Prediction of wind farm energy yield using NWP considering within-cell wake losses

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Prediction of wind farm energy yield using NWP considering within-cell wake losses

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Abstract

Numerical Weather Prediction (NWP) models such as Weather Research and Forecasting[5] (WRF) are widely used for predicting the wind resource at potential wind farm deployment sites and, increasingly, for energy yield prediction. Sub-grid models have previously been developed[1] to represent wind farms by modification of momentum sink and turbulence kinetic energy source terms within cells containing wind turbines. In this study, a sub-group of turbines are parameterized by thrust and power curves determined using semi-empirical wake models to assess influence of within-cell wake losses on net yield. Variation of thrust and power with wind speed and direction was obtained for groups of turbines using the modified PARK and Eddy Viscosity methods in Openwind[4]. Sensitivity to turbine number and spacing relative to the cell were determined. The influence of such wake-losses on yield was evaluated by comparison of energy yield from a power curve and predicted wind speed, from use of a standard turbine representation within WRF and from a modified parameterization to represent wake losses. The case study is based on the Horns Rev farm for time intervals selected to represent the annual wind speed distribution. The parameterization developed provided an energy yield that is within 0.5% of the annual, when scaled for a year, compared to predictions within range 2-4% of measured by standard methods.

Objectives

1. Determine accuracy of energy yield prediction using standard semi-empirical wake models using data from numerical weather prediction models at a range of spatial resolutions.
2. Assess variation of momentum extraction and power output with arrangement of a sub-set of turbines within a farm representing a group of turbines within a cell.
3. Represent sub-groups of turbines, without and with wake losses, in WRF and assess energy yield for a typical range of operating conditions to assess sensitivity of yield to within cell losses.

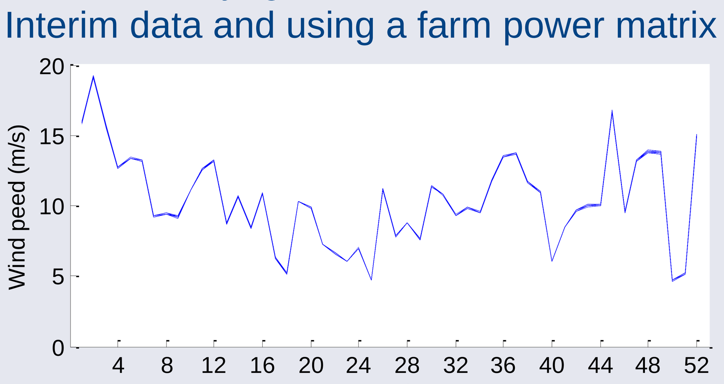
Annual yield is evaluated for the Horns Rev wind farm during the year 2007 using the ERA-Interim dataset and for intervals of one week duration simulated using WRF for resource only, using the Fitch[1] scheme with a standard turbine power and thrust curve and a modified power and thrust curve representing wake losses across a sub-group of turbines.

Annual yield

Net electricity generation obtained over the year 2007 from ERA-Interim data and using a farm power matrix obtained from Openwind[4].

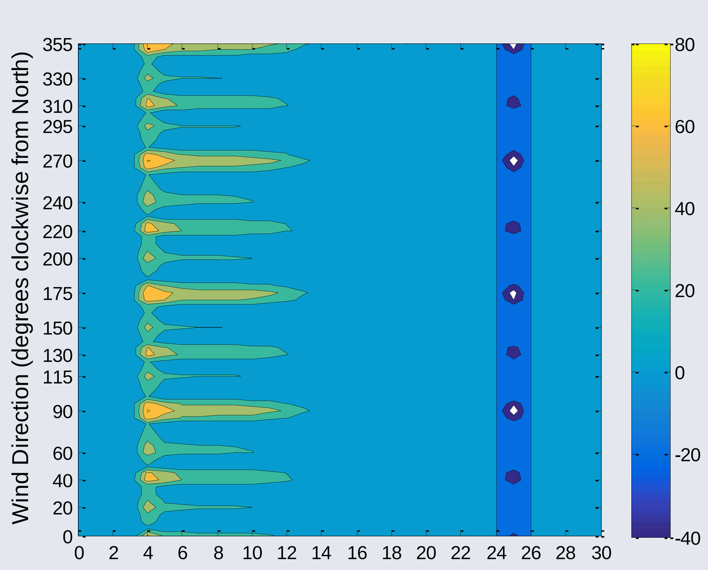
$$E=\sum_{h=1}^{8760} P_h=\sum_{i=4}^{25}\sum_{j=1}^{360} H(u_i,\theta_j)\cdot P(u_i,\theta_j)$$

