Benchmarking of Lillgrund offshore wind farm scale wake models

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

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Support by

SEVENTH FRAMEWORK PROGRAMME

Outline

- Motivation;
- Participants;
- Wind farm location, layout and challenges;
- Wake models;
- Benchmark flow cases;
- Results;
- Conclusion;
- Acknowledgement.

Motivation

- The wake modeling part of the EERA - DTOC (Design Tool for Offshore wind farm Clusters) project is to improve the fundamental understanding of wind turbine wakes and modeling.

- Many different types of wind farm wake models that have been developed during the last three decades.

- Two benchmark campaigns have been organized on the existing wind farm wake models available within the project.

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

- The present benchmark represents an irregular layout of 8 wind turbines - with small internal spacing (3.3 – 4.3 - 7 D).

Participants

- E. Maguire, Vattenfall AB;

- P.-E. Rethoré, DTU Wind Energy;
- S. Ott, DTU Wind Energy;
- T.Göçmen, DTU Wind Energy;
- A. Penã, DTU Wind Energy;

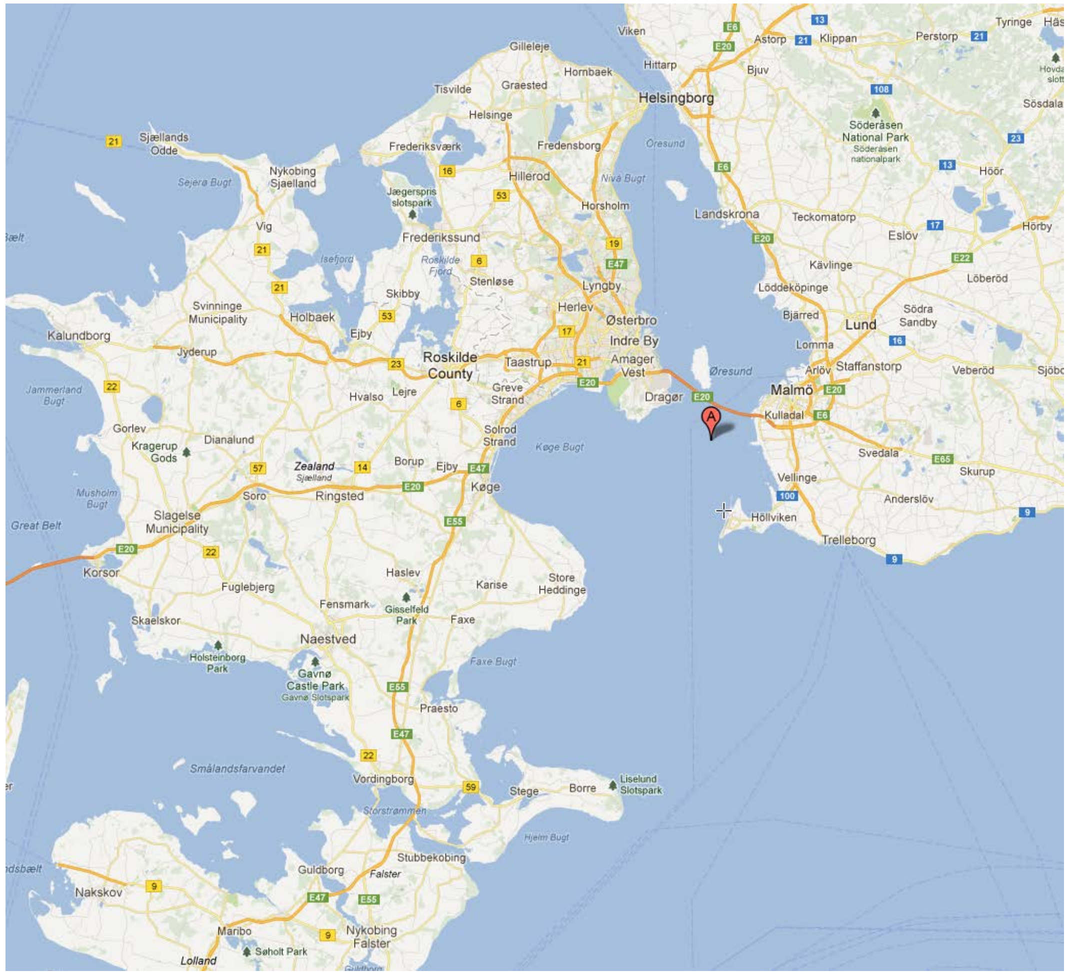
- J.Prospathopoulos, CRES, Greece;
- G.Scheepers, ECN, The Netherlands;
- T. Young, RES-LTD, United Kingdom;
- J.Rodrigo, CENER, Spain.

Benchmark test case: Lillgrund offshore wind farm

Site Description:

- The Lillgrund offshore wind farm is located in Öresund, the body of water between Malmö, Sweden and Copenhagen, Denmark.
- Owner: Vattenfall AB – 100%
- The farm consists of 48 Siemens SWT-2.3-93 wind turbines, each producing a rated power of 2.3 MW with a rotor diameter of 93 m and a hub height of 65 m.
- The turbines are arranged in a dense array with separation of 3.3 rotor diameters (D) within a row and 4.3 D between the rows.

