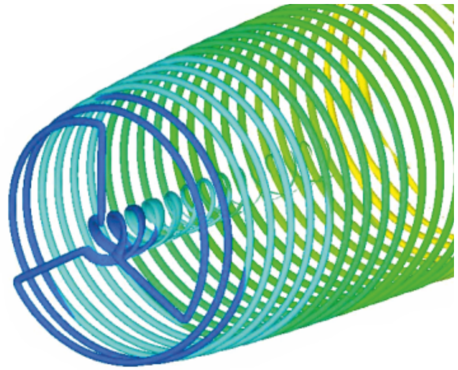
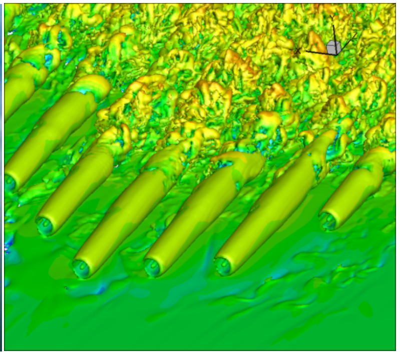
What have we learned about understanding and modelling wake effects from the WakeBench project





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CENER

IEA Wind Task 31
Wakebench

Associate Professor Stefan Ivanell

Head of Section, Wind Energy Campus Gotland & Director, KTH Wind Centre

Javier Sanz Rodrigo

CENER

…and many other Wakebench participants

Outlook

- Motivation
- How to model
- Scope of WakeBench
- Example of Results
- Conclusions

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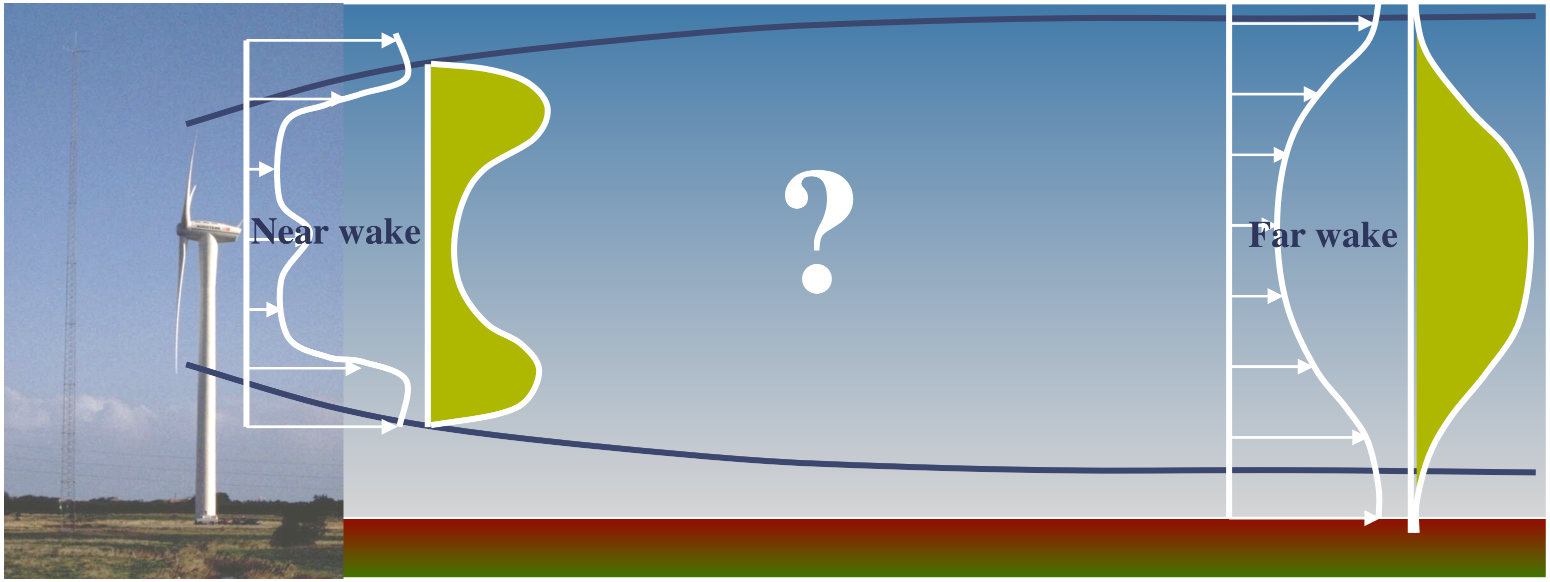
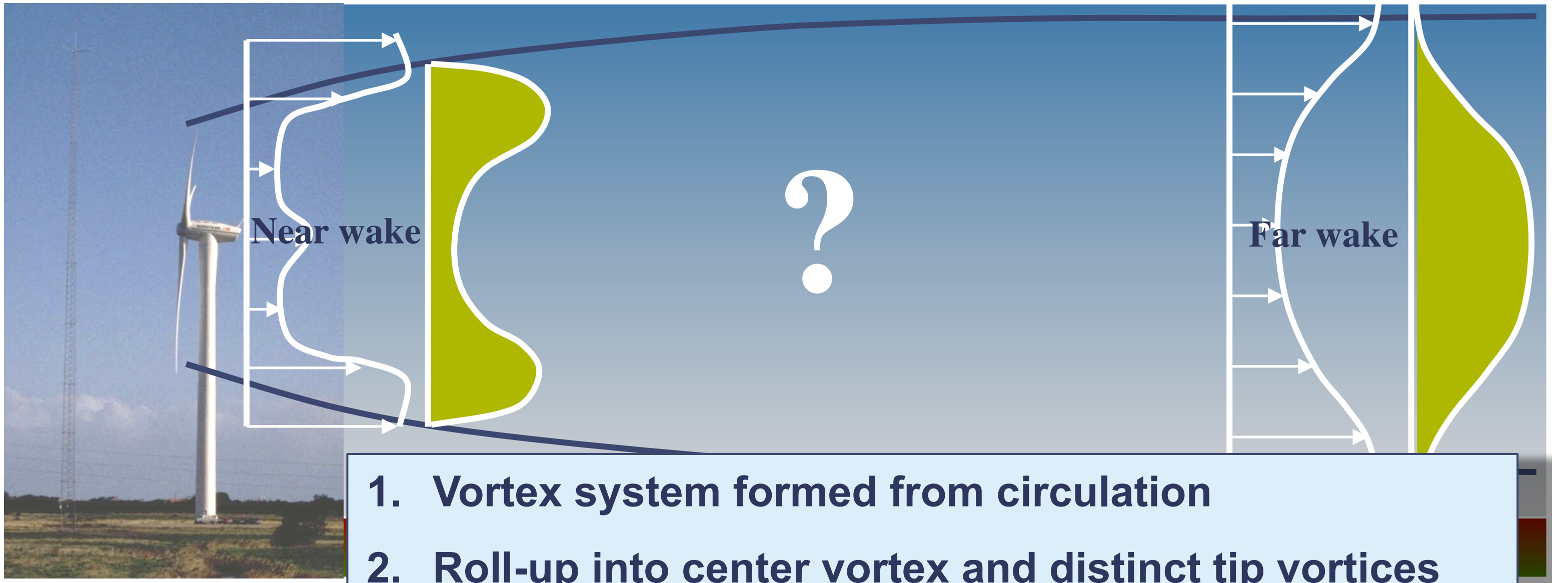
Wake development:



Wake development:



: Turbule

1. Vortex system formed from circulation
2. Roll-up into center vortex and distinct tip vortices
3. Destabilization of tip vortices
4. Break down into large-scale turbulence
5. Turbulent mixing
6. Interplay with meandering

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Why do we need wake models?

- To determine performance of wind farms
- To estimate the life time of turbines in wind farms
- To operate optimally wind turbines in wind farms
- To optimize the location of wind turbines

Factors influencing the wake:

- The distance between the turbines
- The stability of the atmospheric boundary layer

Increasing interest in wind turbine wakes

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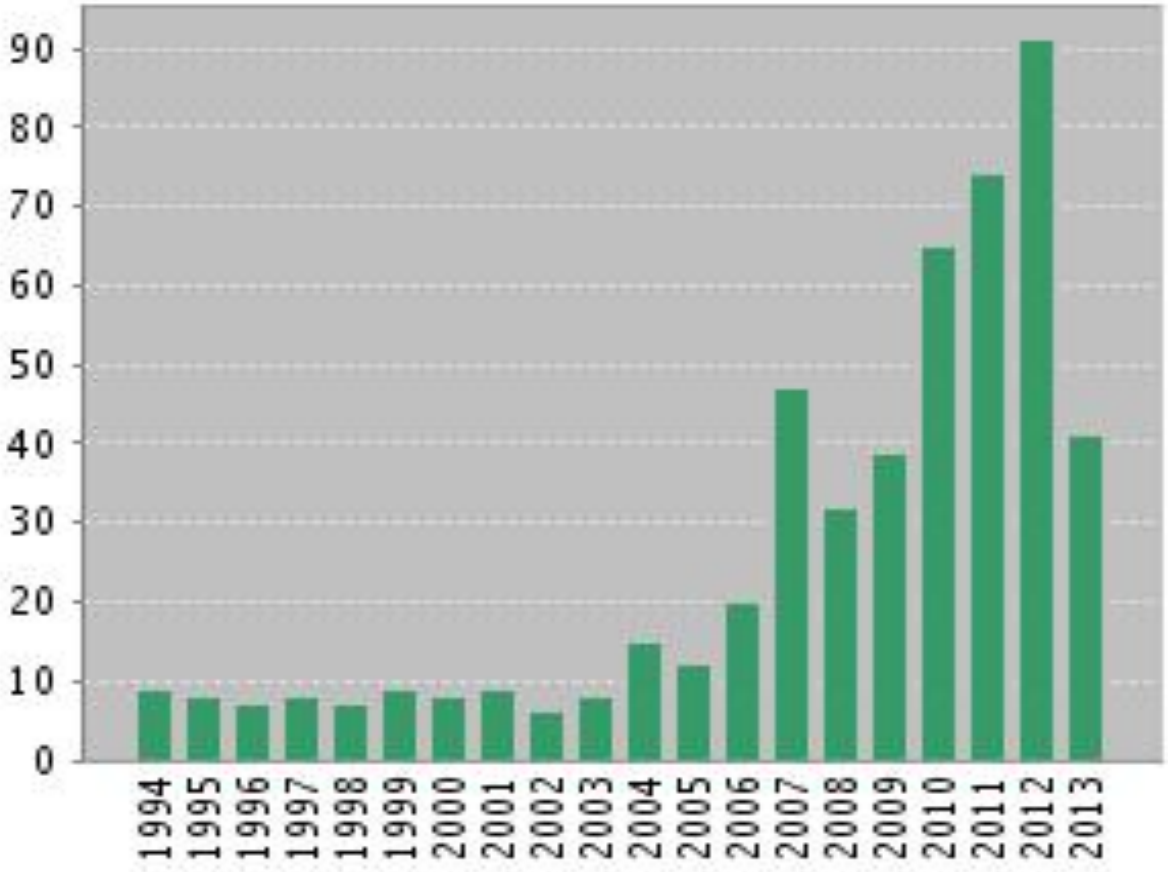


