Analysis of SCADA data from offshore wind farms

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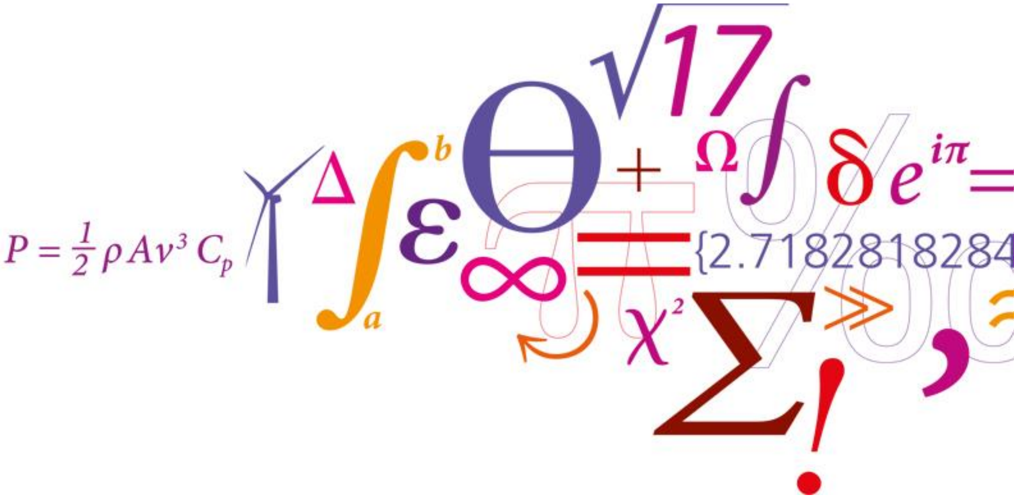

DTU Wind Energy
Department of Wind Energy

CV – Kurt S. Hansen – Senior Scientist

- Department of Wind Energy/DTU ≥ 240 Employees
  - DTU/WE educate 40-60 students on master level annually
  - My working area: research & education
- ≥ 40 years of experience with wind energy
  - Initial projects: (large) proto wind turbines, design & testing.
  - Data analysis as part of research projects.
  - Flow analysis in onshore and offshore wind farms based on SCADA data
  - Analysis of structural loads on single wind turbines and turbines in clusters
- 15 years of experience with education of students of master level in wind turbine measurement technique.

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Outline

- Objectives
- SCADA data
  - Qualification
  - Inflow conditions
- Definition of wake losses
  - Power deficit
  - Park efficiency
- Wind farms
  - Benchmarks
  - Cluster effect
  - Structural loads
- Acknowledgement

Objectives

- Optimisation of wind turbine layout
  - Energy production & turbine loading
    - Wind speed distribution, wind rose (& stratification)
    - Spacing, turbulence & wake effects
    - Investigate coastal effects

- Validate wind farm tools
  - Engineering models (WAsP, FUGA,..)
  - CFD tools based on RANS, LES,.. models

- Benchmarking of flow models
  - EU-Upwind (HR1, Nysted,..)
  - IEA-Annex 31: Wakebench (HR1, Lillgrund,..)
  - EERA-DTOC (HR1, Lillgrund, Nysted/Rødsand2,..)

SCADA data

- SCADA means *Supervisory Control And Data Acquisition* and is used to log all parameters recorded through the control system.
- SCADA was pioneered in the industry, as the need for remote access and control of manufacturing grew in the 1960th.
- The turbine SCADA data **of interest** from a wind turbine includes the basic operational parameters: Active power, Rotor speed, Pitch angle(s), wind speed and wind direction on nacelle and yaw position averaged for 600 seconds.
- The SCADA data from all wind turbines are stored in huge databases and used for supervision of the wind farm operation.

SCADA data qualification & derived inflow conditions

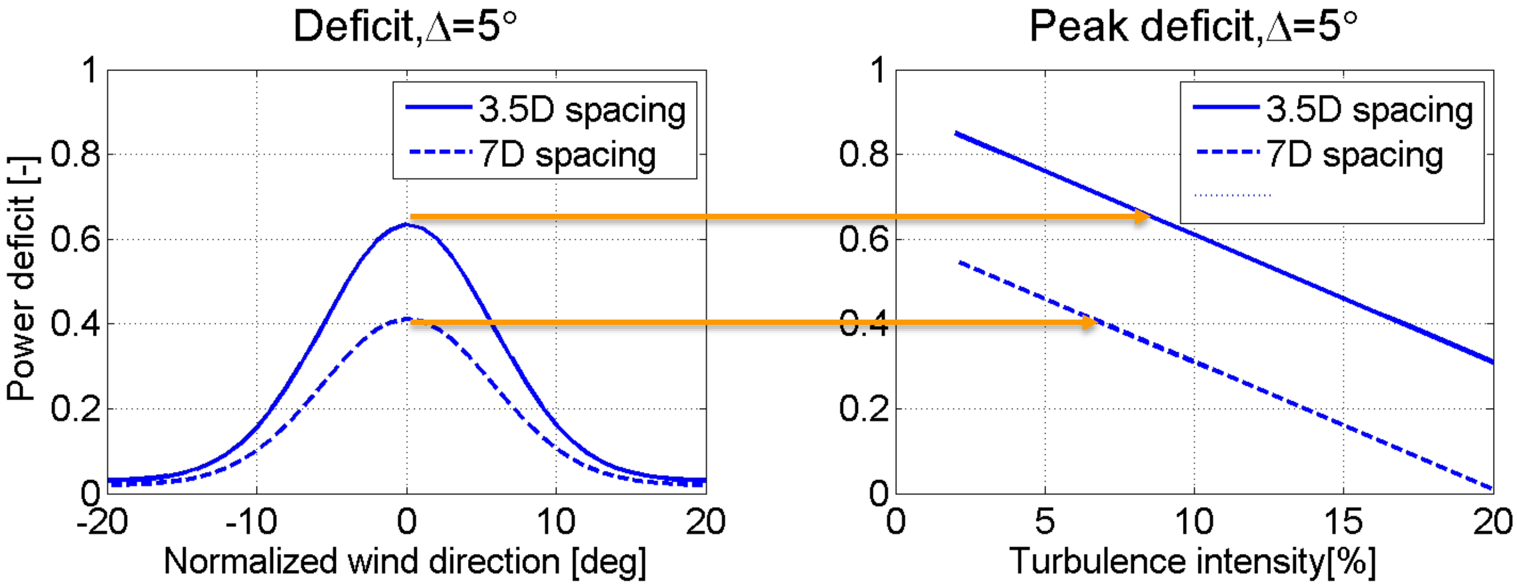
a) Data qualification;
   i. Identification of periods with 100% grid connection;
   ii. Nacelle wind speed is measured behind the rotor;
   iii. Yaw is not calibrated;

