EERA DTOC wake results offshore

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EERA DTOC

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

Support by

Content

- EERA DTOC project in brief
- Wake results at Lillgrund offshore wind farm
- Wake results at Horns Rev 1 offshore wind farm

European Energy Research Alliance: EERA

Design Tool for Offshore wind farm Clusters: DTOC

EERA DTOC project partners

- DTU Wind Energy (former Risø)
- Fraunhofer IWES
- CENER
- ECN
- EWEA
- SINTEF
- ForWind
- CRES
- CIEMAT
- University of Porto
- University of Strathclyde
- Indiana University
- CLS
- Statkraft
- Iberdrola Renovables
- Statoil
- Overspeed
- BARD
- Hexicon
- Carbon Trust
- E.On
- RES

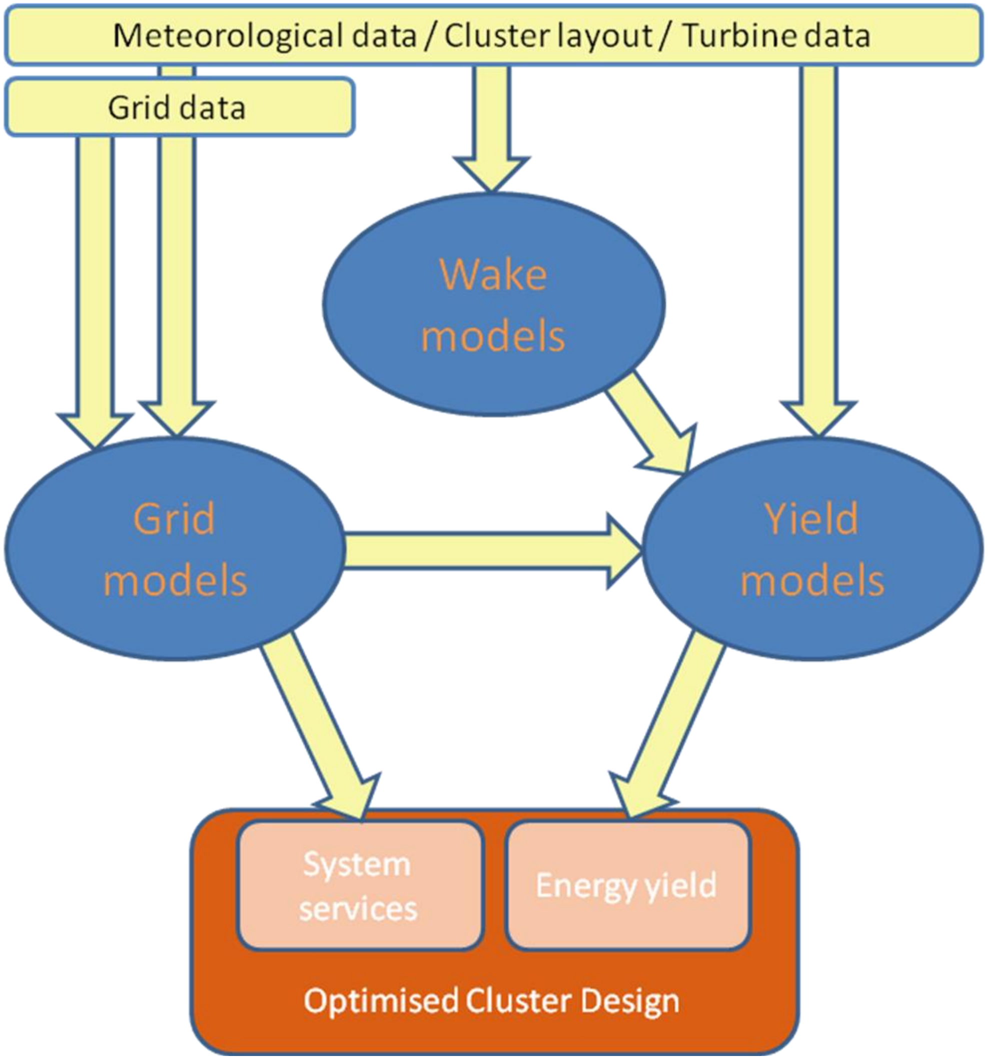
Plus acknowledgment for collaboration with Vattenfall and DONG energy

EERA DTOC vision

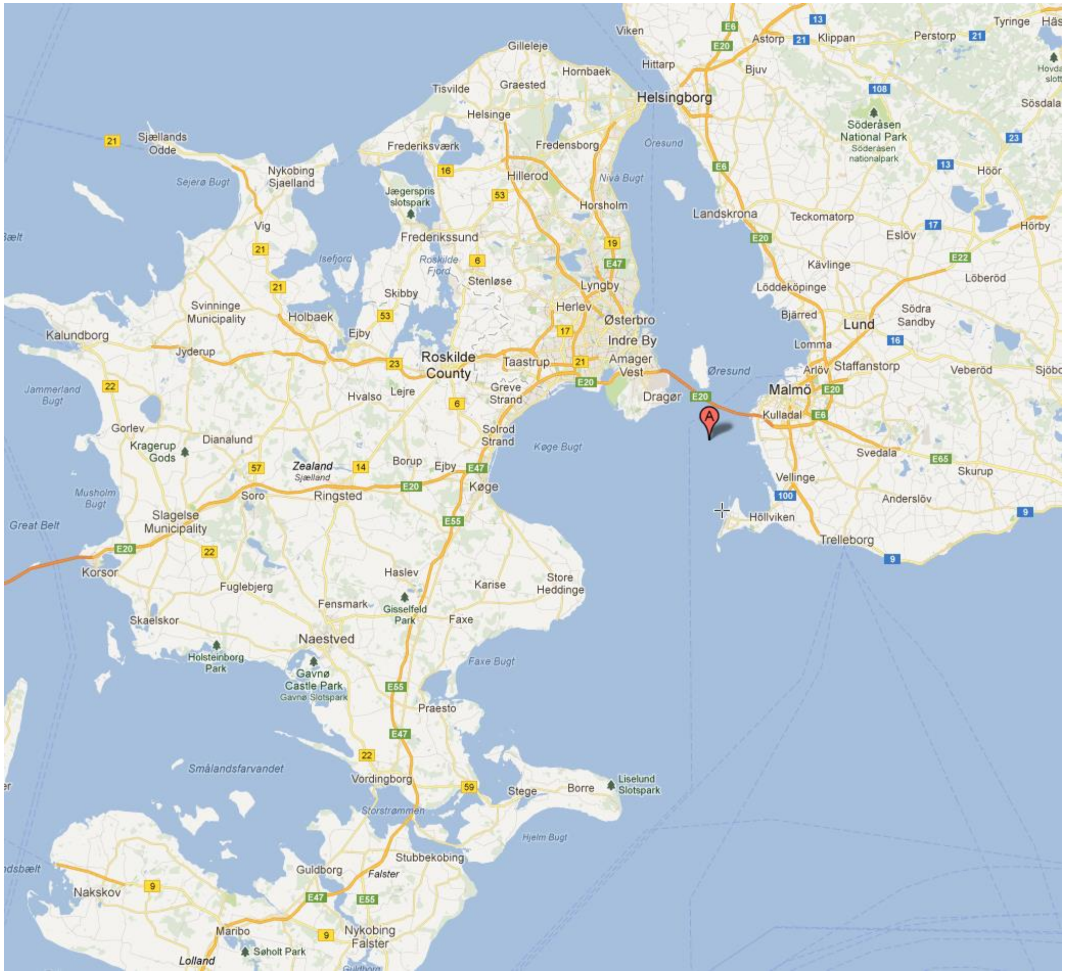
- A **robust, efficient, easy to use** and flexible tool created to facilitate the **optimised design** of individual and clusters of offshore wind farms.

