

Wake model evaluation in the UpWind and POW'WOW projects

R.J. Barthelmie, Indiana UniversityUSA/Risoe DTU DK

K. Hansen, DTU Denmark

S.T. Frandsen, O. Rathmann, RISOE DTU Denmark

E. Politis, J. Prospathopoulos, CRES, Greece

G. Schepers ECN, Netherlands

K. Rados, NTUA, Greece

D. Cabezón CENER

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



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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

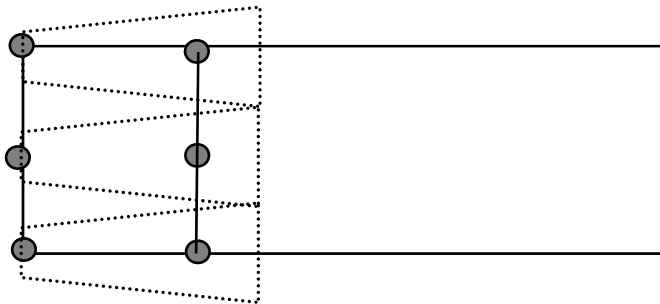
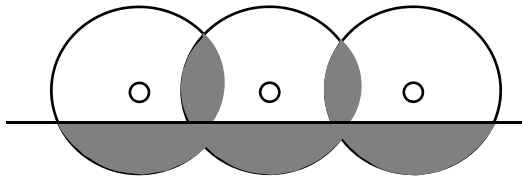
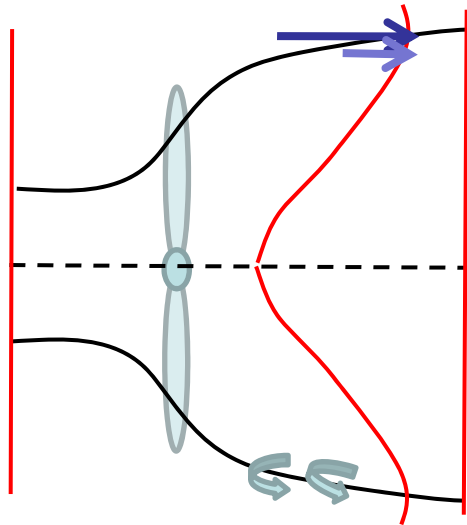
1. Preliminary analysis of wake power losses in large offshore wind farms larger than expected. Amended but high uncertainty.
2. First large wind farms on land being built
3. Resources and wakes very difficult to model in complex terrain

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



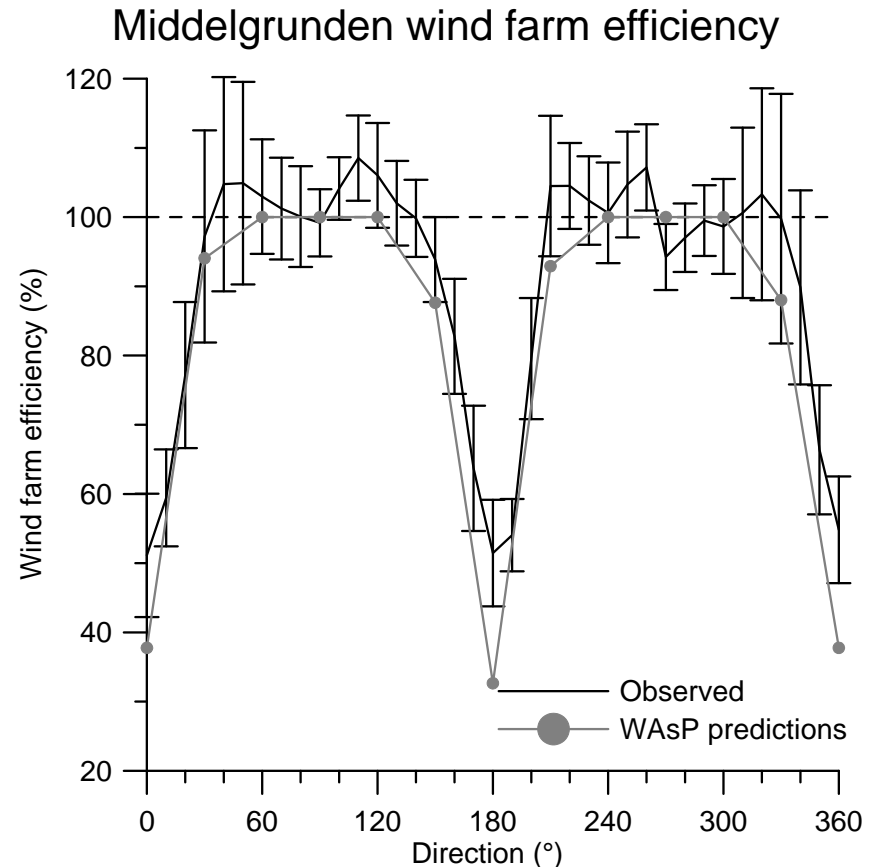
Wake prediction



- 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**)

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/twiki/bin/view.cgi/POWWOW>)
- Middelgrunden one year of power, yaw angle and wind speed data (see attachments below). Zipped power
- ...