▲ **Eq. 1.** Annual energy yield calculation. P_h is the power output for the wind speed and direction occuring at the h^{th} hour. $H(u_i,\theta_j)$ is the total number of hours within a year for which the wind speed of u_i m/s at a direction of θ_j° occurs. $P(u_i,\theta_j)$ is the respective power output of the farm.



◀ **Fig 1.** Weekly averaged annual wind speed time series for 2007, at the Horns Rev wind farm site.

Wake losses result in reduced power per turbine. Variation of power output with wind speed and direction relative to a single turbine power curve, obtained via:



◀ **Fig 2.** Modified PARK

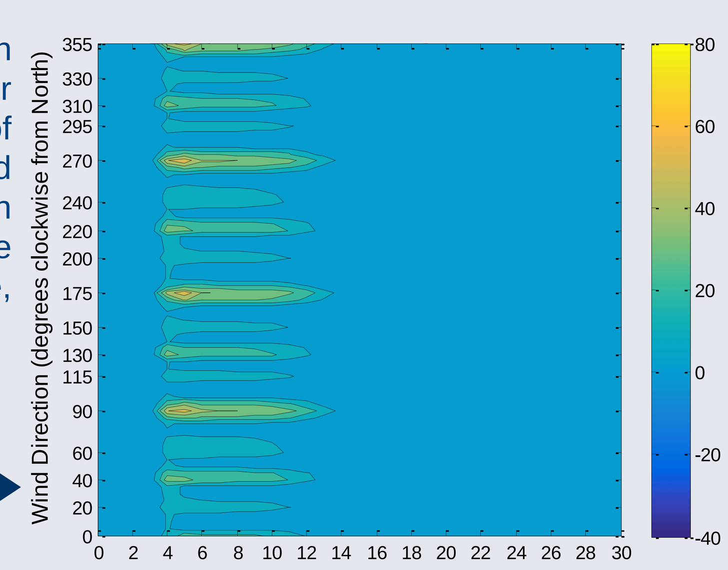
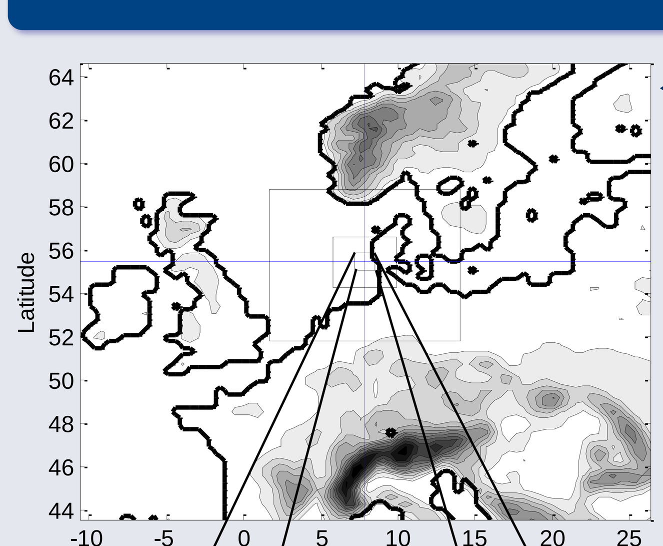


Fig. 3: Eddy Viscosity ▶

Horns Rev energy yield (GWh) for 2007		
Published yield[6]	Modified PARK	Eddy Viscosity
659.52	761.28	778.56
Percentage difference	+15.4%	+18.0%