- A keystone of this optimisation is the precise prediction of the future **long term wind farm energy yield** and its associated uncertainty.

EERA DTOC concept

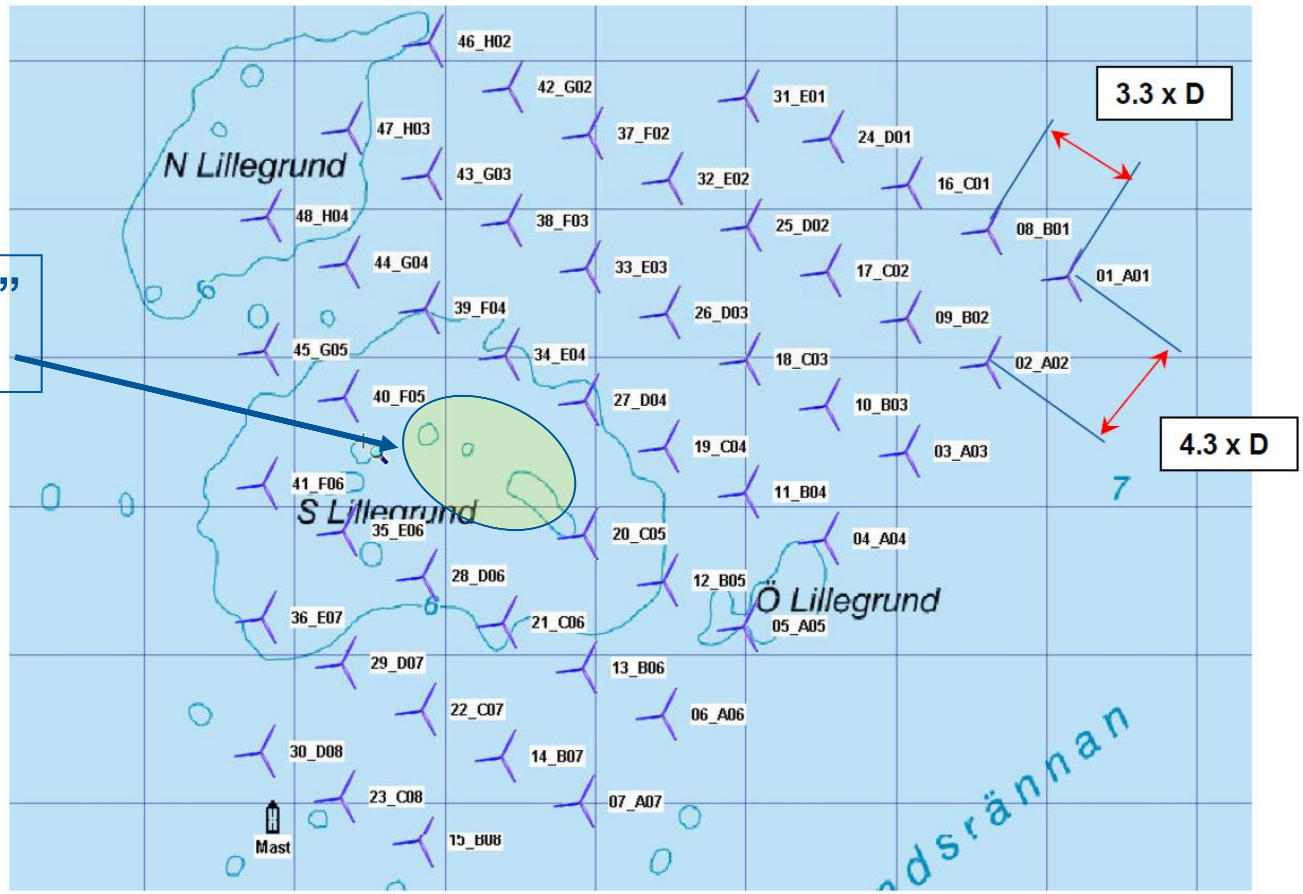


Lillgrund offshore wind farm



Layout of the Lillgrund offshore wind farm (Dahlberg, 2009)

2 "missing" turbines



8 Rows of turbines: NE => SW
8 Columns of turbines: SE => NW

Lillgrund available measurements

EERA DTOC

- 65 m mast
- Data: wind speed, turbulence, wind direction, air temperature
- Period: 2003 to 2006 and 2008 to 2010
  (before wind farm installation with high quality and after medium quality)

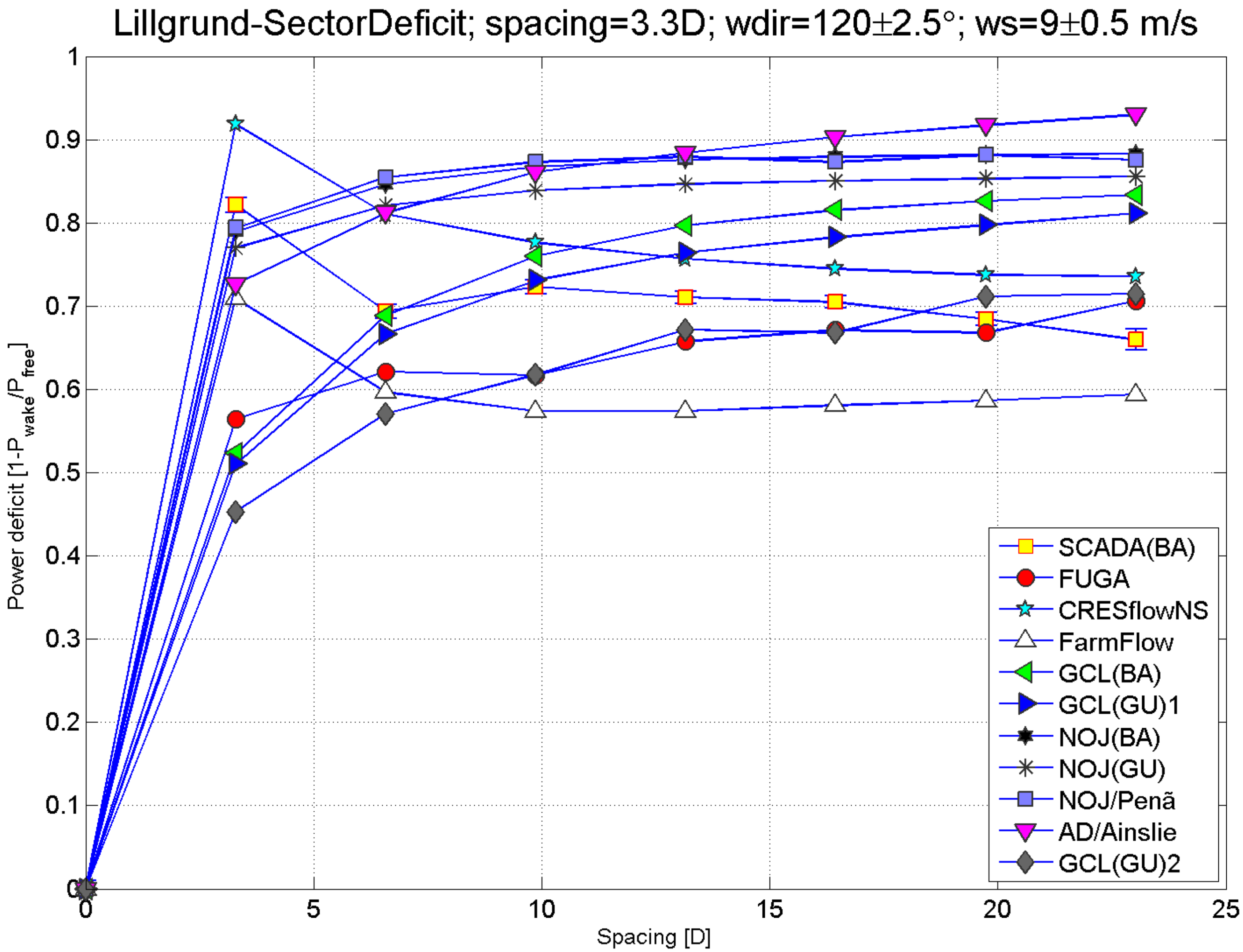
- SCADA data 10 minute statistics (mean values and stddev from each wind turbine).
- Signals: power, pitch, rpm, nacelle wind speed and position
- Period: 2008 to 2012.

