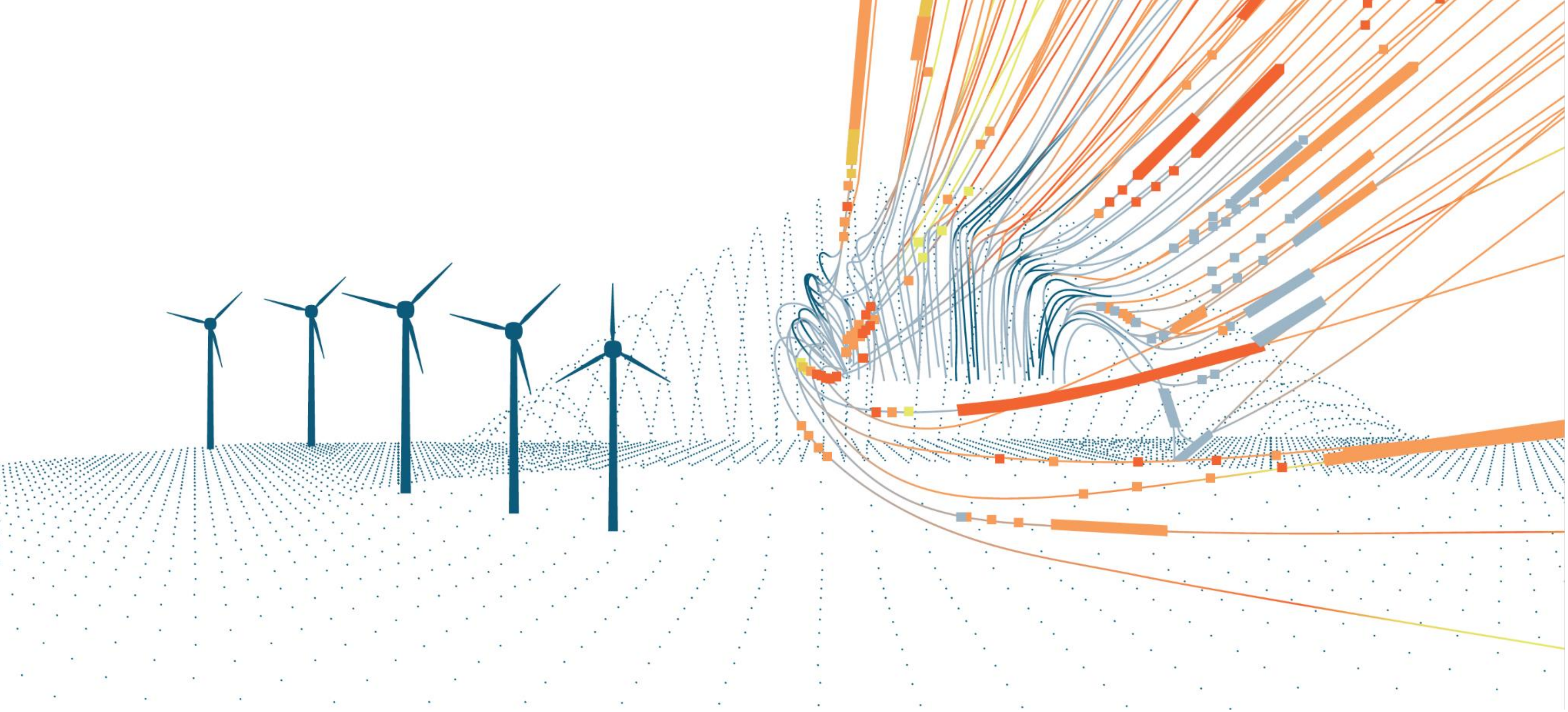

Numerical modelling of local wind fields; terrain and vegetation induced effects

Norwegian Association for Wind Engineering, Trondheim 20 October 2016

PRESENTED BY: ARNE R. GRAVDAHL

windsim

Content – Numerical modelling of local wind fields

- WindSim AS
  - History, market and software
  - Designing profitable wind farms

- CFD modelling
  - Adding physics

- Application areas

- Validations

- Forecasting
  - Dynamic Line Rating

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WindSim AS: History and presence

- 1993 WindSim AS was established, offering CFD consulting directed towards Oil&Gas
- 1998 Establish Norwegian Wind Atlas in cooperation with Norwegian Met. Institute
- 2003 Launch WindSim as PC software for simulation of local wind fields
- 2007 Global expansion within software sales and consulting
- 2016 Establish WindSim Sub-Saharan Africa in South Africa

WindSim • offices and • resellers

WindSim HQ in Tønsberg, Norway

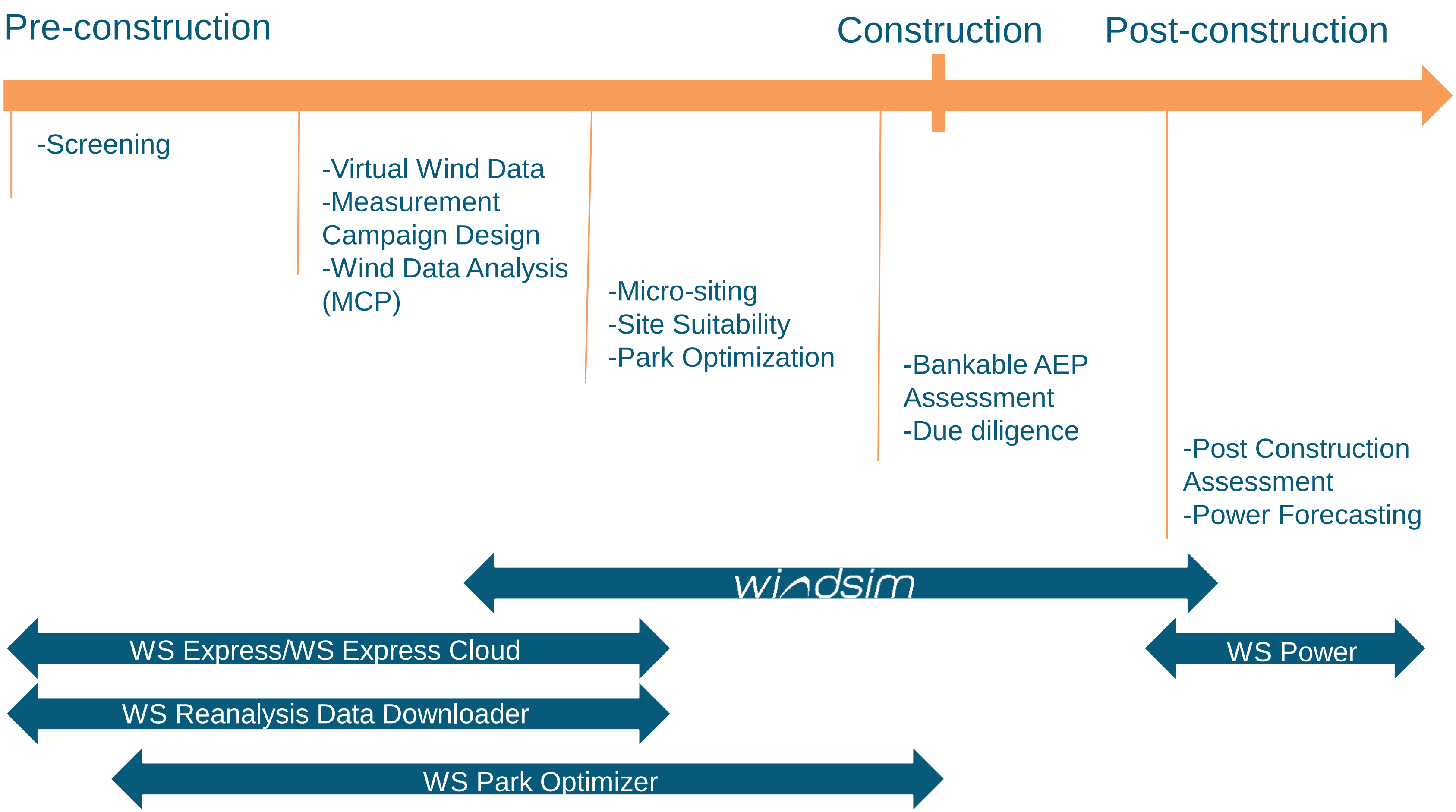
- WindSim AS has offices and resellers partners in; Argentina, Brazil, Canada, Chile, China, Costa Rica, Finland, France, Greece, Italy, India, Kenya, Korea, Mexico, Norway, Serbia, South Africa, Spain, Turkey and USA

