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WHEN TRUST MATTERS

Measuring and Modelling Wind Farm Blockage Offshore

What are the challenges?

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09 September 2021

Quantifying wind farm blockage

Challenges

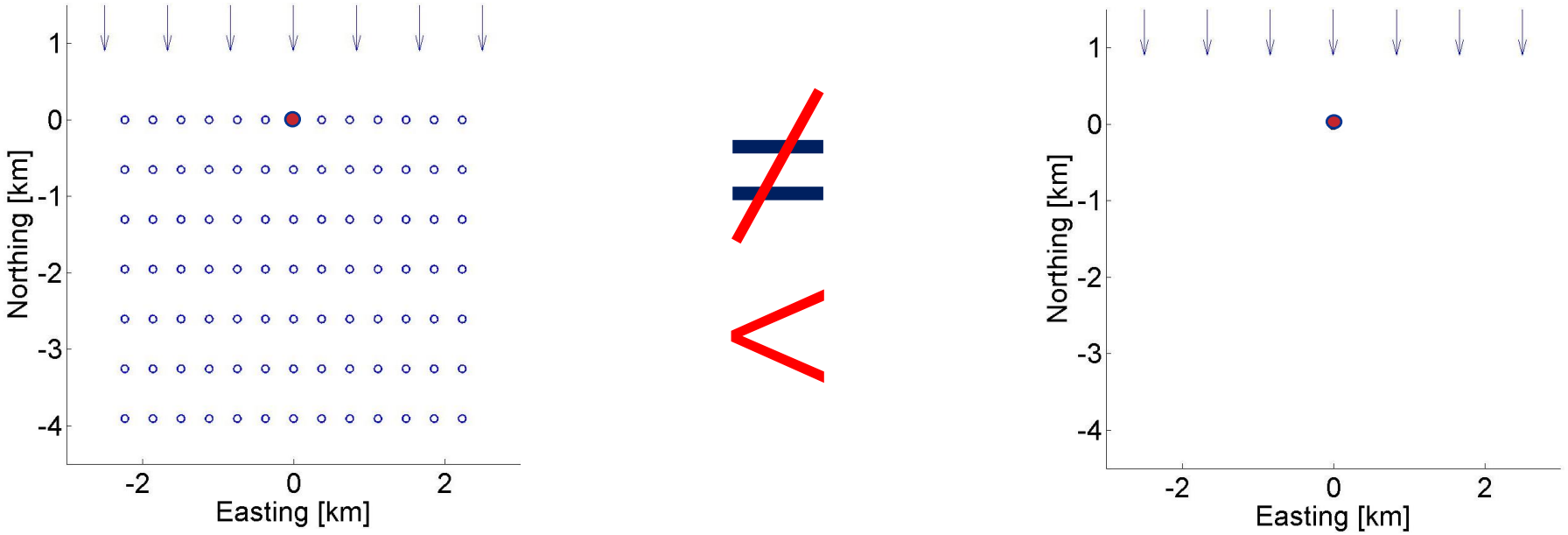
Measurement campaign

Measurements vs simulations
(Wind speed and pattern of production)

Summary

Wind farm blockage

DEFINITION



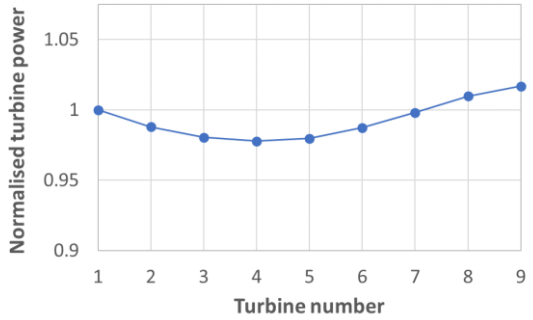
Bias from wind farm blockage – relative difference in power, for the leading turbines, between isolated operation and operation with the whole wind farm.

This bias is neglected by 'wakes-only' models.

Blockage measurement challenges

- Nature of the phenomenon
  1. Signal seen from SCADA data only shows part of the effect

SCADA only: Normalised power for leading turbines

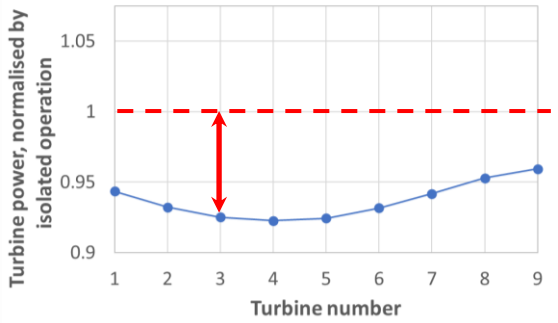


Reference level for isolated production not defined.
Blockage magnitude = ?

