



Wind Energy research at DTU Wind Energy

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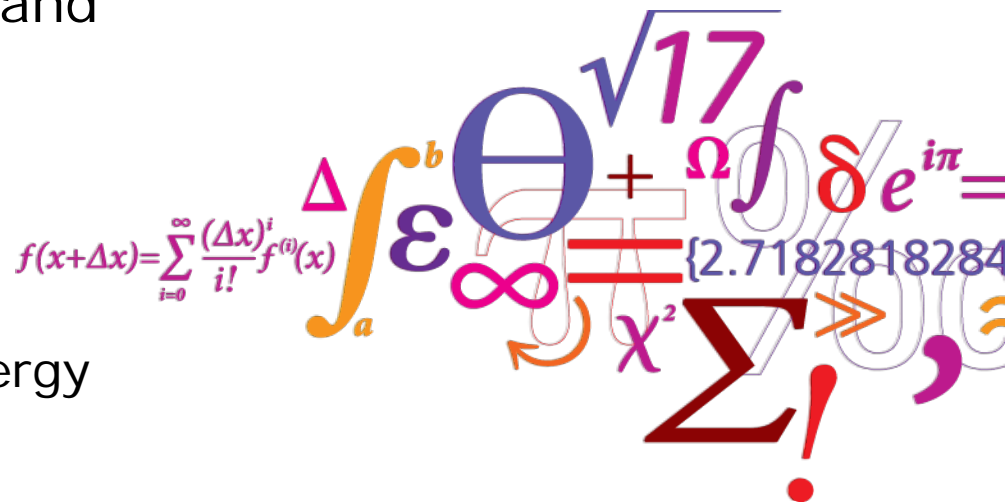
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Wind Energy research at DTU Wind Energy

German-Danish wind energy and automation research day
 Danish Embassy – Berlin
 23rd November 2012

Peter Hauge Madsen
 Head of Department of Wind Energy



Danish Governments Energy Policy Goals – Our Energy 2020

- 100 pct. renewable energy in 2050
- 100 pct. renewable energy in to electricity and heat supply in 2035
- No coal and oil from 2030

- Wind power covers 9 pct. of gross energy consumption in 2020.
- Wind Power covers 49,5 pct. of electricity consumption in 2020.

- EU target for DK:
- Renewable energy covers 30% in 2020, with 10 % i transport (DK expects 35% in 2020)

Wind technology expertise

Risø DTU
National Laboratory for Sustainable Energy

Wind Energy Division

Risø DTU
National Laboratory for Sustainable Energy

Materials Research Division



Fluid Dynamics



Composite Mechanics

DTU Wind Energy Department of Wind Energy

> 240 staff members
Including 150 academic
staff members and 50 PhD
students

Composites and Materials Mechanics

Materials Science and Characterisation

Fluid Mechanics

Test and Measurements

Wind Turbines Structures

Aeroelastic Design

Meteorology

Wind Energy Systems

DTU Wind Energy - 2012

Quality

Scientific excellence

Technical University of Denmark
(founded 1829; first rector H.C. Ørsted)



Ranking

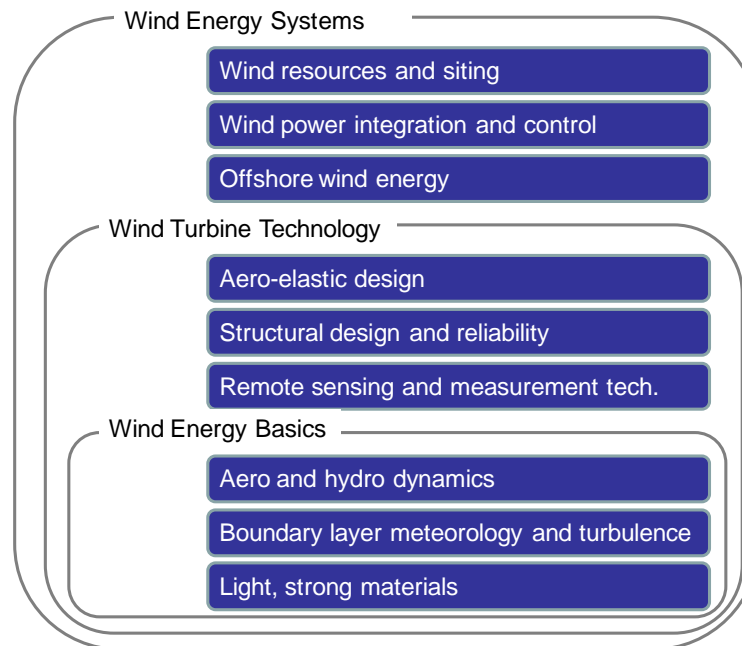
Leiden *Crown Indicator* 2010:

nr. 1 in Scandinavia

nr. 7 in Europe

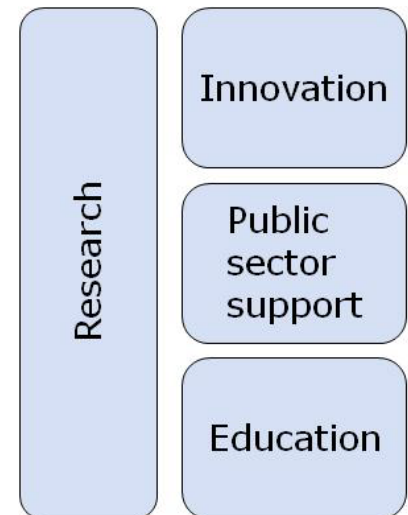
Relevance

Strategic research programmes



Impact

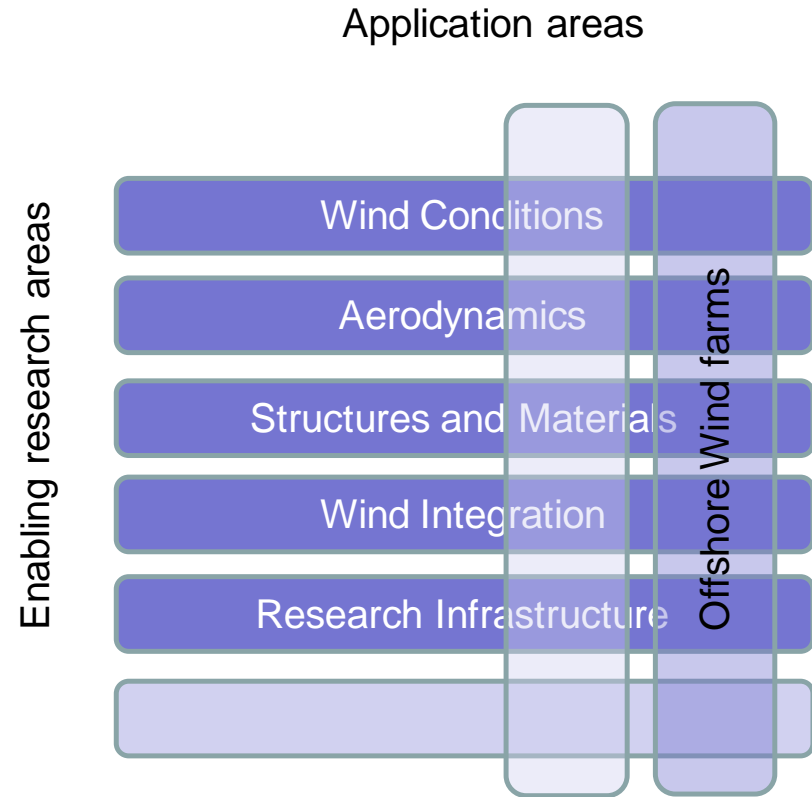
On society



International collaboration

International:

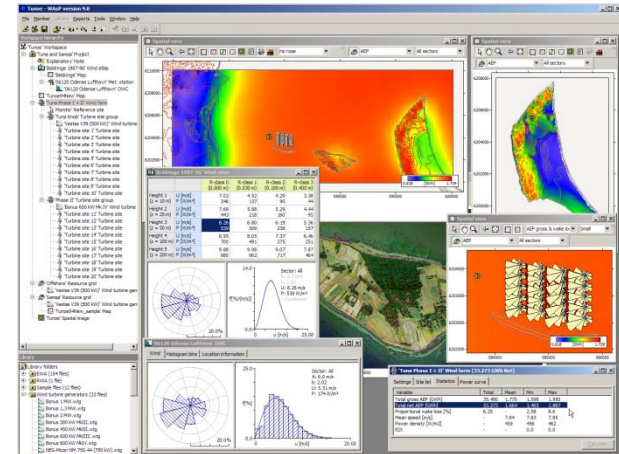
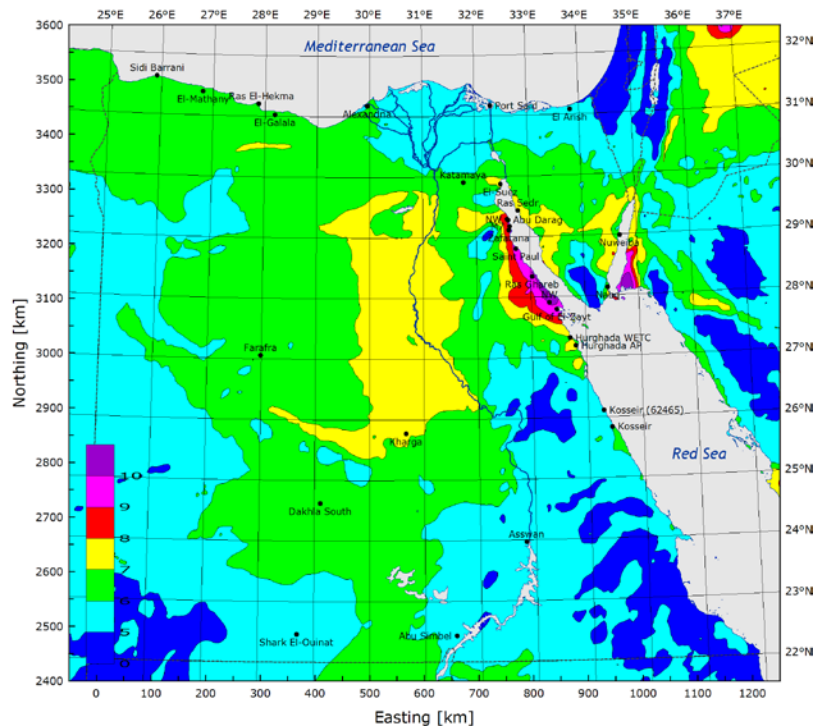
- IEA Wind R&D
- EAWE – European Academy for Wind Energy
- EWEA
- European Wind Energy Technology Platform (EWI)
- EERA – Joint programme on wind energy
- Clean Energy Ministry Initiative (Global wind- and solar atlas)
- Bilateral cooperation