Benchmark matrix

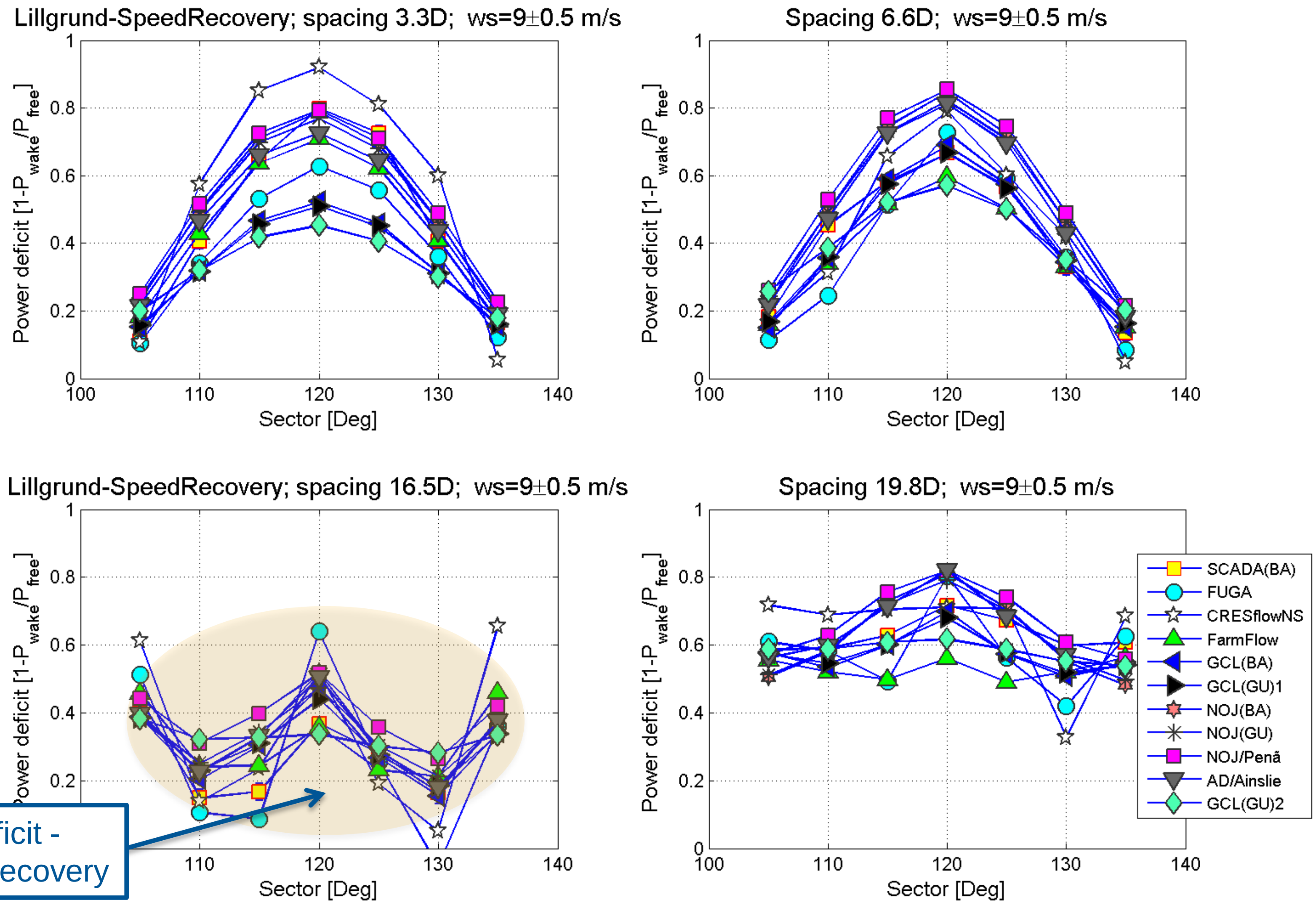
EERA-DTOC		Complete rows		Missing turbine(s)		Turbulence		Park
Institution/model		Row:3-120deg	Row:B-222deg	Row:5-120deg	Row:D-222deg	TI-3.3D	TI-4.3D	Efficiency
DTU	FUGA	1	1	1	1	1	1	1
CRES	CRESflowNS	1	1	1	1			
ECN	FarmFlow	1	1	1	1	1	1	1
DTU	GCJ-BinAve	1	1	1	1	1	1	1
DTU	GCJ-GauUnc	1	1	1	1	1	1	1
DTU	NOJ-BinAve	1	1	1	1			1
DTU	NOJ-GauUnc	1	1	1	1			1
DTU	NOJ(Penã)	1	1	1	1	1	1	1
RES-LTD	AD/Ainslie	1	1	1	1	1	1	1
CENER	GCJ-GauUnc	1	1	1	1	1	1	1
sum		10	10	10	10	7	7	9

63 simulation results have been provided from the 10 participants.

