Wake model evaluation in the UpWind and POW'WOW projects

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

Outline

1. Current wake issues
2. Wake data/POW'WOW project
3. Modelling wakes/Upwind project
4. Future

Wind turbine wake issues

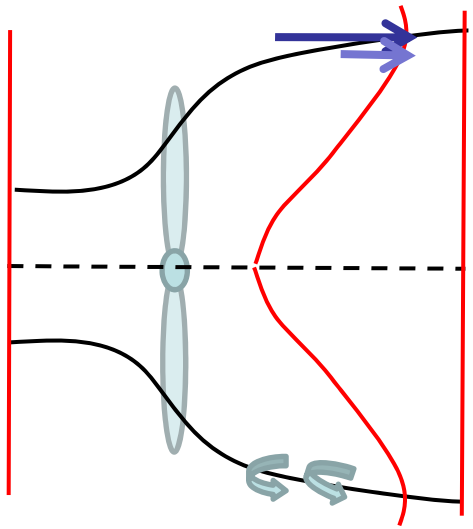
Problems

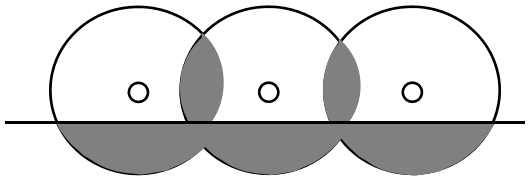
1. Preliminary analysis of wake power losses in large offshore wind farms larger than expected. Amended but high uncertainty.
2. First large wind farms on land being built
3. Resources and wakes very difficult to model in compex terrain

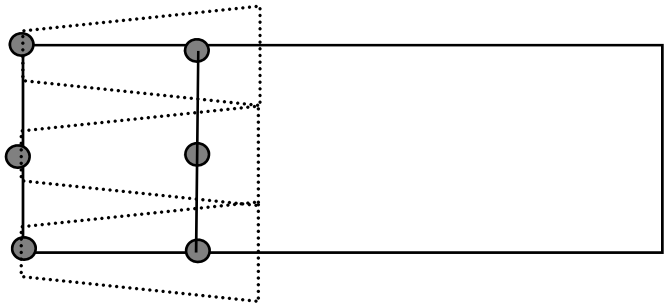
Solutions

1. New parameters and/or next generation of wake models able to account for ‘deep array’ effect
2. Use of CFD to model flow in complex terrain

Wake prediction





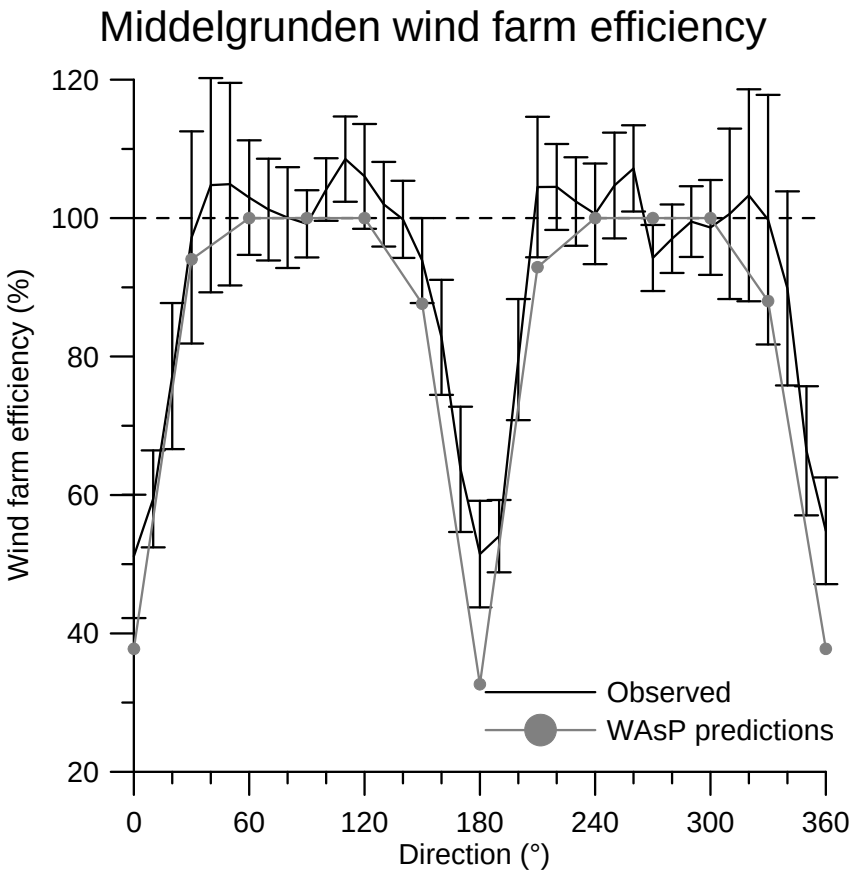


- Wake recovery depends on many factors:
  - Environment - Wind speed, turbulence, atm. stratification
  - Turbine type – Pitch, stall, thrust coefficient, hub-height
- Individual wakes
  - Impact ground
  - Combine laterally
  - Combine downwind

