Wake Detection and Characterisation Utilising Blade Loads and SCADA Data: A Generalised Approach

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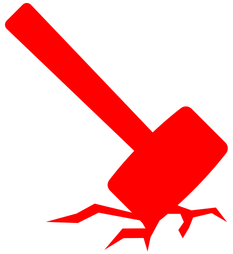
Motivation

Operating a wind turbine affected by a wake deficit results in [1]:

Decreased energy yield



Increased fatigue

Clearly visible wakes at Horns Rev 2 wind farm [2]

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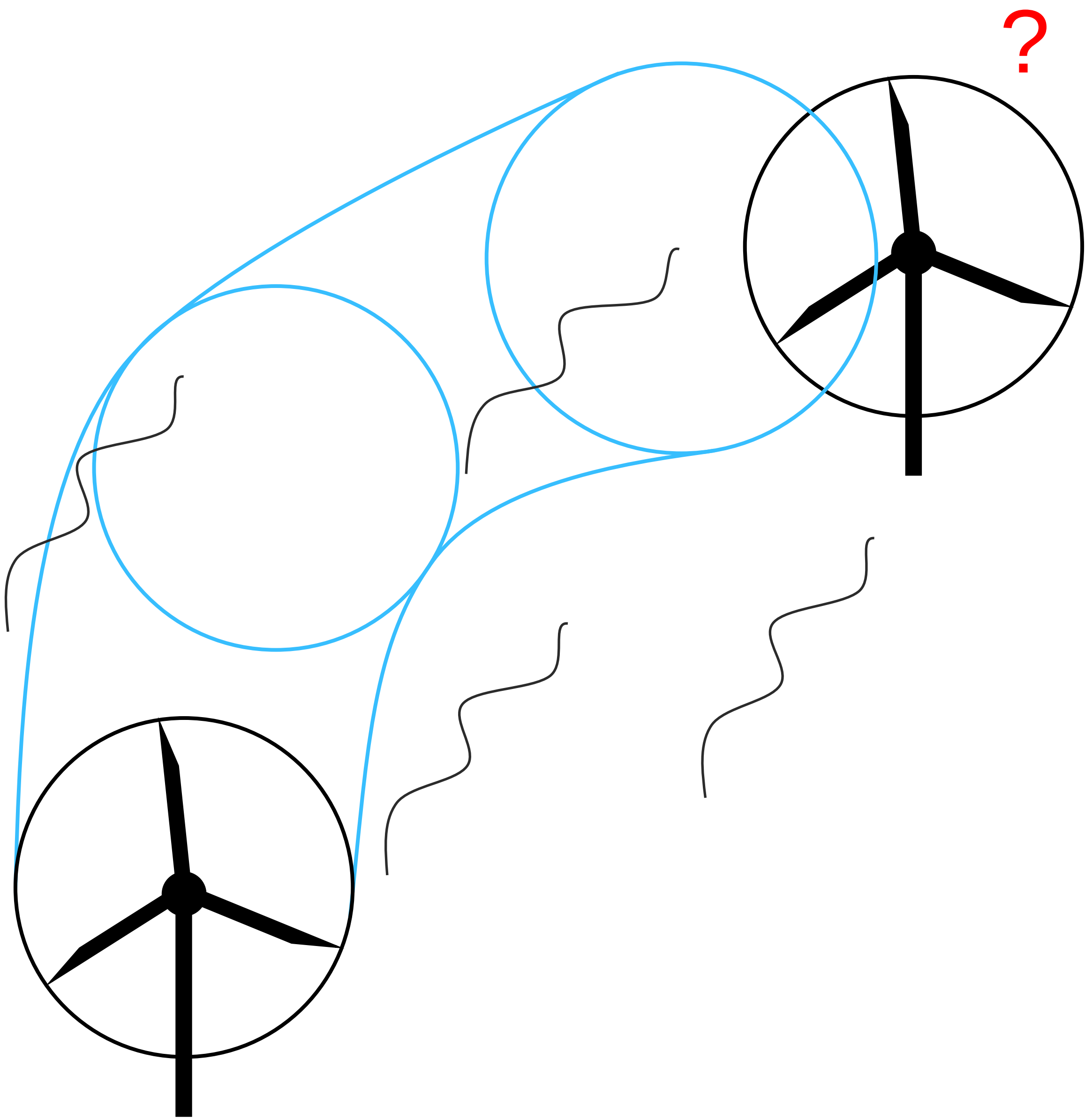
Motivation