1 Flow case, 3.3 D spacing

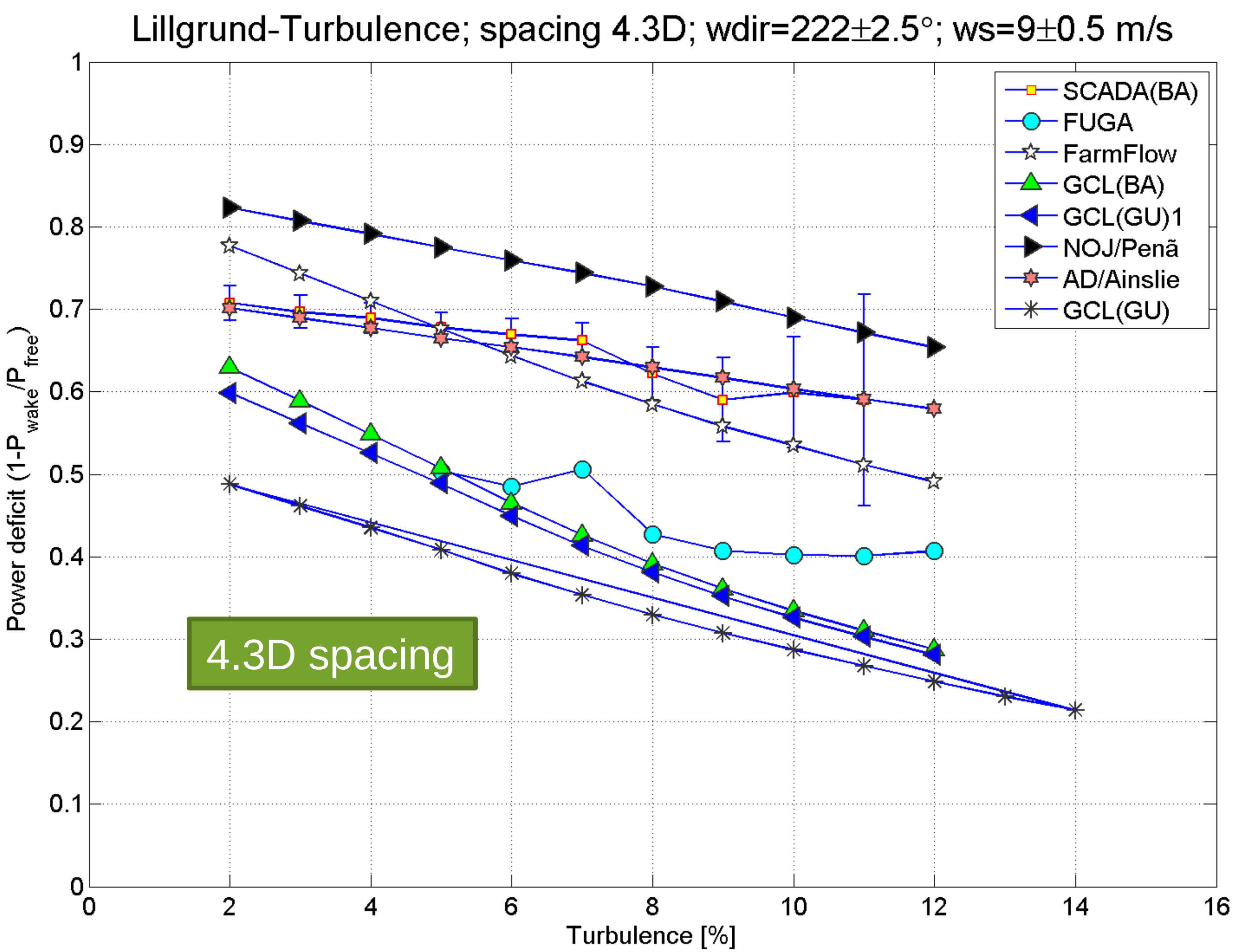


2 Flow case, 3.3 D spacing with ”missing turbines”



Decreased deficit -
due to speed recovery

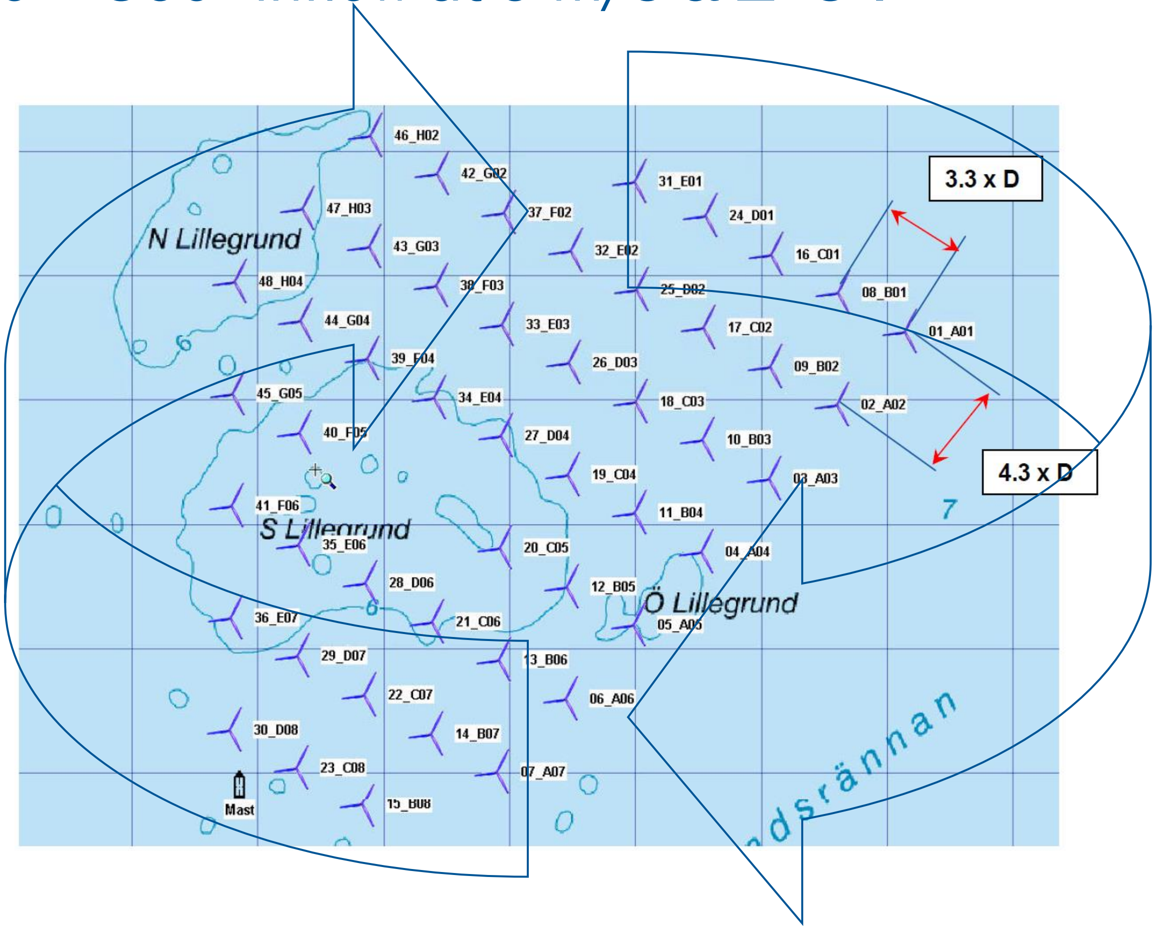
3 Flow case – turbulence dependence



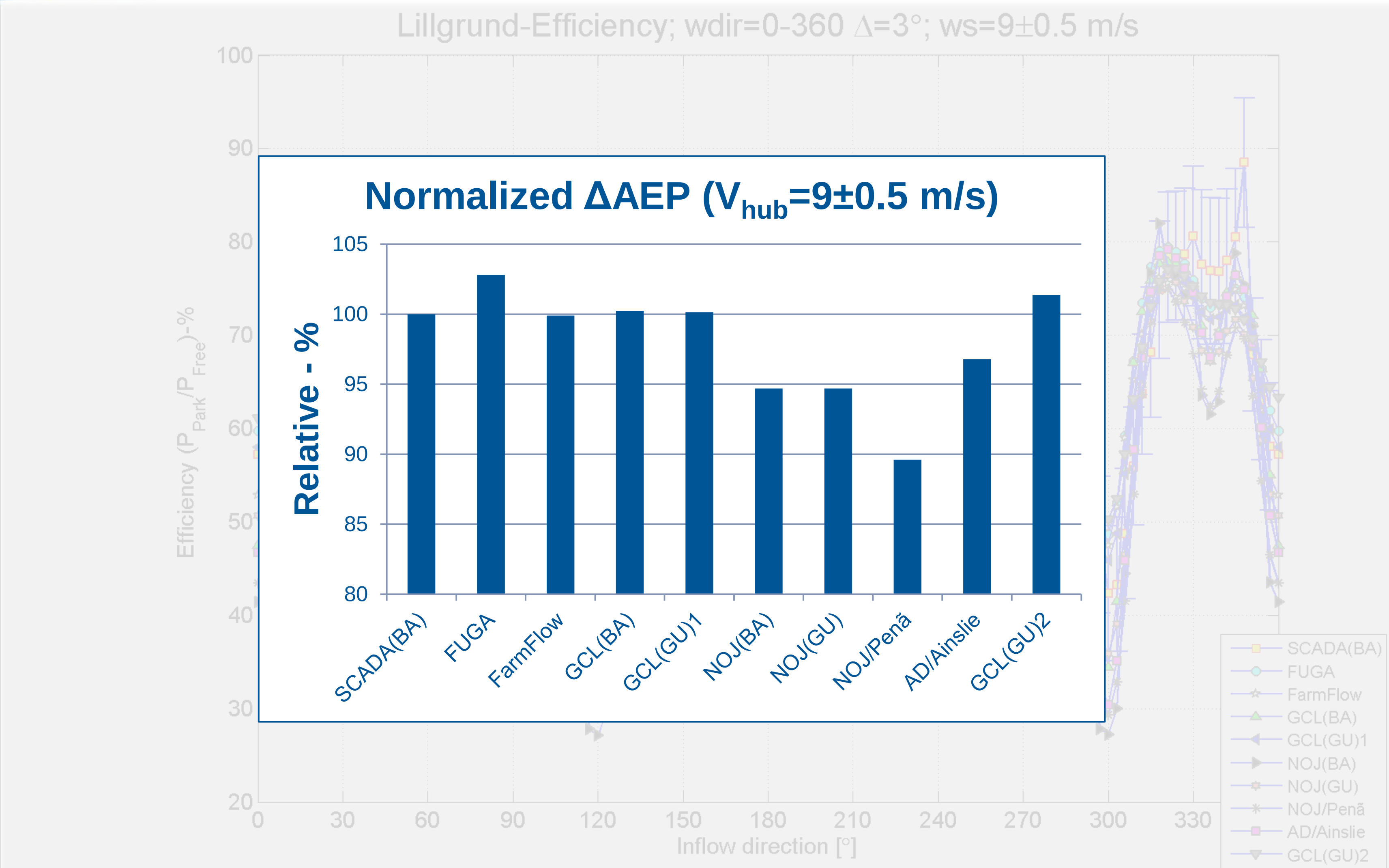
4 Flow case

Park efficiency for 0 – 360º inflow at 9 m/s & Δ=3º.

Inflow conditions:
-Wind direction (derived)
-Wind speed (derived)



4 Flow case – park efficiency



Summary on Lillgrund wake benchmark

- Good agreement between wake model results and measurements;
- All models were able to predict the increased deficit between closely spaced turbines;
- The speed recovery was well reproduced;
- Linear relation between deficit and turbulence was well reproduced;
- Park power deficit for 0 - 360º inflow was well reproduced within 4-5% at 9 m/s;