  } depends on spacing
- Multiple wakes
  - Continue to interact with each other and the environment

Wind farm data

- Data from small /research wind farms have been made available e.g. Vindeby, Blyth, Middelgrunden
- Relatively few large wind farms operating and these are commercial
- SCADA data complex/time consuming to process and understand
- A bottleneck to progress in developing new wind farm models



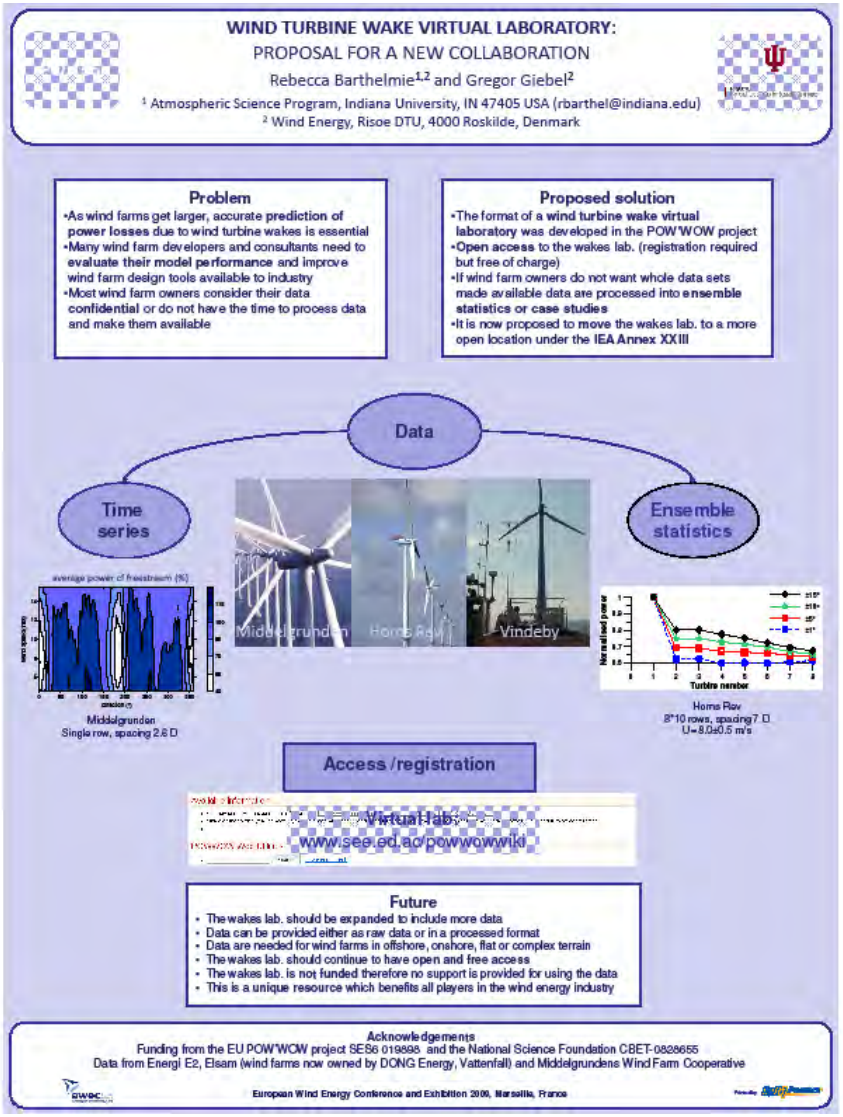
Barthelmie, 2007, Wind Energy

POW'WOW project

- POW'WOW: wind, waves, wakes & short-term forecasting
- In agreement with data owners some wind farm data have been made available
- Access is open and free (registration necessary)
- Offshore wake data from
  - Vindeby
  - Middelgrunden
  - Horns Rev
  - Nysted (in proc)
- Data processed into case studies for Horns Rev, Nysted (performance remains confidential)