b) Determine inflow conditions (0-360°) to the wind farm;
   a) Wind speed at hub height, measured or derived from groups of undisturbed turbines;
   b) Wind direction, based on calibrated yaw positions from groups of undisturbed turbines;

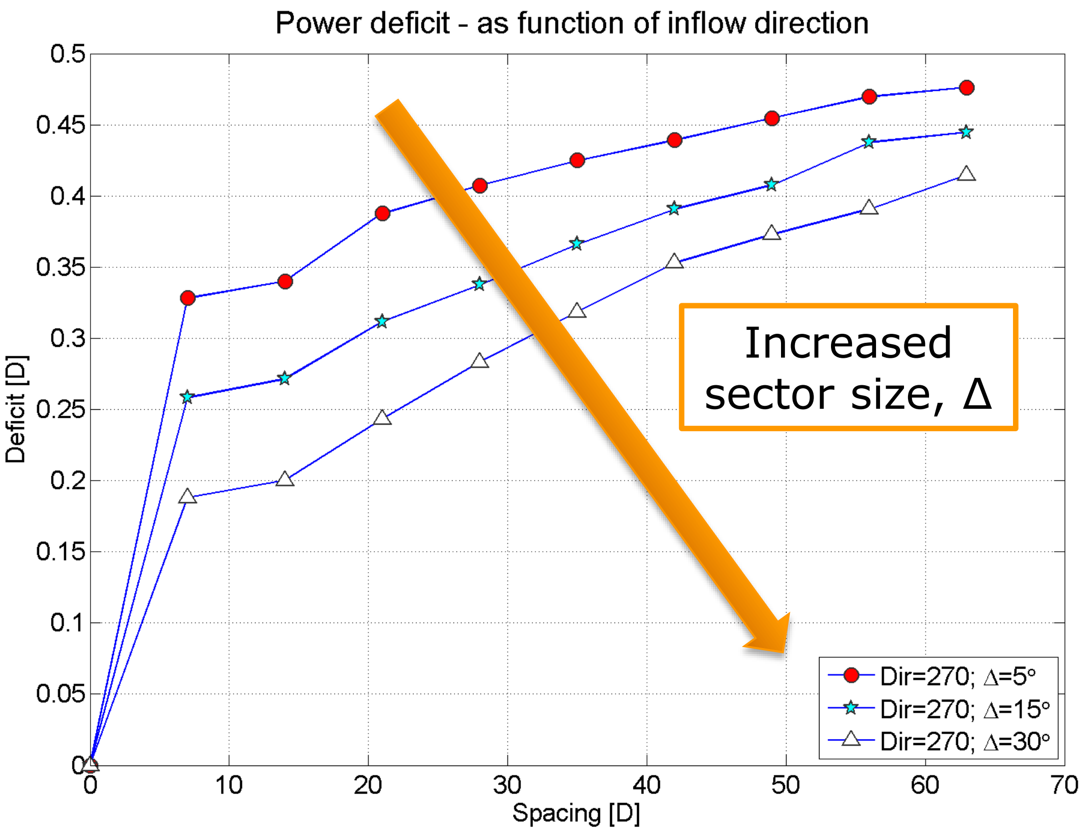
Best Practice Guidelines
http://windbench.net/system/files/wakebench_bestpracticeguidelinesed1_apr15.pdf