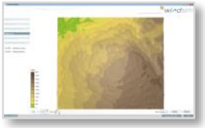
WindSim AS: Market

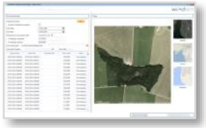
- Since the launch in 2003 there has been strong, steady growth in the adoption of the WindSim technology. Today it is used by leading turbine manufacturers, developers, consulting companies and research institutes

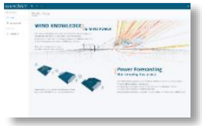
- WindSim software is used in more than 50 countries on all continents

WindSim AS: Software Suite – Wind project time span



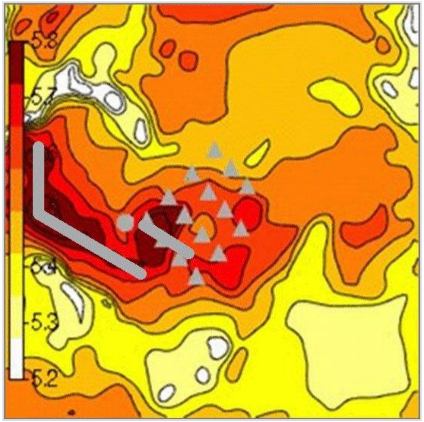




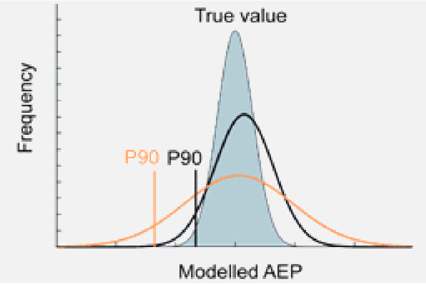


Designing profitable wind farms

- Accurate wind modelling brings higher profit in three ways:
  - Increased Annual Energy Production, AEP
    - *10% AEP increase by alternative layout*



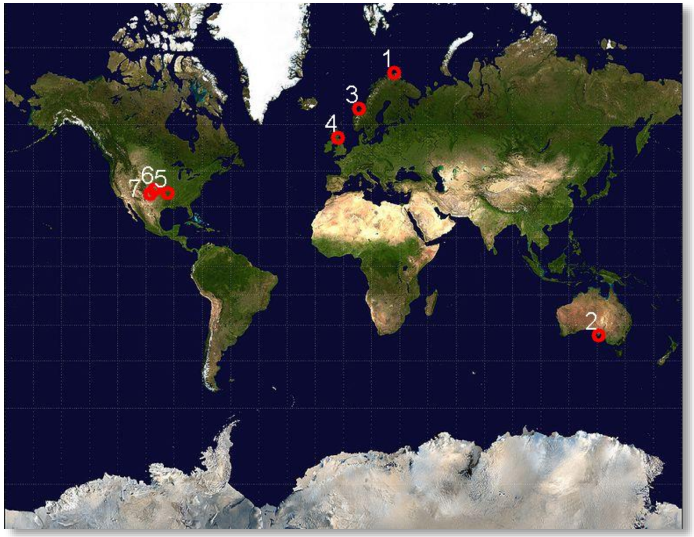
  - Reduced maintenance costs
    - High *correlations between production log and IEC violations (inflow, shear, turbulence)*
    - *Site specific extreme wind*
  - Better financing, higher P90
    - *The uncertainties are set by consultants according to their experiences and methods used*



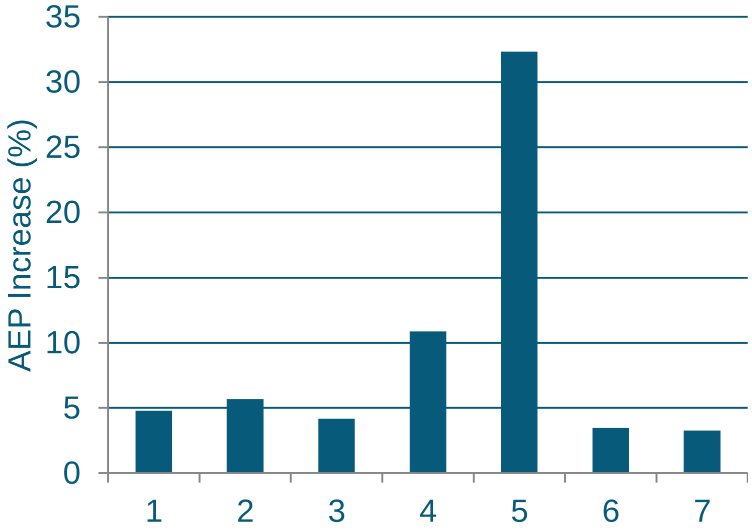
AEP optimization

• Potential AEP improvements for 7 existing wind farms, weighted against reanalysis dataset (MERRA)

• For the cases investigated, we have found optimized AEP increases ranging from 3% to 32% and wake loss decreases up to 7%



Locations of the seven sites used in this study



Increase in annual energy production (AEP) after park optimization for each case

Webinar recording Park Optimizer: https://www.youtube.com/watch?v=0gsMszUEXaUC

Source: Nunalee C.G., Meissner C., Gravdahl A.R., "*From reanalysis data to park optimization*", EWEA, 2014

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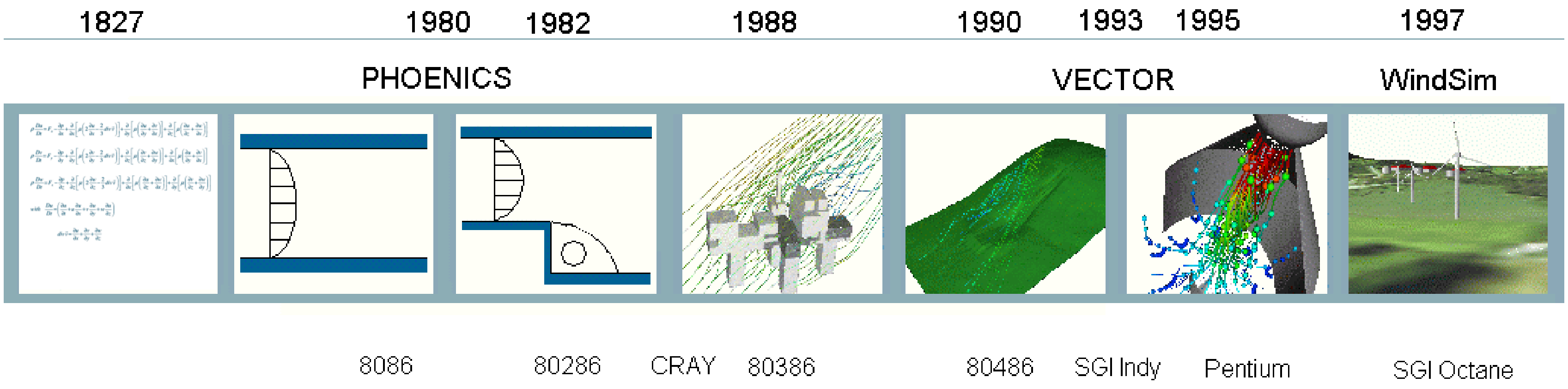
CFD: We have the computing power



