OFFSHORE 2015 COPENHAGEN
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Wind farm wake verification

EERA DTOC
THE EUROPEAN ENERGY RESEARCH ALLIANCE
DESIGN TOOLS FOR OFFSHORE WIND FARM CLUSTER

Support by

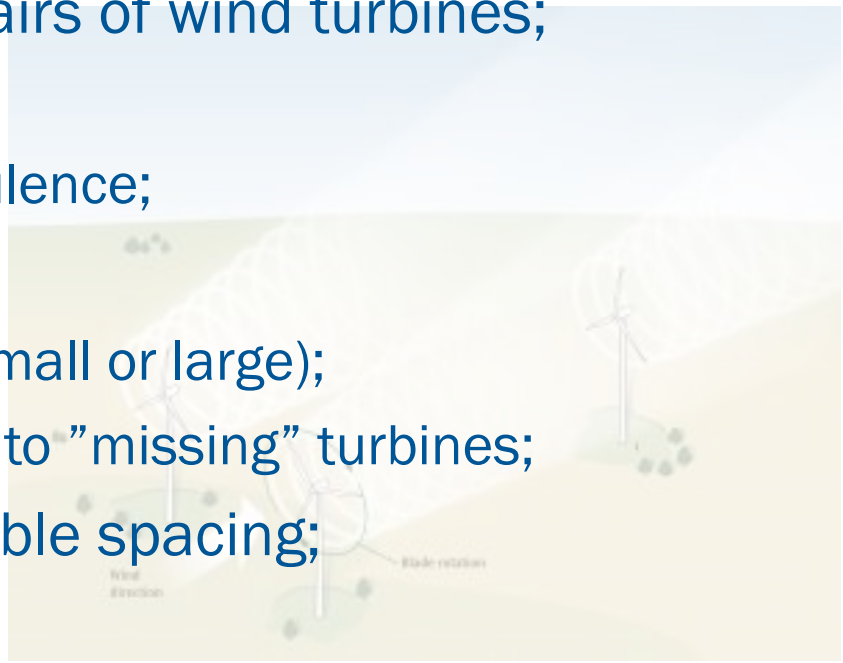
DTU
Kurt S. Hansen
Senior Scientist
DTU Wind Energy – Fluid Mechanics

Outline

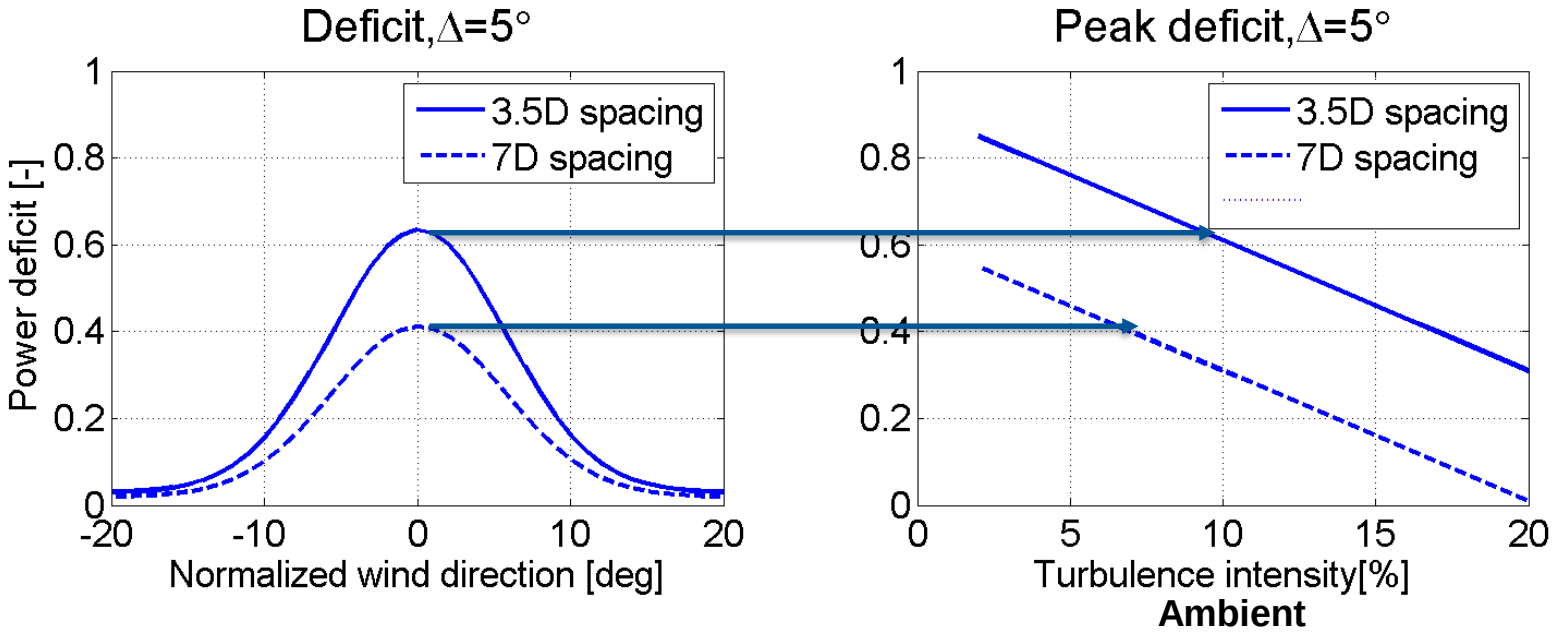
- Introduction wind turbine wakes;
- Participants & models;
- Results
  - Simple wakes and moderate spacing;
  - Wakes for small spacing and speed recovery;
  - Wakes for variable spacing
  - Wind farm clusters;
  - Wake behind a large wind farm;
- Discussion & acknowledgements;

Introduction wind turbine wakes

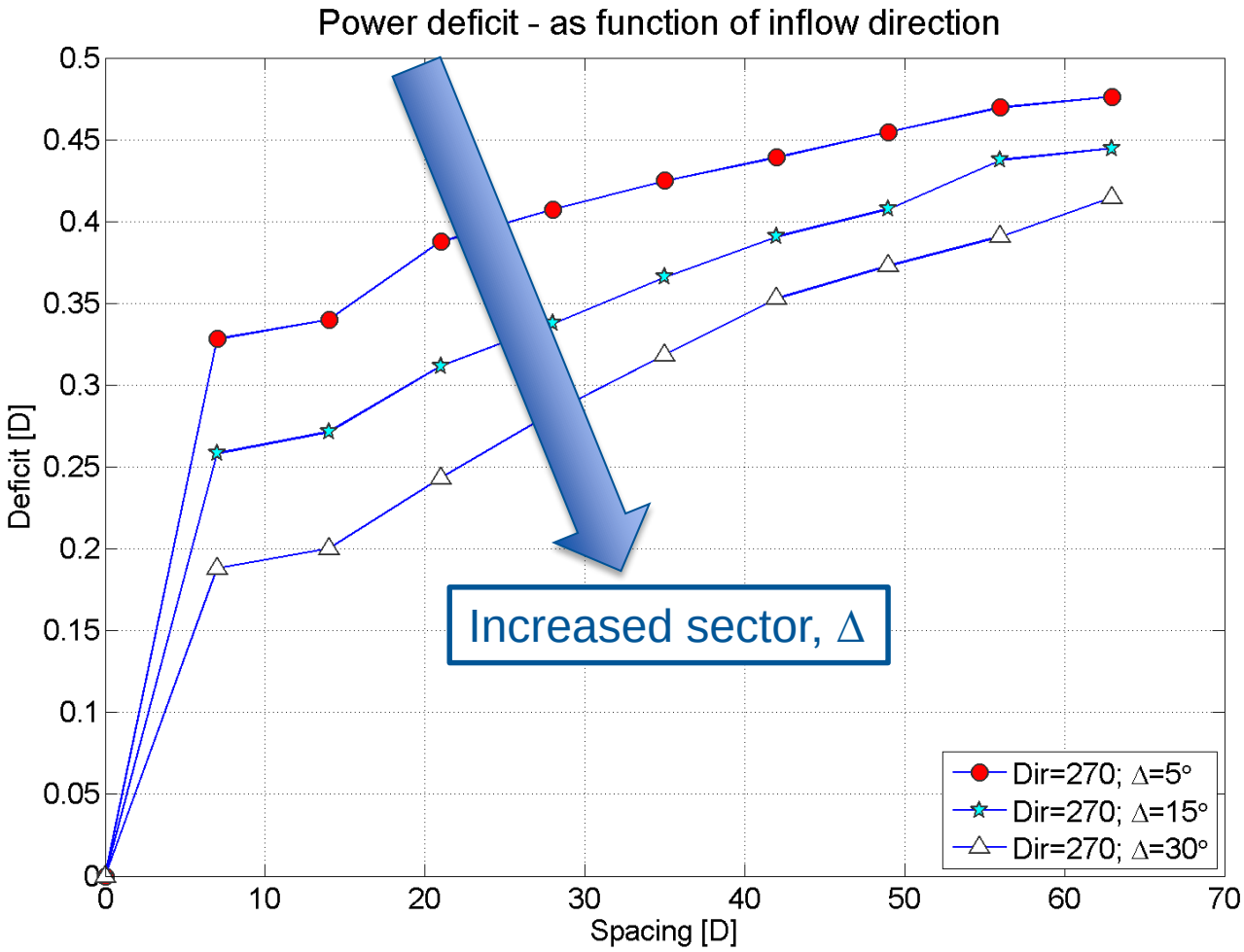
1. Basic wake deficit - pairs of wind turbines;
   a) Power deficit;
   b) Peak deficit vs turbulence;
2. Rows of turbines;
   a) Constant spacing (small or large);
   b) Speed recovery due to ”missing” turbines;
3. Wind farms with variable spacing;
4. Park efficiency;
5. Wind farm clusters = Farm – Farm wake



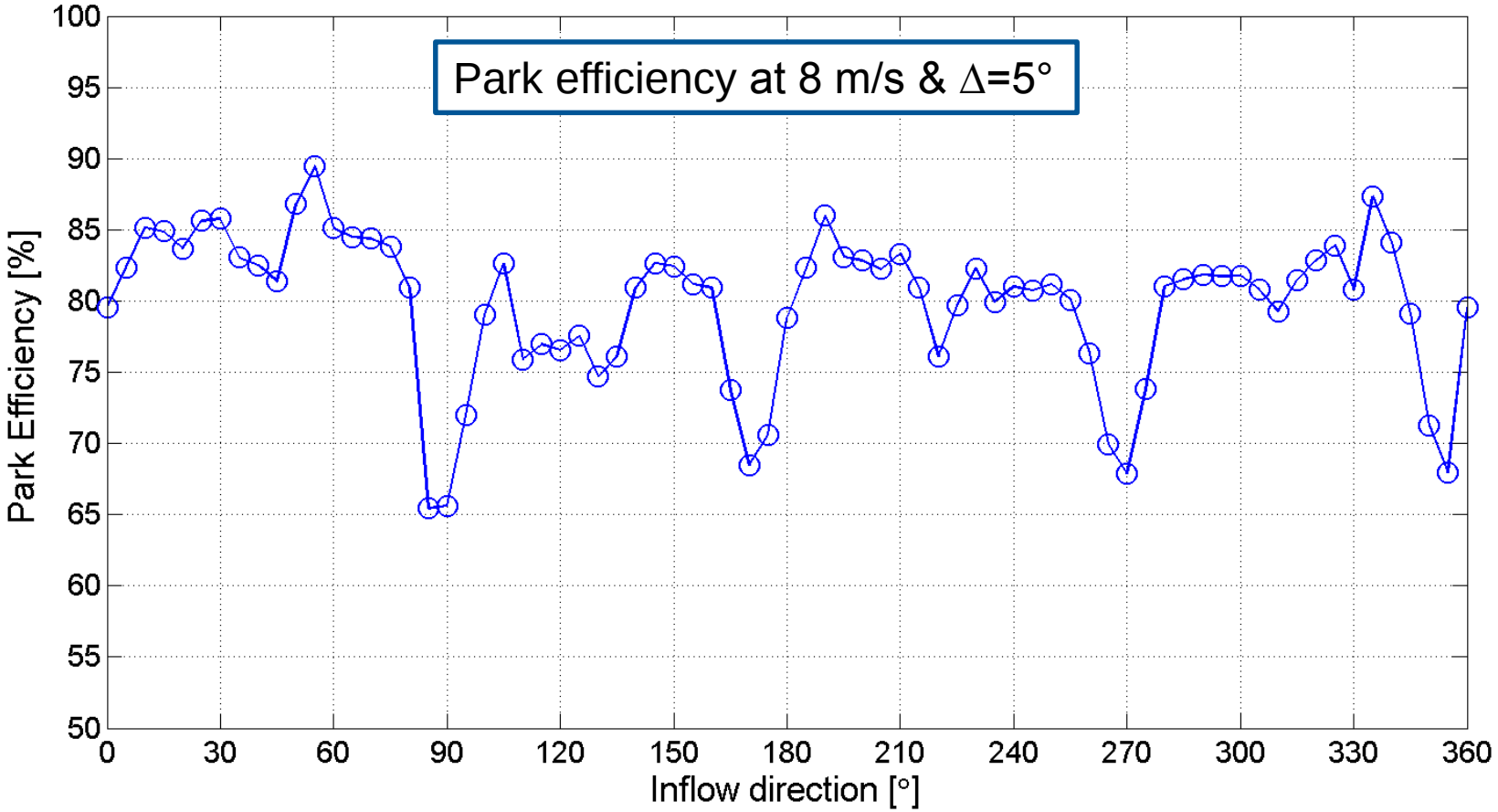
Wake deficit between pairs of wind turbines