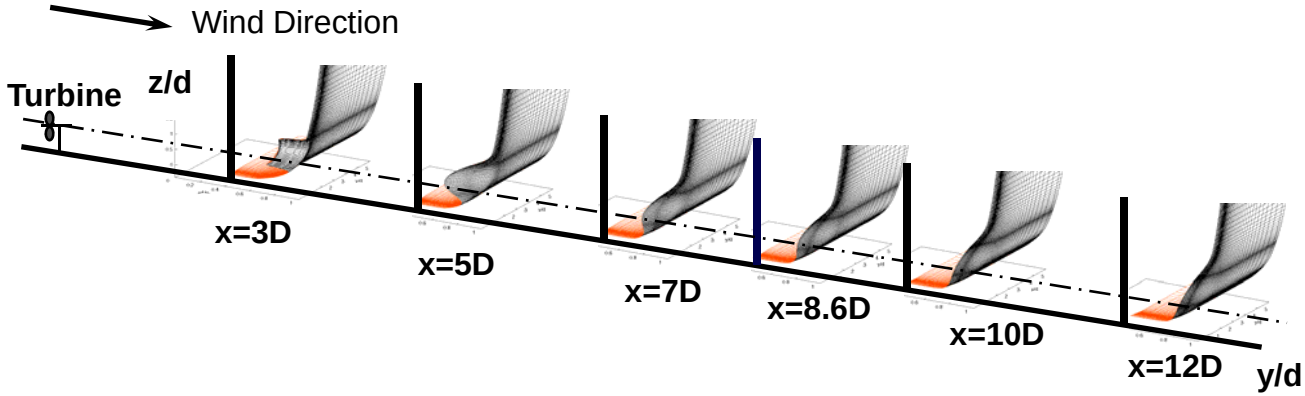
What happens after POW'WOW?

- Wakes wiki should be moved to a more permanent location
  - Needs a more user-friendly format
  - More publicity for wider useage
  - More international participation
- Suggestion is to transfer it to the IEA
- Major issue is no support for documentation and help



UPwind project

- Upwind project (www.upwind.eu)
  - Funded by EU, 40 partners (research & industry), led by Risoe DTU
  - Design of very large wind turbines (8-10MW), both onshore and offshore
- Presentation here is from WP8
  - Improving wake models