POWWOW Web Utilities

- Search - [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

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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

**WIND TURBINE WAKE VIRTUAL LABORATORY:
PROPOSAL FOR A NEW COLLABORATION**

Rebecca Barthelme^{1,2} and Gregor Giebel²

¹ Atmospheric Science Program, Indiana University, IN 47405 USA (rbarthel@indiana.edu)
² Wind Energy, Risoe DTU, 4000 Roskilde, Denmark

Problem

- As wind farms get larger, accurate prediction of power losses due to wind turbine wakes is essential
- Many wind farm developers and consultants need to evaluate their model performance and improve wind farm design tools available to industry
- Most wind farm owners consider their data confidential or do not have the time to process data and make them available

Proposed solution

- The format of a wind turbine wake virtual laboratory was developed in the POW'WOW project
- Open access to the wakes lab. (registration required but free of charge)
- If wind farm owners do not want whole data sets made available data are processed into ensemble statistics or case studies
- It is now proposed to move the wakes lab. to a more open location under the IEA Annex XXIII

Data

Time series

average power of freestream (%)
distance (m)
Middelgrunden
Single row, spacing 2.6 D

Middelgrunden Horns Rev Vindeby

Ensemble statistics

Normalized power
Turbine number
Horns Rev
8*10 rows, spacing 7 D
U=8.0±0.5 m/s

Access / registration

Virtual Lab
www.seg.ed.ac.uk/powwow/wiki

Future

- The wakes lab. should be expanded to include more data
- Data can be provided either as raw data or in a processed format
- Data are needed for wind farms in offshore, onshore, flat or complex terrain
- The wakes lab. should continue to have open and free access
- The wakes lab. is not funded therefore no support is provided for using the data
- This is a unique resource which benefits all players in the wind energy industry

Acknowledgements

Funding from the EU POW'WOW project SES6 019085 and the National Science Foundation CBET-0828655
Data from Energi E2, Easam (wind farms now owned by DONG Energy, Vattenfall) and Middelgrundens Wind Farm Cooperative

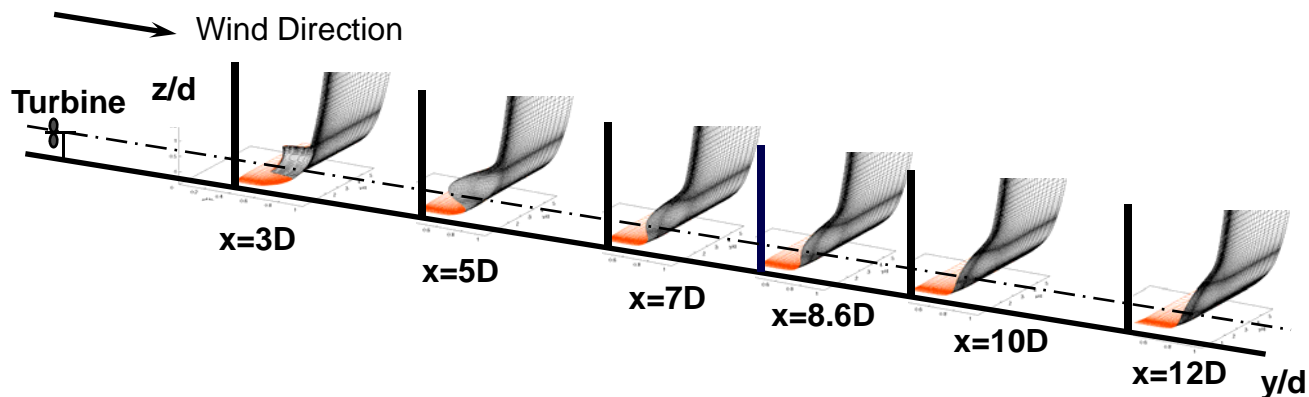
European Wind Energy Conference and Exhibition 2008, Warszawa, France

