

Recent results of research into flow and wakes in large wind farms

R.J. Barthelmie Indiana University USA/University of Edinburgh, UK

S.T. Frandsen, O. Rathmann, K. Hansen, RISOE/DTU Denmark

E. Politis, J. Prospathopoulos CRES, Greece

G. Schepers ECN, Netherlands

K. Rados, NTUA, Greece

D. Cabezón CENER, Spain

W. Schlez, J. Phillips GH, Germany/UK



Funding: EU UPWIND # SES6 019945 /POWWOW #SES6 019898,
Data: DONG Energy A/S & Vattenfall AB (Horns Rev) and Middelgrunden Wind Farm cooperative

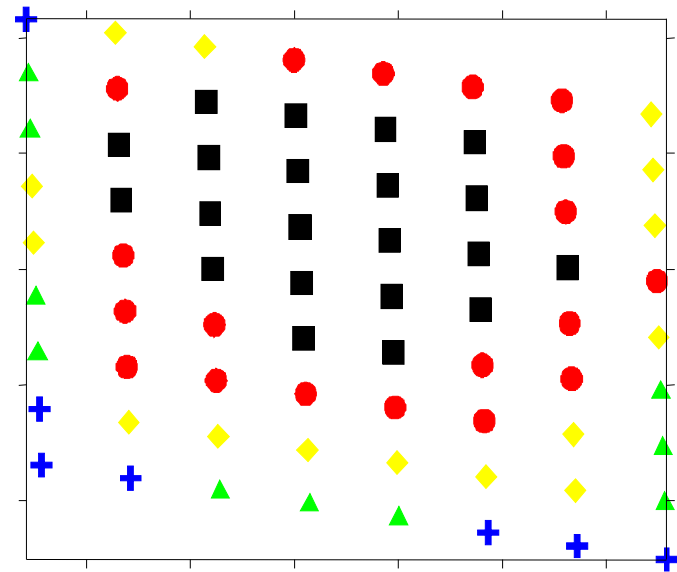
Objectives

- ✧ Previous research in small (<3 row) wind farms indicate wake models capture power losses due to wakes
- ✧ In large offshore wind farms, models over-predicting power output i.e. under-predicting wakes
- ✧ Need new models/measurements to reduce uncertainty and provide accurate power output prediction
- ✧ Bridge gap between CFD and wind farm models
- ✧ Tools to predict loads and power loss for lifetime wind farm assessment in order to determine optimal layout

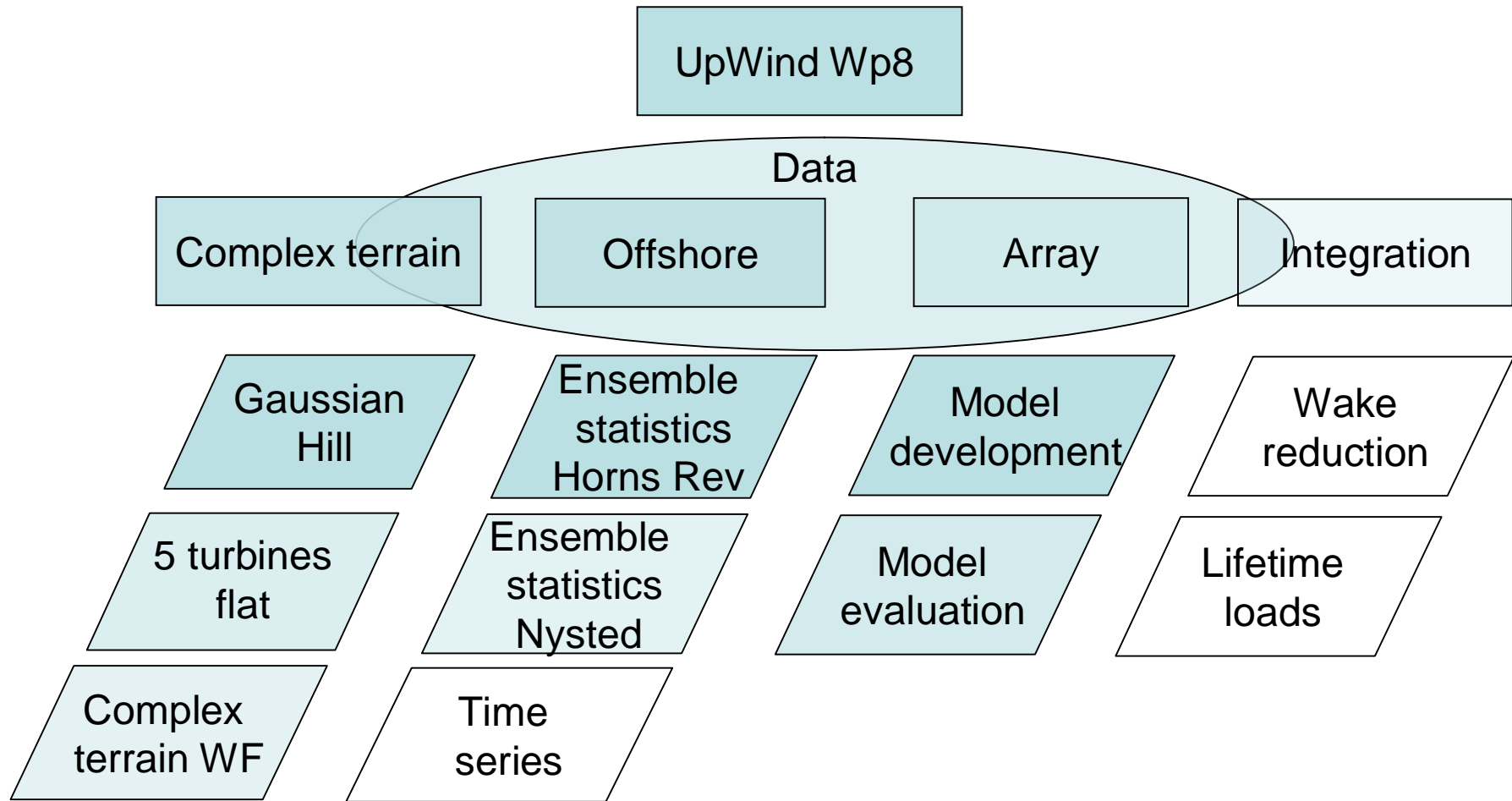


Modelling wind turbine wakes

- ✂ Wind farm models assume turbines $>3D$ spacing
- ✂ Power losses due to wakes in large wind farms estimated at 5-8% but in reality can be (much) larger
- ✂ May be more important offshore due to lower ambient turbulence/atmospheric stability
- ✂ Difficult to estimate in complex terrain due to wake turning

