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Validating Kinematic Wake Models in Complex Terrain

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Abstracts

Due to spatial and economic constraints and the limited number of suitable sites, wind turbines are clustered in wind farms. This clustered arrangement may lead to interactions between the wind turbines. In order to keep wake losses at a minimum, wind farm designers rely on wake models and commercial software to optimize the turbine layout. Kinematic wake models are commonly used because of their low requirement on computational resources.

The main objective of this study is to validate three kinematic wake models in complex terrain with the use of computational fluid dynamics (CFD) using data from a wind farm in Norway.

Methods

Measurements from Nygårdsfjellet wind farm located in northern Norway have been used in the validation process. The wind farm consists of fourteen 2.3 MW turbines with a rotor diameter of 93 meters and a hub height of 80 meters (fig. 1).

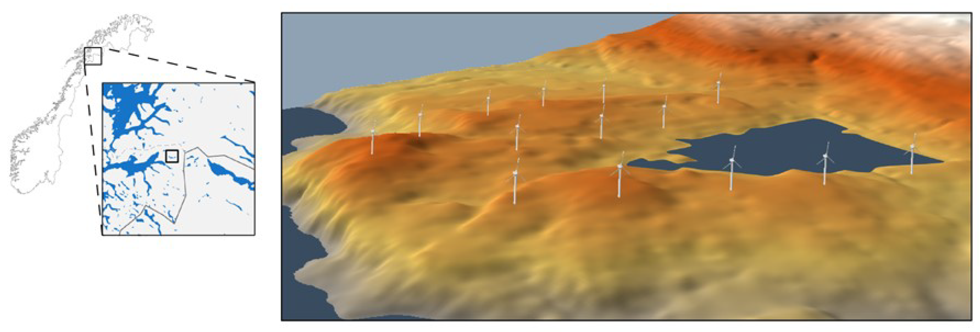

Fig. 1: Map of Nygårdsfjellet Wind Farm, with a computer-generated 3D-view of the farm layout looked upon from southeast with the turbines facing east.

Assisted by the commercial WindSim software, which is based on computational fluid dynamics (CFD), the accuracy of the three models were tested in eight single-wake cases (fig. 2).

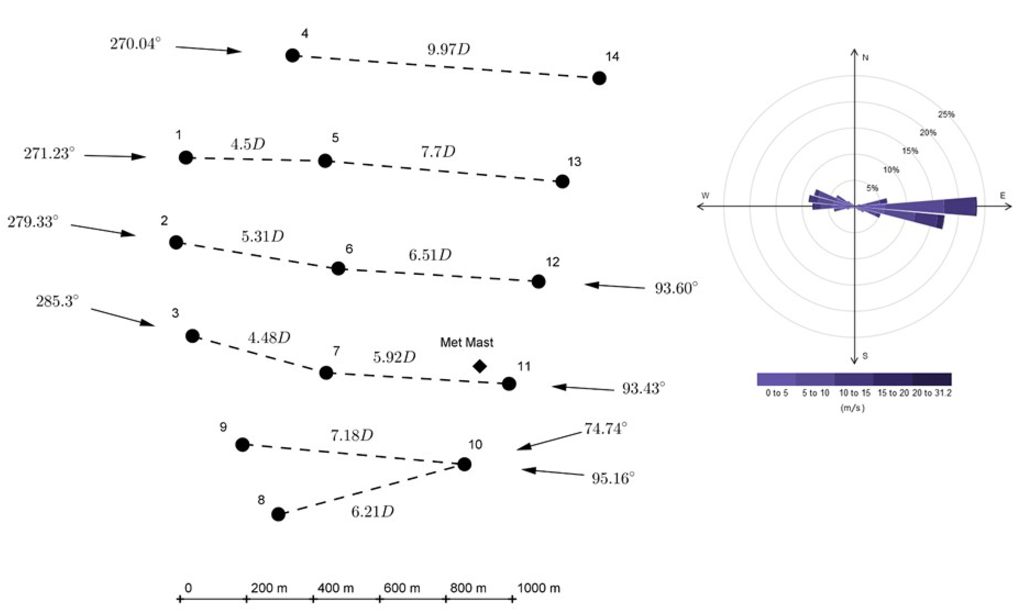

Fig. 2: The turbine layout at Nygårdsfjellet wind farm, pinpointing the eight investigated wake cases, and the wind rose from the site.

Kinematic wake models

Jensen model [2]
$$\delta V = \frac{1-\sqrt{1-C_T}}{\left(1+\frac{2kx}{D}\right)^2}$$

- Linear expansion of the wake

Larsen model [3]
$$\delta V = \frac{\left(C_T A x^{-2}\right)^{\frac{1}{3}}}{9}\left\{r^{\frac{3}{2}}\left(3c_1 C_T A x\right)^{-\frac{1}{2}} - \left(\frac{35}{2\pi}\right)^{\frac{3}{10}}\left(3c_1^{\,2}\right)^{-\frac{1}{5}}\right\}^2$$

- Dependent on the radial distance

Ishihara model [4]
$$\delta V = \frac{C_T^{\frac{1}{2}}}{32}\left(\frac{1.666}{k_1}\right)^2\left(\frac{x}{D}\right)^{-p}\exp\left(-\frac{r^2}{b^2}\right)$$

- Wake recovery dependent on turbulence

Validation procedure

The filtered data from the wind farm was compared to the simulated data (1.3 million simulation cells, checked for grid independence). Several key aspects were investigated, most importantly the profile of the normalized power deficit, the power deficit at the wake centerline and the wake width.