- ✓ Wind farm flow control techniques require instantaneous wake properties as the input
- ✓ A robust wake estimation model needs to be developed
- ✓ Main issues:
  - Wake meandering
  - Atmospheric turbulence
  - Lack of proper flow sensors



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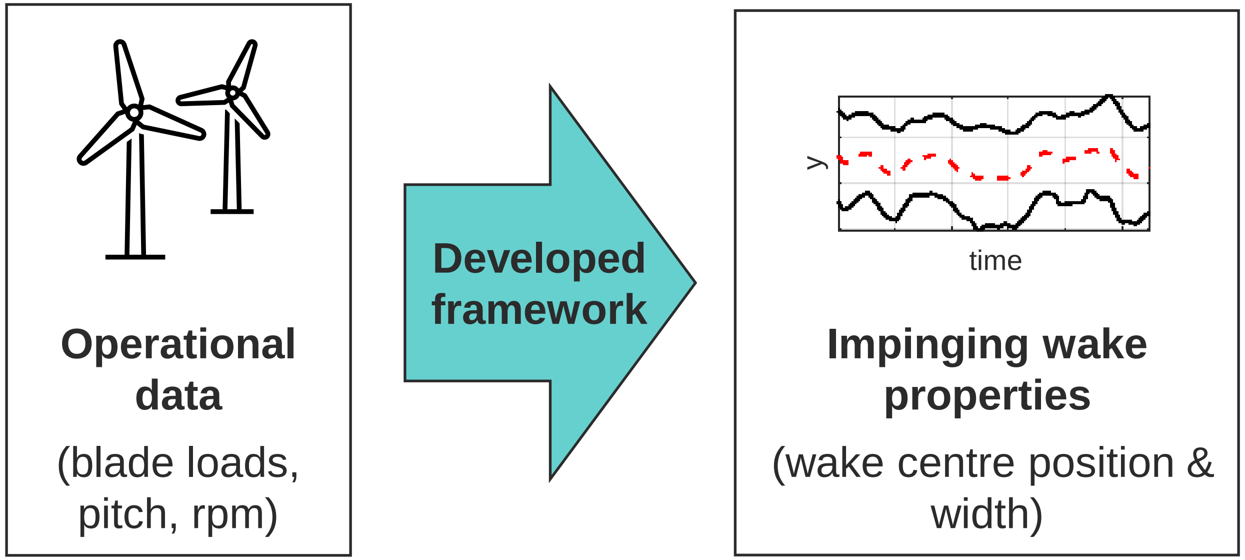
Aim

- ✓ Aim: Develop an estimation framework that robustly deduces impinging wake properties from operational parameters of the turbine
- ✓ Training & validation using simulation tools (DWM + Mann turbulence boxes)



Methodology:
Overview

1. Wind Sensing

Wind field reconstruction using the **flap + edge root bending moments, pitch and rotational speed**

