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

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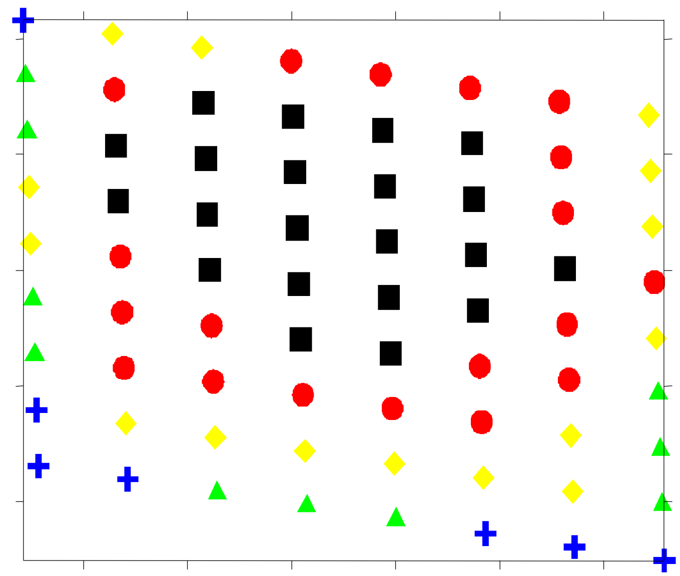
Data: DONG Energy A/S &Vattenfall AB (Horns Rev) and Middelgrunden Wind Farm cooperative

Objectives

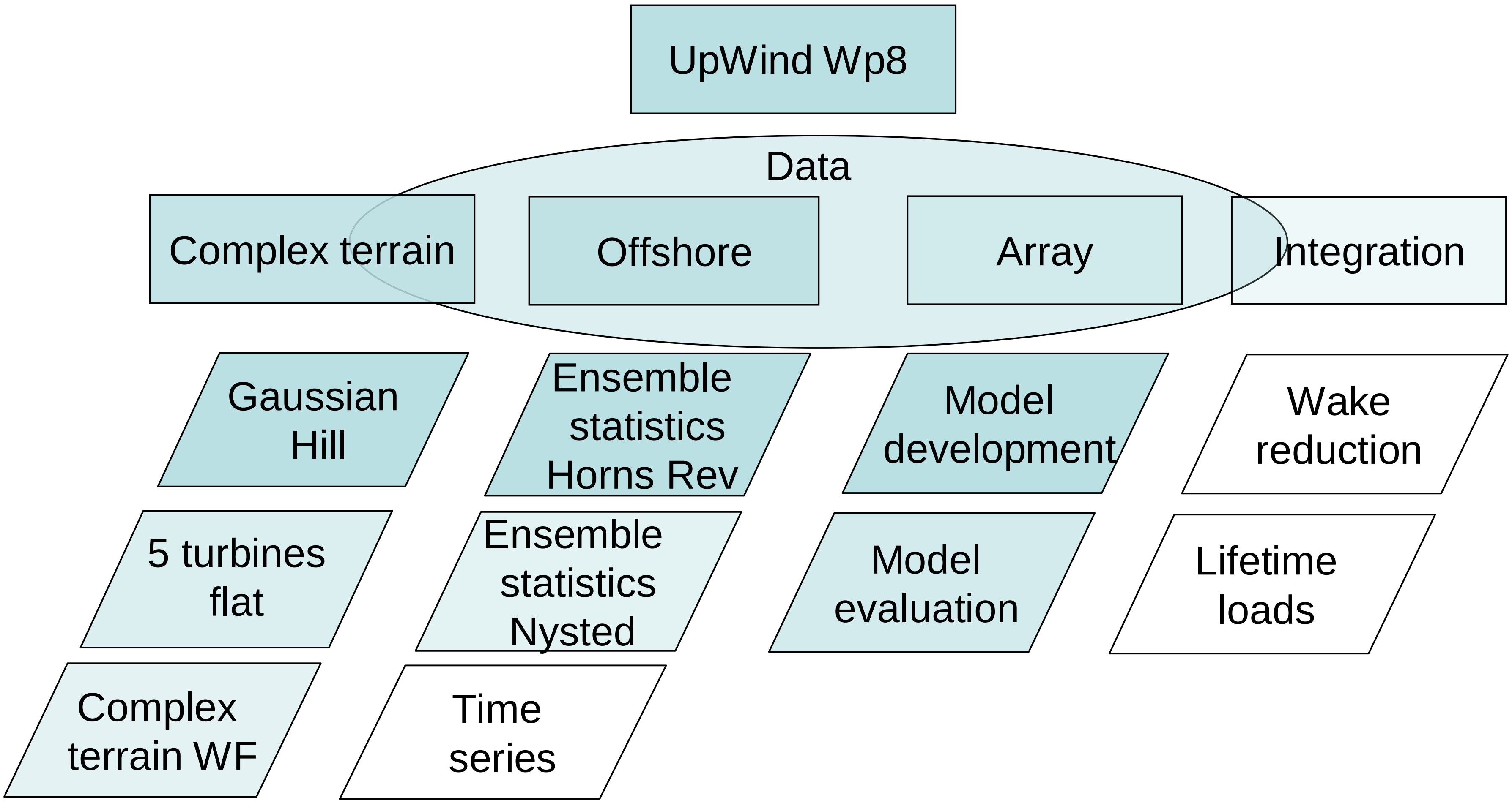
- Previous research in small (<3 row) wind farms indicate wake models capture power losses due to wakes
- In large offshore wind farms, models over-predicting power output i.e. under-predicting wakes
- Need new models/measurements to reduce uncertainty and provide accurate power output prediction
- Bridge 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