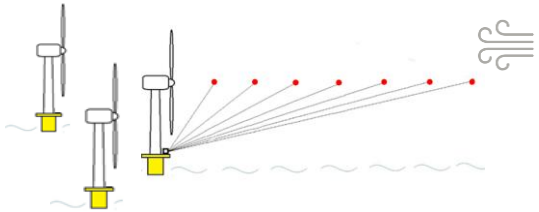
Simulation: Power for leading turbines, turbines normalised with power when operating in isolation

Blockage magnitude can be calculated for each turbine

Validation data required!

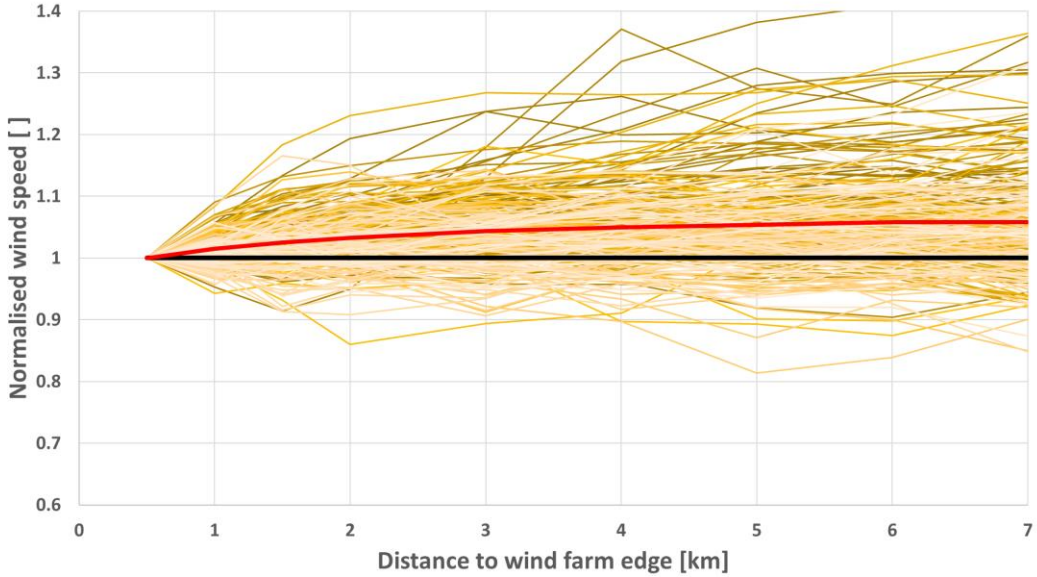


Blockage measurement challenges



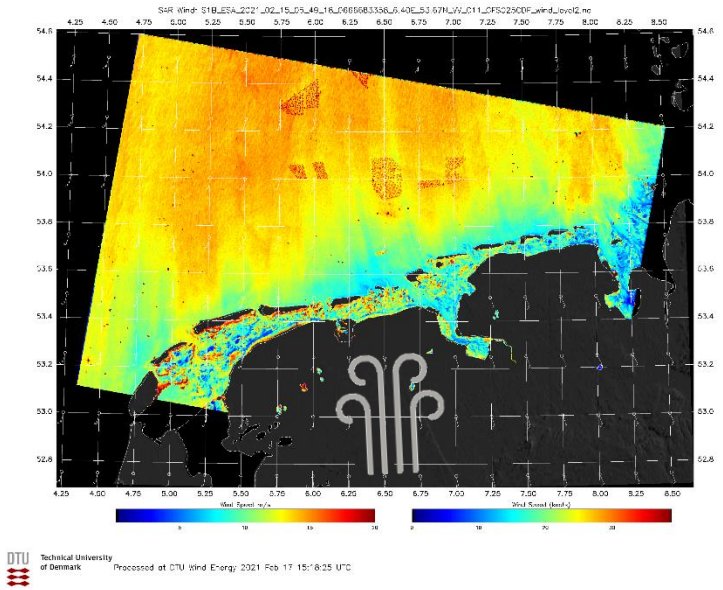
- Nature of the phenomenon
  1. Signal seen from SCADA data only shows part of the effect
  2. Small effect – turbulent background → long data set required for statistical convergence