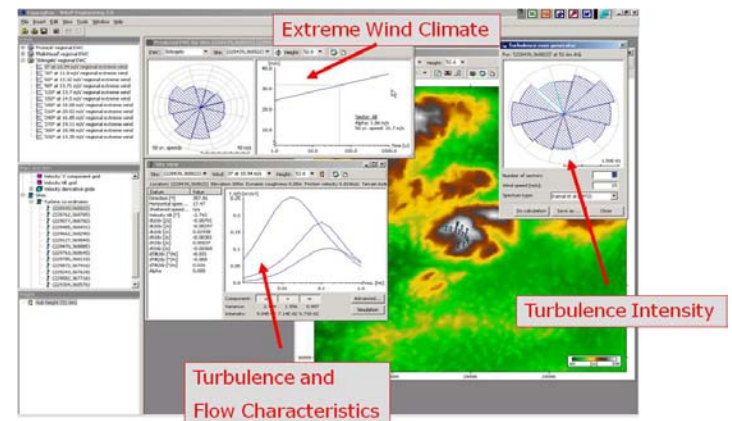
Wind Power Meteorology tools and maps

WASP – the Wind Atlas Analysis and Application Program

Wind Atlas for Egypt (2006)



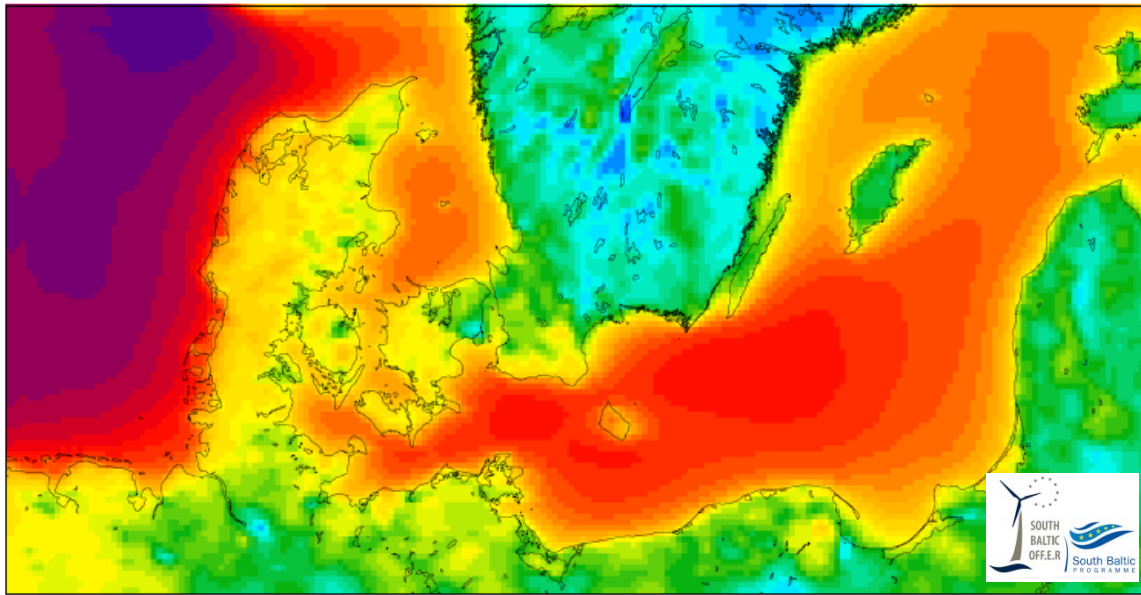
WASP Engineering



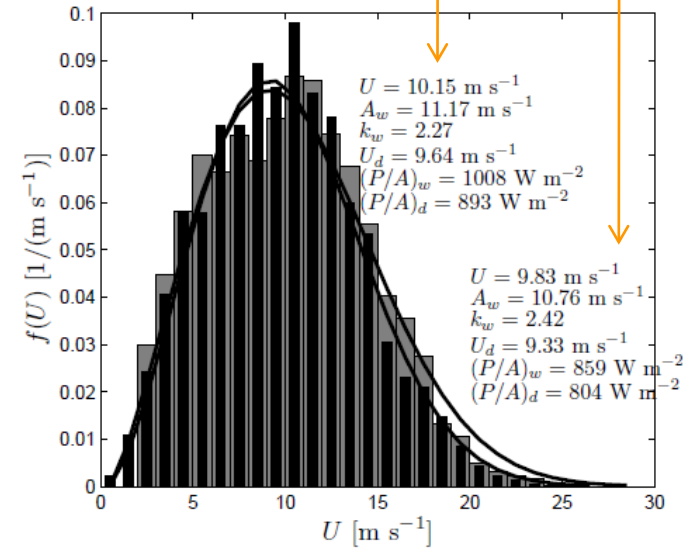
Wind Atlas update

Mean Wind Speed: Jan 2007 - Dec 2009

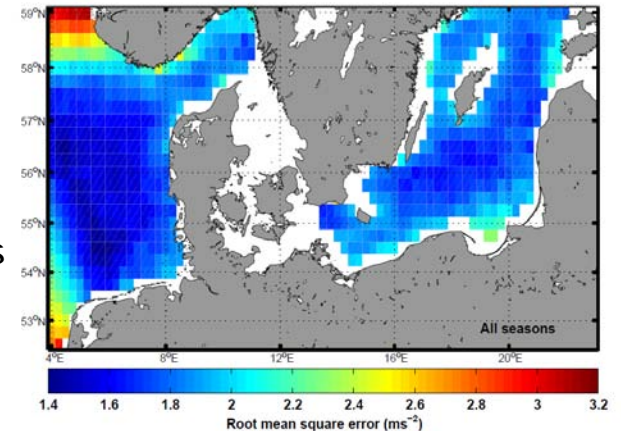
Height: 125 meters



Fino 3 at 100m Obs Model



10 m QuikSCAT comparison



6.5 6.75 7 7.25 7.5 7.75 8 8.25 8.5 8.75 9 9.25 9.5 9.75 10 10.25 10.5

wind speed (m/s)

Wind atlas for South Baltic 5 km WRF simulations

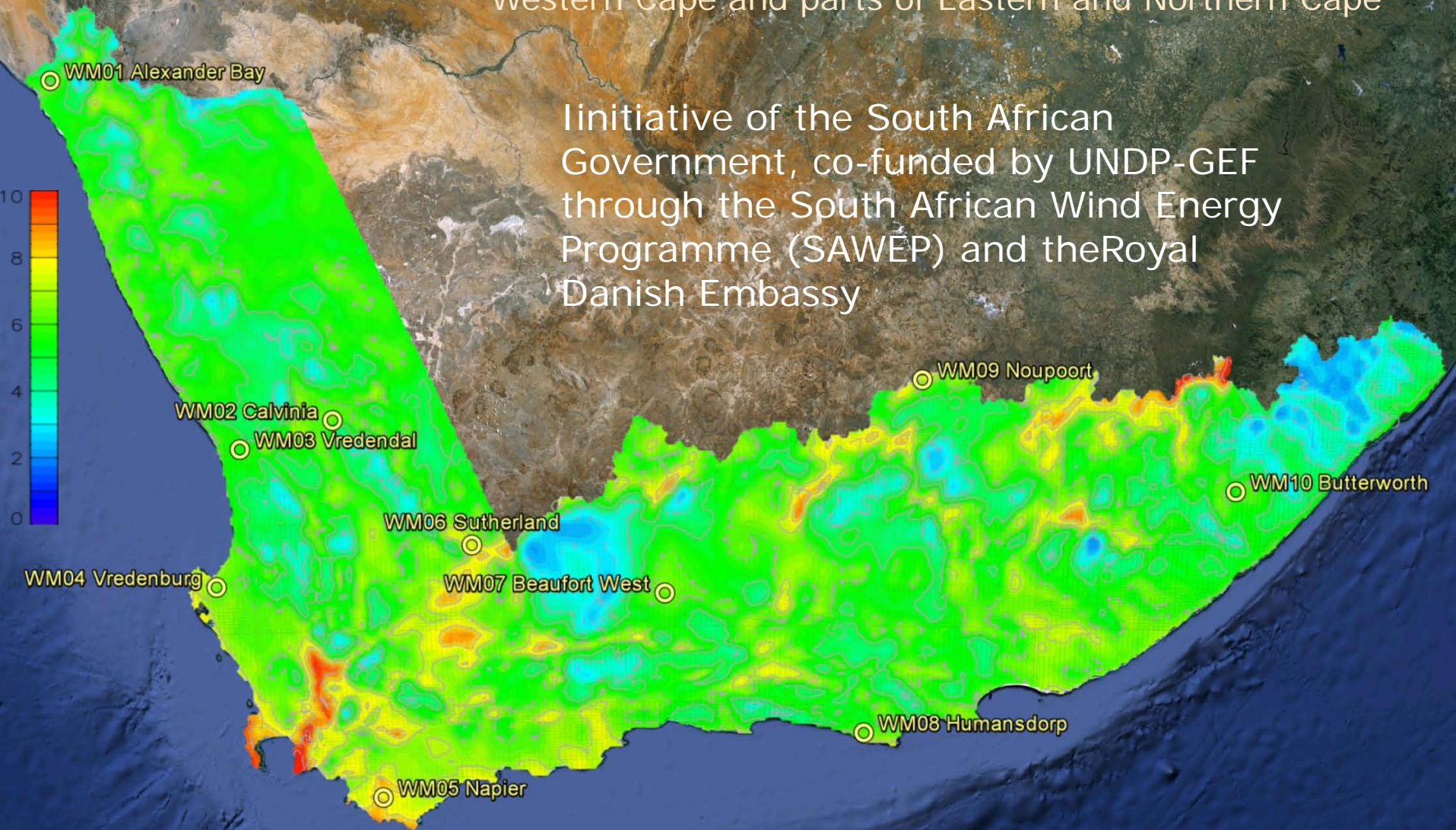
Novel features:

- Verification against high (100 m) offshore measurements
- Comparison over large spatial extent against QuikScat winds
- Climatologies can be calculated for arbitrary periods by applying a wind classification weighting system