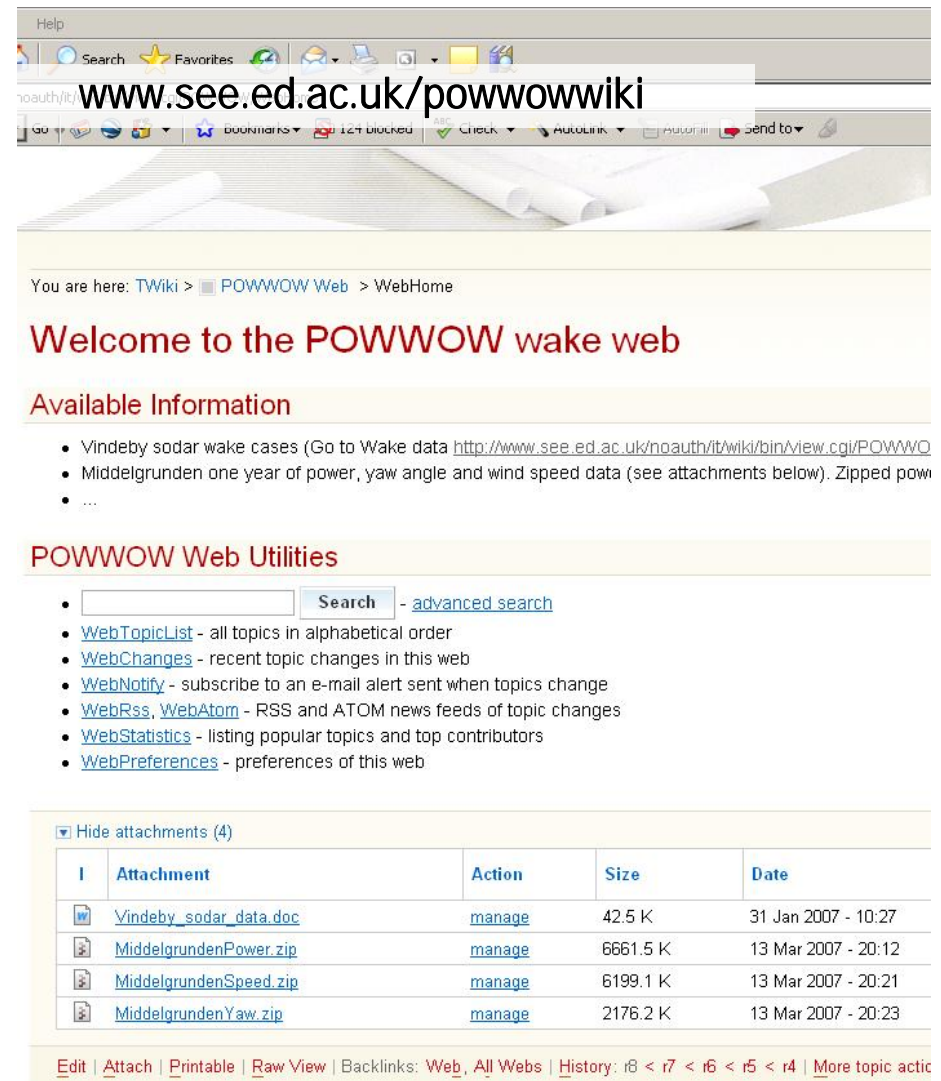


Structure of the EU funded UPwind project



Data

- ✧ Wind farm data are crucial
- ✧ Data processing complex
- ✧ Offshore wake data from Vindeby, Middelgrunden, Horns Rev, Nysted
- ✧ Complex terrain data from test site with five turbines and complex terrain wind farm
- ✧ Some data are publicly accessible via POWWOW project



Help

Search Favorites

www.see.ed.ac.uk/powwowwiki

You are here: TWiki > POWWOW Web > WebHome

Welcome to the POWWOW wake web

Available Information

- Vindeby sodar wake cases (Go to Wake data <http://www.see.ed.ac.uk/noauth/it/wiki/bin/view.cgi/POWWOW>)
- Middelgrunden one year of power, yaw angle and wind speed data (see attachments below). Zipped pow
- ...

POWWOW Web Utilities

- - [advanced search](#)
- [WebTopicList](#) - all topics in alphabetical order
- [WebChanges](#) - recent topic changes in this web
- [WebNotify](#) - subscribe to an e-mail alert sent when topics change
- [WebRss](#), [WebAtom](#) - RSS and ATOM news feeds of topic changes
- [WebStatistics](#) - listing popular topics and top contributors
- [WebPreferences](#) - preferences of this web

Hide attachments (4)