SIXTH FRAMEWORK PROGRAMME

UpWind

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

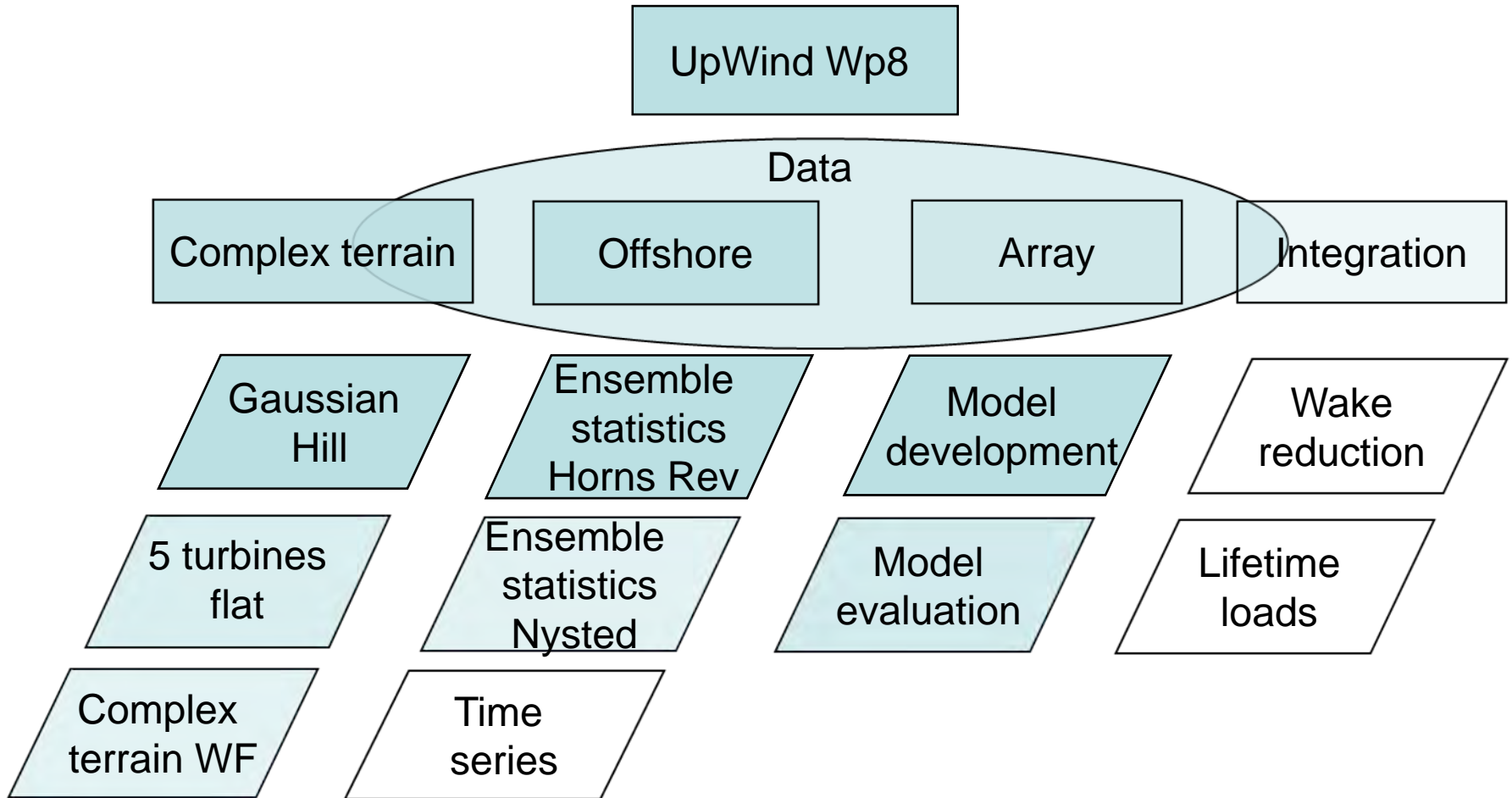


K. Rados, NTUA

Wake models

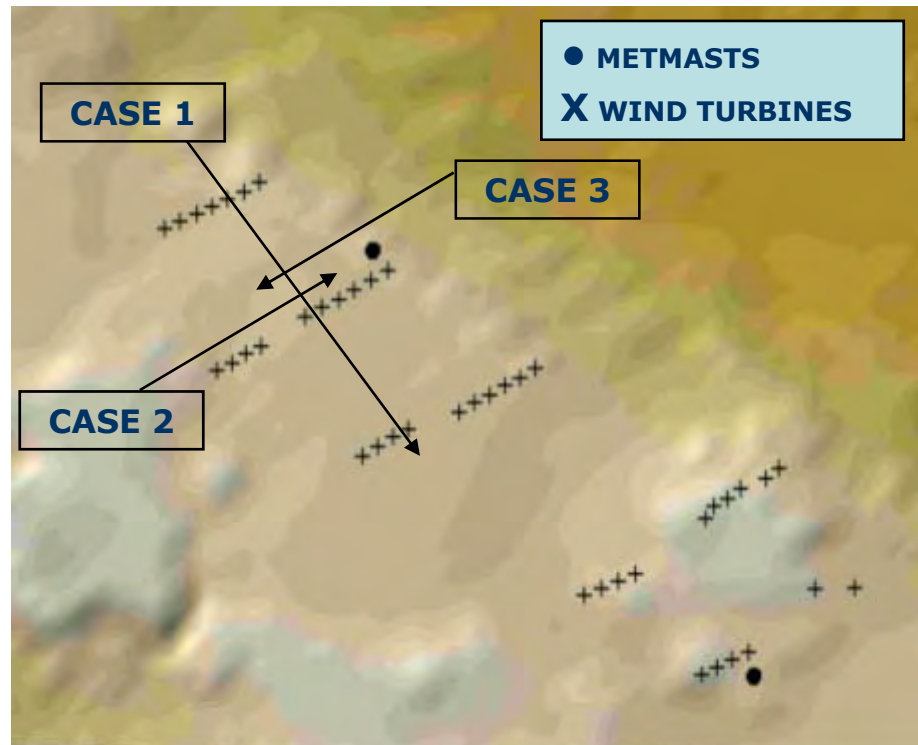
Name	Company	Type	Commercial/ Research
WAsP	Risø DTU	Engineering	C
FLaP	Oldenburg	Ainslie	R
Windfarmer	GH	Ainslie	C
“Canopy”	Risø DTU	Under development	R