Wind speed at hub height upstream of wind farm

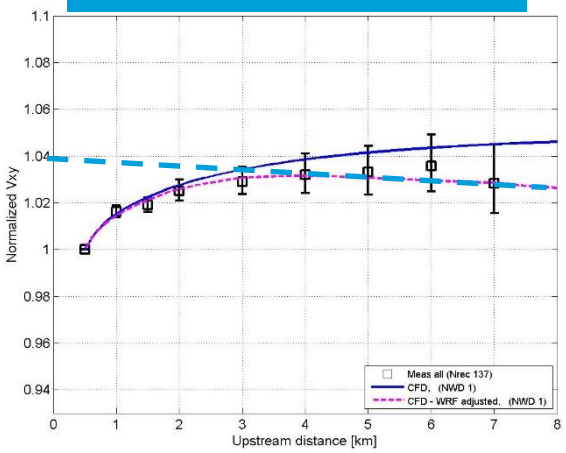


Blockage measurement challenges

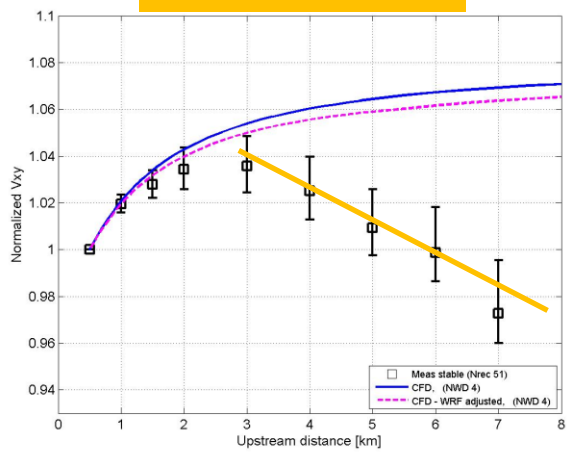
- Nature of the phenomenon
  1. Signal seen from SCADA data shows only part of the effect
  2. Small effect – turbulent background → long data set required for statistical convergence
  3. Non-homogeneous background conditions can drown the effect we are trying to capture
- Demanding requirements on measurement system:
  - Accuracy
  - Low uncertainty
  - Stable throughout campaign



Coastal transition



Cluster wake

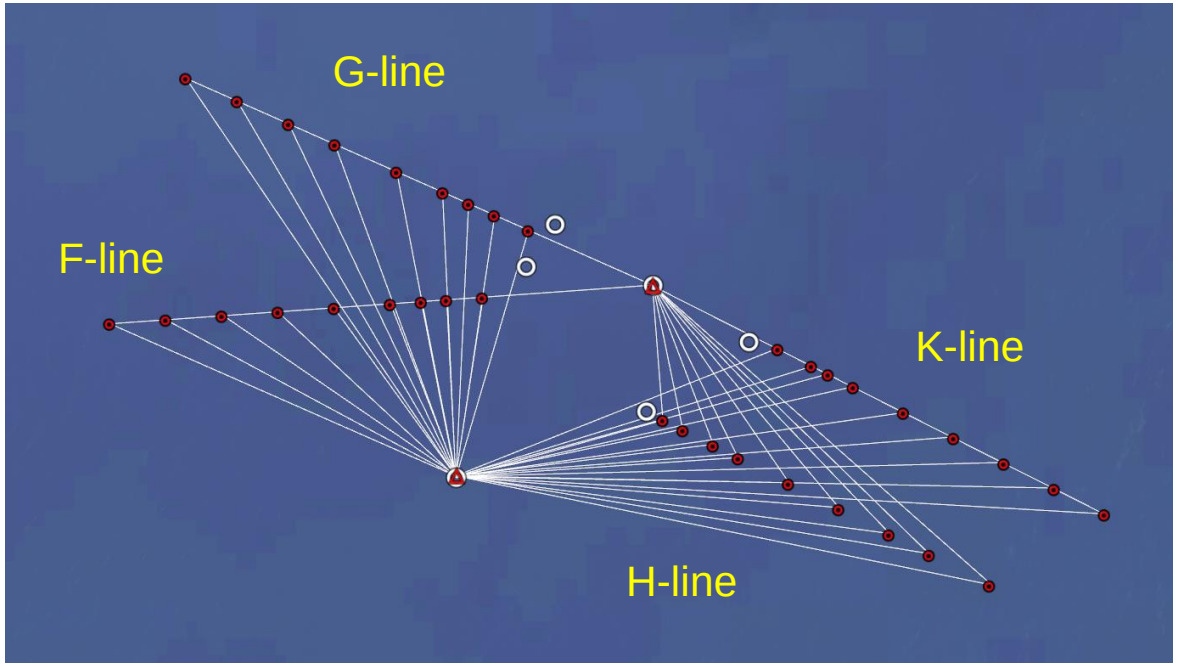


Measurement campaign

Measurement campaign

- Measurement setup
  - Four measurement lines (2x in the west, 2x in the south-east)
  - Each line consists of nine measurement points
  - Measurement distances ranging from
    - 2.5 to 11.5 km from lidar location
    - 0.5 to 7 km from the edge of the wind farm
  - Measurement points K6.0 and K7.0 associated with high uncertainties because of small intersection angle (<30°) and large measurement distance (>10km)
- More details in WESC 2021 presentation
  - J. Riechert et al
    - ‘Measuring Wind Farm Blockage: First results from a 12-month scanning lidar campaign at a German offshore wind farm‘