Number of publications on the Web of Knowledge registered on the topic 'Wind Turbine Wakes'

Wake Aerodynamics

Gotland University

Full scale tests:

- **Lidar measurements:**
  Tjæreborg NM80,
  Risø Nordtank 500kW
- **Wake deficits:**
  Sexbierum, Vindeby, Nibe, Alsvik
- **Park perfomance (power deficits):**
  Horns Rev, Lillgrund, Nysted, NoordZee, Nørrekær Enge

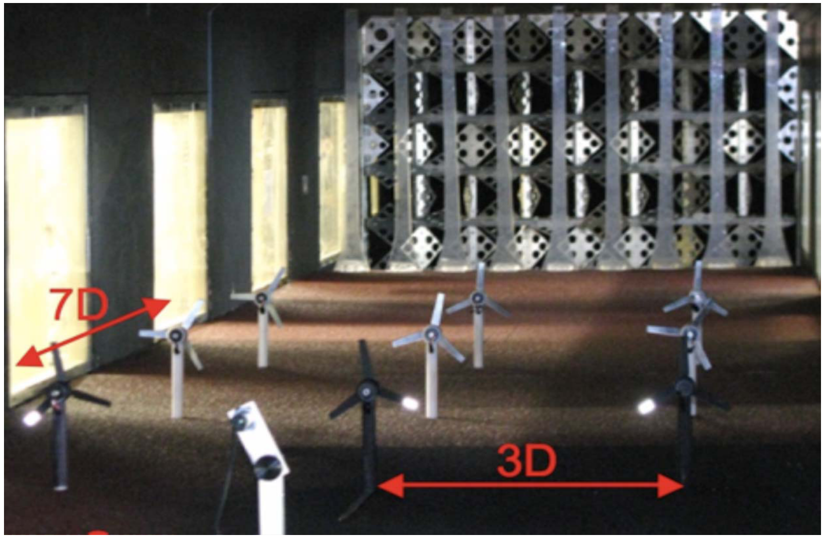
Advantage: **No restriction in model numbers**
Disadvantage: **Difficult to measure and control**

Wake Aerodynamics

Wind/Water Tunnel tests:

- **Wakes from a single turbine:**
  NREL, Mexico, NTNU, Delft, ENSAM, IRPHE, Monash, DTU

- **Wind farms:**
  Univ. Minnesota, Johns Hopkins, Univ. Orleans, ECN



Advantage: Easy to measure and control
Disadvantage: Limitations in Reynolds numbers

Wake structure, wake instabilities and interaction

- Wakes of wind turbines at Horns Rev
- Wakes from first row survives longer than wakes inside park
- Wake breaks down due to instabilities of spiral vortices
- Wake vortices interact and roll up during breakdown process

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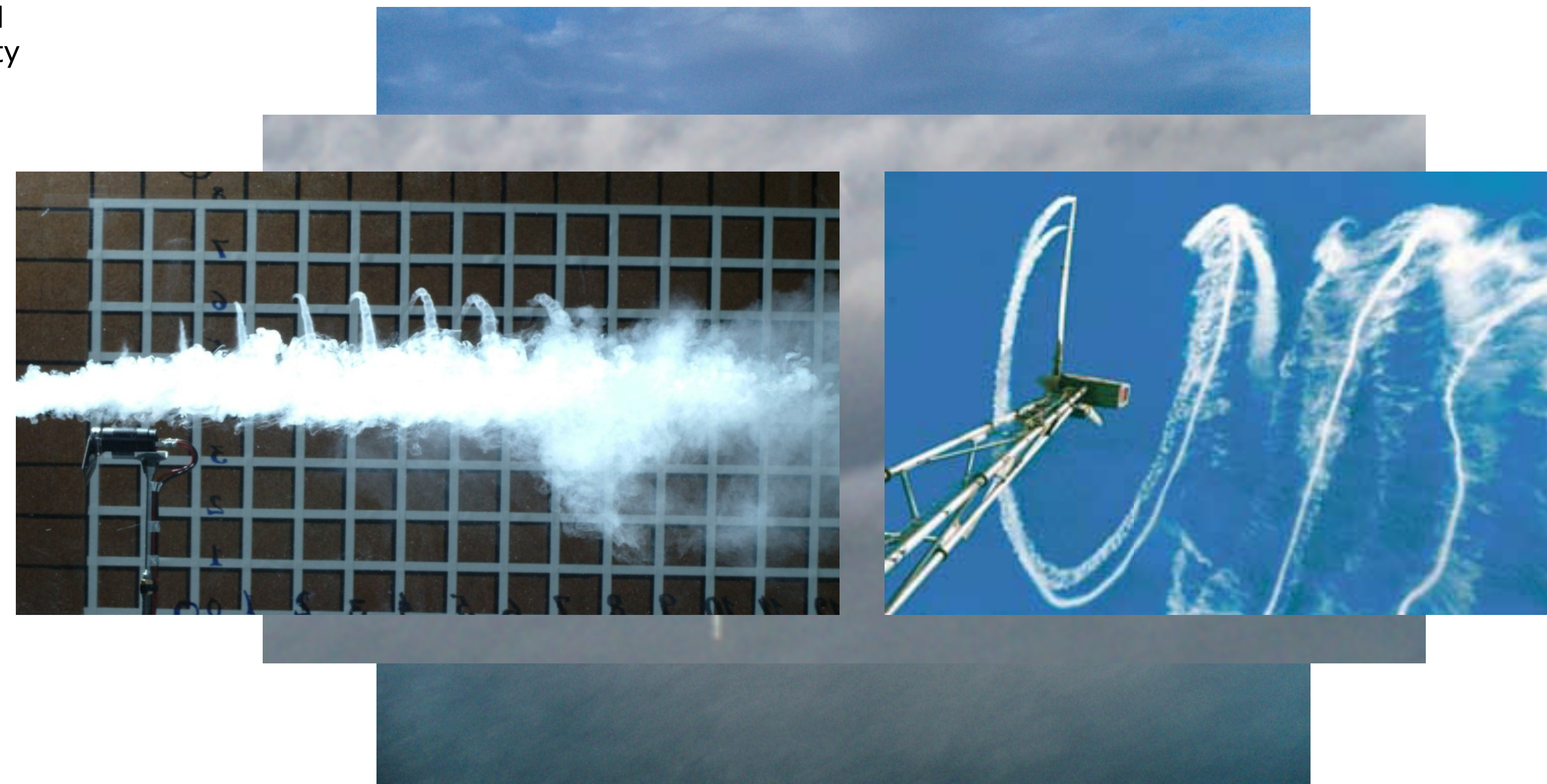

KTH VETENSKAP OCH KONST
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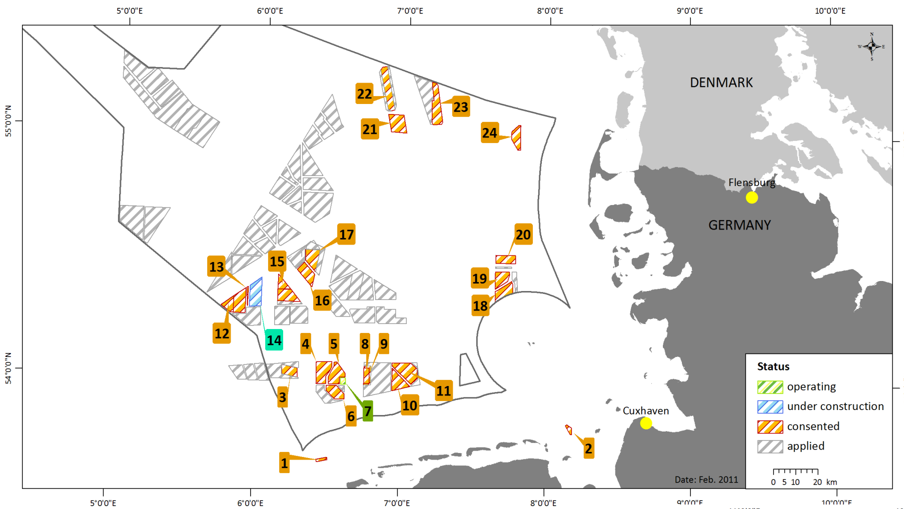
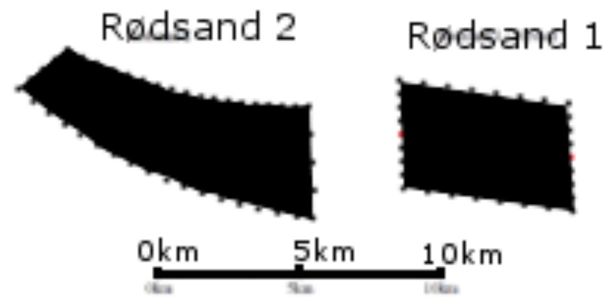
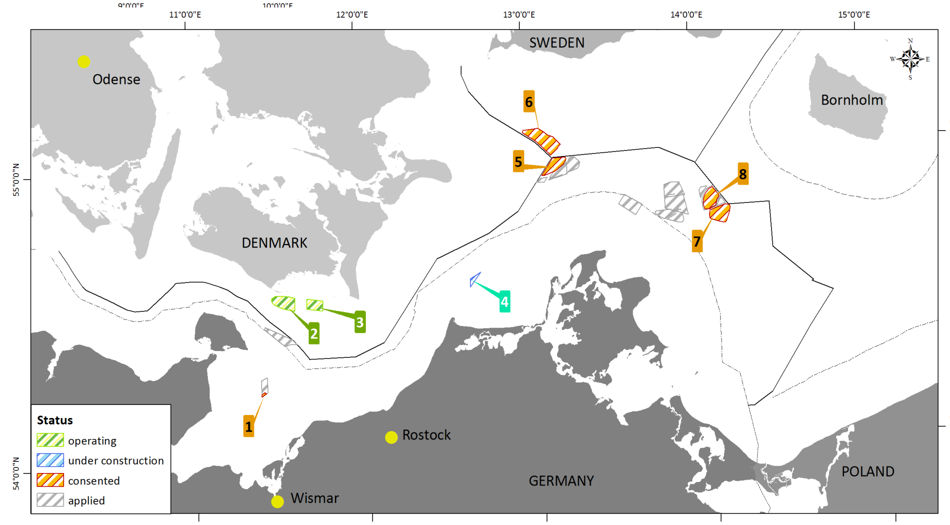
Farm-Farm interaction