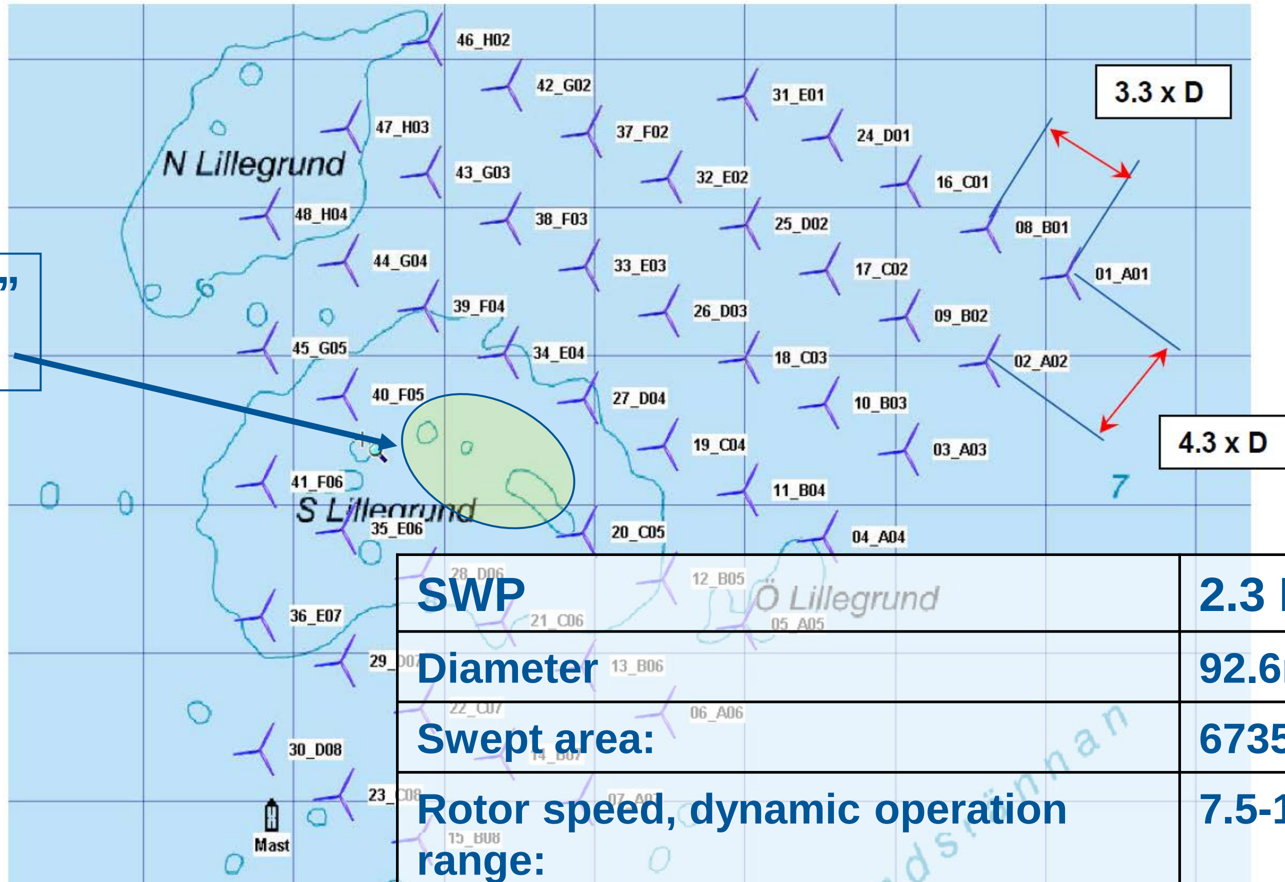
Lillgrund offshore wind farm, located Between Sweden & Denmark



Location of Lillgrund offshore wind farm.

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

2 "missing" turbines



SWP	**2.3 MW**
Diameter	**92.6m**
Swept area:	**6735 m²**
Rotor speed, dynamic operation range:	**7.5-16 rpm**
Hub height:	**65 m**

8 Rows of turbines: NE => SW

8 Columns of turbines: SE => NW

Lillgrund; Available measurements.

- 65 m mast (wind speed, turbulence, wind direction, air temperature), period: 2003 – 2006
(before WF installation, with high quality)

- 65 m mast (wind speed, turbulence, wind direction, air temperature) with medium quality, period: 2008 – 2010.

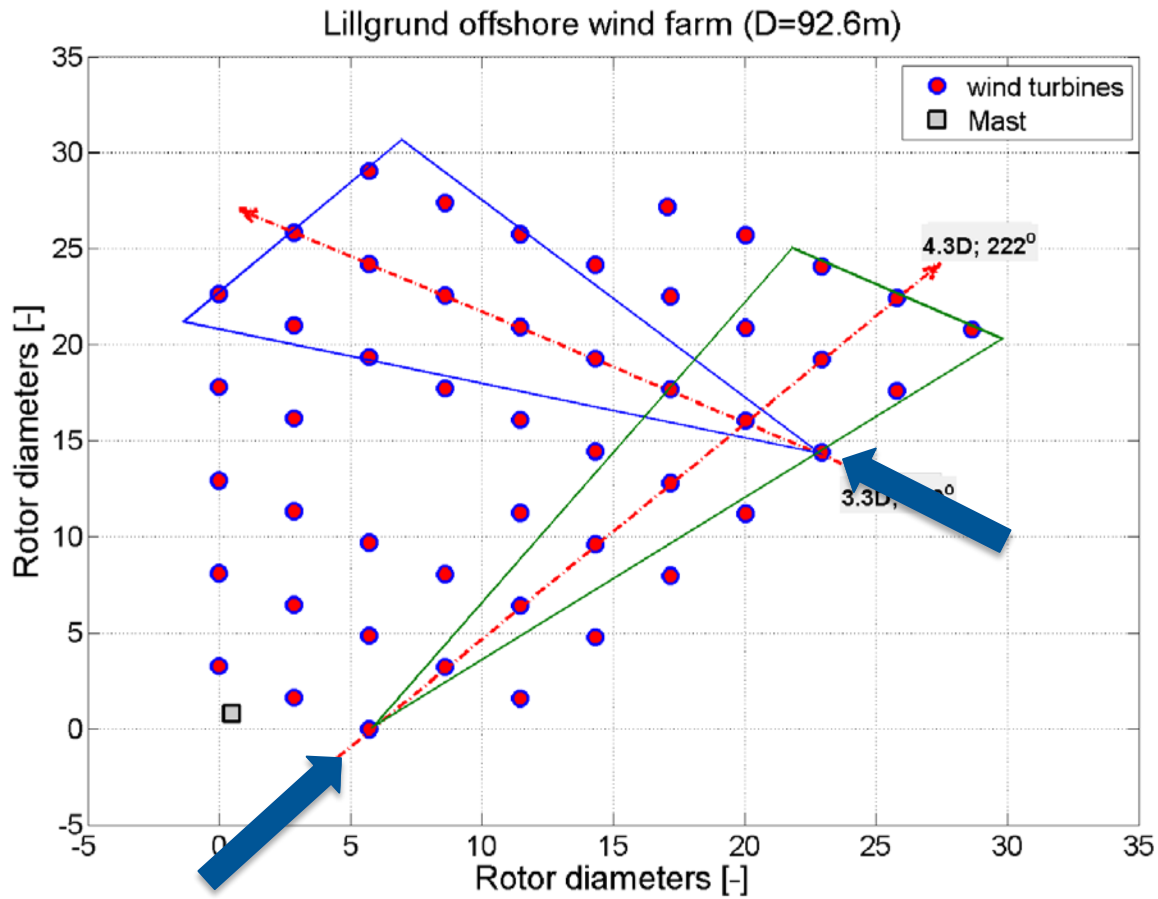
- SCADA data from WF as 10 minute statistics (mean values and stdev from each wind turbine). Period 2008 – 2012. Signals: power, pitch, rpm, nacelle wind speed and position.