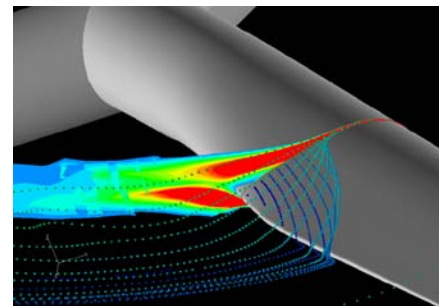
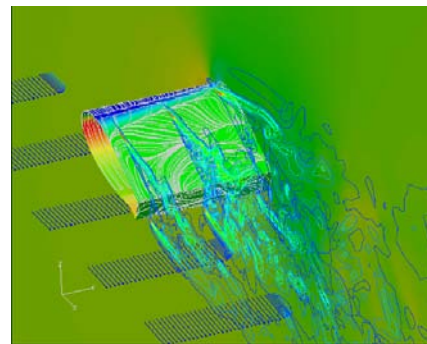
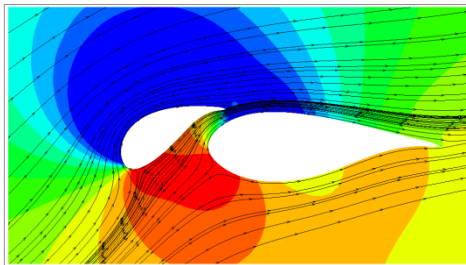
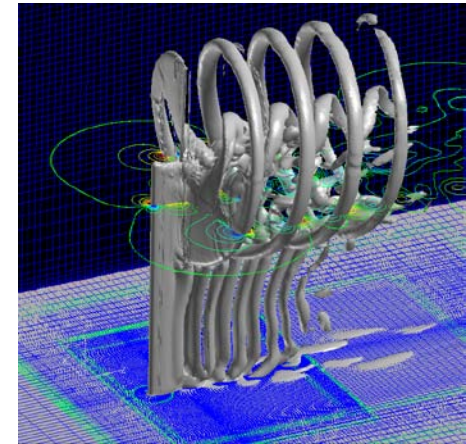
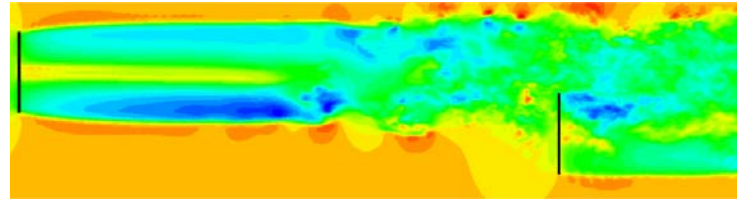
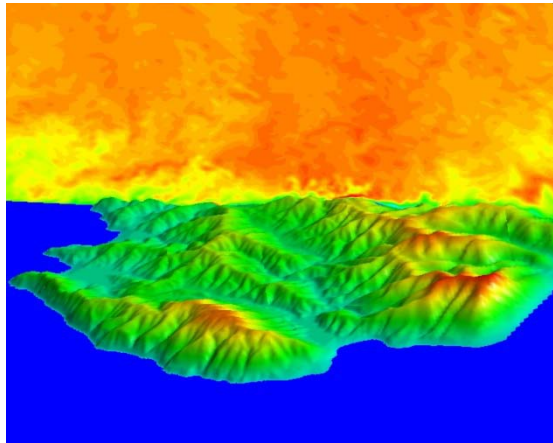
Wind Atlas for South Africa

Western Cape and parts of Eastern and Northern Cape

Initiative of the South African Government, co-funded by UNDP-GEF through the South African Wind Energy Programme (SAWEP) and the Royal Danish Embassy



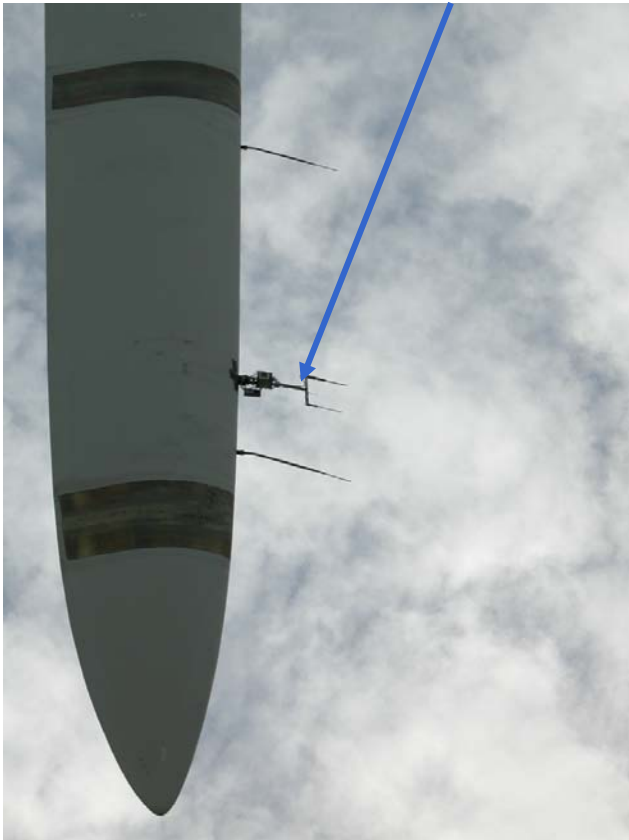
Advanced Design Tools for WT Aerodynamics - modeling and exp. validation



DAN-AERO MW-exp. (Risø, LM, Siemens, Vestas, DONG Energy)

Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

high frequency inflow sensors



five hole pitot tubes



Analysis of the DAN-AERO MW experiment

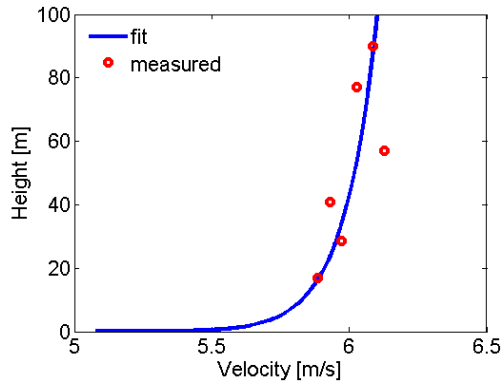
(Risø, LM, Siemens, Vestas, DONG Energy)



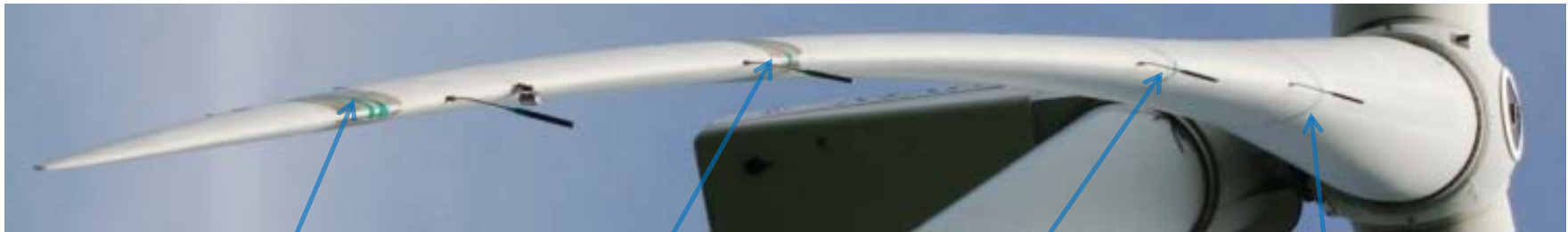
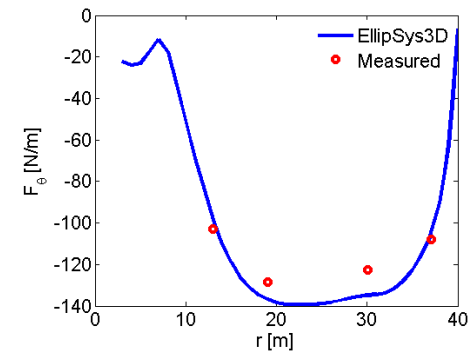
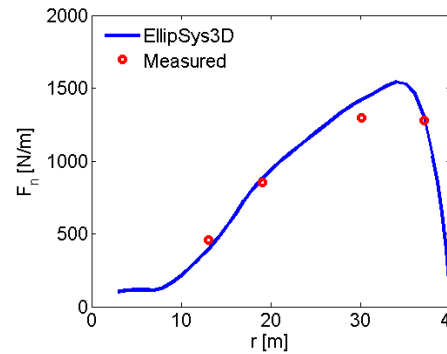
Measured and computed results at nearly uniform inflow condition:

$$V_0(z) = V_\infty \left(\frac{z}{H} \right)^\alpha$$

$\alpha = 0.02$
 $V_\infty = 6.2 \text{ m/s}$
 $TI \approx 10\%$



Normal and tangential loads along blade:

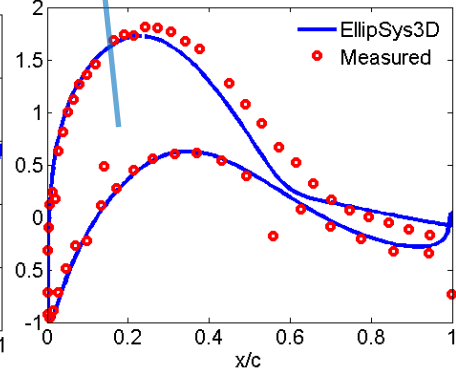
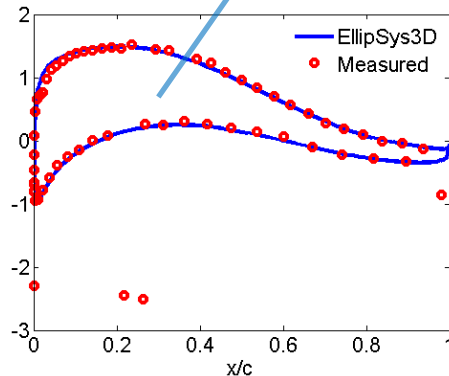
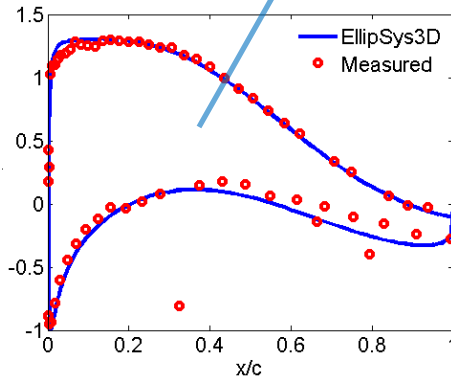
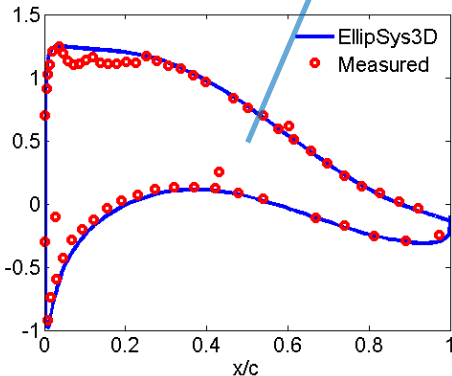