Wake deficit for turbines with constant spacing



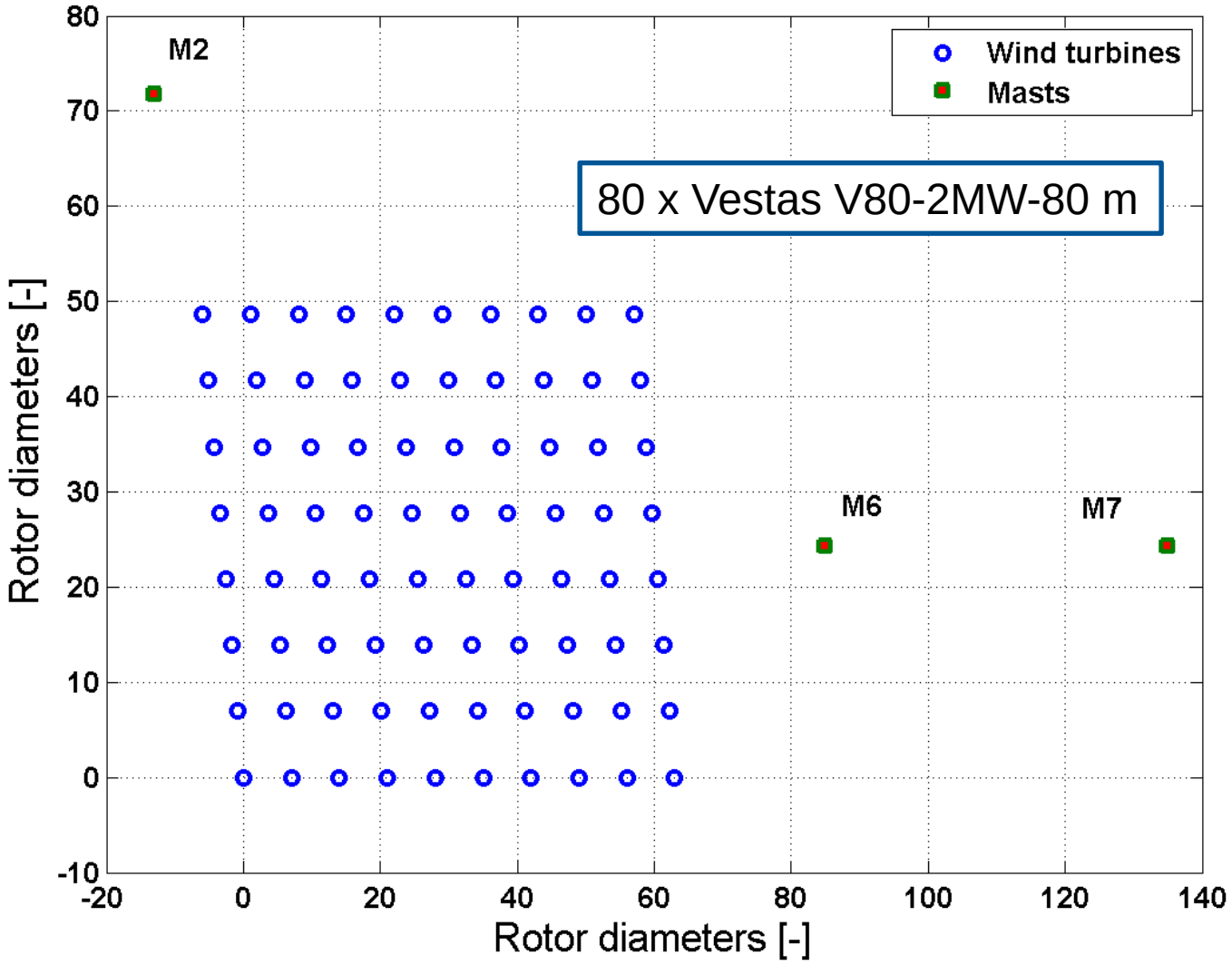
Definition of park efficiency



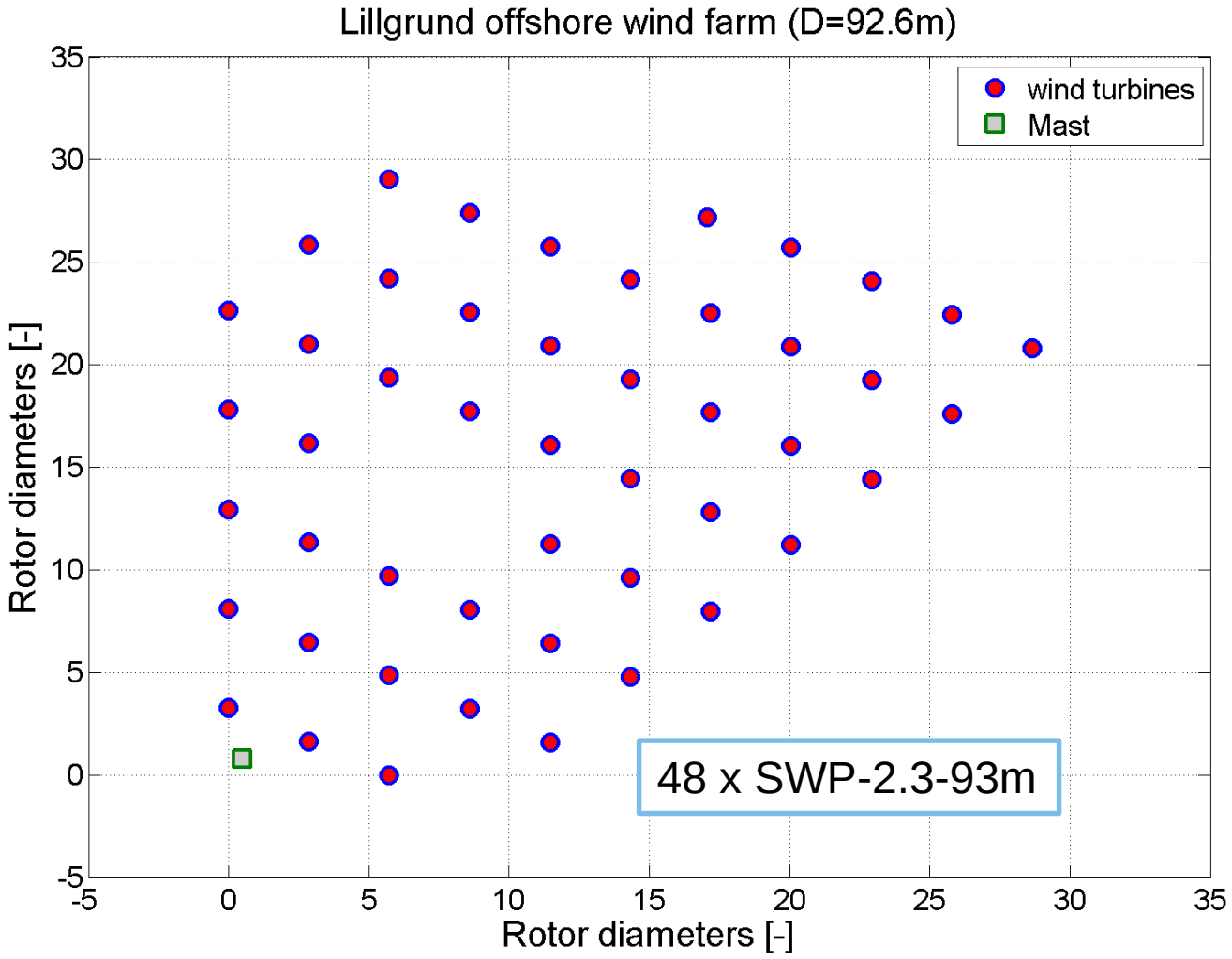
Introduction to wind farms

1. Horns Rev I WF: 80 x Vestas V80 á 2MW
   - Regular layout with 7D spacing;
   - Well know dataset from other benchmarks;
2. Lillgrund WF: 48 x SWP-2.3-93 m
   - Very dense wind farm with 3.3 and 4.3 D fixed spacing;
   - Missing ”turbines” => speed recovery analysis;
3. Rødsand: 90 x SWP-2.3-93 m
   - Variable spacing based on 5 x 18 turbines on archs;
   - Nysted WF: 72 x Bonus-2.3-82 m separated by a distance of 33 diameters;
4. Alpha Ventus WF: 6 x REpower 5 MW & 6 x AREVA 5 MW