Wake losses
Determination of power deficit

Definition of power deficit
= 1 – power ratio
= 1 – P_{wake}/P_{free}



Power deficit along a row of turbines

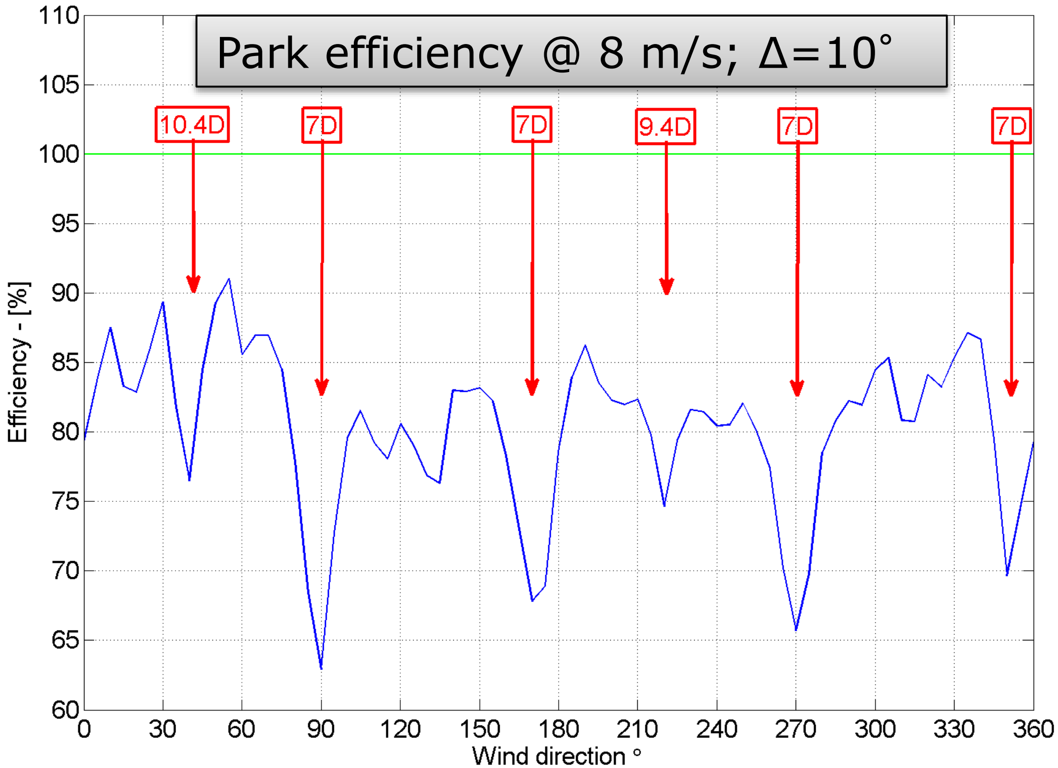


Ex: HR1

Hansen KS, RJ Barthelmie, LE Jensen and A Sommer, *The impact of turbulence intensity and atmospheric stability on power deficits due to wind turbine wakes at Horns Rev wind farm*. **Wind Energy, 2012. WE-10-0149**

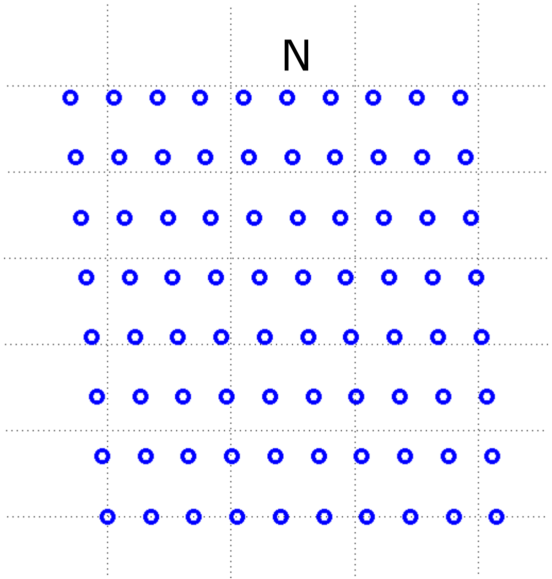
Park efficiency

- Manufacturers power curve represent the power as function of ambient, undisturbed wind speed, measured at hub height is: $P_i = f(U_i)$.
- Theoretical park power is: $P_{Park,i} = n_{park} \times P_i$ where i represent the wind speed interval.
- Definitions of *park efficiency*: $PE_i = 100 \times \left(\sum_{j=1}^{n_{park}} P_{i,j}\right) / \left(n_{park} \times P_{wt,i}\right)$



Ex: HR1

Horns Rev 1 (HR1) offshore wind farm
80 x 2 MW, 7 – 10 D spacing



- Regular 8 x 10 WF layout
- Free, undisturbed inflow S-W-N
- Coastal effect: E
- 2 wake masts

HR1 benchmarks

Objectives are to investigate flow during waked operation.

1) Averaged power deficit along a single row of turbines;

2) Average power deficit as function of
   a) Wind direction;
   b) Turbulence intensity (peak deficit);

3) Averaged power deficit along a single row of turbines
   a) as function of stratification (stable, neutral or unstable);
   b) as function of spacing;

4) Park efficiency;

Lillgrund offshore wind farm
48 x 2.3 MW-93m SWP, spacing 3.3-4.3-7 D

Objectives were to investigate flows during waked operation for very small spacing

- Location: Between Denmark-Sweden
- 2 missing turbines
- Very small spacing

Lillgrund benchmarks

1) Averaged power deficit - as function of inflow direction for a pair of turbines with 3.3D spacing;

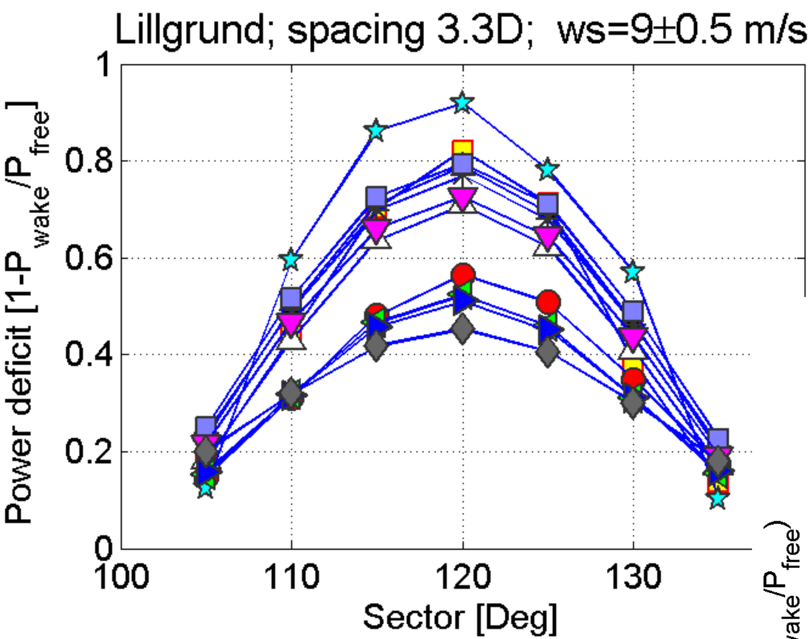
2) Peak power deficit – as function of turbulence intensity for both 3.3D & 4.3 D spacing;

