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

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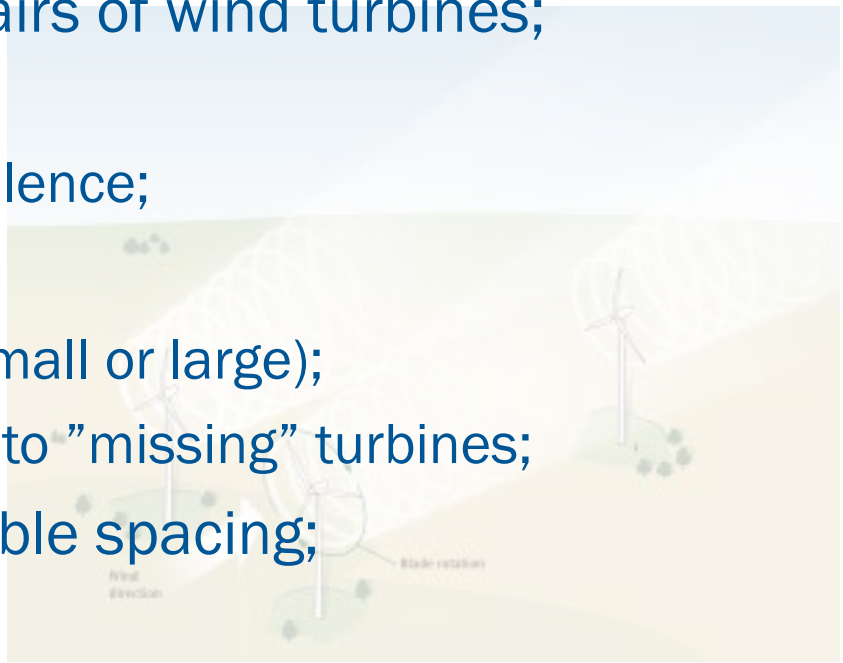
DTU Wind Energy – Fluid Mechanics

Outline

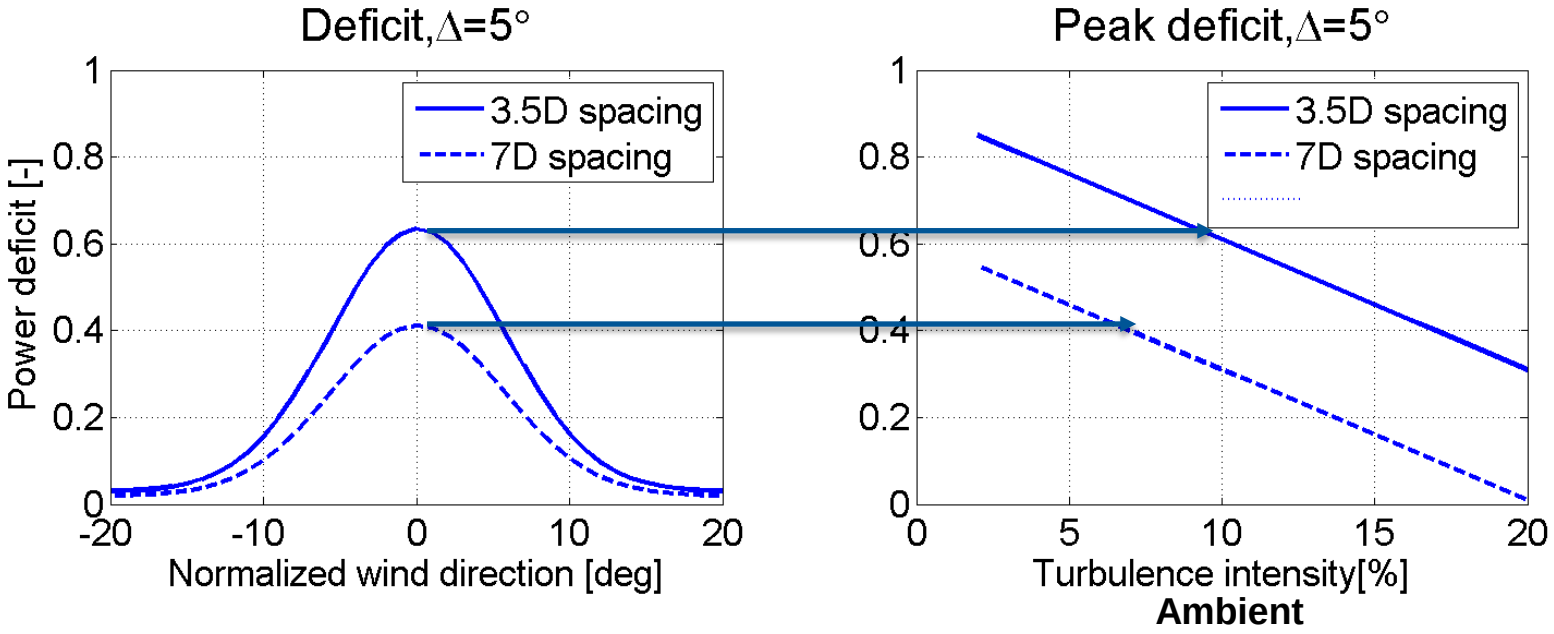
- Introduction wind turbine wakes;
- Participants & models;
- Results
  - Simple wakes and moderate spacing;
  - Wakes for small spacing and speed recovery;
  - Wakes for variable spacing
  - Wind farm clusters;
  - Wake behind a large wind farm;
- Discussion & acknowledgements;

Introduction wind turbine wakes

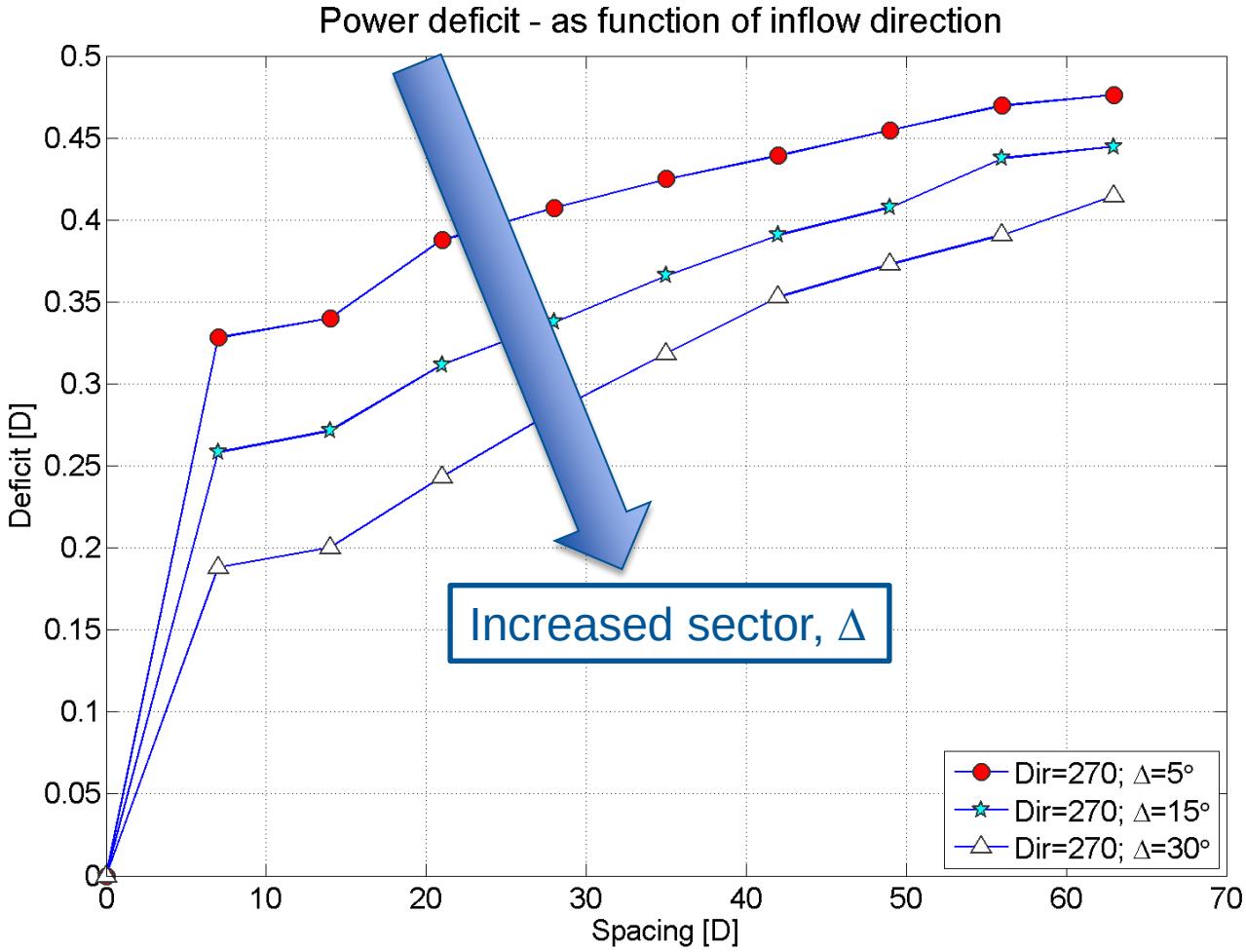
1. Basic wake deficit - pairs of wind turbines;
   a) Power deficit;
   b) Peak deficit vs turbulence;
2. Rows of turbines;
   a) Constant spacing (small or large);
   b) Speed recovery due to ”missing” turbines;
3. Wind farms with variable spacing;
4. Park efficiency;
5. Wind farm clusters = Farm –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



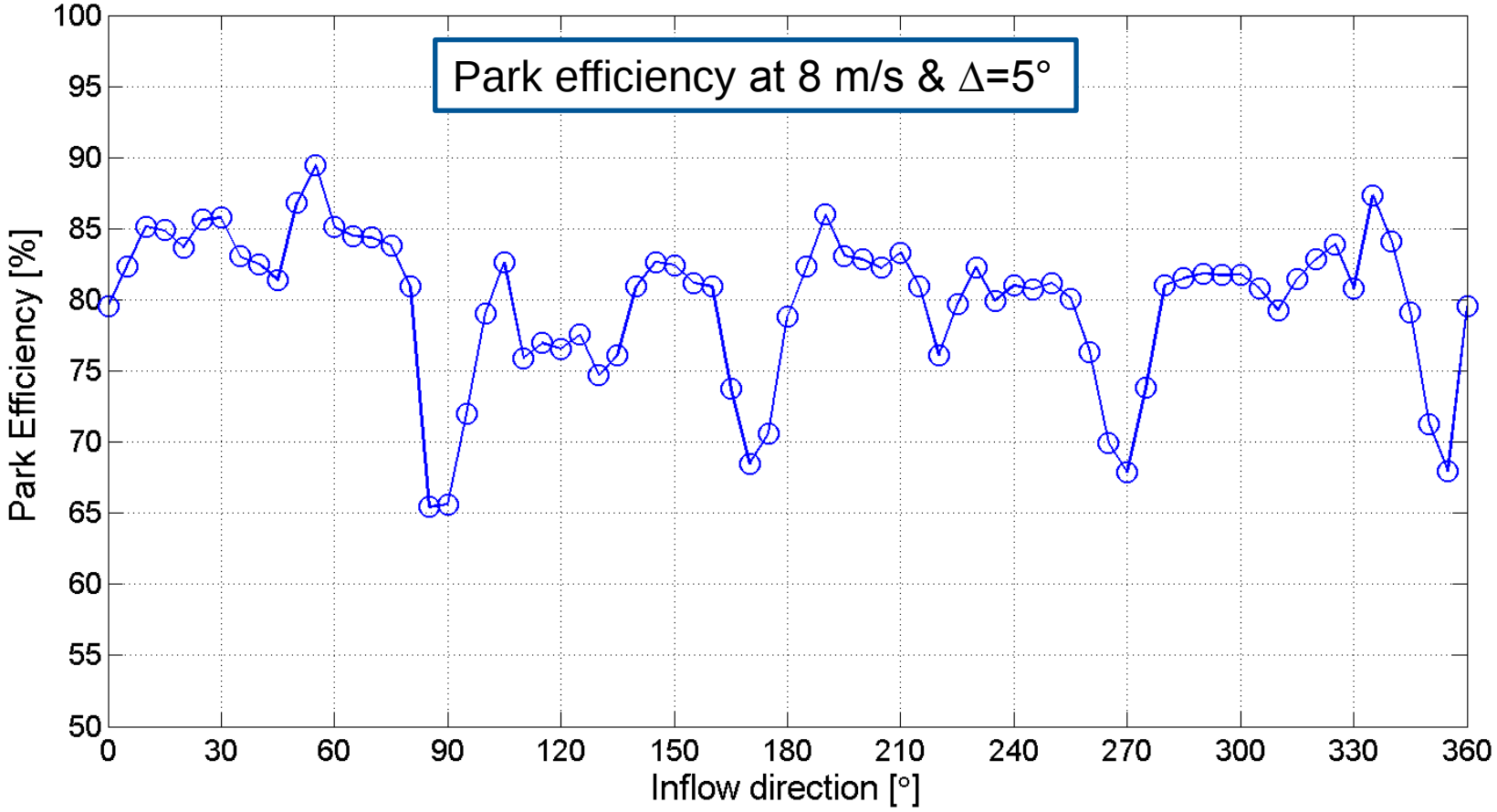
Wake deficit between pairs of wind turbines