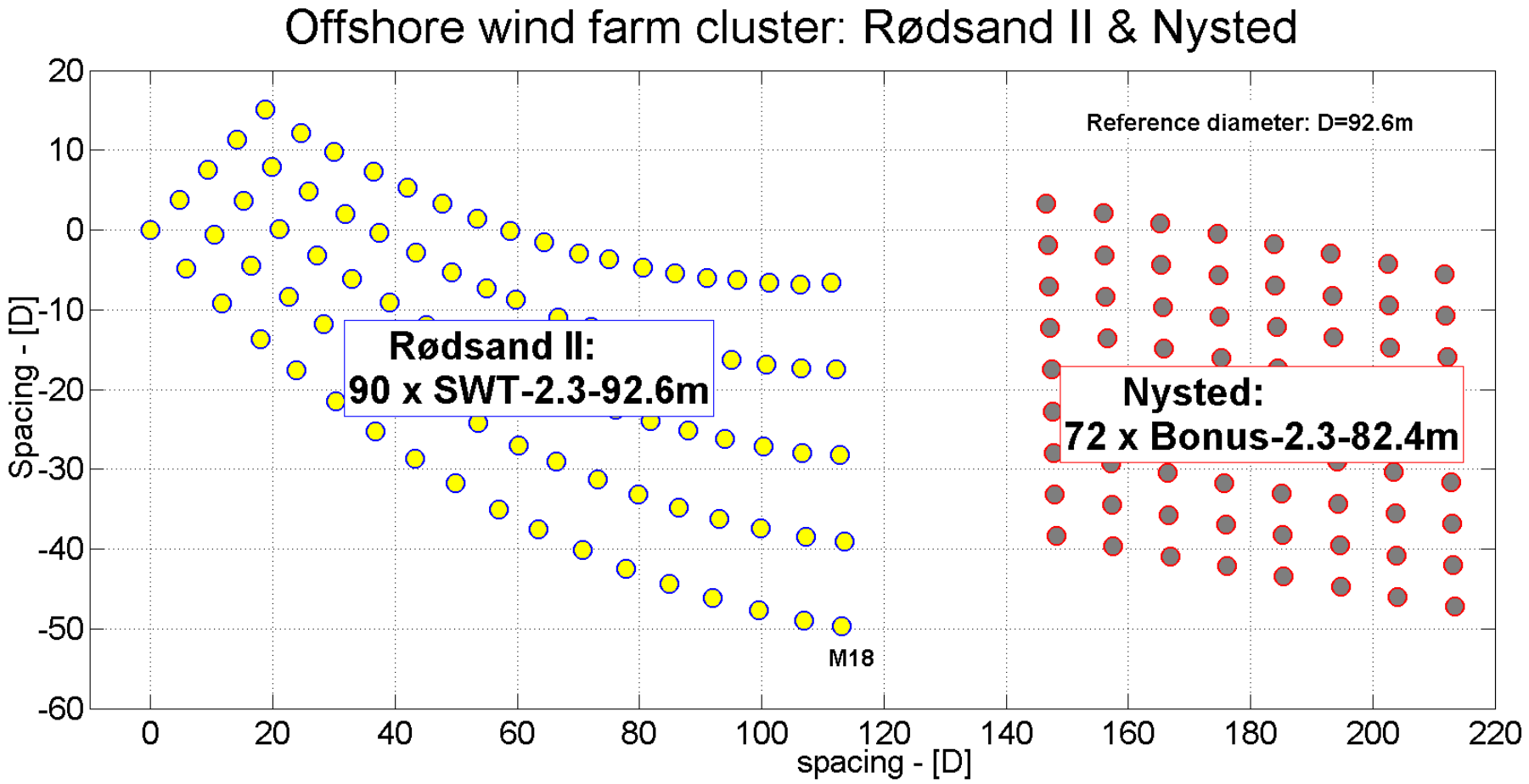
Horns Rev I offshore wind farm, DK



Lillgrund offshore wind farm, SE



Wind farm cluster: Rødsand II WF/Nysted WF

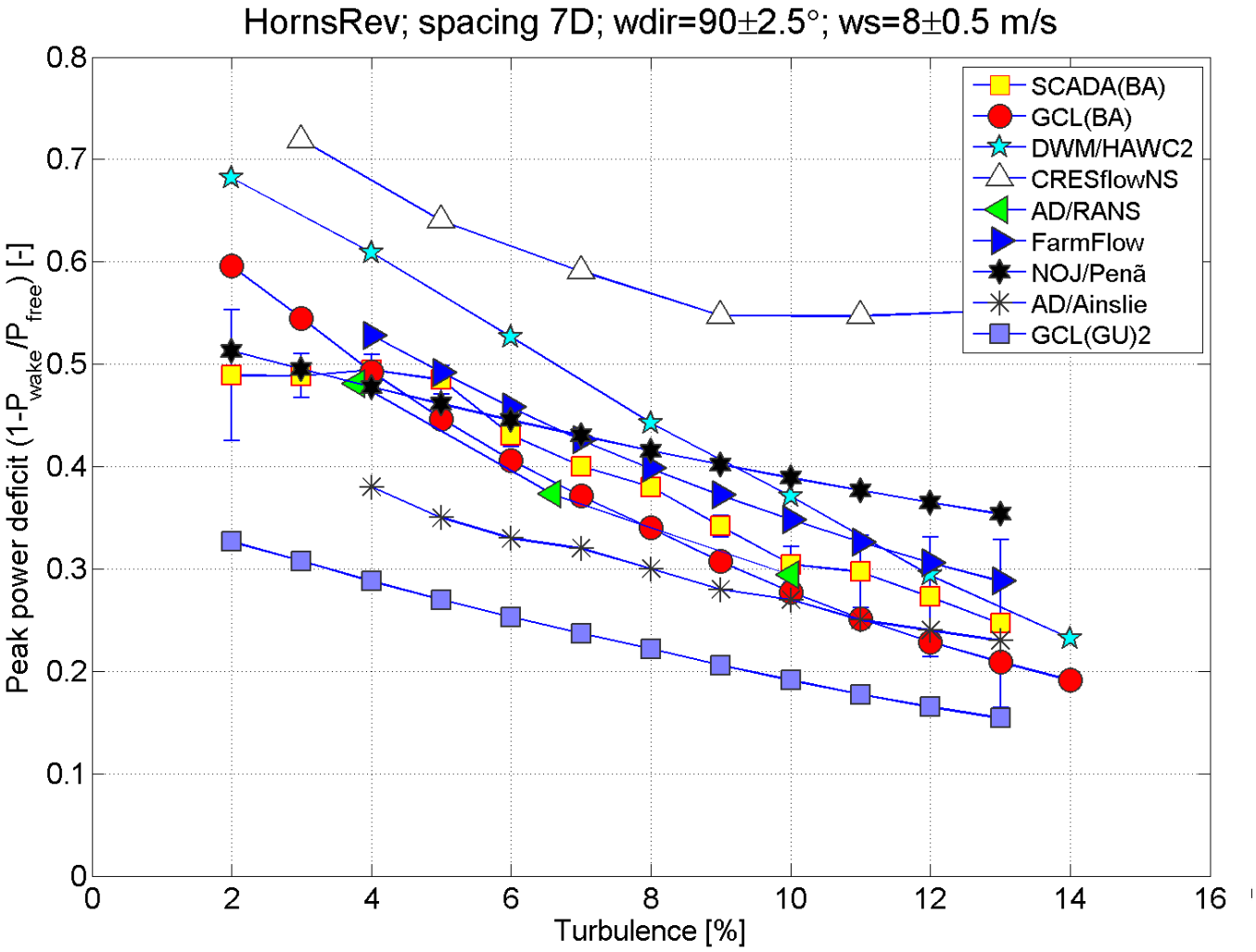


Participants and park models

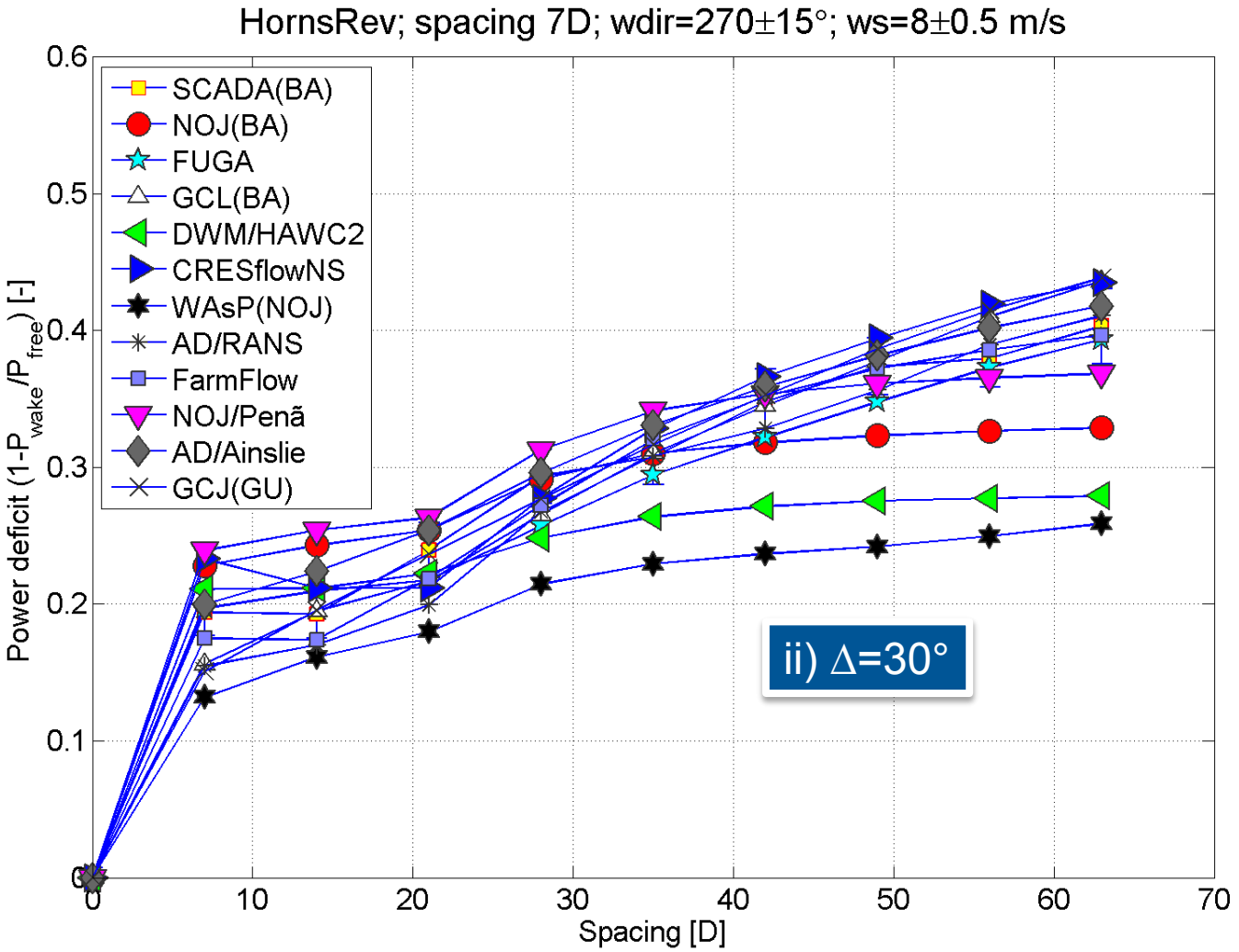
Models	Affiliation	Horns Rev WF	Lillgrund WF	Rødsand II WF	Rødsand II/Nysted WF
SCADA/BA	DTU Wind Energy/K.S.Hansen	x	x	x	(x)
NOJ/BA	DTU Wind Energy/misc		x		
NOJ/GU	DTU Wind Energy/misc		x	x	
NOJ/BA	DTU Wind Energy/A. Pena	x	x	x	
WASP/NOJ	Indiana Uni/RB	x			
GCL/BA	DTU Wind Energy/misc		x		
GCL/GU	DTU Wind Energy/misc	x	x		
GCL(GU)	CENER/JS.Rodrigo	x	x		
FUGA/SO	DTU Wind Energy/S. Ott	x	x	x	
DMW	DTU Wind Energy/TJ.Larsen	x			
AD/RANS	UPORTO/J.L. Palma	x		x	x
CRESflowNS	CRES/ J. Prospathopoulos	x	x	x	
FarmFlow	ECN Wind Energy/J.G Scheepers	x	x	x	x
CFDWake	CENER/B.G. Hevia	x		x	
RANS/f_PC	DTU Wind Energy/P.vd Laan			x	x
Ainslie	RES-LTD/T.Young	x	x		
WRF/UPM	Ciemat/A.Palomares			x	
Mesoscale	DTU Wind Energy/P.Volker			x	