$r = 37\text{m}$

$r = 30\text{m}$

$r = 19\text{m}$

$r = 13\text{m}$



Upscaling



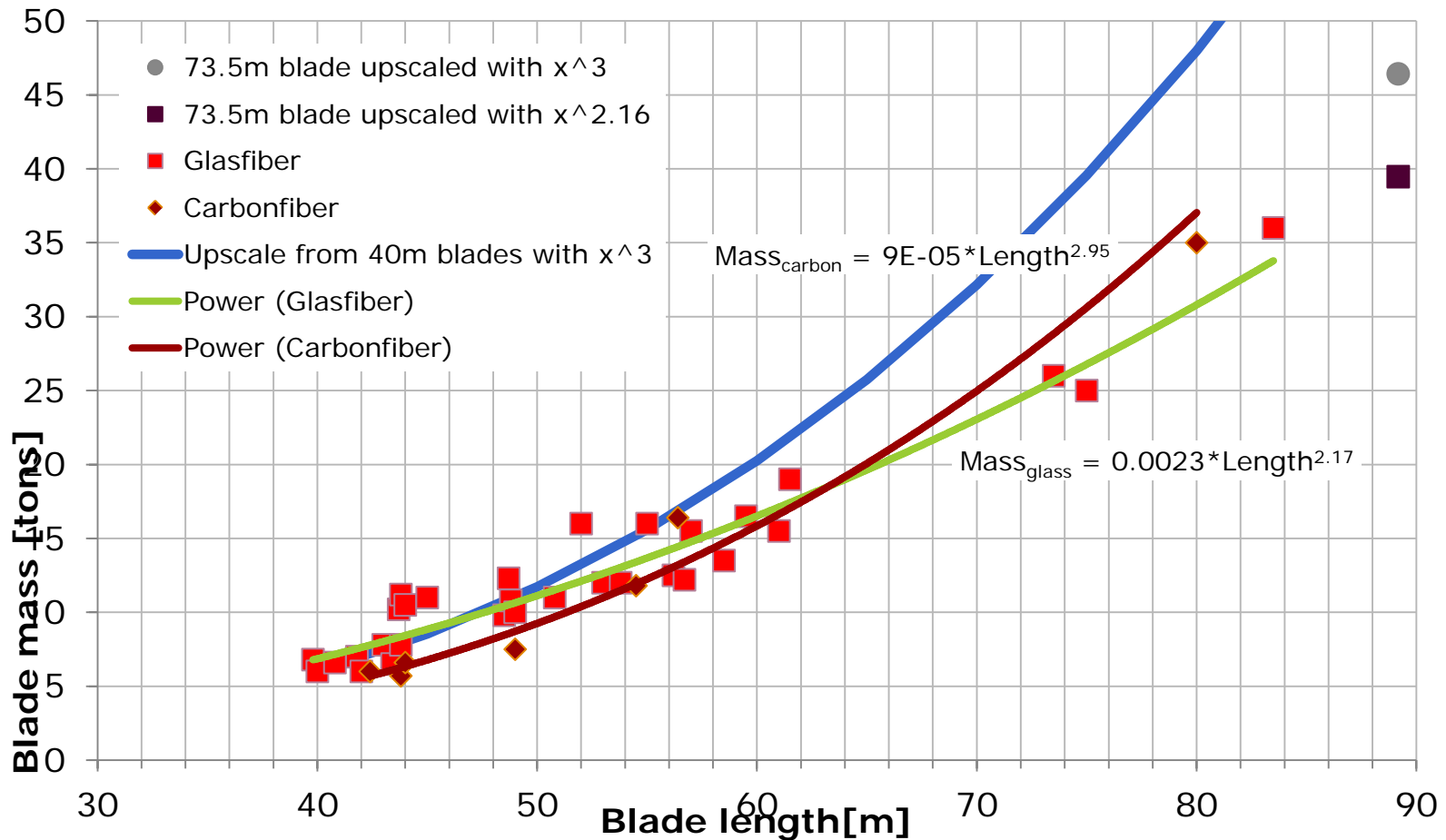
Upscaling: "Square-cube law"

- Power increases as diameter squared
- Mass increases as diameter cubed



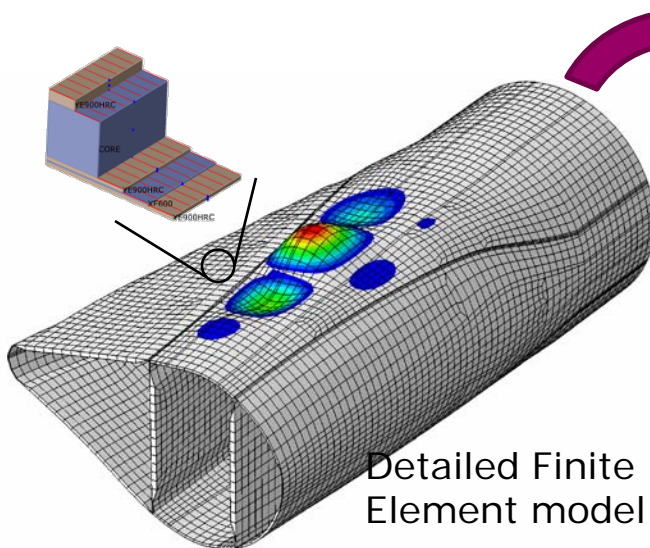
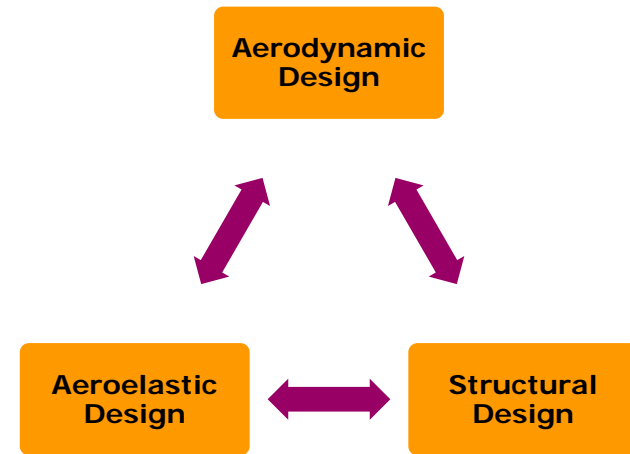
Blade mass increases only close to the diameter squared (exponent 2.1-2.3) due to optimized and thick airfoils and due to optimized structural design

Actual blade mass and upscaled to 10 MW

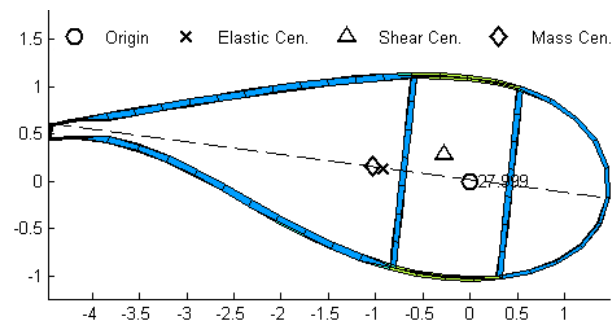


The Light Rotor Project

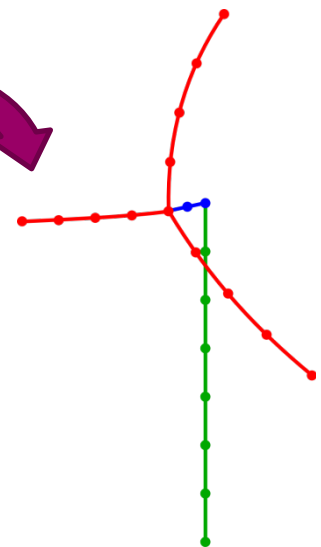
- Future very large rotors ($P=10\text{MW}$, $R=90\text{m}$) require strong emphasis on lightweight design.
 - →Larger relative airfoil thickness
 - →Blade sweep
 - →Optimized structural design
- The project develops an integrated design method incorporating aerodynamic design, aeroelastic design and structural design.
- Topology optimization is used to find innovative structural concepts.
- A very light blade for a 10MW turbine is designed.