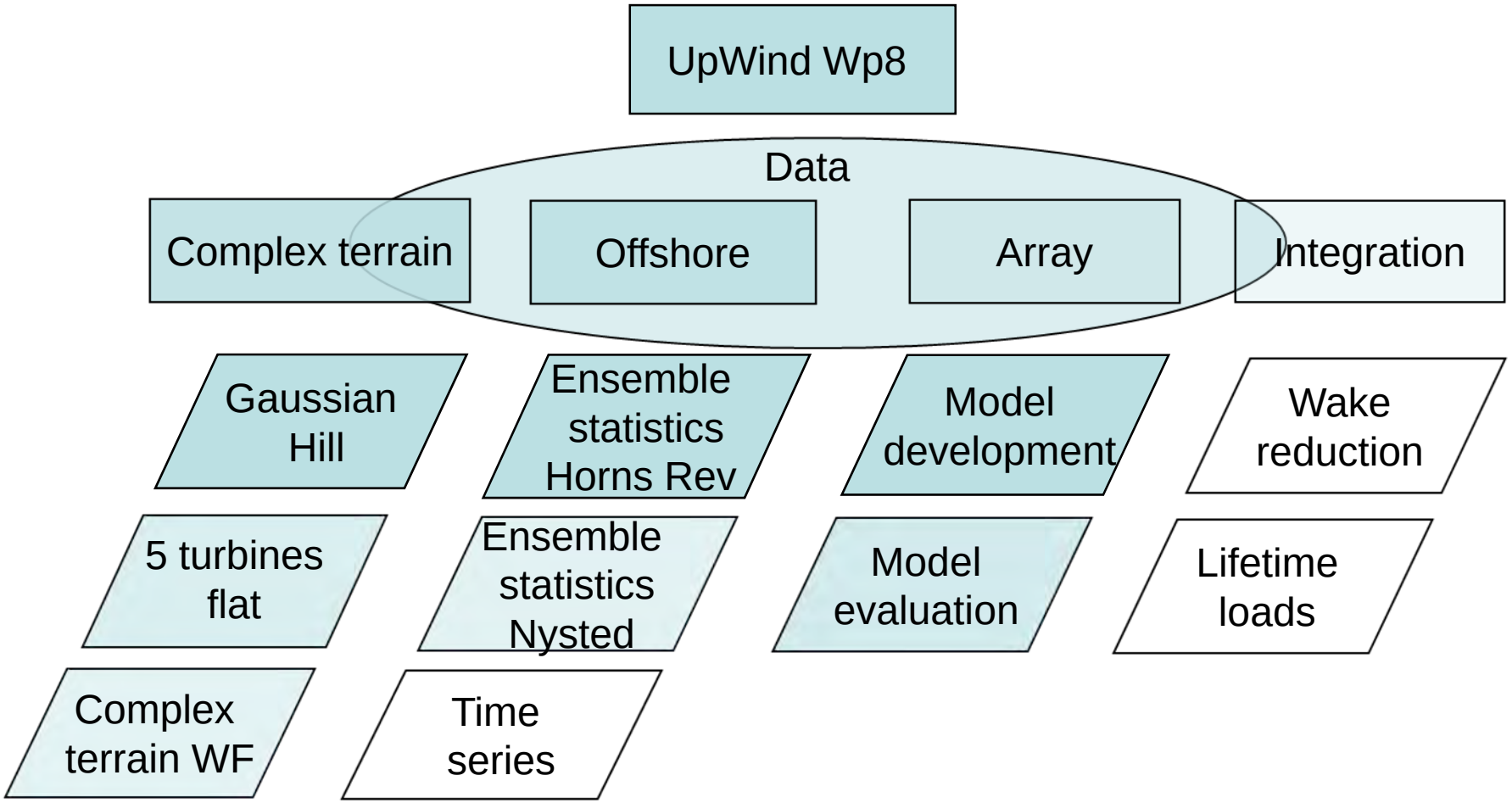


K. Rados, NTUA

Wake models

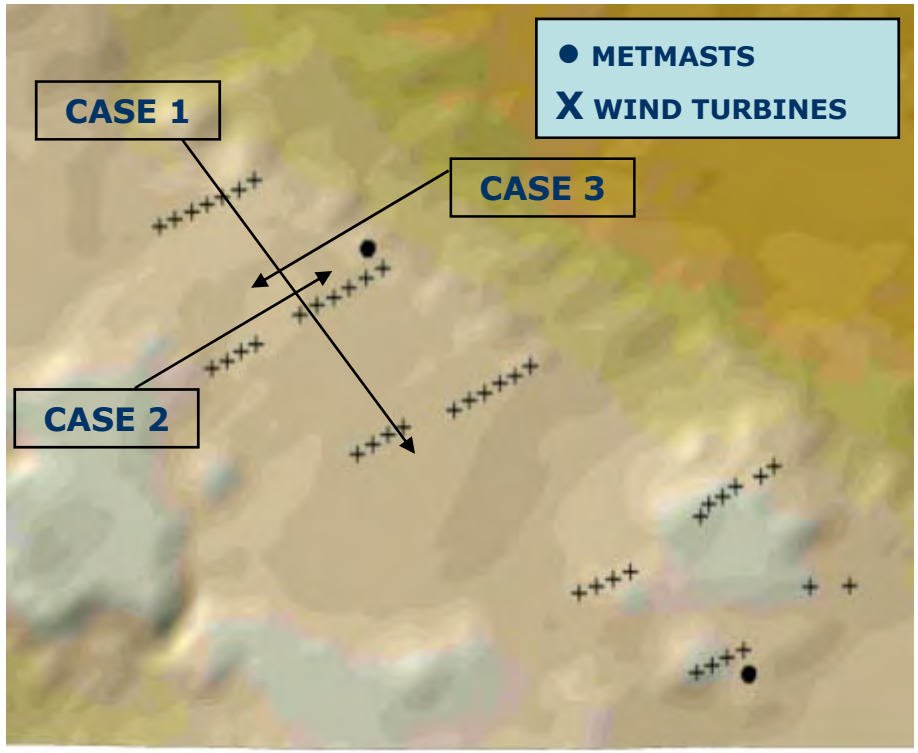
Name	Company	Type	Commercial/ Research
WAsP	Risø DTU	Engineering	C
FLaP	Oldenburg	Ainslie	R
Windfarmer	GH	Ainslie	C
“Canopy”	Risø DTU	Under development	R
Wakefarm	ECN	Parabolised CFD	C/R
CENER Fluent	CENER	CFD	R
NS FLow	CRES	CFD	R
NTUA	NTUA	CFD	R