BA=Bin averaged & GU=Gaussian Uncertainty

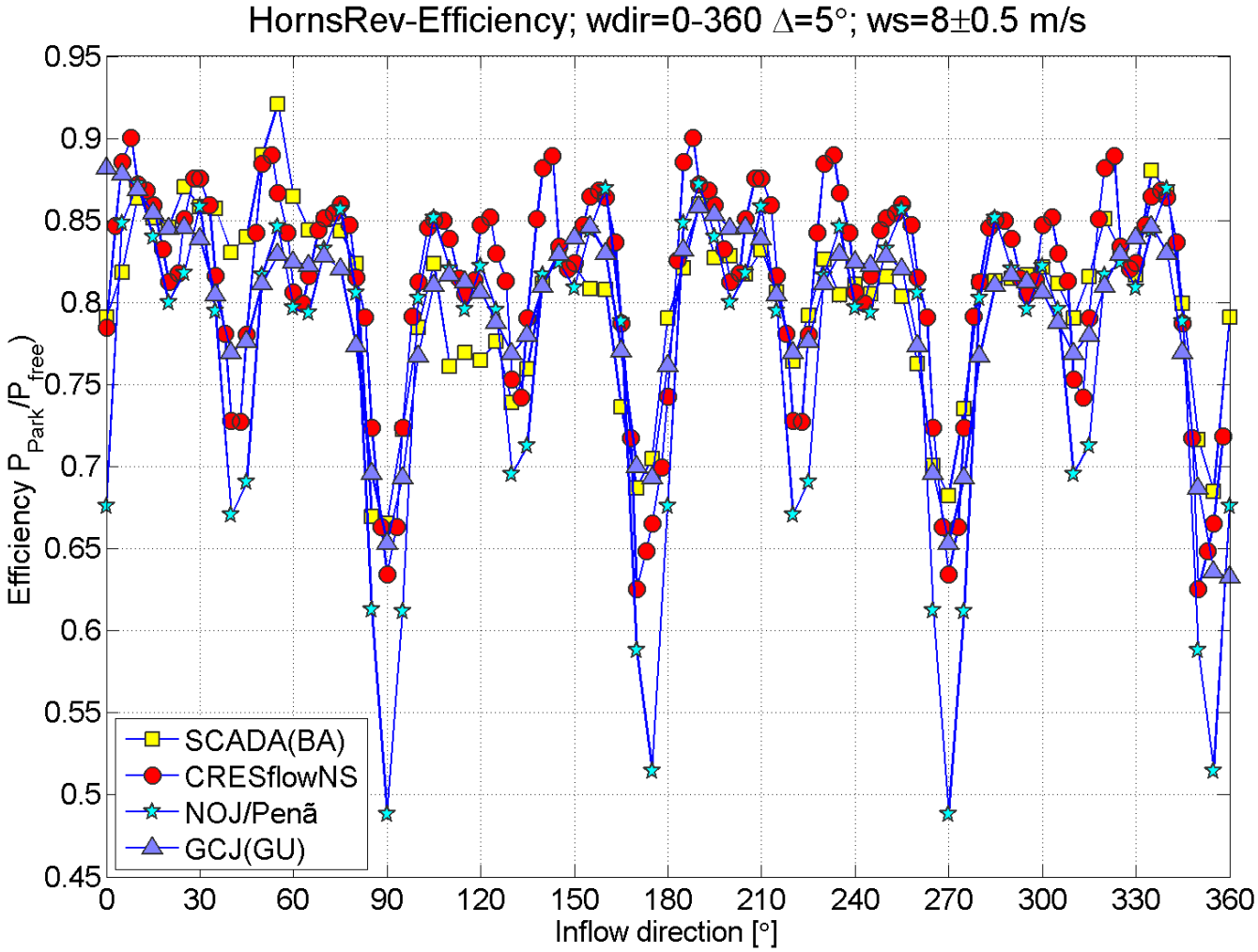
Results from Horns Rev benchmark



Results from Horns Rev benchmark



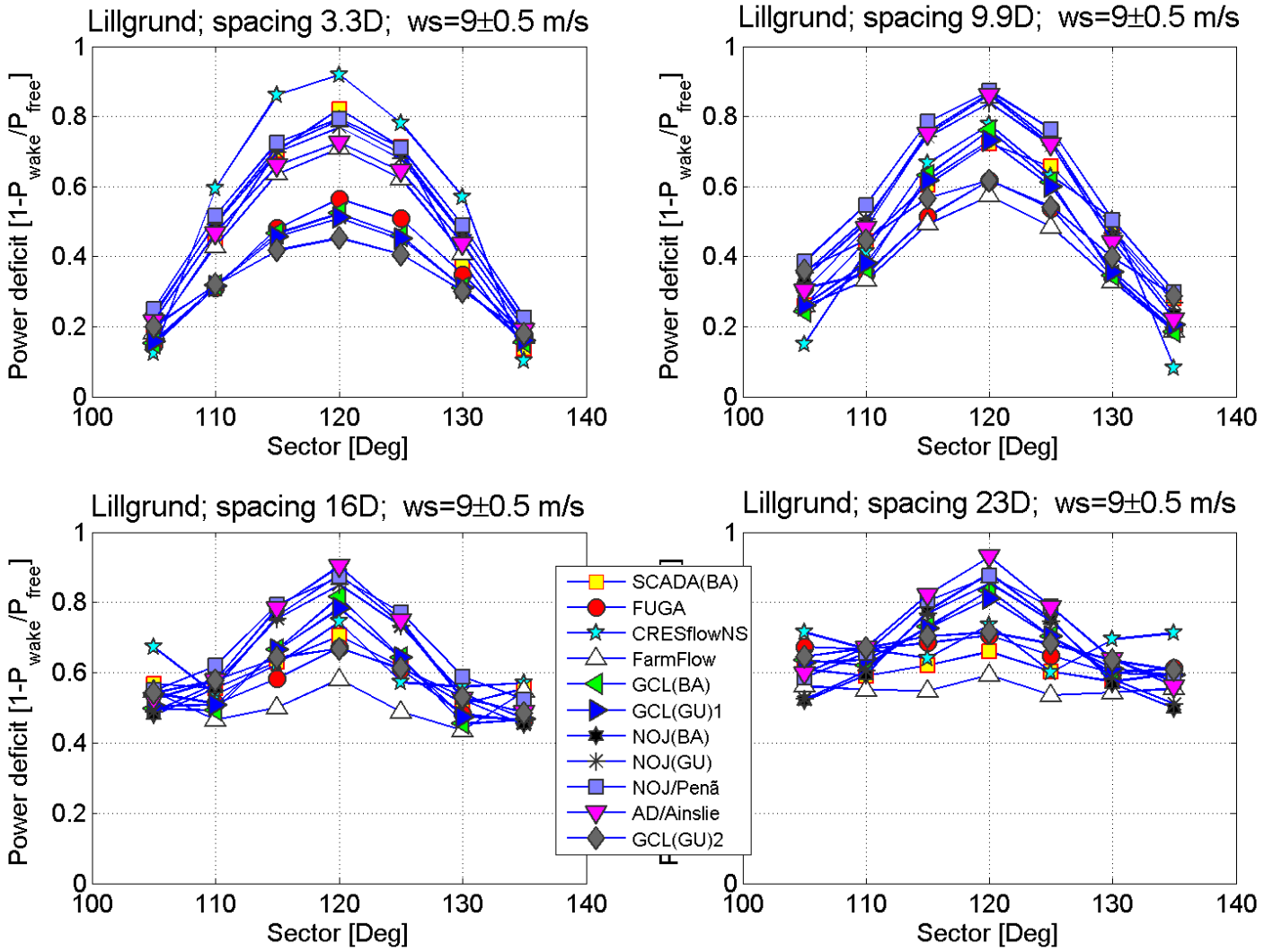
Horns Rev park efficiency; 0 - 360°



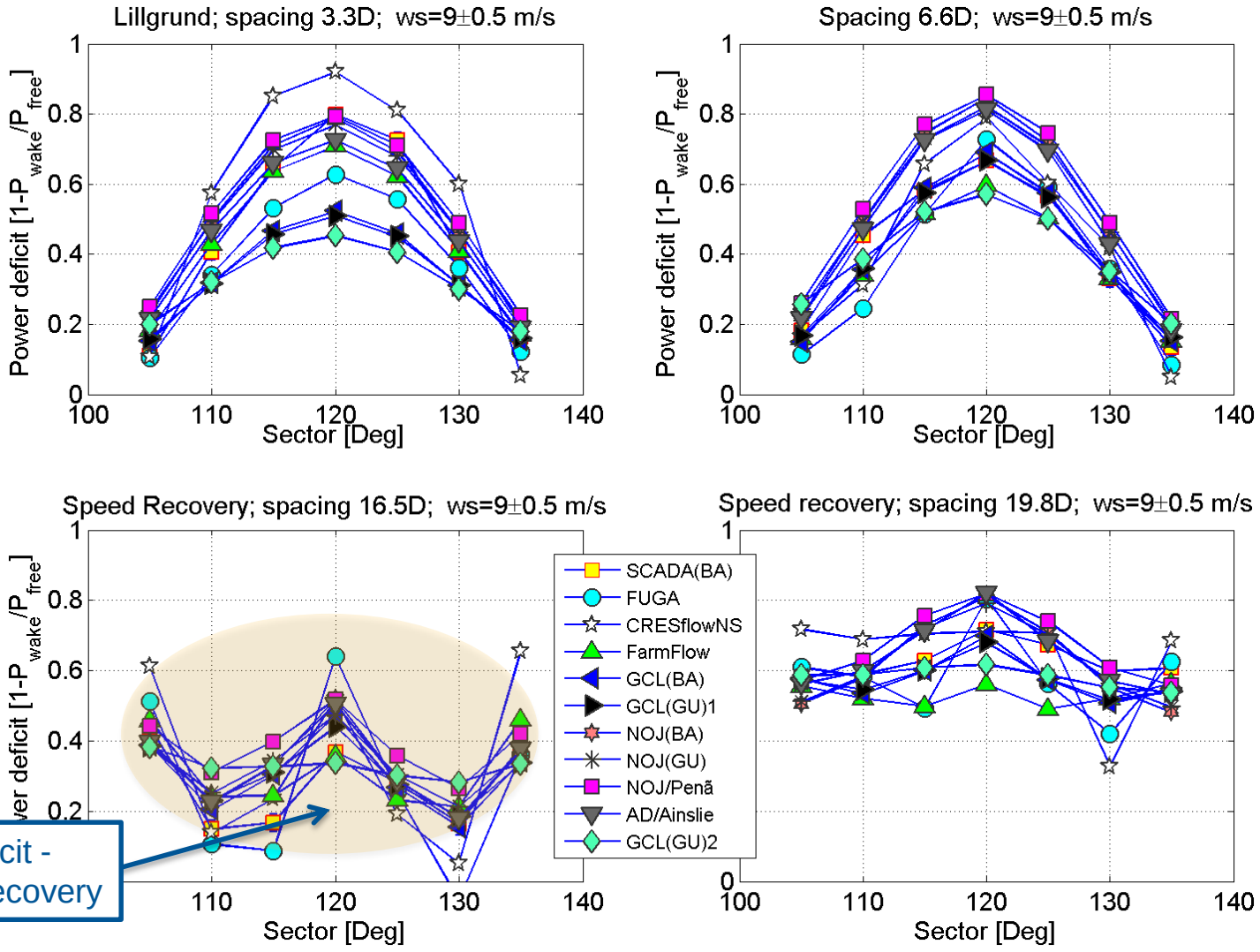
Horns Rev benchmark - discussion

- First EERA-DTOC benchmark included 11 models, which has been implemented succesfull;
- The basic flow cases displayed some sector size dependent differences;
- The park efficiency case demonstrated that the models were able to cover a complete wind farm.