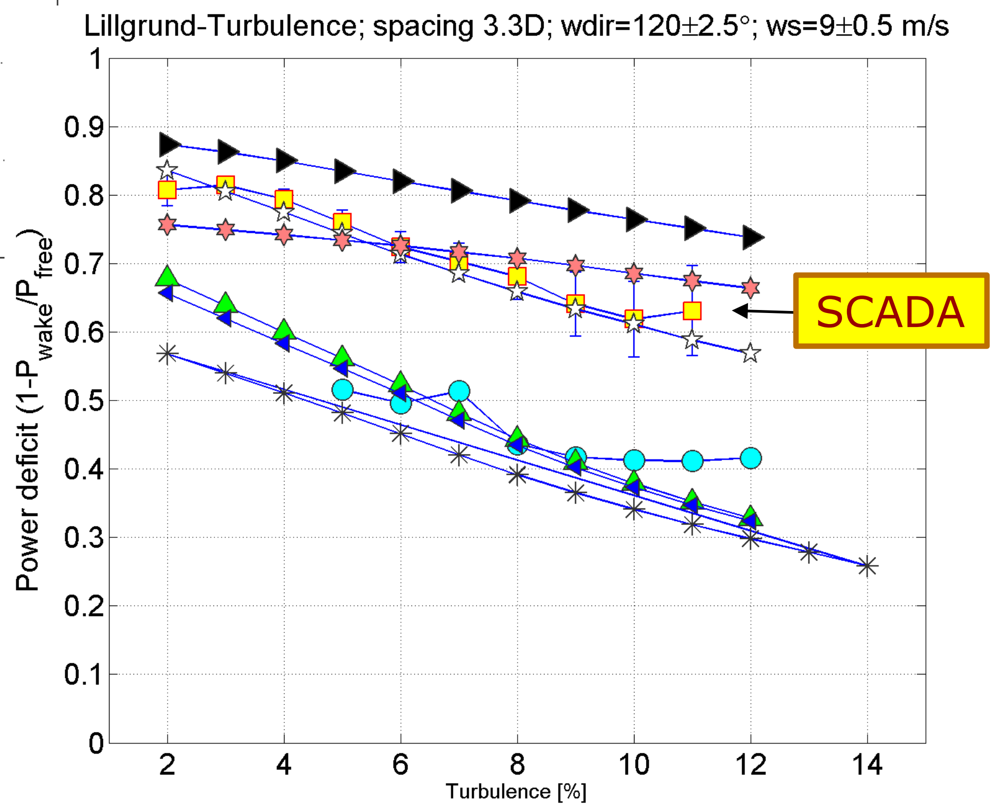
3) Averaged power deficit along a row of turbines for both 3.3D & 4.3 D spacing;

4) Averaged power deficit along a row of turbines for 3.3D & 4.3 D spacing – based on rows with ”missing” wind turbines;

5) Park efficiency.