Results

The Larsen model correlated well with the measured data, while the Jensen model overestimated the normalized power deficit to some degree. The Ishihara model was found to overestimate the normalized power deficit in all investigated cases. Results from four of the investigated wake cases are shown in fig. 4.

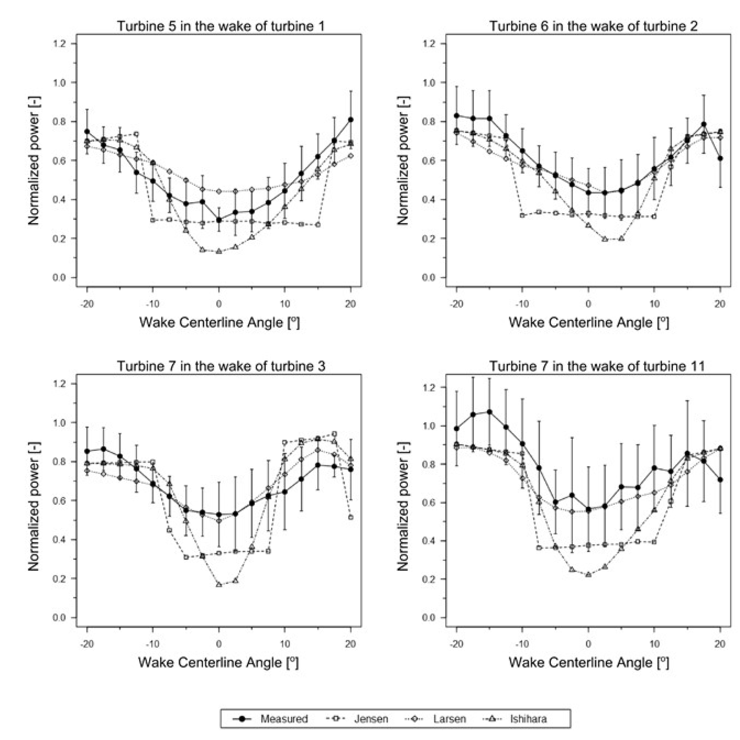

Fig. 4. The normalized power for four of the wake cases, ± 20° of the wake centerline, for free-stream wind speeds of 9 ± 1 m/s. The plot shows the measured data and the data from the three wake models. Whiskers represents the standard deviation from the mean.

Results

At the wake centerline, the Larsen model was by far the most accurate, with a mean absolute error of 7 %. The Jensen- and Ishihara model had a mean absolute error of 21 and 34 % respectively, as shown in fig. 5.

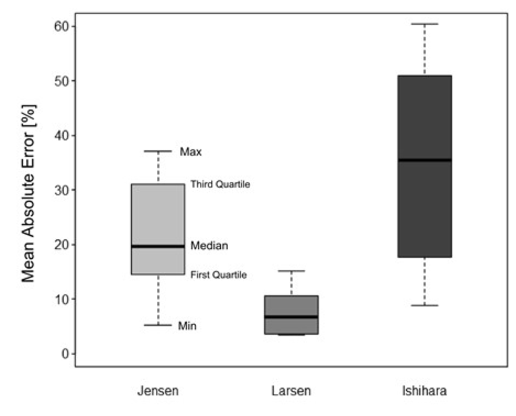

Fig. 5: Mean absolute error of the three wake models compared the measured values at the wake centerline ± 1°, for the free-stream wind speeds of 9 ± 1 m/s, using all eight wake cases.

The Larsen model widely overestimated the wake width in all cases, but with an almost constant offset (fig. 6). Both the Jensen- and Ishihara model agreed well with the observed wake width.

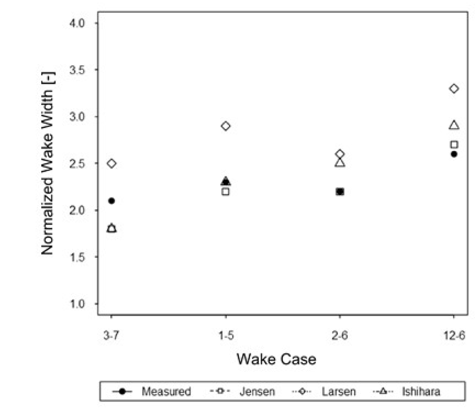

Fig. 6: The normalized wake width for four of the wake cases. The wake is normalized to the rotor diameter of the turbine in front.

Conclusions

This study found significant differences in the prediction capabilities of the three wake models. The Larsen model performed best, but it must be emphasized that the results may to some degree be site-dependent. Uncertainty in measurements prevents any clear-cut conclusions.

References

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