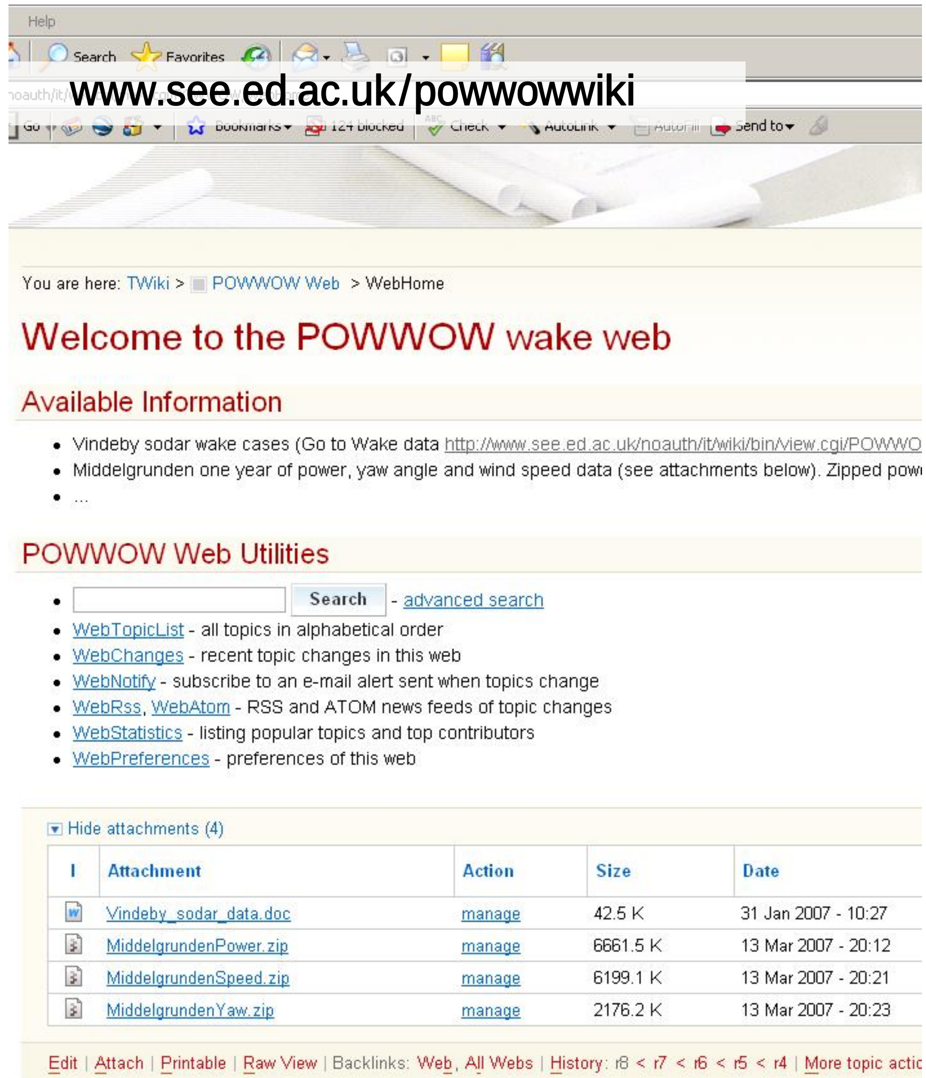
Structure of the EU funded UPwind project