Wind Farm wake models used in the benchmark

1. **SCADA** is the processed wind farm data to be compared with the wind farm wake models;
2. **FUGA** is a linearized actuator disc eddy-viscosity CFD model for offshore wind farm wake developed by DTU;
3. **CRESflowNS** is an elliptic k-ε actuator disc CFD model tailored for offshore wake simulation developed by CRES;
4. **FarmFlow** is a parabolized k-ε actuator disc CFD model tailored for offshore wake simulation developed by ECN;
5. **GCL** is the G.C. Larsen eddy-viscosity wake model v2009 developed by DTU;
6. **NOJ** is the original N.O Jensen model;
7. **AD/Ainslie** is an eddy-viscosity wake model developed by RES-LTD.

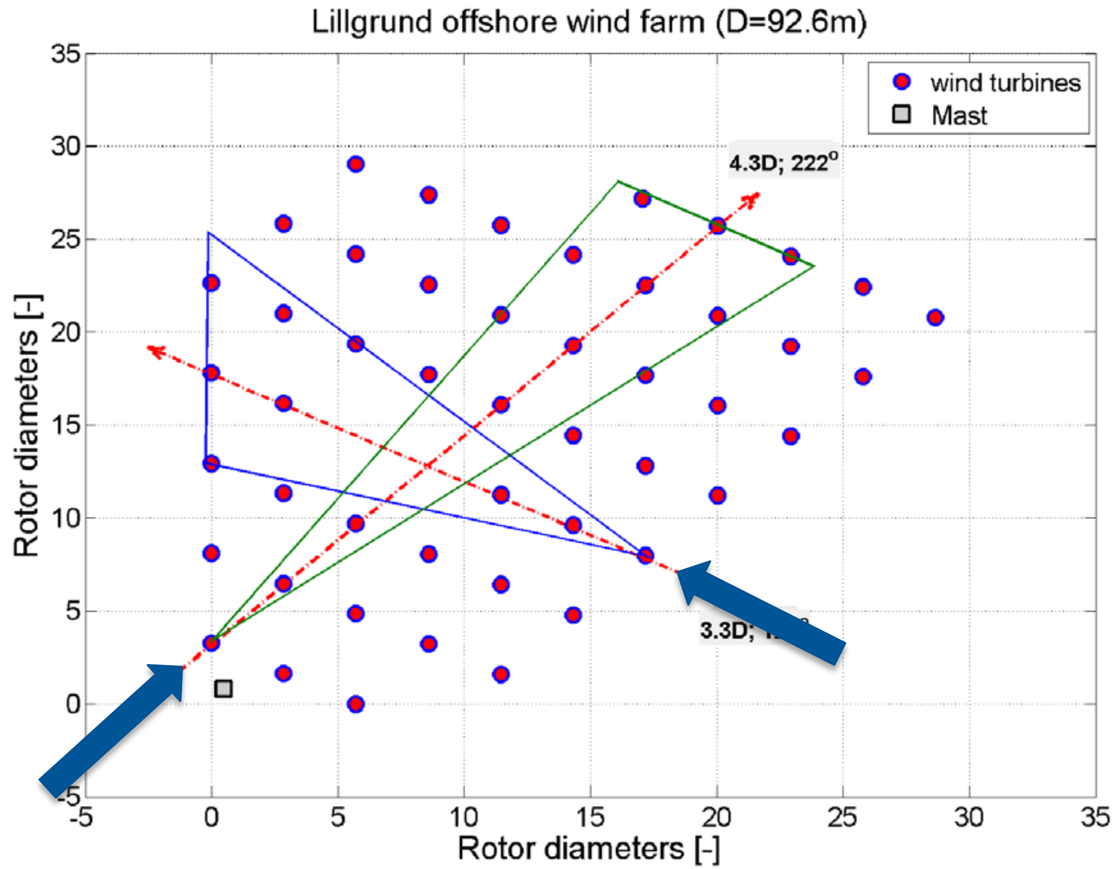
1. Flow case

Power deficit along a row of turbines - 3.3D & 4.3 D spacing at 9 m/s;