Horns Rev 1 offshore wind farm

Benchmark deals with regular 8 x 10 turbines layout and medium internal spacing (7 – 10 D);

Data are courtesy of DONG energy and Vattenfall

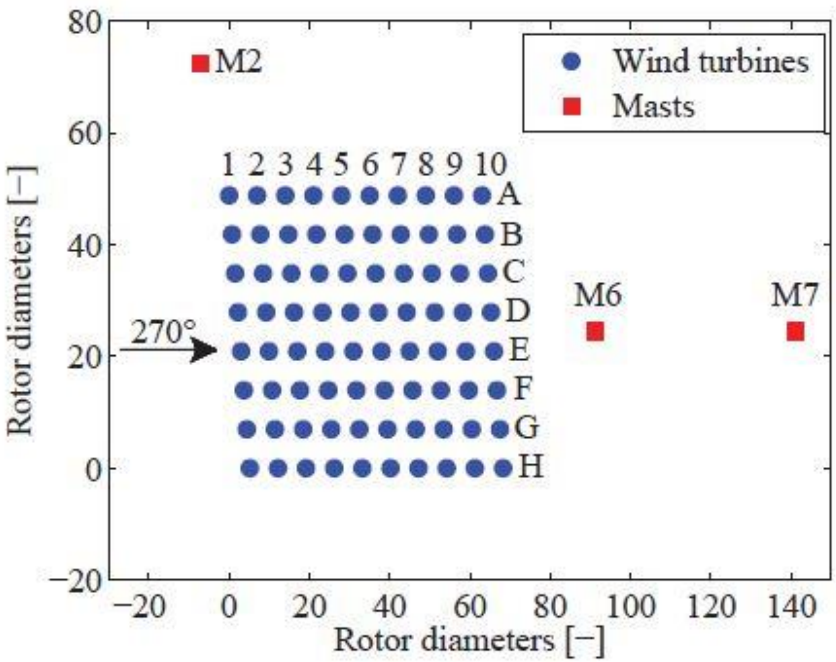


Table 1: Wake models participating in EERA-DTOC Horns Rev benchmark.

Model	Affiliation	Contacts
SCADA(BA)	DTU Wind Energy	pire@dtu.dk
NOJ(BA)	DTU Wind Energy	pire@dtu.dk
FUGA	DTU Wind Energy	pire@dtu.dk
GCL(BA)	DTU Wind Energy	pire@dtu.dk
DWM/HAWC2	DTU Wind Energy	tjul@dtu.dk
CRESflowNS	CRES	jprosp@fluid.mech.ntua.gr
WAsP/NOJ	Indiana University	rbarthel@indiana.edu
RANS	PORTO University	jpalma@fe.up.pt
FarmFlow	ECN Wind Energy	schepers@ecn.nl
Ainslie	RES-LTD	Tom.Young@res-ltd.com
NOJ/Penã	DTU Wind Energy	aldi@dtu.dk
GCL(GU)	CENER	jsrodrigo@cener.com