Detailed Finite Element model

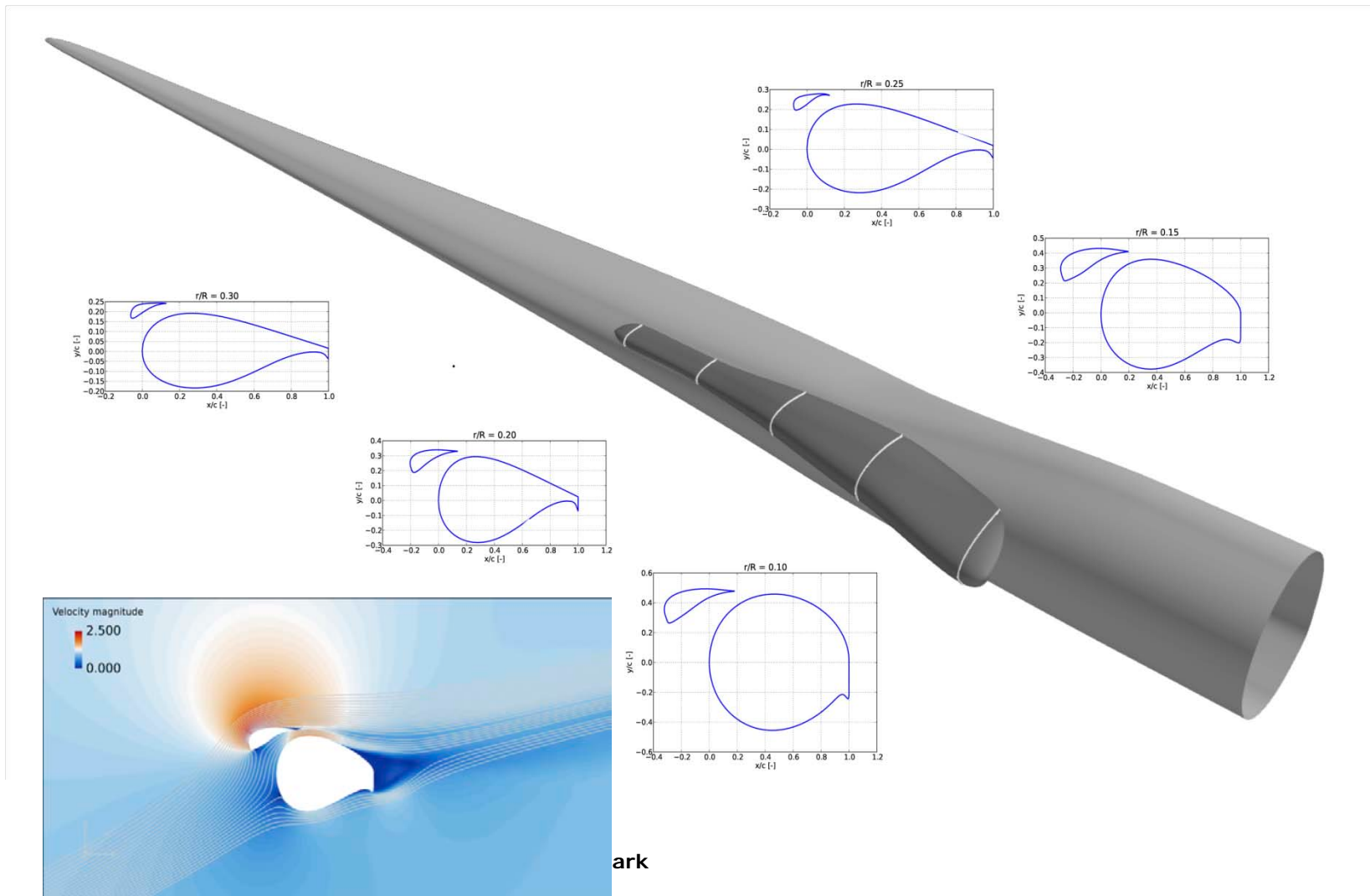


Beam Cross Section Analysis Software (BECAS), taking into account all couplings

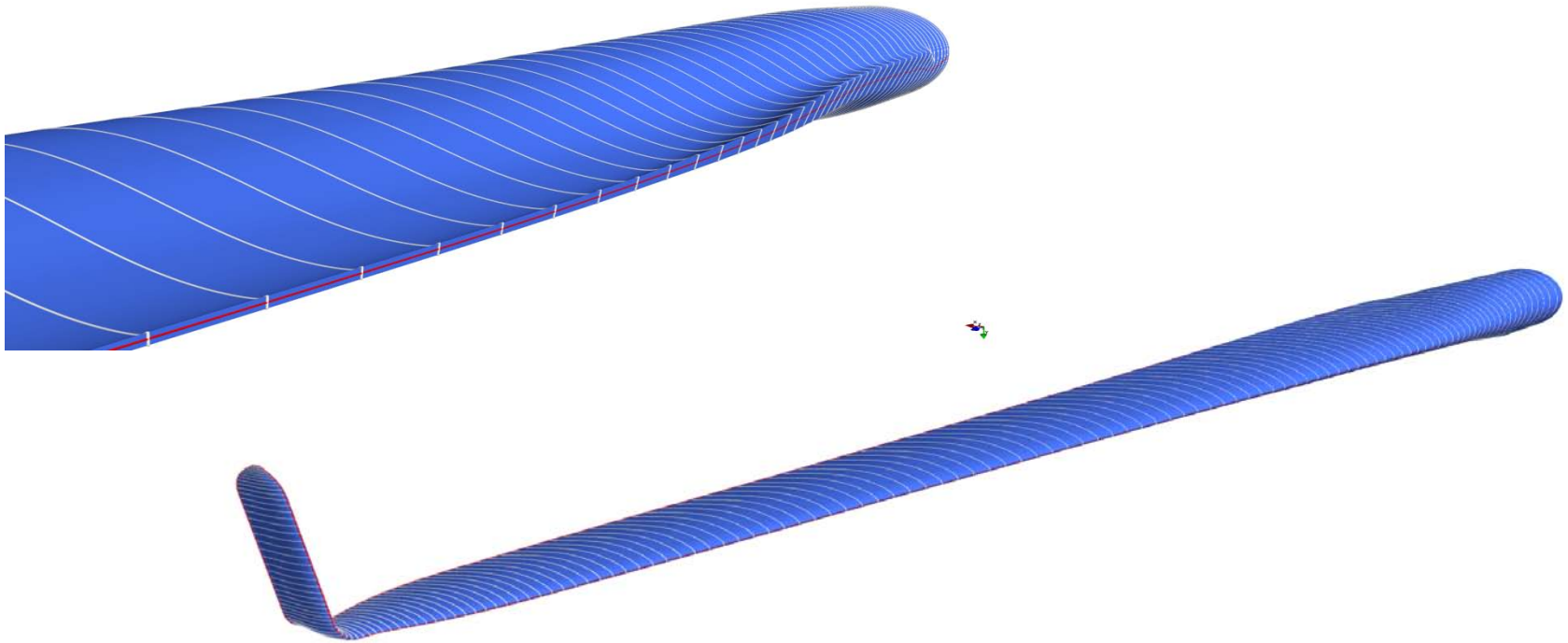


Aeroelastic Analysis (HAWC2)

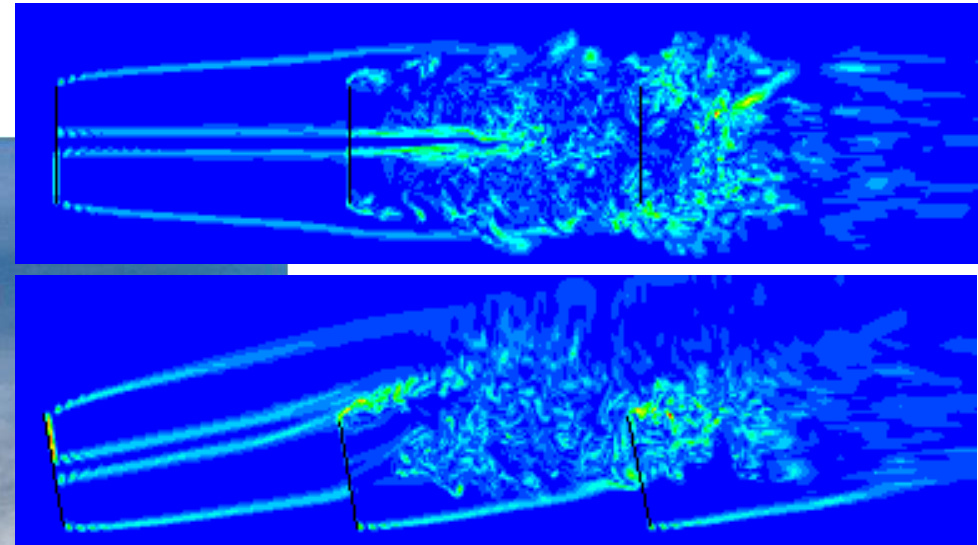
LightRotor 10 MW RWT blade with multi-element airfoils



LightRotor 10 MW RWT blade with adaptive tip/winglet and flat-back airfoils at root



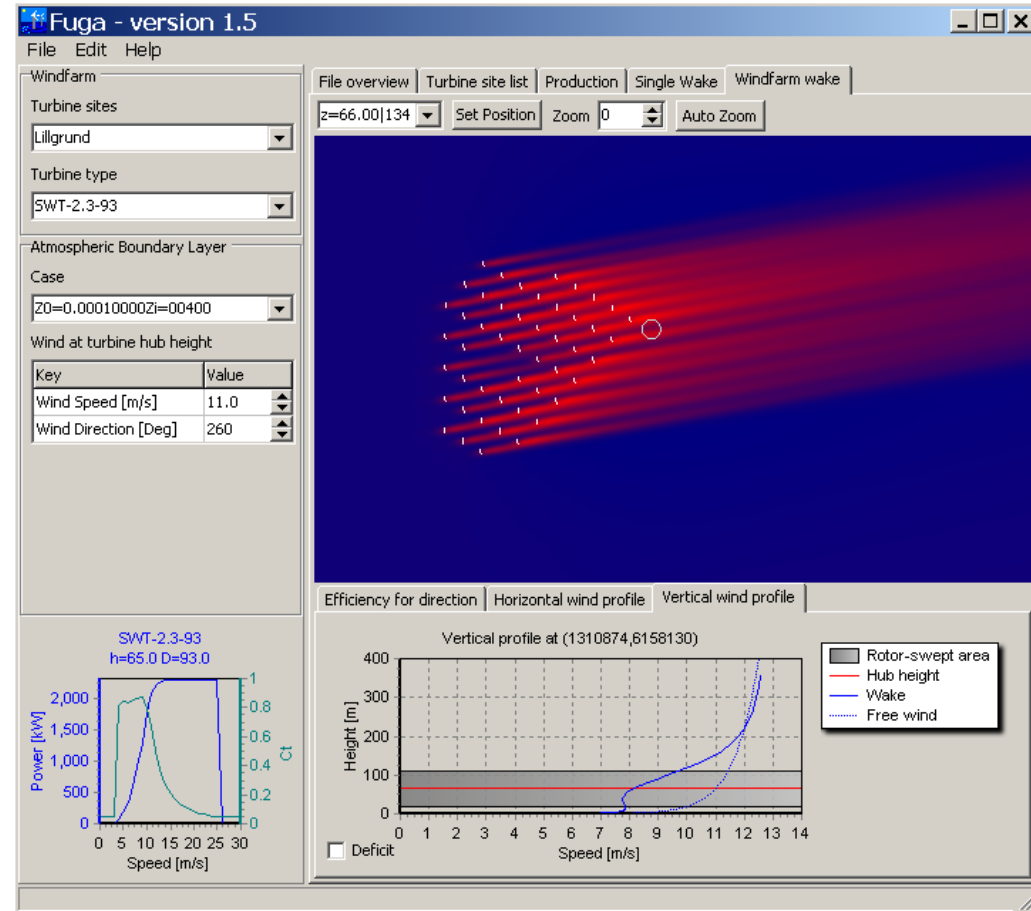
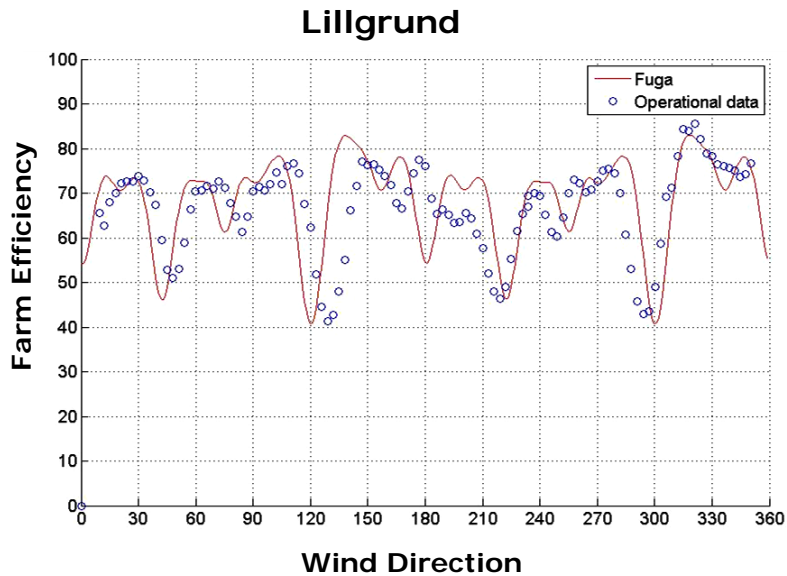
Wake effects – a complex flow essential for performance and loads