CFD development – A personal view

1980 - PHOENICS, first commercial available CFD software

1982 - Stanford, backward facing step, prediction of the size of the recirculation zone

1986 - CRAY XMP 28, 28 MB RAM, Cost 10 Million EURO (First super computer in Norway)

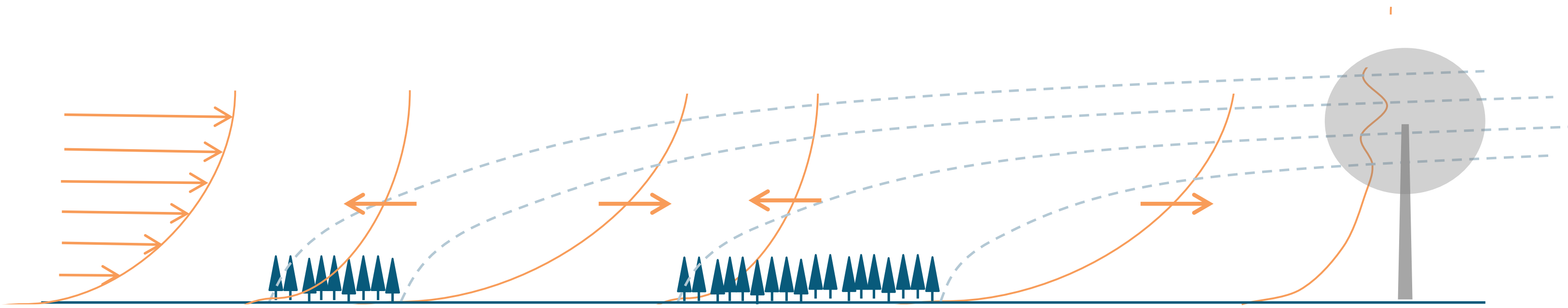
1988 - Troll platform with 100 000 cells, presented as a “monster” model at the CRAY UM

2003 - WindSim 100 000 cells on ordinary PC

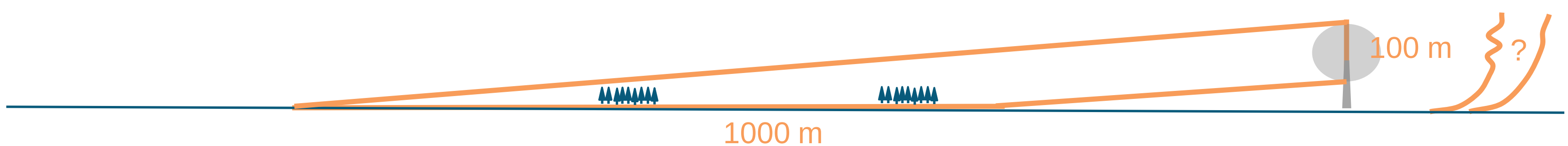
2015 - WindSim 100 000 000 cells on ordinary PC

CFD Adding physics: Boundary layer development

- Even a simple flat case can develop a complex flow field

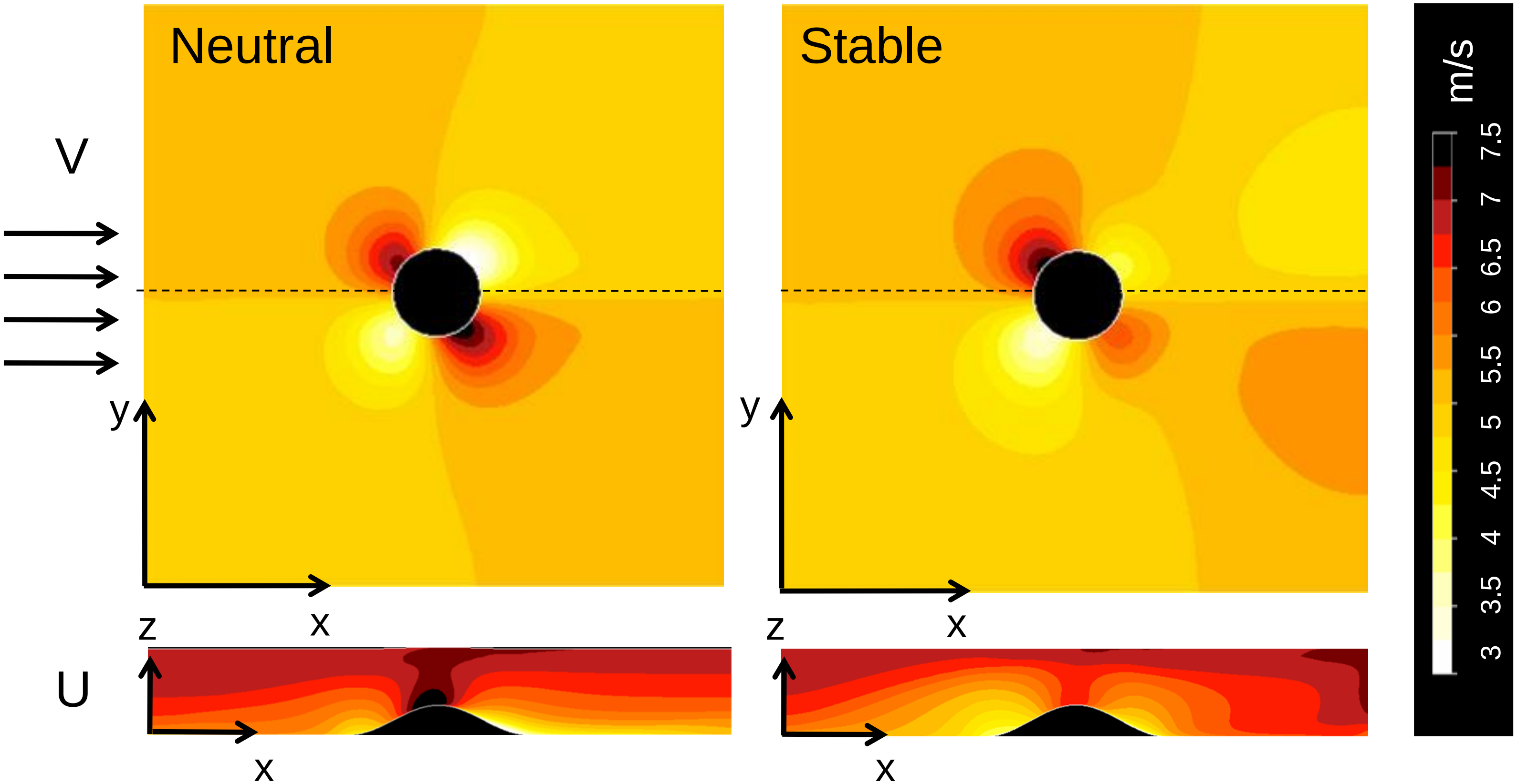


Case with patch wise roughness patterns, illustrating the development of multiple boundary layers resulting in complex wind speed profiles over the swept area of a wind turbine.



Boundary layer growth rule of thumb; 1 unit in travers direction for every 10 units in streamwise direction
Question - How fast will the boundary layers mix? What is the effect of turbulence and stratification?

