FLOWSTAR-Energy Validation
NoordZee Wind Farm

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FLOWSTAR-Energy 5.1

1 Introduction

NoordZee is an offshore wind farm in Denmark. A FLOWSTAR-Energy model of the wind farm was compared with measurements of the power deficit for each turbine.

2 Input Data

2.1 Study Area

The NoordZee wind farm is an offshore wind farm consisting of 36 V90 VESTAS 90m, 3MW wind turbines. Each turbine has diameter 90m and hub height 70m. The turbine layout is an irregular grid, with 4 SE-NW columns containing an unequal number of turbines. The spacing between turbines in each column is 7D (where D is the turbine diameter), apart from an 11D spacing between turbines 4 and 5 in columns 2, 3 and 4. The wind farm layout is shown in Figure 1. The turbine power and thrust curves are given in Figure 2.

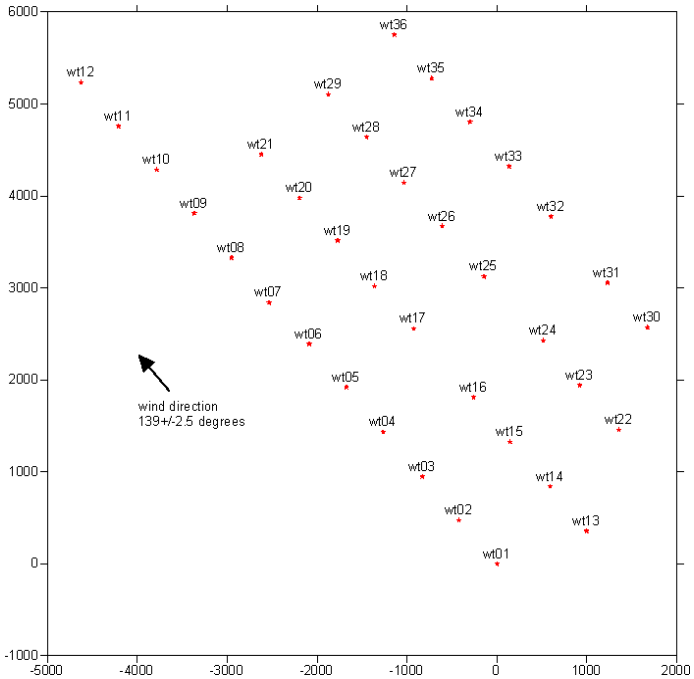

Figure 1 Layout of wind turbines in the NoordZee wind farm. Distance unit is metres; (0,0) is the location of turbine wt01. Arrow shows the wind direction case for which turbine measurements are available.

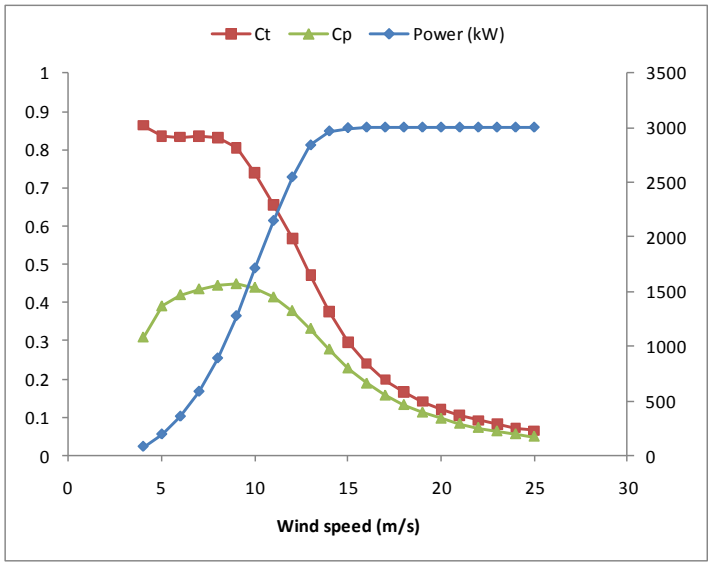

Figure 2 Power output (kW). Power coefficient C_p and thrust coefficient C_T as a function of inflow wind speed for the V90 VESTAS 3MW turbines installed at the NoordZee wind farm.