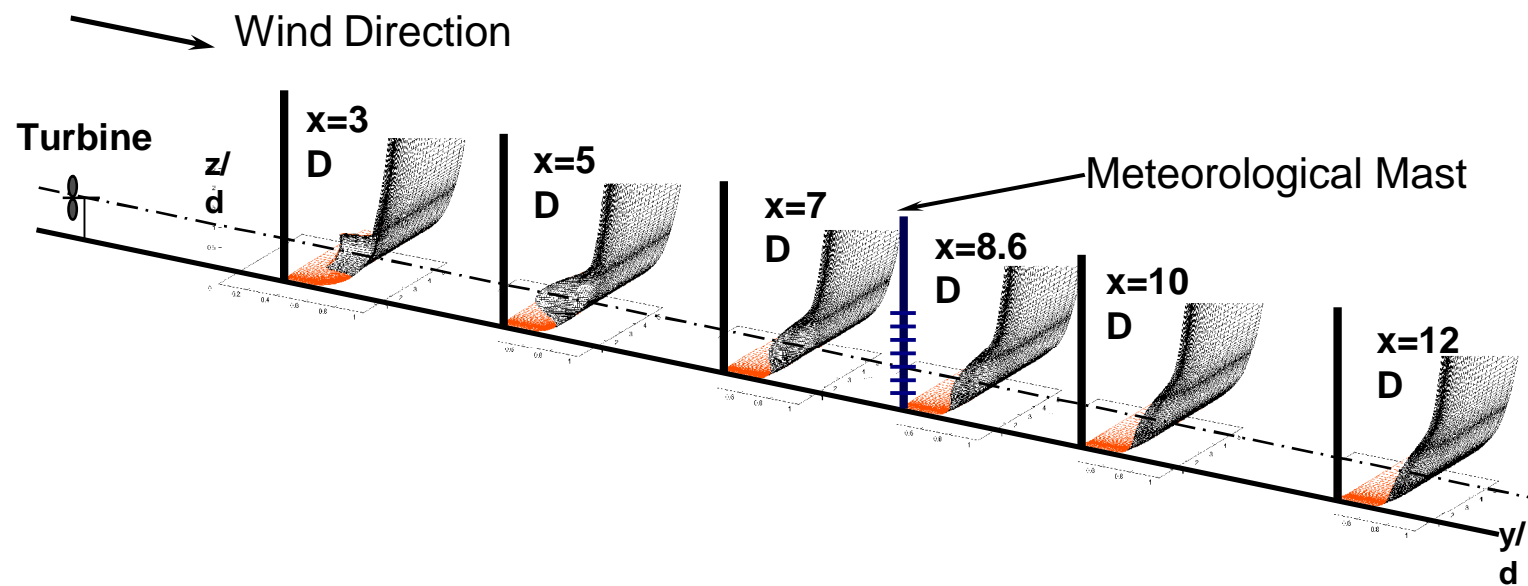
| I | Attachment | Action | Size | Date |
|---|--|------------------------|----------|---------------------|
| | Vindeby_sodar_data.doc | manage | 42.5 K | 31 Jan 2007 - 10:27 |
| | MiddelgrundenPower.zip | manage | 6661.5 K | 13 Mar 2007 - 20:12 |
| | MiddelgrundenSpeed.zip | manage | 6199.1 K | 13 Mar 2007 - 20:21 |
| | MiddelgrundenYaw.zip | manage | 2176.2 K | 13 Mar 2007 - 20:23 |

[Edit](#) | [Attach](#) | [Printable](#) | [Raw View](#) | Backlinks: [Web](#), [All Webs](#) | History: [r8](#) < [r7](#) < [r6](#) < [r5](#) < [r4](#) | [More topic actio](#)

Models

Progression of wake models:

- ↘ Empirical e.g. WASP (under modification)
- ↘ Ainslie Group – e.g. Windfarmer
- ↘ Analytical models (Risoe group)
- ↘ Parabolised CFD e.g. Wakefarm
- ↘ CFD: CRES, CENER, NTUA



K. Rados, NTUA

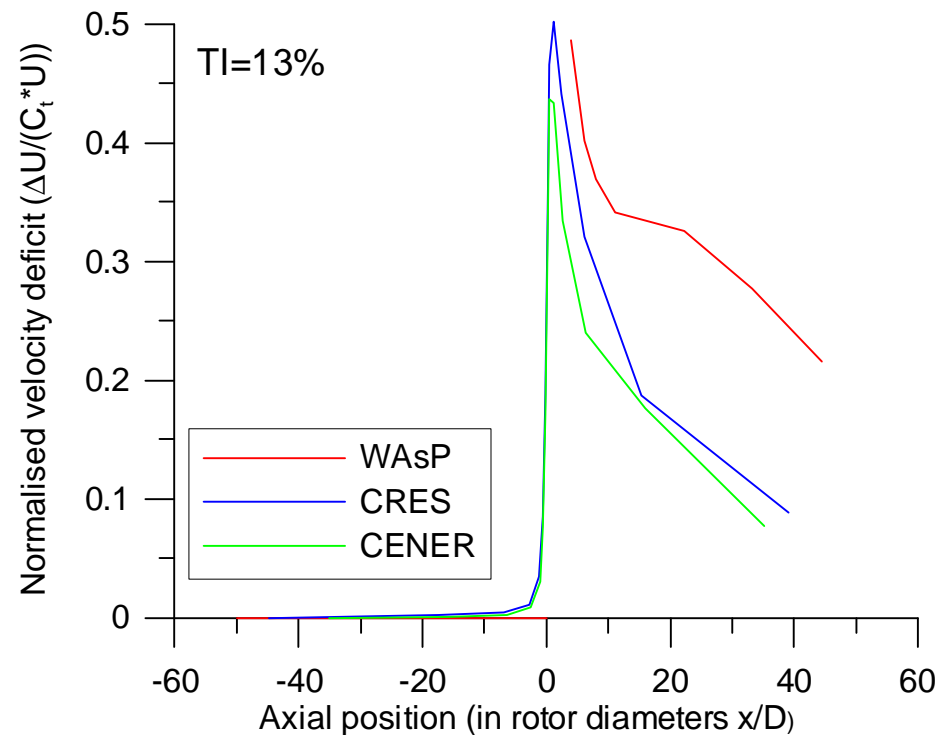
Complex terrain – Gaussian hill

Evaluation of single wind turbine at
the top of a Gaussian Hill

- ↘ CRES CFD
- ↘ CENER Fluent
- ↘ RISOE WAsP

Main results

- ↘ Good agreement between CENER and CRES models
- ↘ Minor discrepancies attributed to surface parameterisation
- ↘ WAsP not shown in near wake

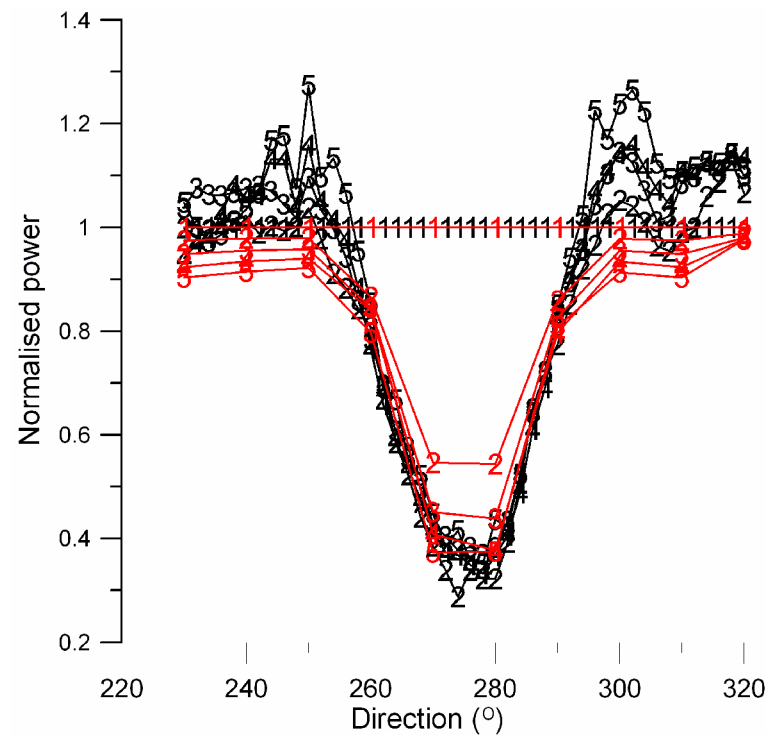


Results courtesy CENER/CRES

Complex terrain - Research farm

Examining multiple wakes in complex terrain:

- Five **research** turbines (2.5 MW) with one 108m high meteorological mast (mm3)



Results courtesy ECN

Complex Terrain – Wind farm data

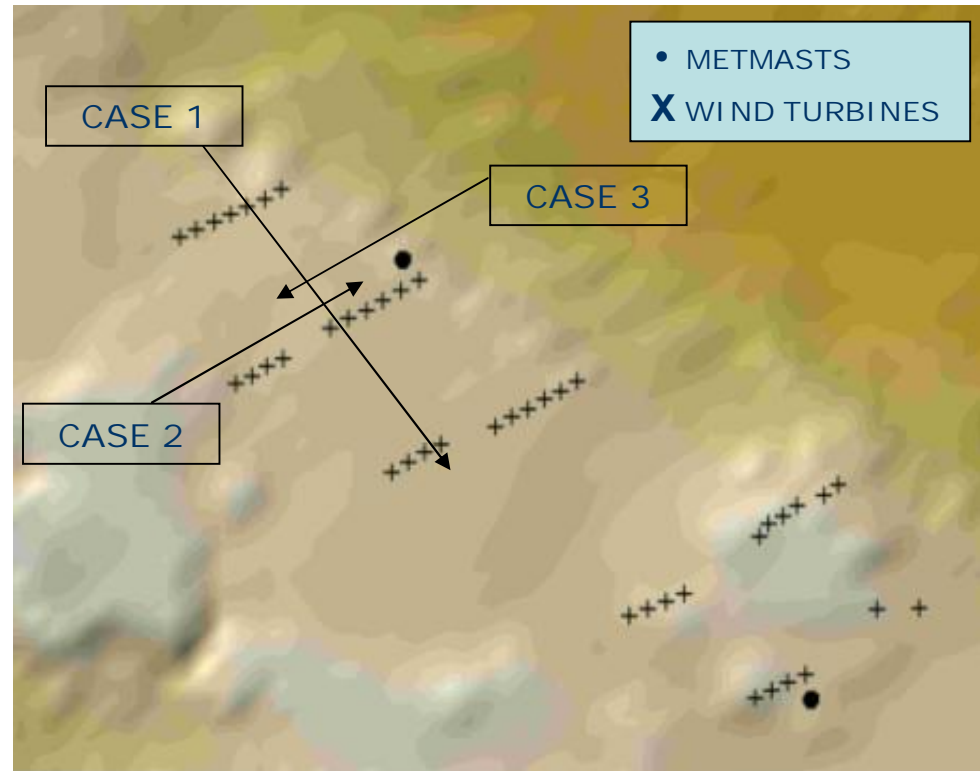
5 alignments NE-SW in moderate complex terrain

Wind farm data:

- ✎ 43 WTs x 700 kW
- ✎ Met masts WS & WD
- ✎ WT Nacelle Power
- ✎ WT Nacelle WS & WD

Three cases:

- ✎ Case 1: $325^{\circ} \pm 5^{\circ}$, 13D spacing
- ✎ Case 2: $247.5^{\circ} \pm 5^{\circ}$, 1.5D spacing
- ✎ Case 3: $67.5^{\circ} \pm 5^{\circ}$, 1.5D spacing

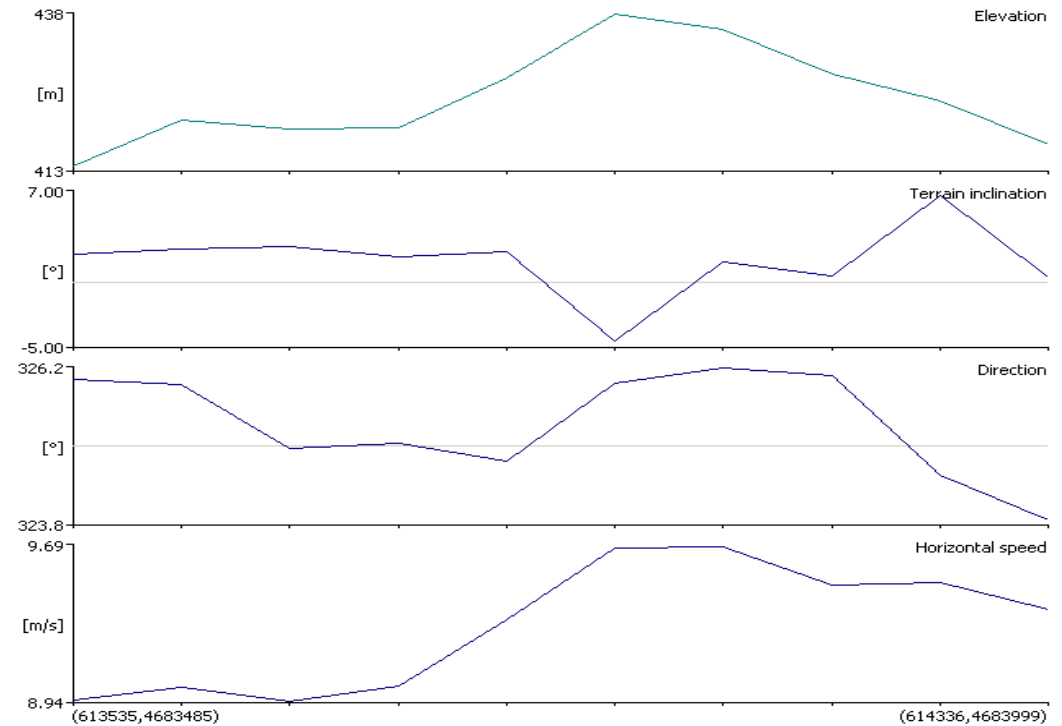
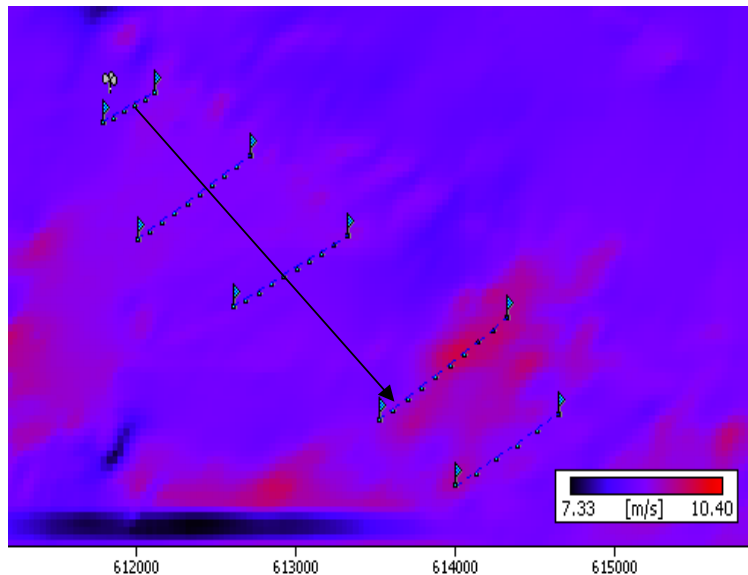