Wakefarm	ECN	Parabolised CFD	C/R
CENER Fluent	CENER	CFD	R
NS FLOW	CRES	CFD	R
NTUA	NTUA	CFD	R

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

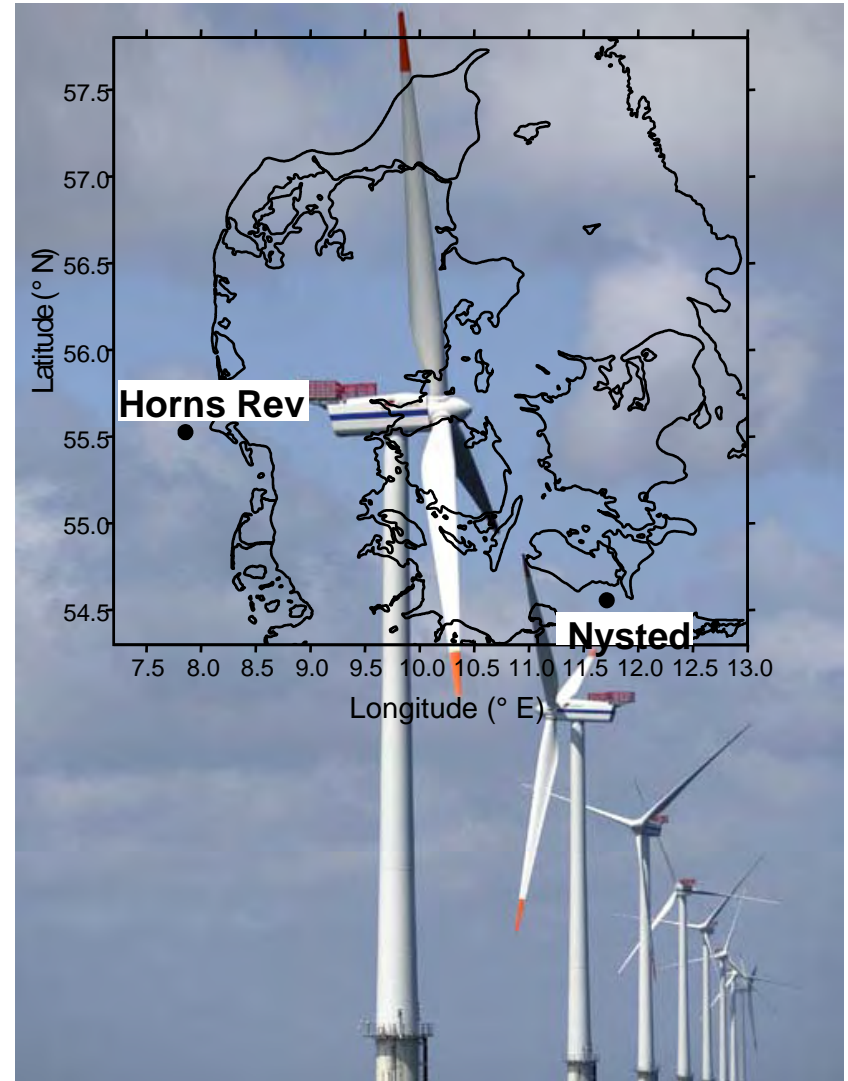
- ✎ 80 Vestas V80 2 MW turbines
- ✎ 8 by 10 grid, spacing 7 D
- ✎ 14 km from Danish west coast
- ✎ Power, yaw and status extracted from SCADA
- ✎ Reference period 10 min
- ✎ Met data M1,M6,M7