Wake deficit for turbines with constant spacing



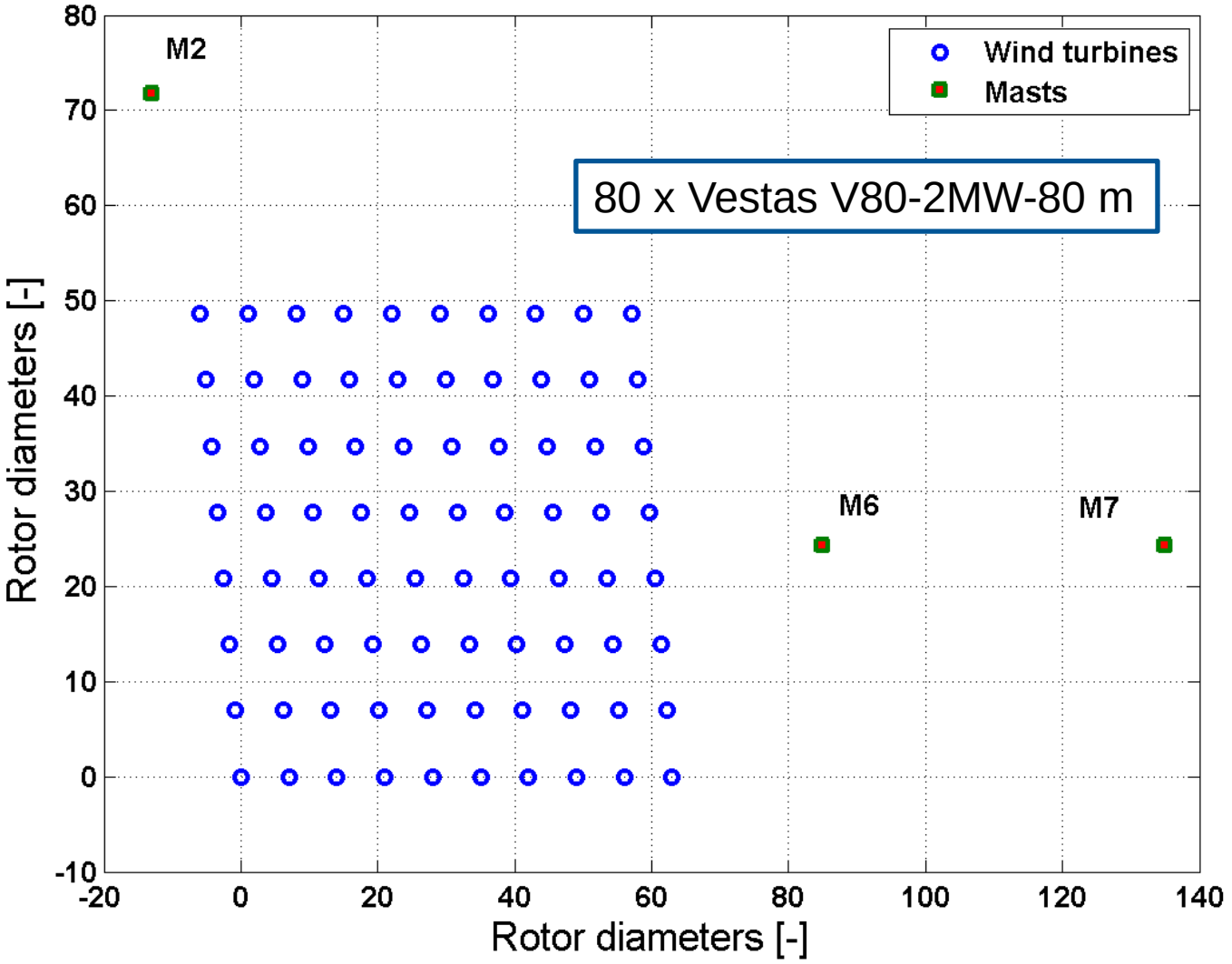
Definition of park efficiency



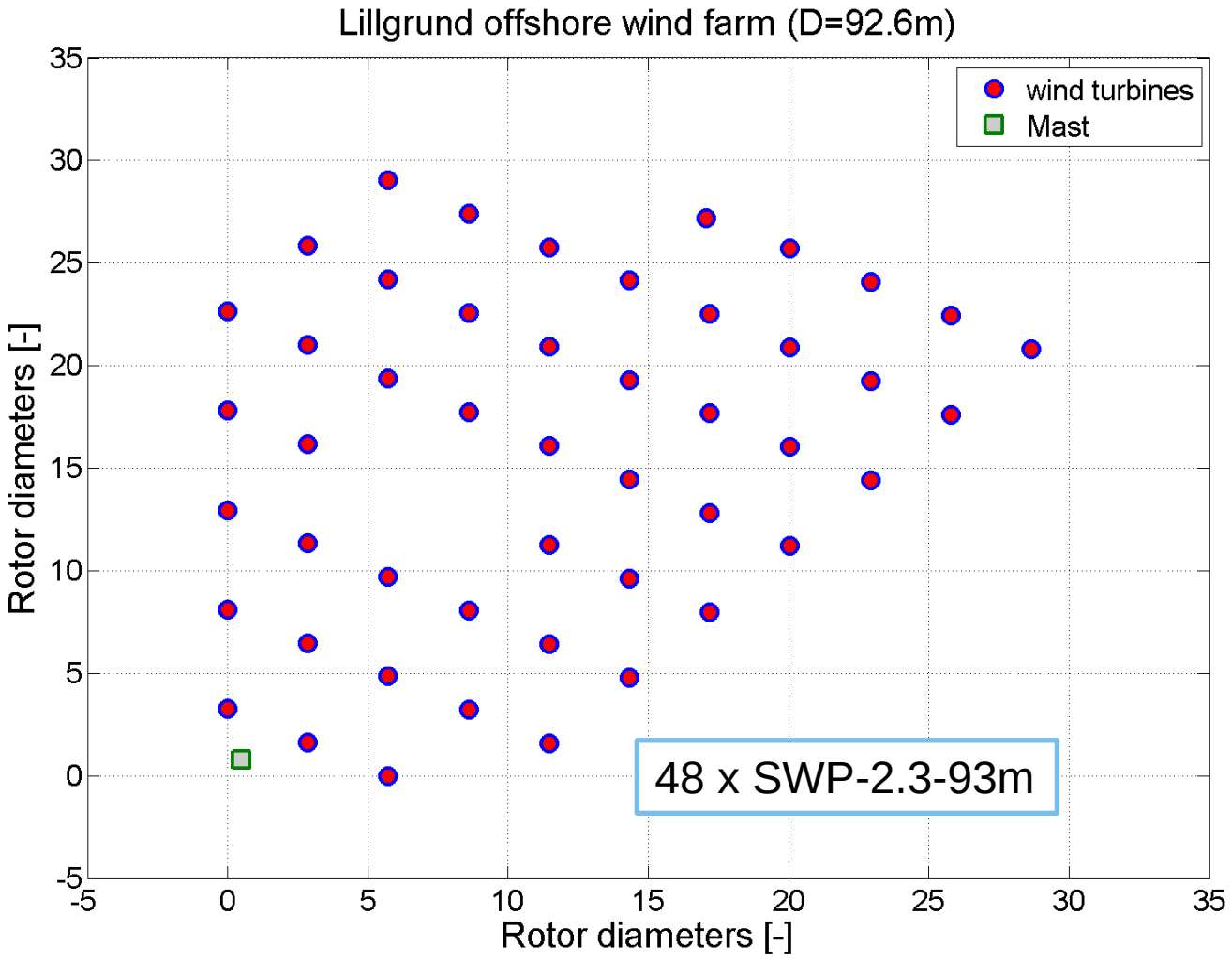
Introduction to wind farms

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

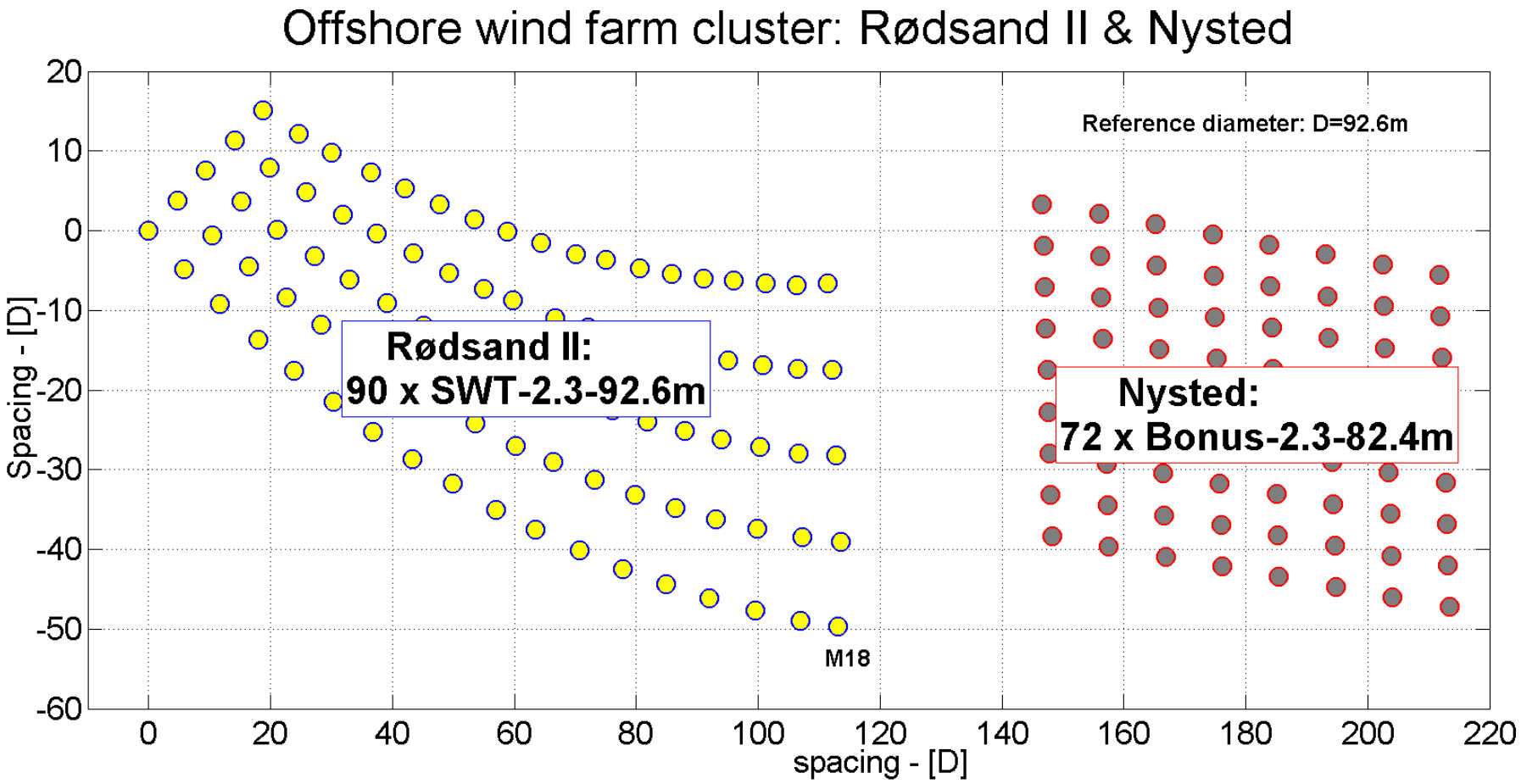
Horns Rev I offshore wind farm, DK



Lillgrund offshore wind farm, SE



Wind farm cluster: Rødsand II WF/Nysted WF

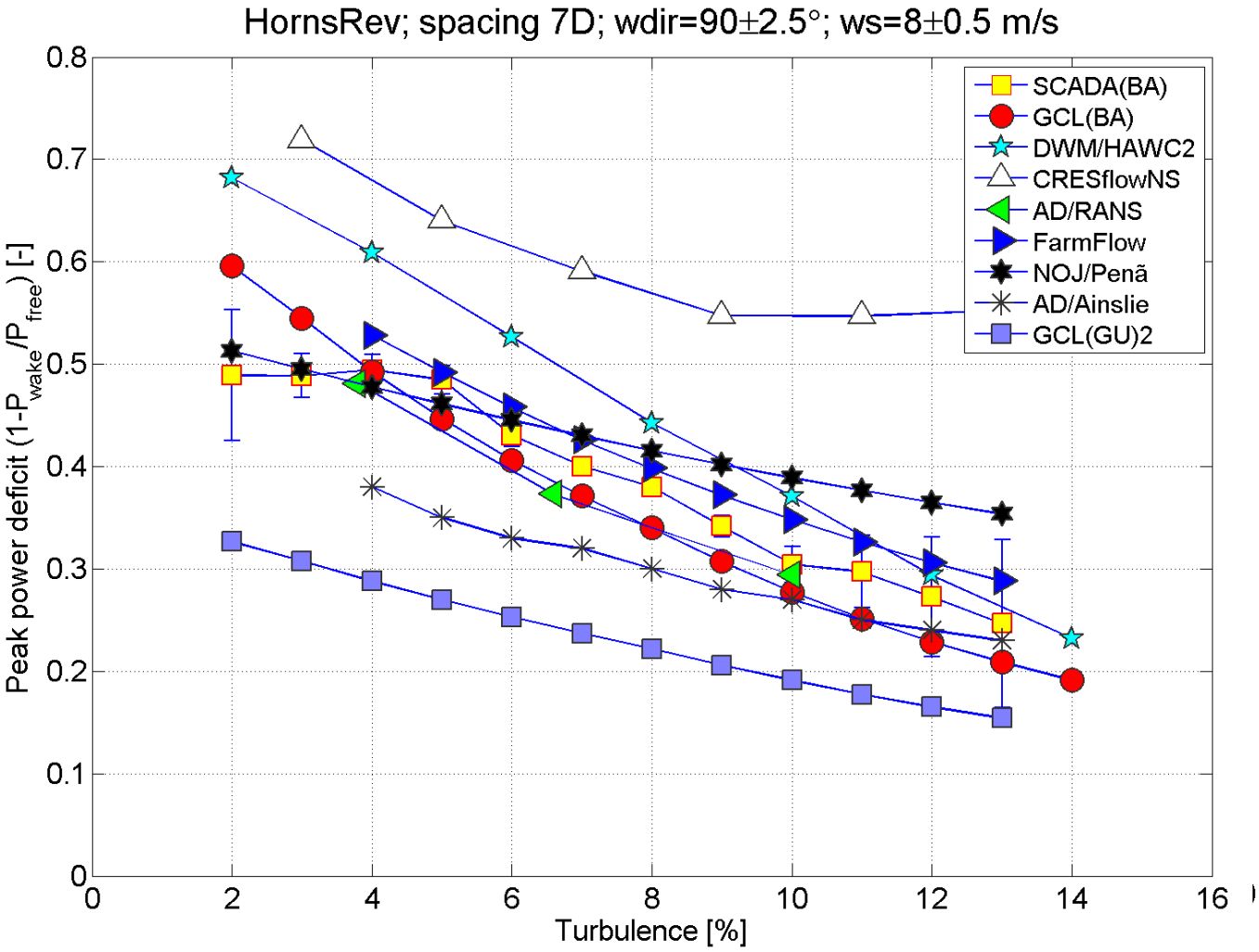


Benchmark participants and models

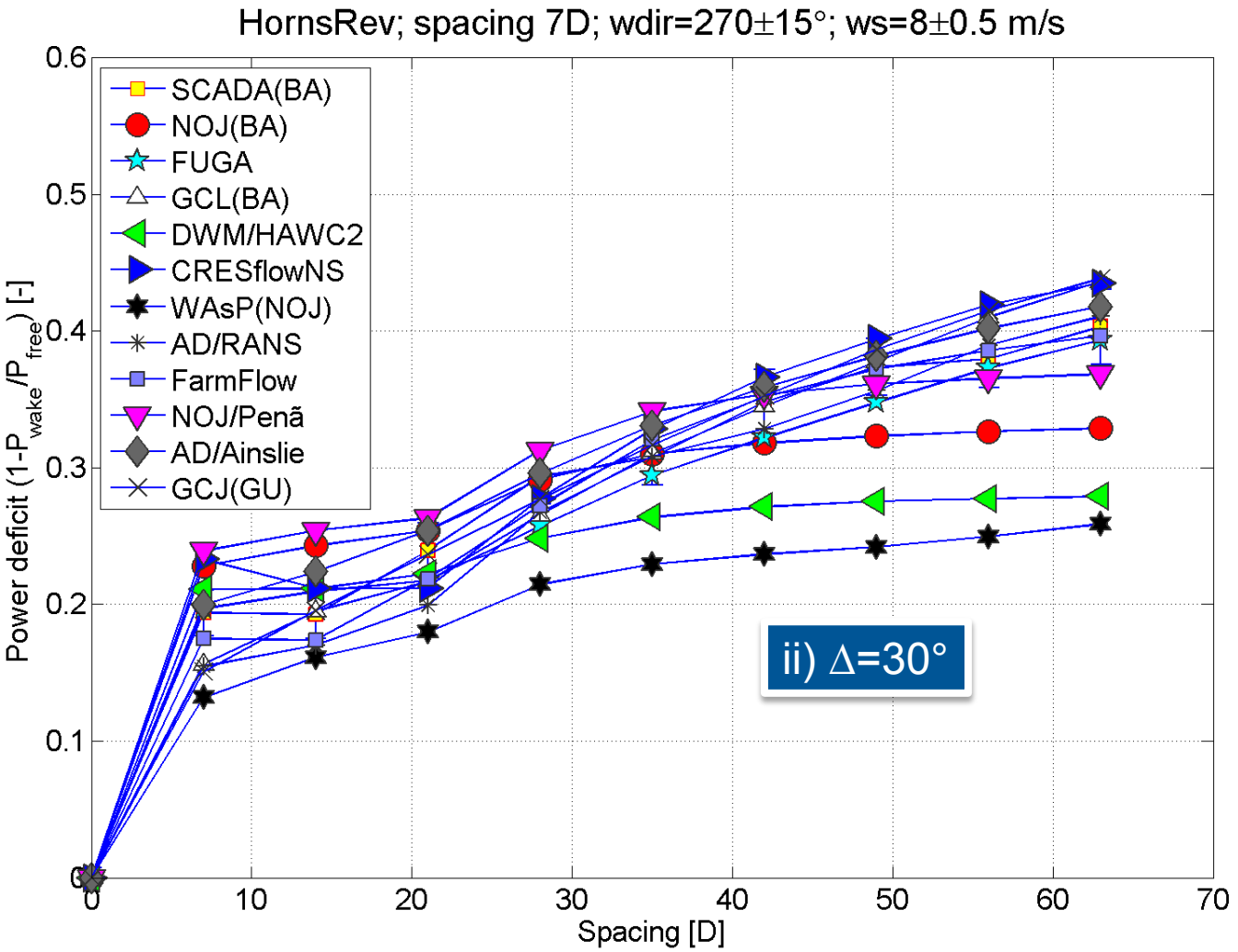
Models	Affiliation	Horns Rev WF	Lillgrund WF	Rødsand II WF	Rødsand II/Nysted WF
SCADA/BA	DTU Wind Energy/K.S.Hansen	x	x	x	(x)
NOJ/BA	DTU Wind Energy/misc		x		
NOJ/GU	DTU Wind Energy/misc		x	x	
NOJ/BA	DTU Wind Energy/A. Pena	x	x	x	
WASP/NOJ	Indiana Uni/RB	x			
GCL/BA	DTU Wind Energy/misc		x		
GCL/GU	DTU 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

