Planning & Development | Ecology & Hydrology | Wind Technical
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# HOW CAN CFD MODELS COMPLEMENT MEASUREMENTS?

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Åarhus
19/09/2013

WIND
MARINE
BIOMASS

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# DATA FROM ADVANCED FLOW MODELS

- **Turbulence Intensity assessed**
- **Inflow angle assessed**
- **Shear modelling in forested terrain**
- **Possibility of time-dependant computations**

☞ This information could be used with multidimensional power curves for Energy Yield Assessment



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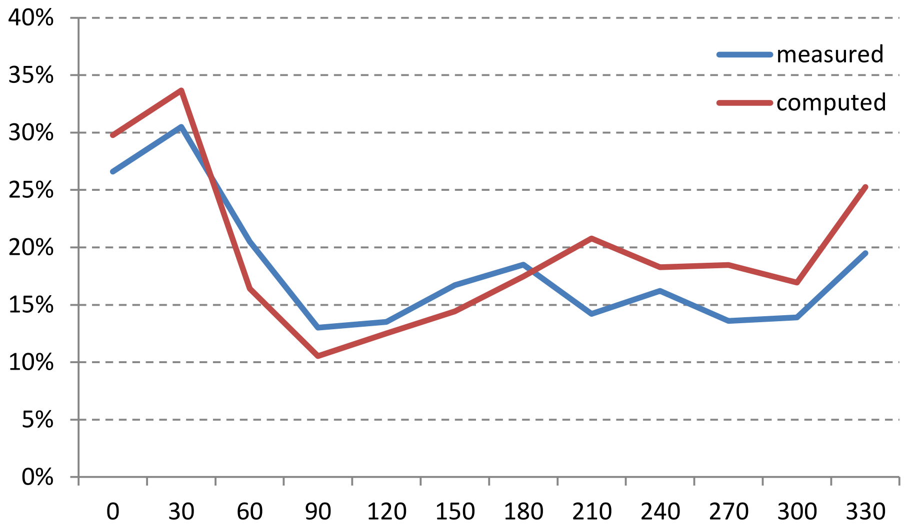
# IS CFD UP TO THE JOB? – TURBULENCE

**Predicted average TI is 1% off** (on average on a selection of sites)




Typical modeled and measured turbulence intensity comparison in forested terrain



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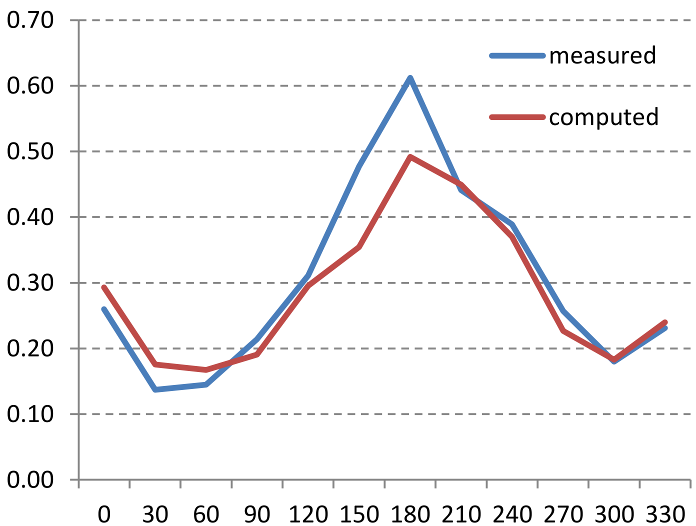
# IS CFD UP TO THE JOB? – WIND SHEAR