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 POW'WOW project

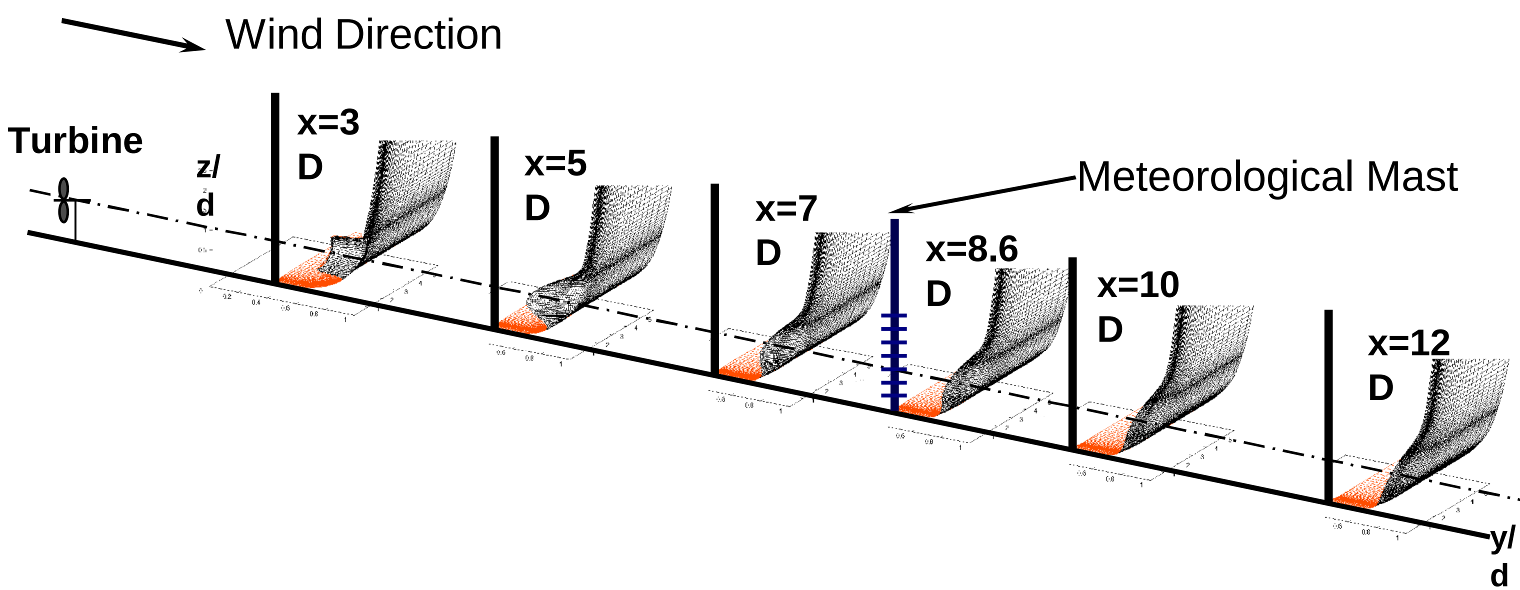
www.see.ed.ac.uk/powwowwiki



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

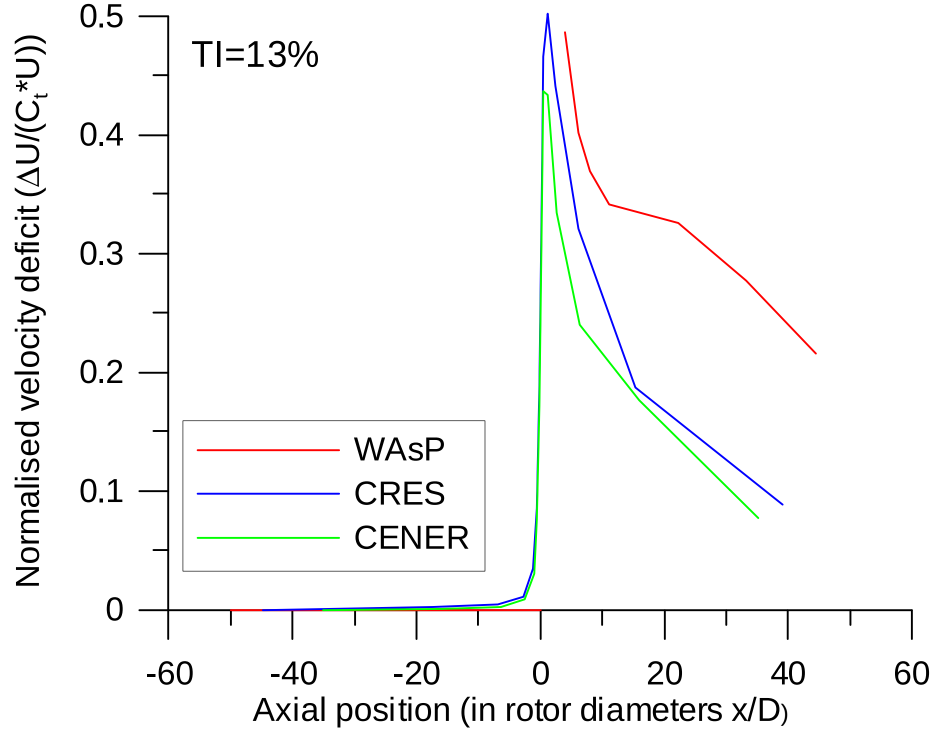
Complex terrain –Gaussian hill

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

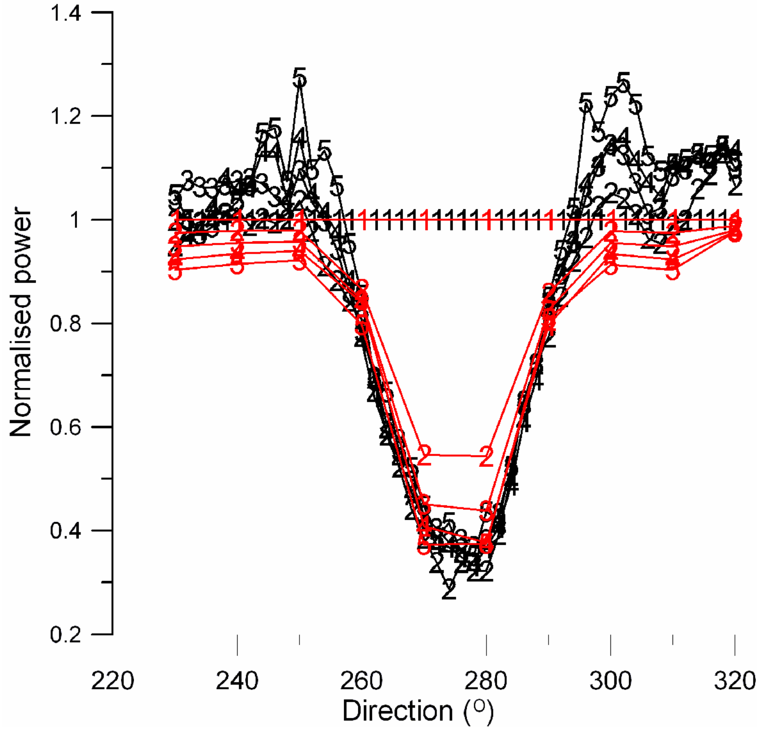