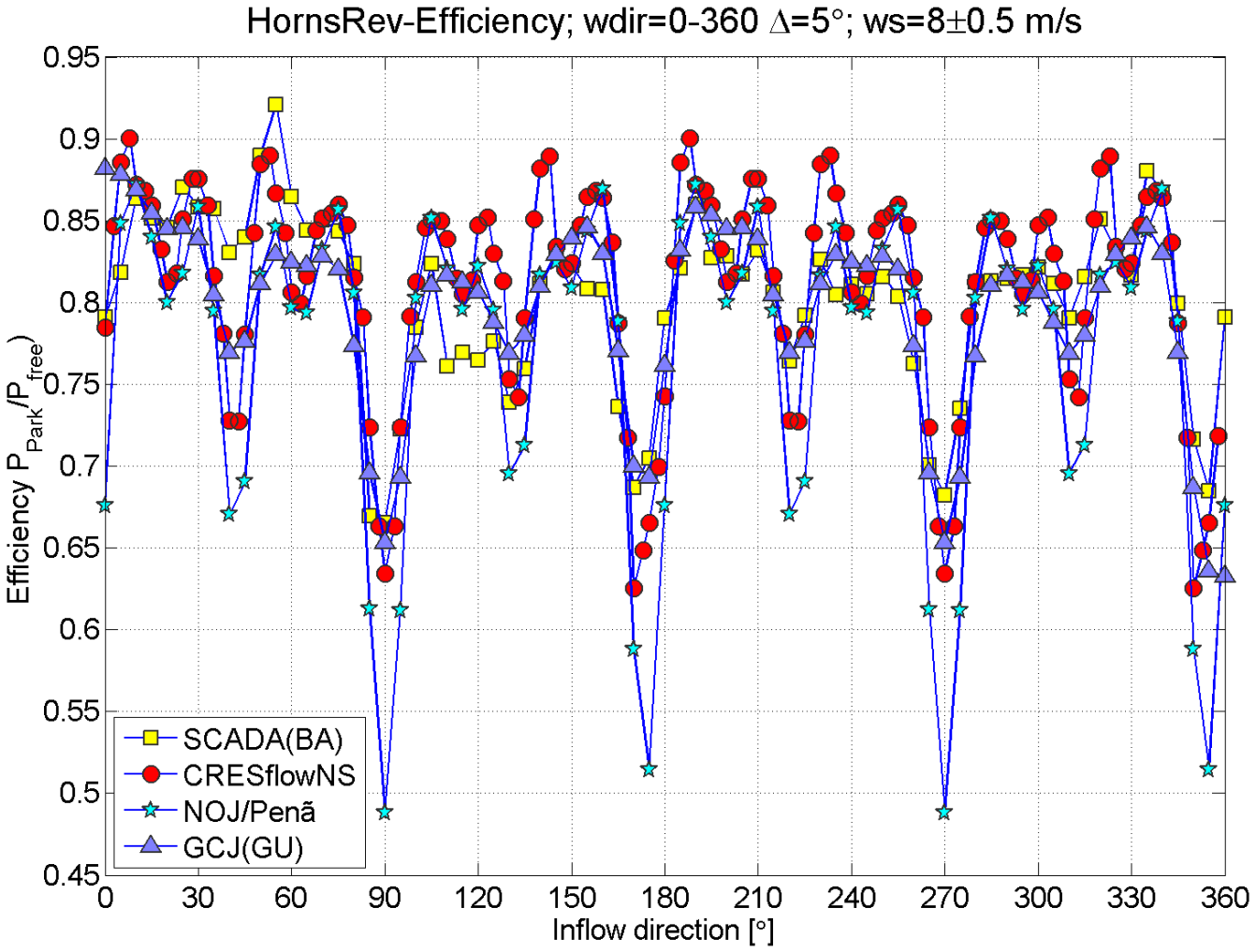
Results from Horns Rev benchmark



Results from Horns Rev benchmark



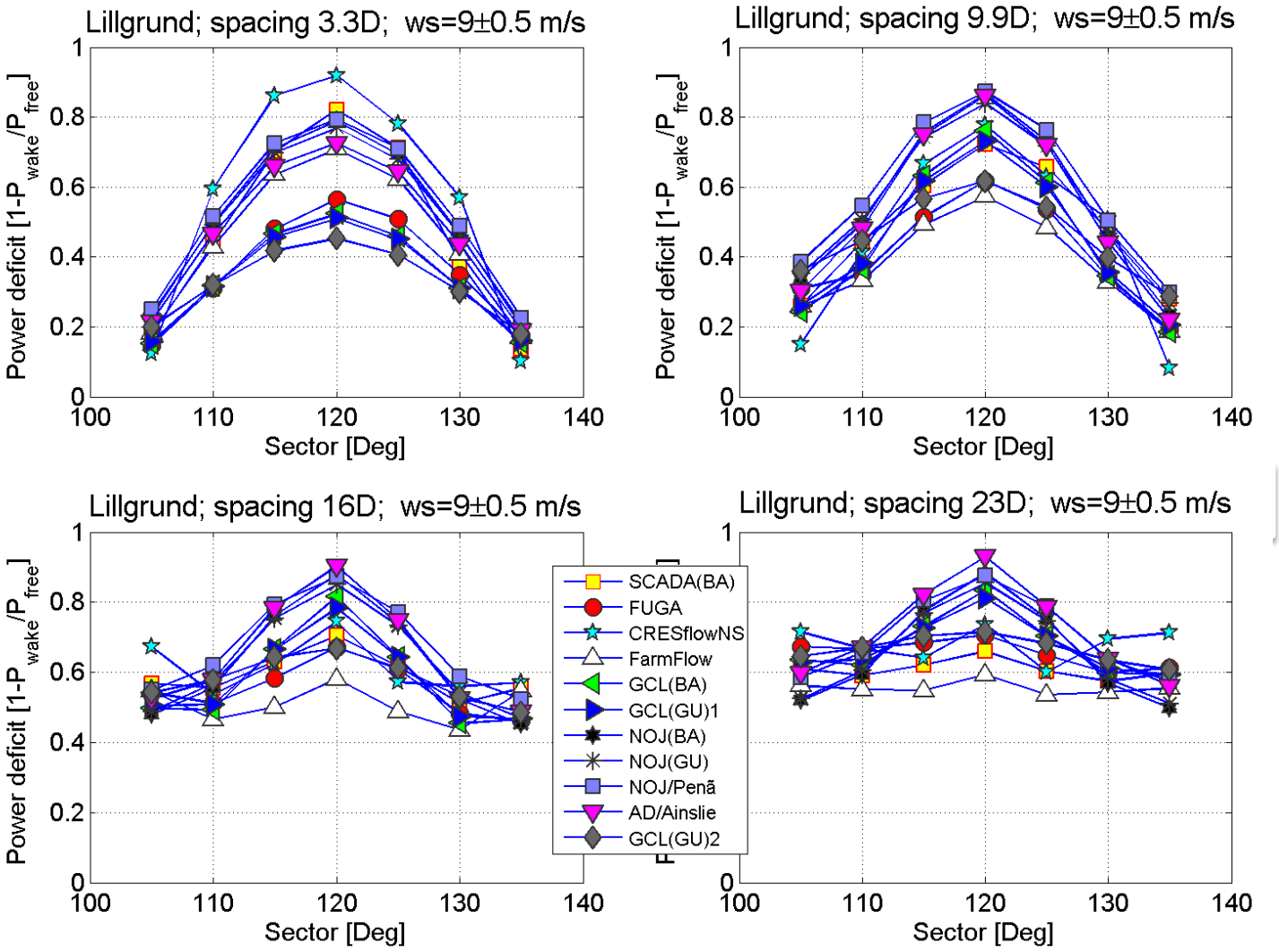
Horns Rev park efficiency; 0 - 360°



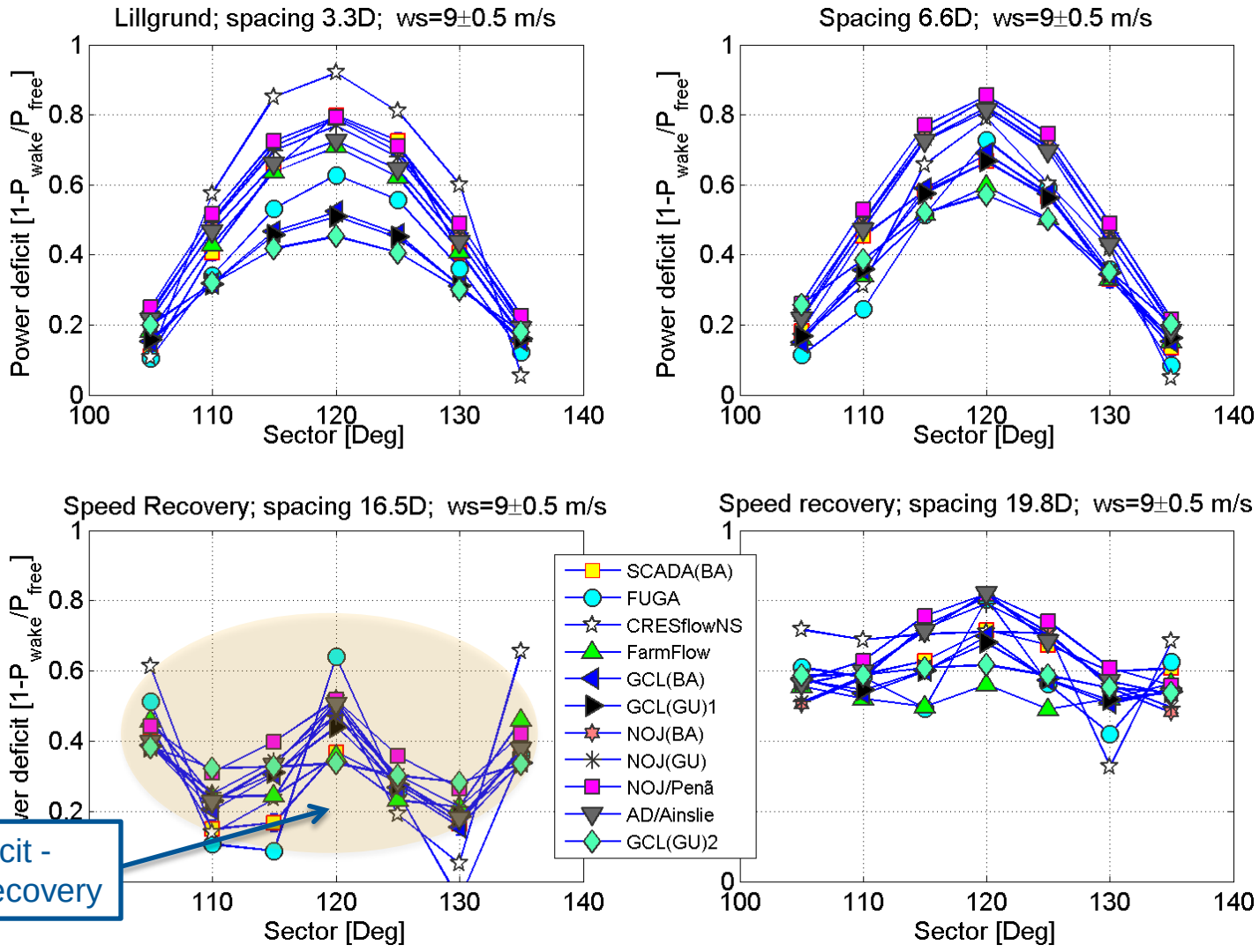
Horns Rev benchmark - discussion

- 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

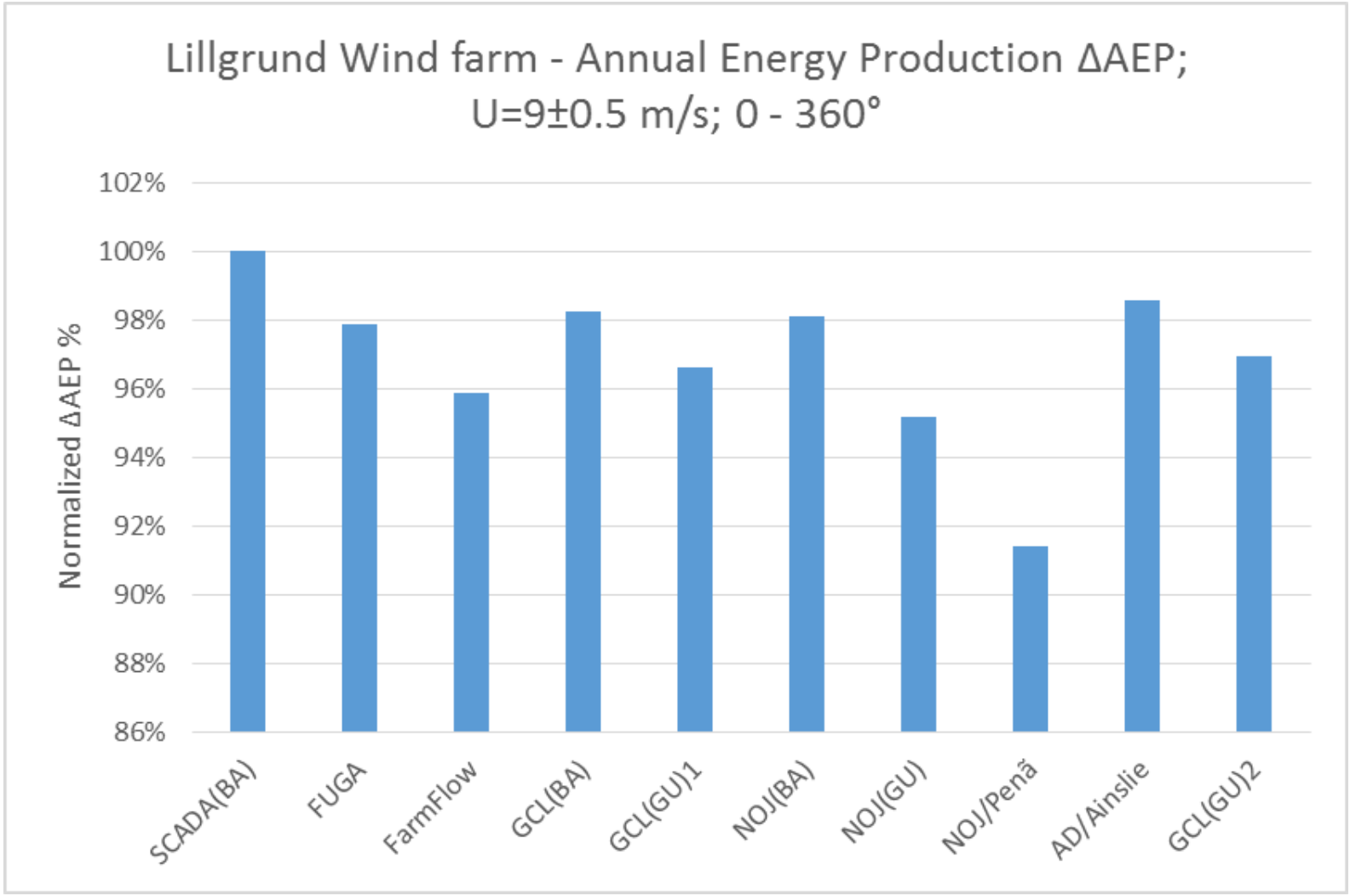


Lillgrund offshore wind farm – 3.3 D spacing



Decreased deficit - due to speed recovery

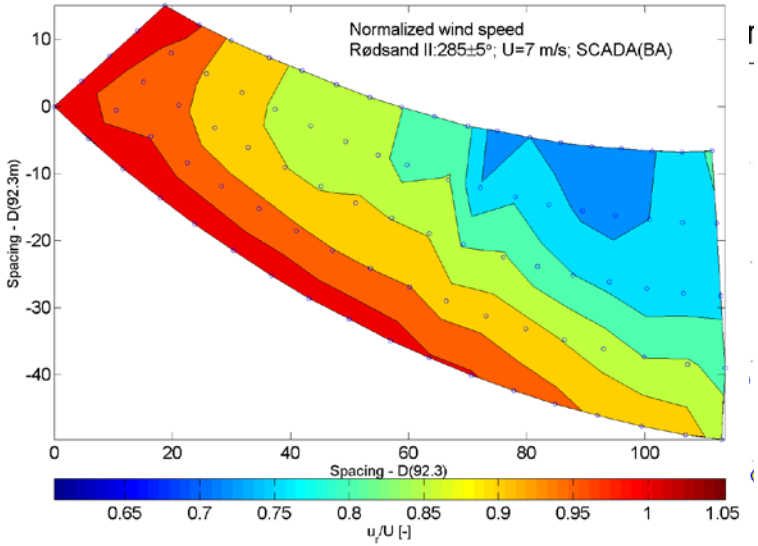