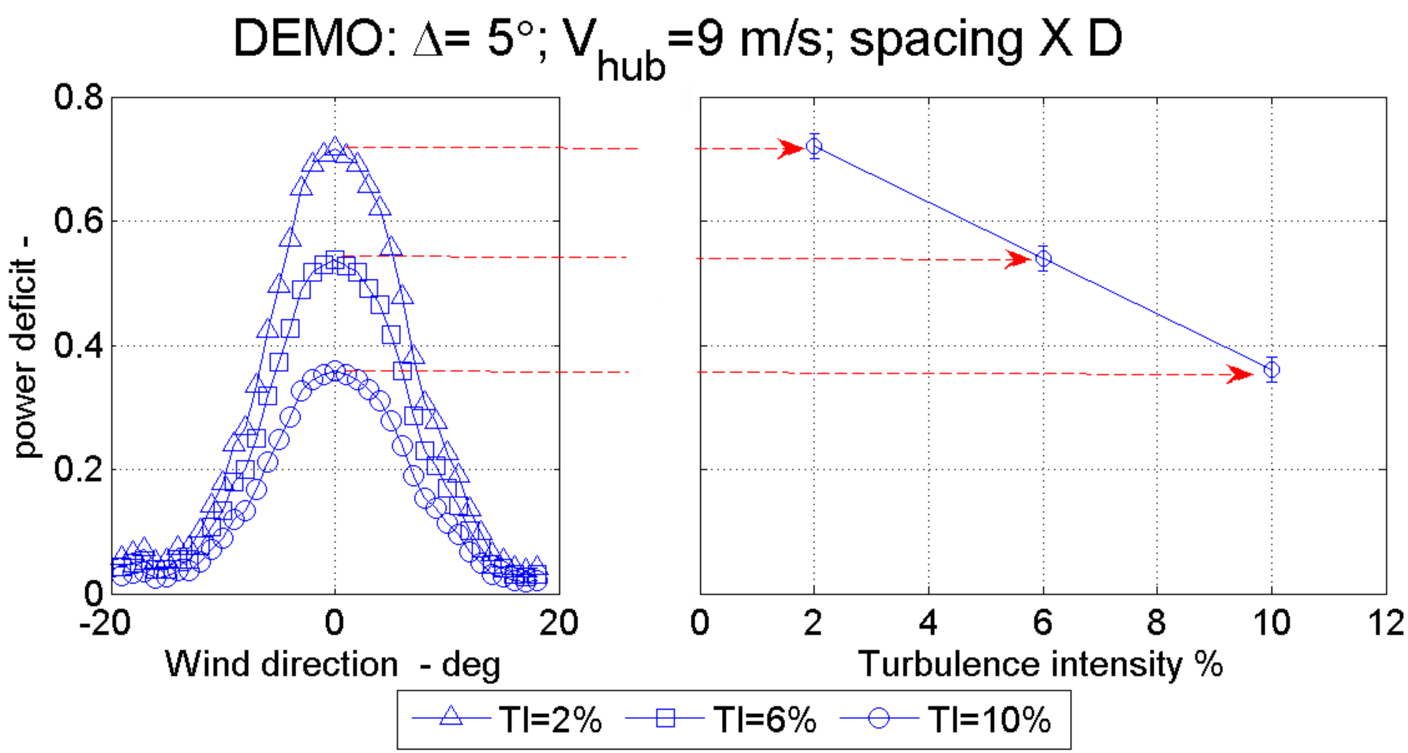
2. Flow case

Power deficit along a row of turbines - 3.3D & 4.3 D spacing – with ”missing” wind turbines at 9 m/s;



3. Flow case

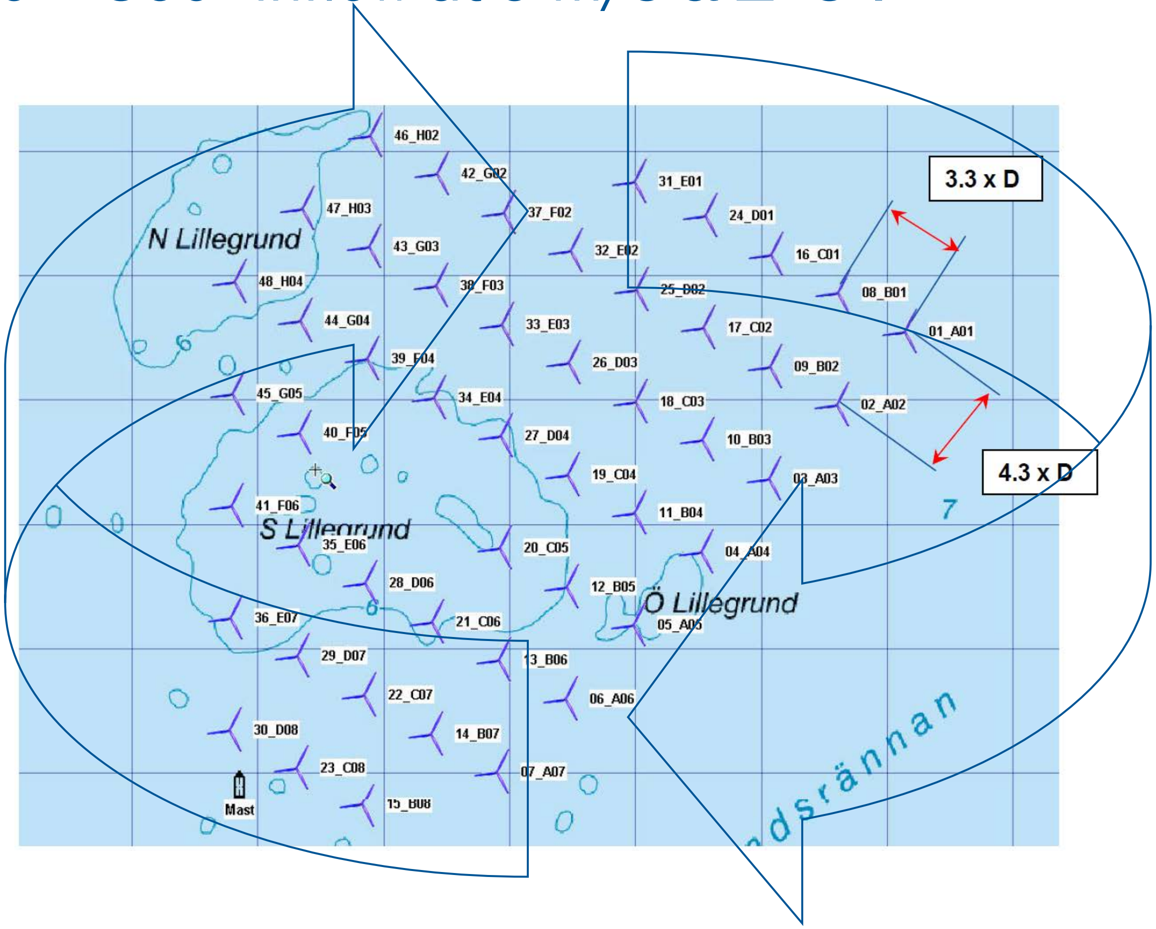
1. Maximum power deficit – as function of turbulence intensity (TI) for a pair of turbines with 3.3D & 4.3 D spacing respectively;