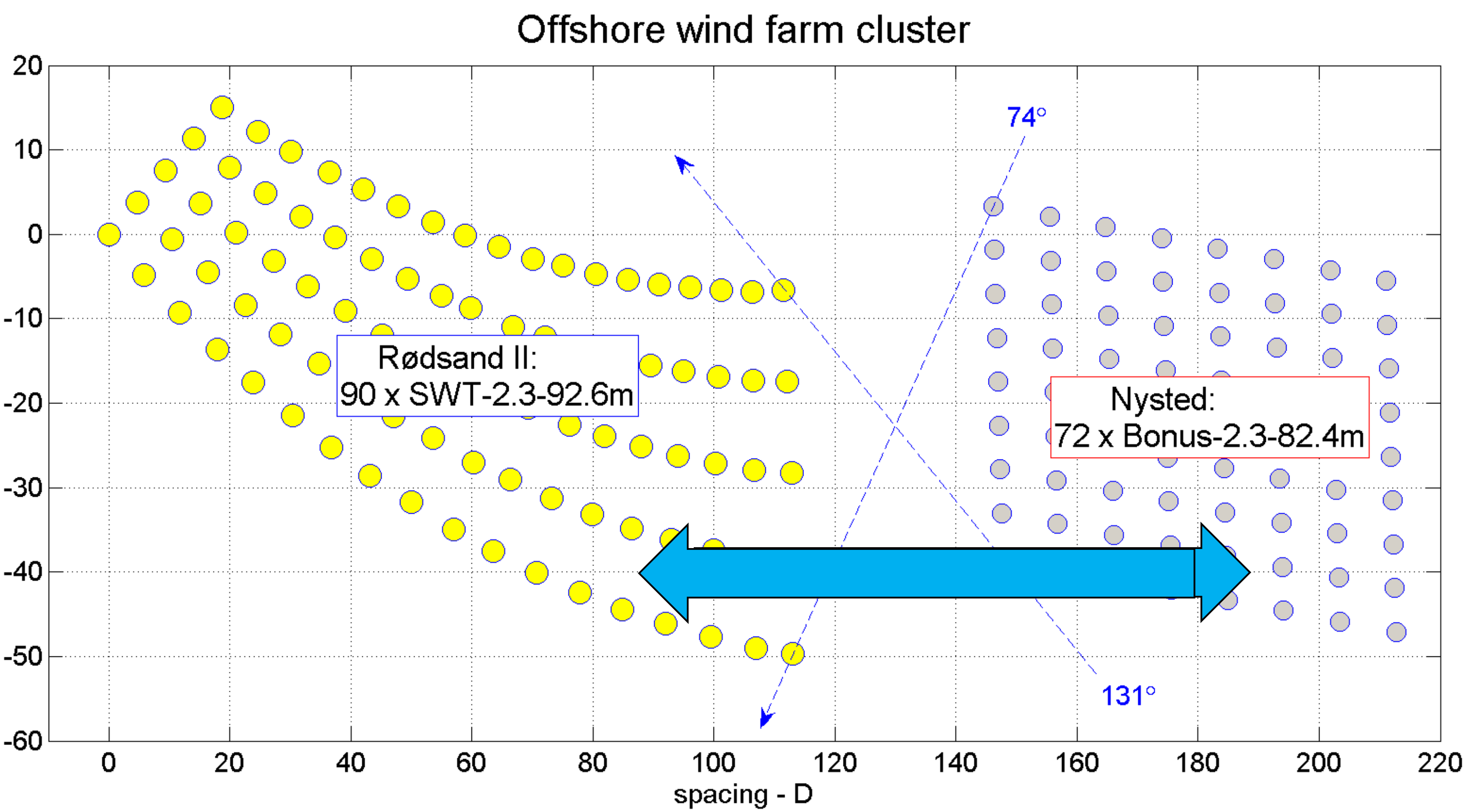
Lillgrund benchmark results





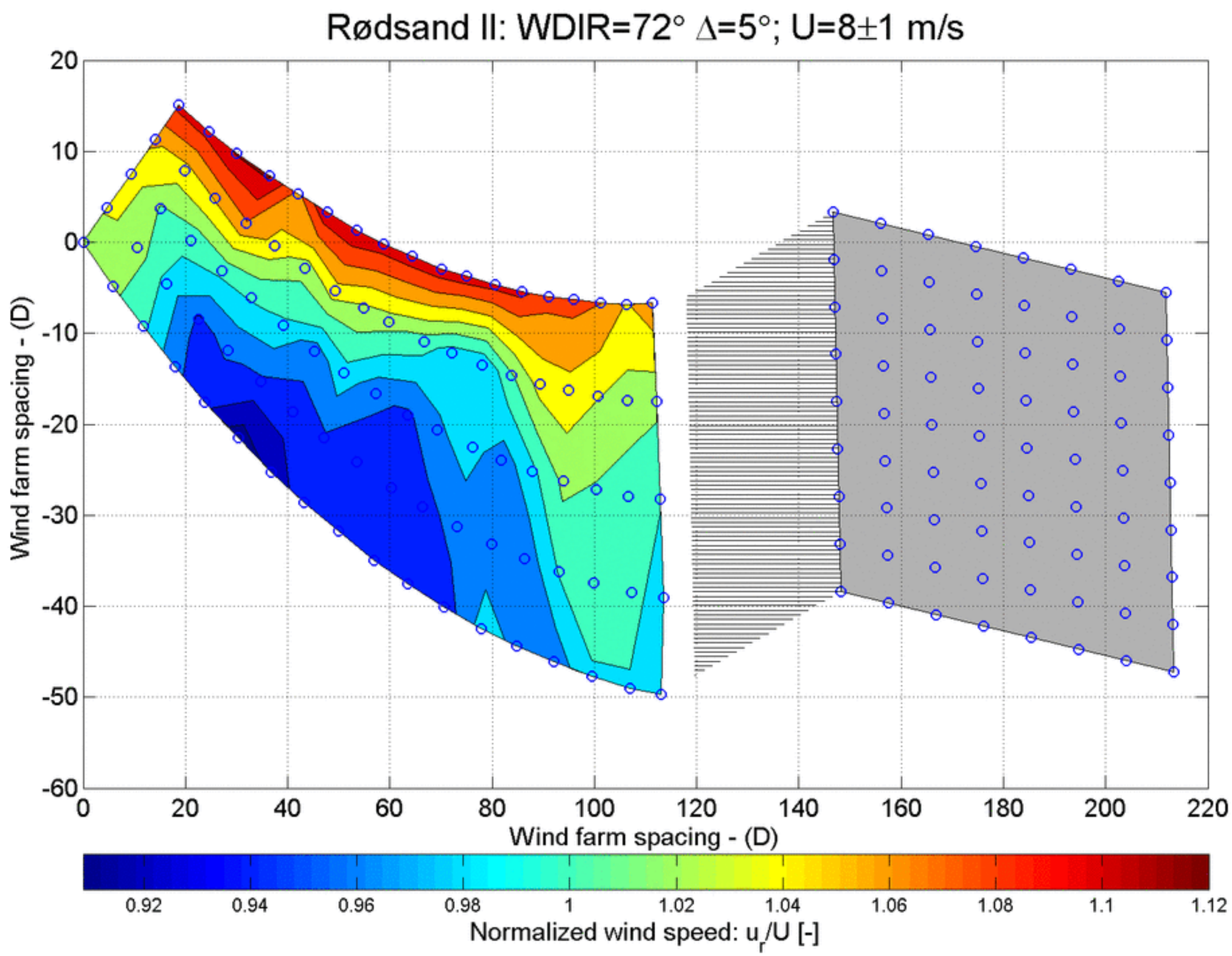
Wind farm clustering effects

Objectives: Model and validate the cluster effects.



Reference: *Simulation of wake effects between two wind farms* KS Hansen et al 2015 J. Phys.: Conf. Ser. 625 012008

Wind speed distribution inside RS II WF - under waked conditions (animation)