Data courtesy CENER

Complex terrain - Wind farm terrain effects

To quantify wakes, data must be 'cleaned' of topographic effects

- ↘ An example at 8 m/s, direction 325°
- ↘ Modelling in WAsP Engineering
- ↘ Terrain induced $\Delta U \sim 0.75$ m/s (4th row)



Offshore - Plan

1. Ensemble statistics at Horns Rev

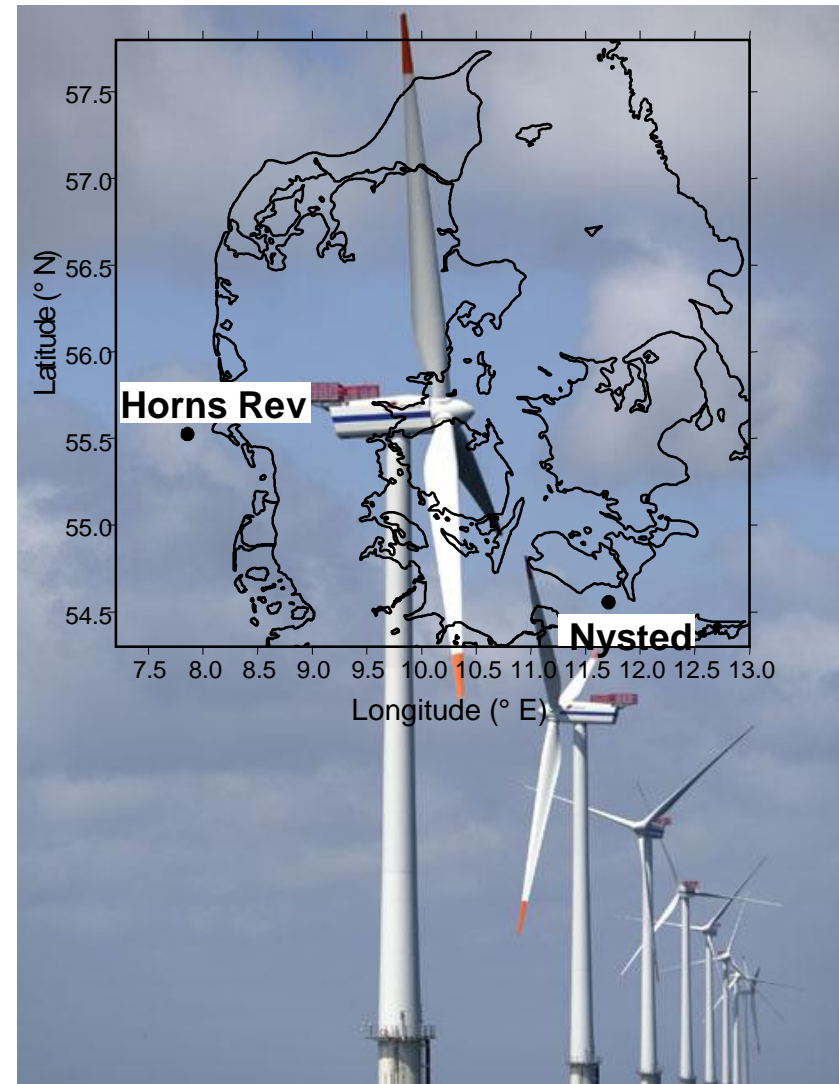
- ↘ 80 Vestas V80 2 MW turbines
- ↘ 8 by 10 grid, spacing 7 D
- ↘ 14 km from Danish west coast
- ↘ Power, yaw and status extracted from SCADA
- ↘ Reference period 10 min
- ↘ Met data M1,M6,M7

2. Ensemble statistics at Nysted

- ↘ 72 Bonus 2.3 MW turbines
- ↘ 8 by 9 grid, spacing 5.8/10.5 D
- ↘ 11 km from Danish west coast
- ↘ Power, yaw and status extracted from SCADA
- ↘ Reference period 10 min
- ↘ Met data M1-M6, plus coastal

3. Time series

4. Others?



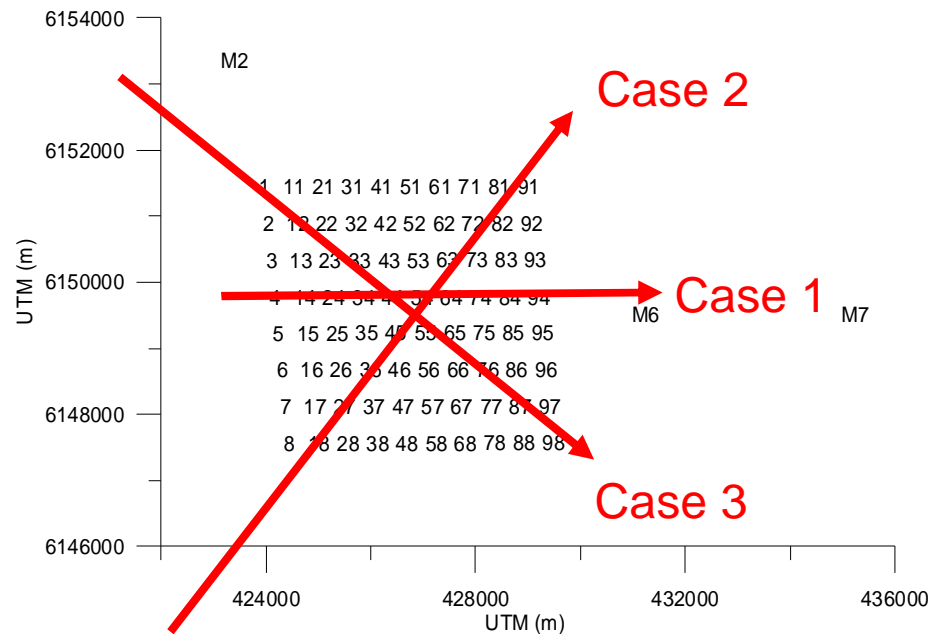
Horns Rev - Ensemble statistics

Averages

- ✂ Identical conditions (w_s, w_d)
- ✂ Maximise number of observations
- ✂ Discrete in time
- ✂ Small wake widths=limited obs.