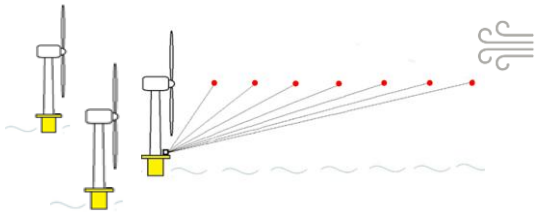
Schematic of the measurement set up, wind farm layout left to your imagination



Lidar locations

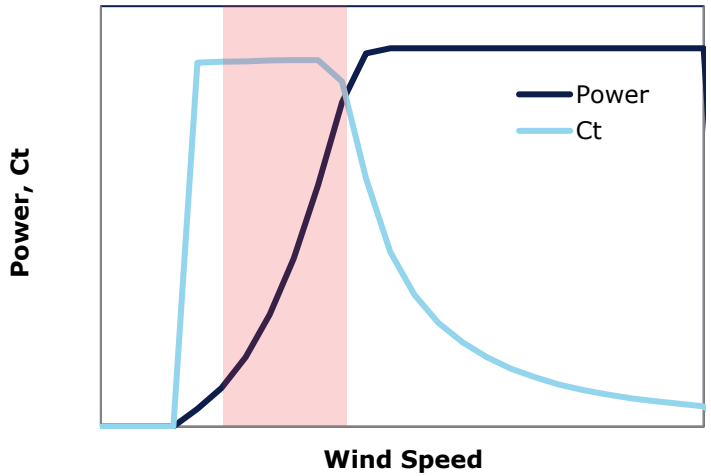
Measurement locations

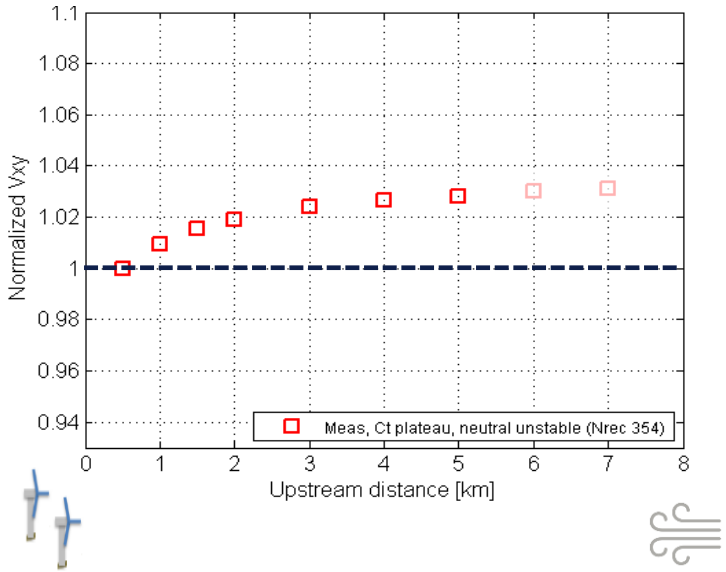
Blockage and wind speed



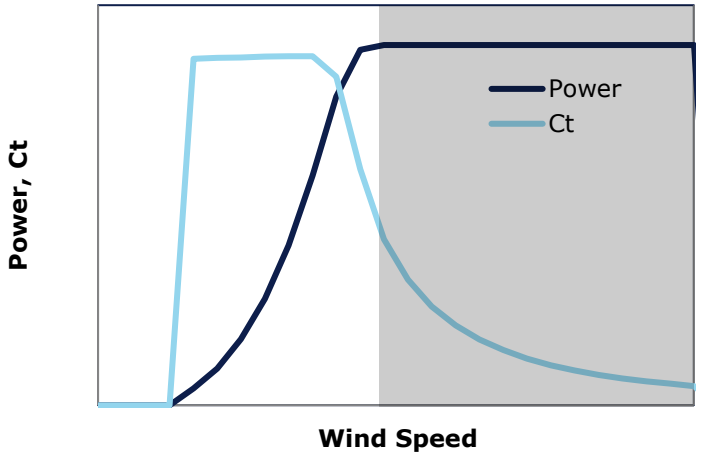
- Power filter for leading turbines → Wind speed between ~ 5 and 10 m/s,