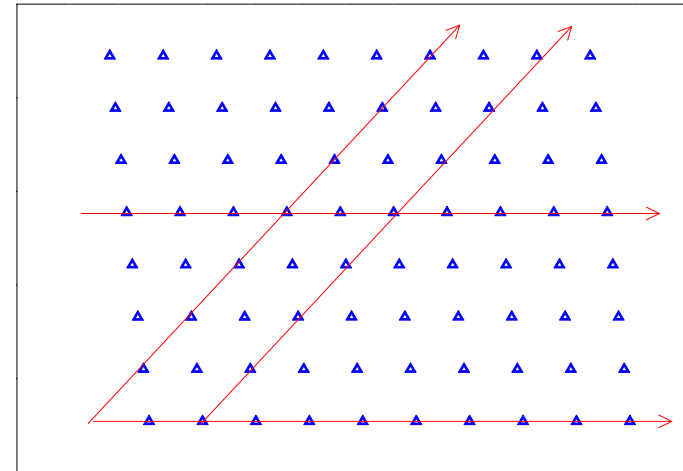
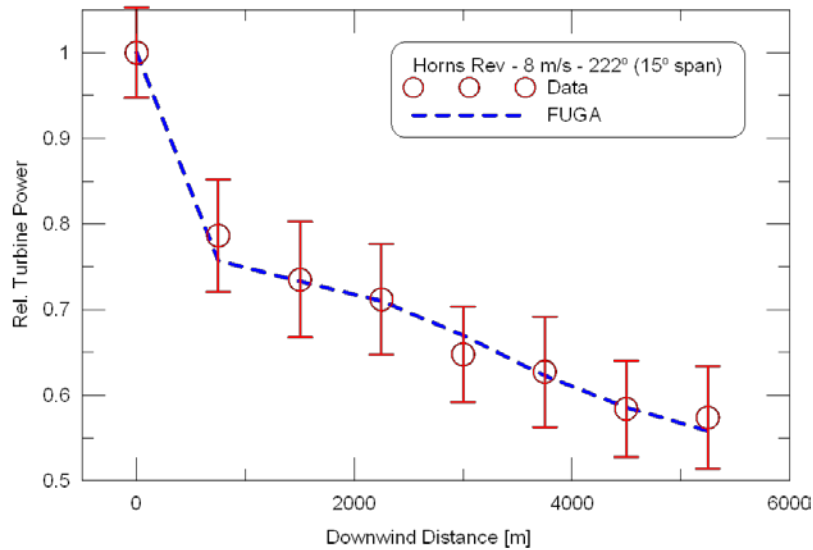
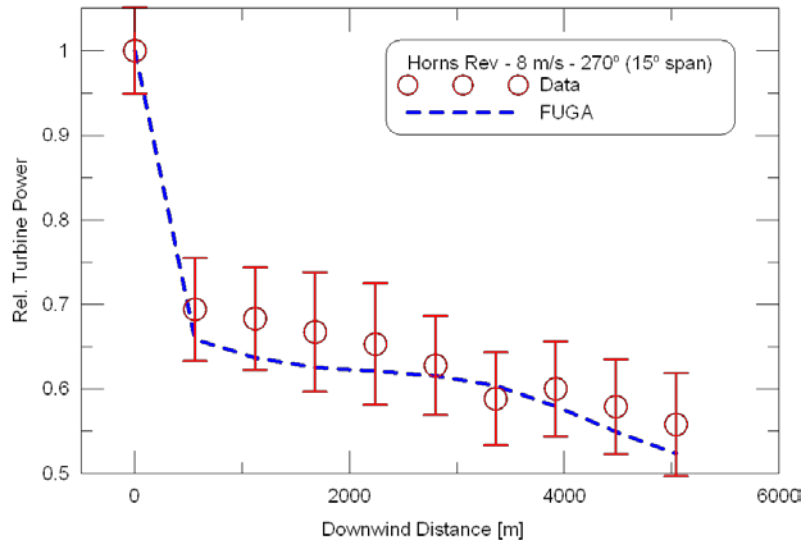
CFD – Large eddy simulation

Fuga – a new wake model

- Linearised CFD
- 10^6 times faster than conventional CFD
- Supported by Carbon Trust
- It Works!



Validation: Horns Rev data. 8 m/s



Simple closure: $v_t = \kappa U_* Z$
 No adjustable parameters!

The Walney Offshore Wind (WOW) Project

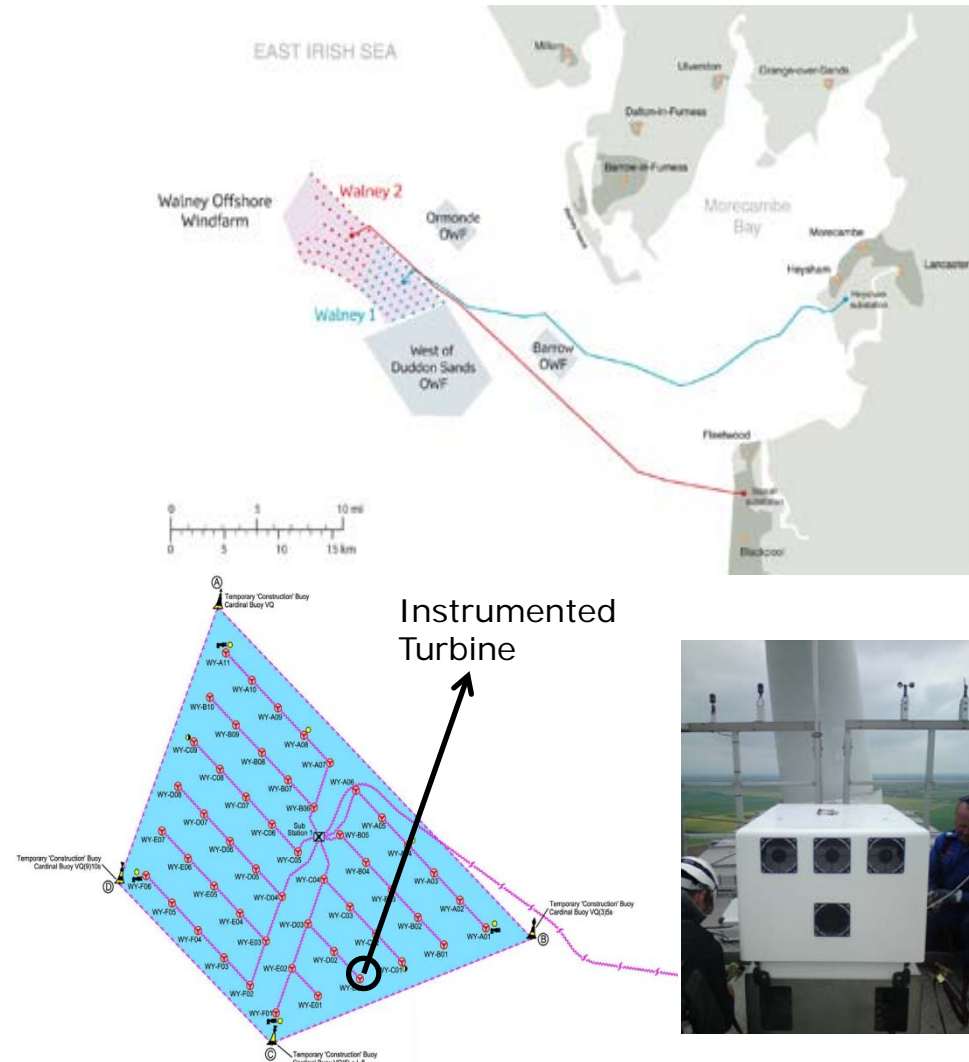
- Comprehensive loads validation on a state of the art 3.6MW wind turbine
- Collaboration with Siemens Wind Energy and DONG energy

Key Measurements

- Nacelle mounted LIDAR for wind measurements
- Wave sonar and Buoy at turbine
- Accelerometers, strain gauges on
- Blade root, drive train, tower and foundation

Scientific Objectives

- Validation of the dependencies of design loads
- Prediction of turbine net damping
- Advanced wind/wave correlation studies
- Wake effects on loads



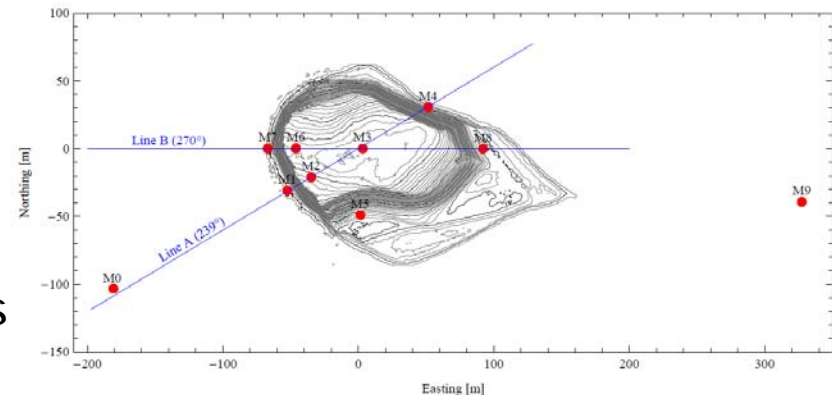
Wind conditions in complex terrain



Bolund
experiment



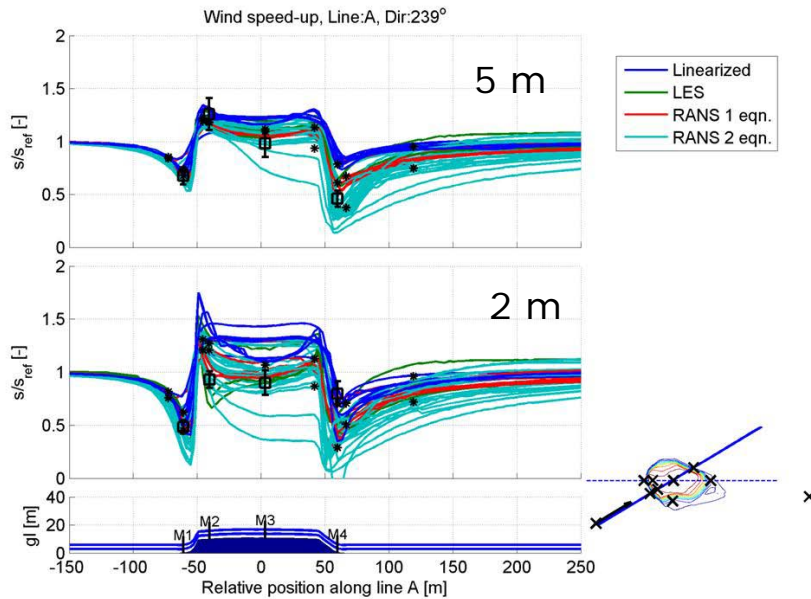
- Well-defined inflow conditions
- Roughness change
- Steep escarpment / "complex"
- Intercomparison study of numerical micro scale flow models



