Evaluation of the Wind Direction Uncertainty And Its Impact on Wake Modelling at the Horns Rev Offshore Wind Farm

Réthoré, Pierre-Elouan; Gaumond, Mathieu ; Bechmann, Andreas; Hansen, Kurt Schaldemose; Pena Diaz, Alfredo; Ott, Søren; Larsen, Gunner Chr.

Publication date:
2013

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Evaluation of the Wind Direction Uncertainty And Its Impact on Wake Modelling at the Horns Rev Offshore Wind Farm

Pierre-Elouan Réthoré*, Mathieu Gaumond, Andreas Bechmann, Kurt Hansen, Alfredo Pena, Søren Ott, Gunner Larsen

Aero-elastic Section, Wind Energy Department, DTU, Risø

Windpower Monthly’s Wind Farm Data Management and Analysis forum
23-25 September
Outline

1. Why Uncertainty Matters?
   - Introduction
   - Method: Modelling the wind direction uncertainty
   - Results

2. Adding Value to Wind Farm Data
   - Machine Learning and Physical Modelling
   - The FUSED-Wind project
   - A Future Business Concept

3. Conclusion and Future Works
Introduction

Overview of DTU’s Wind Farm Flow Models

[Diagram showing a classification of wind farm flow models based on time and physics categories, with labels for various models and keywords like 'Instationary', 'Stationary', 'Cluster', 'PC', 'Infinite WF', 'Rapid-DWM', 'DWM-HAWC2', 'FUGA', 'Larsen’s stationary', 'NO Jensen']
Introduction

What Are Those Models used for?

- Estimating Annual Energy Production
- Wind Farm Optimization
Introduction

The Horns Rev test case - Western winds

Reference wind direction
Introduction

Results of the Wake Model Benchmarking: Confusion!

270° ± 2.5°

270° ± 15°

Wind Turbine Number (i) [-]
Normalized Power (P_{Ei} / P_{E1}) [-]

Data
N.O. Jensen
G.C. Larsen
Fuga

P.-E. Réthoré
DTU Wind Energy

Uncertainty & Wake
Introduction

The effect of wind direction uncertainty on wind farm wake measurement
Introduction

The effect of wind direction uncertainty on wind farm wake measurement
Introduction

The effect of wind direction uncertainty on wind farm wake measurement
Introduction

The effect of wind direction uncertainty on wind farm wake measurement
Introduction

Sources of wind direction uncertainty

Random/temporal bias from the measurement device
- Yaw misalignment (when yaw sensor is used to measure direction)
- Time drift of the calibration
- Failures
Introduction

Sources of wind direction uncertainty

Random/temporal bias from the measurement device
- Yaw misalignment (when yaw sensor is used to measure direction)
- Time drift of the calibration
- Failures

Atmospheric turbulence
- Small scale turbulence (sub 10-minute)
  -> This *should* be accounted by the models
- Large scale turbulence (i.e. wind directional trends, over 10-minute)
Introduction

Sources of wind direction uncertainty

Random/temporal bias from the measurement device
- Yaw misalignment (when yaw sensor is used to measure direction)
- Time drift of the calibration
- Failures

Atmospheric turbulence
- Small scale turbulence (sub 10-minute) -> This *should* be accounted by the models
- Large scale turbulence (i.e. wind directional trends, over 10-minute)

Wind direction coherence
- Spatial variability of the wind direction
- Different time-control volume averaging
Introduction

Spatial decorrelation of wind direction

The wind direction correlation between M2 and the wind turbines decreases linearly with the distance.
1. Why Uncertainty Matters?
   - Introduction
   - Method: Modelling the wind direction uncertainty
   - Results

2. Adding Value to Wind Farm Data
   - Machine Learning and Physical Modelling
   - The FUSED-Wind project
   - A Future Business Concept

3. Conclusion and Future Works
Method: Modelling the wind direction uncertainty

The "traditional" method

- Step 1: Run simulations with fixed and homogeneous wind direction covering the desired wind direction sector
- Step 2: Apply a linear average to reproduce the data post-processing

Final Output (e.g. 270° ± 2.5°)
Method: Modelling the wind direction uncertainty

The proposed method

Step 1: Run simulations with fixed and homogeneous wind direction
Method: Modelling the wind direction uncertainty

The proposed method

◆ Step 1: Run simulations with fixed and homogeneous wind direction
◆ Step 2: Apply a weighted average based on the probability function of a normal distribution on the interval $\pm 3\sigma$
Method: Modelling the wind direction uncertainty

The proposed method

- Step 1: Run simulations with fixed and homogeneous wind direction
- Step 2: Apply a weighted average based on the probability function of a normal distribution on the interval $\pm 3\sigma$
Method: Modelling the wind direction uncertainty

The proposed method

- Step 1: Run simulations with fixed and homogeneous wind direction
- Step 2: Apply a weighted average based on the probability function of a normal distribution on the interval $\pm 3\sigma$
- Step 3: Apply a linear average to reproduce the data post-processing
Results

All the rows, using a row-specific wind direction uncertainty

270° ± 2.5°

270° ± 15°
#### Result for the whole wind farm in $\theta = 270^\circ$

<table>
<thead>
<tr>
<th></th>
<th>$270 \pm 2.5^\circ$</th>
<th>$270 \pm 15^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Data</td>
<td>64.7%</td>
<td>73.9%</td>
</tr>
<tr>
<td>NOJ, Baseline</td>
<td>-20.9%</td>
<td>+0.4%</td>
</tr>
<tr>
<td>GCL, Baseline</td>
<td>-20.9%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>Fuga, Baseline</td>
<td>-21.7%</td>
<td>-0.3%</td>
</tr>
</tbody>
</table>
### Results