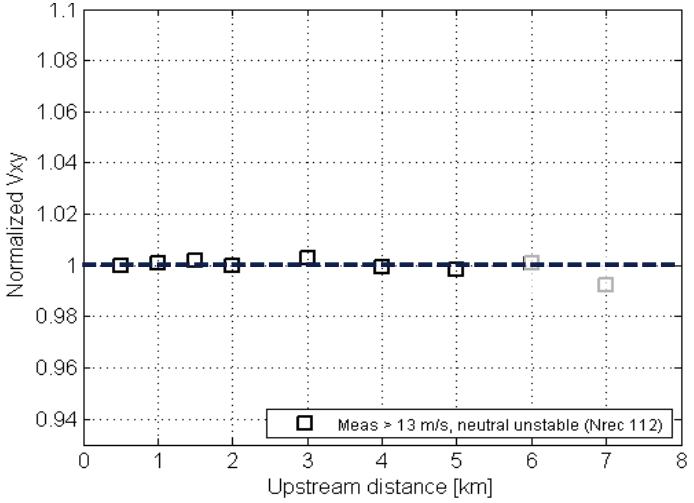
  roughly on the plateau of the thrust curve



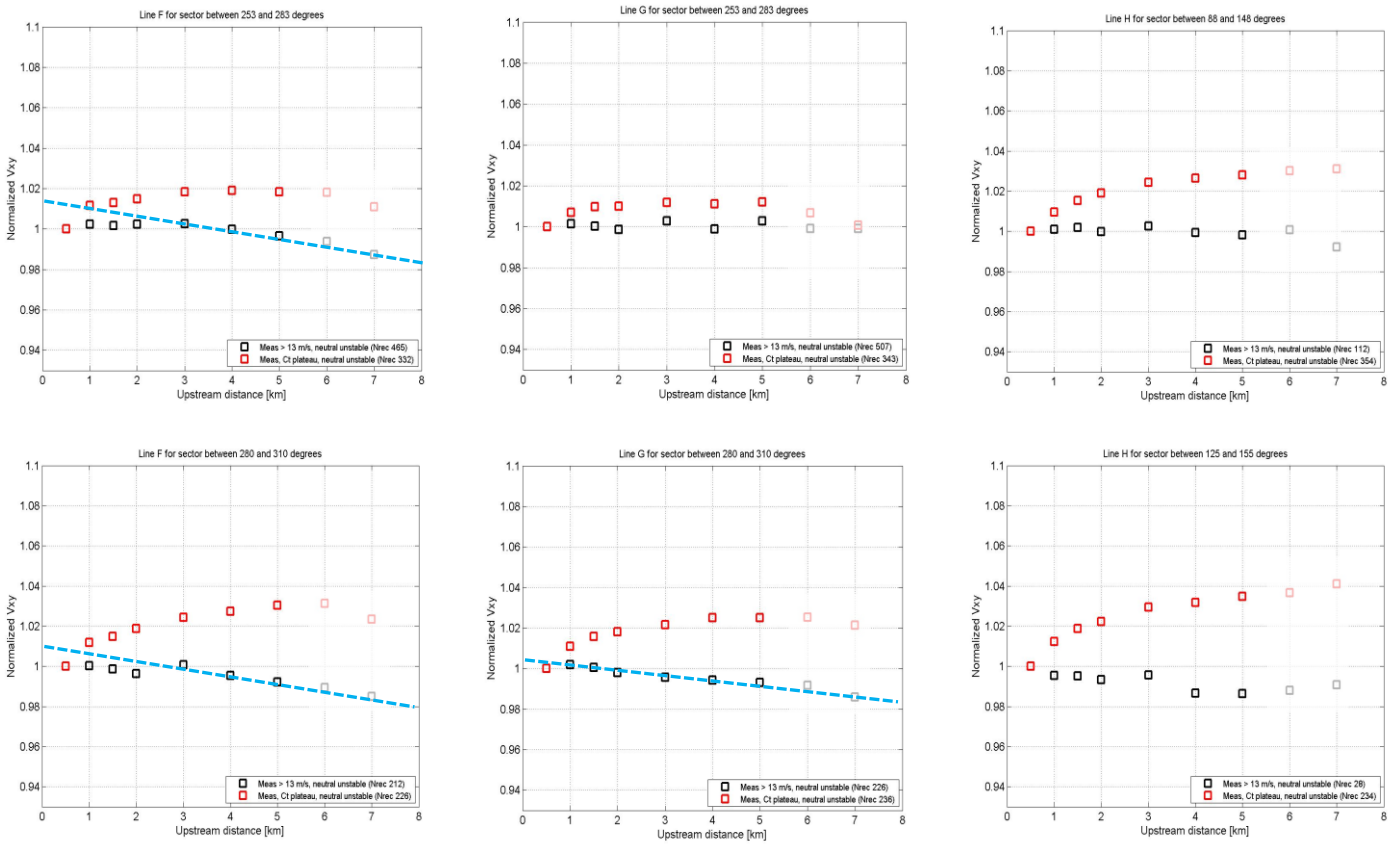


- Wind speed filtered above 13 m/s





Blockage and wind speed – all lines show same trend



→Blockage is seen with significant wind speed reduction upstream of the wind farm for wind speeds on the plateau of the thrust curve