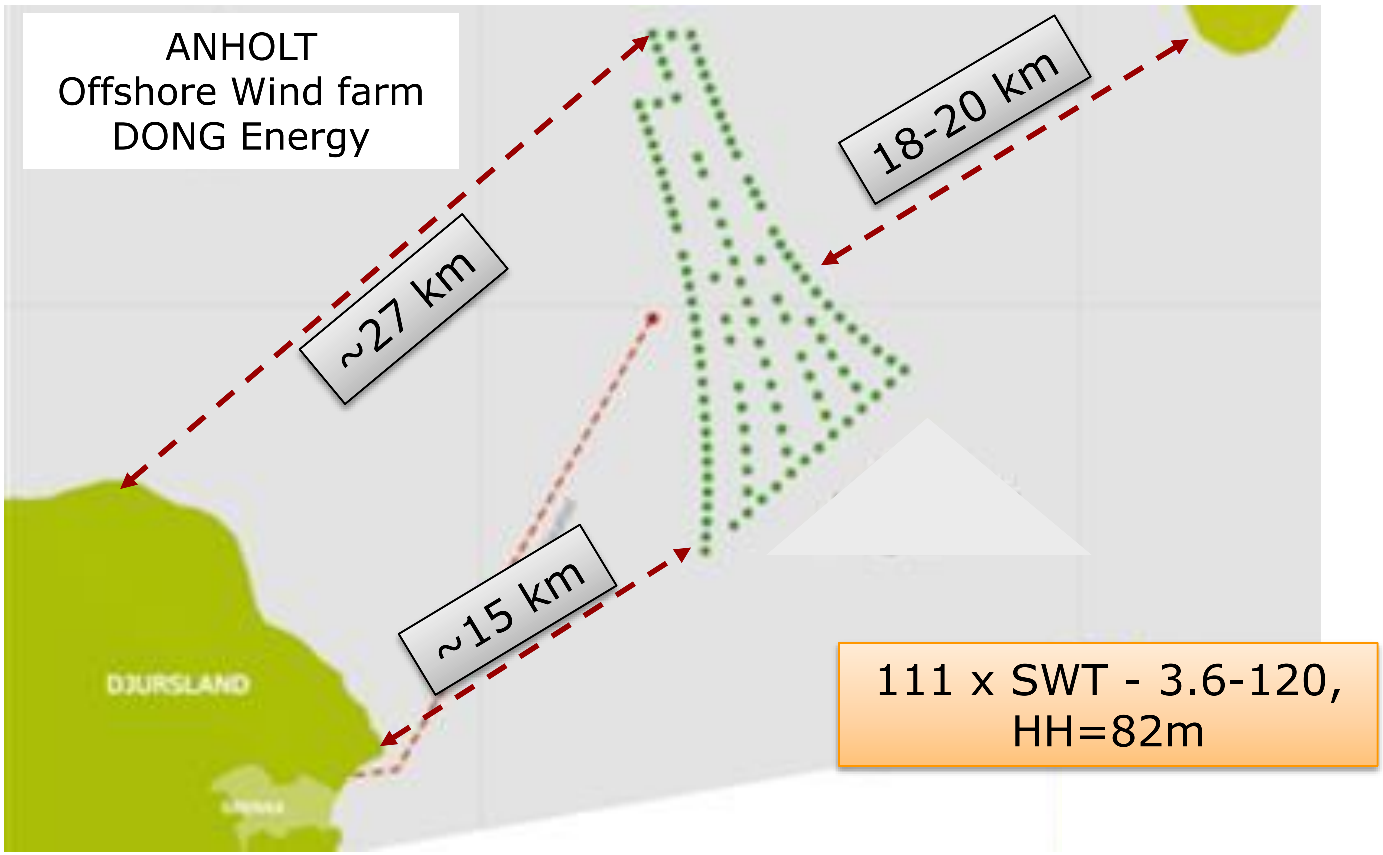


Anholt offshore wind farm - ANH

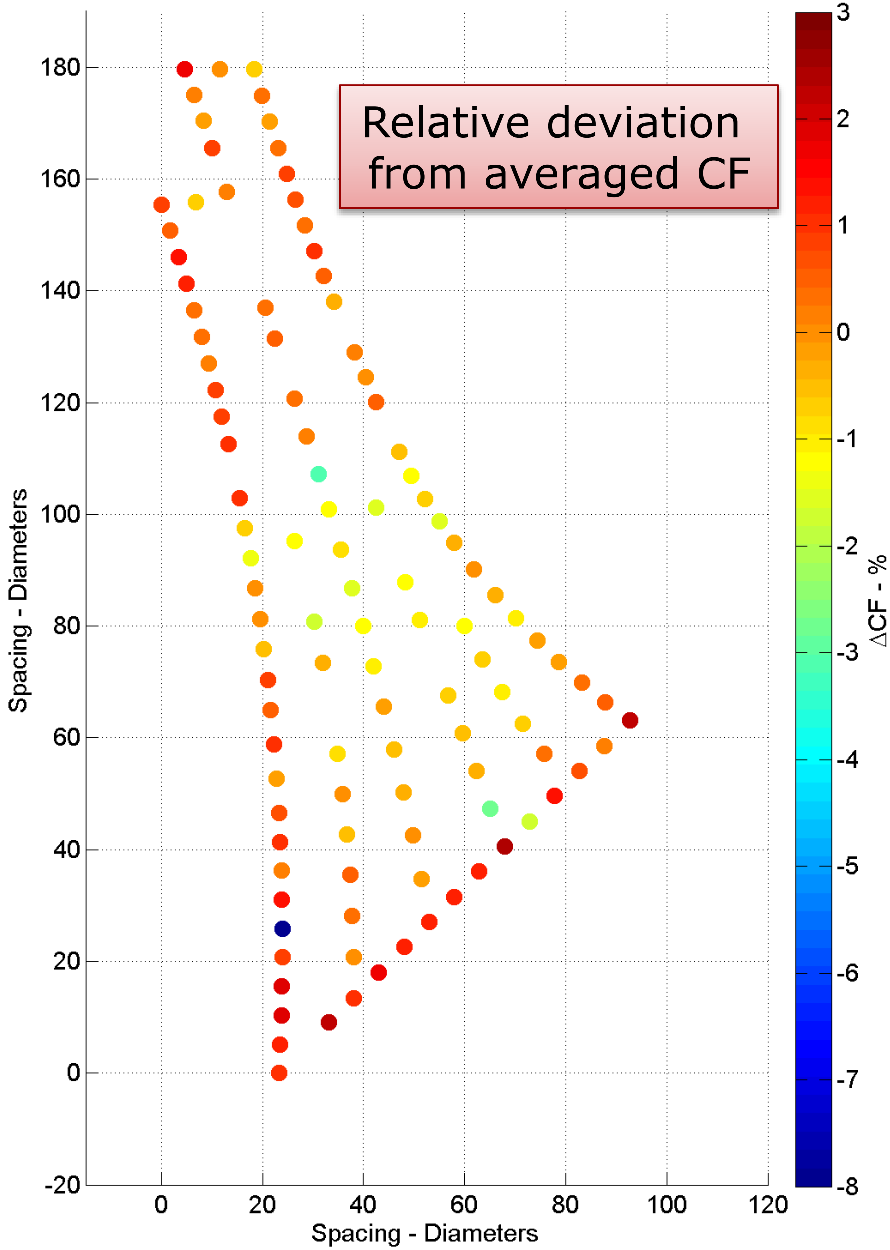
Objectives: Model and validate of coastal effects on a large wind farm.