Lillgrund Park efficiency: 0 - 360°

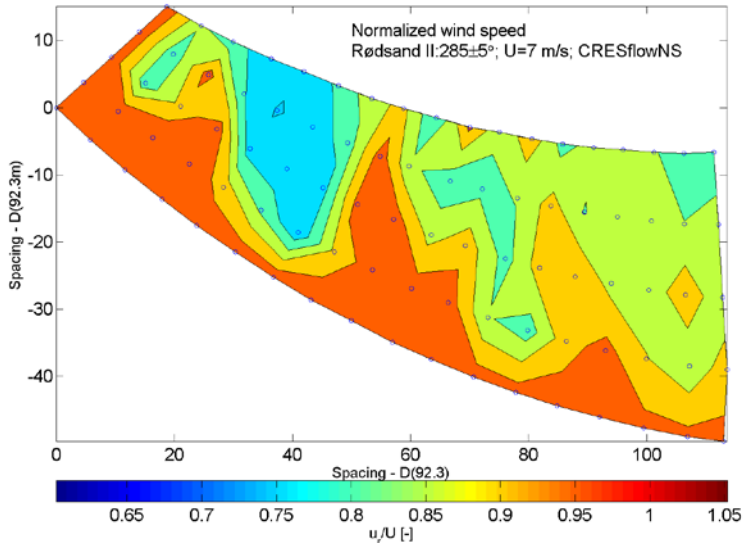


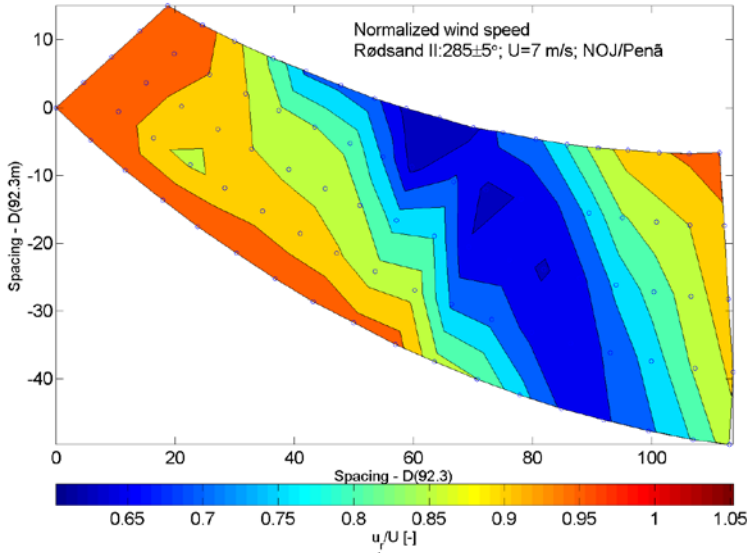
Lillgrund benchmark - discussion

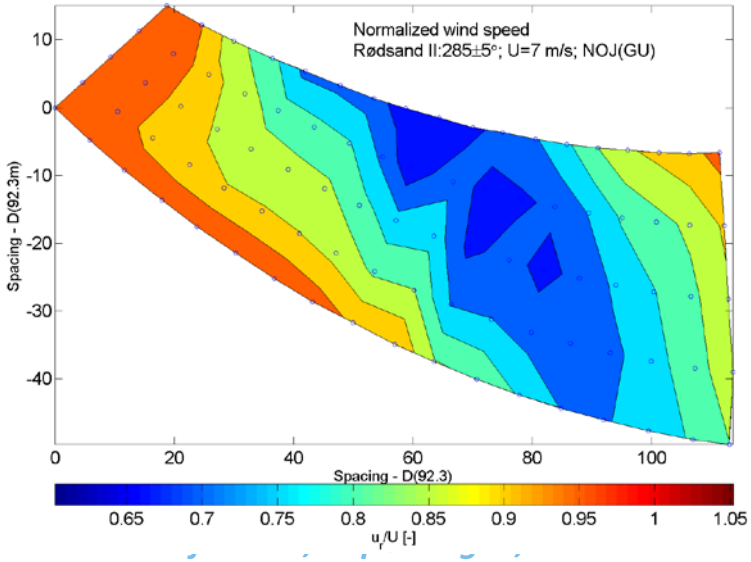
- All models handles 3.3 and 4.3D spacing well;
- All models handles the speed recovery due to ”missing” turbines;
- All models ware able to simulate the park efficiency for 0 - 360° inflow;
- The simulated ΔAEP demonstrates a variation of ±3% compared to the measured value;