First set

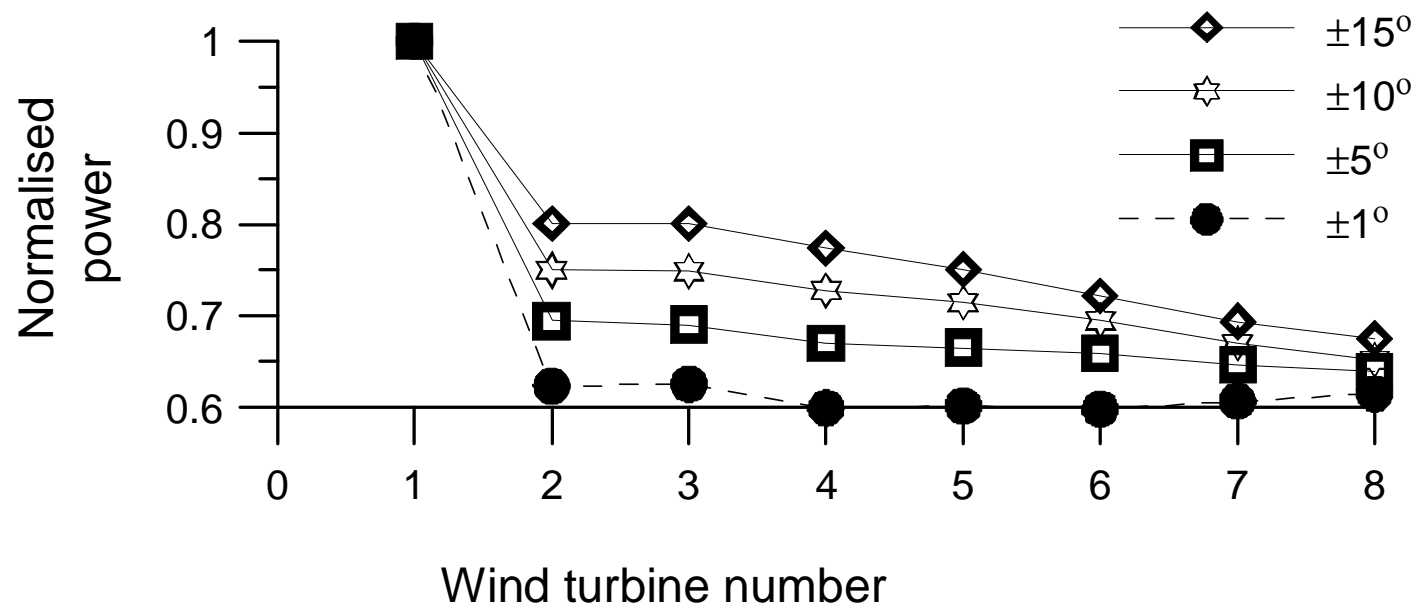
- ✂ Direct down or across rows
- ✂ Different wake widths



Measurements at Horns Rev

Measurements directly down the row

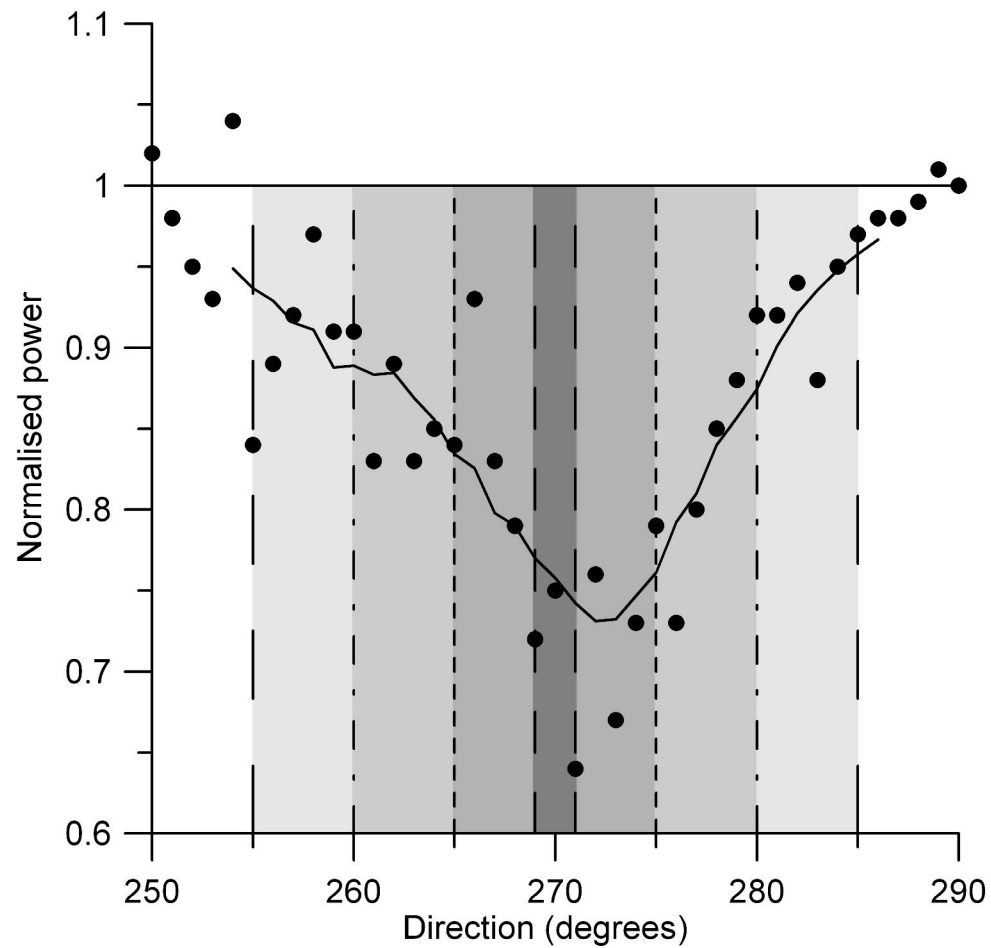
- Case 1 (7D)
- Normalised power
- U at first turbine 8.0 ± 0.5 m/s