Lillgrund offshore wind farm – 3.3 D spacing

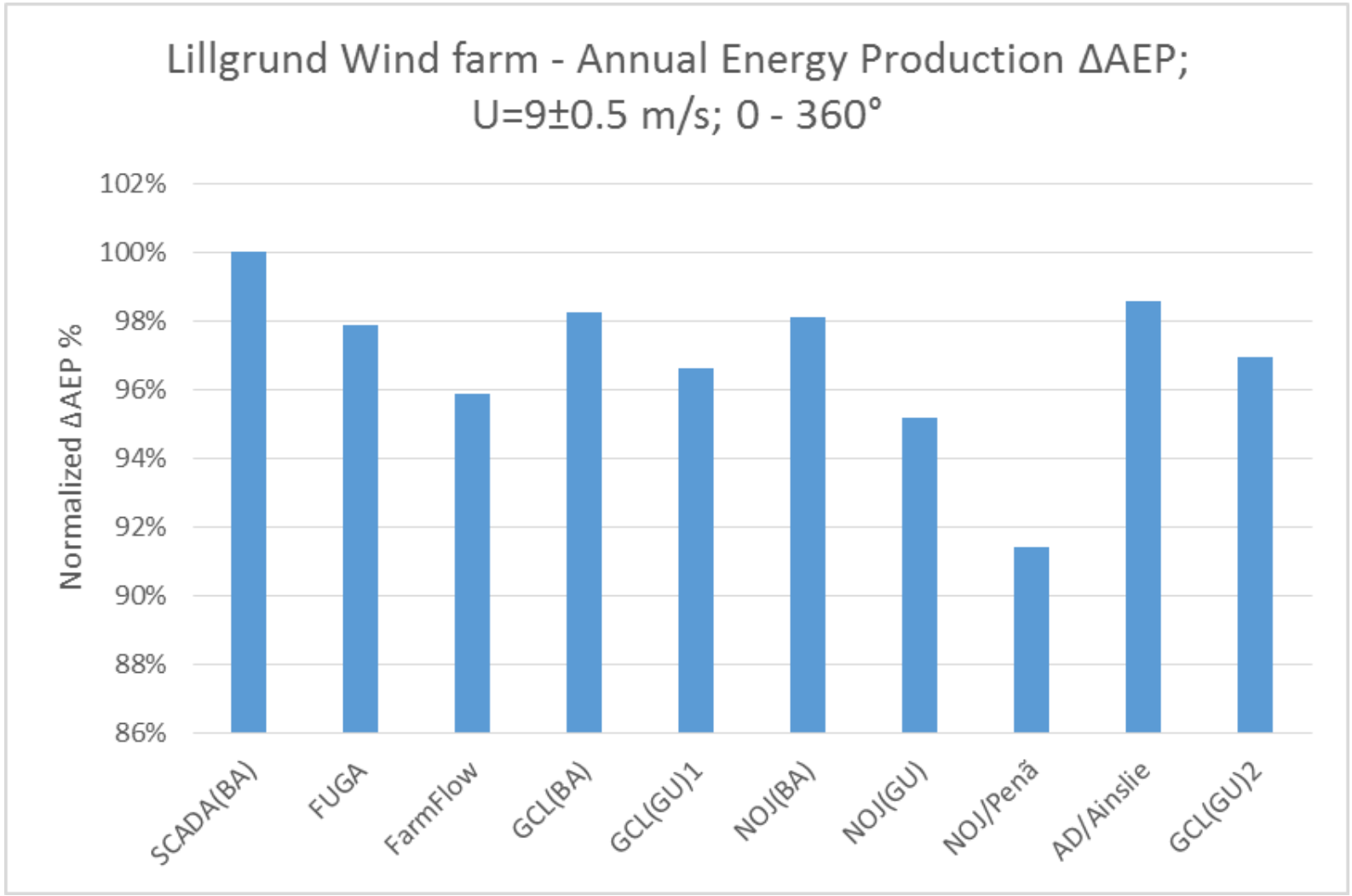


Lillgrund offshore wind farm – 3.3 D spacing



Decreased deficit - due to speed recovery

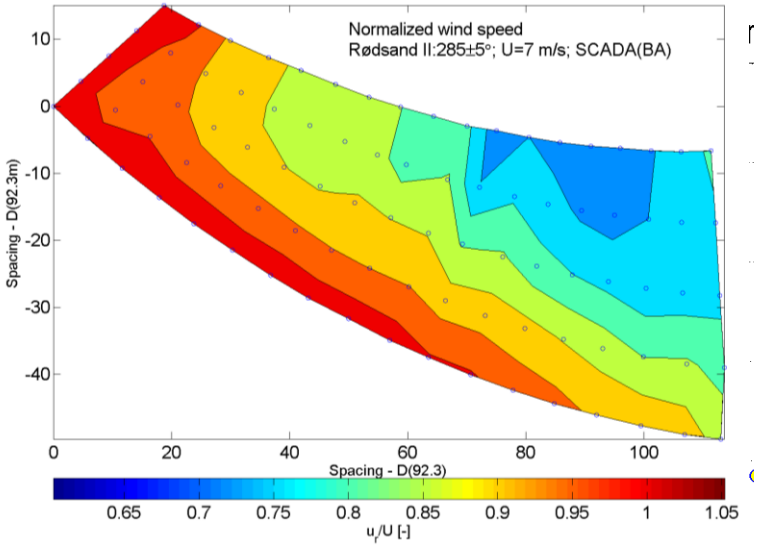
Lillgrund Park efficiency: 0 - 360°

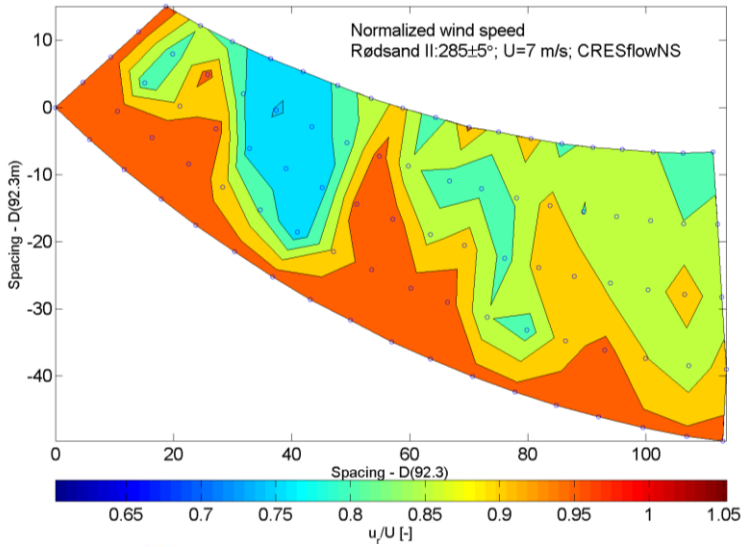


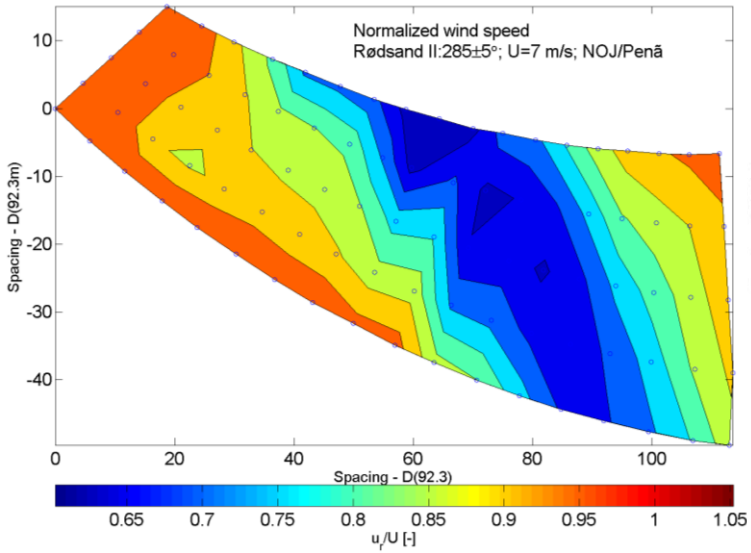
Lillgrund Park benchmark - discussion

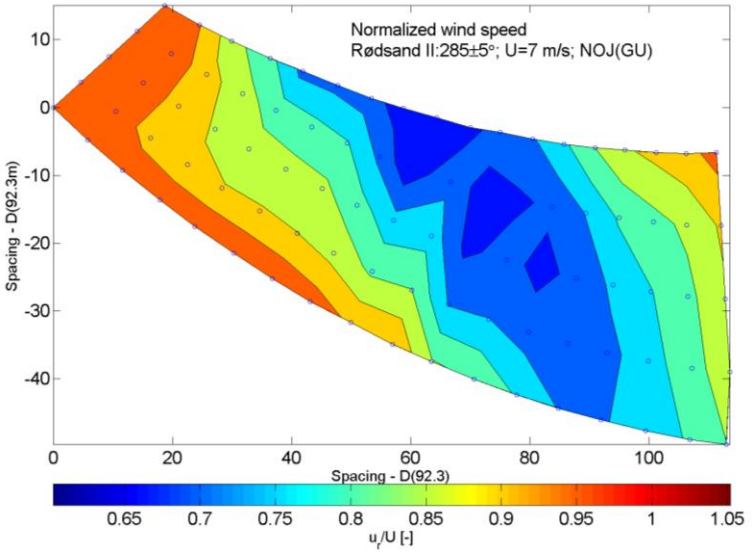
- All models handles 3.3 and 4.3D spacing well;
- All models handles the speed recovery due to ”missing” turbines;
- All models ware able to simulate the park efficiency for 0 - 360° inflow;
- The simulated ΔAEP demonstrates a variation of ±3% compared to the measured value;