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?



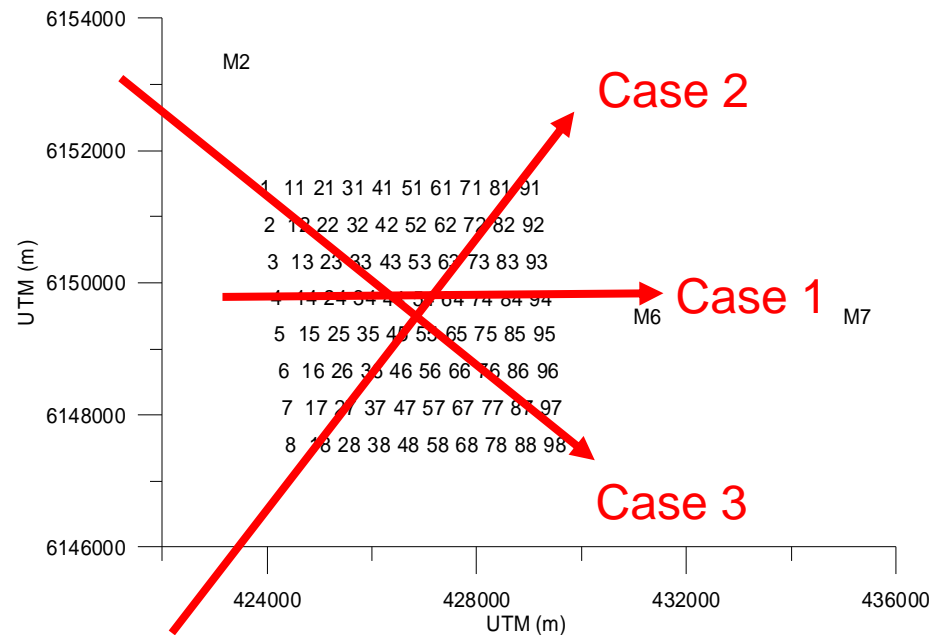
Horns Rev - Ensemble statistics

Averages

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

First set

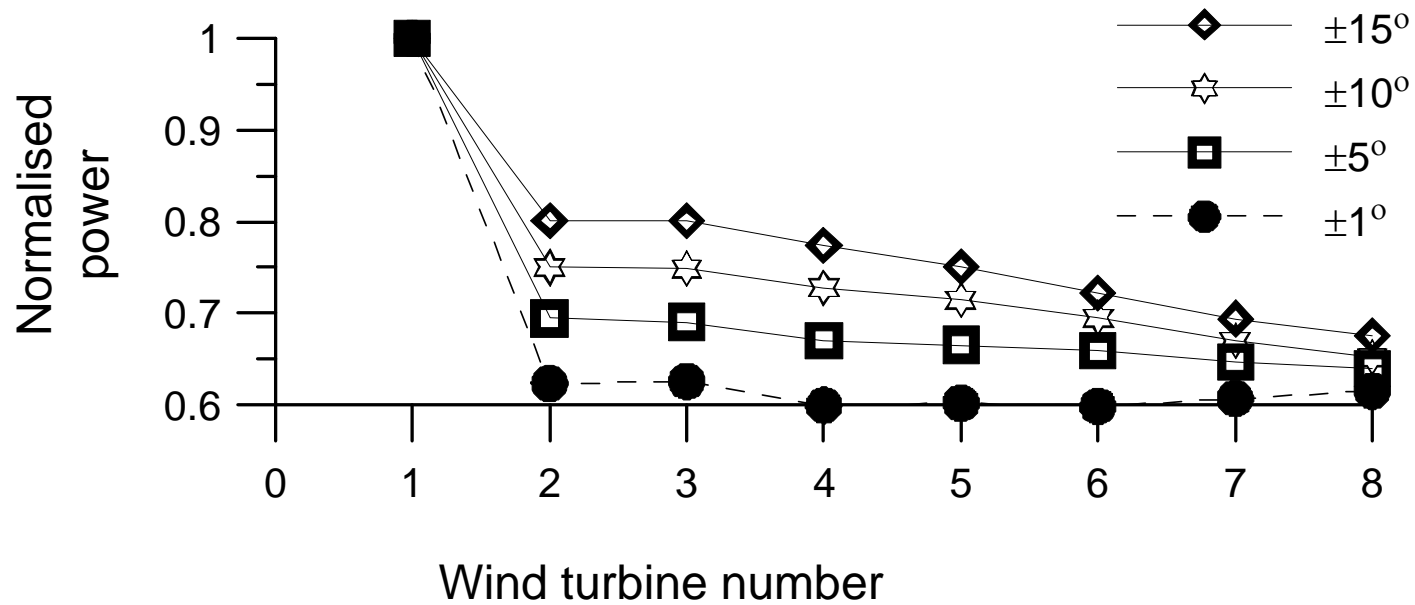
- ↘ Direct down or across rows
- ↘ Different wake widths