**Result for the whole wind farm in $\theta = 270^\circ$**

<table>
<thead>
<tr>
<th></th>
<th>$270 \pm 2.5^\circ$</th>
<th>$270 \pm 15^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Data</td>
<td>64.7%</td>
<td>73.9%</td>
</tr>
<tr>
<td>NOJ, Baseline</td>
<td>-20.9%</td>
<td>+0.4%</td>
</tr>
<tr>
<td>GCL, Baseline</td>
<td>-20.9%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>Fuga, Baseline</td>
<td>-21.7%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>NOJ, $\sigma=3.5^\circ$</td>
<td>-11.6%</td>
<td>+0.0%</td>
</tr>
<tr>
<td>GCL, $\sigma=3.5^\circ$</td>
<td>-8.2%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Fuga, $\sigma=3.5^\circ$</td>
<td>-8.5%</td>
<td>-0.2%</td>
</tr>
</tbody>
</table>
## Results

Result for the whole wind farm in $\theta = 270^\circ$

<table>
<thead>
<tr>
<th></th>
<th>$270 \pm 2.5^\circ$</th>
<th>$270 \pm 15^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Data</td>
<td>64.7%</td>
<td>73.9%</td>
</tr>
<tr>
<td>NOJ, Baseline</td>
<td>-20.9%</td>
<td>+0.4%</td>
</tr>
<tr>
<td>GCL, Baseline</td>
<td>-20.9%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>Fuga, Baseline</td>
<td>-21.7%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>NOJ, $\sigma=3.5^\circ$</td>
<td>-11.6%</td>
<td>+0.0%</td>
</tr>
<tr>
<td>GCL, $\sigma=3.5^\circ$</td>
<td>-8.2%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Fuga, $\sigma=3.5^\circ$</td>
<td>-8.5%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>NOJ, row-specific</td>
<td>-3.1%</td>
<td>+0.1%</td>
</tr>
<tr>
<td>GCL, row-specific</td>
<td>-0.7%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Fuga, row-specific</td>
<td>-0.8%</td>
<td>-0.2%</td>
</tr>
</tbody>
</table>
Outline

1. Why Uncertainty Matters?
   - Introduction
   - Method: Modelling the wind direction uncertainty
   - Results

2. Adding Value to Wind Farm Data
   - Machine Learning and Physical Modelling
   - The FUSED-Wind project
   - A Future Business Concept

3. Conclusion and Future Works
\[ \zeta_i(x_i) = \eta(x_i) \]
\[ z_i = \zeta_i(x_i) + \varepsilon_i = \eta(x_i, \theta) + \delta(x_i) + \varepsilon_i \]
Machine Learning and Physical Modelling

System Engineering

[Diagram of model components and interactions with inputs, outputs, measurements, parameters, and model inadequacy.]
The FUSED-Wind project
Connecting All Wind Energy Models in a Workflow

- Collaborative effort between DTU and NREL to create a Framework for Unified System Engineering and Designed of Wind energy plants.
- Based on OpenMDAO, a python based Open source framework for Multi-Disciplinary Analysis and Optimization.
- FUSED-Wind will offer built in capabilities for Uncertainty Quantification, Machine Learning and Optimization.
A Future Business Concept

I want to plan a wind farm

WAsP
SmartWake client

Cloud Cluster
SmartWake Server

Wind farm SCADA owners

Wake Modelers
A Future Business Concept

I want to plan a wind farm

WAsP
SmartWake client

I want my wake model to be useful

Concept

Wind farm SCADA owners

Modelers
A Future Business Concept

Concept

WAsP
SmartWake client

I want to plan a wind farm

I want my wake model to be useful

Cluster
Wake Server

I want add value my wind farm SCADA data

Wind farm SCADA owners

P.-E. Réthoré
DTU Wind Energy

Uncertainty & Wake
A Future Business Concept

Concept

WAsP SmartWake client

Cloud Cluster SmartWake Server

Wind farm SCADA owners

Wake Modelers

P.-E. Réthoré

DTU Wind Energy

Uncertainty & Wake
A Future Business Concept

Concept

Uncertainty of AEP, fatigue

t0 result

t1 result

WAsP
SmartWake client

Cloud Cluster
SmartWake Server

Wind farm SCADA owners

Wake Modelers
A Future Business Concept

Concept

Uncertainty of AEP, fatigue

WAsP
SmartWake client

Cloud Cluster
SmartWake Server

Wind farm SCADA
owners

Wake Modelers

P.-E. Réthoré
DTU Wind Energy

Uncertainty & Wake
Conclusion

- The N.O. Jensen model, the G.C. Larsen model and Fuga are robust engineering models able to provide accurate predictions using wind direction sectors of 30°.

- The discrepancies for narrow wind direction sectors are not caused by a fundamental inaccuracy of the current wake models, but rather by a large wind direction uncertainty included in the dataset.

- We need some models and measurements for wind direction uncertainty to move forward from this stage.

- Do not "tune" your wake models to match the ±2.5° measurements!!!
Future work

Wind Farm Flow Model Uncertainty
- The method will be applied to other wake models and datasets
- Sample based uncertainty quantification to be investigated
- Work on estimating the wind direction uncertainty using the wind farm dataset

System Engineering
- Opening FUSED-Wind to the public
- Adding Uncertainty Quantification to FUSED-Wind
Thank you for your attention!

- Work funded by EUDP-WakeBench and EERA-DTOC
- Dataset graciously made available by DONG Energy and Vattenfall.
- Article submitted to wind energy and master thesis available on request