Rødsand II wind farm – variable spacing

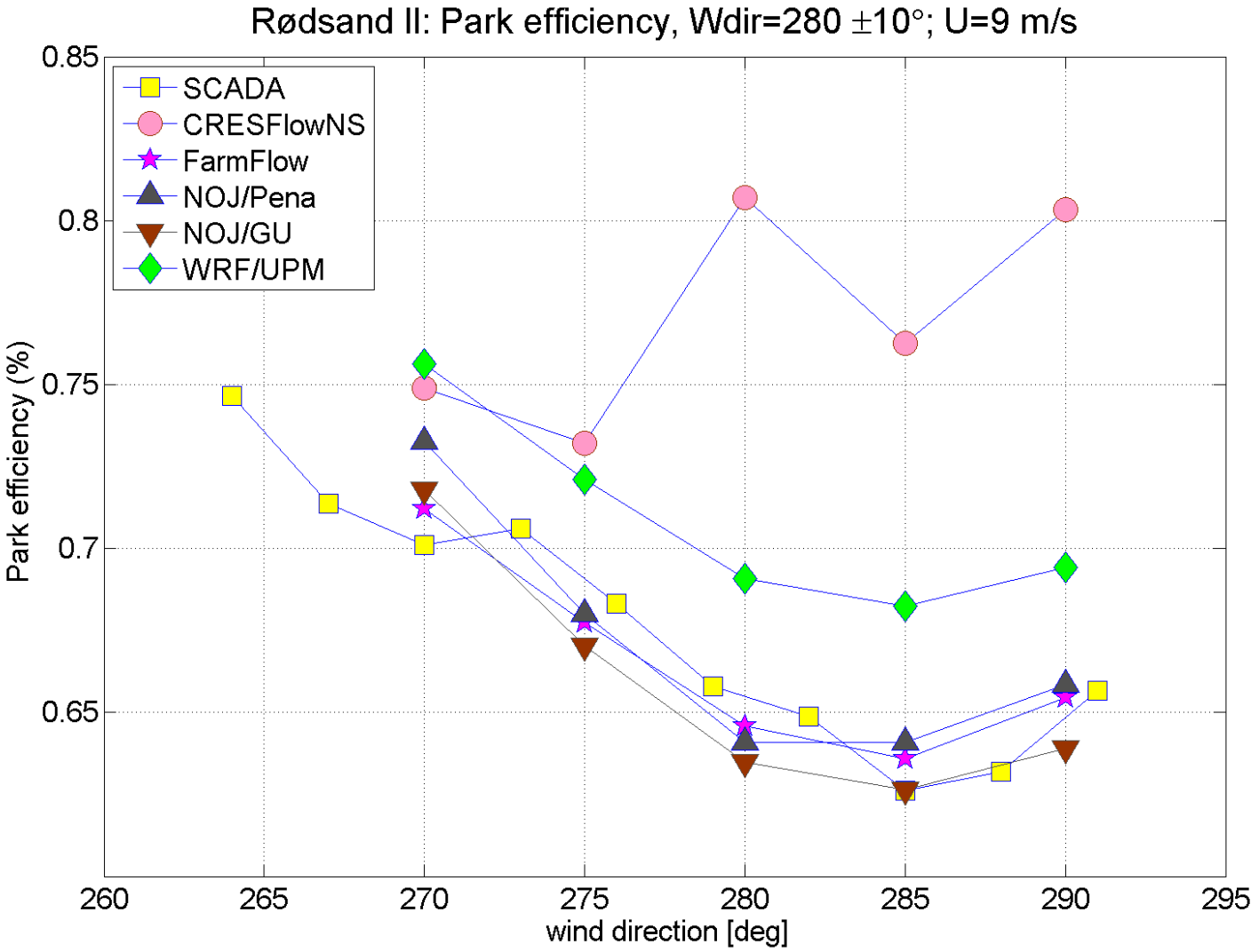




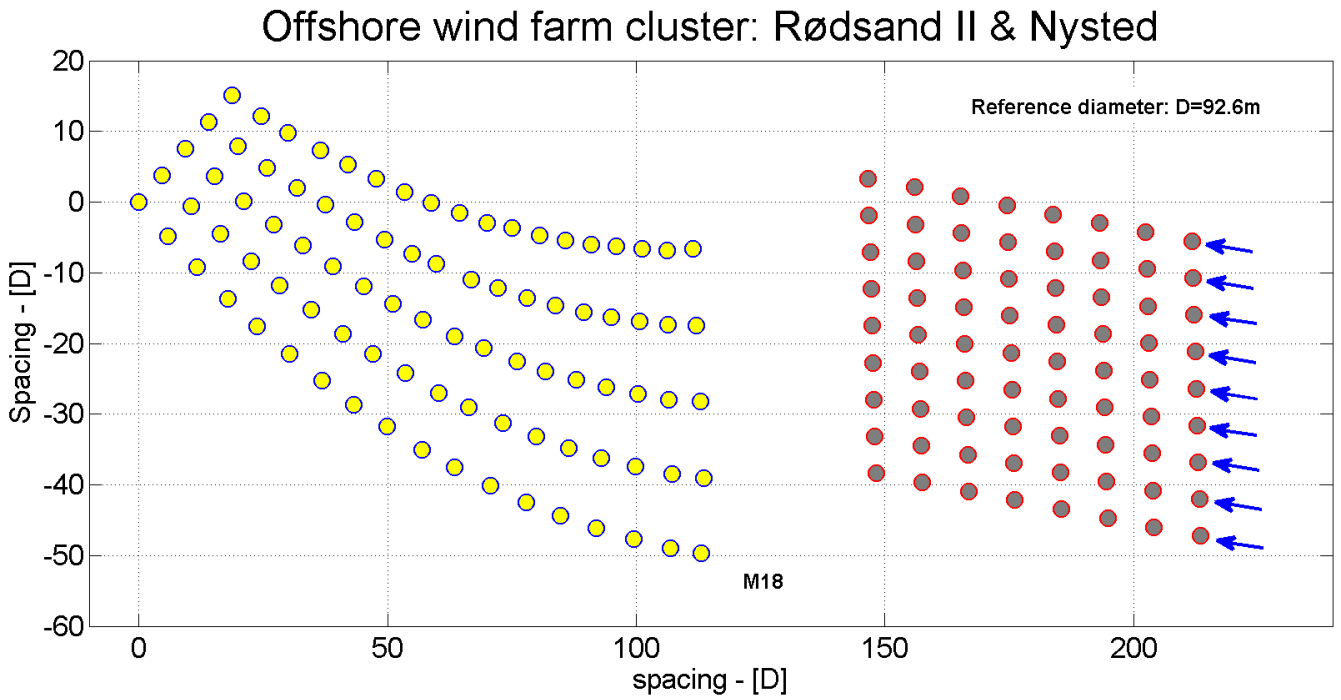




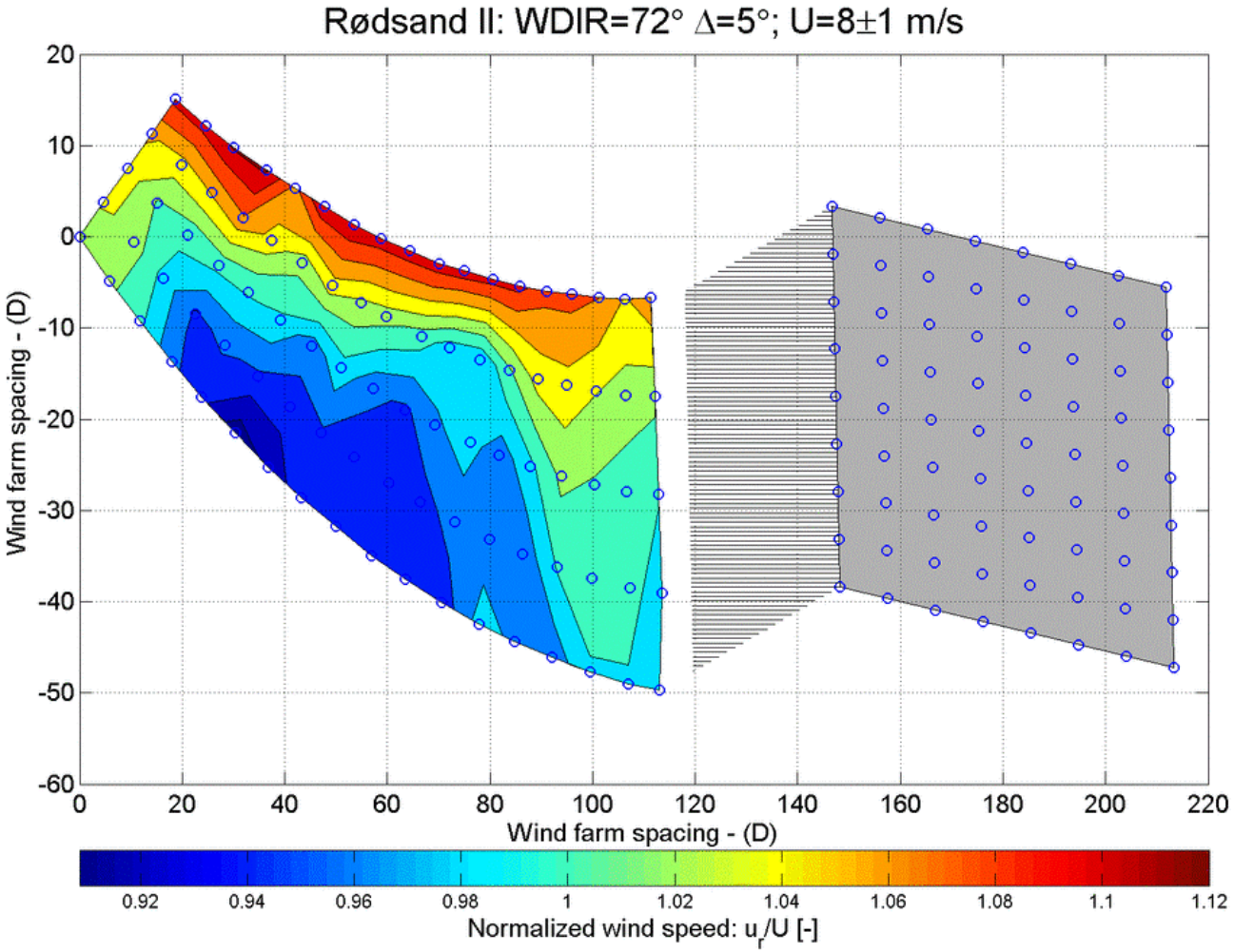
Rødsand II wind farm – park efficeincy



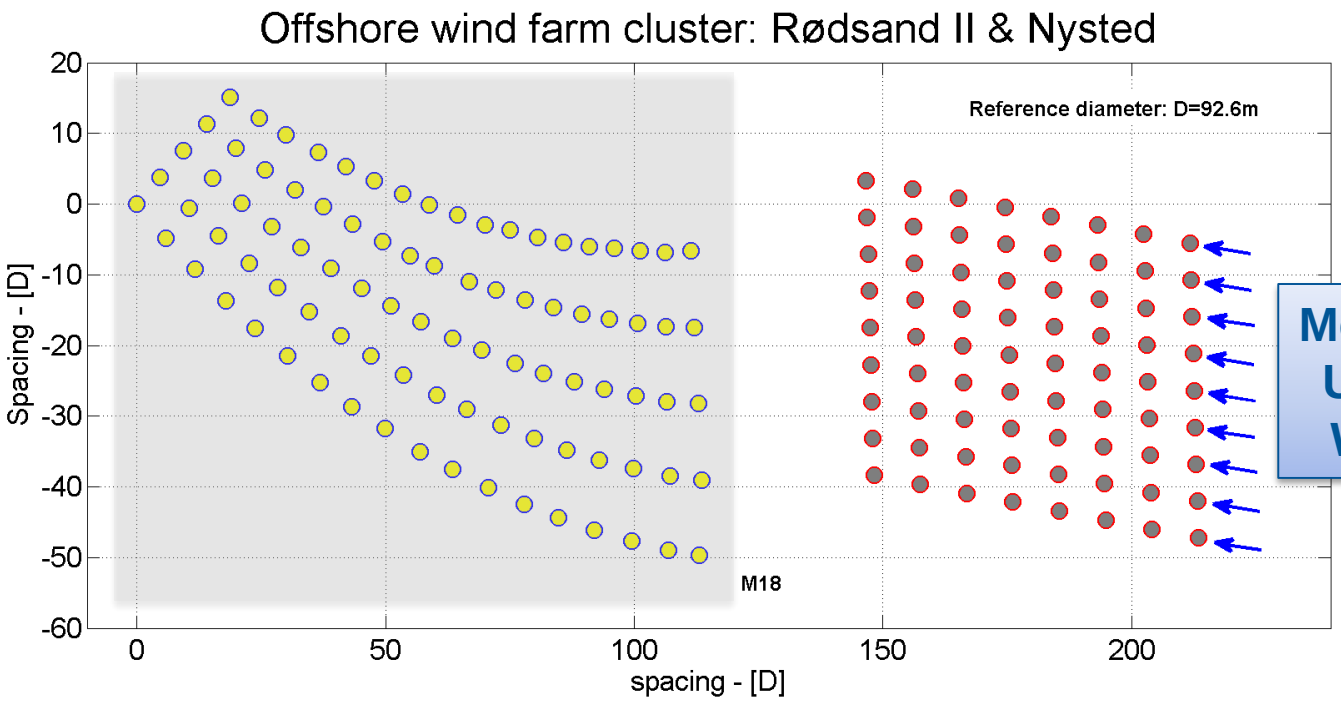
Measured wind farm cluster effects.



Measured wind farm cluster effects.

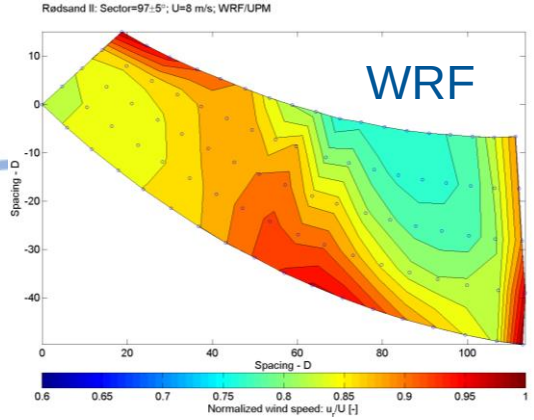


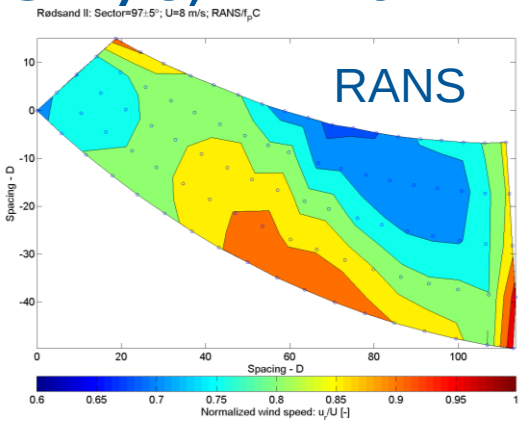
Offshore wind farm cluster effects.