**Predicted average shear is 0.04 off** (on average on a selection of sites)

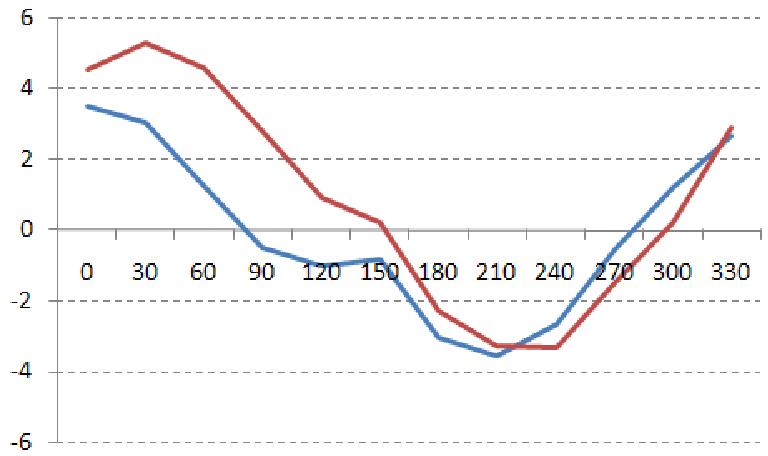



Typical modeled and measured wind shear comparison with an accurate forest dataset

Forested sites should be handled appropriately:

- **garbage in garbage out**
- **canopy model** typically significantly **enhances results**

# IS CFD UP TO THE JOB? – INFLOW ANGLE




Typical plot of measured (blue) and CFD-modeled (red) inflow angle (°) vs. wind direction



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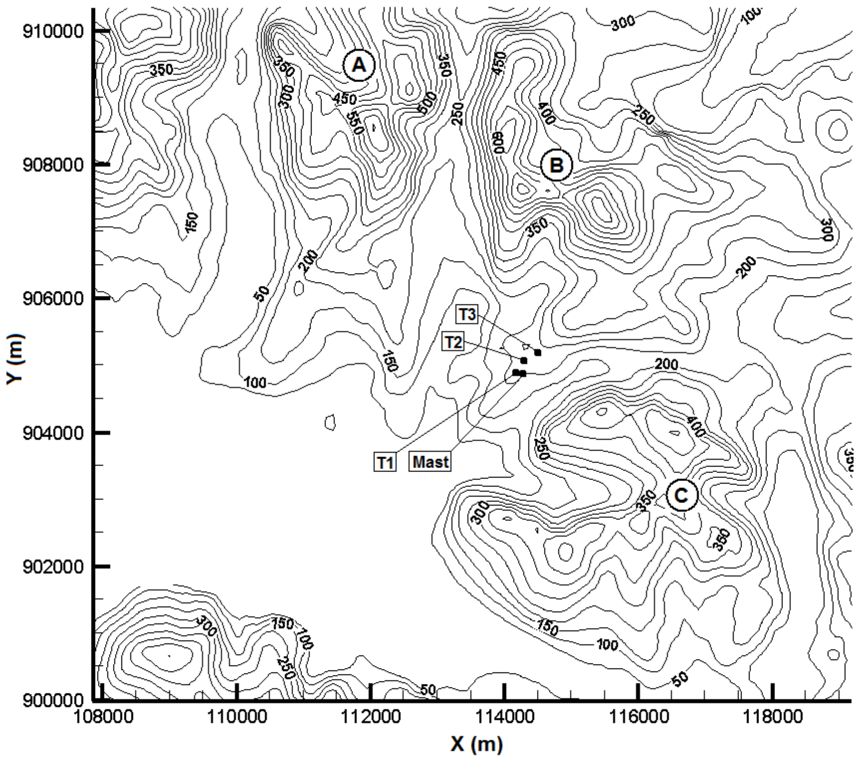
# CASE STUDY 1 – IS CFD UP TO THE JOB? – RECIRCULATIONS




Highly complex topography:

– RIX of 12.8% on average

– 30% in sectors 30 and 150

– 5% in sectors 90 and 270

No trees

1 mast with 1Hz measurements

3 planned turbines

From Abiven C., Palma J.M.L.M and Brady O. 2011: High-frequency field measurements and time-dependent computational modelling for wind turbine siting. J. Wind. Eng. Ind. Aerodyn. 99, 123-129, 2011.