The measurement data available for the wind farm are mean power output at each turbine for one wind direction case, 139±2.5 degrees, for three hub height wind speed cases: 6, 8 and10m/s.

2.2 Model setup

The inputs to FLOWSTAR-Energy were as follows:

- 36 turbine sources, locations as shown in Figure 1
- Turbine height 70m
- Turbine diameter 90m
- C_p as a function of wind speed (see Figure 2)
- C_T as a function of wind speed (see Figure 2)
- Output receptors at each turbine location at hub height
- 3 flow cases: U=6, 8 and 10m/s
- Wind direction 139 degrees, no wind direction averaging
- Boundary layer height 800m, ground heat flux 0W/m^2, i.e. neutral conditions
- Surface roughness 0.01m

Output is power deficit at each receptor (i.e. turbine location) for each flow case, with reference to the power output available from the upstream flow.

3 Results

Below are graphs of observed and modelled normalised power at each turbine for each of the three flow cases. The observed value for each turbine in a particular column is the power produced by that turbine divided by the power produced by the upstream turbine in that column (turbine 1 for columns 1 and 2, turbine 2 for column 3 and turbine 3 for column 4). The same is true for the modelled values, but because the model assumes spatially-uniform upstream flow the power produced by the upstream turbines is the same.

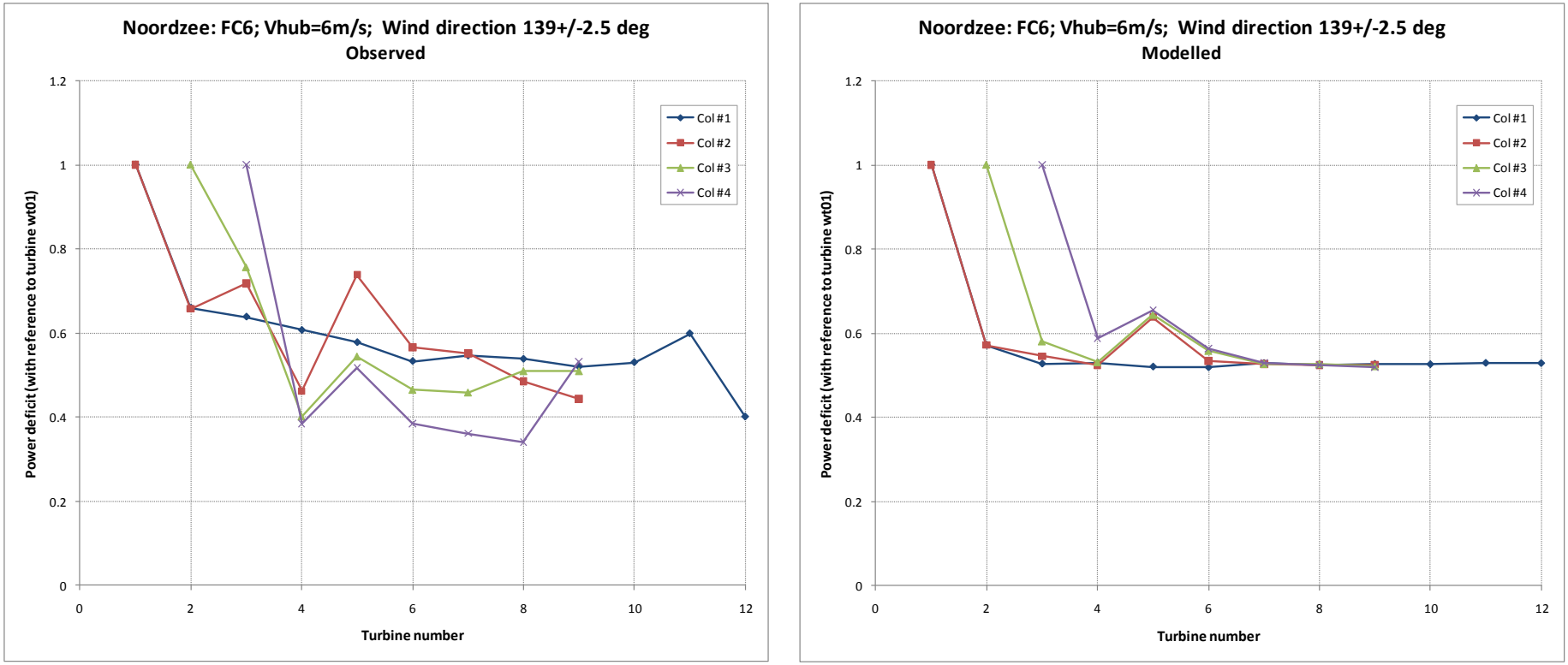

Figure 3 U = 6 m/s: Observed (left) and modelled (right) normalised power at each turbine.

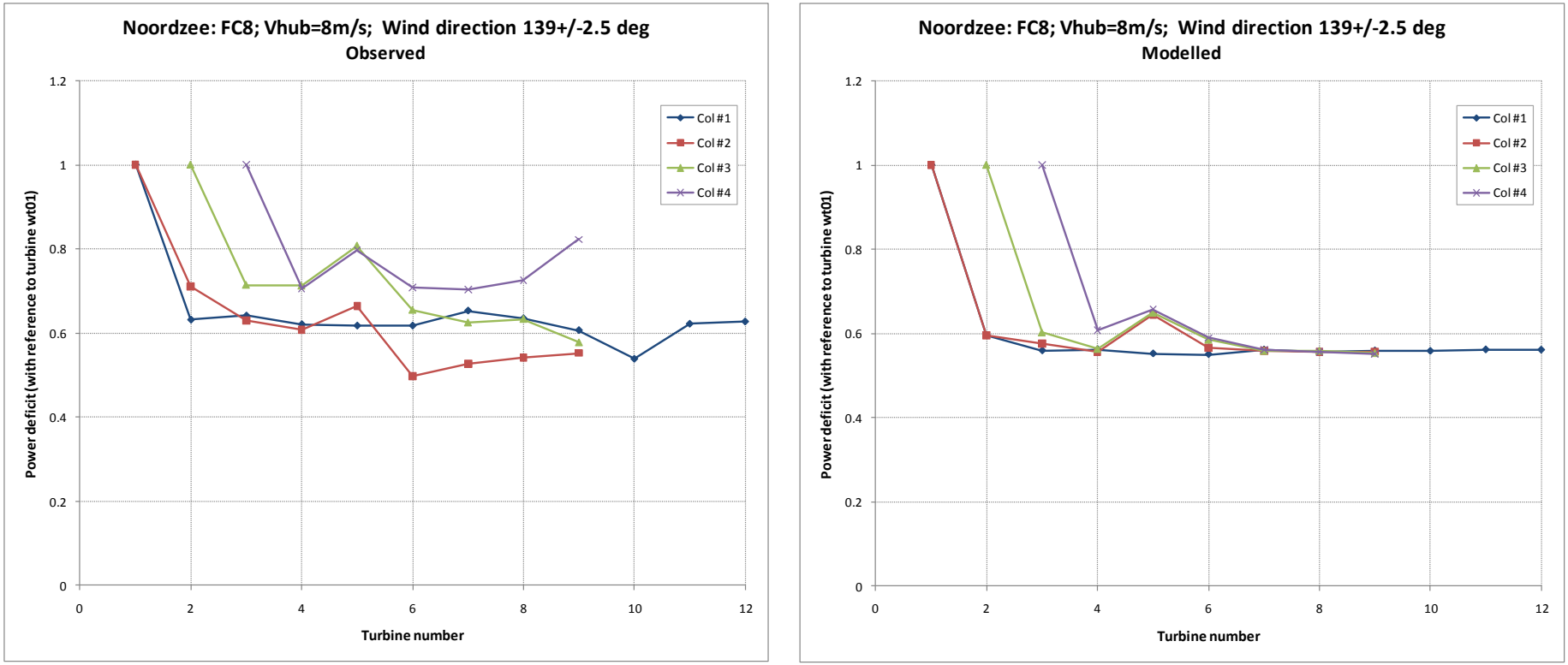

Figure 4 U = 8 m/s: Observed (left) and modelled (right) normalised power at each turbine.