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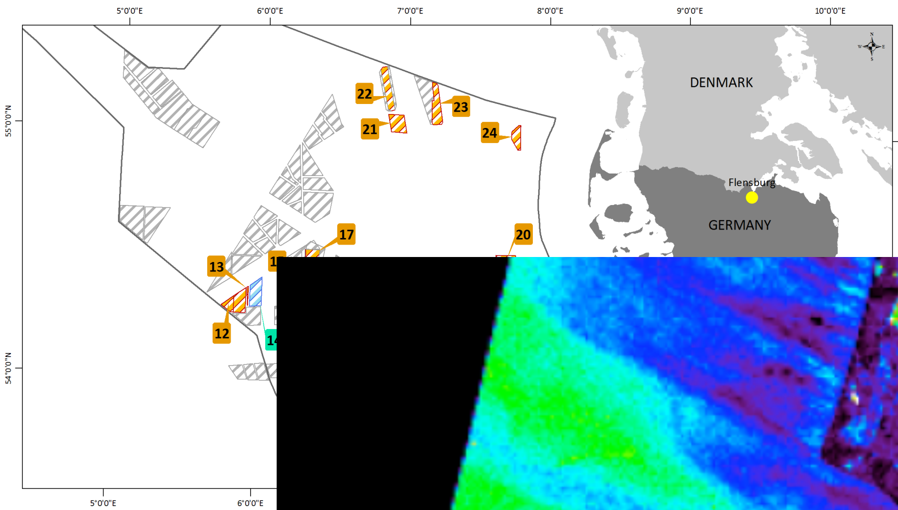

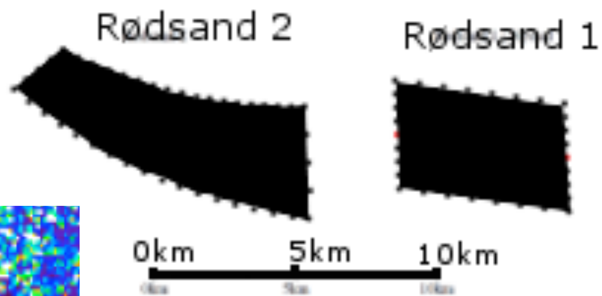

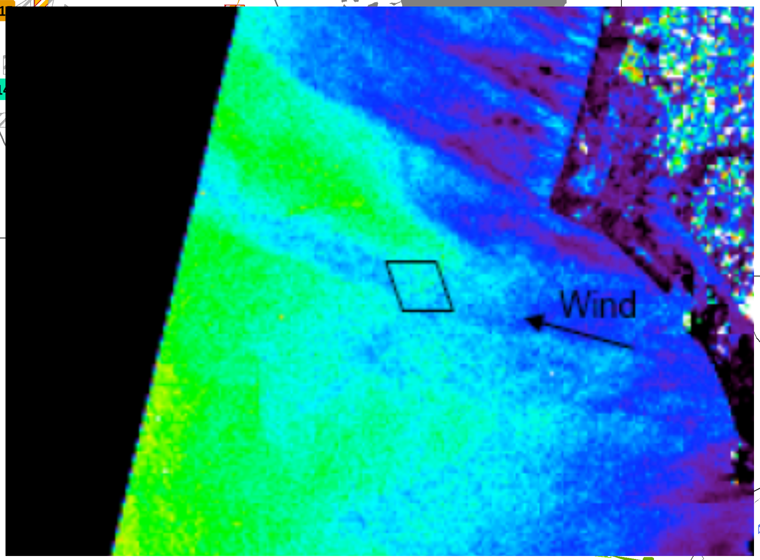

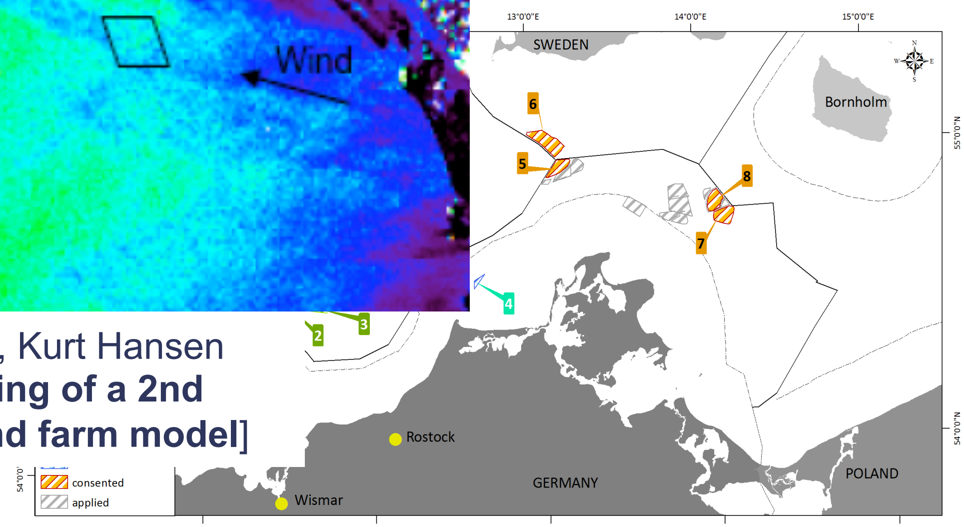

[Sten Frandsen, Kurt Hansen et.al., **The making of a 2nd generation wind farm model**]

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Numerical Methods – ACD/ACL

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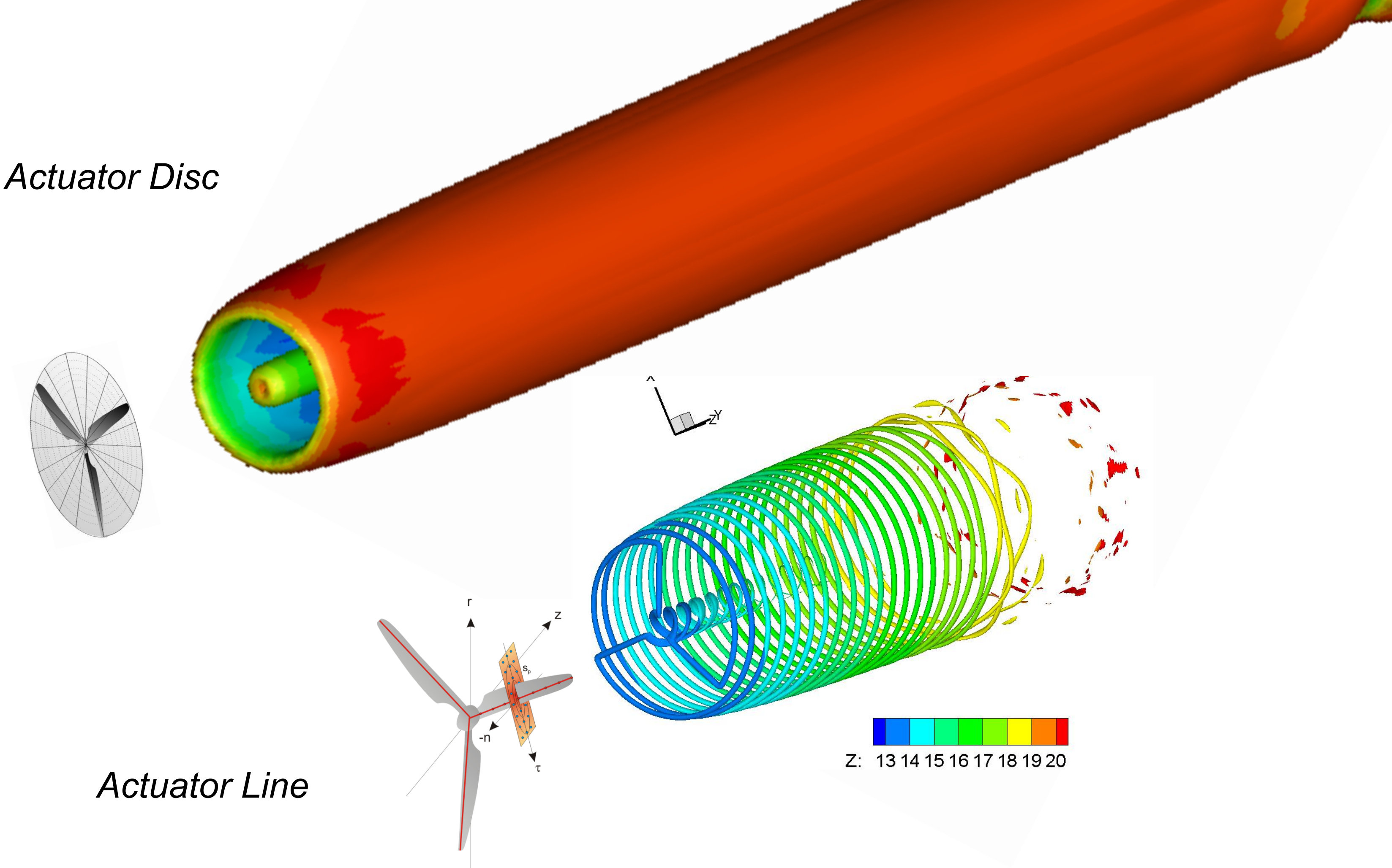

- Lift and drag forces from airfoil data applied along line/disc
- No need to mesh blade, additional gridpoints in wake