4. Flow case

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

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



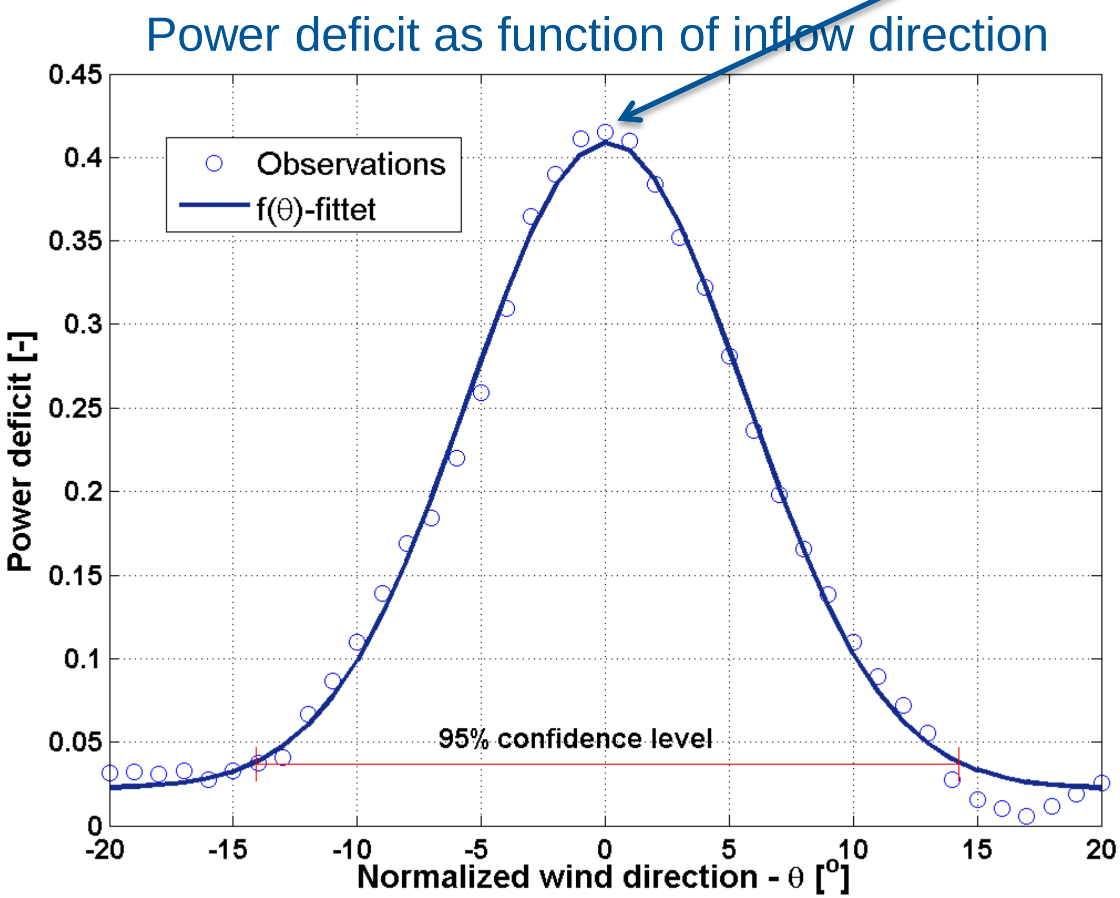
Benchmark matrix

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

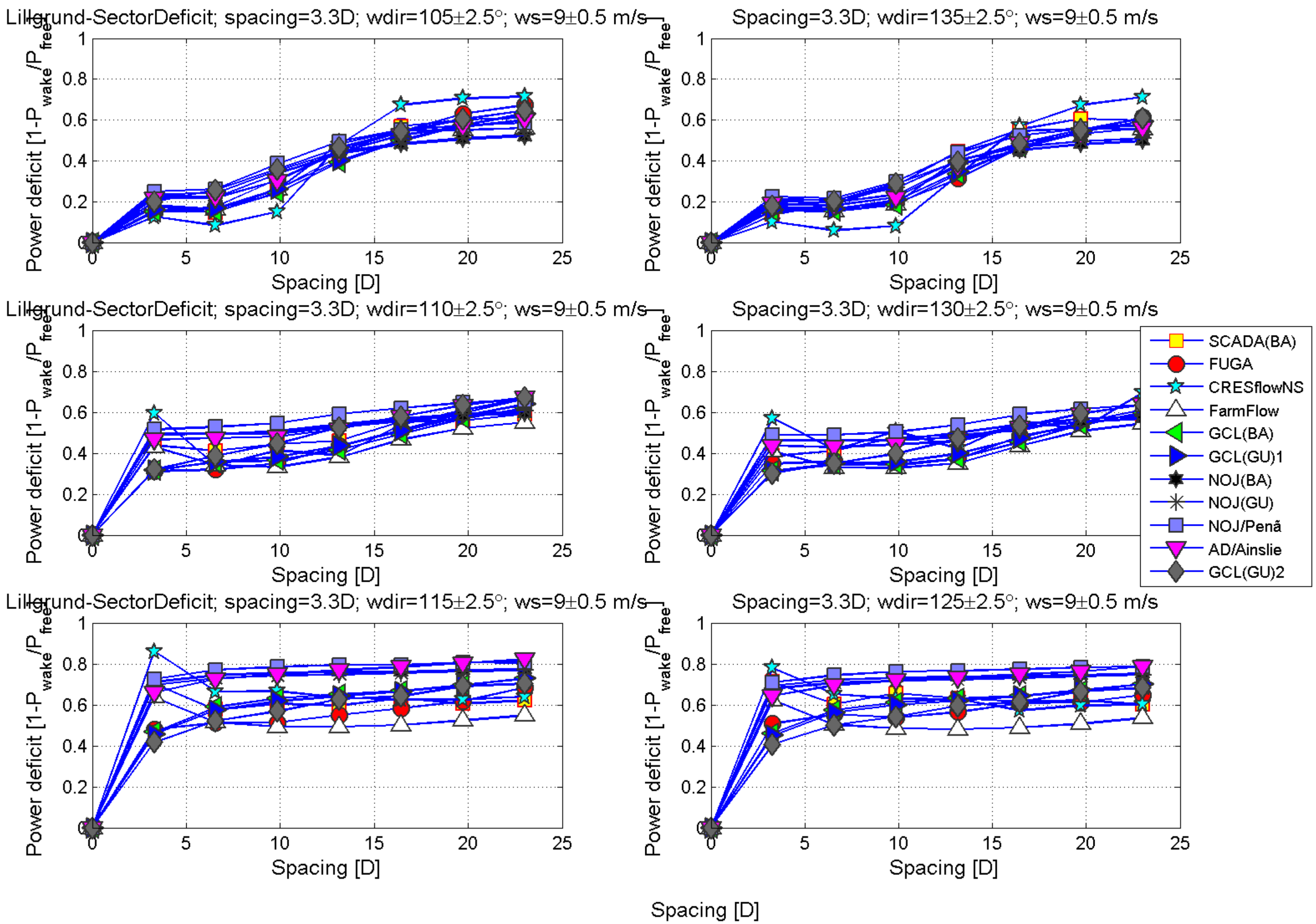
63 simulation results have been provided from the 10 participants.