Structure of the EU funded UPwind project WP8



Complex Terrain

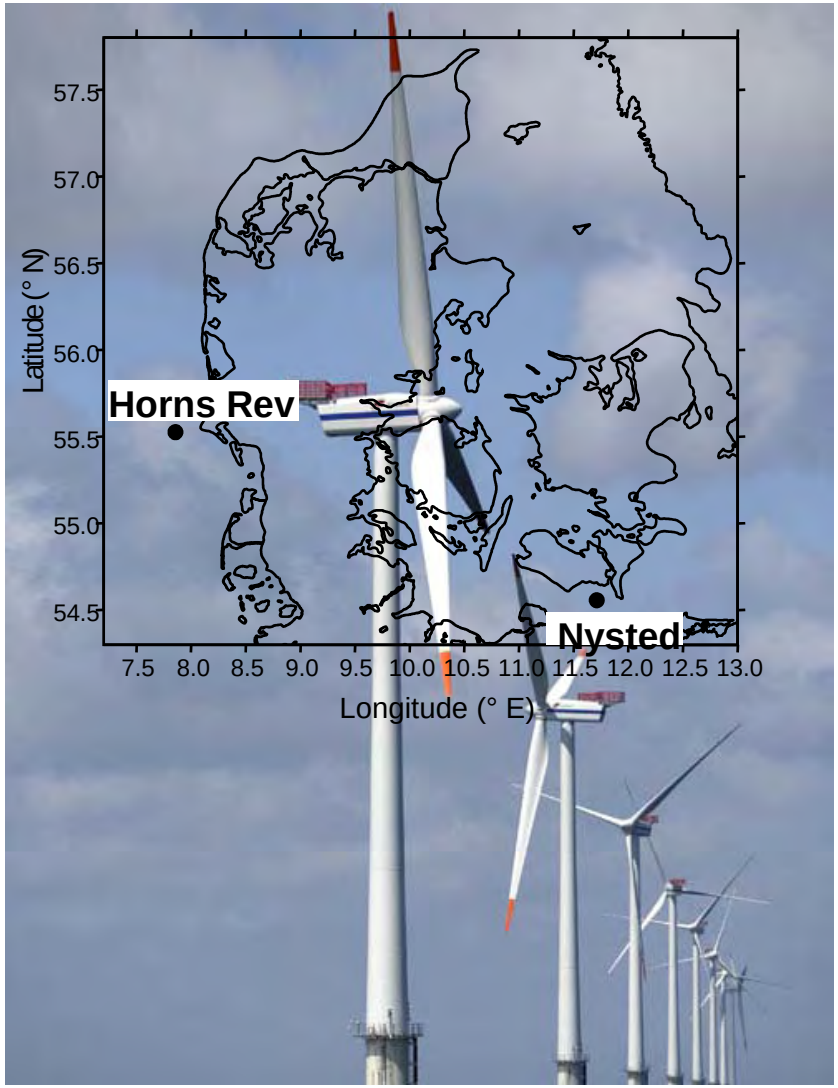
1. Evaluation of CFD performance for single wind turbine on Gaussian Hill
   - CRES CFD, CENER Fluent, RISOE WAsP
   - Test this
   - Minor discrepancies CFD attributed to surface parameterisation
2. Evaluation of CFD performance for multiple wakes
   - Five research turbines, tall met mast in flat terrain
3. Three cases in moderate complex terrain
   - 43 WTs x 700 kW
   - Met masts WS & WD
   - 1.5D or 13D spacing
   - WT Nacelle Power WS & WD



Data courtesy CENER

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?