Kurt S. Hansen prepared the SCADA data and did the wake comparisons

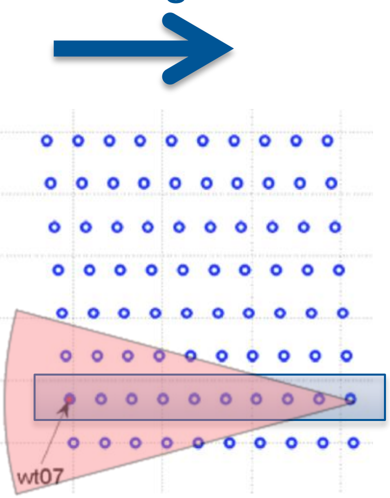
Horns Rev 1 wake bench results

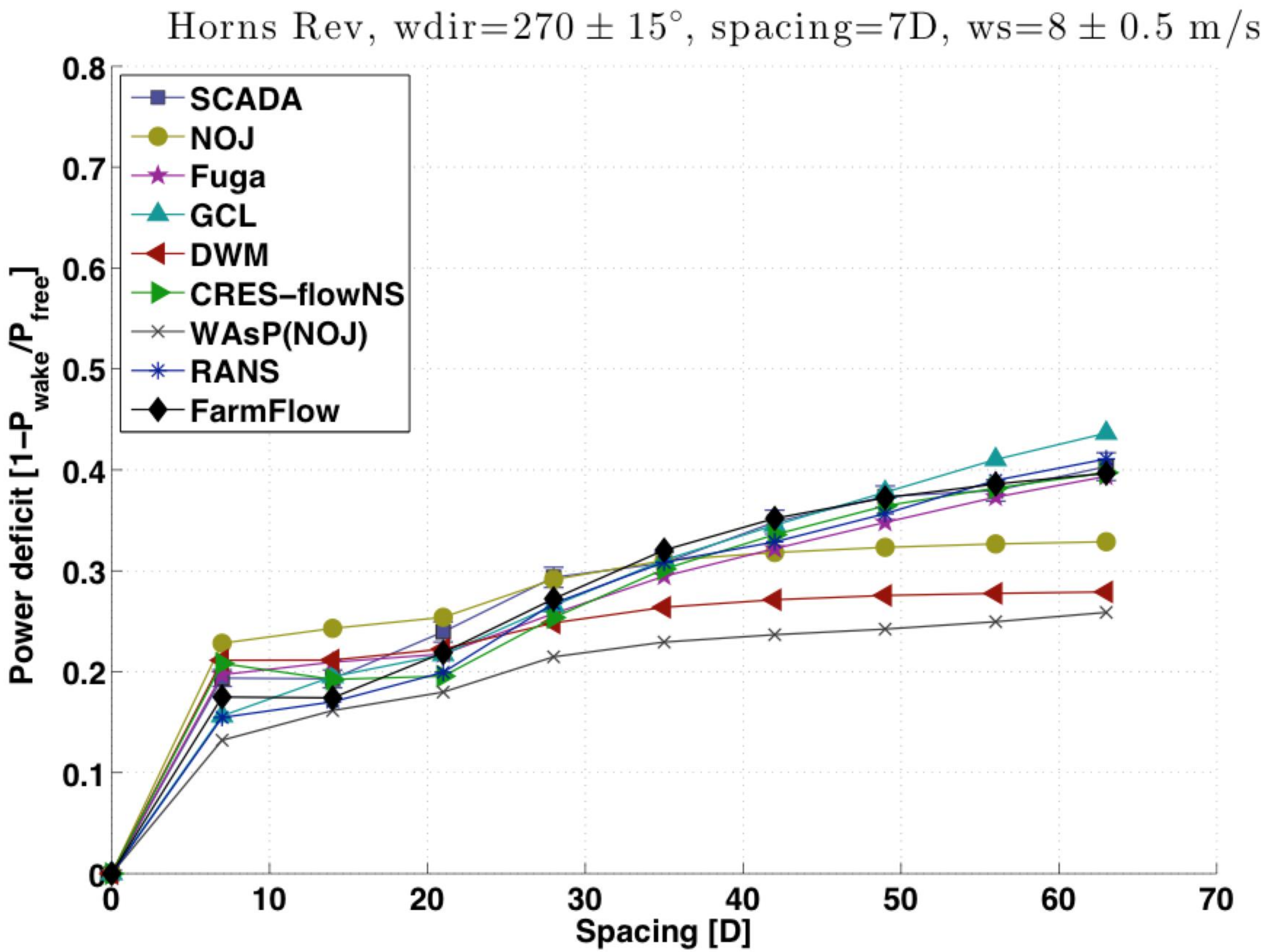
EERA-DTOC	Flow sector			Stratification			Turbulence			Spacing			Park efficiency
	1.1	*1.2*	*1.3*	*2.1*	*2.2*	*2.3*	*3.1*	*3.2*	*3.3*	*4.1*	*4.2*	*4.3*	*5.1*
WASP (NOJ)		1	1							1	1	1	
NOJ(BA)	1	1	1				1			1			
FarmFlow	1	1	1				1	1	1	1	1	1	
FUGA	1	1	1				1			1			
GCL(BA)	1	1	1				1	1	1	1			
DWM/HAWC2	1	1	1	1	1	1	1	1	1	1	1	1	
CRESflowNS	1	1	1	1	1	1	1	1		1		1	1[a]
Ainslie	1	1	1				1	1	1				
RANS	1	1	1				1			1	1	1	
NOJ/Penã	1	1	1	1	1	1	1	1	1	1	1	1	1
GCL(GU)	1	1	1				1	1	1	1	1	1	1
sum	10	11	11	3	3	3	10	7	6	10	6	7	3