Basic definitions

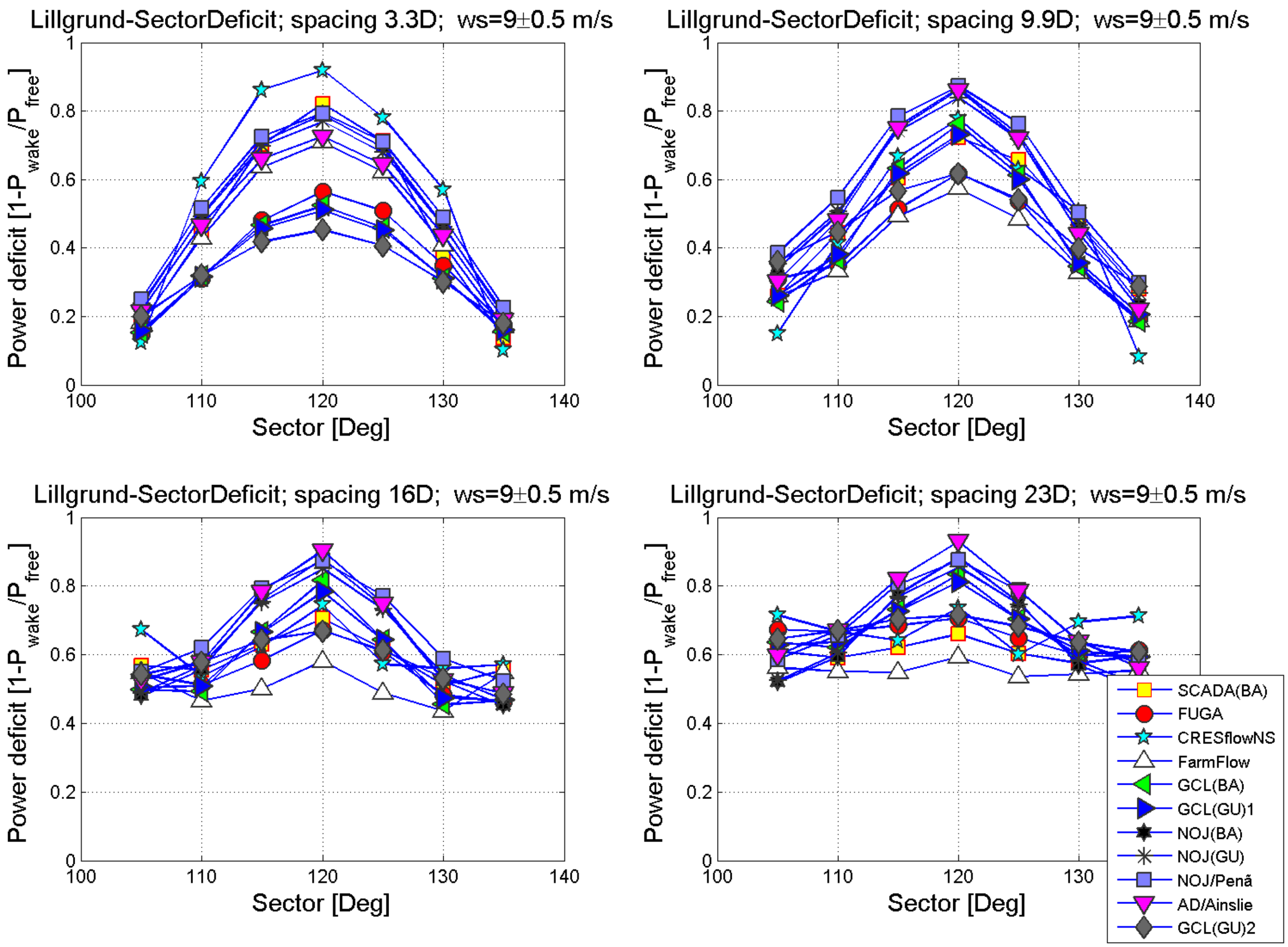
Maximum deficit



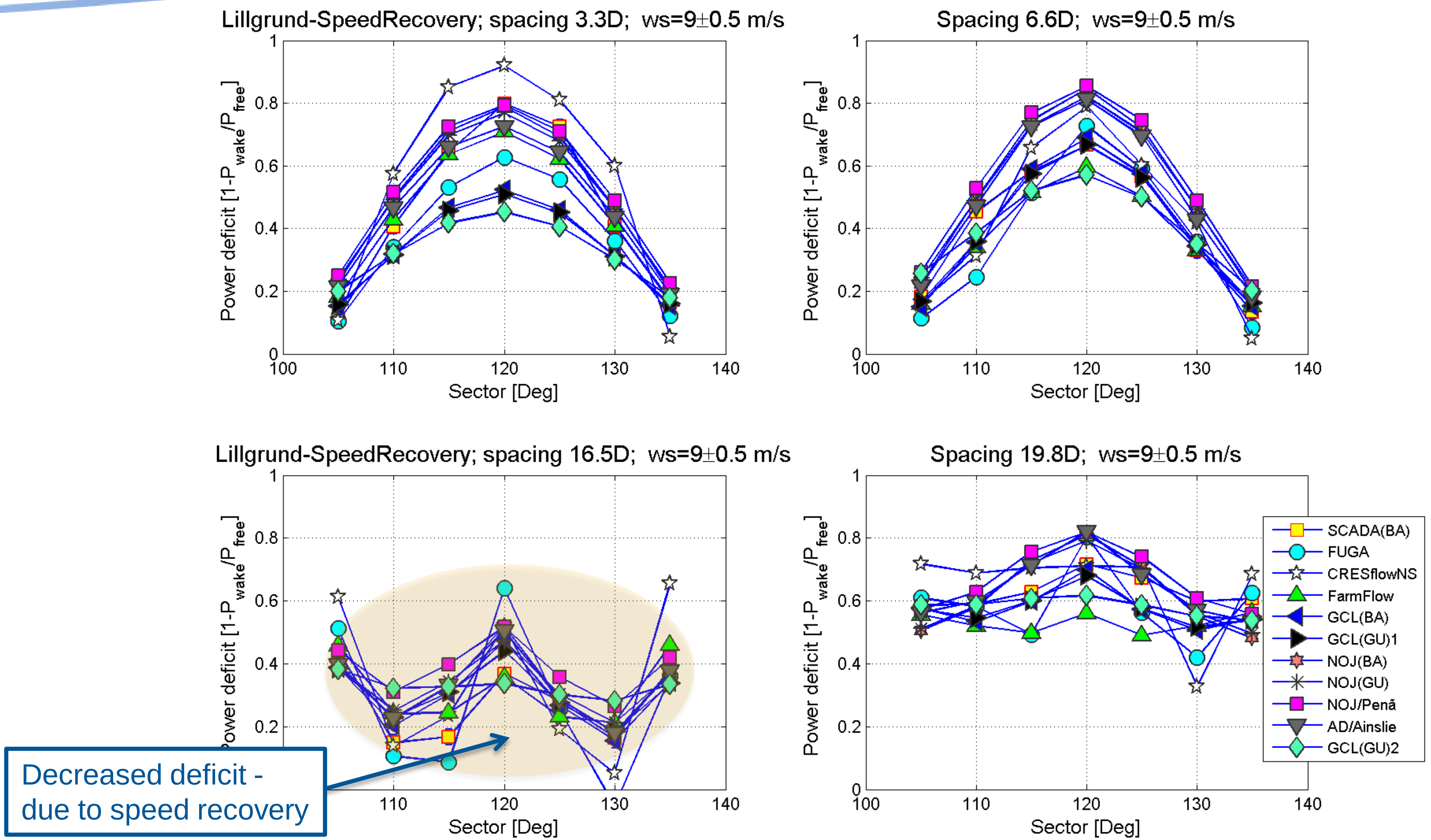
1 Flow case, 3.3 D spacing



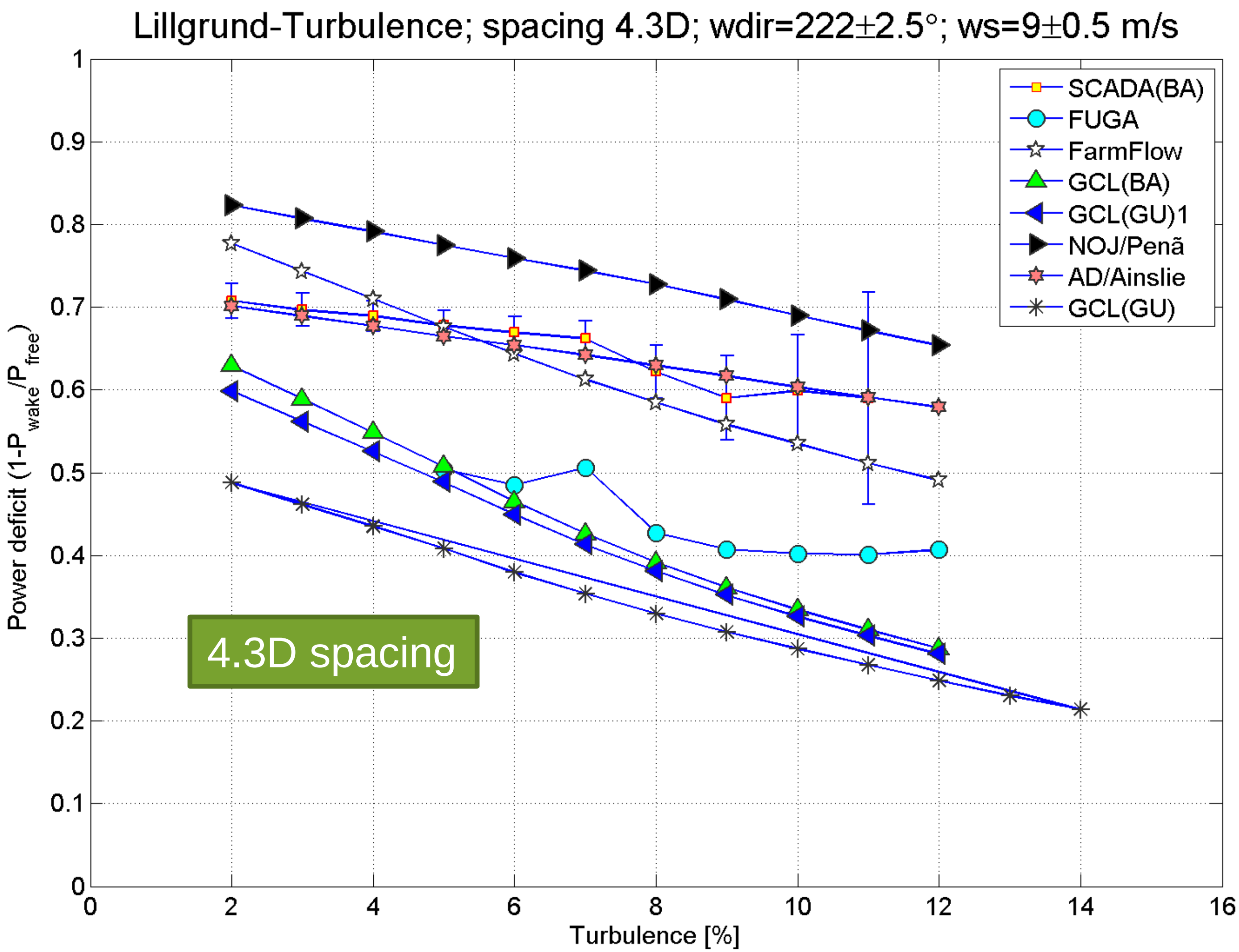