→ **Linear regression**

+

2. Wake Detection

Detecting a **clear** wake impingement from a **nearby** turbine

→ **Convolutional Neural Network (CNN)**

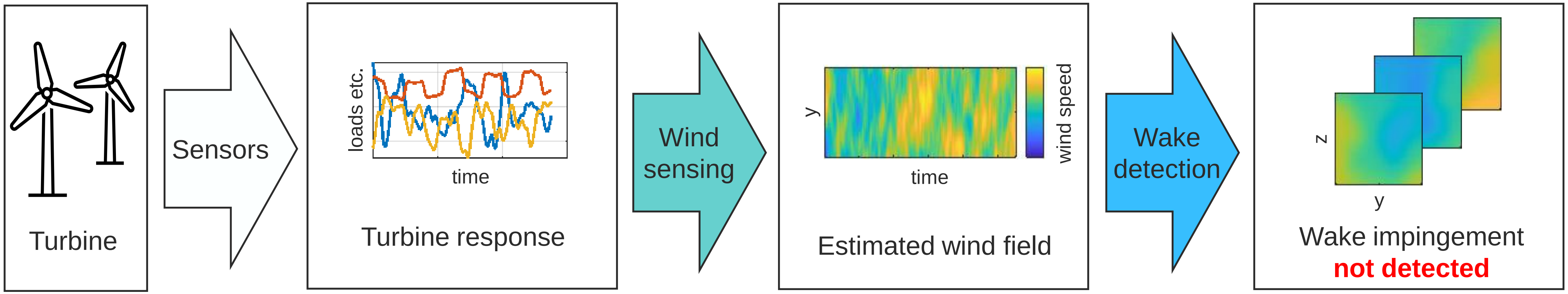
+

3. Wake Characterisation

If wake impingement is present, characterising the properties of a wake

→ **2D Gaussian least squares fitting**

Methodology:
Use case example A



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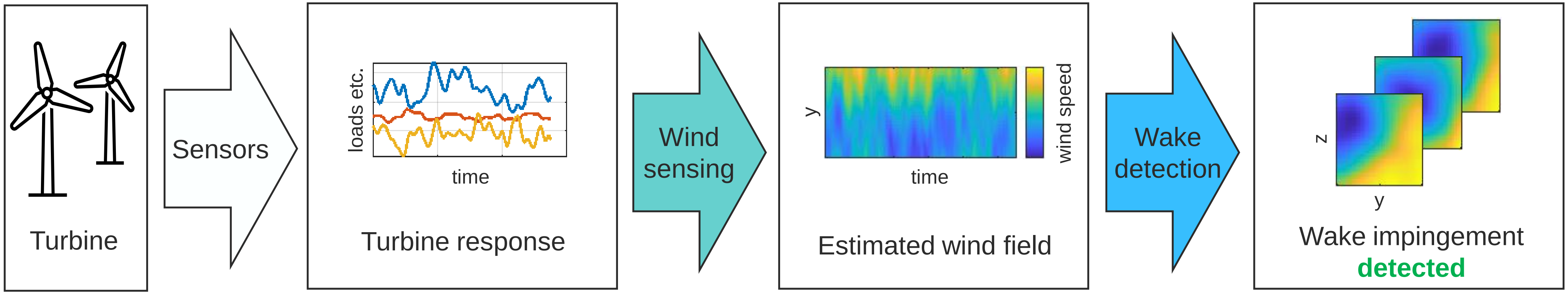
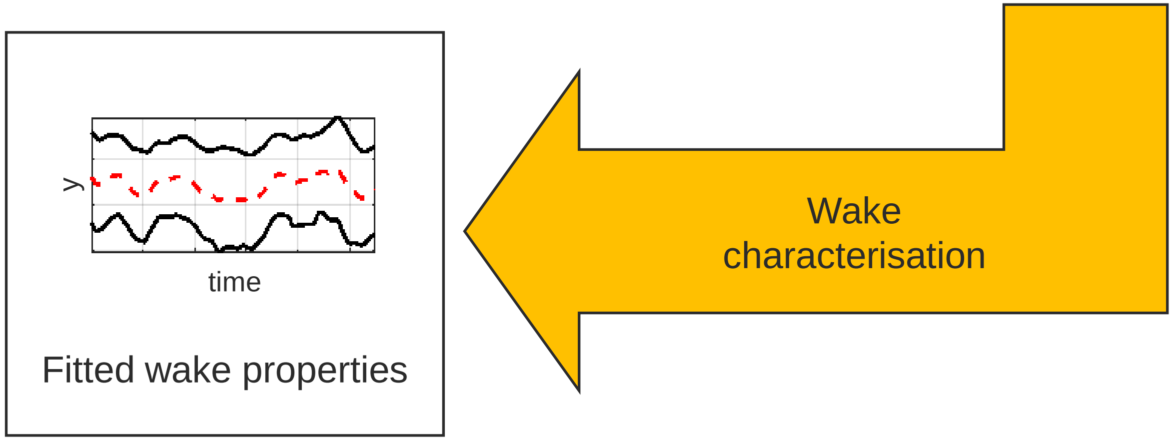
Framework output A:

No clear wake impingement detected

Methodology:
Use case example B



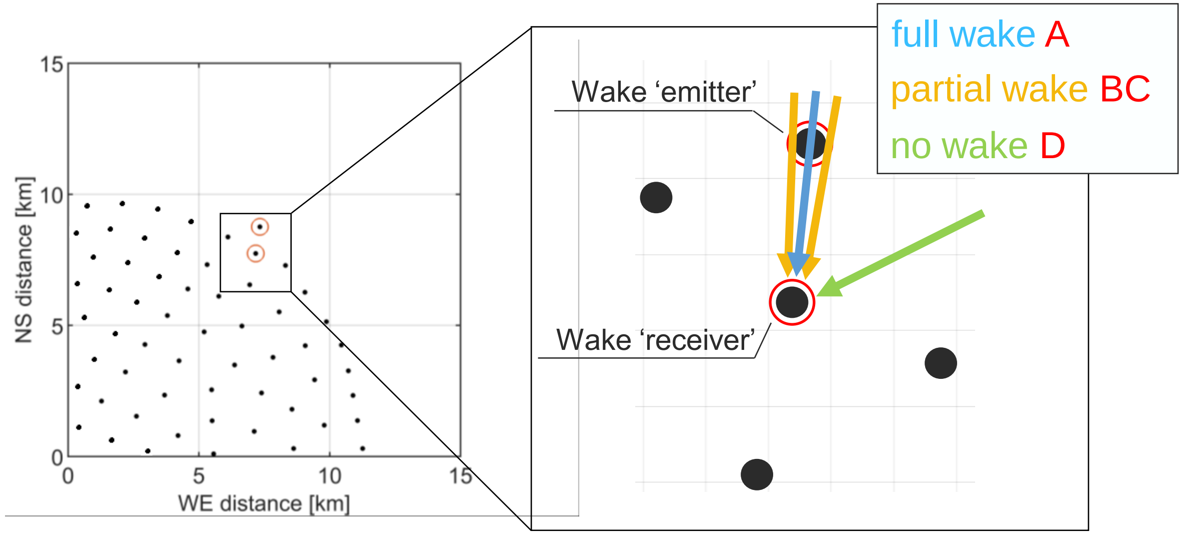


Framework output B:

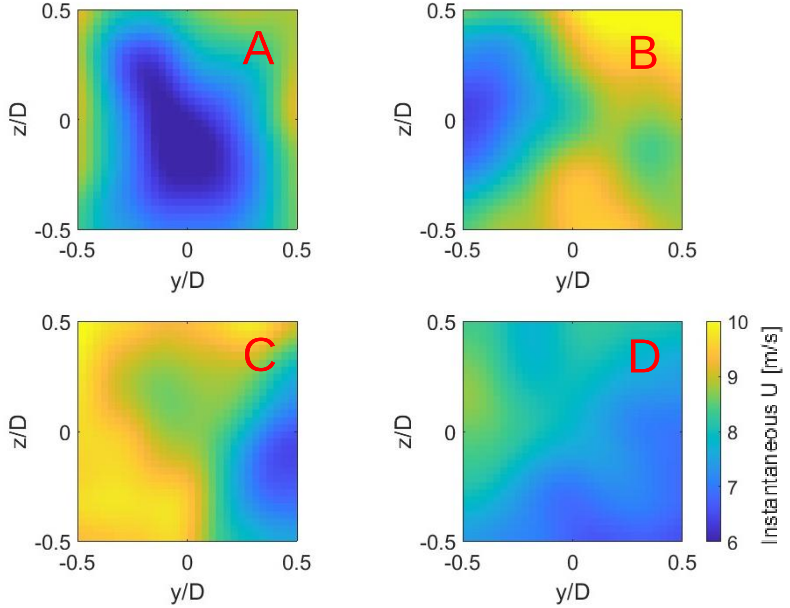
Wake impingement detected, its properties characterised

