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Benchmarking of Wind Turbine Wake Models in Large Offshore Windfarms

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Abstract

Quantifying accurately wind turbine wakes is a key aspect of wind farm economics in large wind farms. This research compares three engineering wake models with power production data from the Horns Rev and Lillgrund offshore wind farms. Single and multiple wake cases are investigated to verify the performance of the models in different conditions. The simulations reveal that the three wake models have similar behaviours for both wind farms although the turbine spacing and the turbulence intensity are different. The results prove the robustness of the models to provide accurate power predictions when the simulations are averaged over wind direction sectors of 30°. However, all models significantly underpredict the power production of a single row of wind turbines using narrow sectors of 3° or 5°. This discrepancy is discussed and justified by the wind direction uncertainty included in the datasets.

Site and measurements

Fig. 1 shows the layout of the Horns Rev and Lillgrund offshore wind farms. The measured turbulence intensity for westerly winds at Horns Rev is 7% and the turbine spacing is 7 rotor diameters (D). At Lillgrund, the turbulence intensity for southwesterly winds is 5.6% and the turbine spacing is $4.3D$.

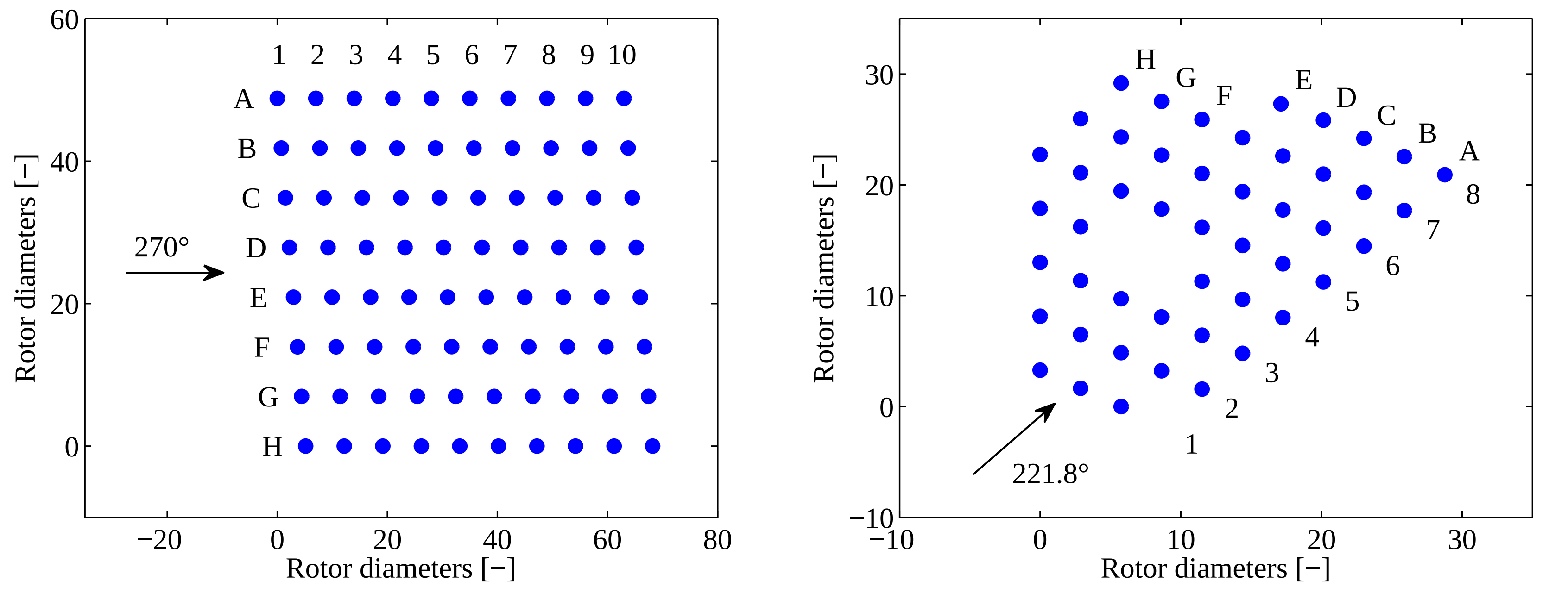

Figure 1: Layout of the Horns Rev wind farm (left) and Lillgrund wind farm (right)