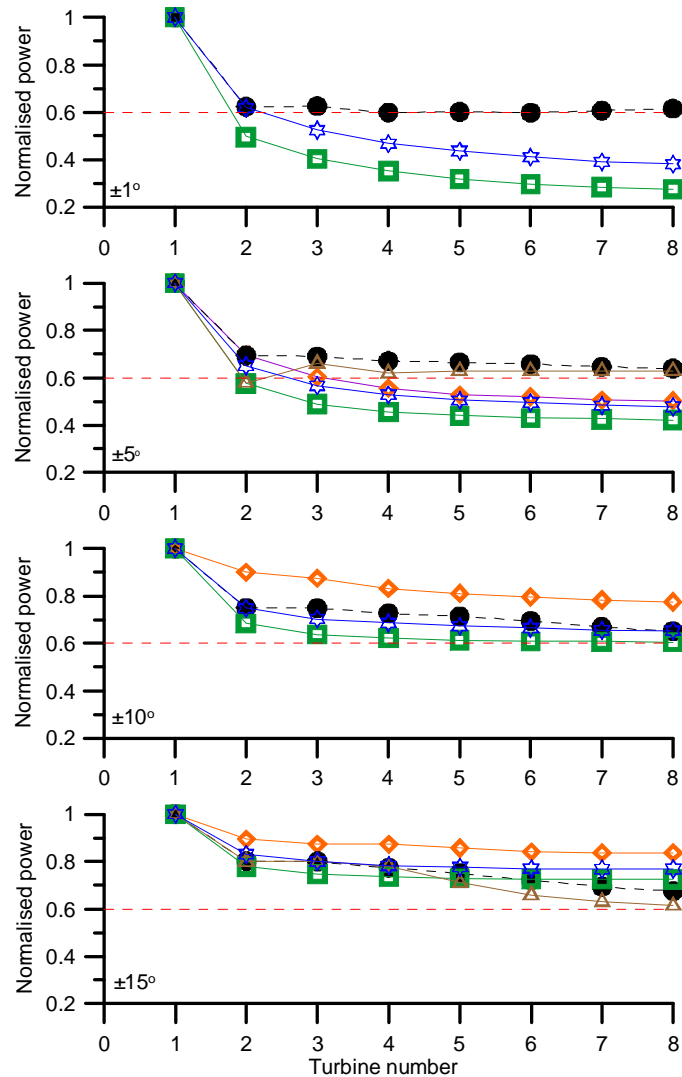
Data courtesy DTU

Wake width

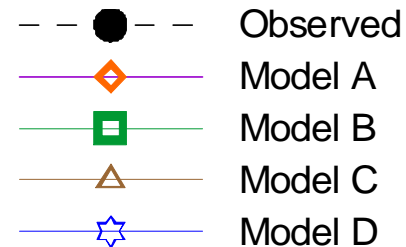
- ✧ Initial drop is larger for narrow angles
- ✧ Observations are in the maximum wake loss (approx. Gaussian)



Horns Rev case studies - 7D spacing



- Direct down the row wake losses are the largest esp. at low wind speeds
- Defining narrow rows and wind sectors gives few values
- Not representative for all wind speeds and directions
- Case 1 270° , 7D spacing

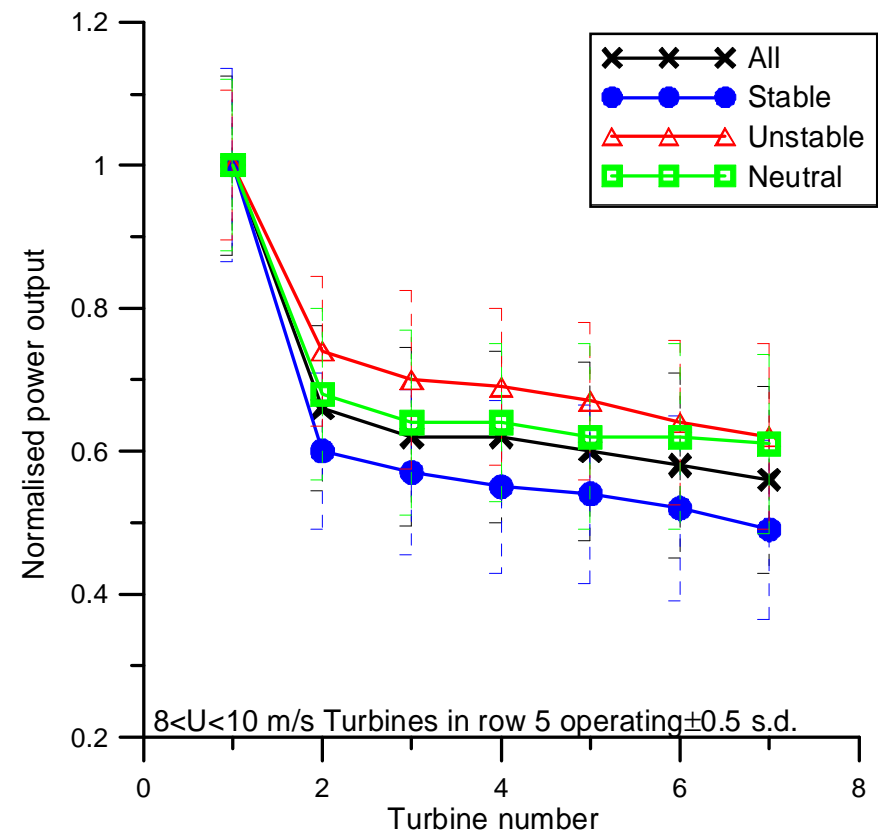


8 ± 0.5 m/s

Nysted

Data from Nysted

- Recently released to Upwind
- Wind farm spacing 5.8 and 10.5D
- Stall regulated two speed turbine
- Analysis on atmospheric stability