Pre-generated turbulent atmospheric boundary layer

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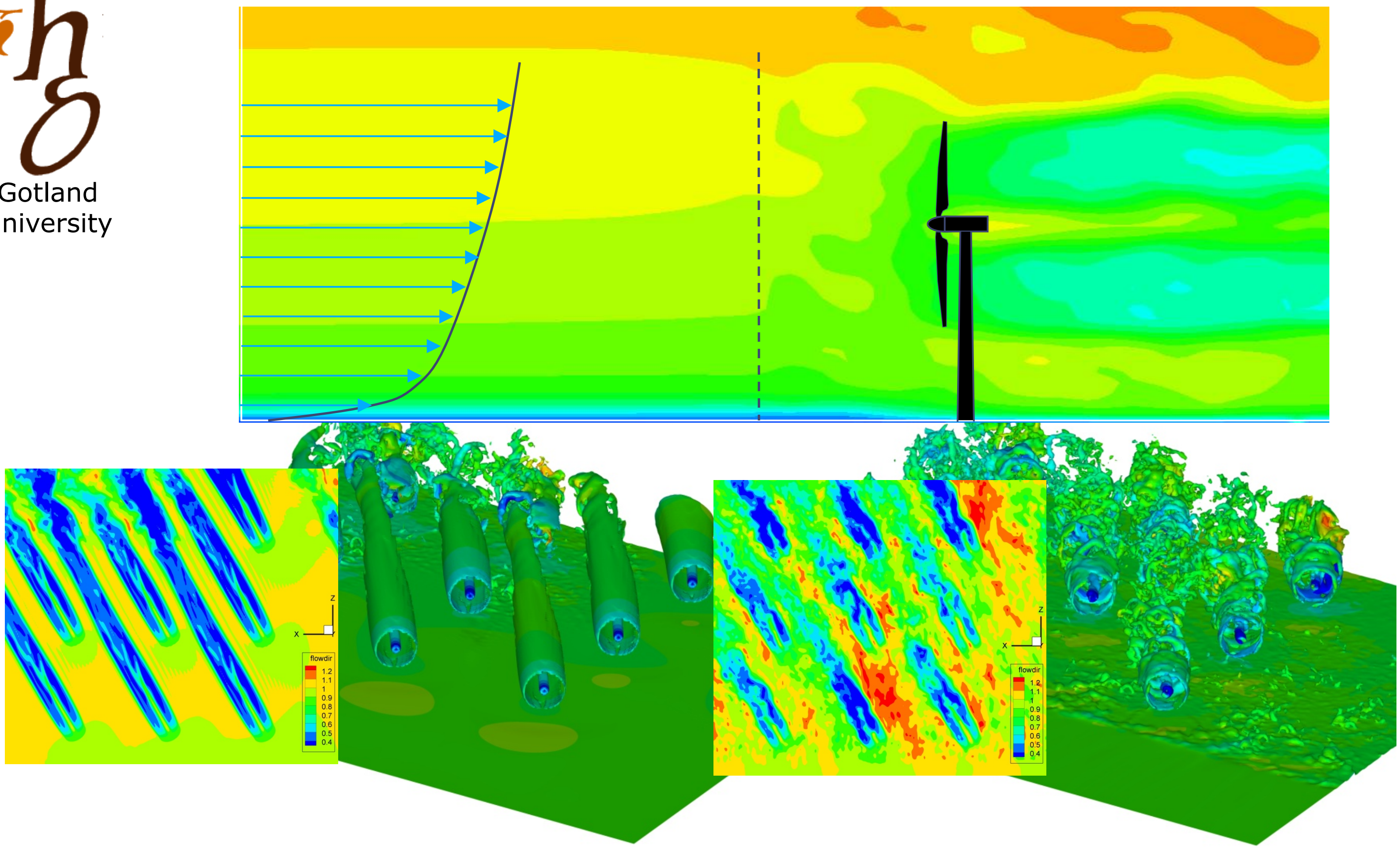

Combination of fundamental and applied reseach needed.

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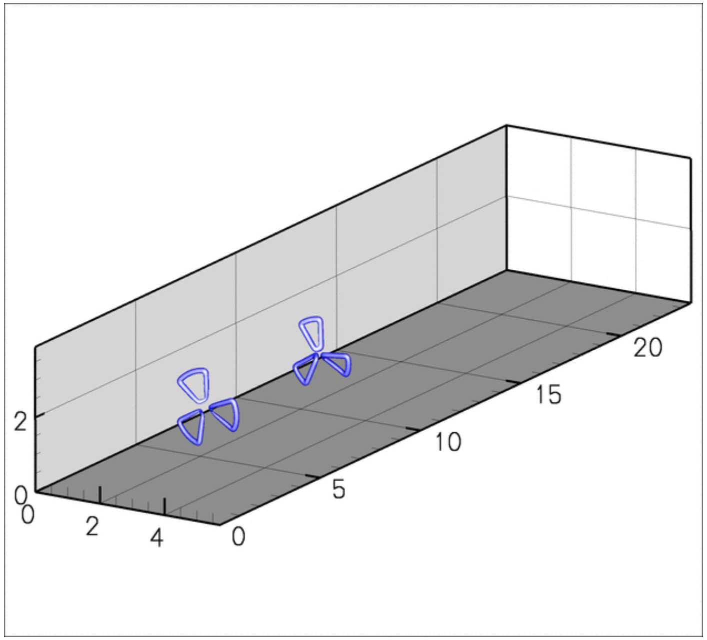

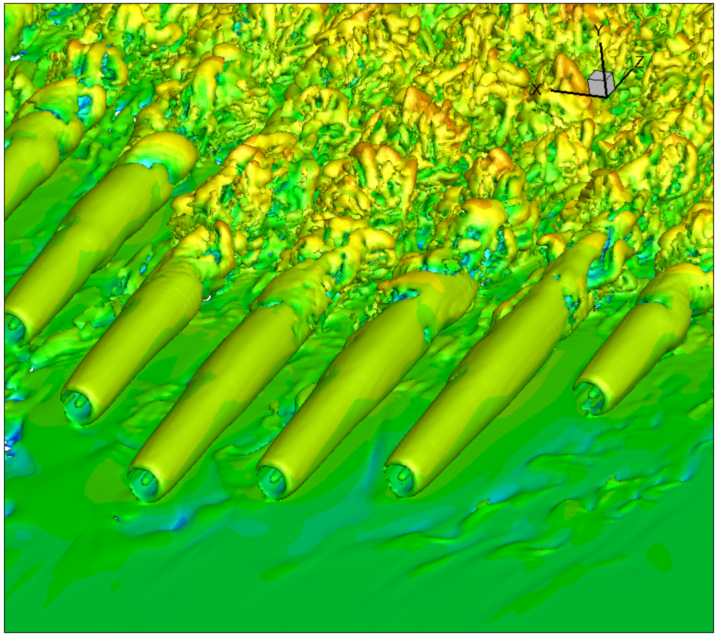

A fundamental understanding of the wake structure is needed to optimize the design of wind farms, i.e., maximize production and minimize loads and maintenance needs.

Outlook

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IEA-Wind Task 31 “WAKEBENCH”

WAKEBENCH *Benchmarking of Wind Farm Flow Models*

Participants for 14 IEA Countries

- Canada, China, Denmark, Germany, Greece, Italy, Japan, Netherlands (to sign), Norway, Spain, Sweden, Switzerland, U.K., U.S.

Task Organization

- 2 Operating Agents: CENER (2/3) and NREL (1/3)
- 10 Working Groups
- Advisory and Scientific Committees
- 80+ organizations have expressed interest
- 200+ people in the mail list

Period: Oct’11 – Sep’14 (M20/36)

IEA Task 31 “Wakebench”: Objectives

- To improve wind farm modeling techniques and provide a forum for industrial, governmental and academic partners to develop, evaluate and improve atmospheric boundary layer and wind turbine wake models for use in wind energy
  - from flat to complex terrain,
  - from single to multiple wakes,
  - both onshore and offshore,
  - using well defined test cases from the literature and test wind farms (“research” conditions) as well as from industrial sites (“real-life” conditions)
- To build consensus on flow model evaluation procedures

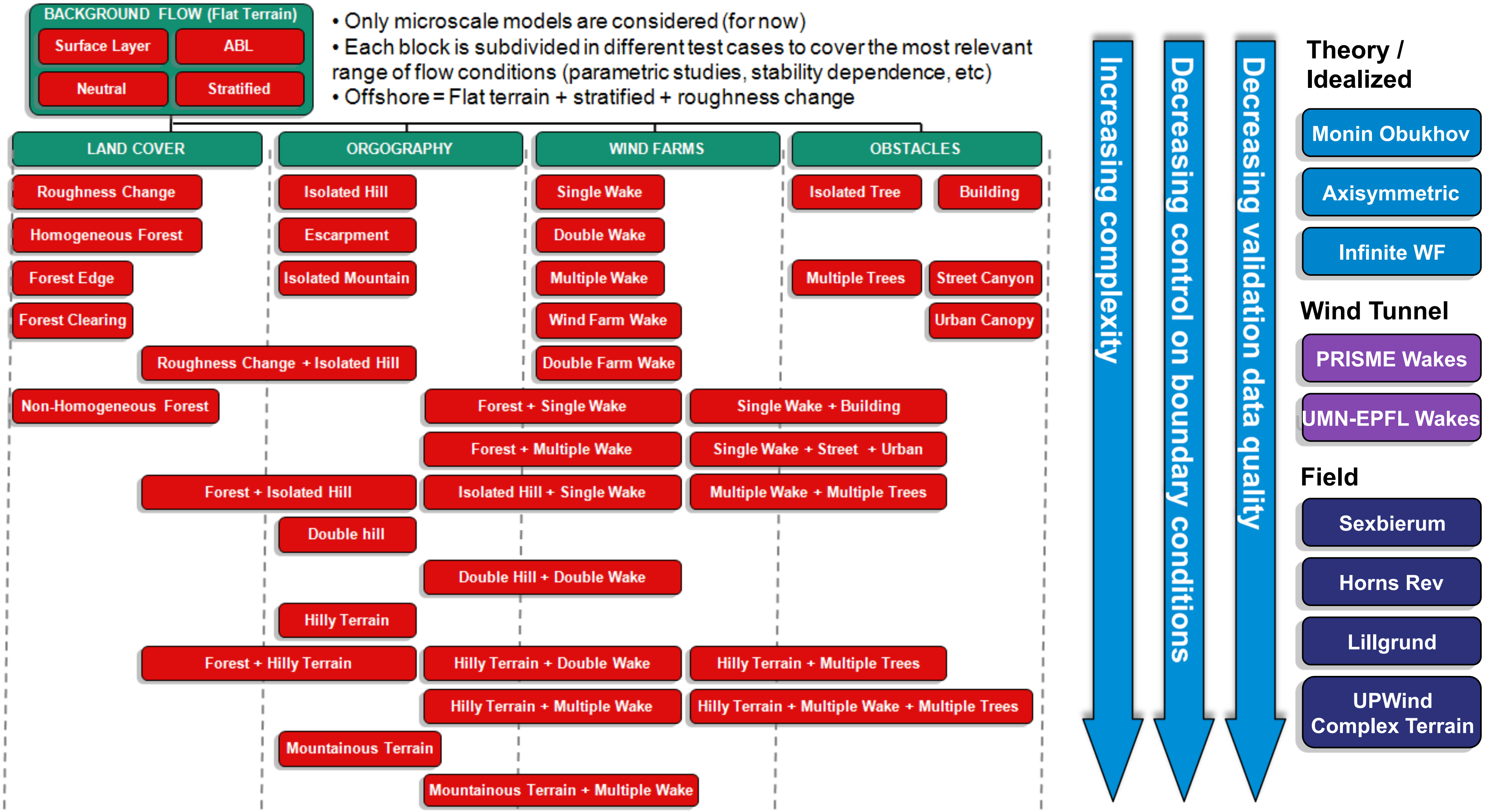
Deliverables

- **Model Evaluation Protocol**
- **Inventory of models and test cases**
- **Best practice procedures**