Wake models

The Jensen model, the Larsen model and Fuga are cluster wake models that assume neutral atmospheric stability. Here, the Jensen model refers to the cluster wake model suggested by Katic *et al.* [2] using the single wake model of Jensen [1]. The Larsen model corresponds to the most recent update of the model from Larsen [3] where the velocity recovery and wake expansion are controlled by the turbine's thrust coefficient and the ambient turbulence intensity. Fuga is a linear flow solver based on the steady-state RANS equations. No numerical grid is required by the solver, which eliminates user dependency and numerical diffusion. The complete description of Fuga and its evaluation with wind farm datasets can be found in Ott *et al.* [4]. In this study, Fuga version 2.0.0.28 is used with a roughness length of 0.0001 m and a boundary layer height of 500 m.

Interaction between two turbines

Except for the Larsen model at Lillgrund, Fig. 2 shows that the numerical simulations agree very well with power production data for the two single wake flow cases investigated. Since the wake radius in the Larsen model was calibrated from measurements at $9.6D$ [3], the overprediction of this model at Lillgrund might be caused by the short turbine spacing.

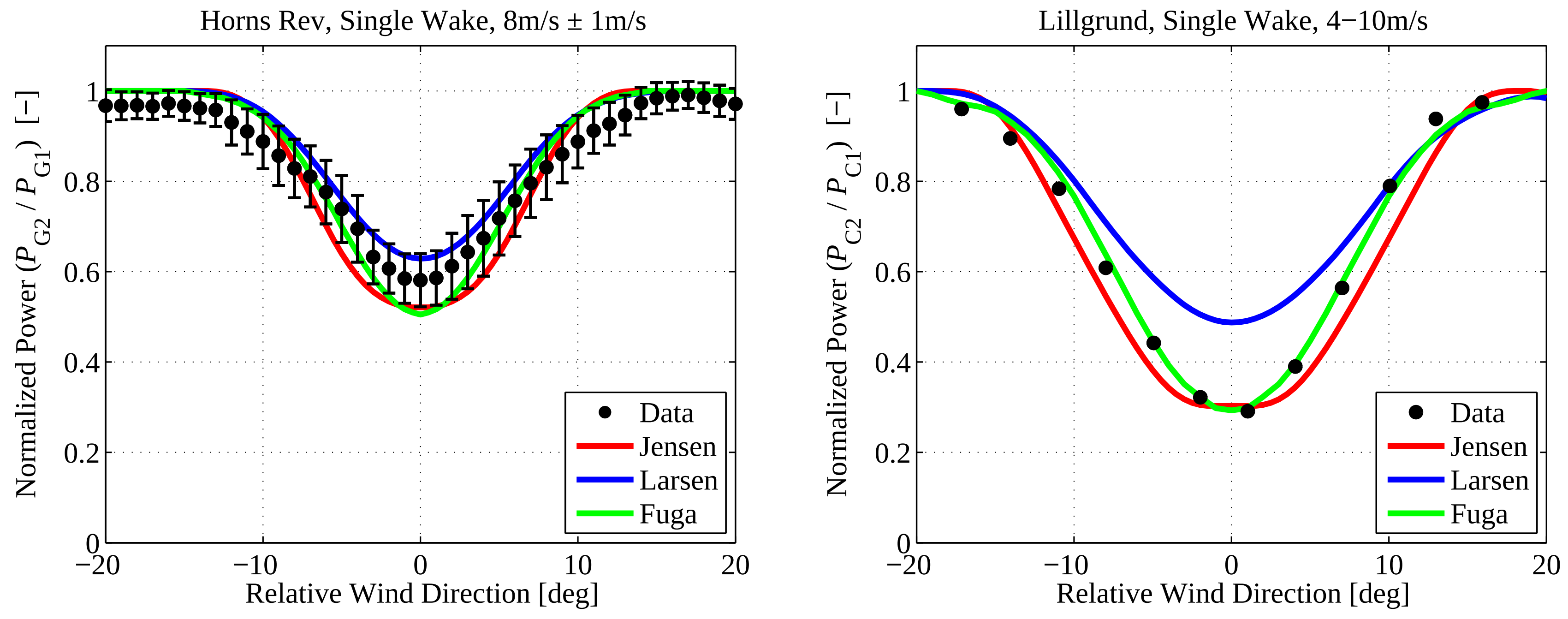

Figure 2: Normalized power of the second turbine in row G at Horns Rev (left) and in row C at Lillgrund (right)