Results courtesy CENER/CRES

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

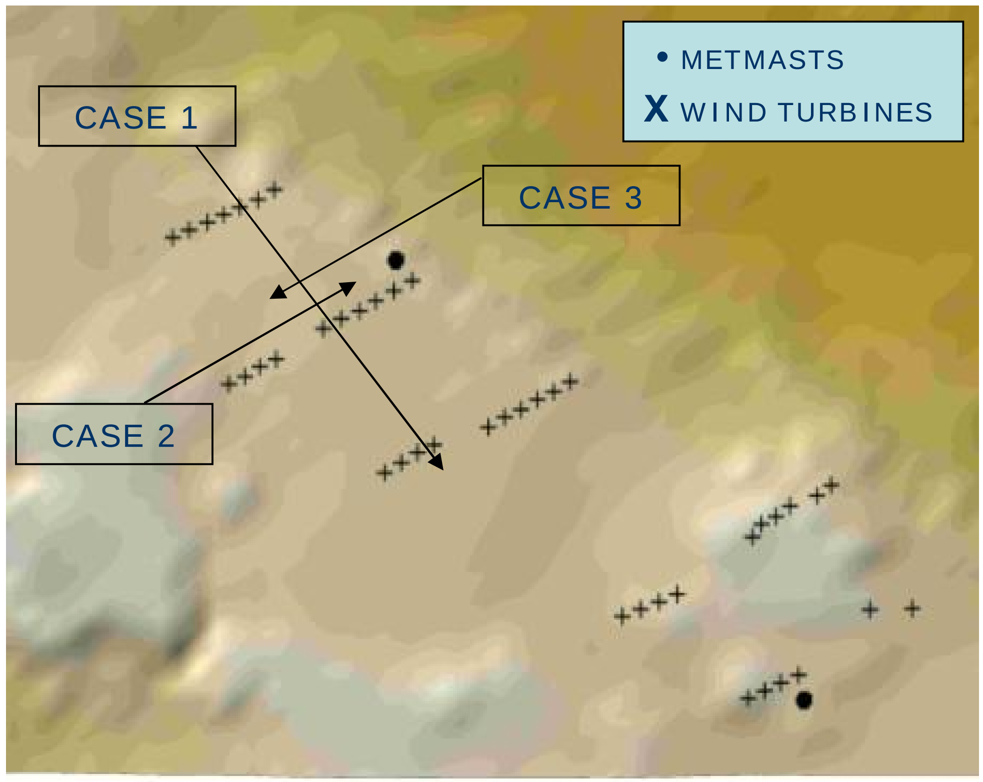
5 alignments NE-SW in moderate complex terrain

Wind farm data:

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

Three cases:

- Case 1: 325º±5º, 13D spacing
- Case 2: 247.5º±5º, 1.5D spacing
- Case 3: 67.5º±5º, 1.5D spacing