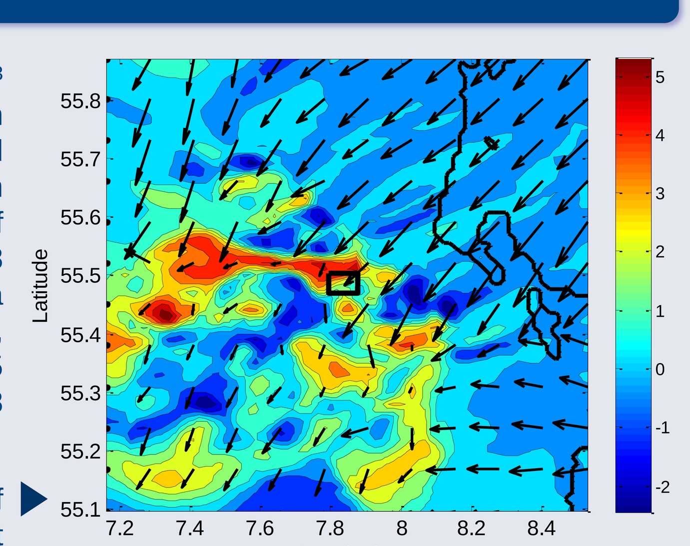
◀ **Table 1.** Horns Rev energy yield for 2007 calculated via Eq 1.

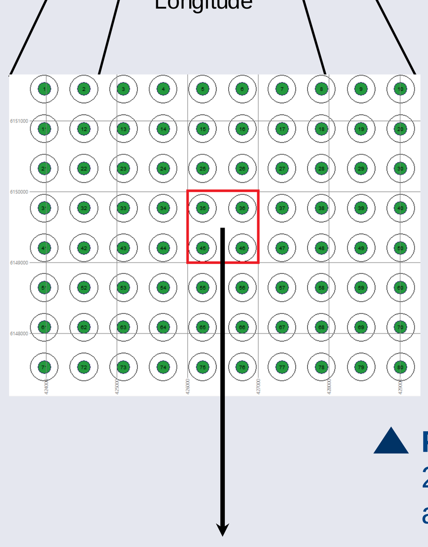
WRF Model



◀ **Fig 4.** Surface elevation[3] specified for WRF[5] simulation with four two-way nested domains indicated. Each domain centered at mid-point of Horns Rev and defined as 78 by 78 horizontal points and a horizontal resolution of 30.240, 10.080, 3.360 and 1.120 km. 45 vertical levels were specified, 8 of which cover the rotor area.

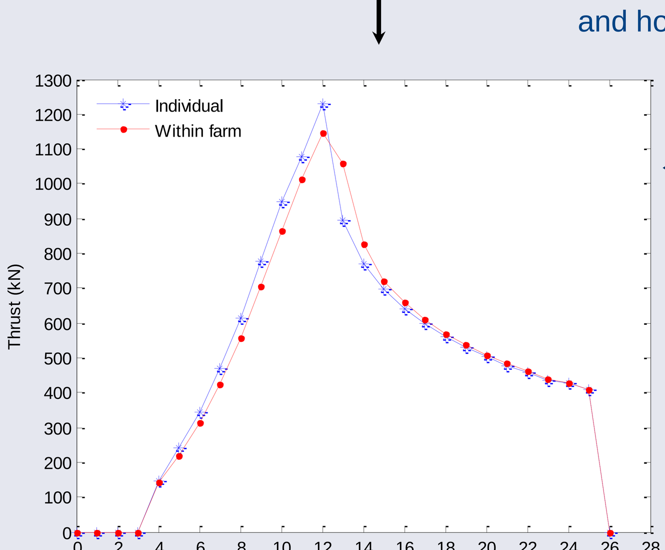
Fig 5. Instantaneous impact of the wind farm on wind speed at hub height. ▶





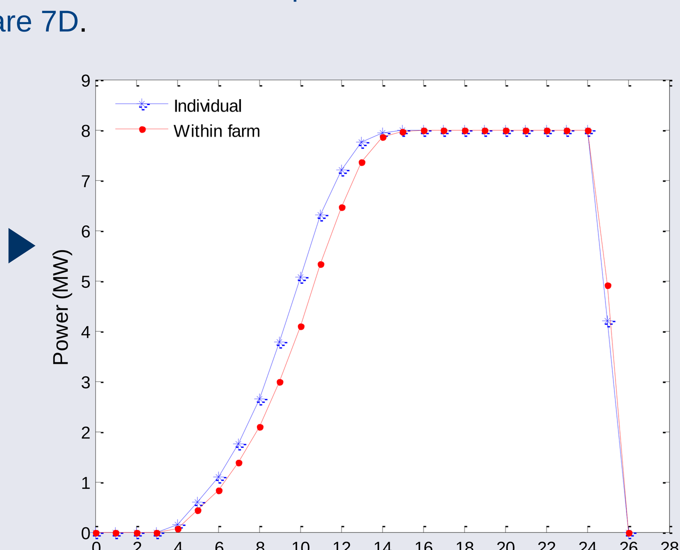
A 2×2 sub-grid of turbines was simulated using Openwind[4] to determine its power and thrust profile, taking into account the impact of the wakes. The modified parameterization describing the power and thrust coefficient curves[2] of the Vestas V80-2.0MW turbines, which takes into account the within-cell wake losses, was then implemented within WRF using the Fitch[1] scheme.