Rødsand II wind farm – variable spacing

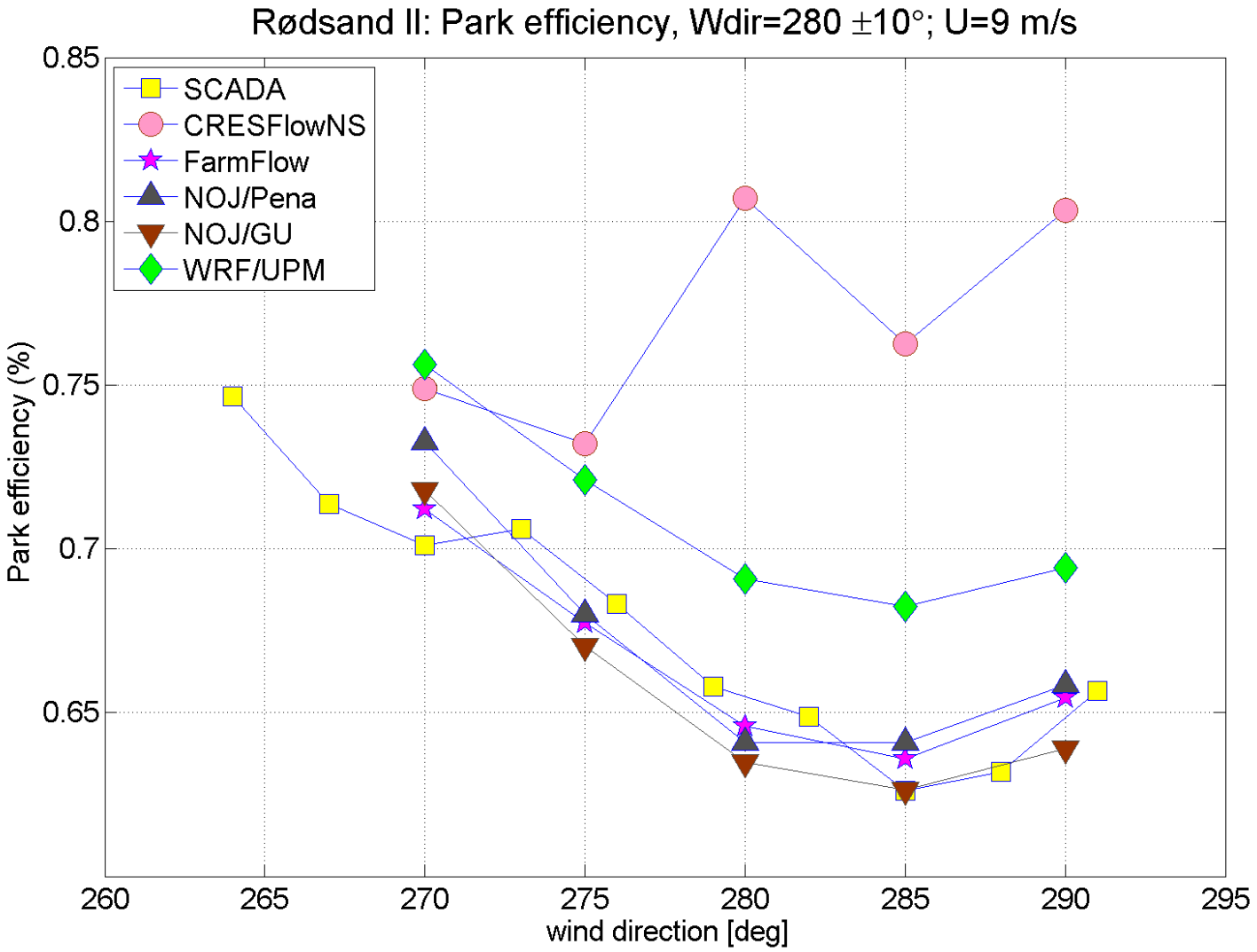




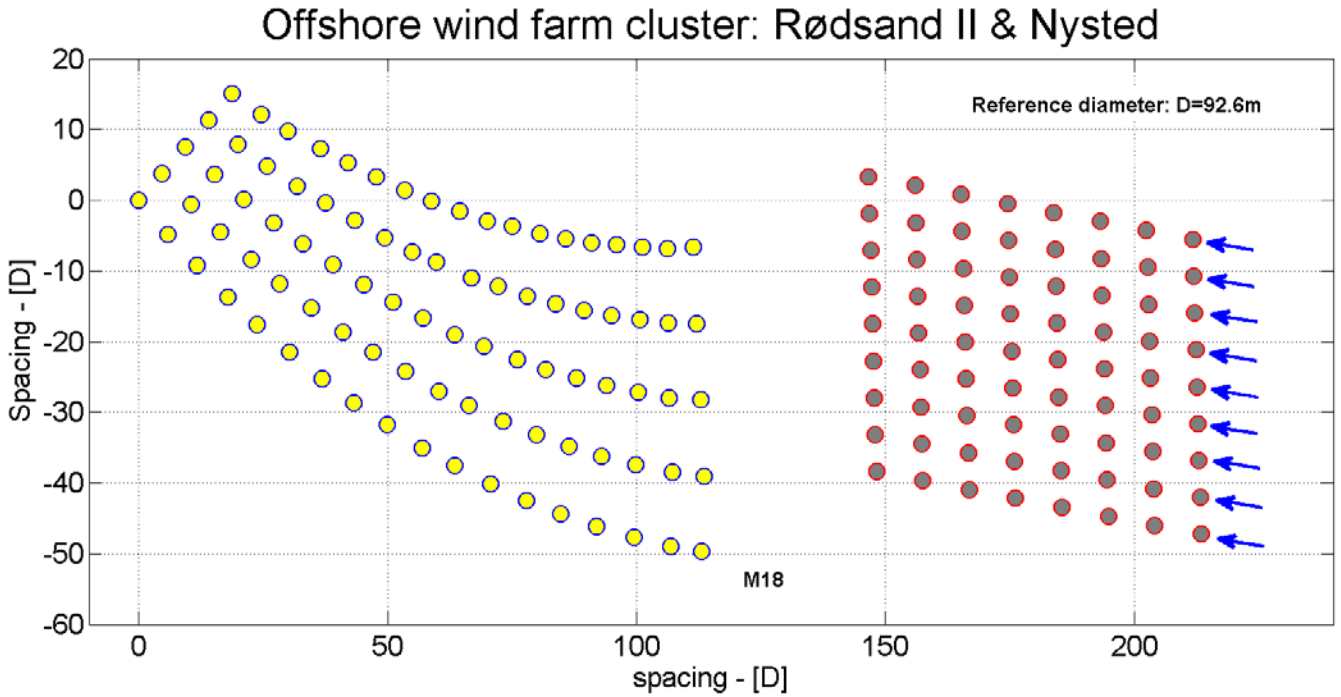




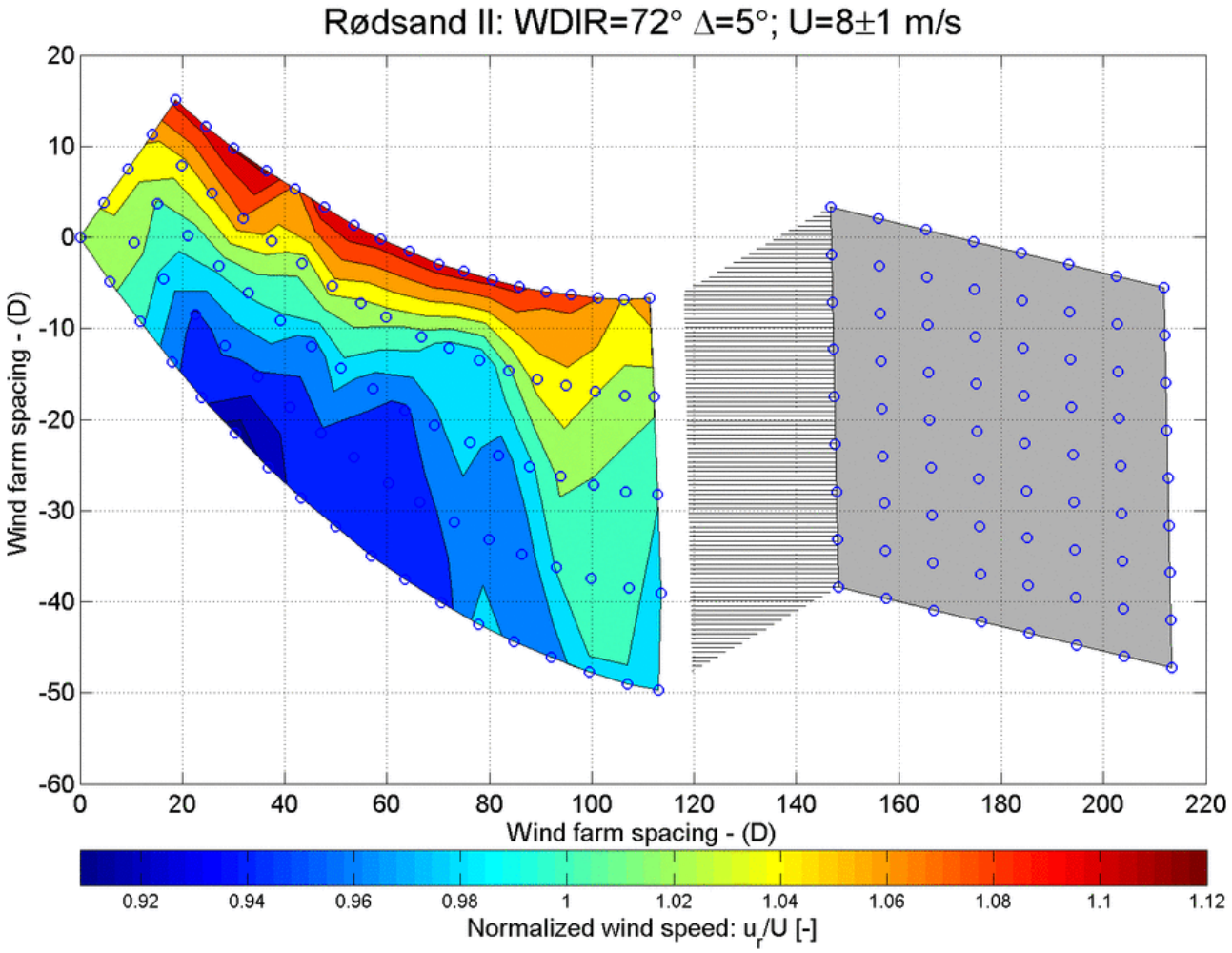
Rødsand II wind farm – park efficeincy



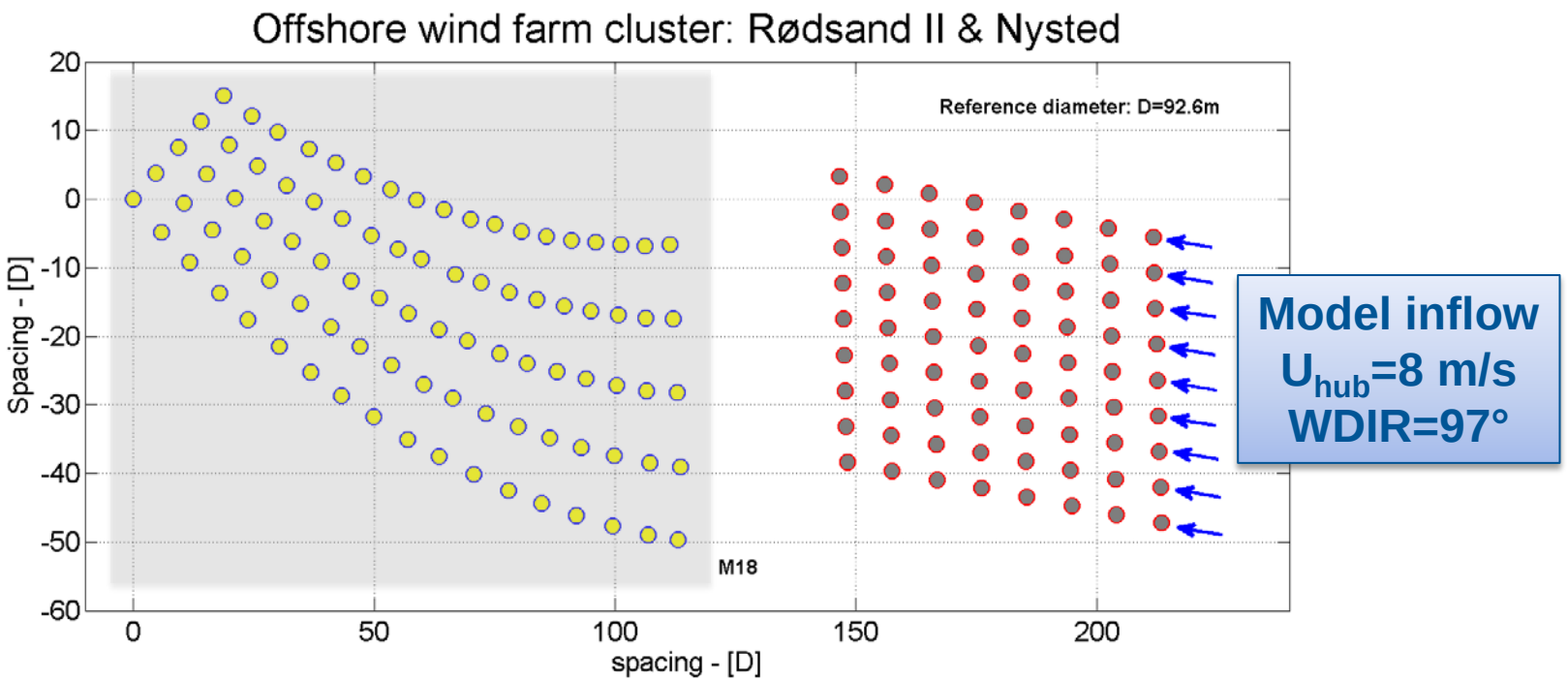
Measured wind farm cluster effects.



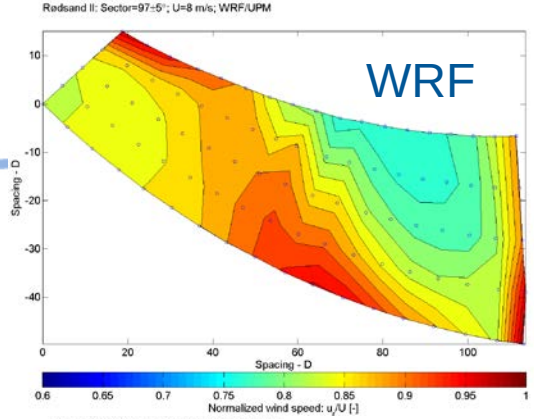
Measured wind farm cluster effects.