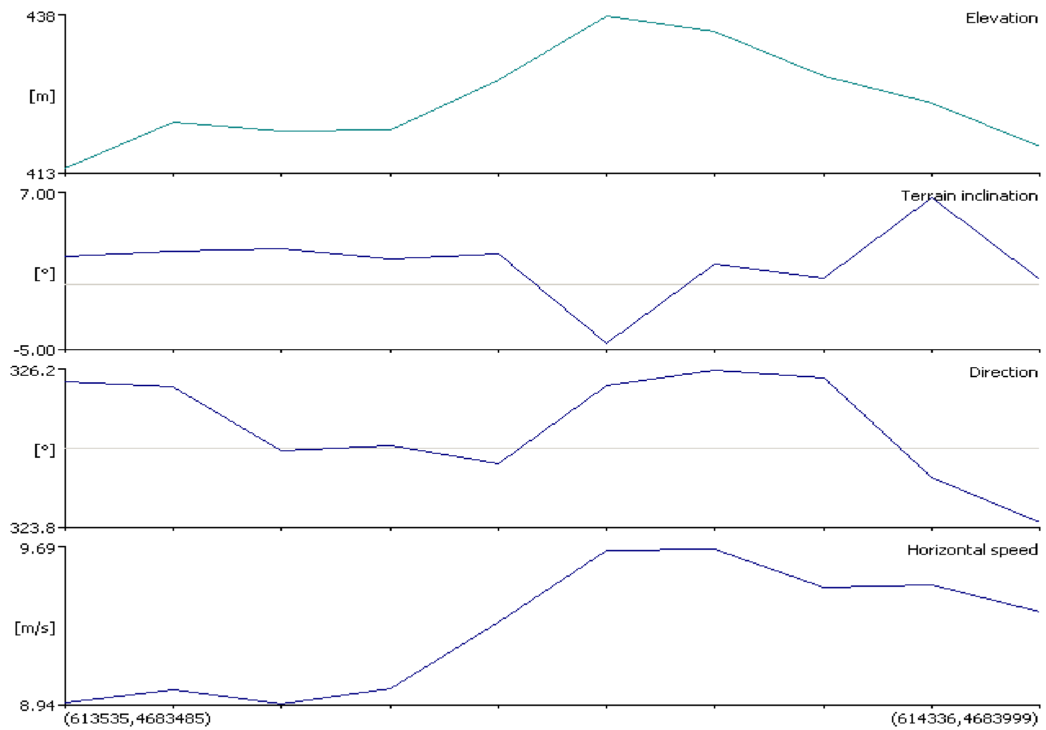


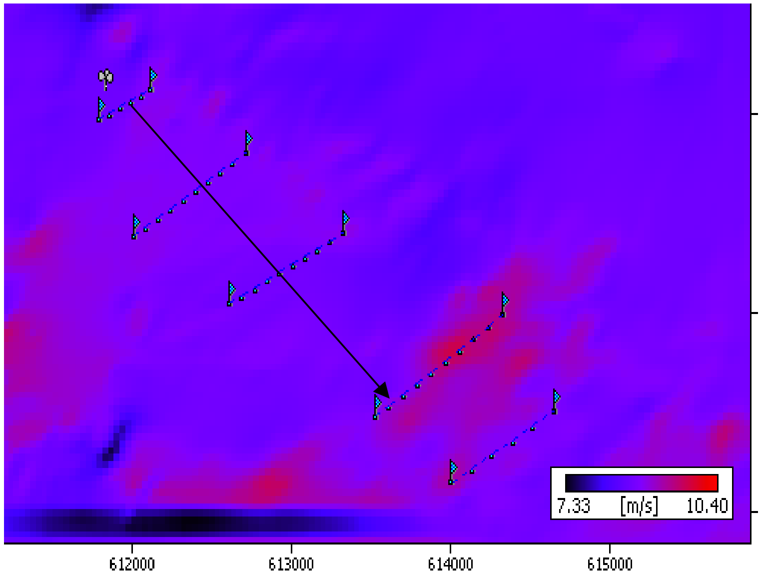
Data courtesy CENER

Complex terrain - Wind farm terrain effects

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

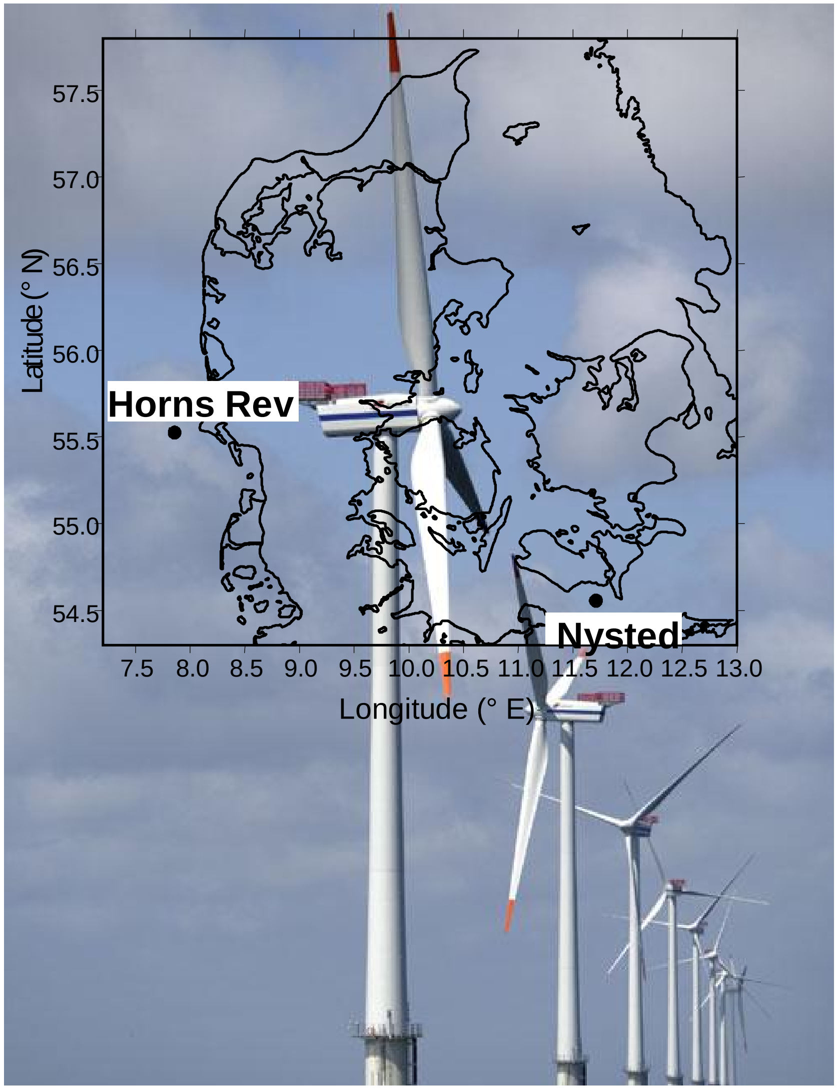
- An example at 8 m/s, direction 325º
- Modelling in WAsP Engineering
- Terrain induced ΔU~0.75 m/s (4th row)





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?