▲ **Fig 6.** Idealization of Horns Rev layout comprising 8×10 arrangement of 80 Vestas V80-2.0MW turbines, with a cut-in speed of 4 m/s and cut-out speed of 25 m/s. The vertical and horizontal inter-turbine distances are 7D.



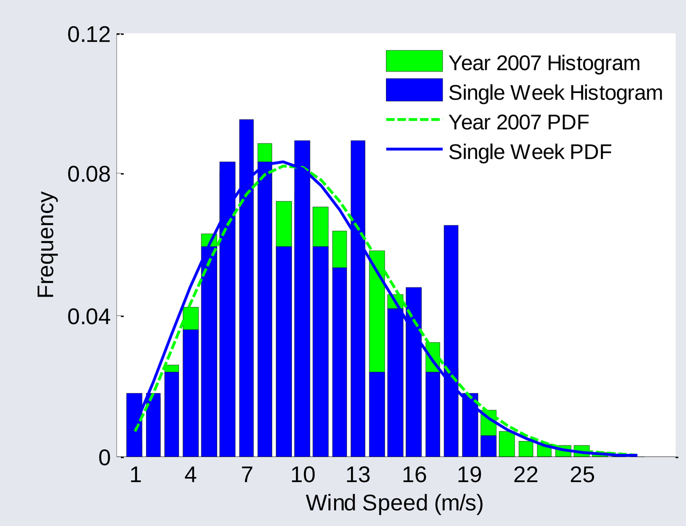
◀ **Fig 7.** Thrust curve and

Fig 8. Power curve of a 2×2 rectangular sub-group of turbines when considered in isolation and within the center of the farm, averaged over the whole range of wind directions. ▶



Sub-set of wind data

The electrical energy yield was calculated from WRF simulations over intervals of one week duration selected to represent the range of operating conditions experienced during the year 2007.



◀ **Fig 9.** Comparison between the wind speed distribution of the whole year of 2007 with a single week with comparable Weibull distribution of wind speeds.

Fig 10. Time series comparison of the wind speed obtained by the ERA-Interim dataset and the one derived by WRF, for the example selected week. ▶

Energy yield predictions

The energy yield for the selected week was calculated through Eq. 1. The wind speed and direction at hub height for each case were specified for each 2×2 sub-layout –cell– either through the ERA-Interim dataset or through WRF. For the WRF case, the energy yield was predicted by considering the available wind resource, the elevated momentum sink parameterization[1] and a modification of the manufacturer's thrust and power curves to account for within-cell wake losses. The Modified PARK and Eddy Viscosity wake models were used to define the power profile for the entire farm as well as for the 2×2 sub-layout .