CFD Adding physics: Atmospheric stability



Cosine hill: height = 200 m, length = 800 m, transversal (upper) and longitudinal (lower) velocity component

- Neutral conditions gives a higher speed at hilltop

CFD Adding physics: Atmospheric stability - High lee side production

- The Tararua Wind Farm is located in New Zealand, with a total capacity of 160 MW

- The wind farm was first commissioned in 1999 and has been upgraded twice since

- The Bessakerfjellet Wind Farm is located in Roan municipality in Sør-Trøndelag, Norway

- It consists of 25 turbines, commissioned in 2008

- Stratification, adding new transport equation, coupling with momentum and turbulence

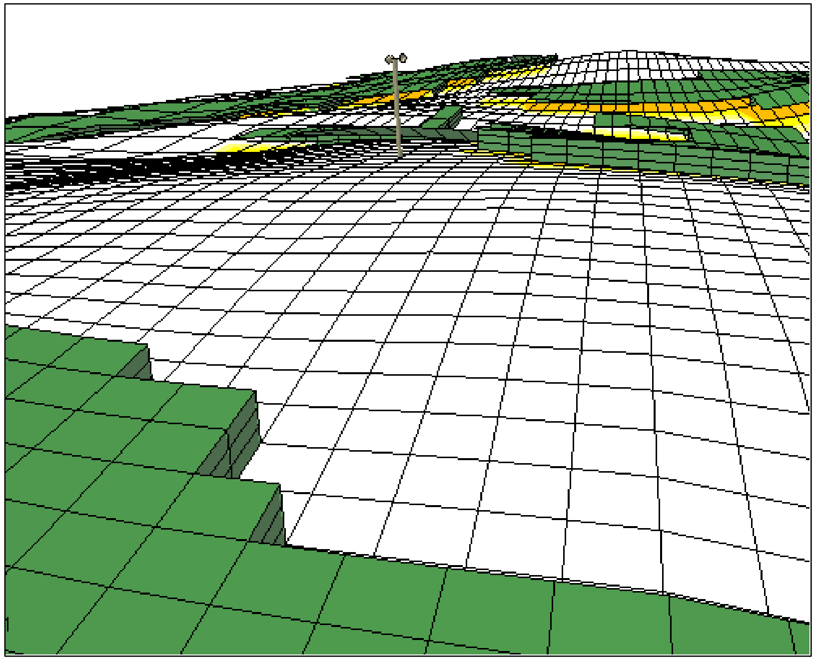
Gravity waves over obstacle in a stable atmosphere, a clear wave structure is present, involving high wind speeds in the lee side of the obstruction. Only a fully coupled stability approach will be able to capture this phenomenon (Luke Norris 2011)

CFD Adding physics: Forest Modelling

- The modelling takes account for forest height, porosity and resistive force, which is proportional to velocity squared for extraction of momentum from the flow by the forest

- Variable forest height

- Forest definition based on roughness height



Species of tree	porosity [%]	C_1 [1/s]
Fluid	100	-
Beech	84	1,394E-03
Black cherry	77	2,294E-03
Birch	55	7,703E-03
Lime	54	8,116E-03
Ash	48	1,116E-02
Mature maple	47	1,178E-02
Scots pine	38	1,980E-02
Firs	30	3,378E-02
Spruce	29	3,638E-02
Cypresses	15	1,451E-01
Solid	0	-

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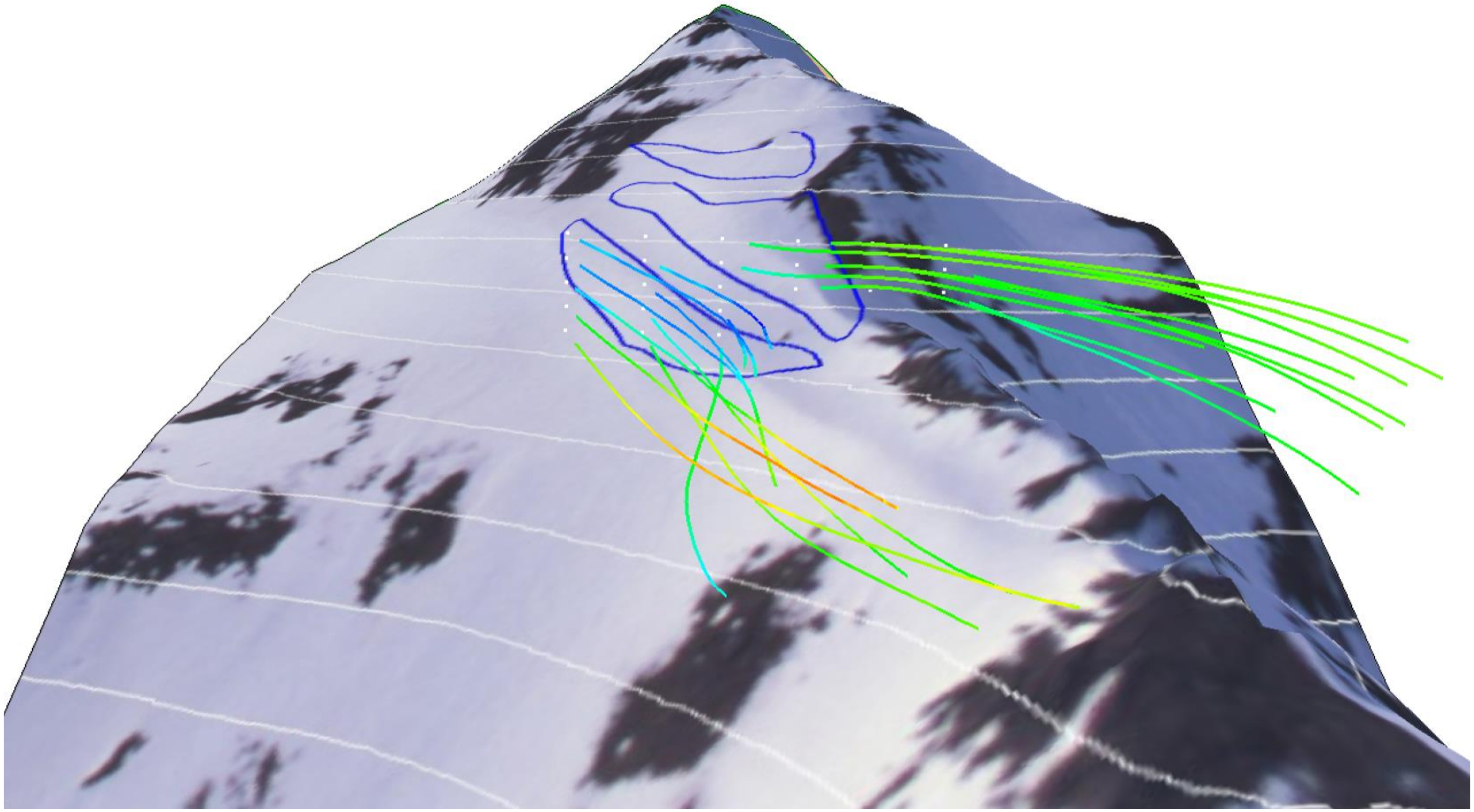
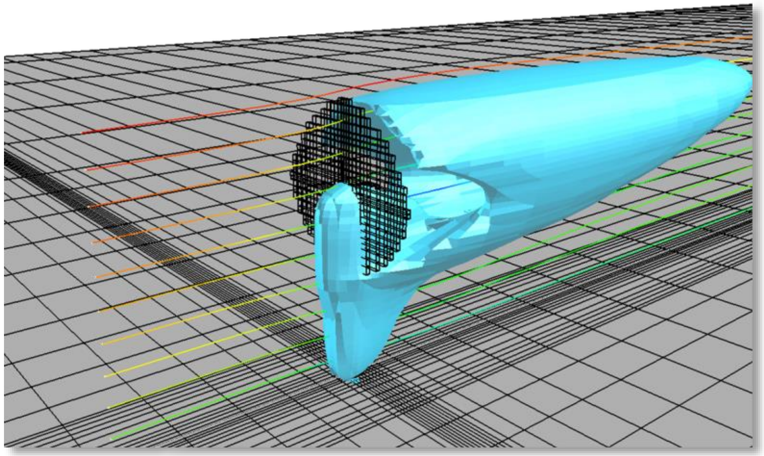
Application areas: Snow drift accumulation