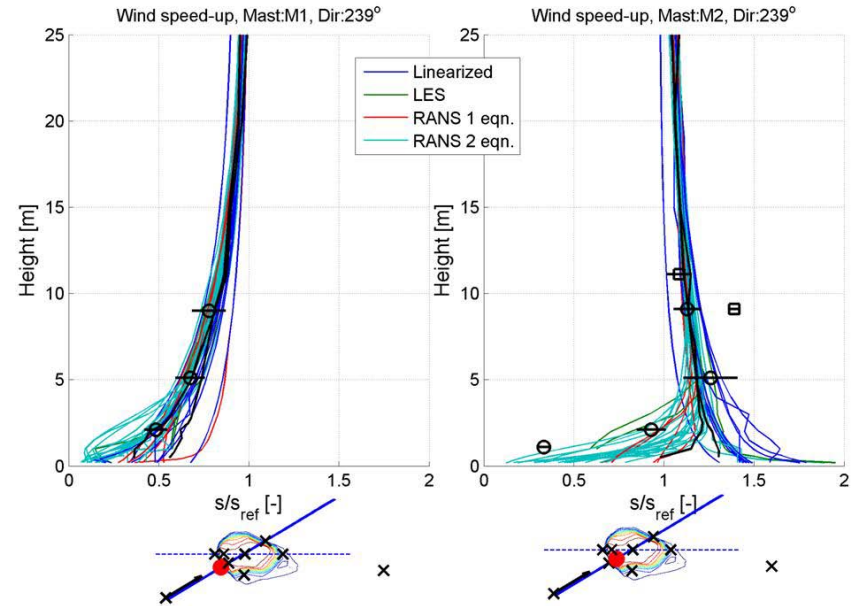
Mast Positions
CFD were used to find the
10 positions

Numerical results

Speed-up along line A

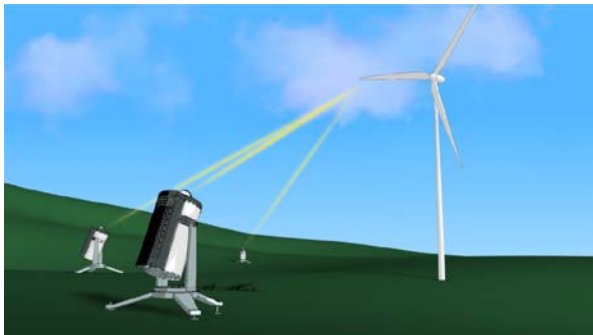
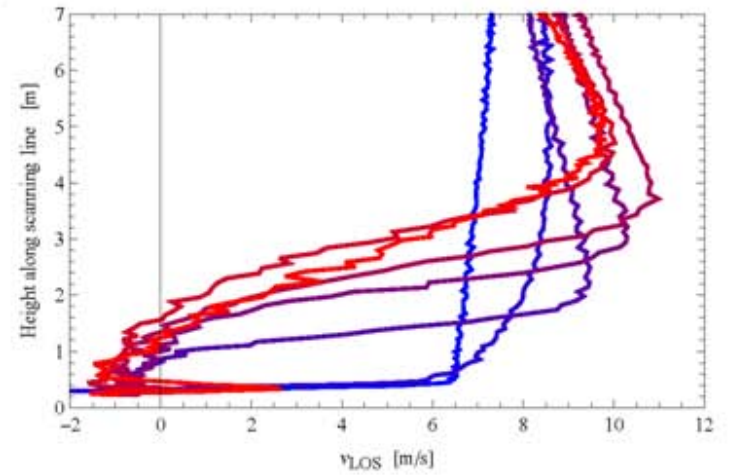
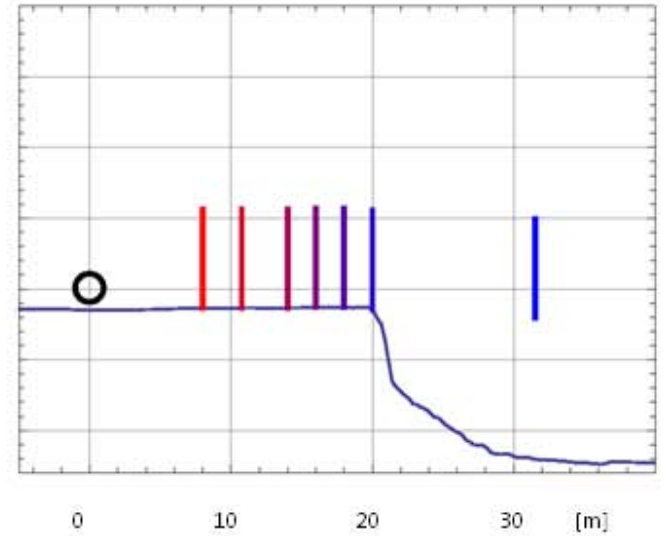


Speed-up at M1 & M2



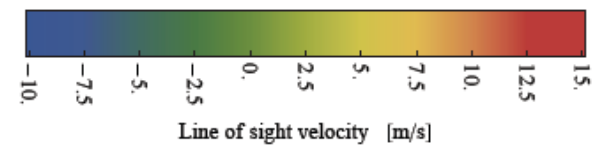
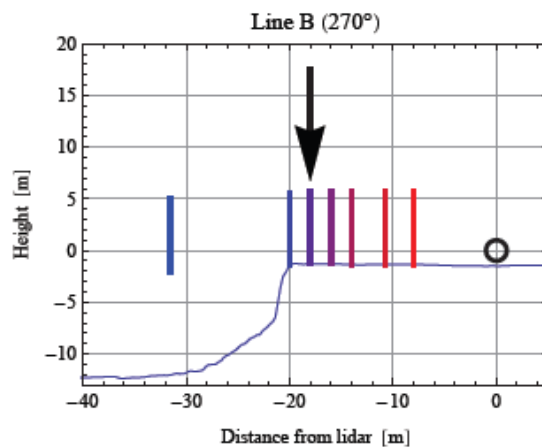
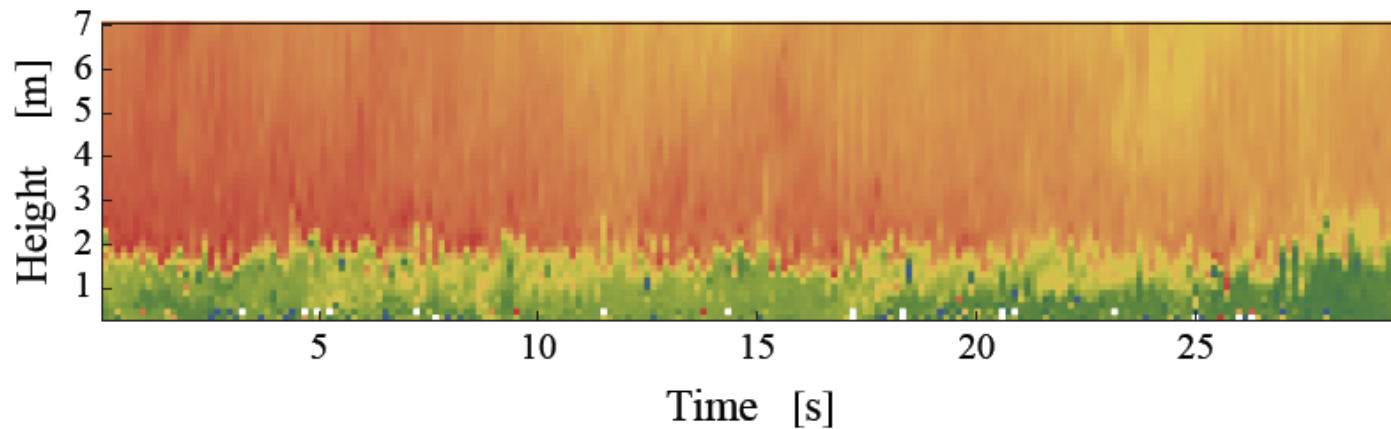
Mean Error:	26%
Linearized:	35%
LES:	26%
RANS 1 eqn.:	25%
RANS 2 eqn.:	20%

WindScanner.dk - Bolund Hill Experiment - October 2011:



Half a minute of scanning data

390 line-of-sight velocities per second

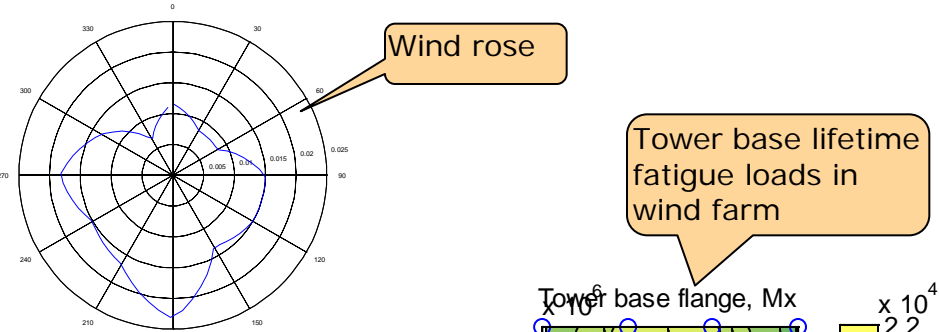


Topfarm wind farm optimization approach

- loads and power

- Optimum wind turbines position for the lowest cost of energy
- Wake modeling using DWM (Dynamic Wake Meandering)
- Quick lookup for power and fatigue loads in a database based on HAWC2 aeroelastic simulations
- Cost function including: Annual energy production and costs of: Turbines, Grid, Foundation and O&M