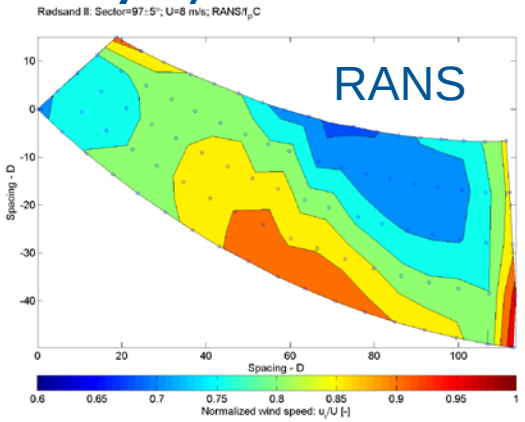


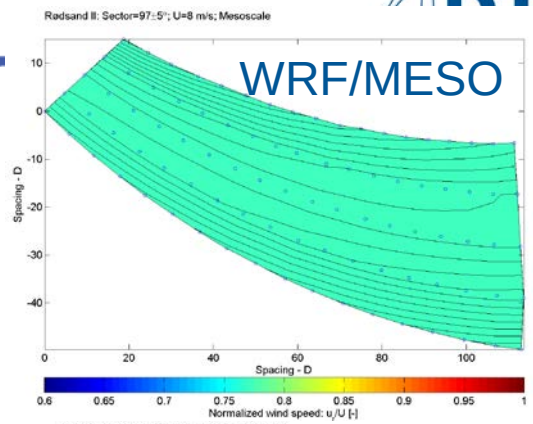
Offshore wind farm cluster effects.