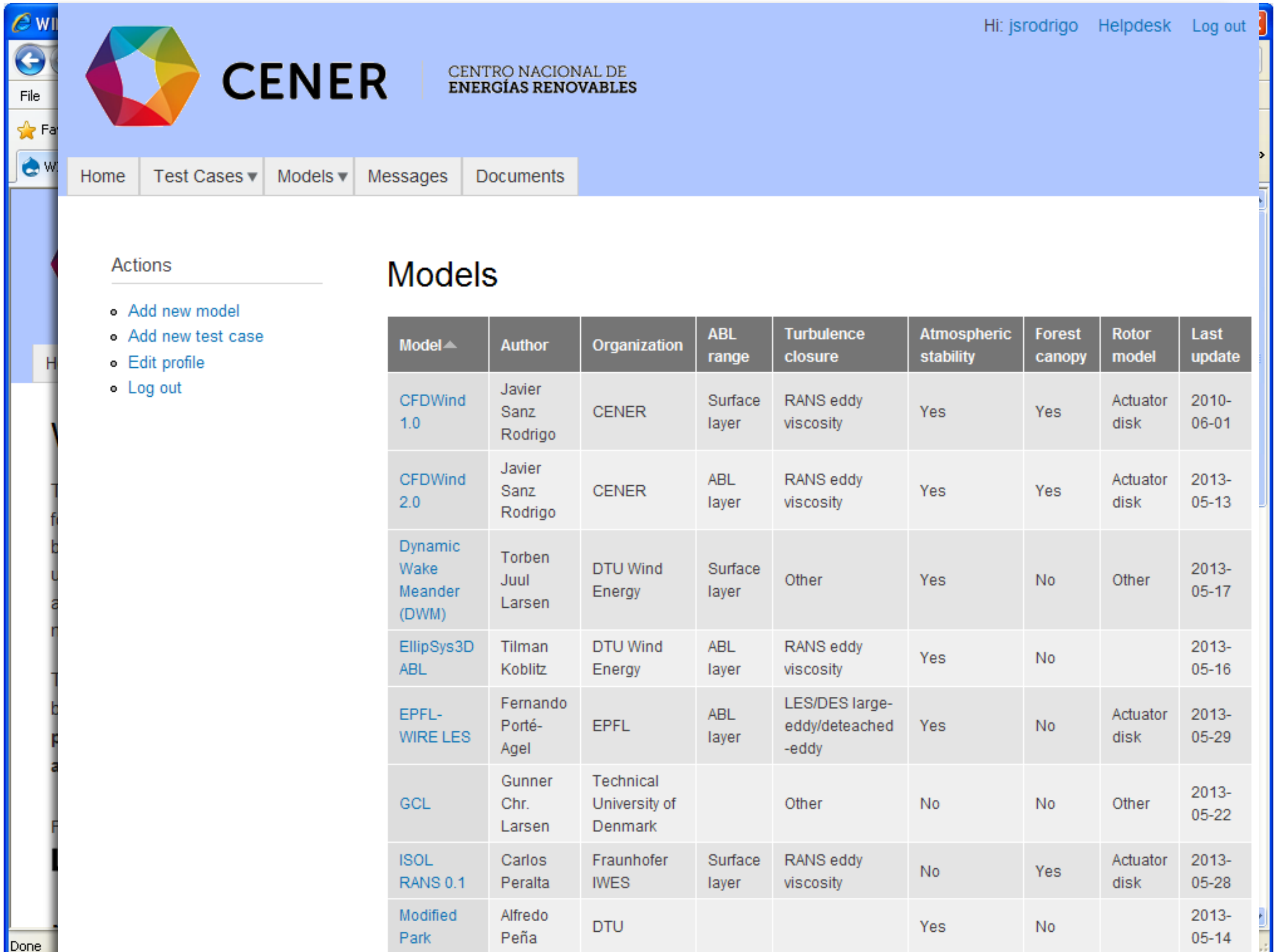
Integrated on a web-based validation portal: **https:\\www.windbench.net**

The building-block approach on model validation

- Only microscale models are considered (for now)
- Each block is subdivided in different test cases to cover the most relevant range of flow conditions (parametric studies, stability dependence, etc)
- Offshore = Flat terrain + stratified + roughness change



Windbench.net: Online management of validation benchmarks



Hi: jsrodrigo Helpdesk Log out

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Home | Test Cases ▾ | Models ▾ | Messages | Documents

Actions

- Add new model
- Add new test case
- Edit profile
- Log out

Models

Model ▲	Author	Organization	ABL range	Turbulence closure	Atmospheric stability	Forest canopy	Rotor model	Last update
CFDWind 1.0	Javier Sanz Rodrigo	CENER	Surface layer	RANS eddy viscosity	Yes	Yes	Actuator disk	2010-06-01
CFDWind 2.0	Javier Sanz Rodrigo	CENER	ABL layer	RANS eddy viscosity	Yes	Yes	Actuator disk	2013-05-13
Dynamic Wake Meander (DWM)	Torben Juul Larsen	DTU Wind Energy	Surface layer	Other	Yes	No	Other	2013-05-17
EllipSys3D ABL	Tilman Koblitz	DTU Wind Energy	ABL layer	RANS eddy viscosity	Yes	No		2013-05-16
EPFL-WIRE LES	Fernando Porté-Agel	EPFL	ABL layer	LES/DES large-eddy/deteached-eddy	Yes	No	Actuator disk	2013-05-29
GCL	Gunner Chr. Larsen	Technical University of Denmark		Other	No	No	Other	2013-05-22
ISOL RANS 0.1	Carlos Peralta	Fraunhofer IWES	Surface layer	RANS eddy viscosity	No	Yes	Actuator disk	2013-05-28
Modified Park	Alfredo Peña	DTU			Yes	No		2013-05-14

- ✓ **Repository** of models, test cases and benchmarks
- ✓ **IPR protection** ensured by allowing data owners to control the users accessibility
- ✓ **Peer-reviewed** by Scientific Committee members

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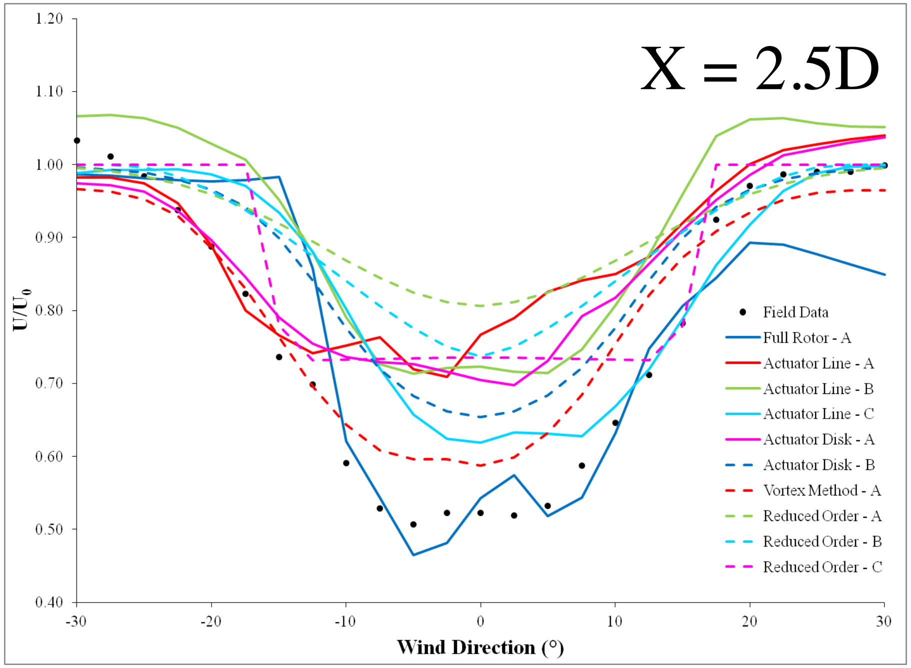
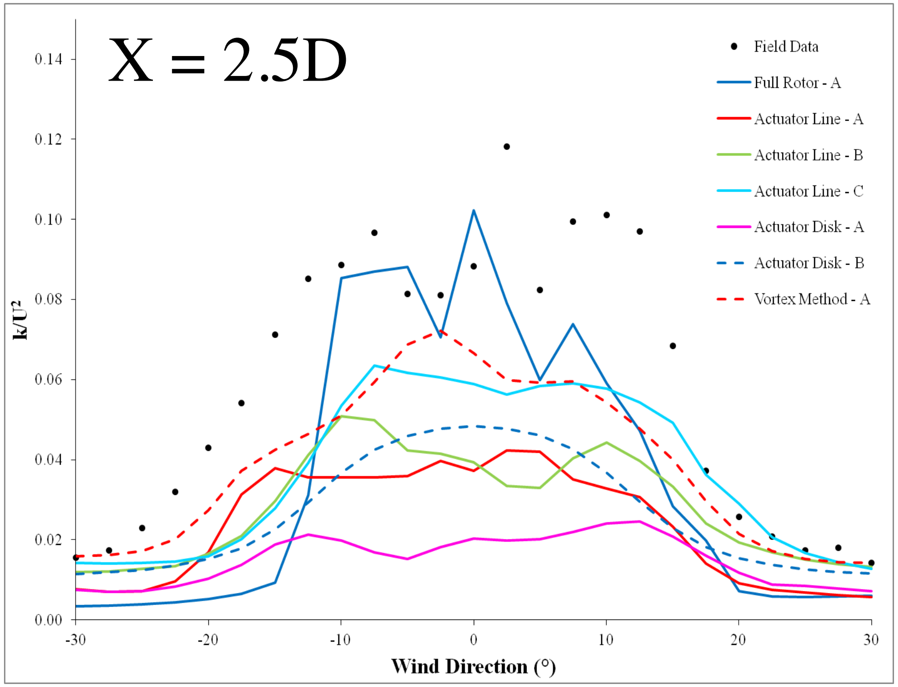
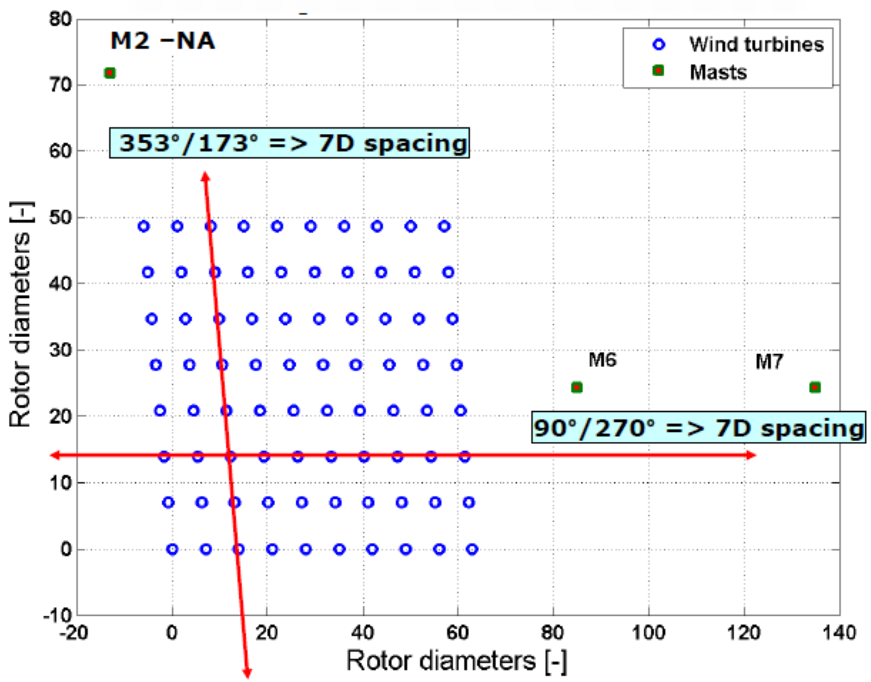
Sexbierum (1992): Single-Wake, Neutral