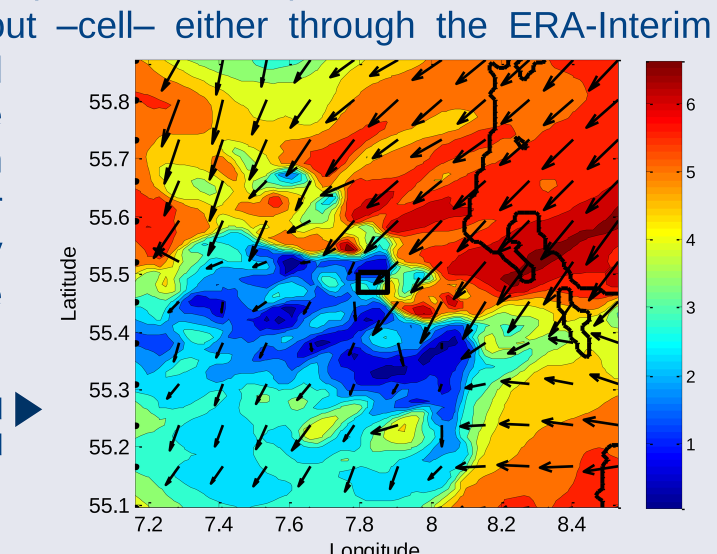
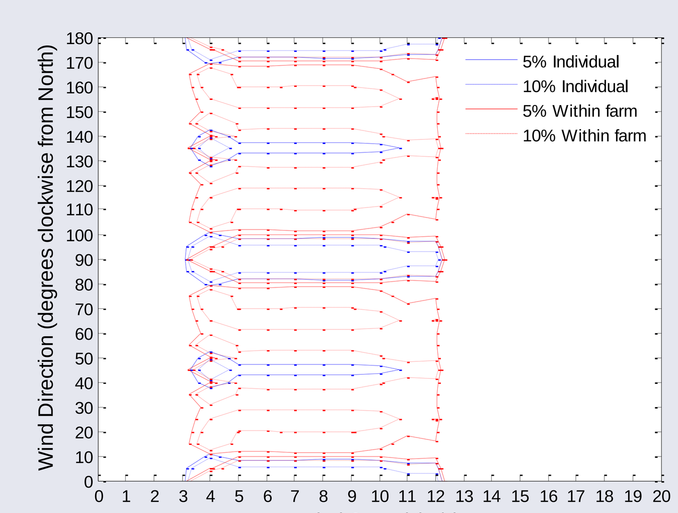
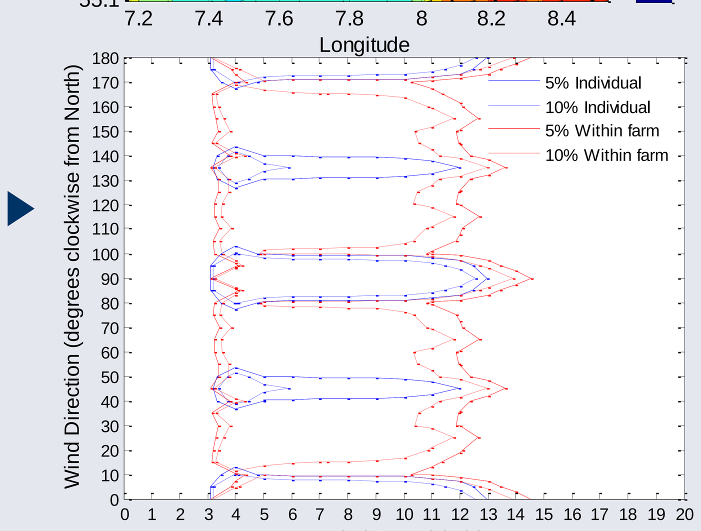


Fig 11. Instantaneous wind profile. The background indicates the wind speed whereas the arrows the wind direction. The wind speed is significantly affected downstream the wind farm due to the wakes. ▶



◀ **Fig 12.** Reduction in thrust and

Fig 13. Reduction in power due to wakes, when a 2×2 sub-cell of the idealized layout is considered individually and within the center of the farm, expressed as a percentage over the first case. ▶



Energy yield in GWh		
ERA-Interim dataset		Difference relative to ERA-Interim with Eddy Viscosity model
Modified PARK	Eddy Viscosity	
15.792	16.153	
WRF: Wind prediction only		
Modified PARK	Eddy Viscosity	
12.965	13.265	-21.8%
WRF with Fitch Model		-
Standard Model	13.912	-16.1%
Modified Thrust and Power	13.655	-18.3%

◀ **Table 2:** Energy yield for a single week with wind speed distribution comparable to 2007 annual distribution. Yield shown for alternative sources of wind resource and for negligible losses within the farm and losses approximated by the Modified PARK and Eddy Viscosity models. The energy yields, for the two cases where the wake losses are neglected were calculated by considering the wind speed and direction at the center of each 2×2 cell.

Conclusions

- Thrust coefficient curve and a power curve describing subgroups of four turbines within each cell occupied by turbines within WRF increased energy yield prediction relative to standard Fitch scheme.
- Annual energy yield obtained by modified parameterisation scaled to a year is within 0.5% of measured compared to range 2% overprediction to 4% underprediction obtained by standard WRF models.

Acknowledgements

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