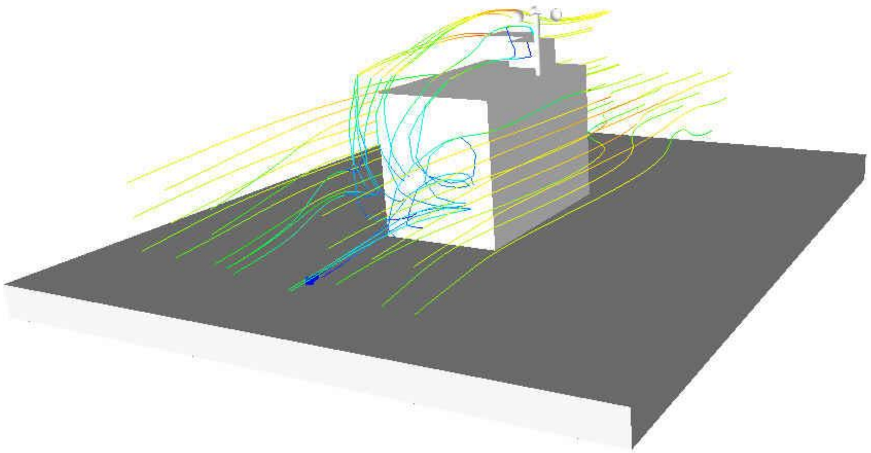


High snow accumulation in the blue areas which is coinciding with the area where two streams from each side of the mountain collide (simulations done by Orion Consulting, Iceland)

Application areas: Forces on obstacles

Complex obstacles can be introduced in the flow field. The pressure field around the obstacle can be integrated to yield the forces on the obstacles.





Perspective view of the actuator disc, streamlines and iso surface of turbulent kinetic energy (1,4 m^2/s^2, U_e 10 m/s at 500m a.g.l.) (left) and streamlines around building (right)

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Validation – The Bolund experiment, 2010

• The Bolund experiment was a field campaign for validating numerical models of flow in complex terrain and was the basis for a unique blind comparison of flow models. WindSim participated in the Bolund experiment conducted as an anonymous blind test

• 50 results was handed in and grouped in 4 categories; Linearized, LES (Large Eddy Simulations) and 1 and 2 equations RANS (Reynolds Averaged Navier-Stokes)

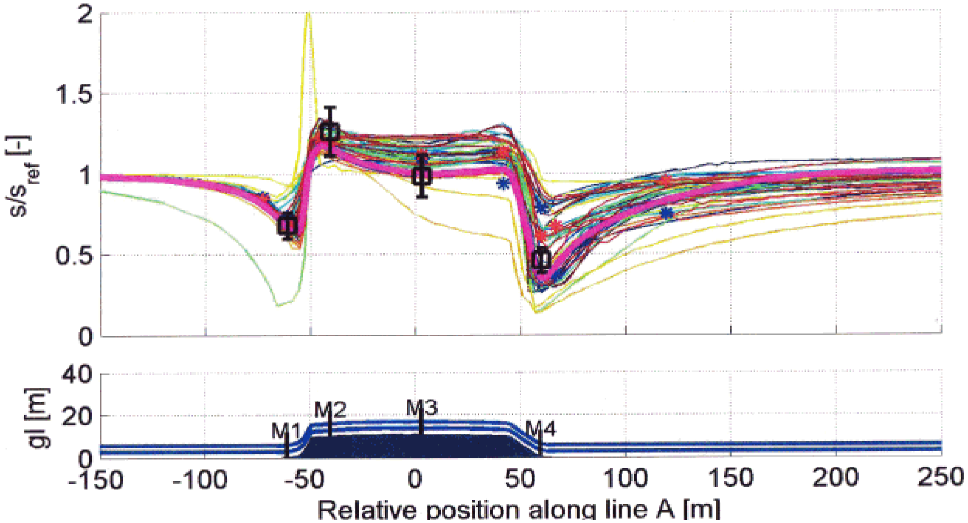
Bolund

Linearized	35%
LES (CFD)	26%
RANS 1 eqn. (CFD)	25%
RANS 2 eqn. (CFD)	20%

Average wind speed errors based on all measurement points, WindSim is a RANS 2 eqn. model

Validation – The Bolund experiment, 2010

- The CFD methods – including WindSim as the best commercial software in the test – showed the lowest errors among the various methods



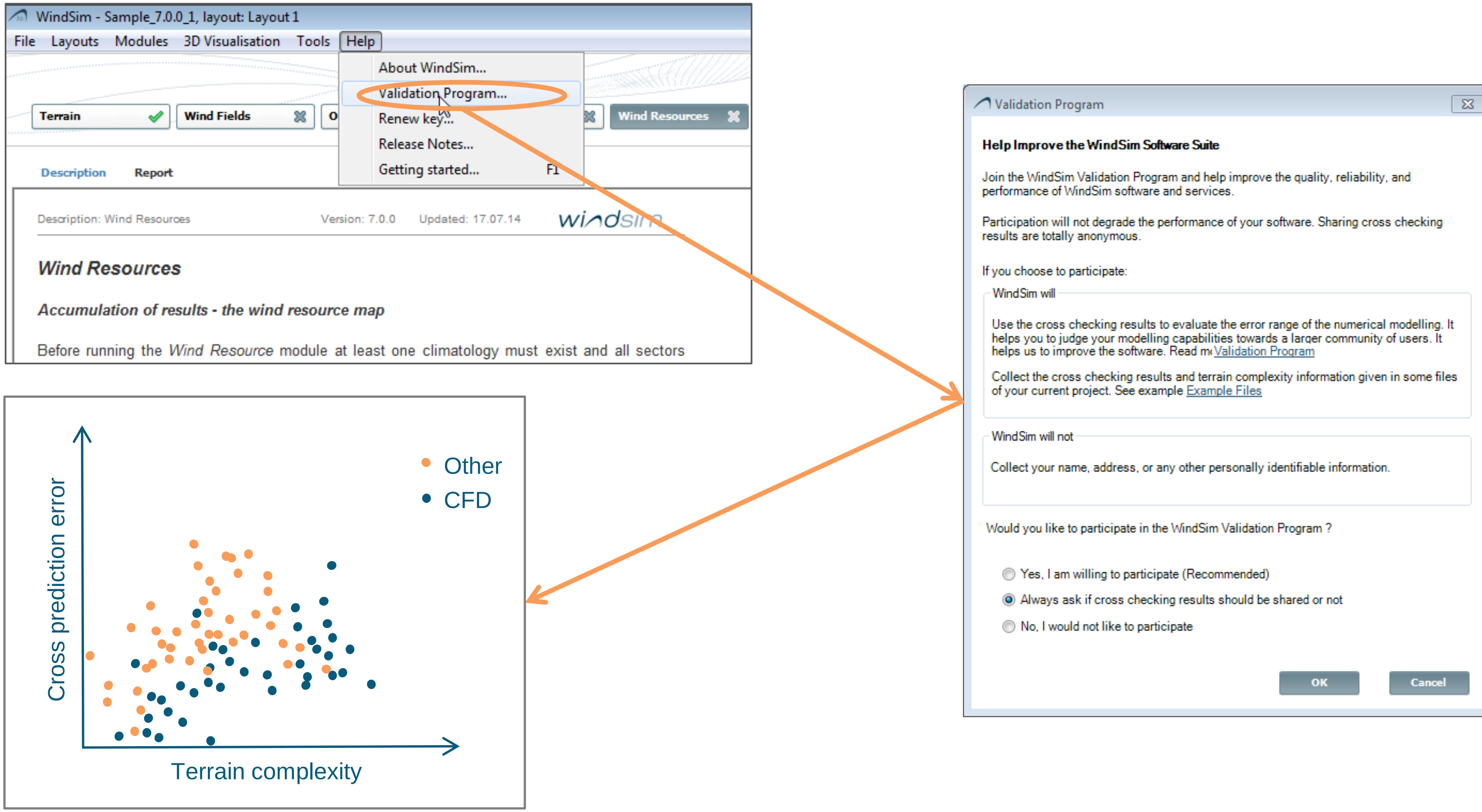
Top 10 ListID	Turb.model	Error 5m [%]
ID0053	RANS k-epsilon	6
ID0037	RANS k-epsilon	4
ID0000	RANS k-epsilon	5
ID0036	RANS k-epsilon	5
ID0016	RANS k-epsilon	5
ID0015	RANS k-epsilon	5
ID0077	RANS k-epsilon	5
ID0010	RANS k-epsilon	7
ID0009	RANS k-epsilon	5
ID0034	RANS 1 eqn.	7
ID0068	RANS k-epsilon	10
ID0006	RANS k-epsilon	6