Horns Rev (2005-07): Multiple-wake from regular array

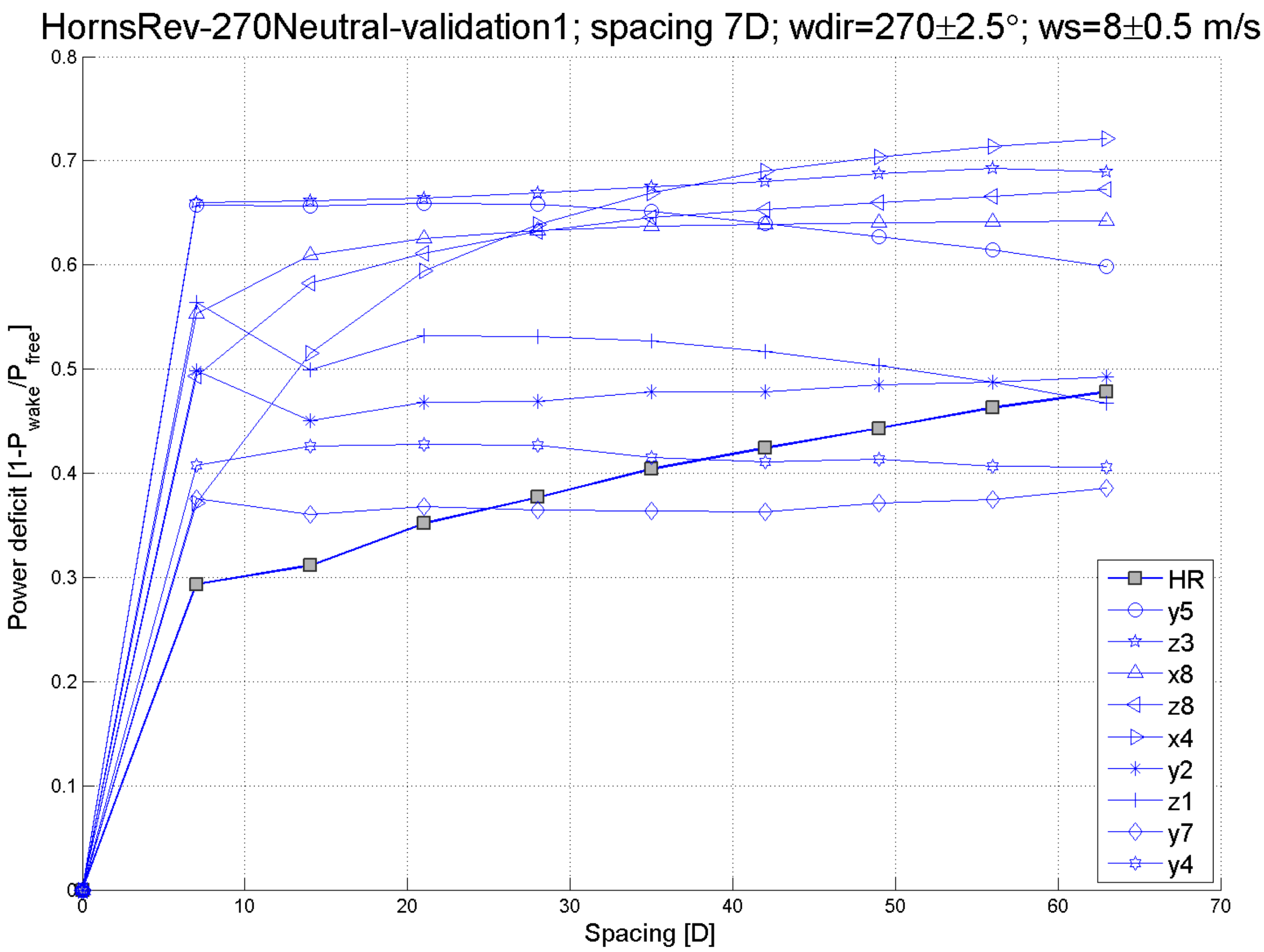
- Validation of power deficit based on qualified SCADA data analysis from a 8x10 regular array of Vestas V80-2MW
- Re-engineered turbine specs using generic NREL's turbine model
- Benchmarks:
  - ❑ Neutral, direction sector width: 270º ± {2.5º, 7.5º, 15º}
  - ❑ stability: stable, neutral, unstable
  - ❑ turbulence intensity
  - ❑ turbine spacing: 7D, 9.4D, 10.4D



- In collaboration with the EERA-DTOC EU project

Managed by: Kurt S. Hansen (DTU Wind, Denmark)

Horns Rev (2005-07): Sensitivity to wind direction sector



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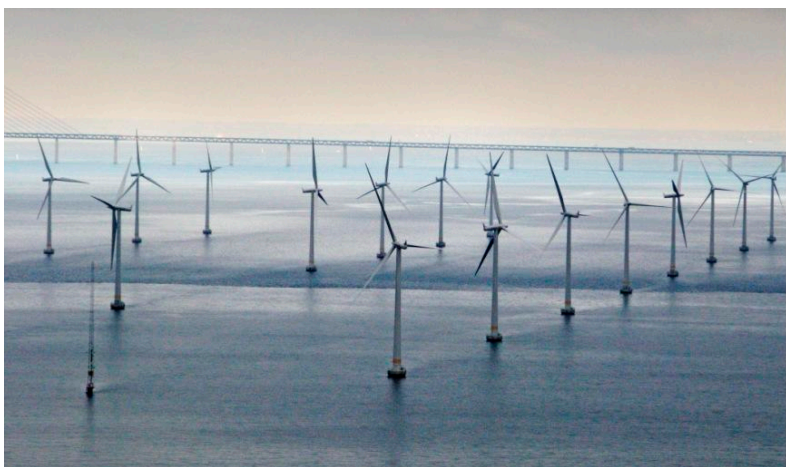
GOBIERNO DE ESPAÑA | MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO | MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

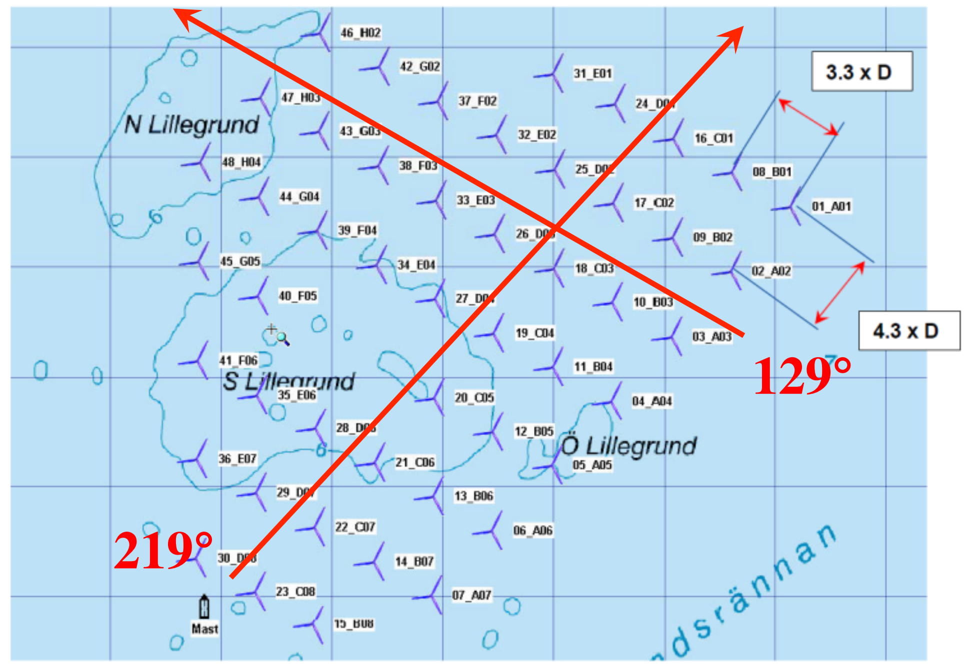
Ciemat

Gobierno de Navarra

Lillgrund (2008-13): Closely-spaced array with clearing

- 48 Siemens SWT-2.3-93, 2.3MW
- Follow-up of Horns Rev benchmarks for closely-spaced turbine alignments and study the recovery of velocity inside the clearing
- Re-engineered turbine specs using generic NREL's turbine model
- Benchmarks:
  - ❑ Single direction runs
  - ❑ Wind farm wake efficiency vs wind direction





Managed by: E. Maguire (Vattenfall, Denmark), K.S. Hansen (DTU Wind, Denmark) and M. Churchfield (NREL, USA)