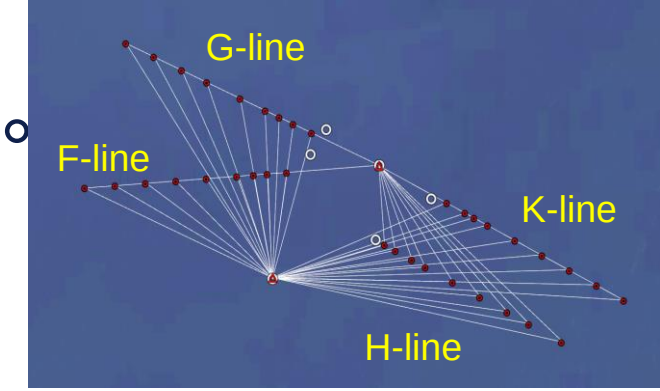
→No obvious blockage visible for wind speeds above 13 m/s

→Effect visible for all lines and sectors, with a varying amplitude and reach

→When little or no blockage is visible at high wind speed, the wind speed shows increasing wind speeds towards the wind farm for some directions → manifestation of coastal transition

Measurements vs simulations – on plateau of thrust curve

F- Line – WRF informed CFD - sector 285°-295°
Raw and WRF adjusted CFD results vs lidar

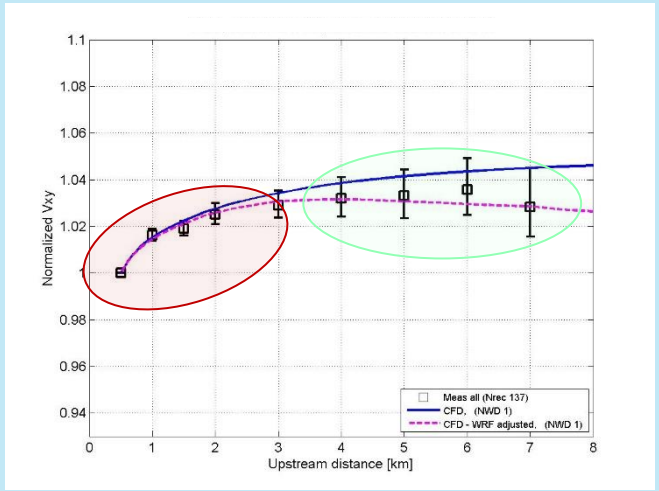


Windfarm blockage dominated

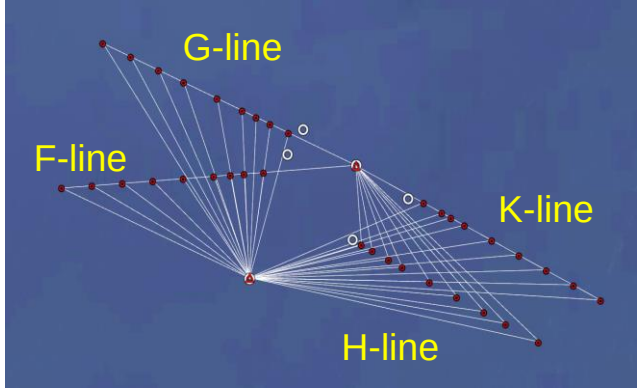
Background gradients dominated

Line F

All stability

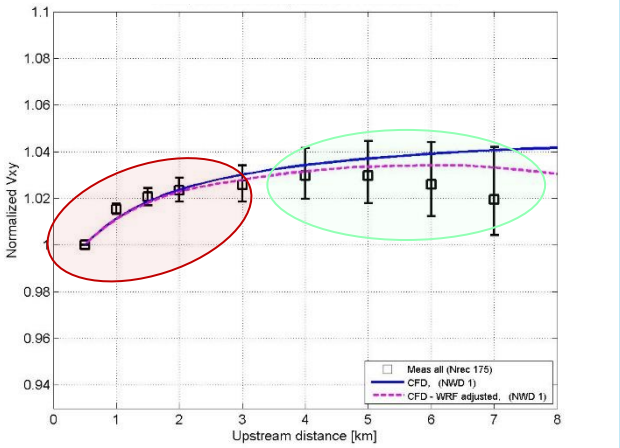


WRF informed CFD - sector 285°-295°
Lidar lines & pattern or production (PoP)