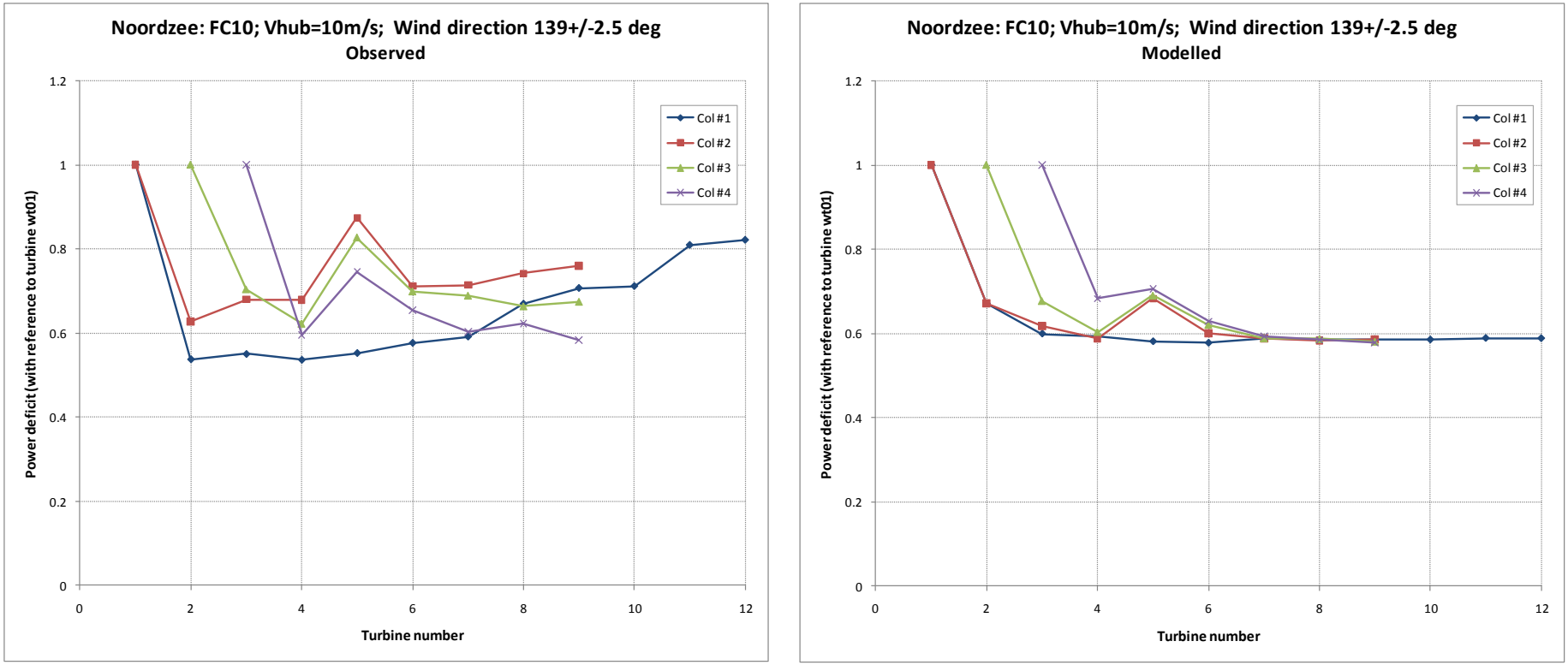

Figure 5 U = 10 m/s: Observed (left) and modelled (right) normalised power at each turbine.

4 Discussion

The model generally agrees well with observations; in particular it captures well the increase in production between turbines 4 and 5 in columns 2, 3 and 4 due to the larger spacing between turbines 4 and 5 in these columns.

For the 6 and 8 m/s flow cases the model captures well the sharp decline in power production between the first and second turbines in each column, and then the more gradual reduction in power production through the wind farm due to the effect of the wakes. However for the 10 m/s flow case the observations show the same sharp reduction in power production between the first and second turbines in each column, but then an unexplained gradual increase through the wind farm, which is not simulated by the model.

5 Acknowledgements

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