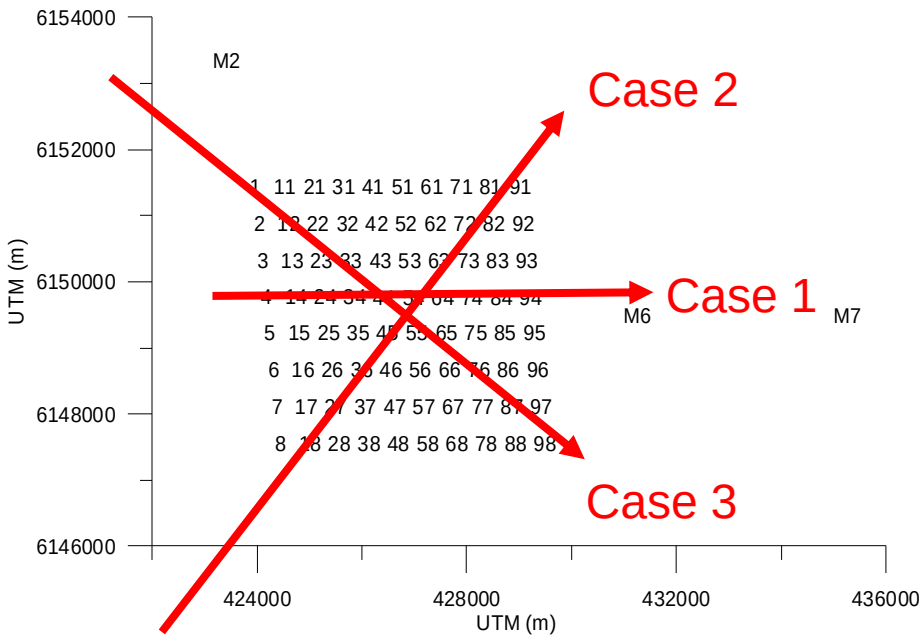
Horns Rev - Ensemble statistics

Averages

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

First set

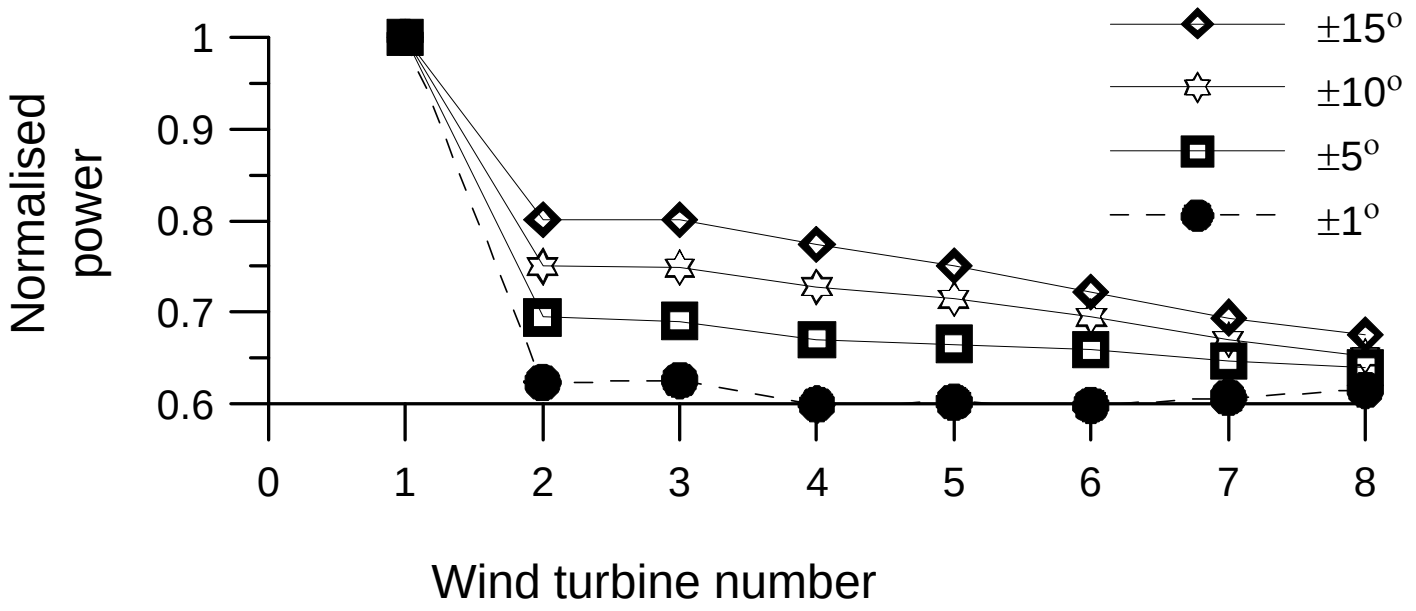
- Direct down or across rows
- Different wake widths