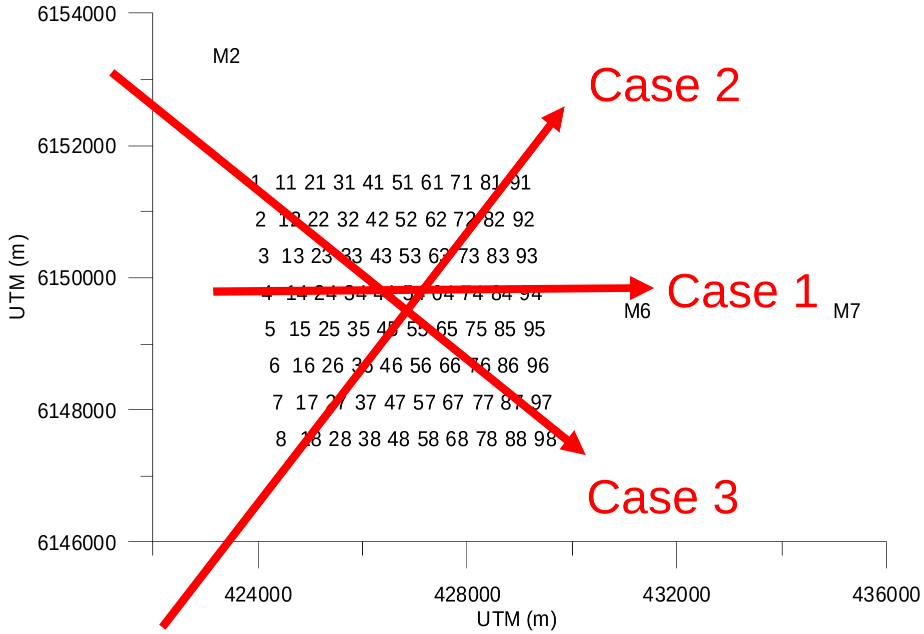
Horns Rev - Ensemble statistics

Averages

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

First set

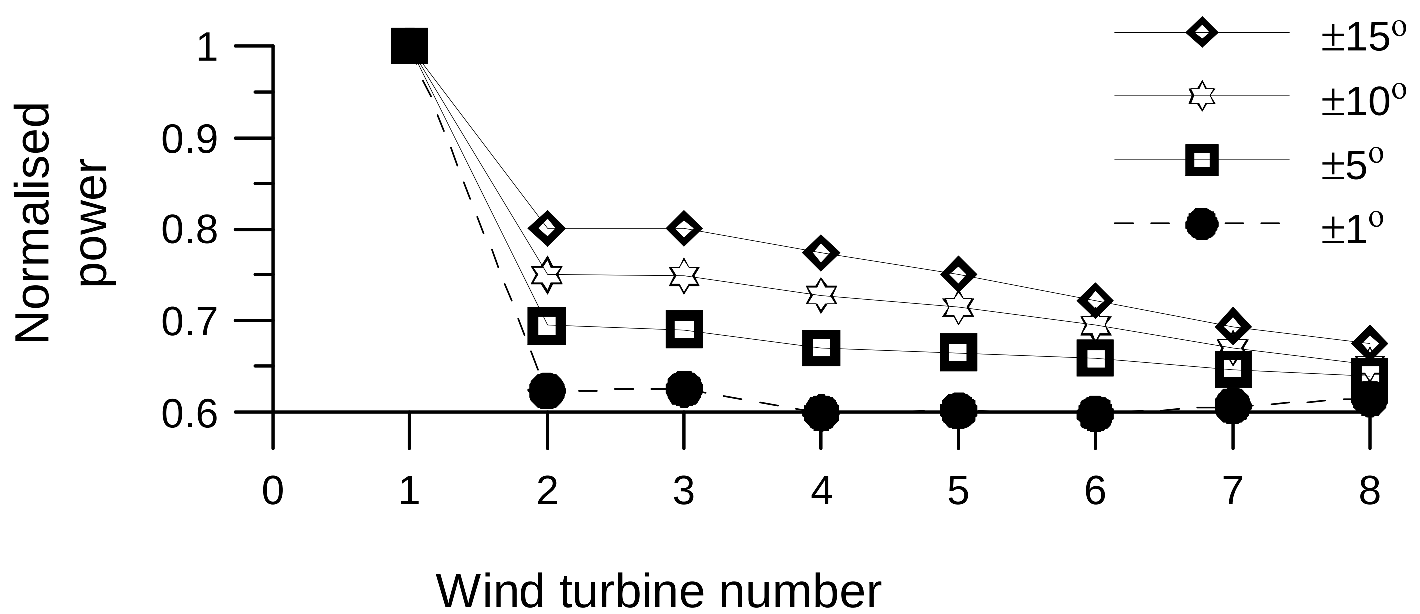
- Direct down or across rows
- Different wake widths



Measurements at Horns Rev

Measurements directly down the row

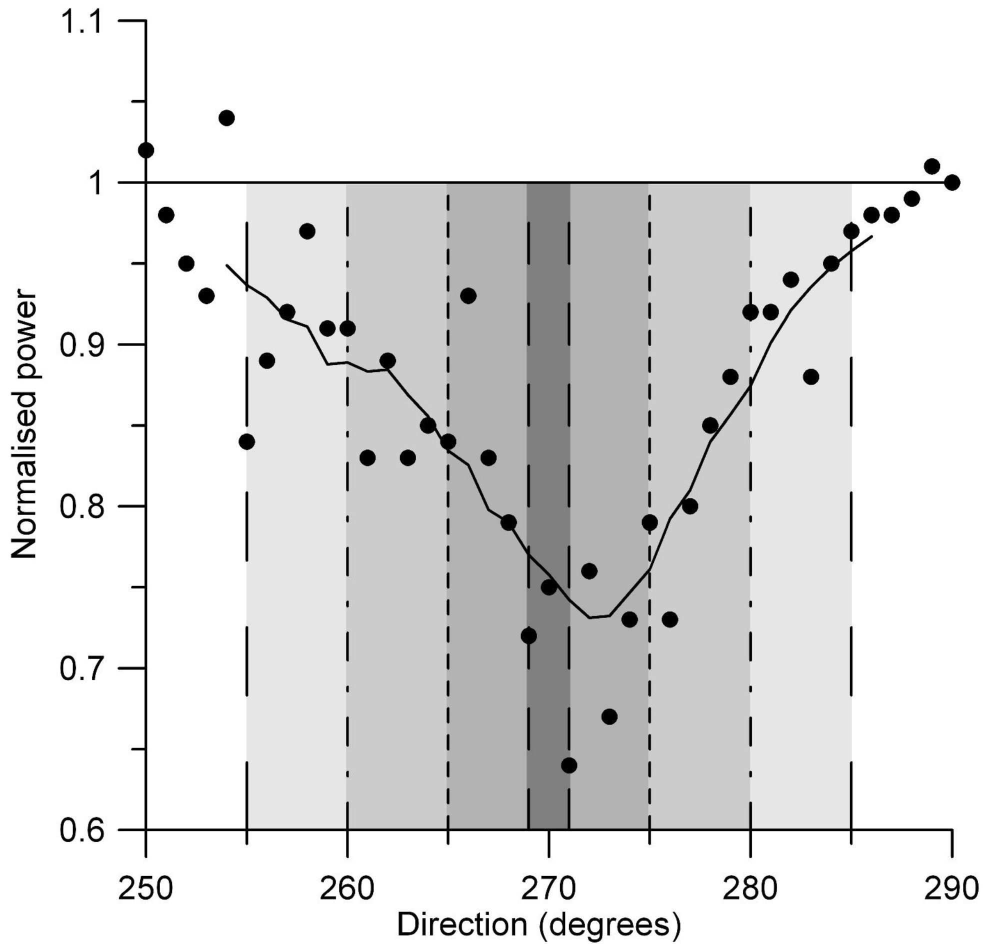
- Case 1 (7D)
- Normalised power
- U at first turbine 8.0±0.5 m/s



