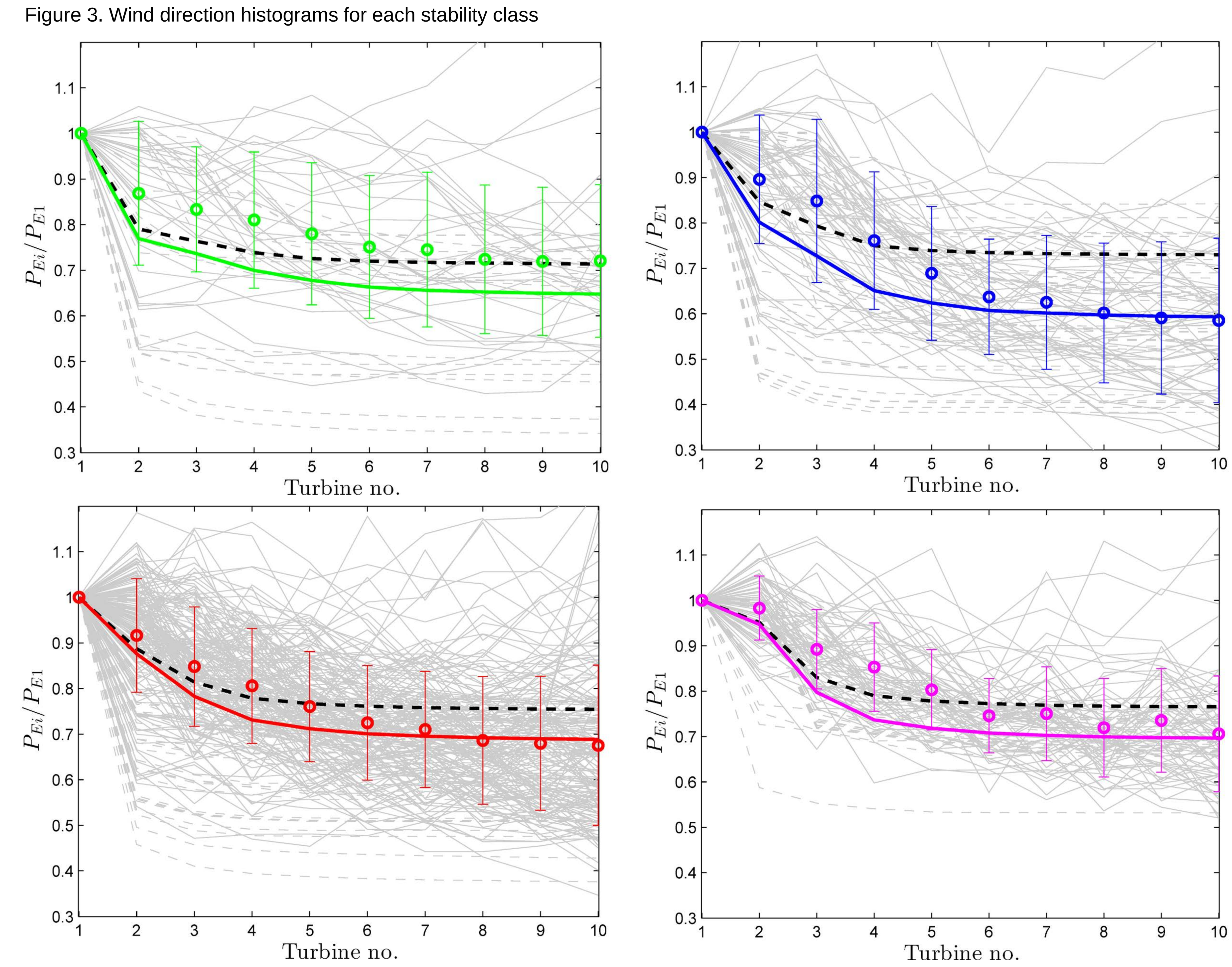

Figure 4. Normalized power deficits of row E for neutral (top left), stable (top right), unstable (bottom left) and very unstable (bottom right) conditions. Gray solid lines show the 10-min power deficits (dashed lines for simulations), the cicles the ensemble average, solid thick line the simulations' ensemble average with the stability specific wake decay and dashed tick line the simulation average with the wasp value

Conclusion

This study shows that although its simplicity and assumptions, the engineering Park wake model is able to reproduce fairly well the wind speed reductions observed at the Horns Rev I offshore wind farm under different atmospheric stability and wind conditions, once we account for the effect of stability on the wake decay coefficient and the wind direction uncertainty.

References

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[3] Peña A. and Hahmann A.N. (2012) Atmospheric stability and turbulent fluxes at Horns Rev—an intercomparison of sonic, bulk and WRF model data. Wind Energ. 15:717-730
[4] Gaumond M. et al. (2013) Evaluation of the wind direction uncertainty and its impact on wake modeling at the Horns Rev offshore wind farm. Wind Energ., in press

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