Measurements at Horns Rev

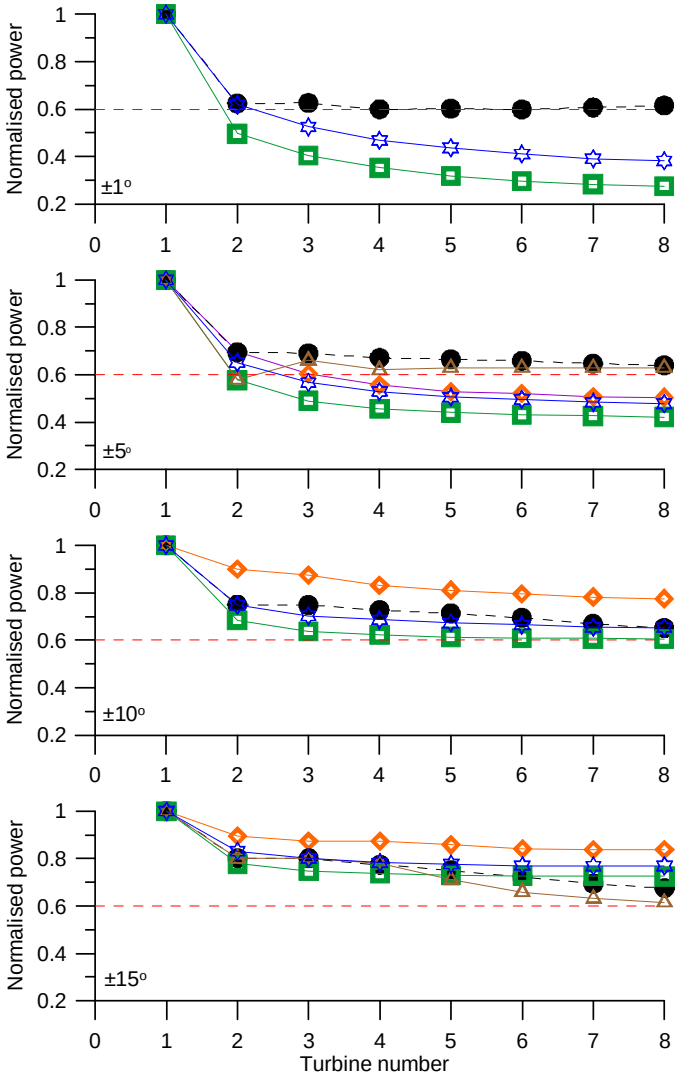
Measurements directly down the row

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

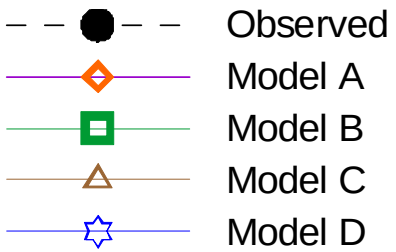


Data courtesy DTU

Horns Rev case studies - 7D spacing



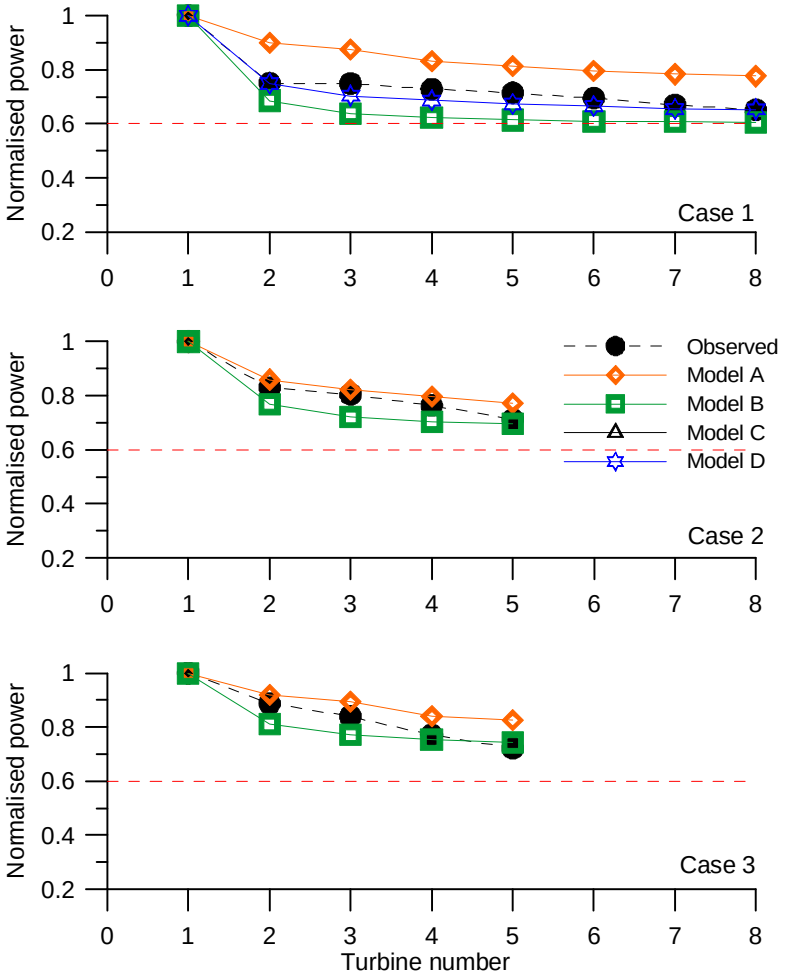
- Direct down the row wake losses are the largest esp. at low wind speeds
- Defining narrow rows and wind sectors gives few values
- Not representative for all wind speeds and directions
- Case 1 270°, 7D spacing



Model results from
Barthelmie et al. EWEC 2008

8±0.5 m/s

Horns Rev case studies – Different spacing



Model results from Barthelmie et al. EWEC 2008

Three cases 8±0.5 m/s

- Case 1 7 D
- Case 2 9.4 D
- Case 3 10.5 D

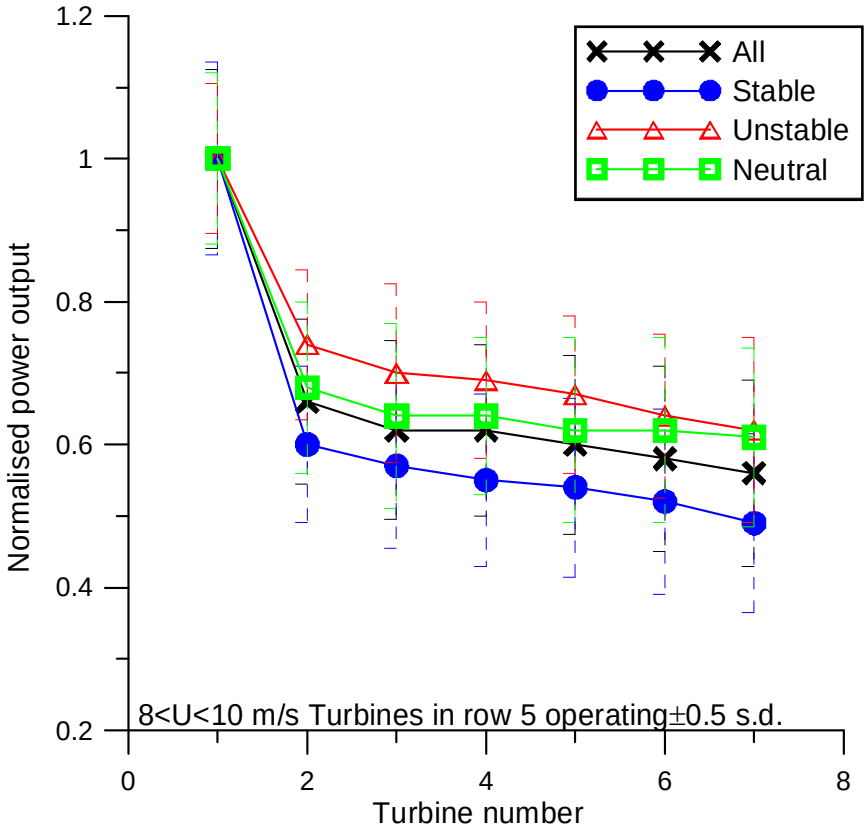
As spacing increases:

- Initial drop is reduced
- Power goes on decreasing in row
- Beyond 8 turbines ??