Measurements at Horns Rev

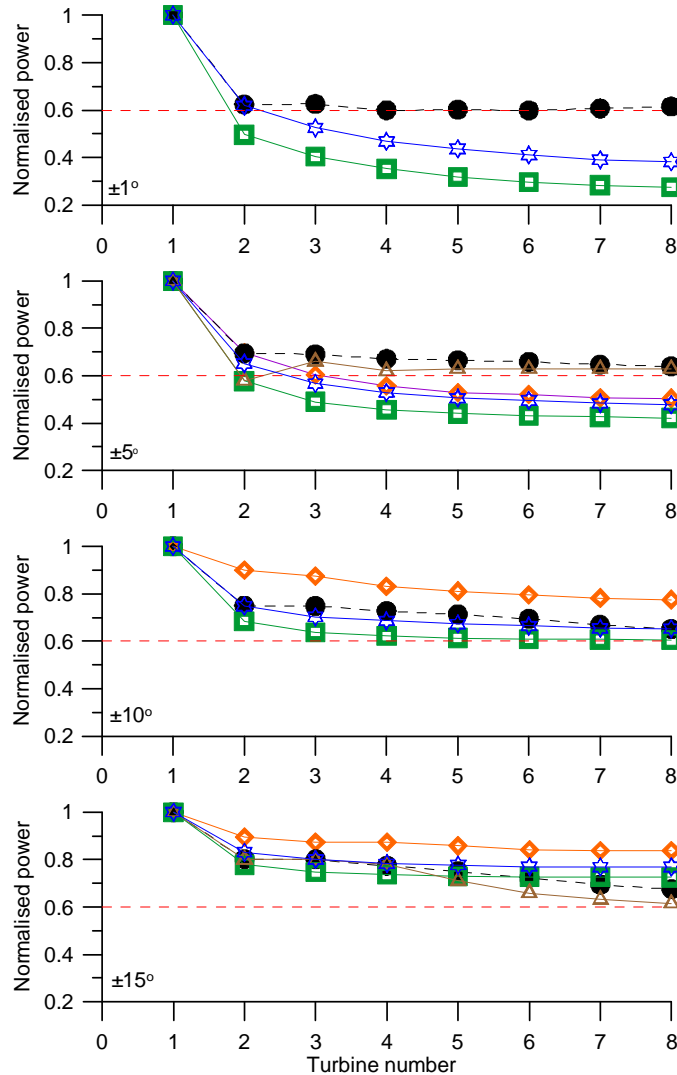
Measurements directly down the row

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

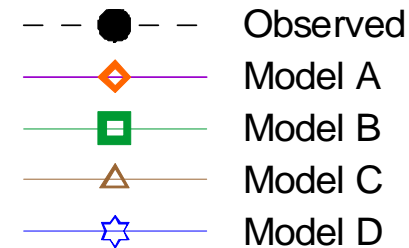


Data courtesy DTU

Horns Rev case studies - 7D spacing



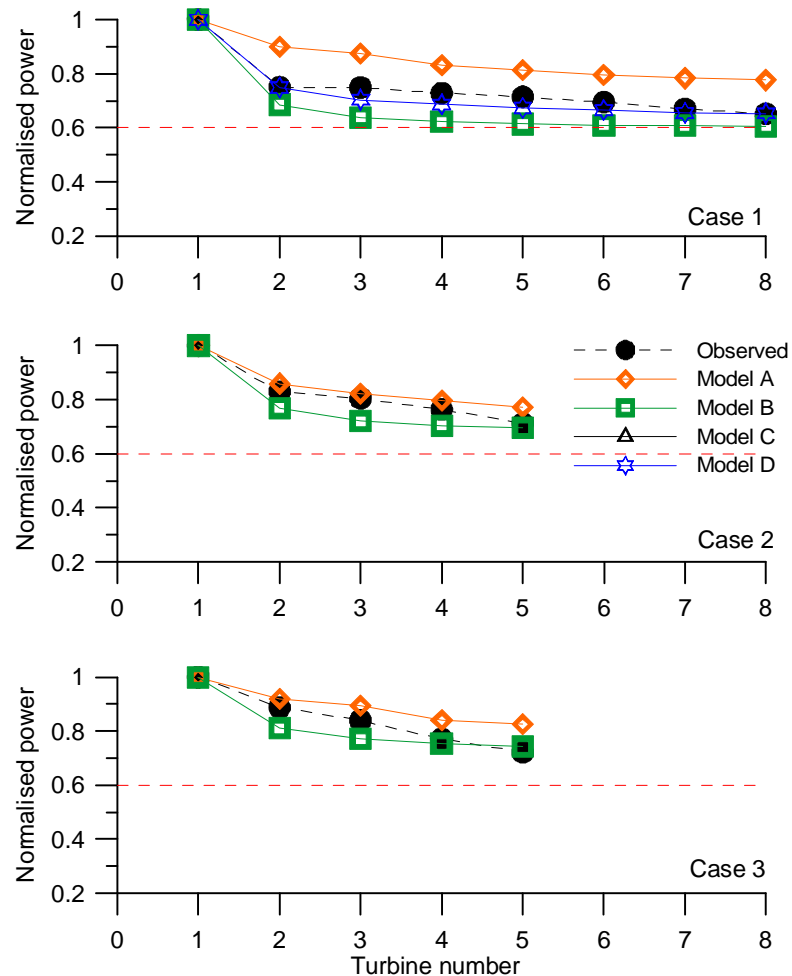
- ✎ Direct down the row wake losses are the largest esp. at low wind speeds
- ✎ Defining narrow rows and wind sectors gives few values