Methodology: Training

- ✓ 1200 simulations
- ✓ 4 classes for CNN training:
  - Full wake impingement (A)
  - Partial wake impingement left (B)
  - Partial wake impingement right (C)
  - No wake impingement (D)
- ✓ Varied ambient wind speed and turbulence intensity



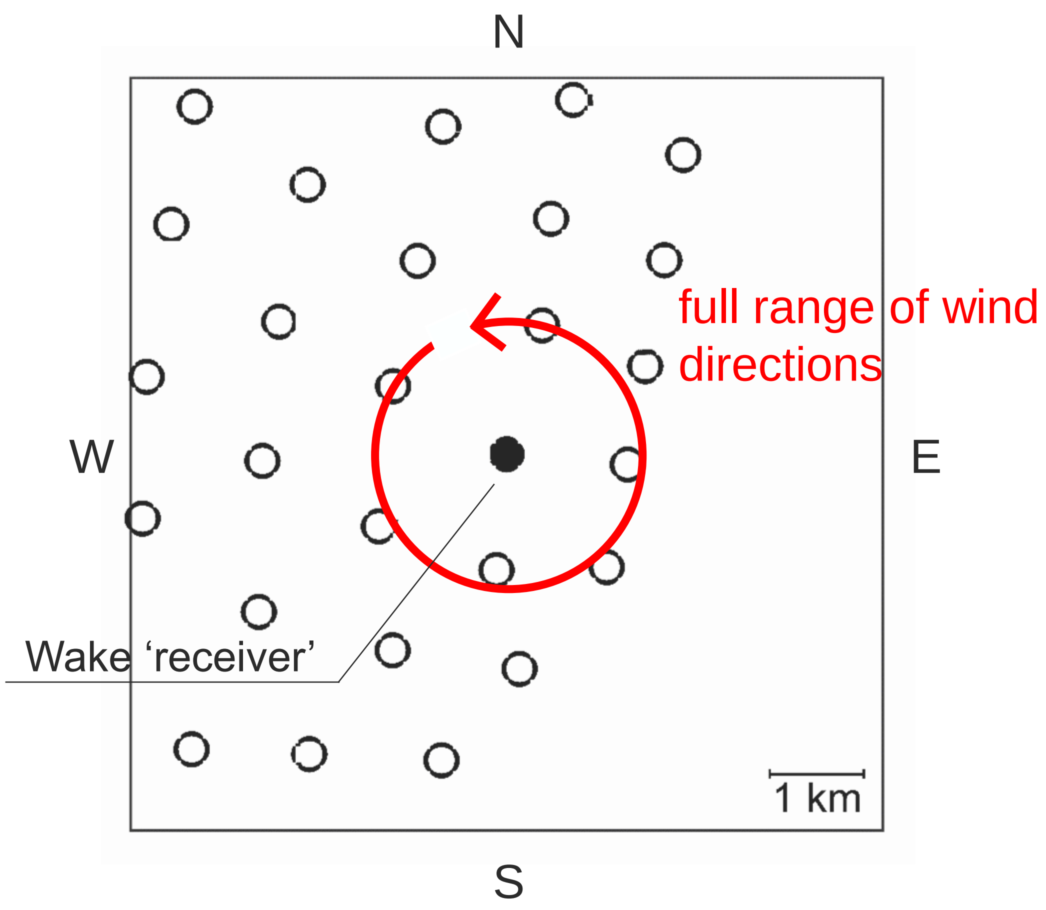
Wind directions used for training marked with different colours