Nysted

Data from Nysted

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



Results from Barthelmie et al. European Offshore Wind 2007

Array effects - Plan

Objective

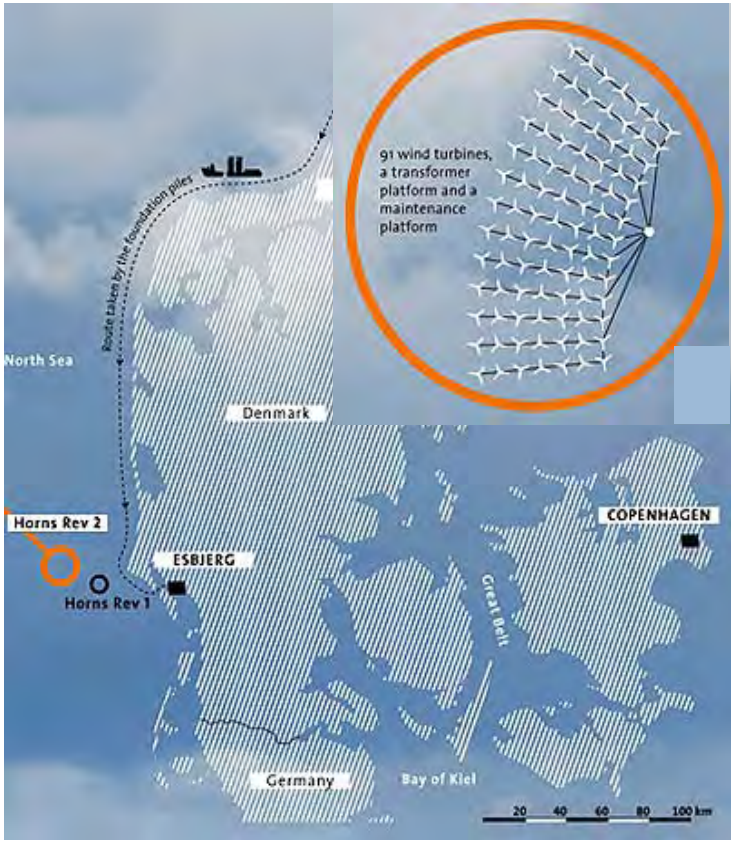
- Assess optimal spacing between wind farm clusters e.g. Horns Rev, Horns Rev 2

Modelling

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

Data

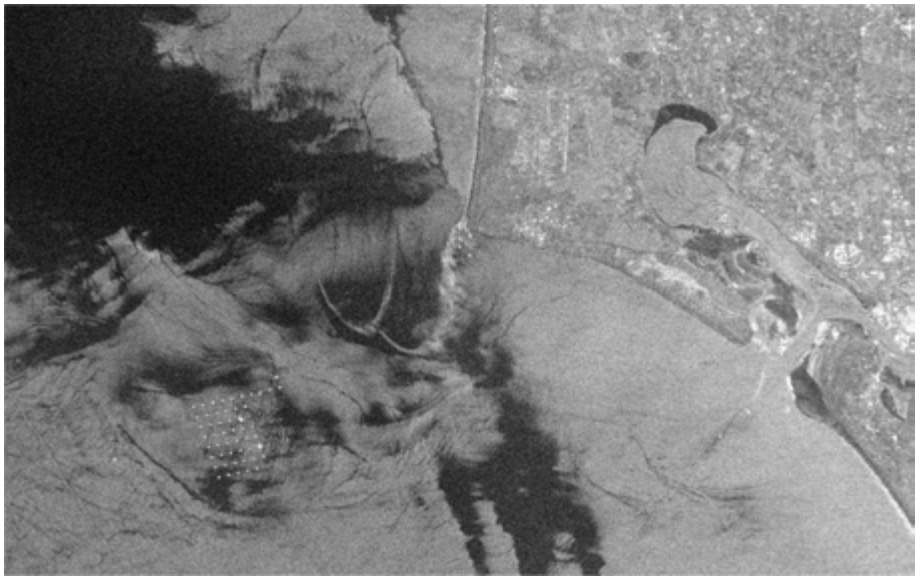
- Horns Rev/Nysted – both have downstream masts



Bilfinger Berger Magazine 2/2008

Array effects - results so far

- Current wind farm models don't capture array effects
- 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 ~5 km of wind farm end
- Agrees with satellite analysis
- Further recovery over ~20 km
- More: Frandsen et el. EWEA 2008/Risø-R-1615



Satellite view of Horns Rev wind farm
(C.B. Hasager and M.B. Christiansen 2007)

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