Lillgrund (2008-13): Results…

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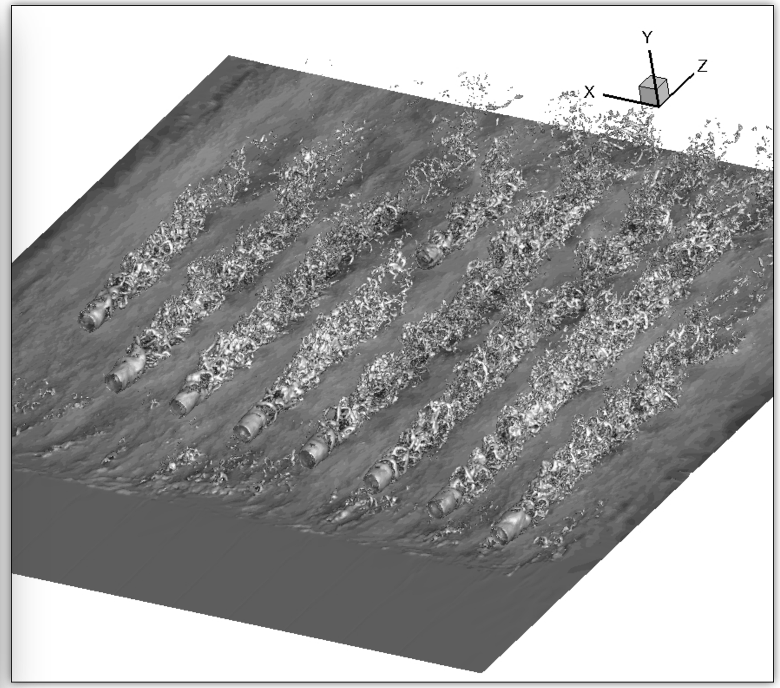
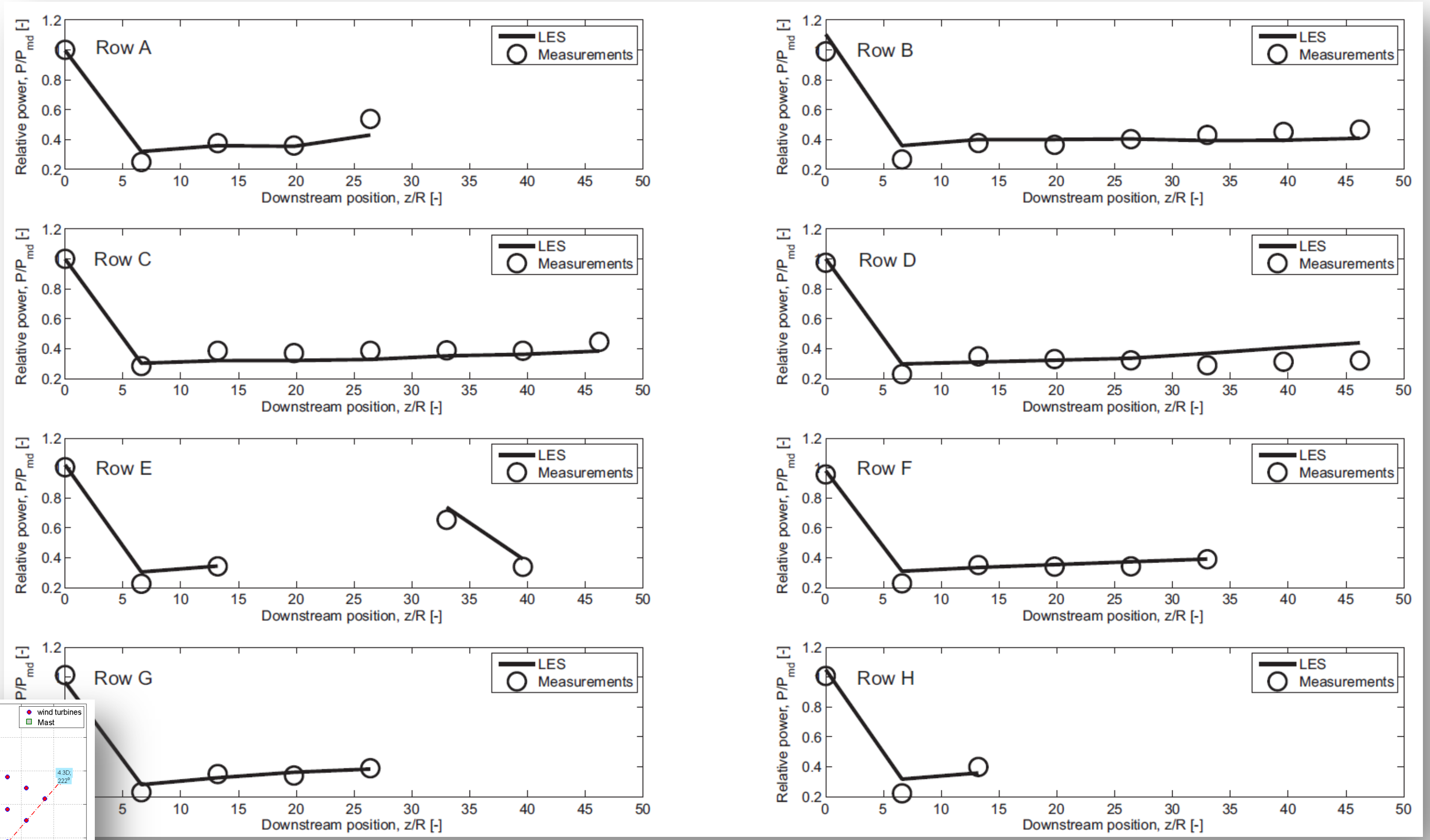
Real case

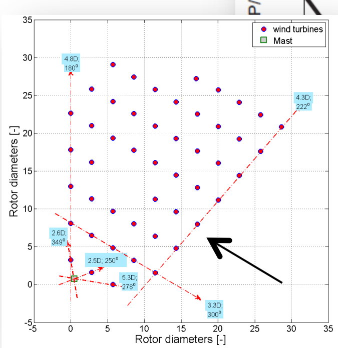


Large-eddy simulation

Nilsson, Ivanell et al.

Lillgrund (2008-13): Results…





$$120 \pm 2.5 \text{ degrees}, \; U_0 = 8 \pm 0.5 \text{ m/s}, \; TI \approx 5\%$$

Nilsson, Ivanell et al.

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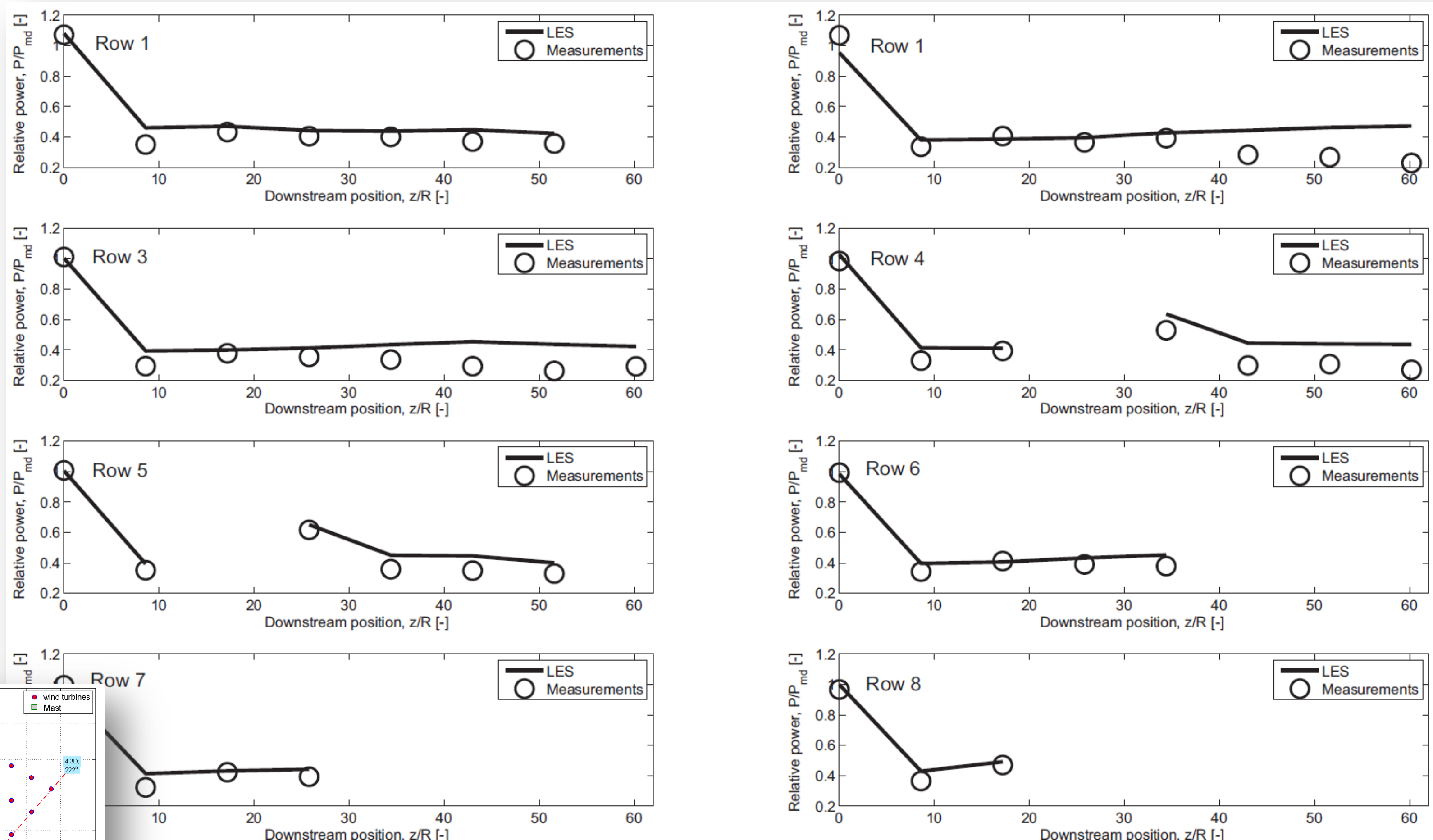
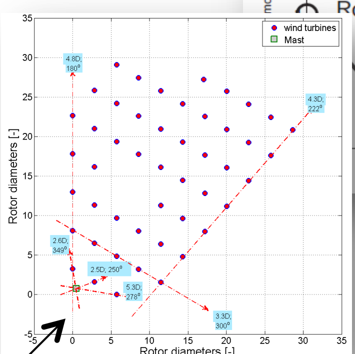
Lillgrund (2008-13): Results…