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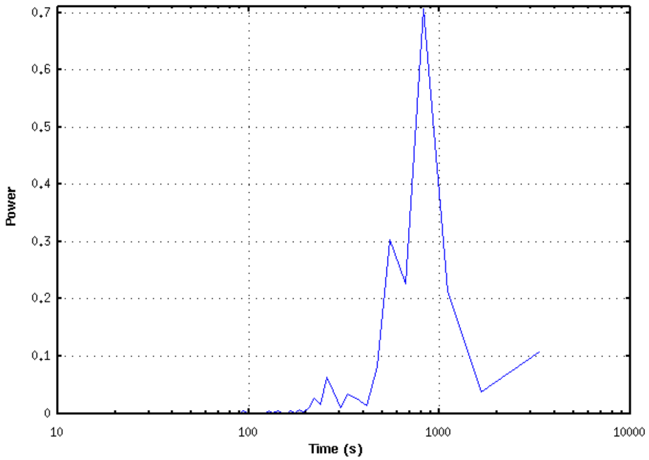
# CASE STUDY 1 – SPECTRAL ANALYSES




Measured time-series are analyzed using power spectral analyses.

Preferred time scales are found in the flow, i.e. phenomena come back in time with a specific periodicity

Time-dependent simulations are carried out

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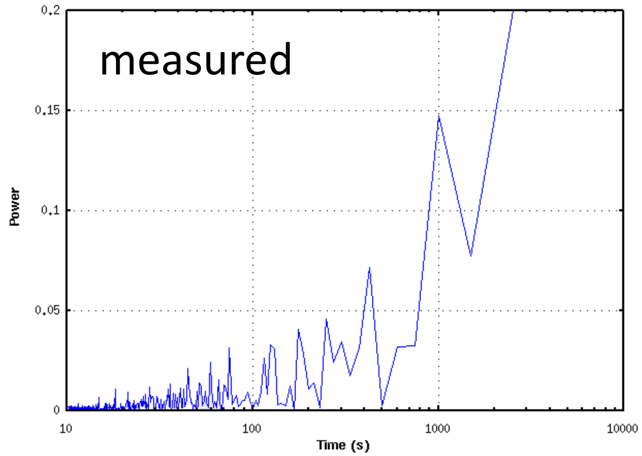
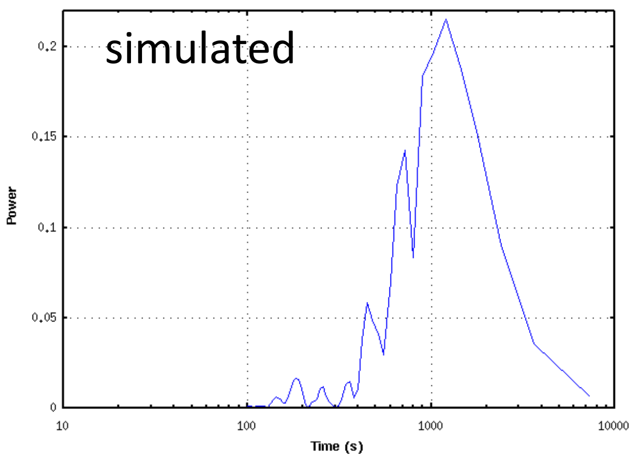
# CASE STUDY 1 – VENTOS®(1) MODEL VALIDATION




Simulations are shown to be able to reproduce preferred frequencies measured at the mast

☞ Simulations can help us understand the reason for these peaks

(1) The utilisation of the computer code called VENTOS® was made under the agreement between Natural Power Consultants Ltd. and CEsA-Centre for Wind Energy and Atmospheric Flows of FEUP-Faculty of Engineering of the University of Porto.