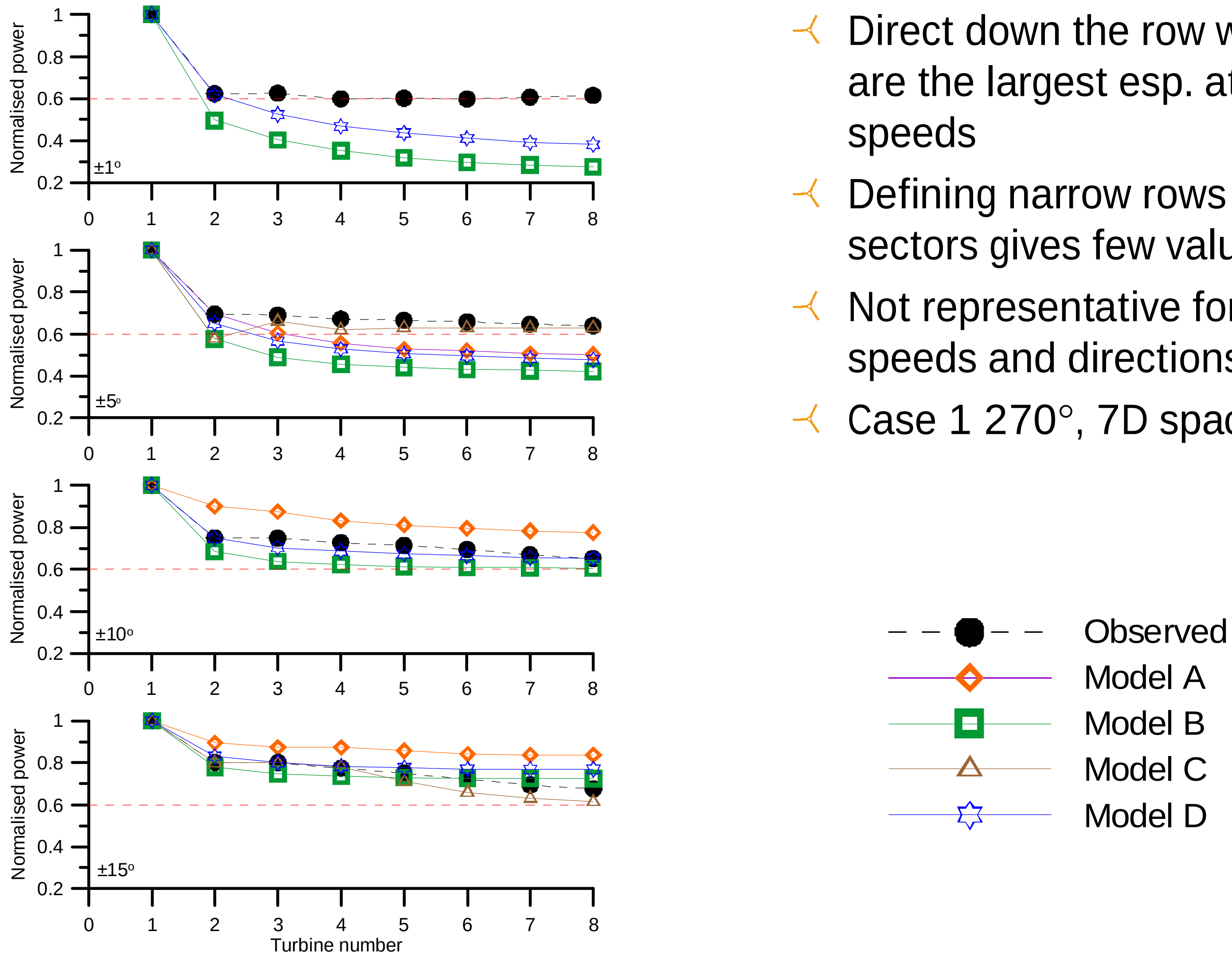
Data courtesy DTU

Wake width

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



Horns Rev case studies - 7D spacing



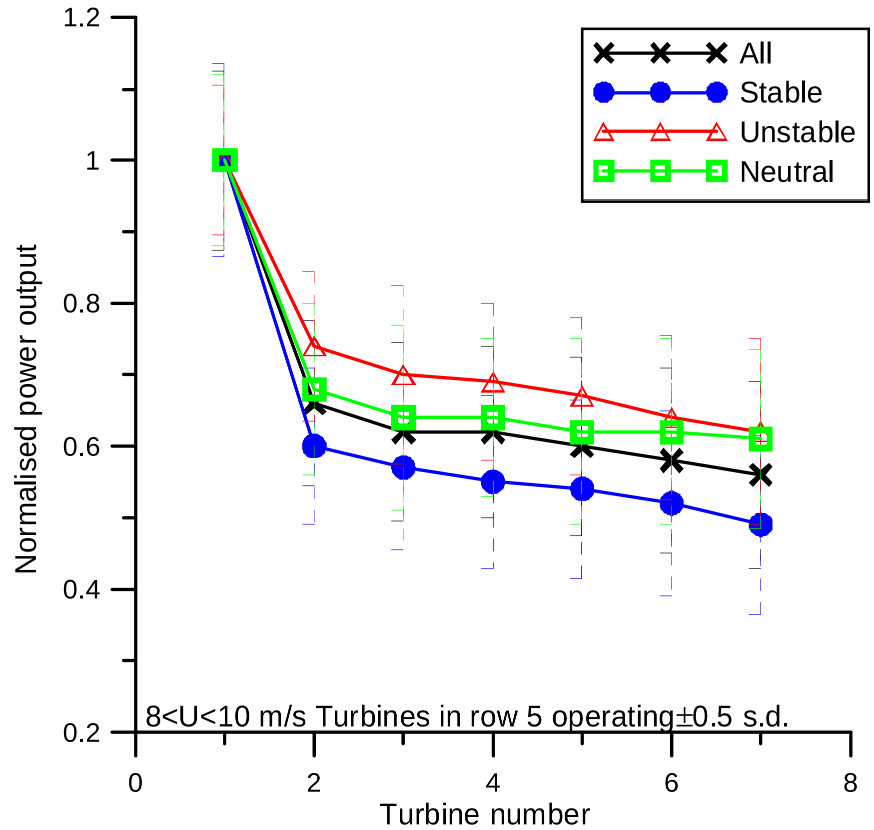
- Direct down the row wake losses are the largest esp. at low wind speeds
- Defining narrow rows and wind sectors gives few values
- Not representative for all wind speeds and directions
- Case 1 270°, 7D spacing