Example: A 20 WT wind farm



Collaboration with industry

DTU offers

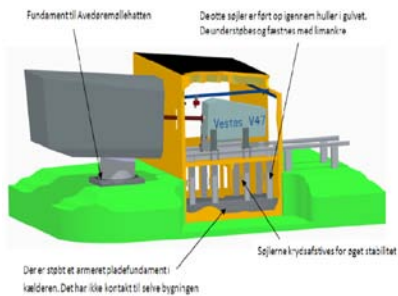
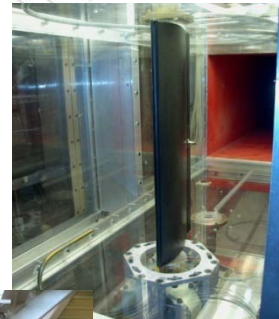
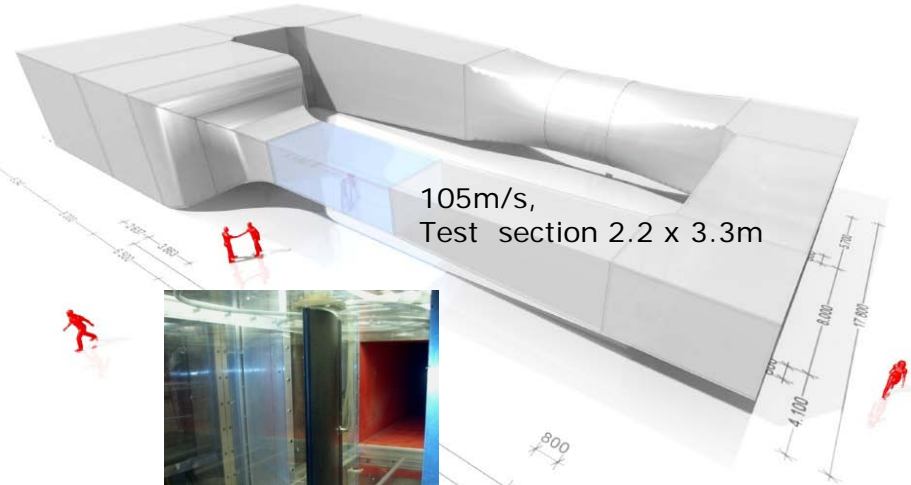
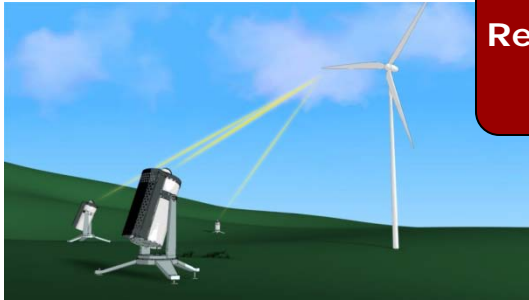
- Research cooperation
- Software with training
- Standardization
- Licenses / patents
- Technology development services
 - Applied R&D
 - Consulting: Analysis and studies
 - Testing & measurements
- Education and training
 - PhD programmes
 - Training courses
- Dialogue & access to Danish wind cluster and international network

Industry partners

- Wind Turbine manufacturers
 - Vestas
 - Siemens
 - Gamesa
 - Repower
 - GE
 - Envision
 - ...
- Energy companies
 - Dong Energy
 - Vattenfall
 - EON
 - ...
- Component suppliers
 - LM
 - ...

Experiments, Validation and Test

Research and test facilities



Risø Test Stations – Prototype Testing



Risø 1979



Høvsøre 2007

5 test beds
 < 165 m
 < 8 MW
 Spacing 300 m

7 test beds
 < 250 m
 < 16 MW
 Spacing 600 m



Østerild 2011

Østerild Test Center – inaugurated 6 Oct 2012

- Installation of Siemens
 - 6 MW
 - Rotor diameter 154 m



www.windturbinetest.dk

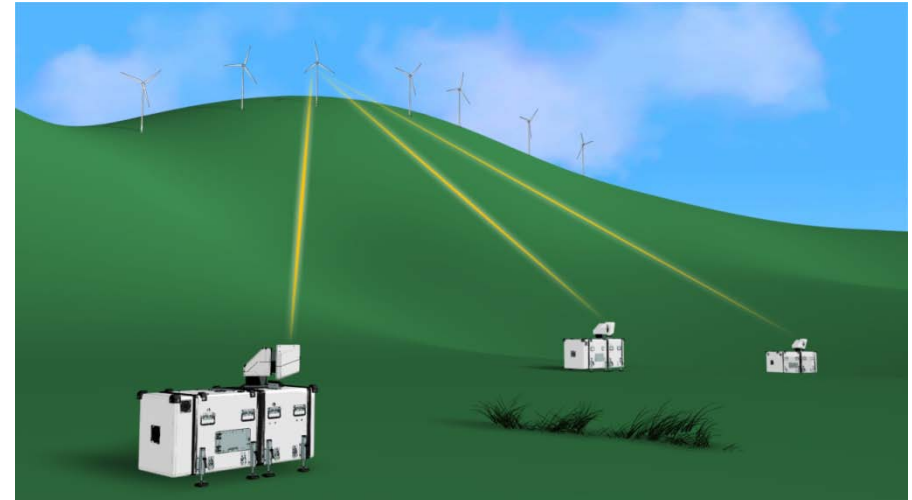
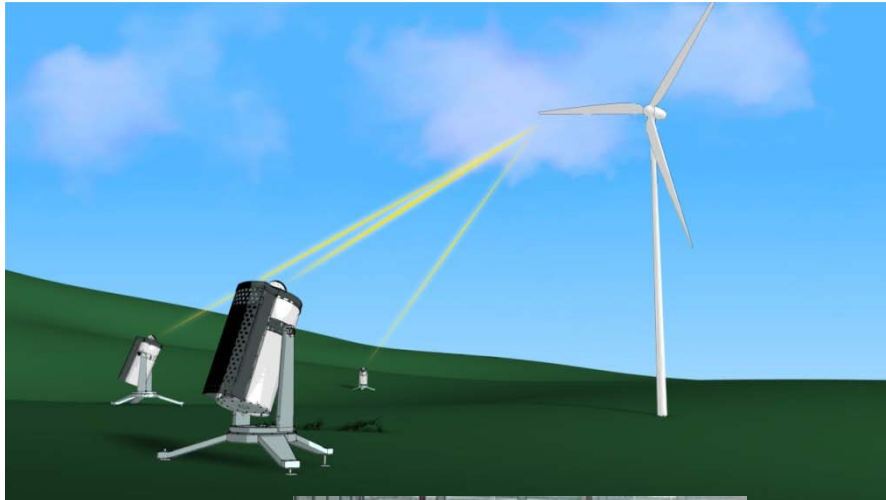
Call for tenders – Test beds 1 and 4

[Tender](#)

[Questions & answers](#)

[Time schedule](#)

Short range (~200 m) & Long range (~5 km)



DTU Wind

enmark



Wind turbine blade testing

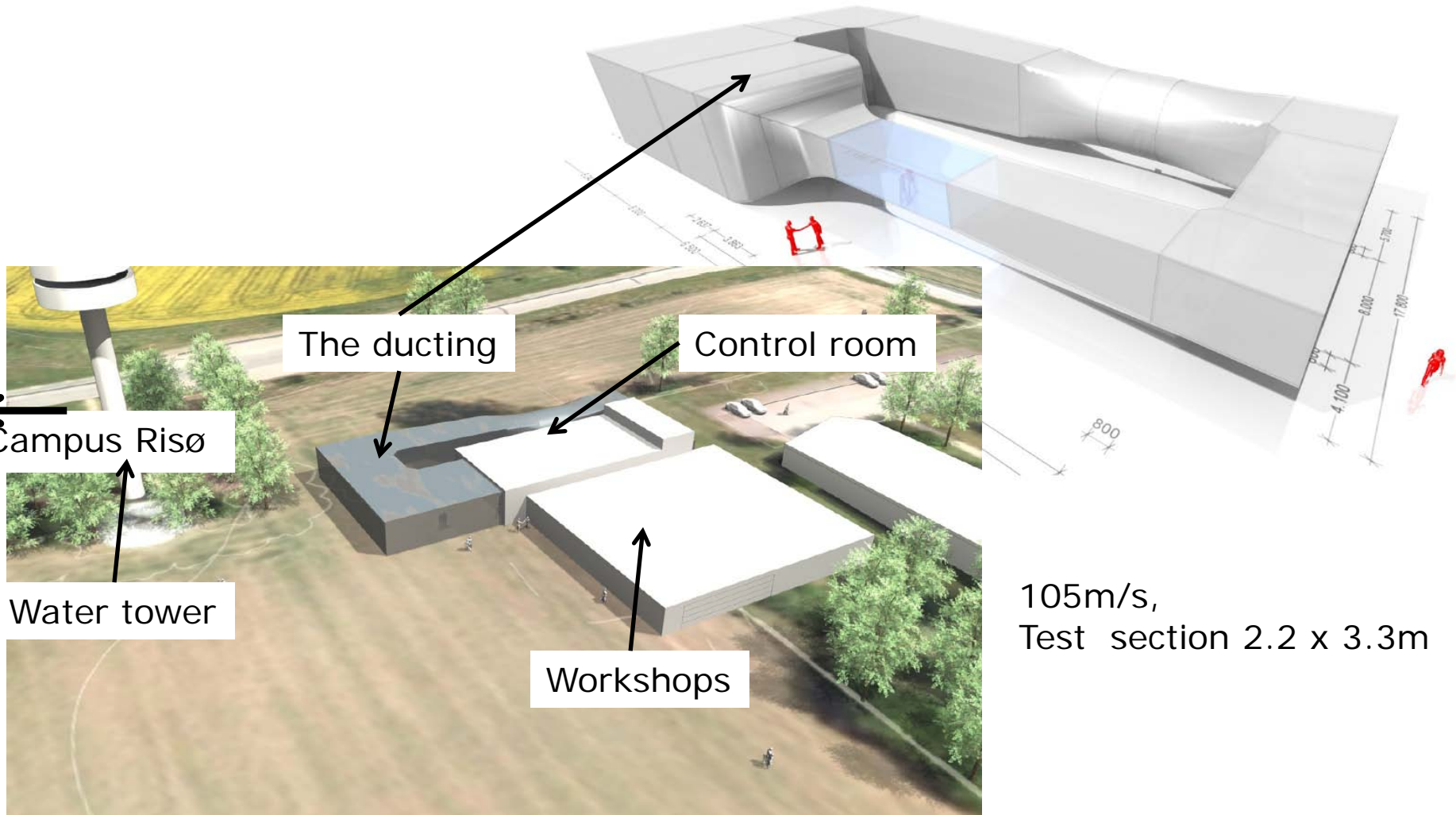


Commercial testing at Blade Test centre A/S, a private limited company with the following shareholders:

Det Norske Veritas AS
Technical University of Denmark
FORCE Technology



A large national wind tunnel at Risø Park



105m/s,
Test section 2.2 x 3.3m

Proposed wind tunnel specifications



Description	Value
<i>Test section</i>	
Design Reynolds number [-]	6.0×10^6
Design flow speed [m/s]	82
Maximum Reynolds number [-]	7.8×10^6
Maximum flow speed [m/s]	106
Height/Width [m]	3.30
Width/Height [m]	2.20
Maximum turbulence intensity [%]	0.1
Anechoic chamber with background noise at 60m/s [dB]	Max 50
Constant temperature [°C]	$\sim 20 \pm ?$
Uniform velocity profile	X
<i>House</i>	
Area [m ²]	~ 1000
Height [m]	5
Indoor temperature [°C]	10 to 35
Separate workshops	X
Easy work flow for exchanging test sections	X

Risø Park

Science Park under development

50 hectares at DTU Risø campus

Leading and most sustainable park for cleantech in Europe

Target group: Businesses and institutions within cleantech research

4-5,000 employees





Thank you for your attention