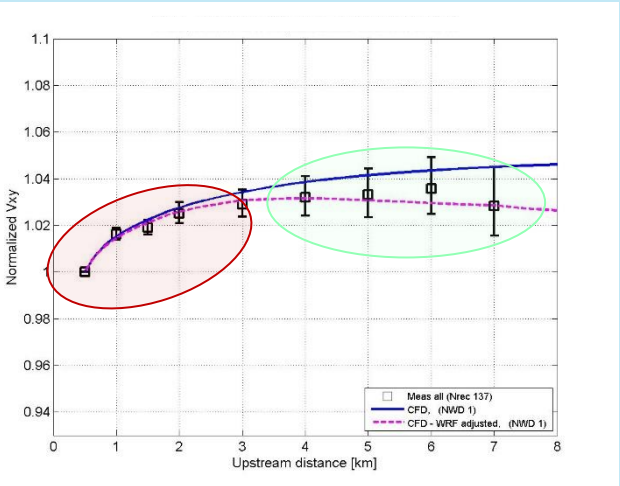


Lidar lines

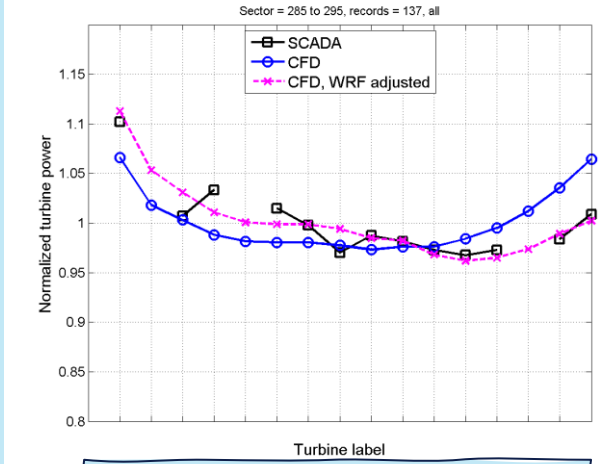
Line G



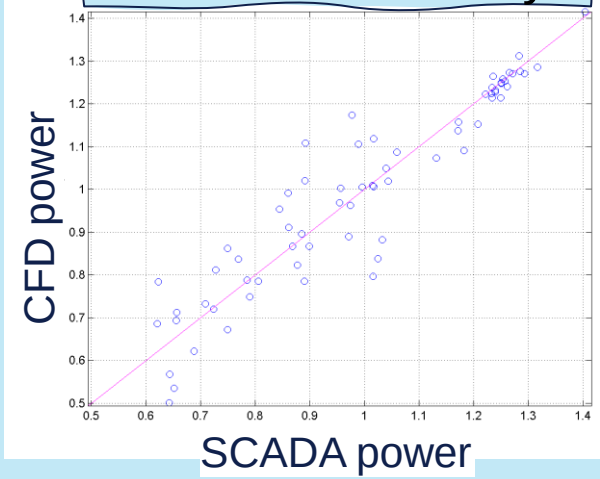
Line F



PoP - leading turbines



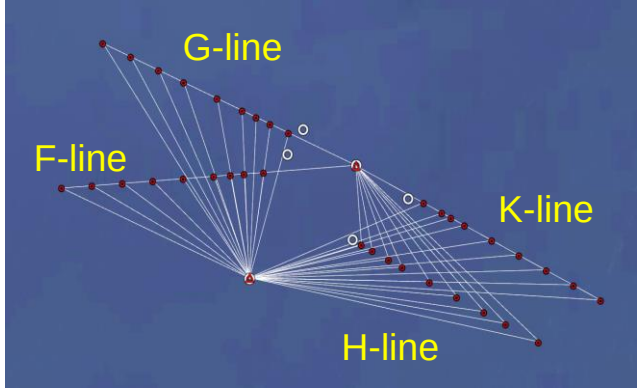
PoP - whole array



- Wind farm blockage dominates first 3 km
- WRF adjustment helps improve the match:
  - along the lidar lines at larger distances
  - the skew for the PoP along the leading turbines
- PoP for the whole array captured without bias (i.e. slope of the CFD vs SCADA data points close to the 1:1 slope)
- Noise in PoP for whole array is due to small number of simulated directions (1 per 10° sector)