# CASE STUDY 1 – CONCLUSIONS

VENTOS® was shown to be able to reproduce time-dependent phenomena

Mast data and time-dependant CFD analysis enable:

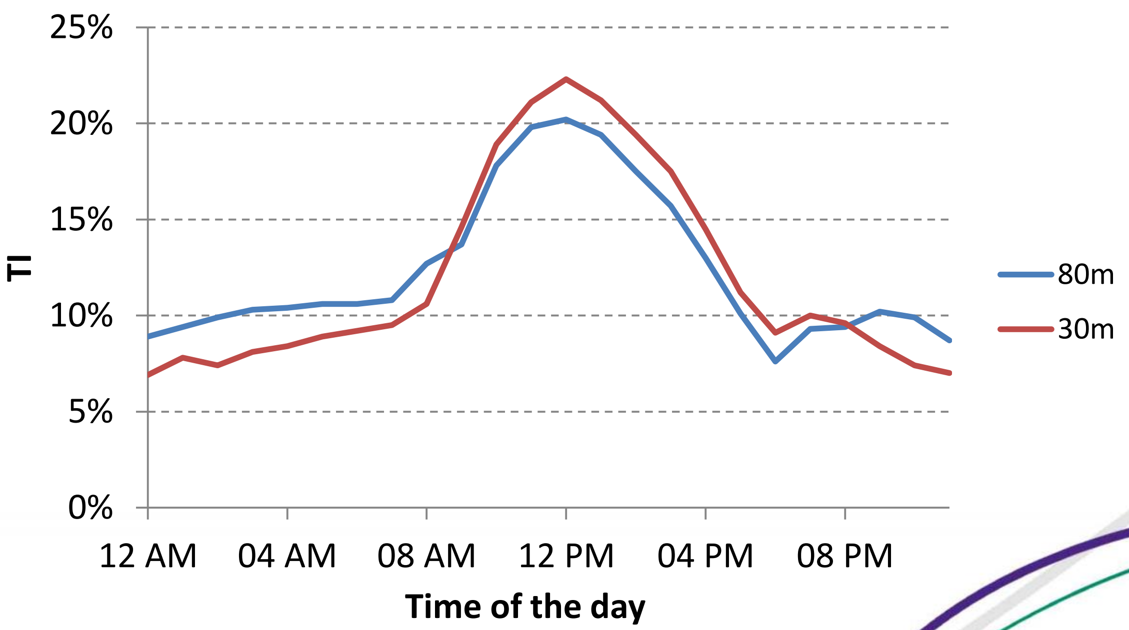
- understanding of flow behavior on site
- characterize complex flow structures

Time-dependant simulations can be required/useful in complex terrain for proper decisions to be made regarding:

- site suitability
- appropriate operating restrictions

# MODELLING – INDUSTRY STATE

- **Wind flow depends on temperature and heat fluxes**
- **Many common models do not properly model thermally-driven flows**



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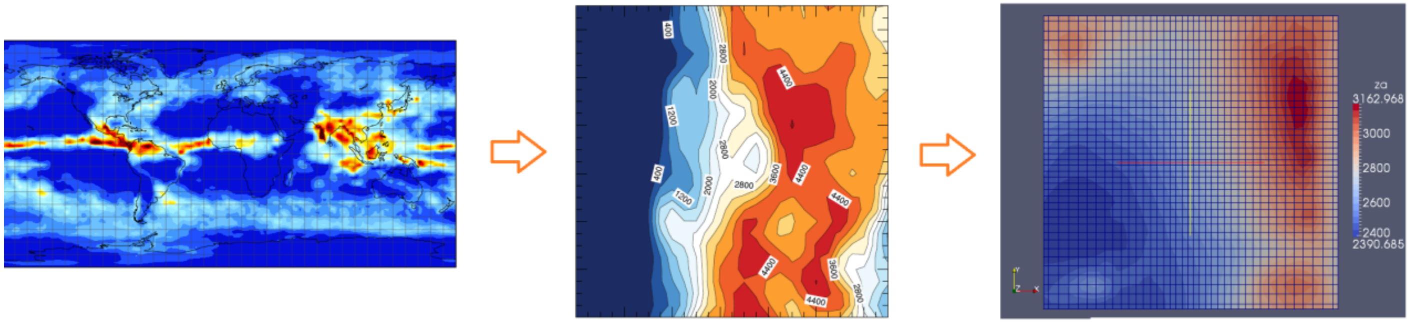
# COUPLED CFD – MODEL DESCRIPTION