Normalized wind speed at 5 meters height, measurements are given by black boxes, solid pink line is the WindSim results, while the other lines are results from other methods

Best results are obtained with RANS k-epsilon models. The errors at 5 meters height are in the order of 5-6% for the best models

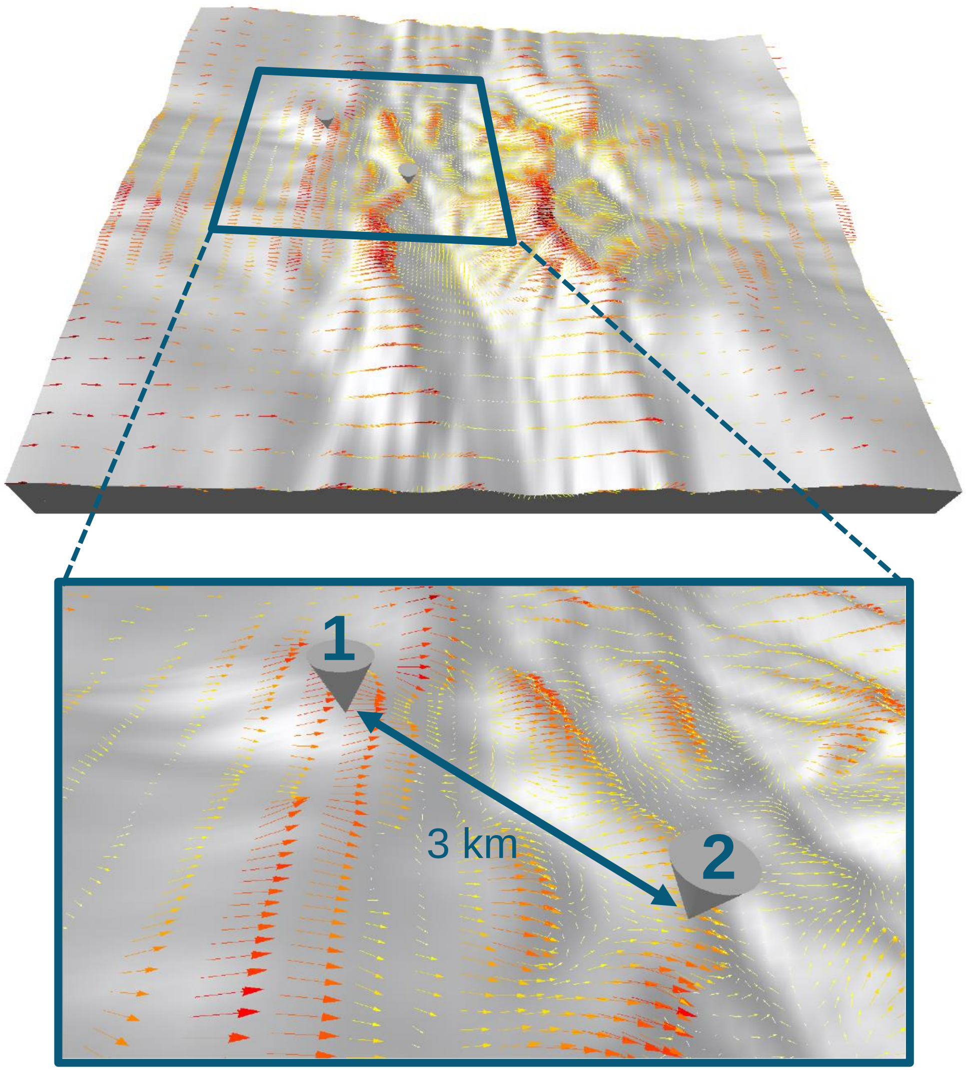
Source: Meissner C., Gravdahl A.R., Weir D., “CFD Validation – A Simple Approach”, European Wind Energy Conference, Brussels, 2011

Cross checking – Feed-back form



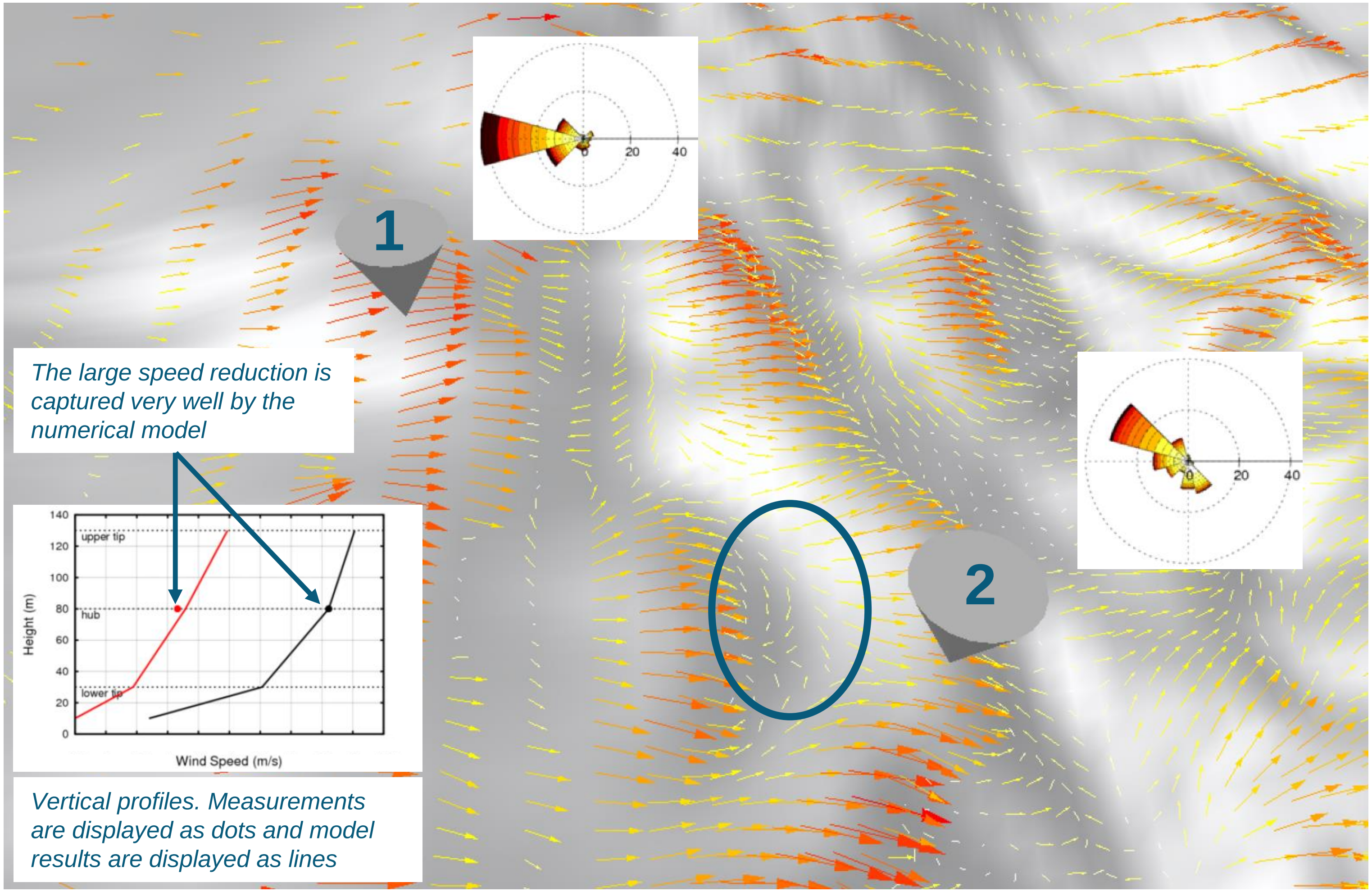
Cross prediction errors, basis for flow modeling uncertainty gradually building up at the WindSim web site