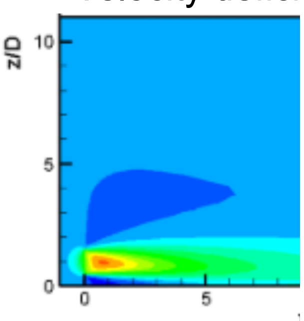


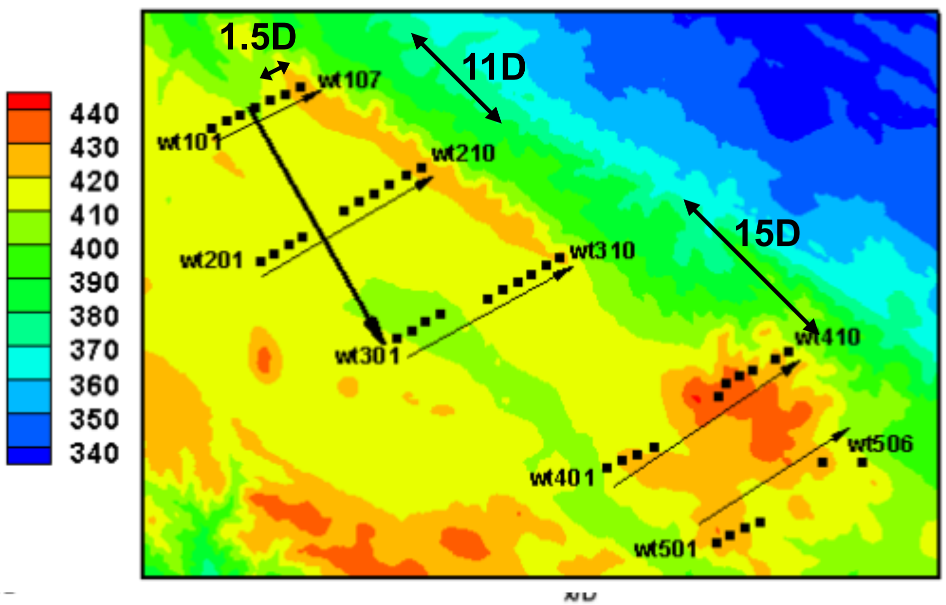
$$220 \pm 2.5 \text{ degrees}, \; U_0 = 8 \pm 0.5 \text{ m/s}, \; TI \approx 5\%$$

Nilsson, Ivanell et al.

UpWind (2011): Complex Terrain

- Complex terrain test cases will be discussed next in Wakebench
- Follow-on activities of the wakes group of the UpWind EU project
- Validation of power deficit based on qualified SCADA data analysis. The quality of the data is low but the data qualification procedure is consistent with Horns Rev and Lillgrund benchmarks, all analyzed by K.S. Hansen
- Focus on terrain-wake interaction
- Precursor sim ... terrain) to understand wak...





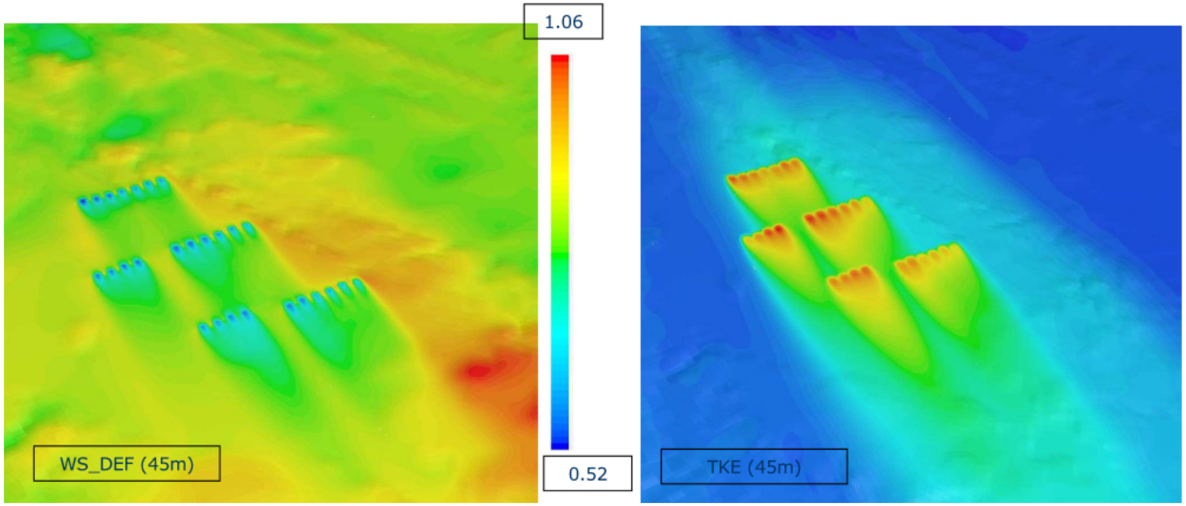
Wake effects still significant at 40D while in flat terrain the wake influence extends to 20D

Politis et al., 2012, Wind Eng 15:161-182

Managed by: R. Barthelmie (Indiana University, USA) and K.S. Hansen (DTU Wind, Denmark)

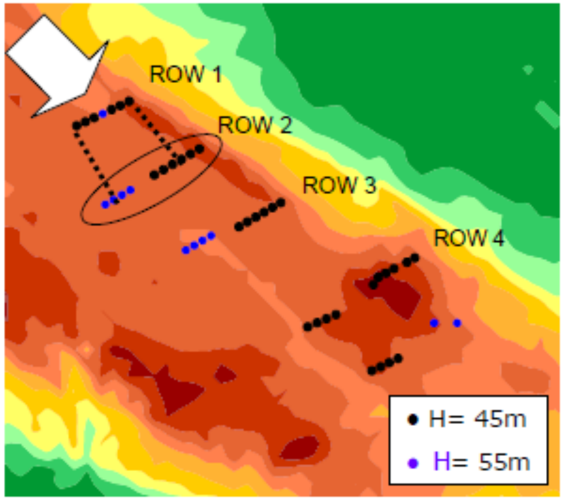
UpWind (2011): Complex Terrain

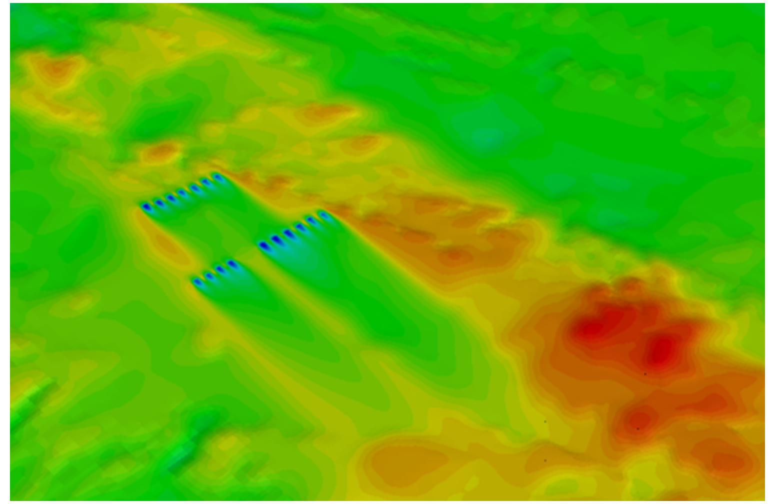
- Two-step analysis
  - ❑ Decoupled terrain and wake effects: validation data is not available
  - ❑ Coupled terrain + wake effects: validation based on power ratio relative to wt101
- Actuator disk model: analysis of reference “freestream” velocity for Ct by adding rows sequentially

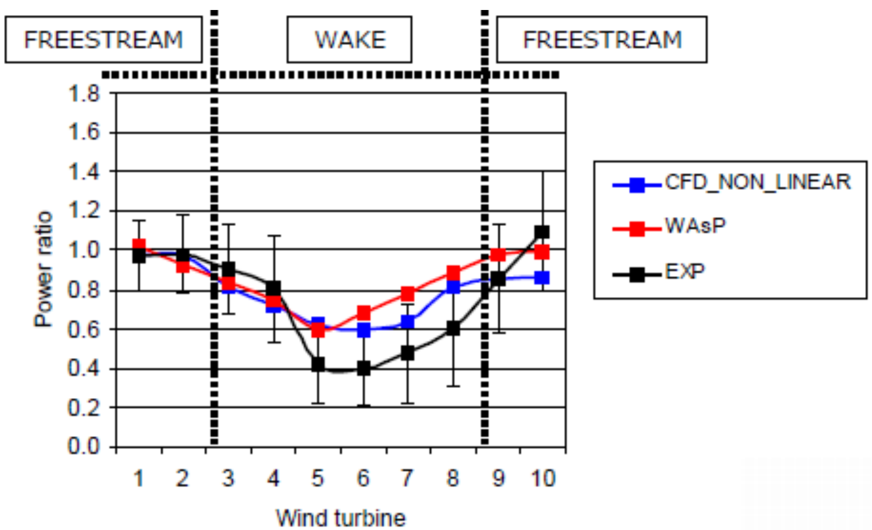


- Wind conditions:
  - ❑ Neutral
  - ❑ U_{hub} = 8 m/s
  - ❑ TI_{hub} = 12%
- Models:
  - ❑ CENER, CFDWake (CFD actuator disk model)
  - ❑ CRES, CRES-flowNS (CFD actuator disk model)
  - ❑ DTU, WAsP (Algebraic Park model)

UpWind (2011): Complex Terrain







At the 2nd row (11D) wake models underestimate the power deficit by 10-20%

Cabezón et al., EWEA-2010

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Conclusions & Outlook

- IEA Task 31 welcomes modelers from industry and academia to benchmark models on a wide range of site conditions
- High quality experimental data is of the utmost importance for an efficient and consistent development of models
  - ❑ Test sites and wind tunnels shall be the main sources of validation data
  - ❑ SCADA data is always questionable due to the lack of calibration and maintenance procedures on operational sensors
  - ❑ IPR on turbine specs and field data is also an important bottleneck. The Windbench portal takes care of IPR protection though
- Data qualification procedures and fit-to-purpose evaluation metrics are key elements of the Model Evaluation Protocol to be presented in 2013
- Next Wakebench Meeting: 12-15 November 2013, Frankfurt
  - ❑ Workshop with the topic "Model Uncertainties“, together with IEA Task 11 Topical Expert Meeting on “Complex Terrain Siting”
  - ❑ Contact: Javier Sanz Rodrigo, jsrodrigo@cener.com

Thank you for your attention!

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