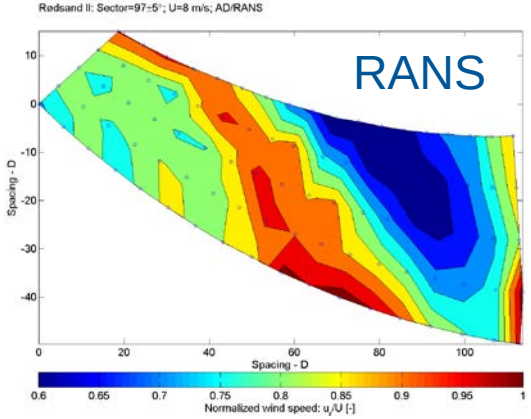


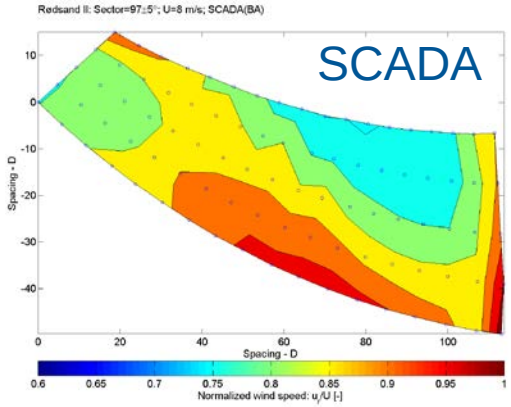
Cluster effect for U=8 m/s; WD=97°

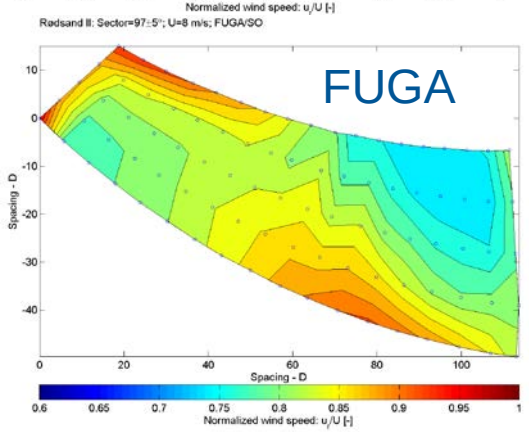


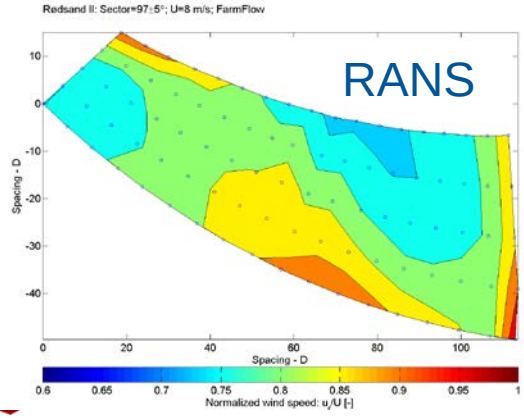


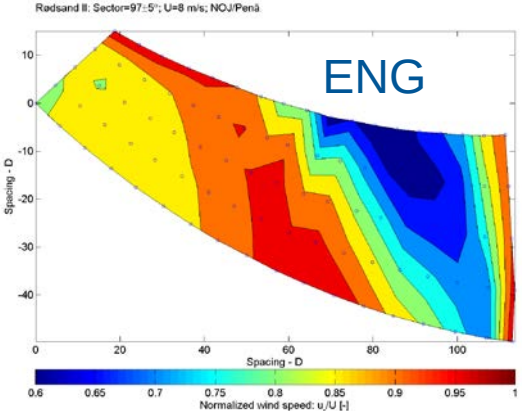


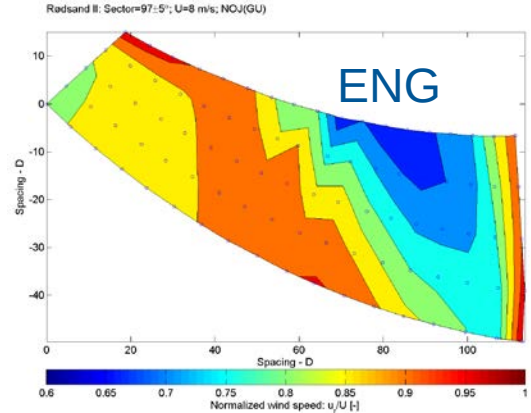




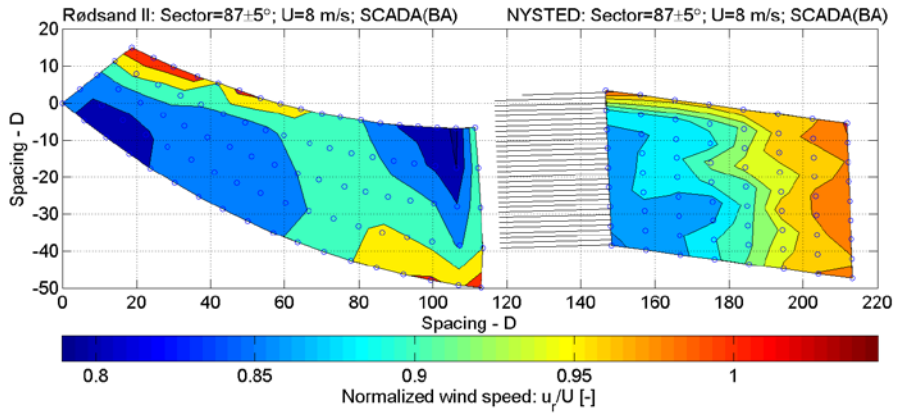


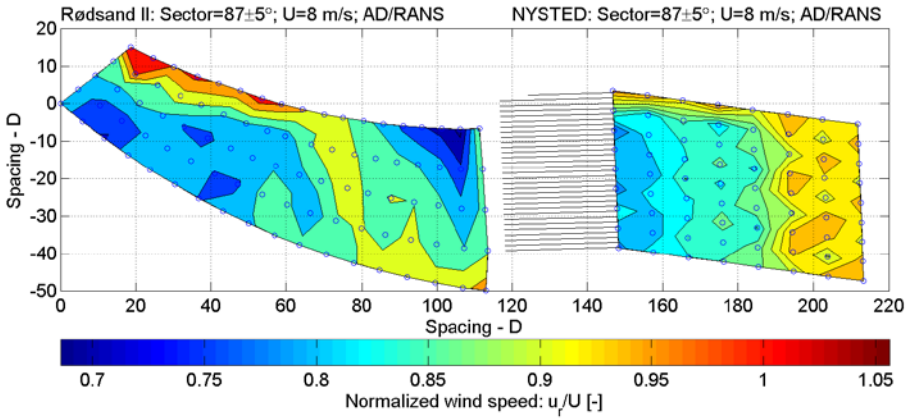


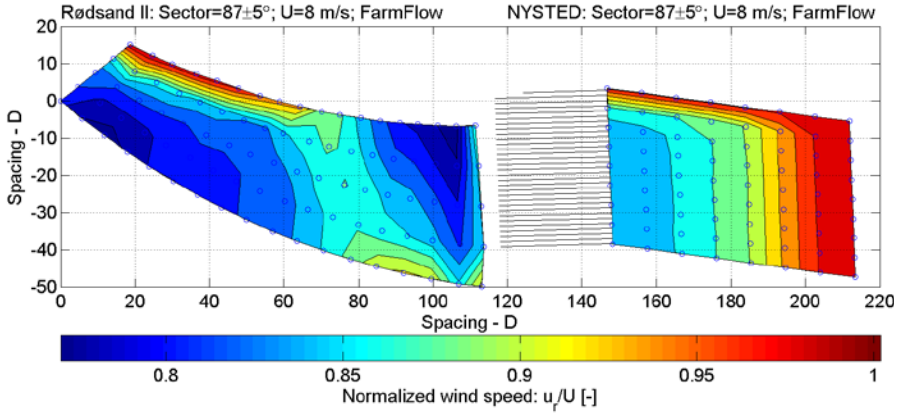


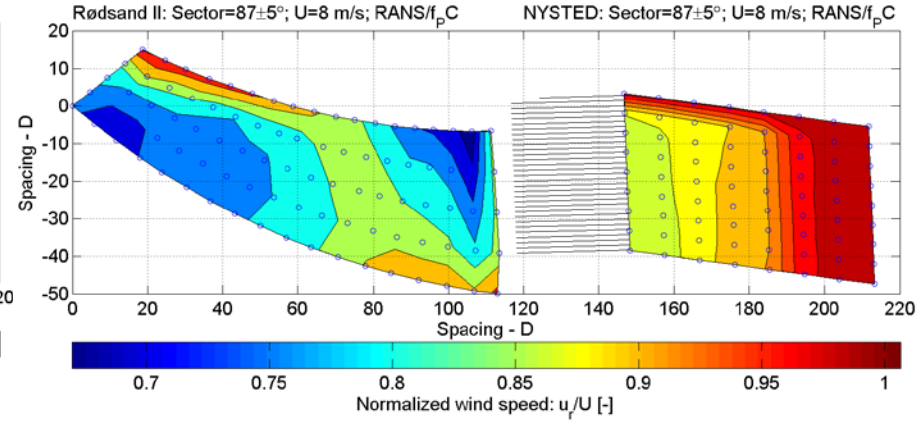


Cluster modeling results, U=8 m/s; WD=87°

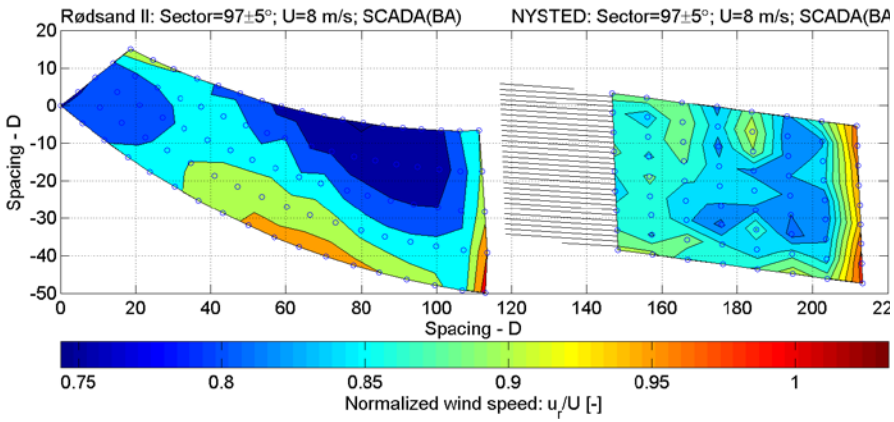


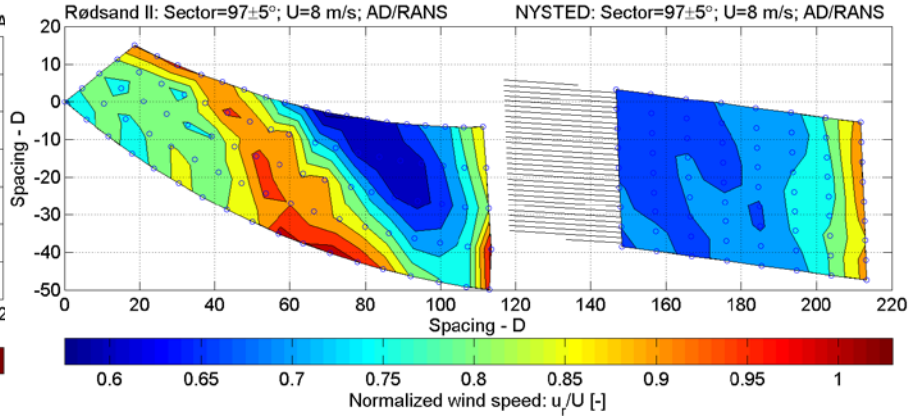


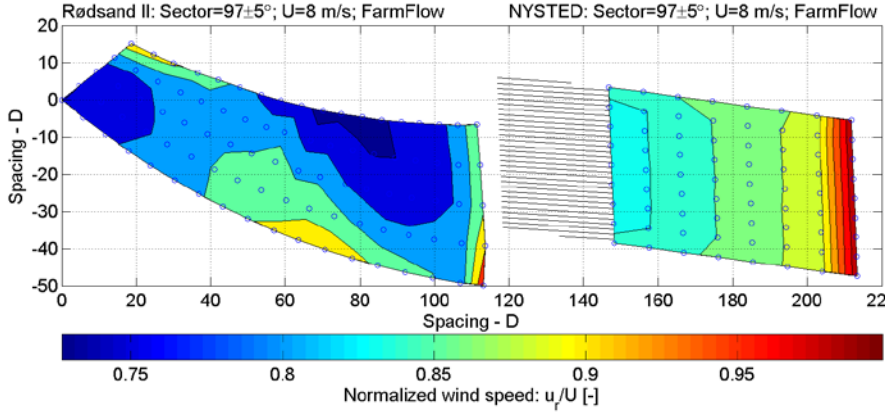


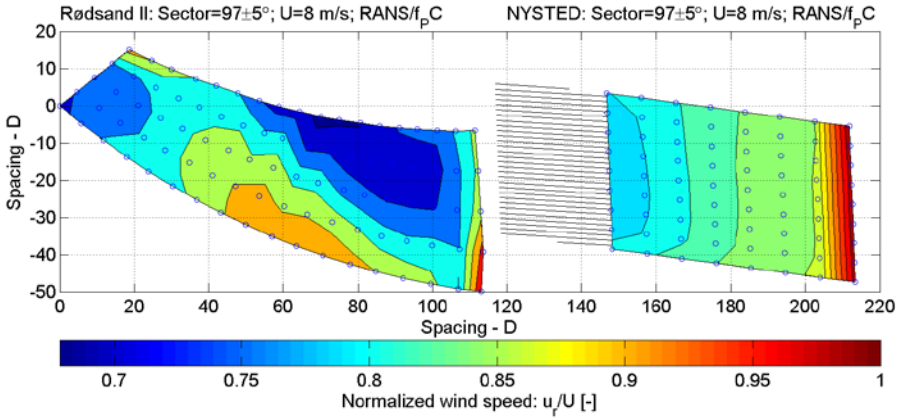