- **Example of the VENTOS/M(1) coupled CFD model:**
  - Solve the time-dependant RANS equations
  - Solve the transport equation for potential temperature
  - Initial and boundary conditions are obtained from WRF




- **We expect:**
  - More precise EYA, especially for unstable & stable atmospheres
  - Less need for site measurements

(1) Developed by the Centre for Wind Energy and Atmospheric Flows, University of Porto under a joint venture with RES and Natural Power



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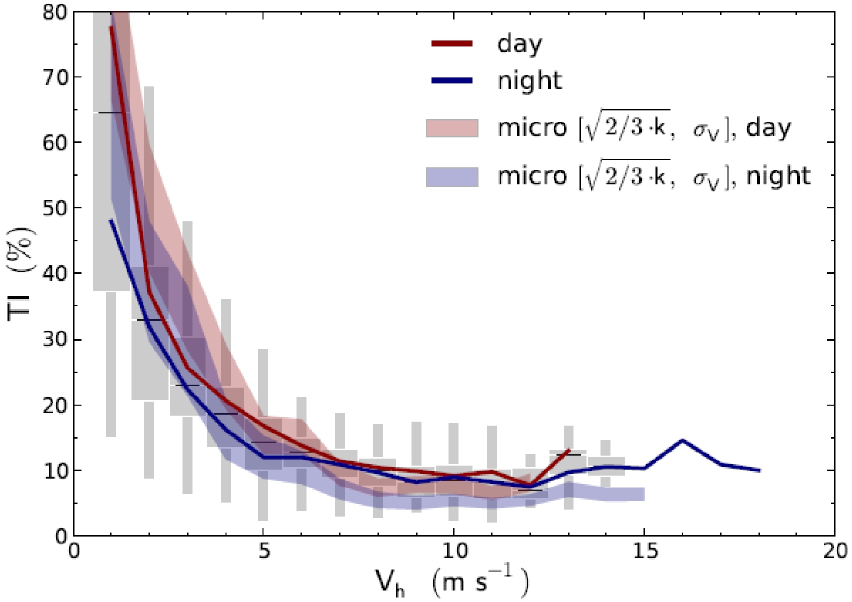
# ADDED VALUE OF COUPLED CFD OVER CFD AND LINEAR

- Stability taken into account
  - **TI and shear are a function of Vh**
  - **Diurnal/seasonal variations of TI, shear, IA are modelled**

- Absolute modelling
  - **PDFs are not bound to resemble PDFs measured at masts**

- Time-dependant modelling
  - **Time-series based EYA/Stress analysis can be performed**
  - **Extreme values at each turbine location**

# EXAMPLE OUTPUT – TI(VH)




**Picture by courtesy of the University of Porto**



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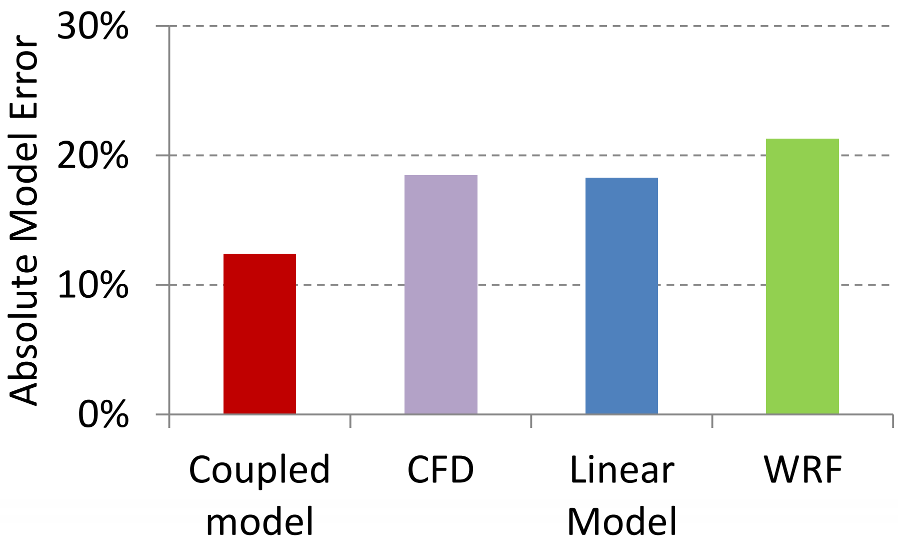
# EXAMPLE OUTPUT – ERROR ON WIND SPEED ON A SITE SHOWING STRONG THERMAL VARIATIONS