Multiple wake cases along a row of wind turbines

Fig. 3 and 4 show that the models underpredict the power production of the narrow sectors (±2.5° and ±1.5°), while obtaining good to excellent accuracy for ±15°. Hence, there is a clear correlation between the accuracy of the power predictions and the span of the averaging sector.

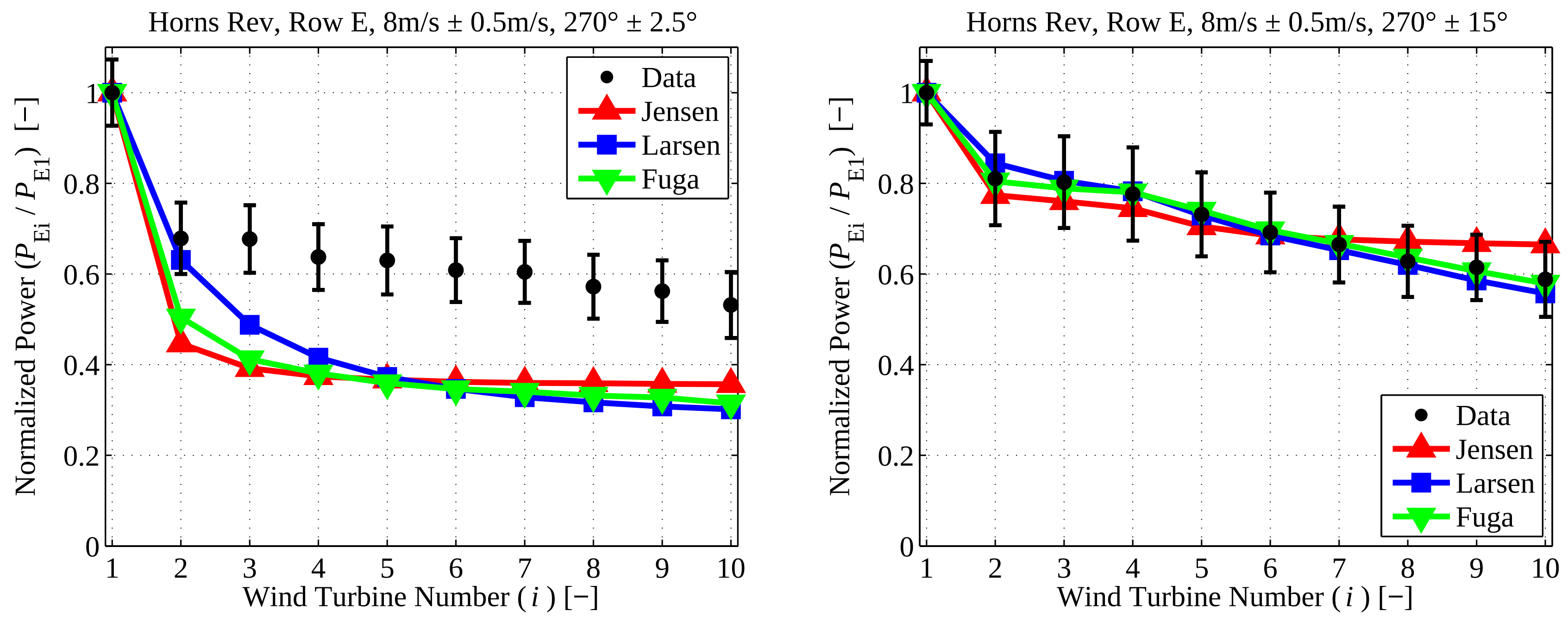

Figure 3: Normalized power in row E at Horns Rev for the wind direction sector 270° ±2.5° (left) and ±15° (right).