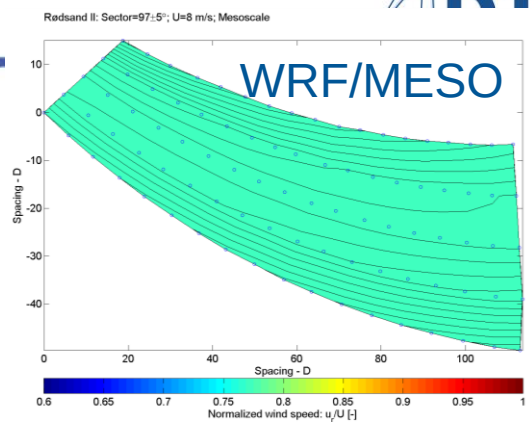


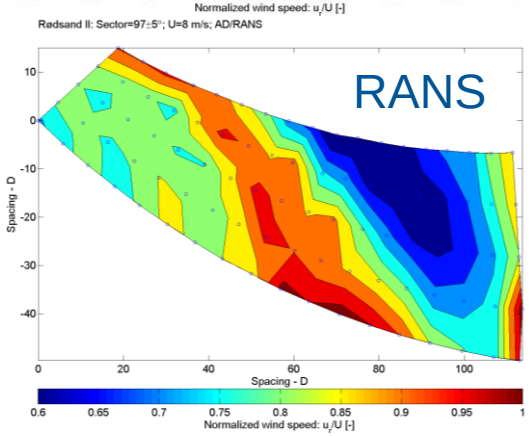
Model inflow
U_{hub}=8 m/s
WDIR=97°

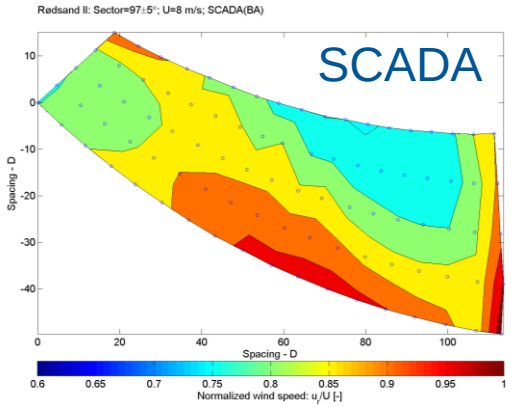
Cluster effect for U=8 m/s; WD=97 °

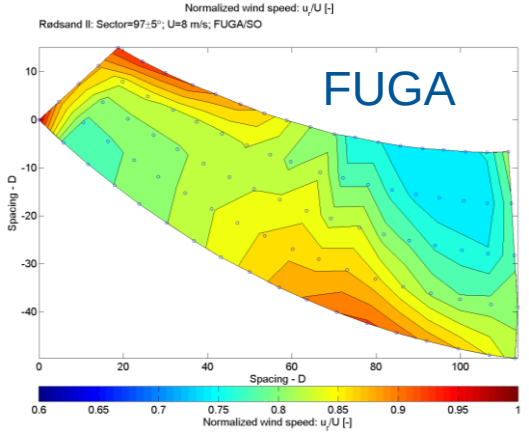


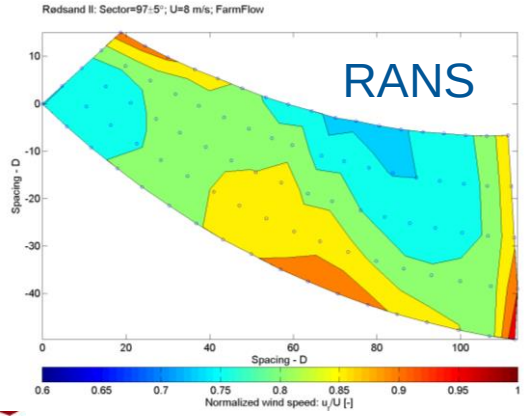


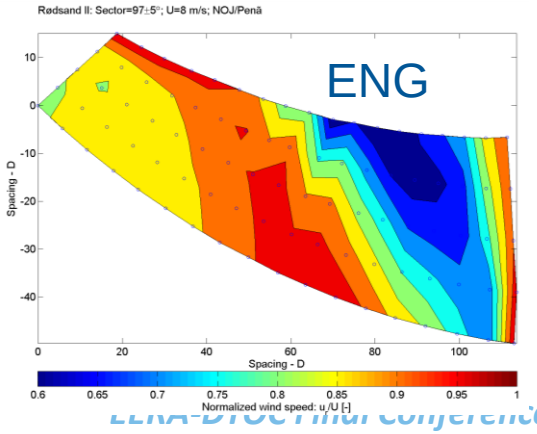


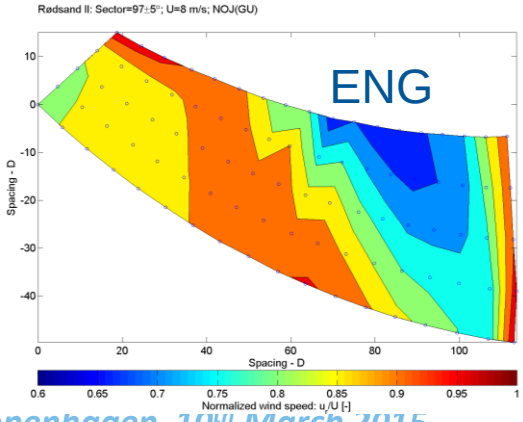




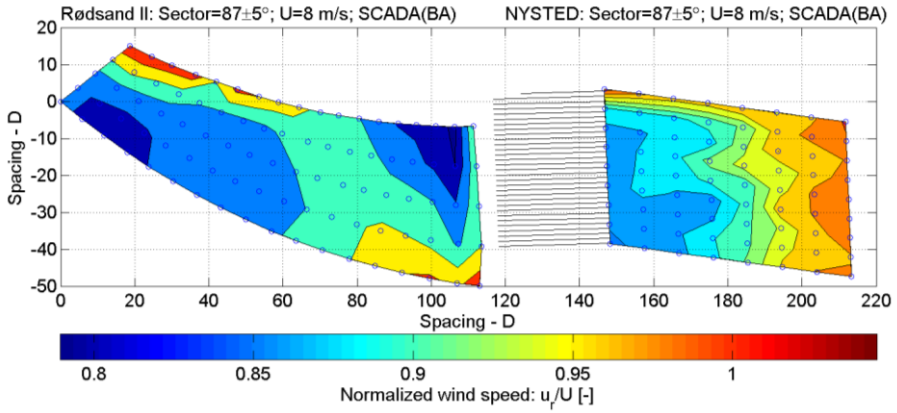


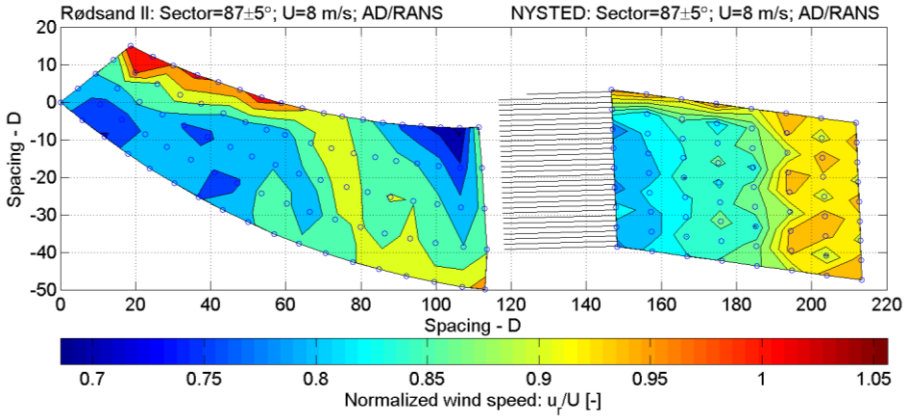


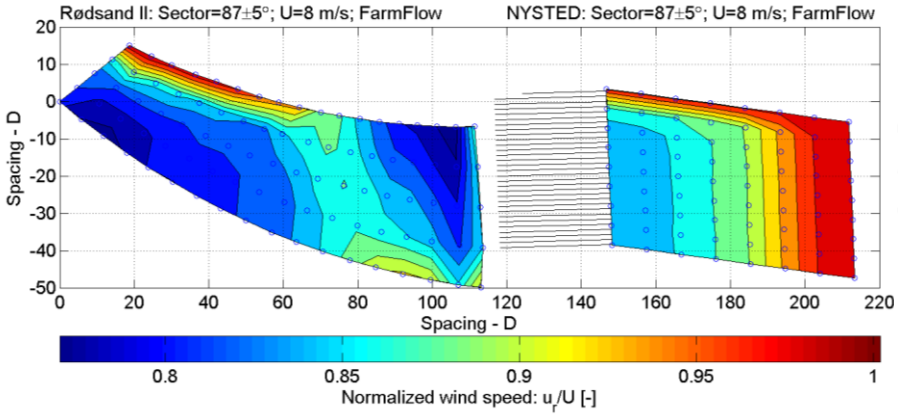


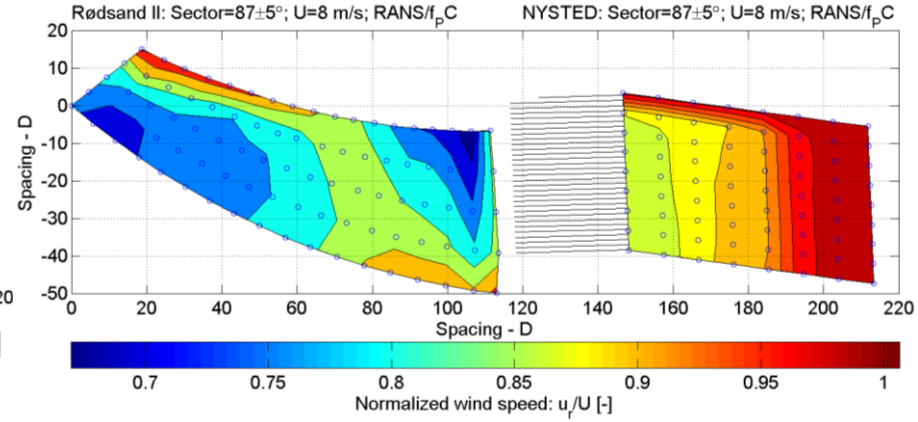


Cluster modeling results, U=8 m/s; WD=87°

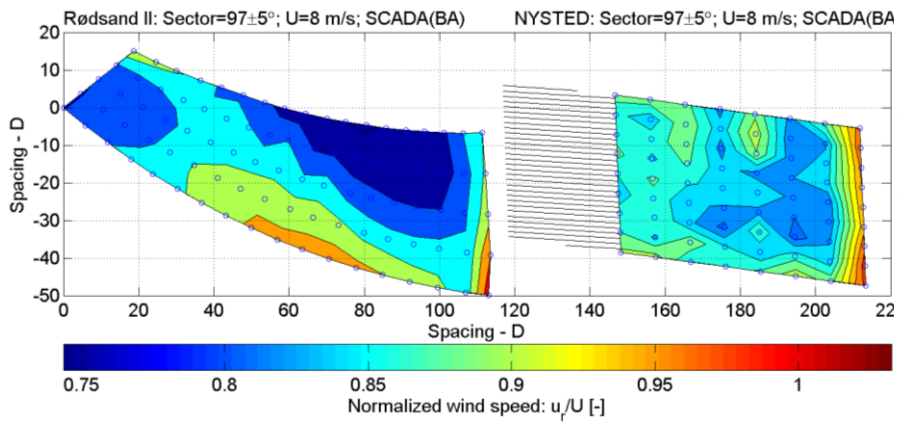


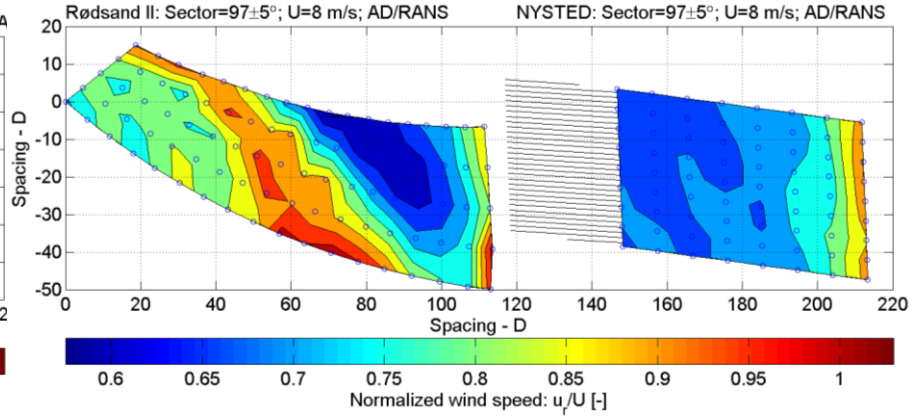


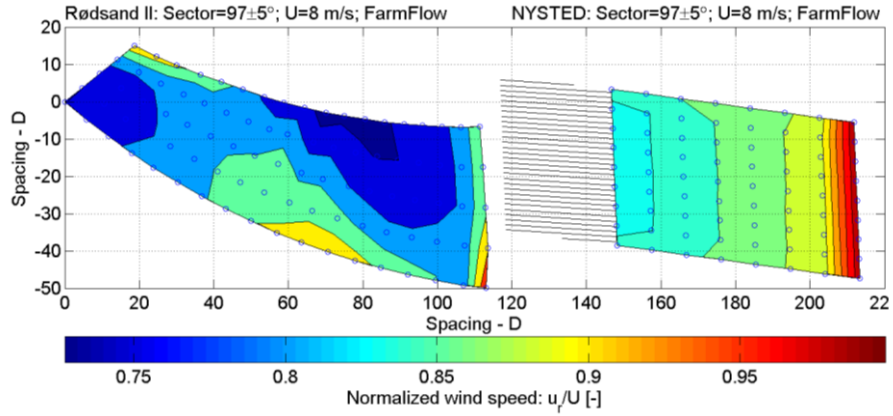


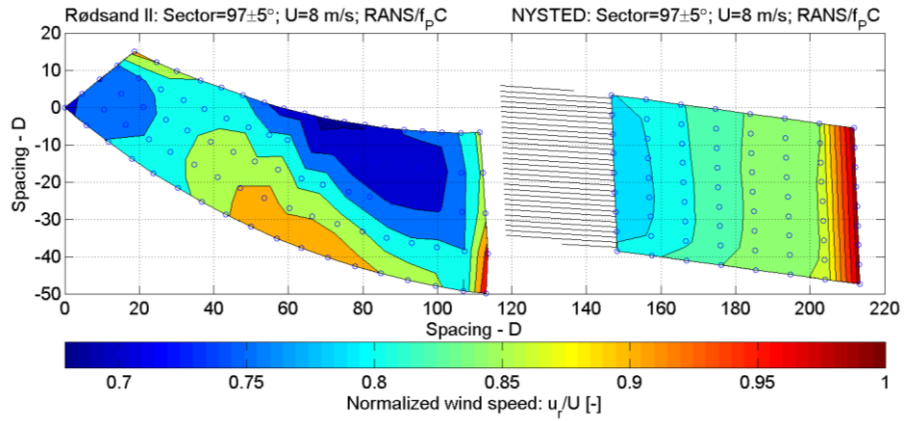


Cluster modeling results, U=8 m/s; WD=97°

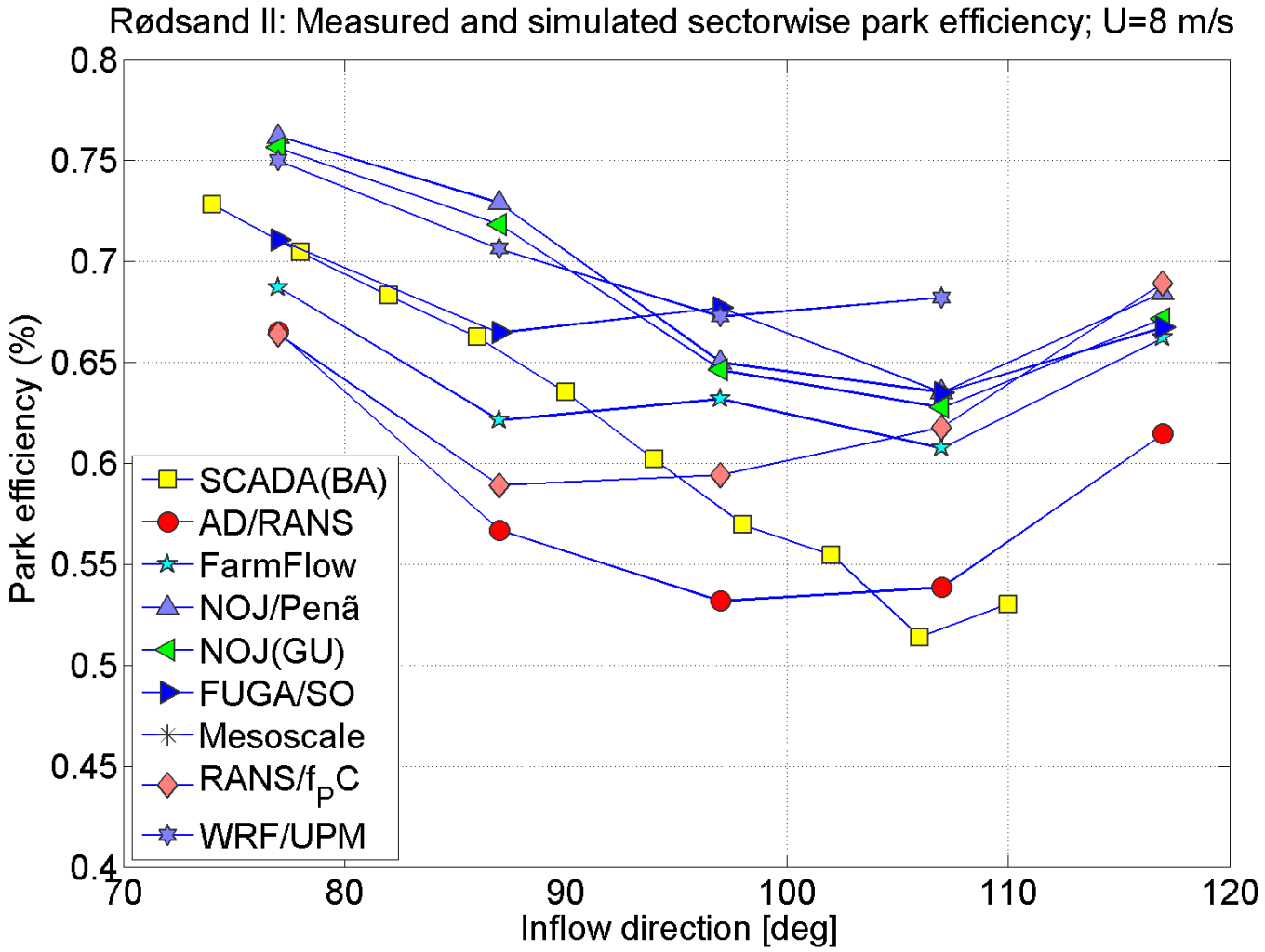








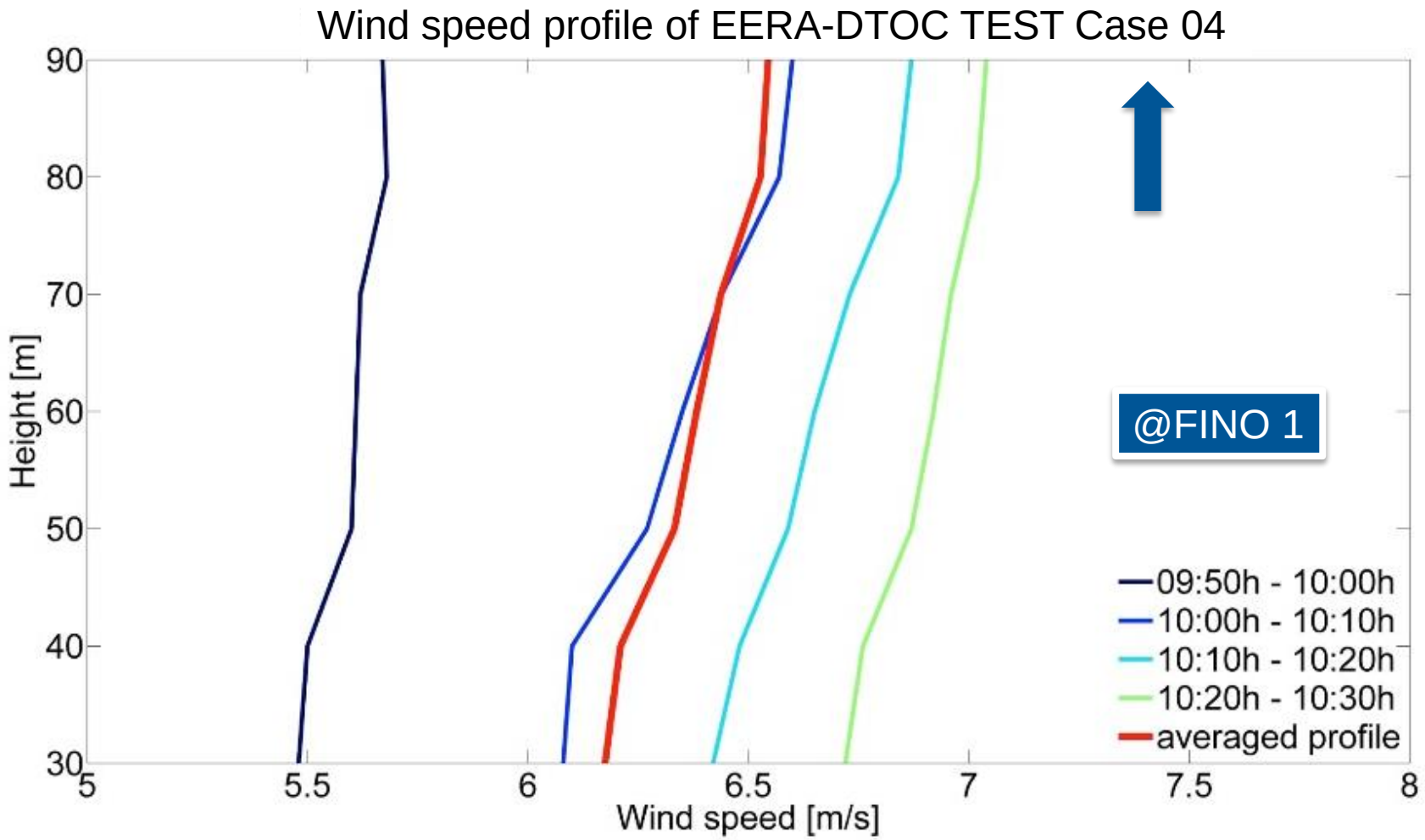
Park efficiency comparison



Cluster effects - discussion

- Quantification of the cluster effect is not possible due to lack of measurements and park asymmetry.
- The benchmark have demonstrated that both size and location of the distinct deficit zones - caused by the Nysted wind farm have been predicted quite well by the models.
- The benchmark concludes that several models were able to handle the clustering of wind farms.

Wake measurements from Alpha Ventus WF



Wind farm wake verification from Alpha Ventus
Results and discusion

- Comparison represent 40 minutes measurements and model results;
- The magnitude of the deficit can be simulated in average within a tolerance of 7% for 40 m and 90 m (=hub) heights, but with increasing deviations above hub height;
- The position of the wakes from the simulations show a trend for the AREVA turbines to match the measurements in a better manner than for the Senvion turbines;

Acknowledgements

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