Array effects - Plan

Objective

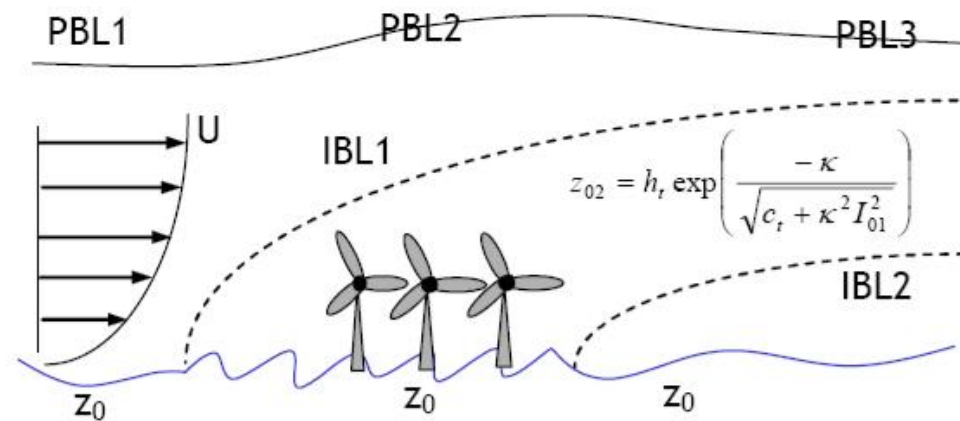
- ↪ Assess optimal spacing between wind farms

Modelling

- ↪ Added roughness, canopy type model, new analytical model
- ↪ Modifications to the WAsP/Windfarmer models

Data

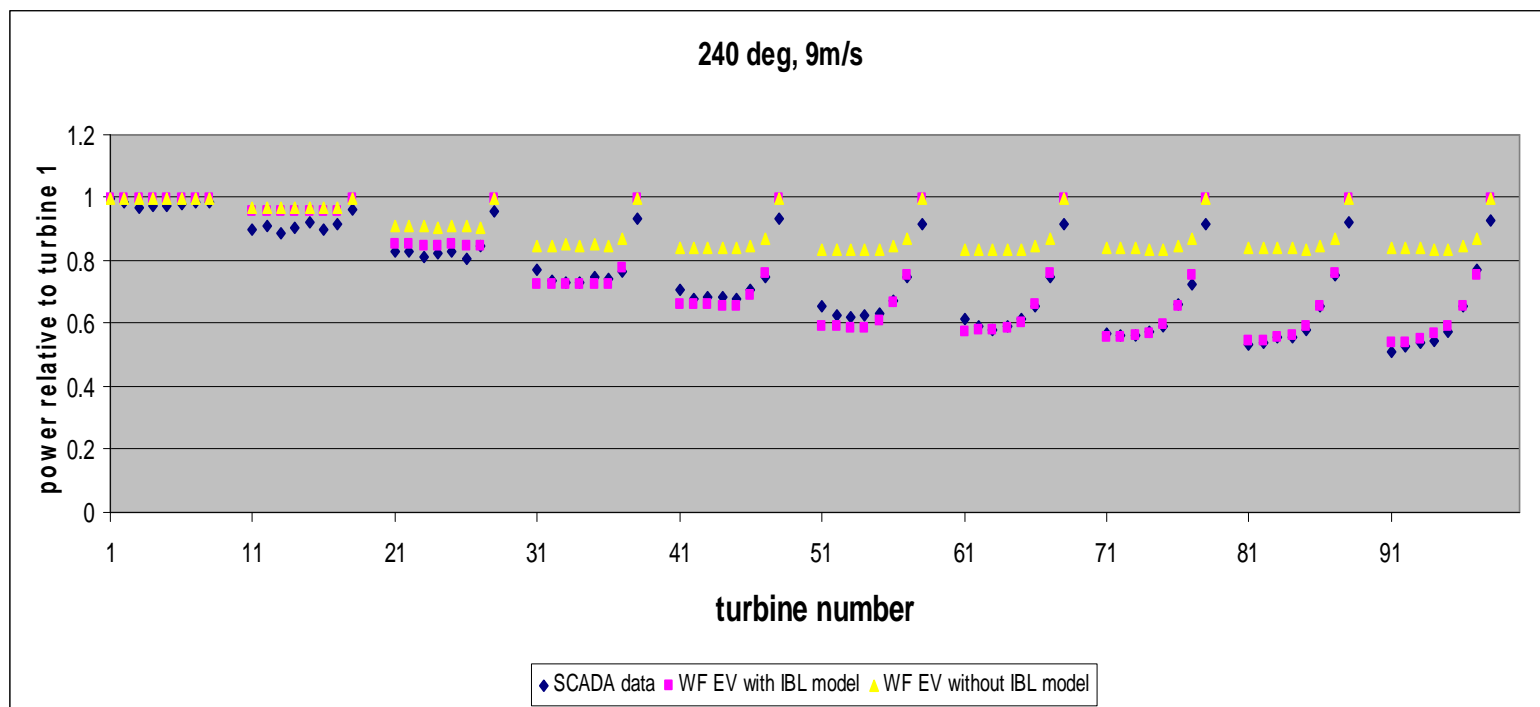
- ↪ Horns Rev/Nysted – both have downstream masts



R.Barthelmie IU/UE

Array effects - Results

- ↘ Tuning of TI (or via roughness) - good agreement with measurements
- ↘ Wind speed within the wind farm drops < 80% of freestream
- ↘ Recovery to ~ 90% occurs within ~5km of wind farm end
- ↘ Further recovery over ~20 km
- ↘ More: Frandsen et al. EWEA 2008/Risø-R-1615



W. Schlez, Garrad Hassan & Partners

What are the ultimate goals?

1. Minimise power losses due to wakes
 - ↪ Based on maximising energy output in a given area
 - ↪ Modelling based on concepts developed at ECN e.g. changing pitch or yaw angles
2. Optimise the wind farm for lifetime power and loads
 - ↪ Examine new tools to link power and load modelling
 - ↪ Power losses can be minimised but the impact on loads also needs to be examined



Summary and future work

- Objective
 - ✧ Reduce costs of wind energy by reducing uncertainty in predicting power losses from wakes
- UpWind project
 - ✧ Provides platform for undertaking model evaluation
 - ✧ Provides platform for data sharing
 - ✧ Combined activity is most effective
- Progress made
 - ✧ Data sets collated and analysed
 - ✧ Model evaluation complete/underway
 - ✧ Areas for model development illustrated
 - ✧ Deliverables available at www.upwind.eu
- Future
 - ✧ Minimise power losses due to wakes
 - ✧ Integration of loads and power to give optimal layouts