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

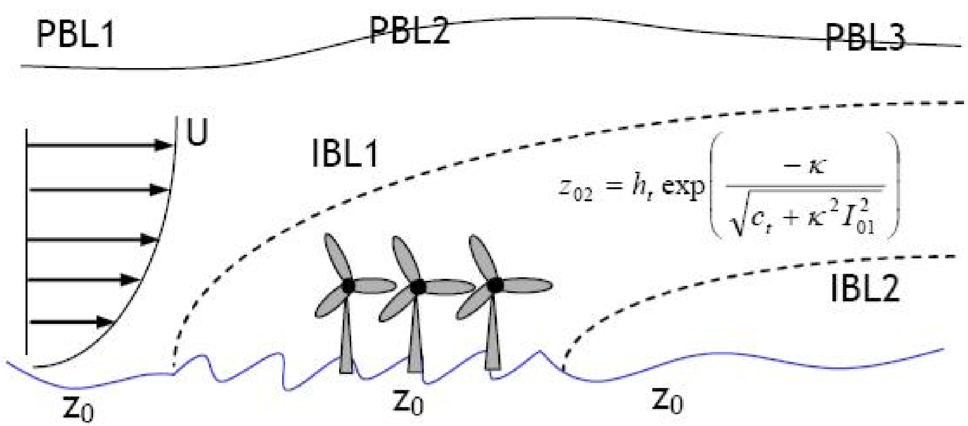
- Assess optimal spacing between wind farms

Modelling

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

Data

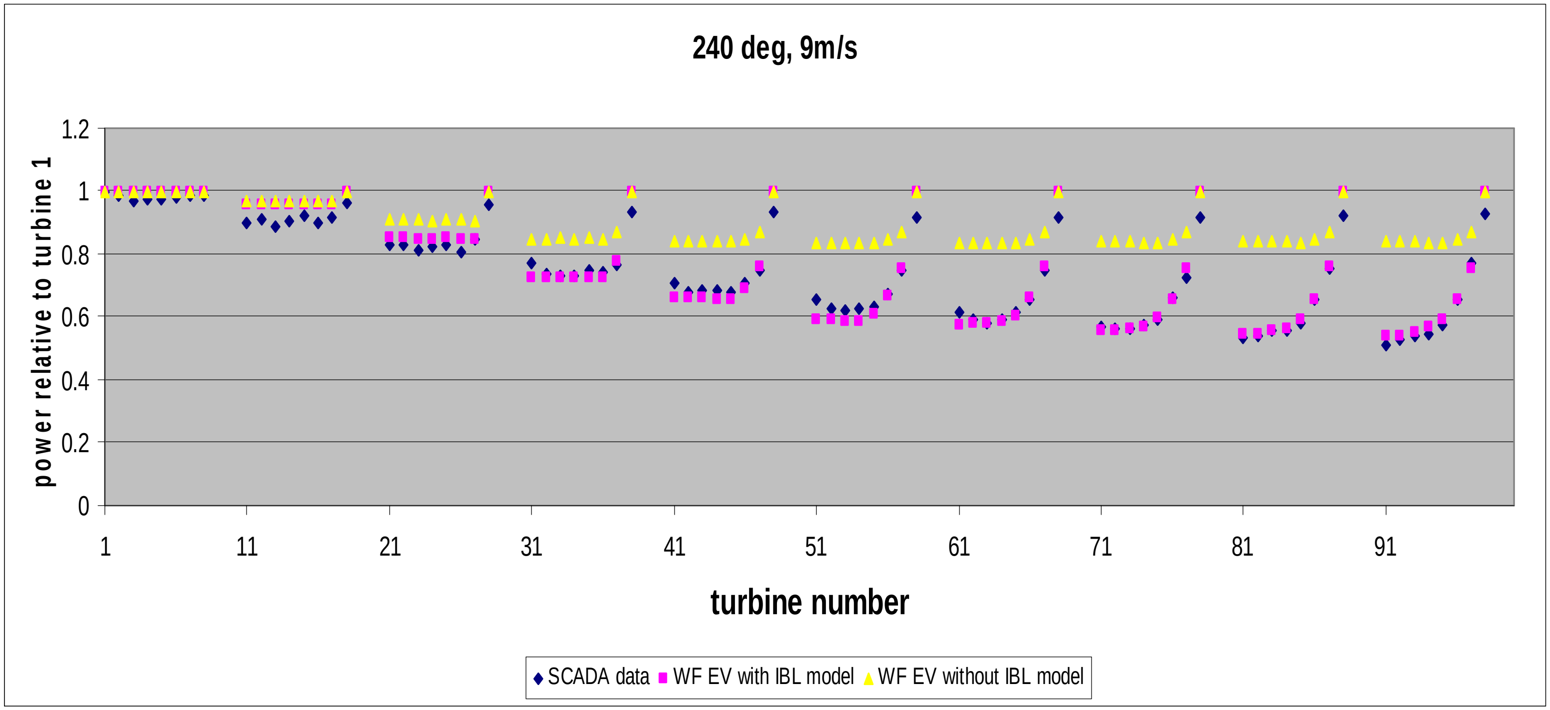
- Horns Rev/Nysted –both have downstream masts



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 el. 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