Cluster modeling results, U=8 m/s; WD=97°

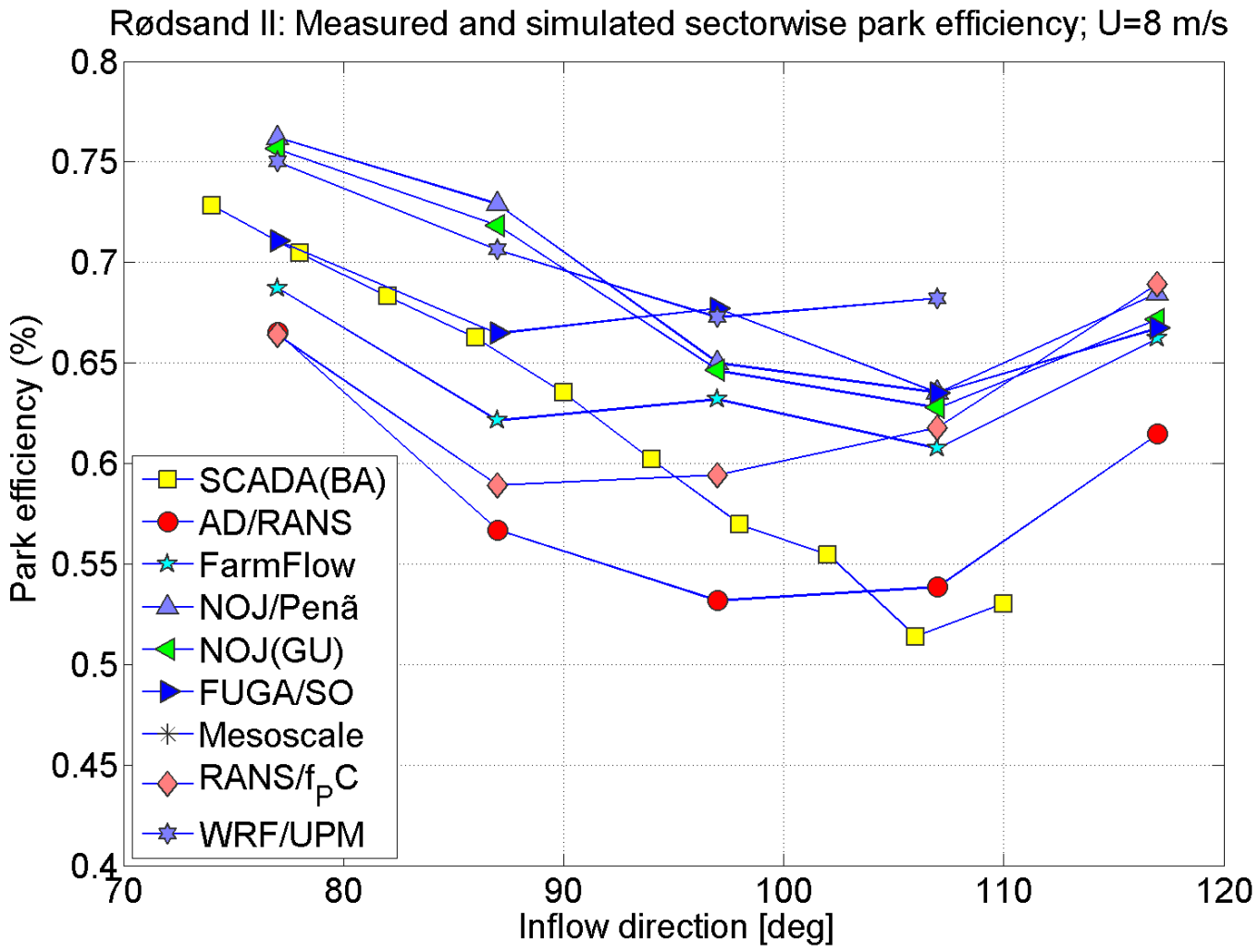








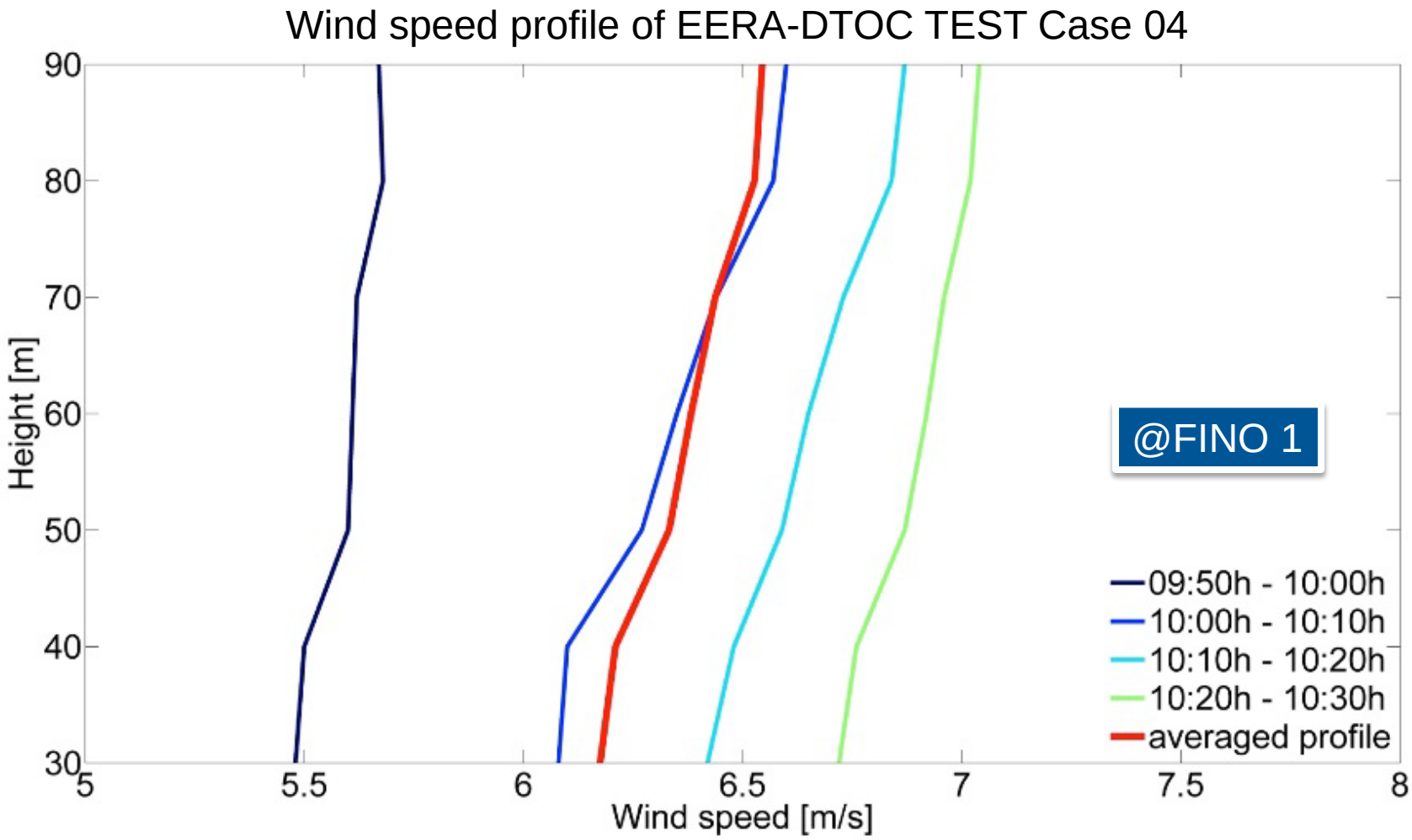
Park efficiency comparison



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 behind Alpha Ventus WF



Alpha Ventus wind farm wake verification
Results and discusion

- The comparison represent 40 minutes of 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 do match well the initial wakes from the AREVA turbines.
- The modeled Senvion wakes deviates from the measured, probably caused by a change in the wind direction (5-10°).

Acknowledgements

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