CFD: Complex site – Coarse resolution numerical model



- Model extension 18x18 km
- Only 300 000 cells (92x81x40)
- Resolution100x100 meters in refinement zone
- Highest inclination is 35 degrees
- Multiple stagnant and recirculation zones
- Simulation time for a given wind direction is 6 minutes
- Distance between measurement mast 1 and 2 is in the order of 3 km
- What resolution is required for grid independency?
- What size is required for boundary condition independency?

CFD: Complex site – Flow pattern validation



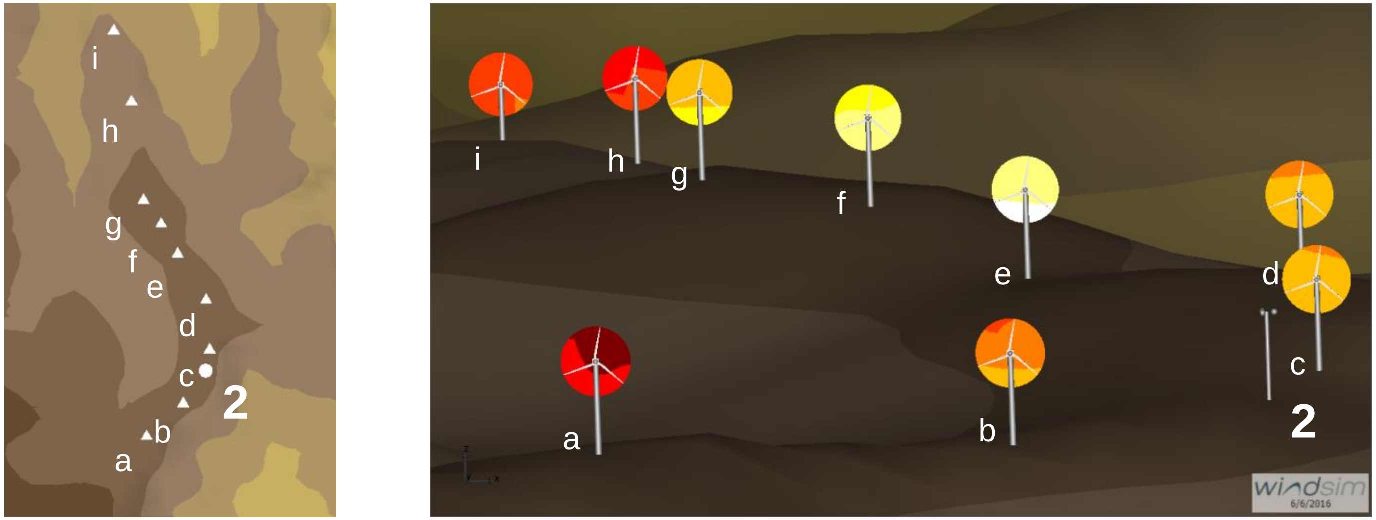
Complex site where a recirculation is established upstream of mast 2. The flow model reproduces the significant speed reduction and the directional shift caused by the recirculation (Velocity vectors are shown at 10 meters height to better visualize the recirculation)

What is the response from the financiers?

• Difference in wind speed between mast 1 and 2 is 2 m/s
  • Wind speed 6 m/s -> 371 kW for a 2MV turbine
  • Wind speed 8 m/s -> 901 kW for a 2MV turbine

• The wind speed and power variability would create a large uncertainty in the project

• Flow simulations explain why the variability occurs and where the high wind speed regions are, reducing this uncertainty, making it possible to optimize the AEP



Arbitrary distribution of turbines along the ridge where met mast 2 is located (left), the corresponding 2D wind speed over the swept area of the turbines, illustrating the significant variability (right)

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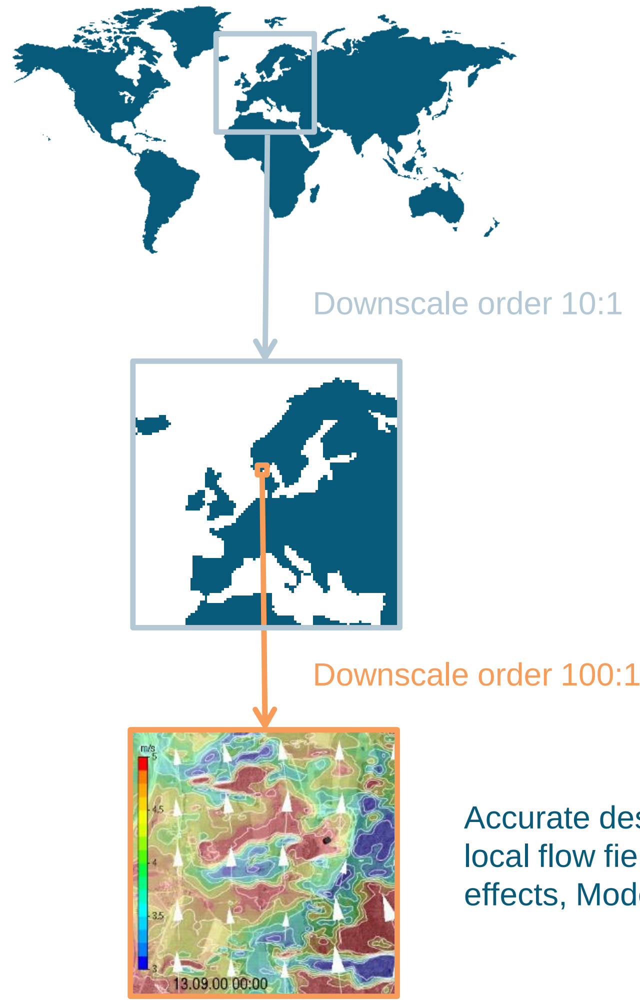
Bridging scales

Global Models
ECMWF, GFS (100 - 16 km)

Meso/Regional Models
WRF (9 - 1 km)

Micro Model
WindSim (100 - 10 m)