1 Flow case, 3.3 D spacing



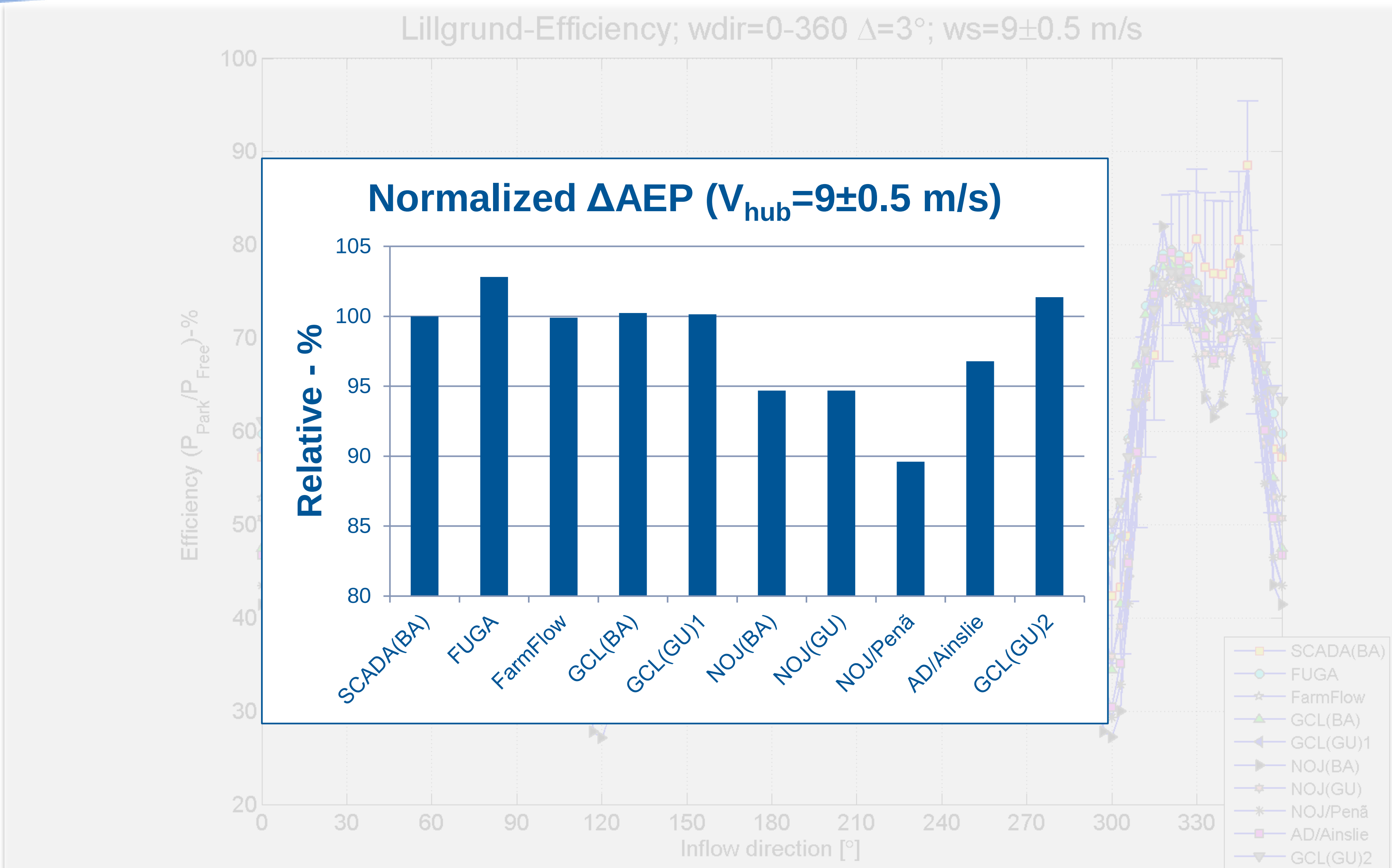
2 Flow case, 3.3 D spacing with ”missing turbines”



3 Flow case – turbulence dependence



4 Flow case – park efficiency



Conclusion

- 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;

Acknowledments

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Thank you for your attention