Peña et.al. *On wake modeling, wind-farm gradients and AEP predictions at the Anholt wind farm*. Wind Energy Science 2018

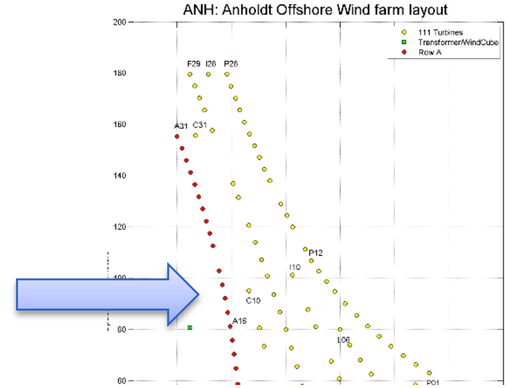
ANH-Location

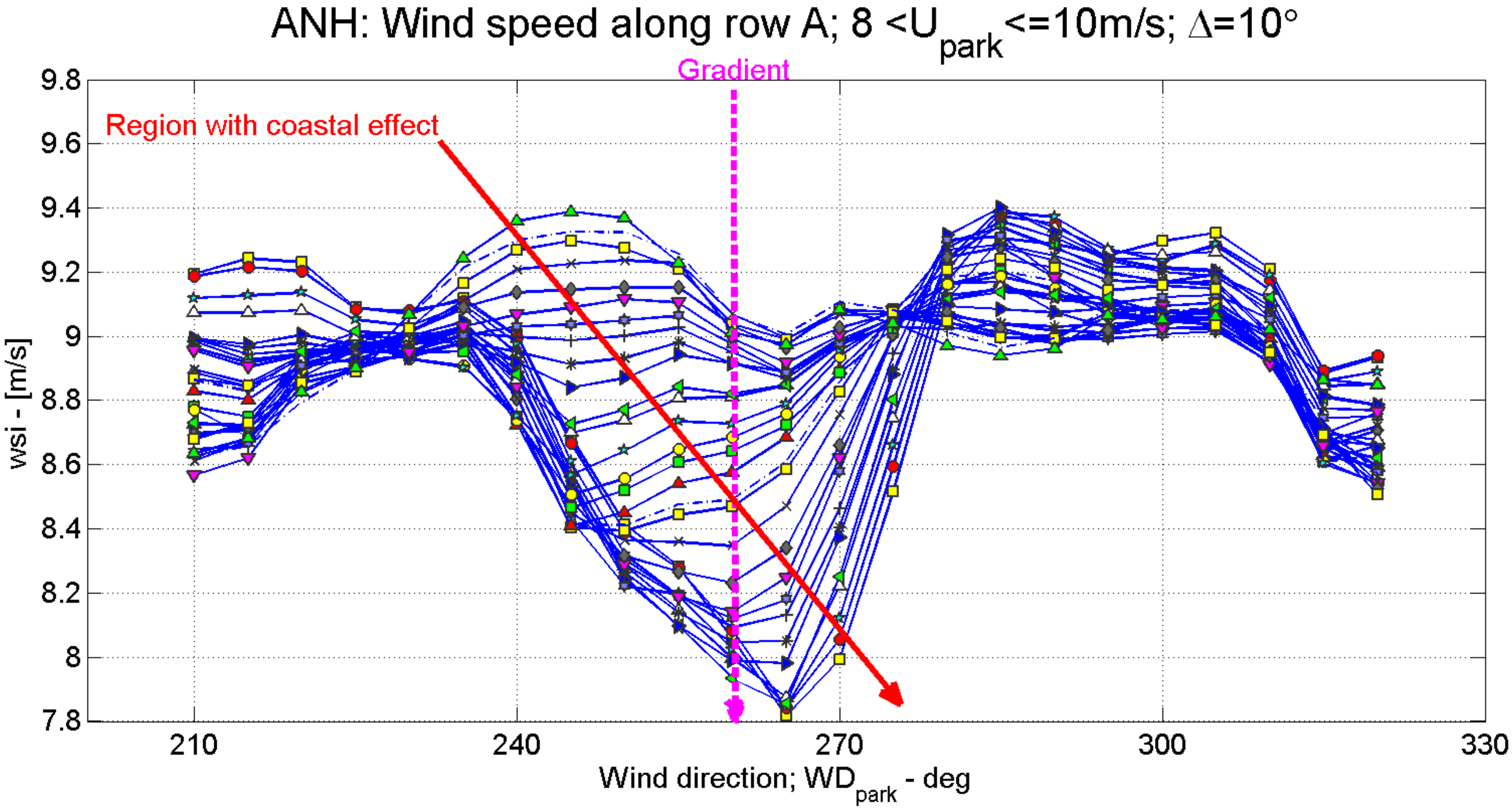


ANH: Distribution of WT capacity factors in 2014 based on tech. availability

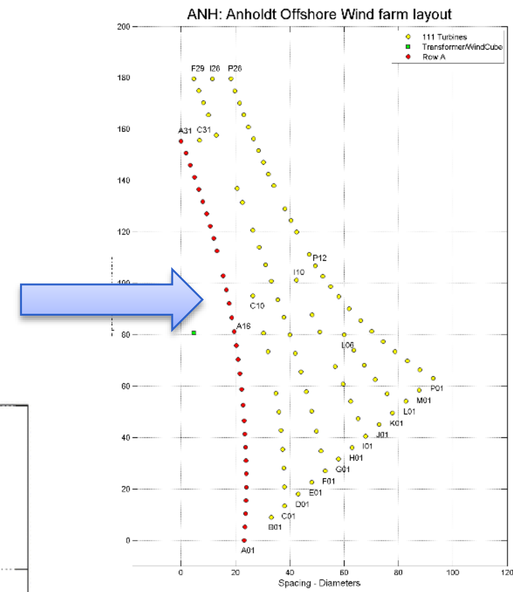


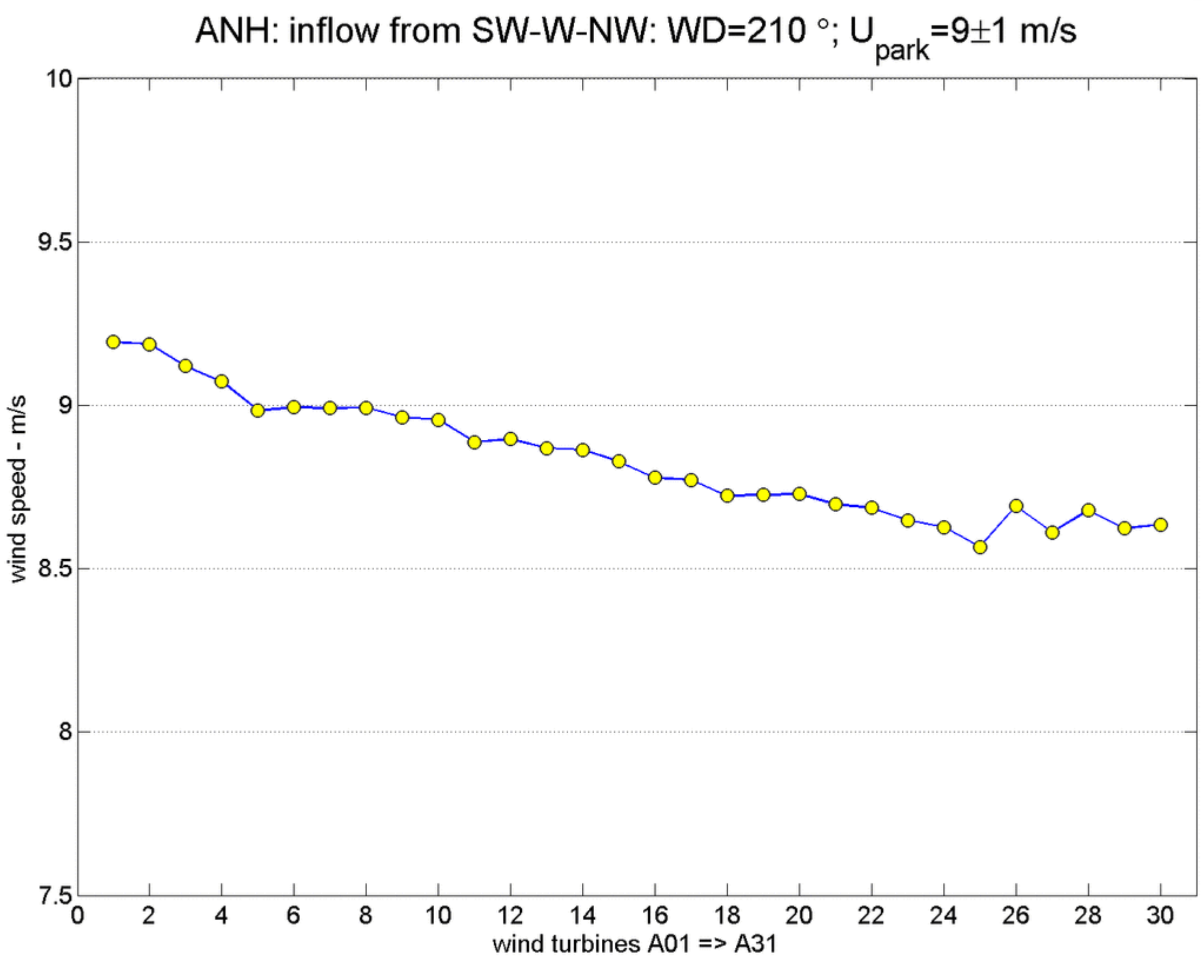
ANH: Gradient analysis =>Westerly inflow





ANH: Wind speed gradient for westerly inflow

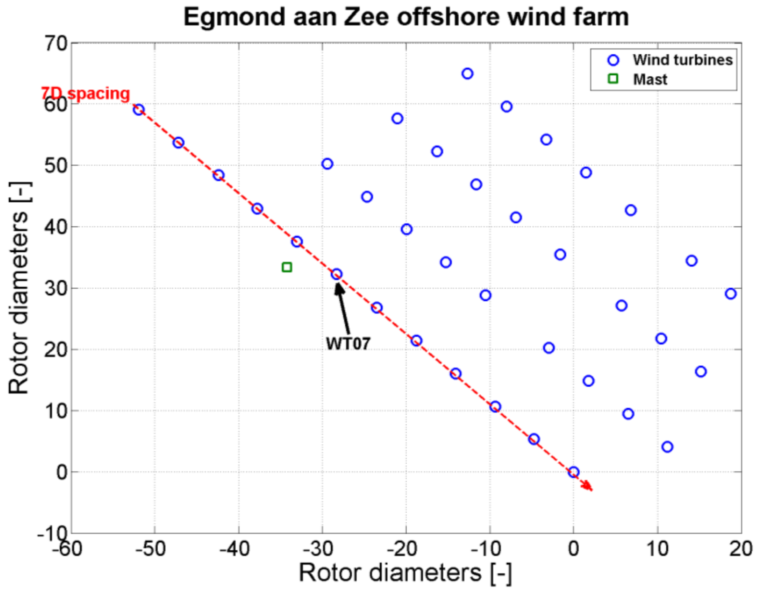




Structural load analysis for wind turbines operating in wind farms

Objectives are to validate the structural wind turbine loads for waked operation.

- Load analysis for single turbines have been performed for several wind farms.
  a) Horns Rev 1 offshore wind farm
  b) Egmod an Zee offshore wind farm
  c) Lillgrund offshore wind farm
  - in progress;



TJ Larsen et.al *Validation of the dynamic wake meander model for loads and power production in the Egmond aan Zee wind farm*
WIND ENERGY 2013; 16:605–624 DOI: 10.1002/we.1563

Acknowledgements

We acknowledge E•ON, Ørsted (formerly DONG Energy) and Vattenfall for having the access to the SCADA data from the Rødsand II, Nysted, Horns Rev, Anholt, Egmond aan Zee and Lillgrund offshore wind farms.


Thanks for your attention
by courtesy of E•ON