1[a] Amended GCL calibrated with CRESflowNS

Horns Rev 1 wake bench results

Example:
Power deficit
along one row





Horns Rev 1 wake bench results

7.2 Run 1: Wind direction 0°± 2.5°, 5°± 2.5°, 10°± 2.5°, .. ,355°± 2.5° & 360° ± 2.5°.

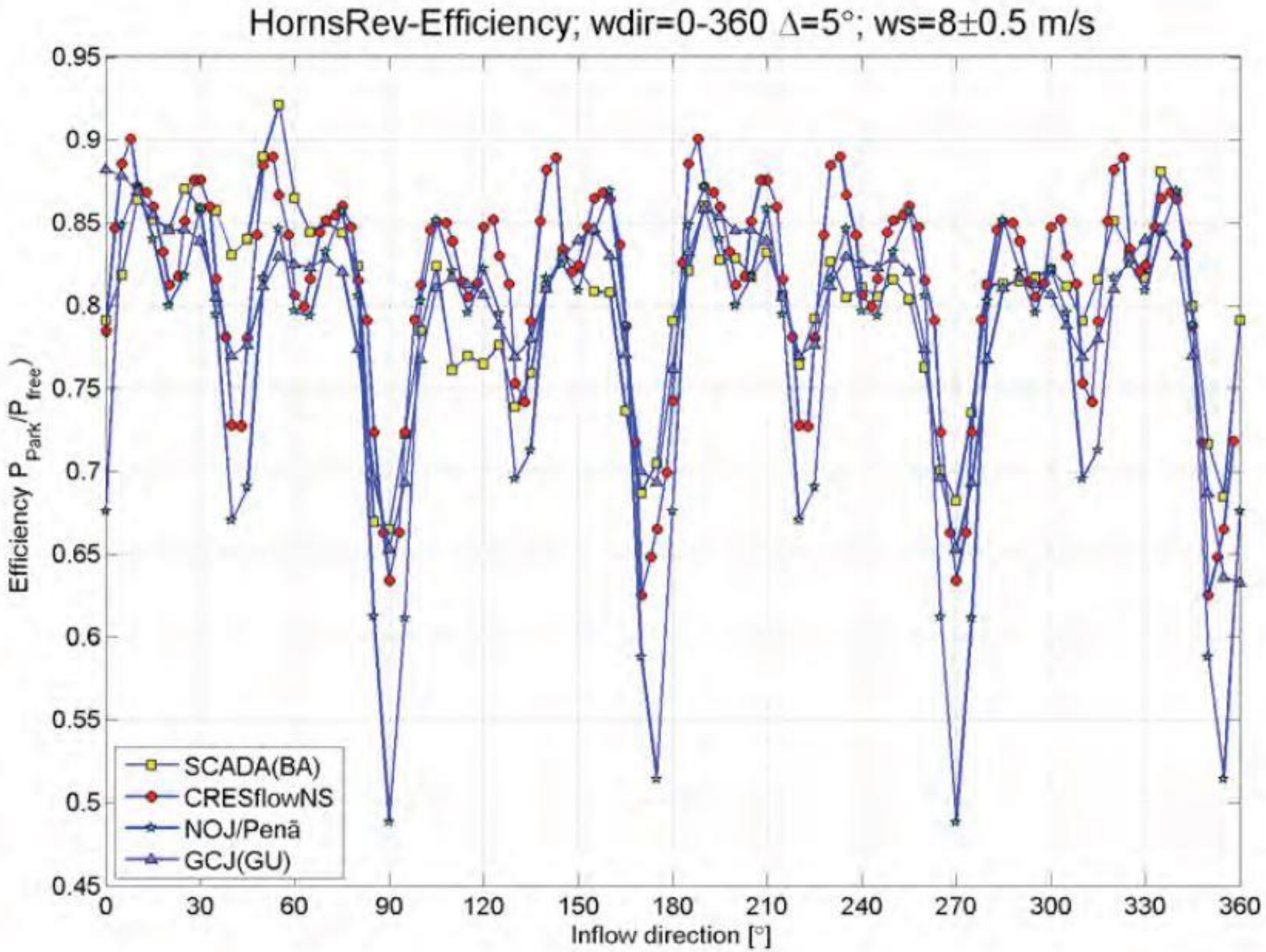
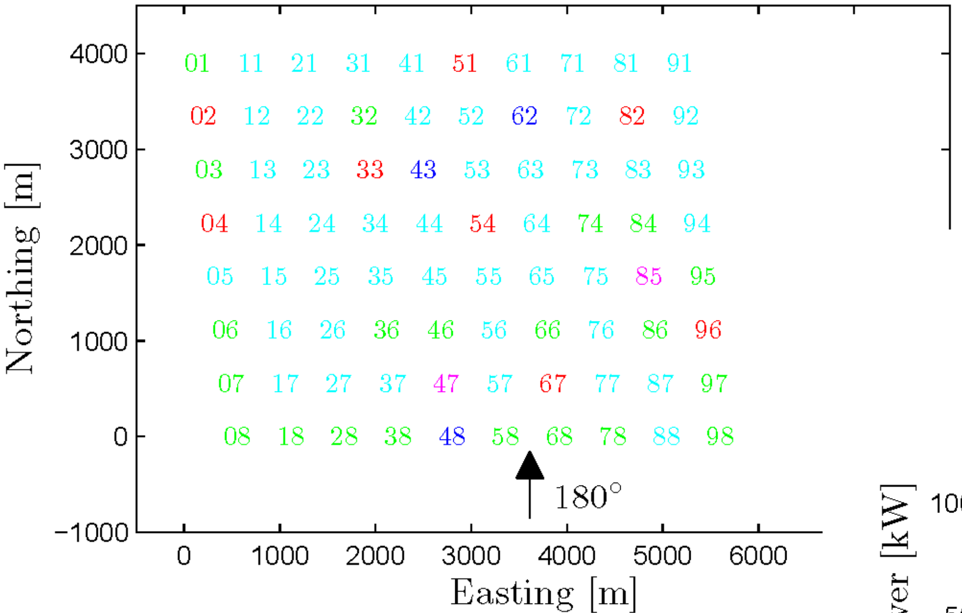
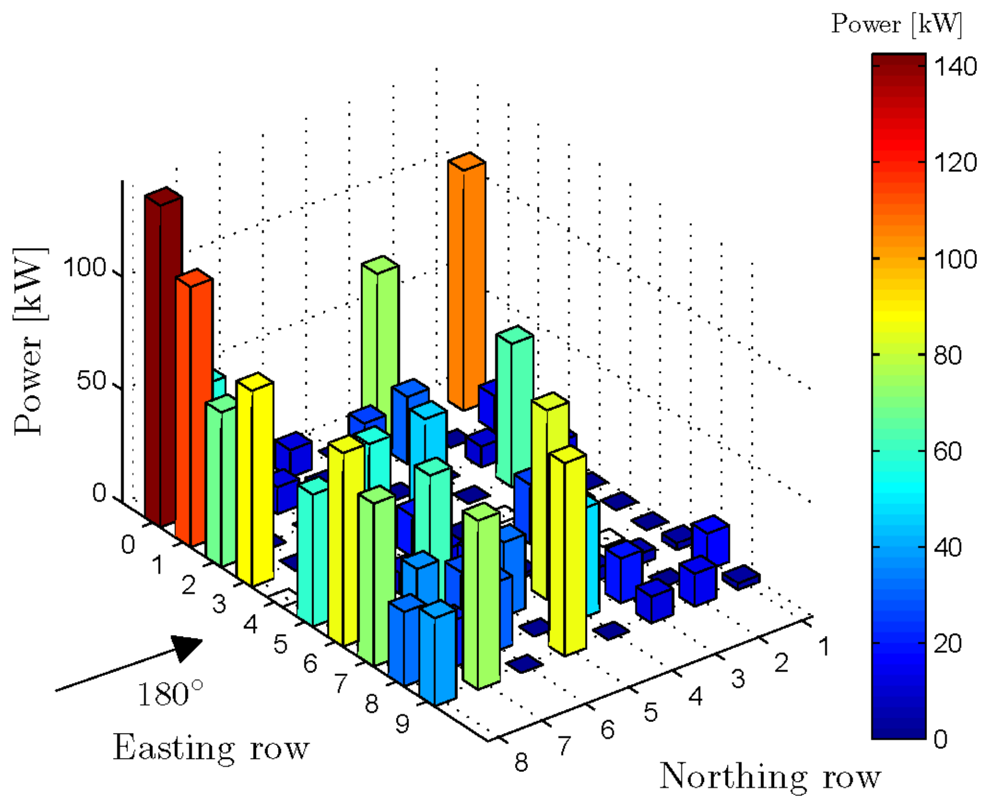


Figure 13: Park power efficiency at 8 m/s inflow - as function of inflow direction.

Horns Rev 1 offshore wake photo study case

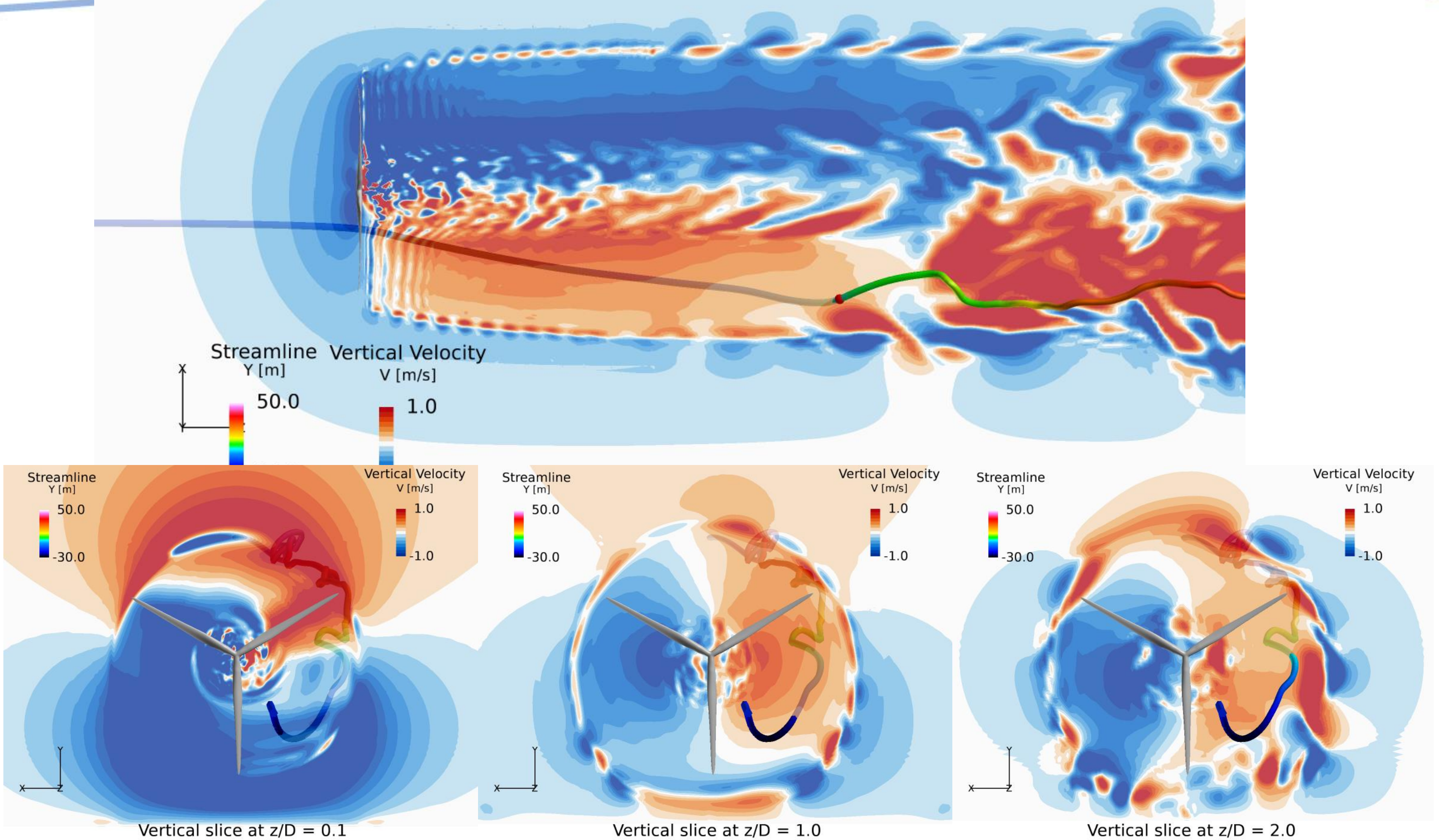
Horns Rev 1 offshore wake photo study case