Examples for each of four classes

Methodology:
Testing

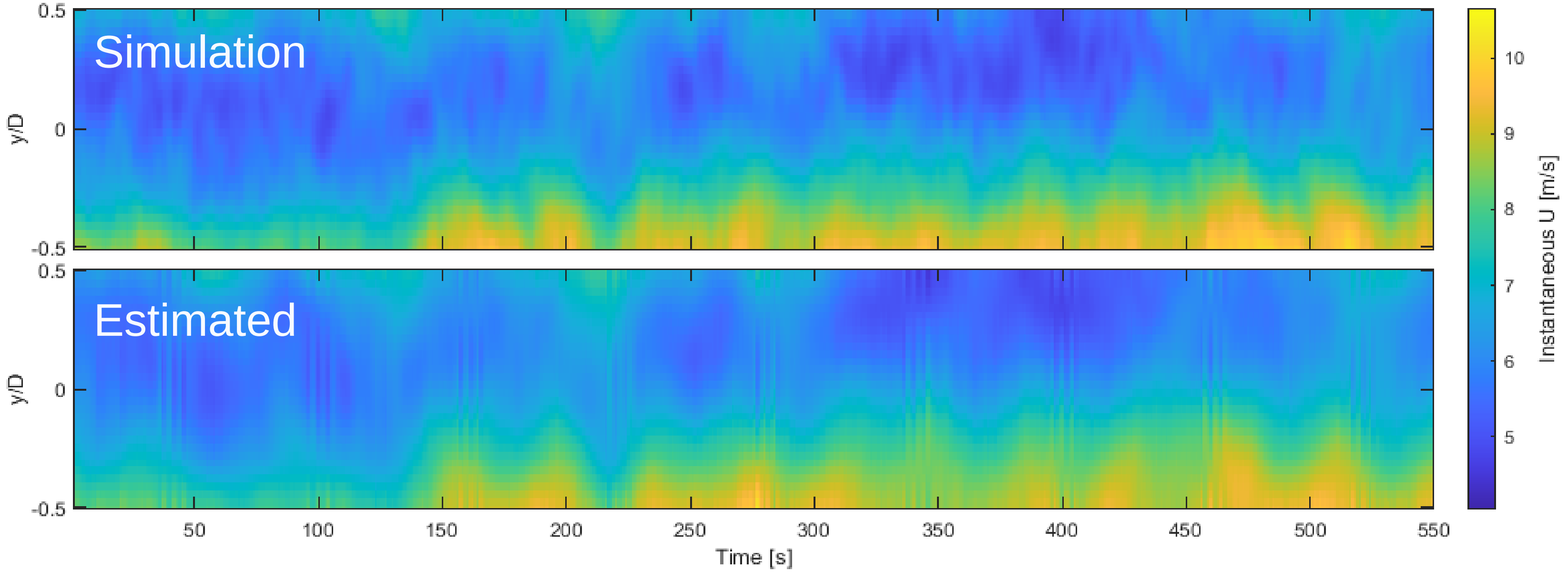
- ✓ 3600 new simulations
- ✓ Depicting **one turbine** under full range of wind directions
- ✓ Varied ambient wind speed and turbulence intensity
- ✓ Analysing the performance **of each constituent model**



Results

1. Wind Sensing (wind field reconstruction using the turbine response)

- ✓ Overall great estimation quality, with very limited discrepancies
- ✓ Average RMSE in U estimation: 0.35 m/s, or 5.23% when normalized with mean ambient wind speed value