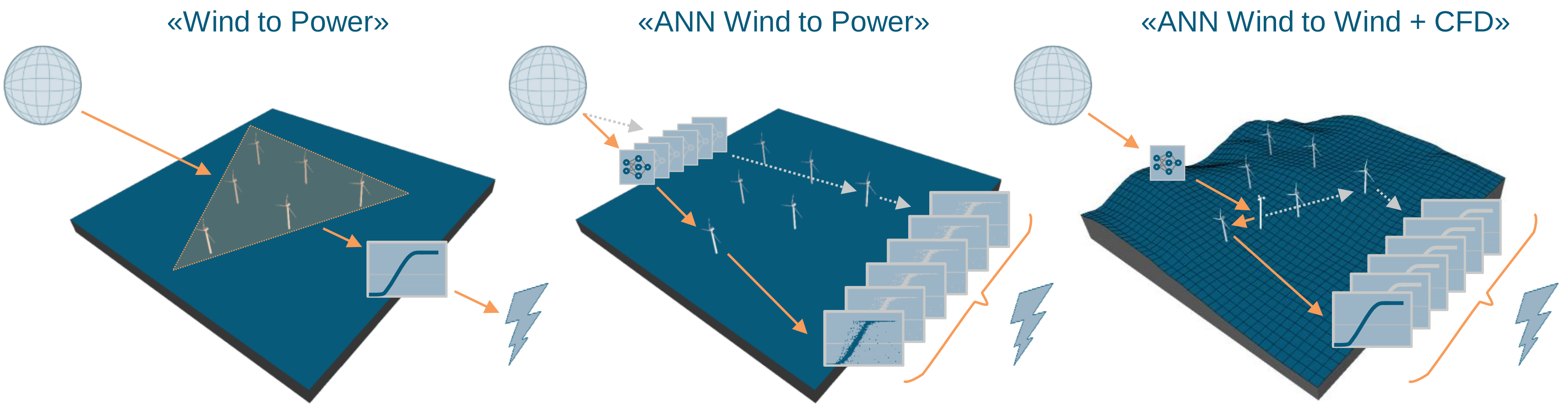


Accurate description of the local flow field and the wake effects, Model size 2x2 km

Power Forecasting Strategies

• The power forecasting system couples Numerical Weather Prediction (NWP) data, Artificial Neural Network (ANN) and Computational Fluid Dynamics (CFD)

• The power forecasting can be setup in various ways, using so-called strategies, depending on available data and required accuracy level

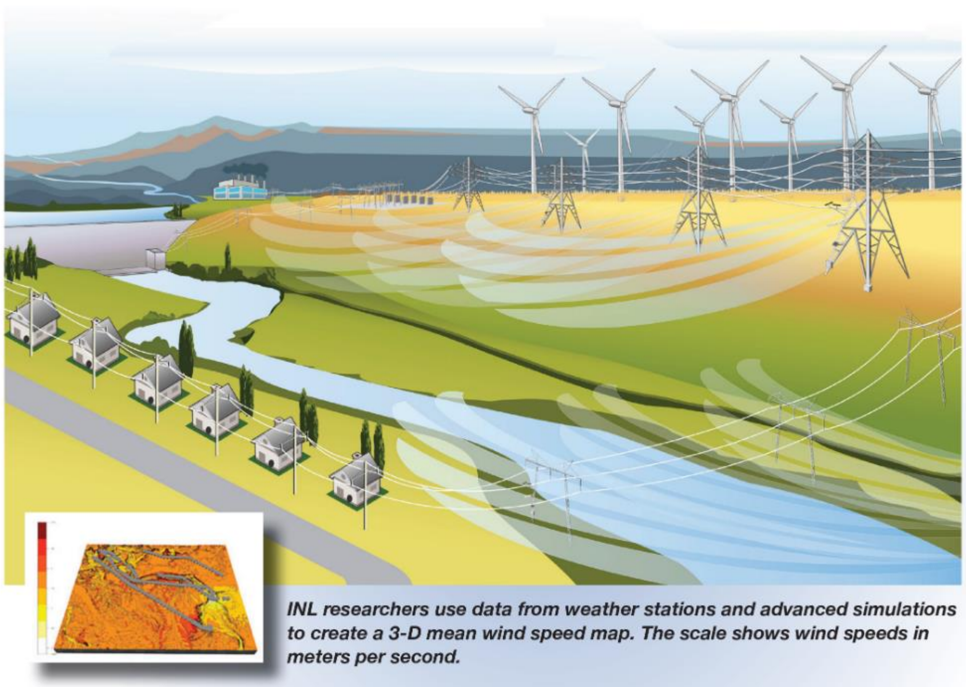


Power Forecasting strategies using various combinations of Artificial Neural Networks and Computational Fluid Dynamics

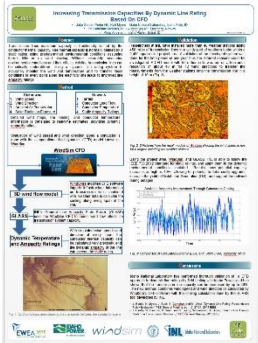
Dynamic Line Rating (DLR) – Increase amount of current by 10-40%

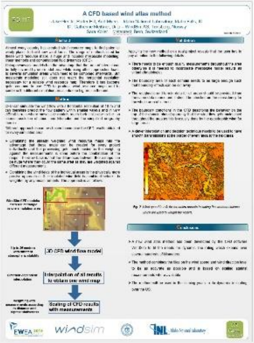
- An increase in wind speed blowing at a right angle to a high-voltage line can cool the line enough to safely increase the amount of current it can carry by 10 to 40 percent

- Two operational modes:
  - Nowcasting (Weather stations)
  - Forecasting (Numerical weather prediction model)



INL researchers use data from weather stations and advanced simulations to create a 3-D mean wind speed map. The scale shows wind speeds in meters per second.





Winner EWEA Poster Award 2015

Idaho National Laboratory – Cooperation since 2009

- 2009 INL buys a WindSim license, training and guidance towards their special usage within DLR

- 2014 First JIP were “power line” object with wind speed and direction in the mid section of each power line segment was established. The “Power line” module was first launched in WindSim 7.0

- 2015 Second JIP were we have developed a «Wind Atlas» method for wide area usage of the «Power line» module. INL has merged 4 models with 50 million cells each

- 2016 Third JIP is ongoing, were we will create wind statistics for power line routing optimization

Idaho National Laboratory

Motto	*The energy of innovation*
Established	1949
Research type	Nuclear energy, national security, energy, and environment
Budget	~ $1 billion (2010)
Director	Mark Peters
Staff	~ 4,100 (2010)
Location	Idaho Falls, Idaho, U.S. & a large area to the west
Campus	890 sq mi (2,310 km^2)
Operating agency	Battelle Energy Alliance
Website	inl.gov

Development of WindSim Power Forecasting

• Power Forecasting has been developed through R&D and Joint Industry Projects (JIP)

• It started with extensions in WindSim, developed into a separate software, further into services and now we plan to gather both software and services in a web portal

- 2008 JIP; China Electric Power Research Institute; Power time series
- 2009 – 2011 JIPS; KIER, TUBITAK, ZAMG
- 2011 JIP; StormGeo, Leviathan, WindSim; Chinese market
- 2012 Launch of WindSim Power Forecasting
- 2012 JIP; Aquiloz; Common software/service offer
- 2013 R&D, NFR Energix; Artificial Neural Networks, Meso-micro coupling
- 2014 JIP; Shenyang University of Technology; common software/service offer
- 2014 Launch of service with UK Met Office
- 2015 R&D, NFR Energix; Nowcasting
- 2015 JIP; Pattern Energy; Launch of WindSim Portal
- 2015 Partner outlets; Breeze, Baze technology, KOS ….
- 2015 Pre-qualified for major trial (power forecasting of 1500 MW wind energy)
- 2016 R&D,NFR Energix; Nowcasting (Met.no)

Summary – Value for E39

- Simulation of local wind fields (10 meters resolution)
  - Based on historical data
    - Construction; site specific mean and extreme loading
  - Based on prognostic data
    - Secure traffic

Thank you

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