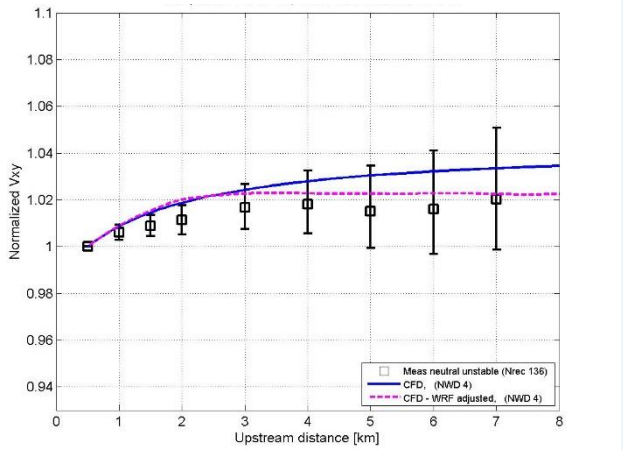
EnBW DNV

Blockage sensitivity to surface stability
Sector 120°-150°

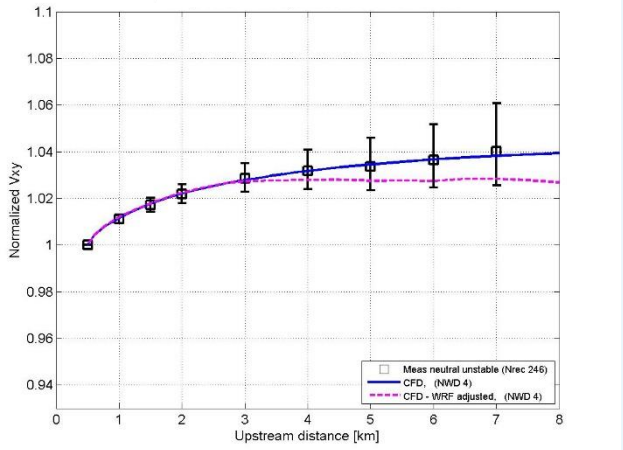


Neutral + unstable

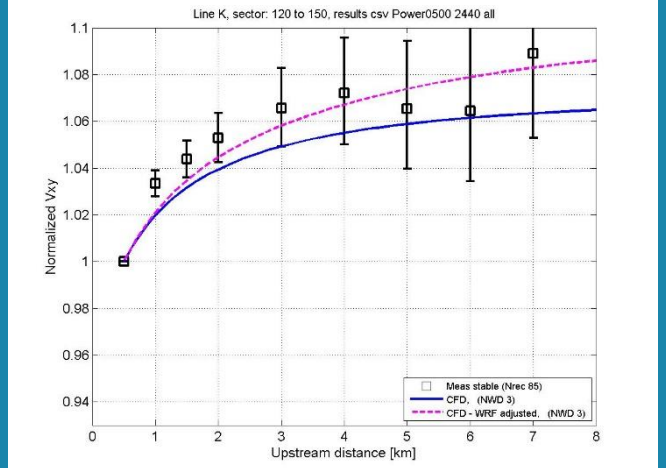
Line K

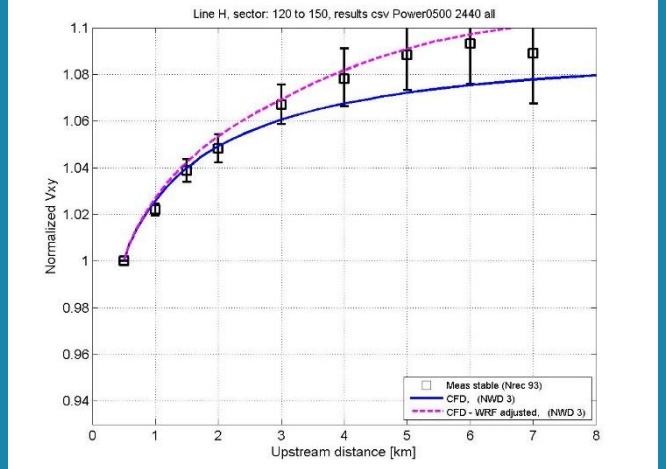


Line H



Stable





- Wind farm blockage stronger in stable than in neutral/unstable conditions
- Blockage measured in stable AND in neutral/unstable conditions
- WS reduction between 0.5 and 3 km is
  - ~1.5-2.5% in neutral/unstable conditions
  - > 6% in stable conditions !
- WRF adjustment generally helps (except for line H in neutral/unstable conditions)

Summary

Measuring wind farm blockage is a tall order, but a well-designed (and long enough campaign) can measure the wind speed reduction upstream of a wind farm with low enough uncertainty to identify blockage.

Blockage is far-reaching: data set shows that it can extent to at least ~3-5 km upstream of the wind farm (> 25 rotor diameters).

Blockage is significantly stronger in stable than in neutral conditions (still visible in neutral conditions).

CFD simulations with WRF informed boundary conditions are catching the magnitude of the blockage and the PoP along the string of leading turbines and within the array with good accuracy.

Non-homogeneous background conditions (coastal transition or recovering wakes from neighbouring wind farms) can reduce the apparent magnitude of blockage or even mask it (though not suppress its effect).

Thank you,

More info in WESC 2021 presentations:

- J. Riechert et al
  - ‘Measuring Wind Farm Blockage: First results from a 12-month scanning lidar campaign at a German offshore wind farm‘
- C. Montavon et al
  - ‘Modelling Wind Farm Blockage: First results from a 12-month scanning lidar campaign at a German offshore wind farm‘

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