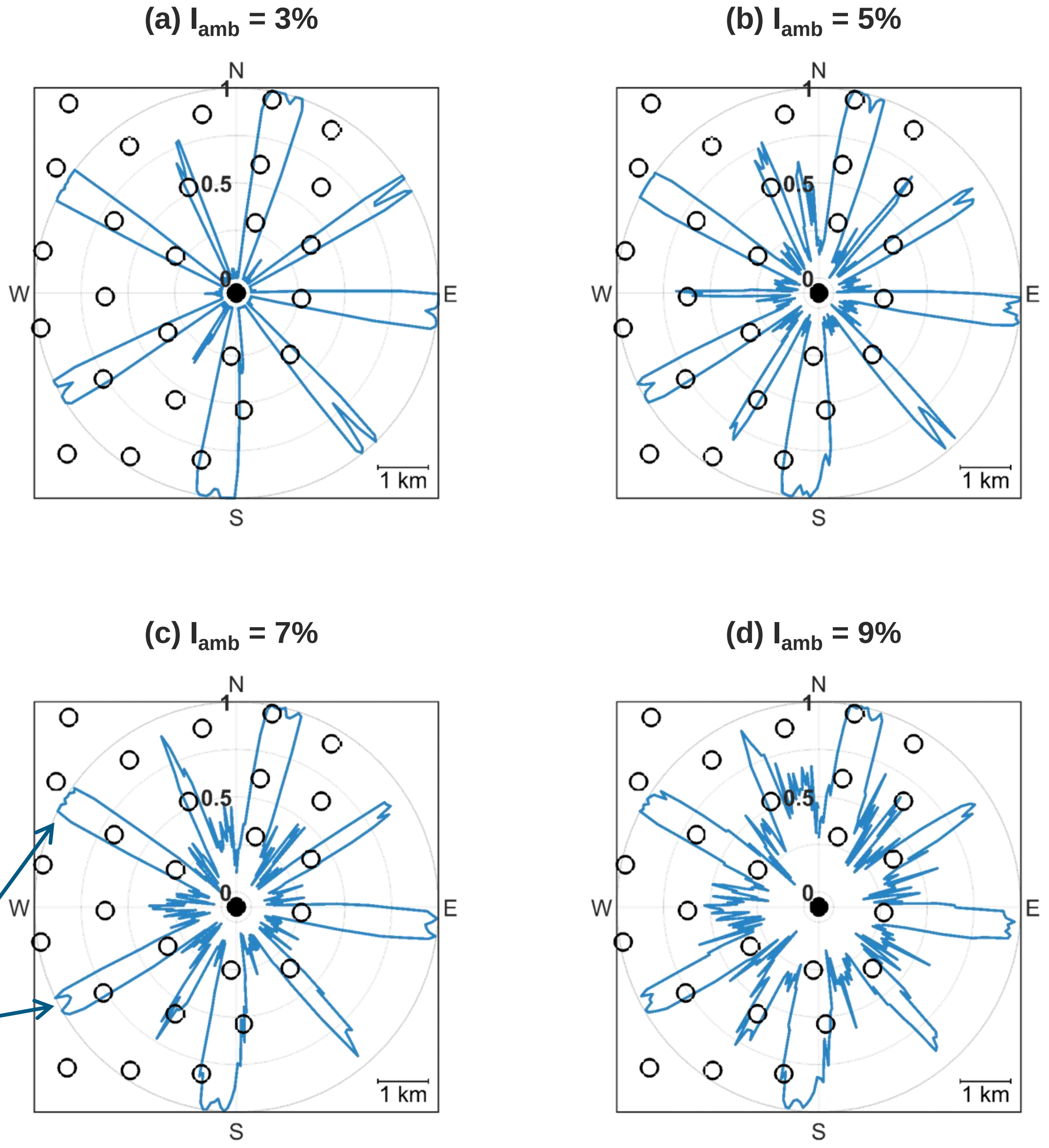
Example wind field

Results

2. Wake Detection

- ✓ Results for varying ambient turbulence intensity (U_{amb} kept at 10 m/s)
- ✓ Confident detection of clear wake impingement for all cases
- ✓ Wake detection performance decreasing with rising I_{amb} (noise from atmospheric turbulence)