Horns Rev 1 offshore wake photo study case

Detached eddy simulation results showing vertical velocity



Horns Rev 1 offshore wake photo study case

EERA DTOC

The special atmospheric conditions are characterized by a layer of cold humid supersaturated air that re-condensates to fog in the wake of the turbines. The process is fed by humid warm air up-drafted from below and adiabatic cooled air down-drafted from above by the counter-rotating swirl generated by the rotors.

The large-scale structure of the fog has an imprint of rotational spiraling bands similar to wake flow characteristics deduced from CFD DES modeling.

Wind speed near cut-in.

Reference: Hasager, C.B., Rasmussen, L., Peña, A., Jensen, L.E., Réthoré, P.-E., 2013, Wind farm wake: The Horns Rev photo case, *Energies*, *6*(2), 696-716

Horns Rev 1 offshore wake photo study case

Mesoscale coupled wake modelling

WRF simulations with the EWP parametrization.

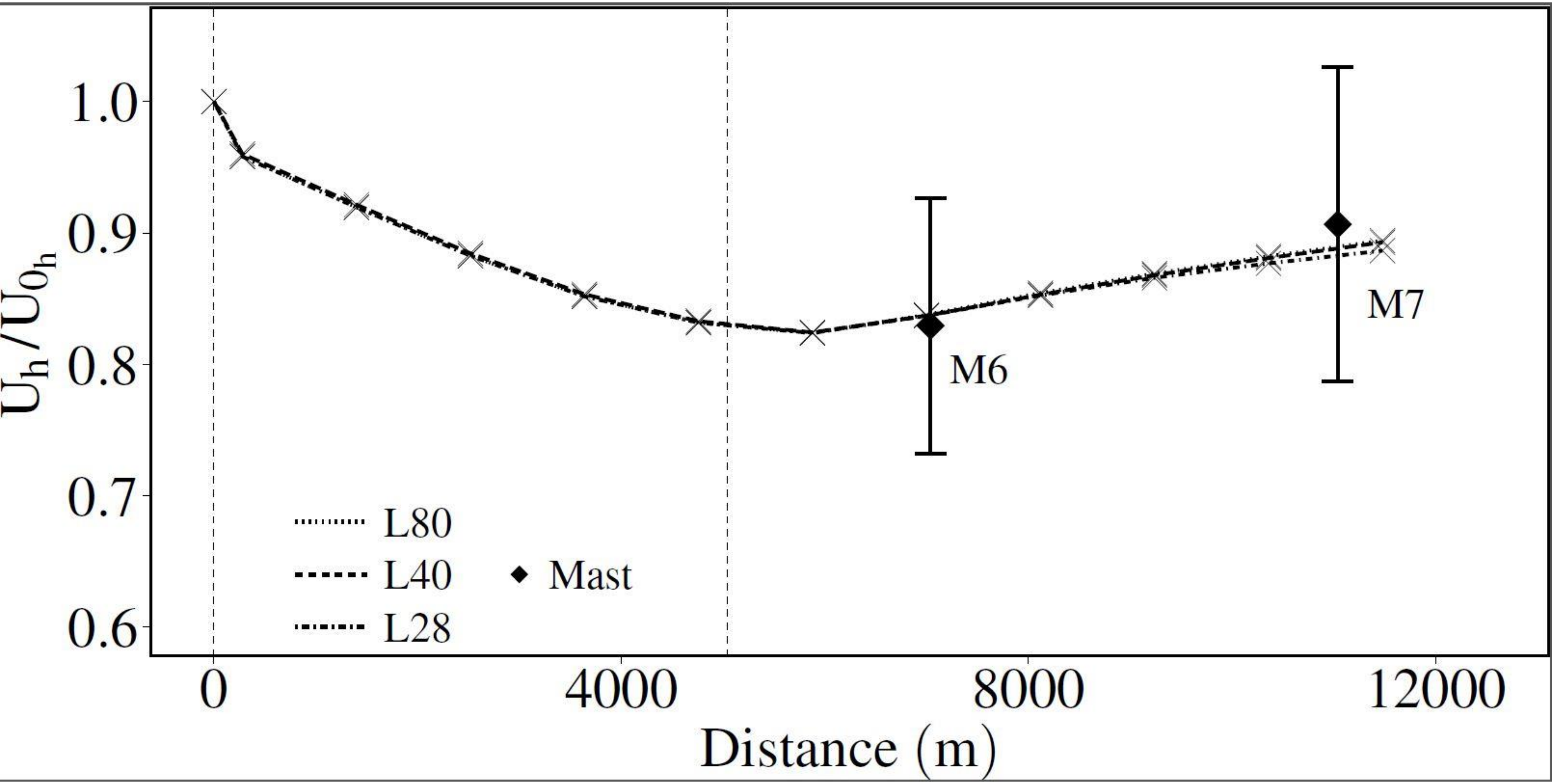
Homogeneous initial conditions, no forcing from the lateral boundaries and a zero heat flux at the lower boundary. The horizontal resolution was 1120m.

The normalized velocity at hub-height for three different vertical resolutions (28, 40 and 80 layers) against met mast (M6, M7) measurements. The normalized velocity is the ratio between the velocity from the wind farm simulations and the reference simulation without wind farm.

The model velocity is obtained by averaging 7 simulations, in which the flow angle ranged from 258.75 to 281.25 degrees.

The mast measurements were provided by Kurt S. Hansen (long-term time average over a flow angle ranging from 255 to 285 degrees).

Mesoscale coupled wake model results



P. J. H. Volker, J. Badger, A. N. Hahmann and S. Ott Implementation and Evaluation of a Wind Farm Parametrization in a Mesoscale Model, BLM in review

Support by

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SEVENTH FRAMEWORK PROGRAMME

We acknowledge Vattenfall AB for having access to the SCADA data from the Lillgrund offshore wind farm and SCADA data from the Horns Rev 1 wind farm from DONG energy and Vattenfall.