- ✎ Not representative for all wind speeds and directions
- ✎ Case 1 270° , 7D spacing



Model results from
Barthelmie et al. EWEC 2008

8 ± 0.5 m/s

Horns Rev case studies – Different spacing



Three cases 8 ± 0.5 m/s

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

As spacing increases:

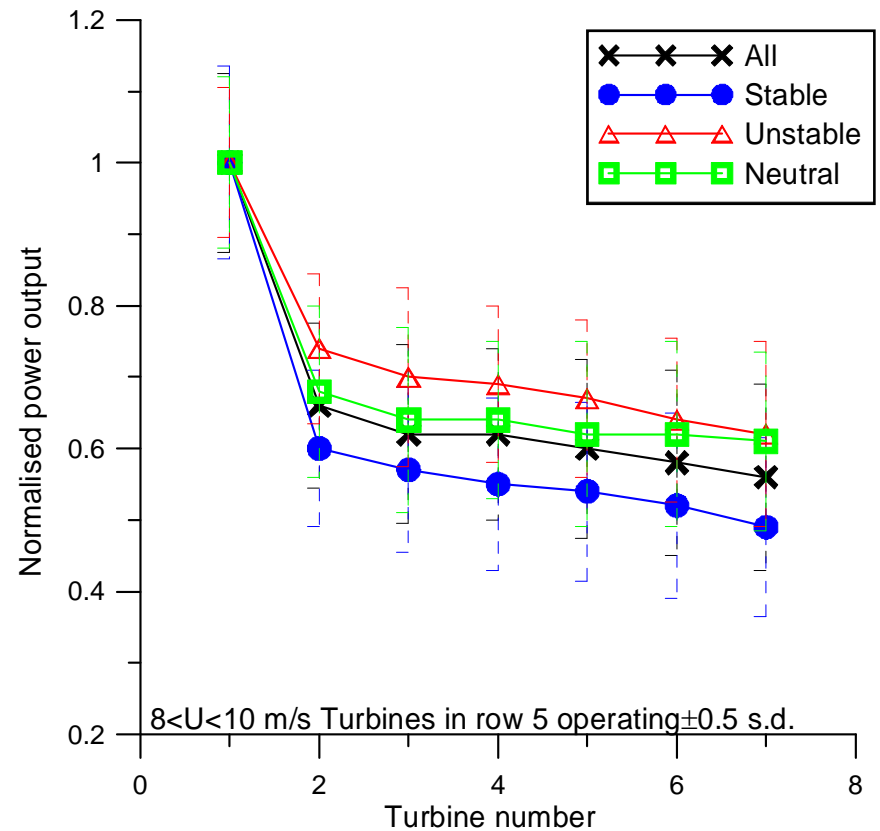
- Initial drop is reduced
- Power goes on decreasing in row
- Beyond 8 turbines ??