Proportion of samples identified as a wake for each wind direction

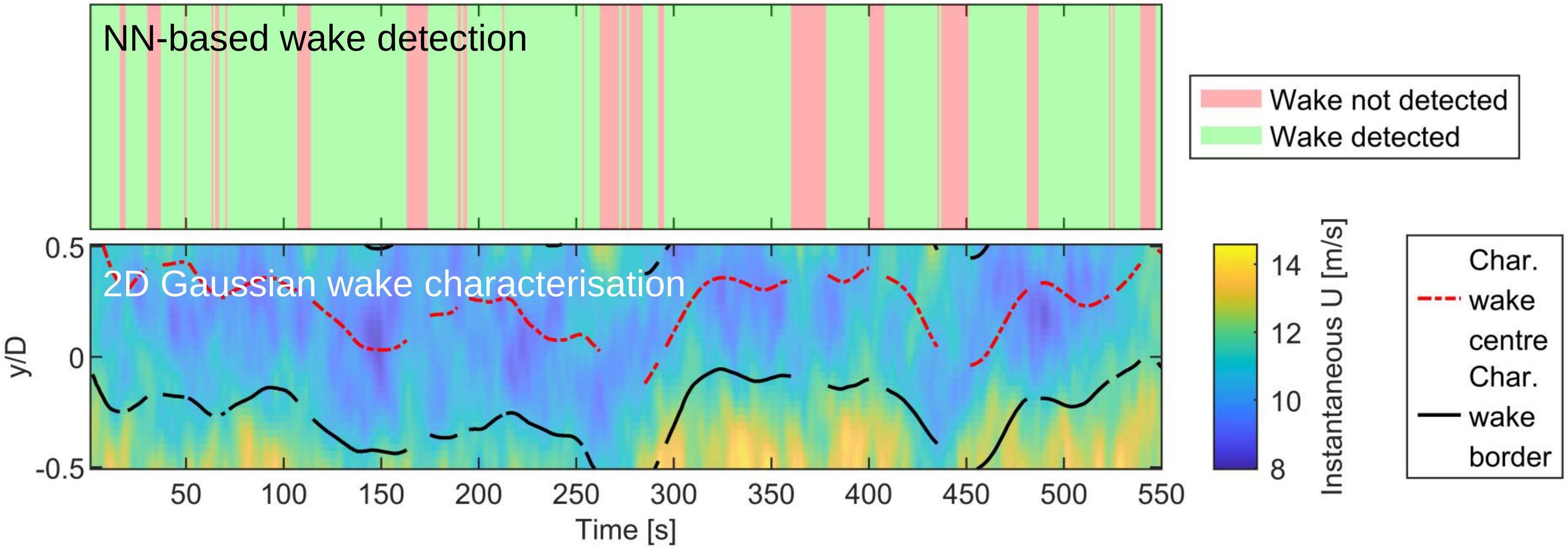


Ambient turbulence intensity sensitivity study

Results

3. Wake Characterisation

- ✓ 2D Gaussian function is fitted for every YZ slice where a wake deficit was detected, allowing for flexible tracking of the wake deficit
- ✓ Due to applied moving average filtering, characterised properties experience a minor lag



Example wind field

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Conclusion & Future Work

- ✓ Results show a great potential of the generalised wake estimation approach
- ✓ Sub-optimal performance for more severe wind conditions
- ✓ Models can be easily trained with different data to address more complex wake scenarios
- ✓ Next framework development aimed at:
  - Decreasing the lag in the characterised wake properties
  - Solving the inconsistent tracking
- ✓ **Kalman filtering** could solve these issues
- ✓ Further validation on higher fidelity wake models, and eventually on field data is required

✓ Upcoming publication in Wind Energy Science Journal

✓ Please reach out at piotr.fojcik@strath.ac.uk or via LinkedIn:

[1] Larsen, T. J., Madsen, H. A., Larsen, G. C., and Hansen, K. S.: Validation of the dynamic wake meander model for loads and power productionin the Egmond aan Zee wind farm, Wind Energy, 16, 605–624, https://doi.org/10.1002/we.1563, 2013
[2] Hasager, C., Nygaard, N., Volker, P., Karagali, I., Andersen, S., andBadger, J.: Wind Farm Wake: The 2016 Horns Rev Photo Case,Energies, 10, 317, https://doi.org/10.3390/en10030317, 2017.