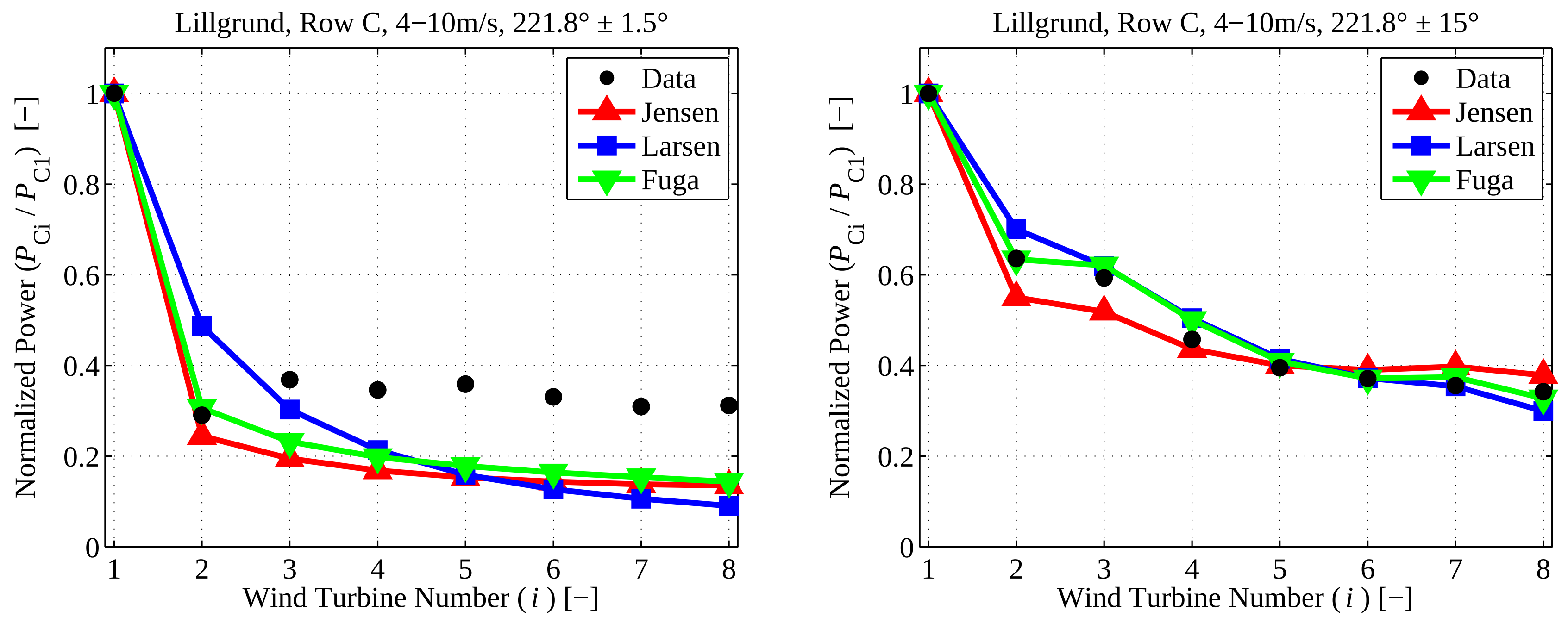

Figure 4: Normalized power in row C at Lillgrund for the wind direction sector 221.8° ±1.5° (left) and ±15° (right).

Discussion

The main sources of wind direction uncertainty in the datasets are the yaw misalignment of the reference wind turbine, the spatial variability of the wind direction within the wind farm and the variability of the wind direction within an averaging period. Filtering a dataset for narrow wind direction sectors of 3° and 5° therefore include situations where the turbines operate in conditions outside the span of the sector. This means that the turbines operate more often in wake free or partial wake situations (i.e. higher power outputs) than what is modelled by the numerical simulations. In turn, when the sector width increases the wind direction uncertainty becomes less significant and less cases are filtered in the wrong bins. The agreement in Fig. 3 and 4 for the 30° sectors is therefore improved because the simulations are more representative of the datasets.

Main conclusions

- The three wake models perform similarly at Horns Rev and Lillgrund although the turbine spacing and the turbulence intensity are different.
- The power predictions are accurate for wide directional sectors of 30°.
- The discrepancies for narrow wind direction sectors are caused by the wind direction uncertainty present in the datasets.

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