Model results from Barthelmie et al. EWEC 2008

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

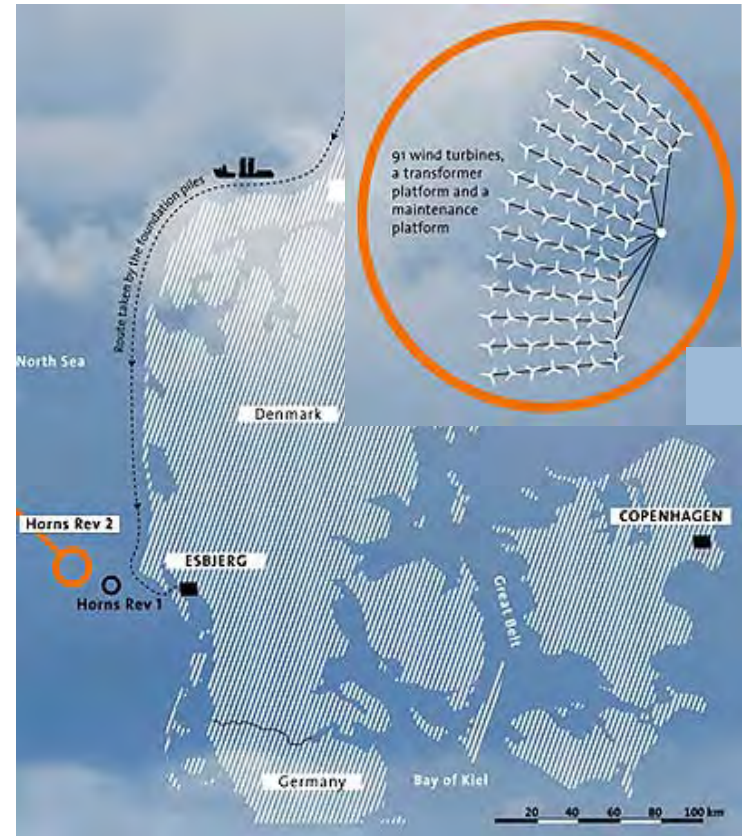
- Assess optimal spacing between wind farm clusters e.g. Horns Rev, Horns Rev 2

Modelling

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

Data

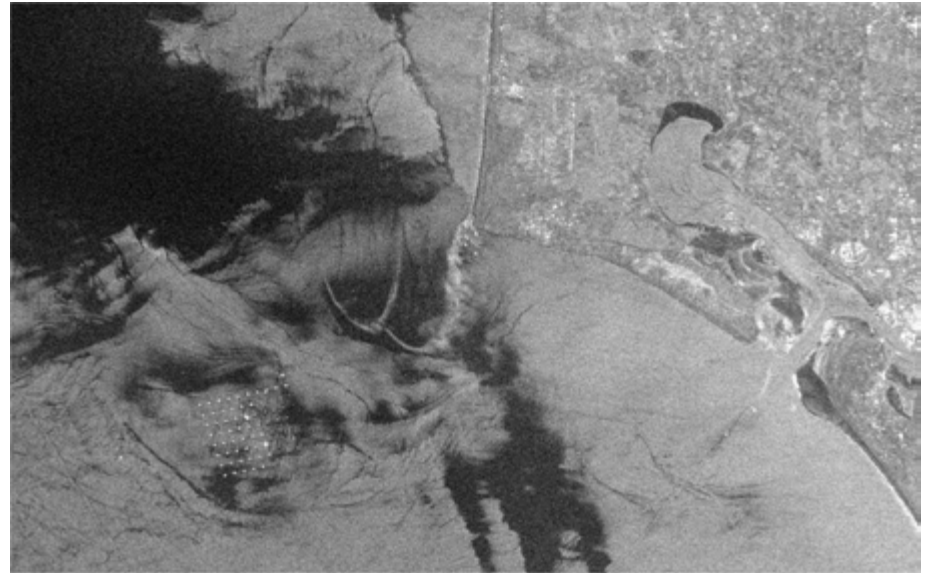
- Horns Rev/Nysted – both have downstream masts



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 $\sim 90\%$ occurs within ~ 5 km of wind farm end
- ↪ Agrees with satellite analysis
- ↪ Further recovery over ~ 20 km
- ↪ More: Frandsen et al. 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