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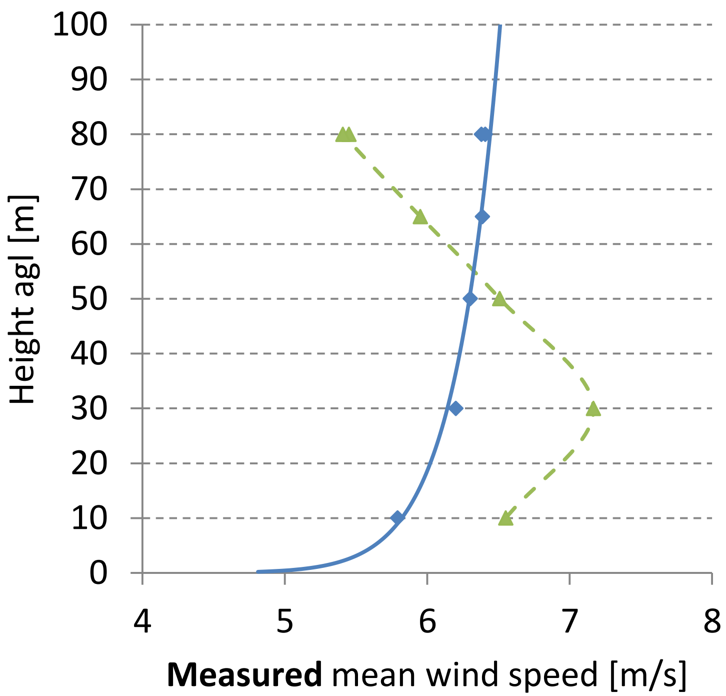
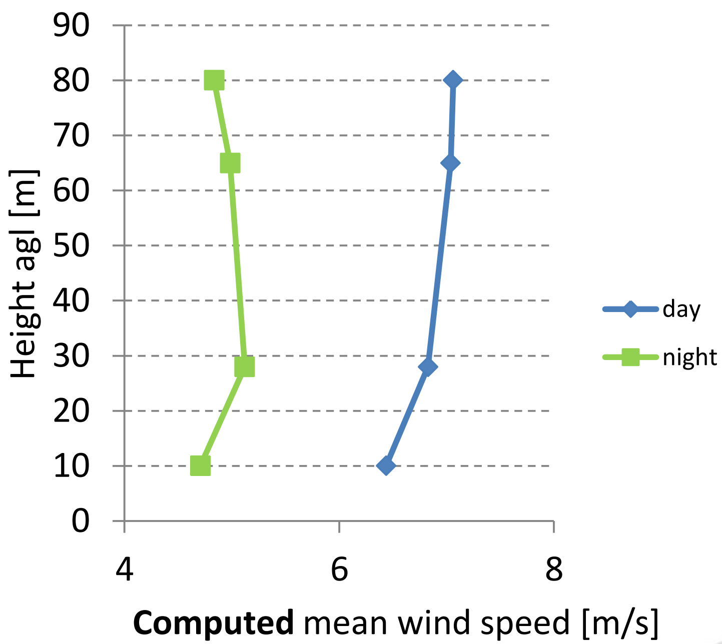
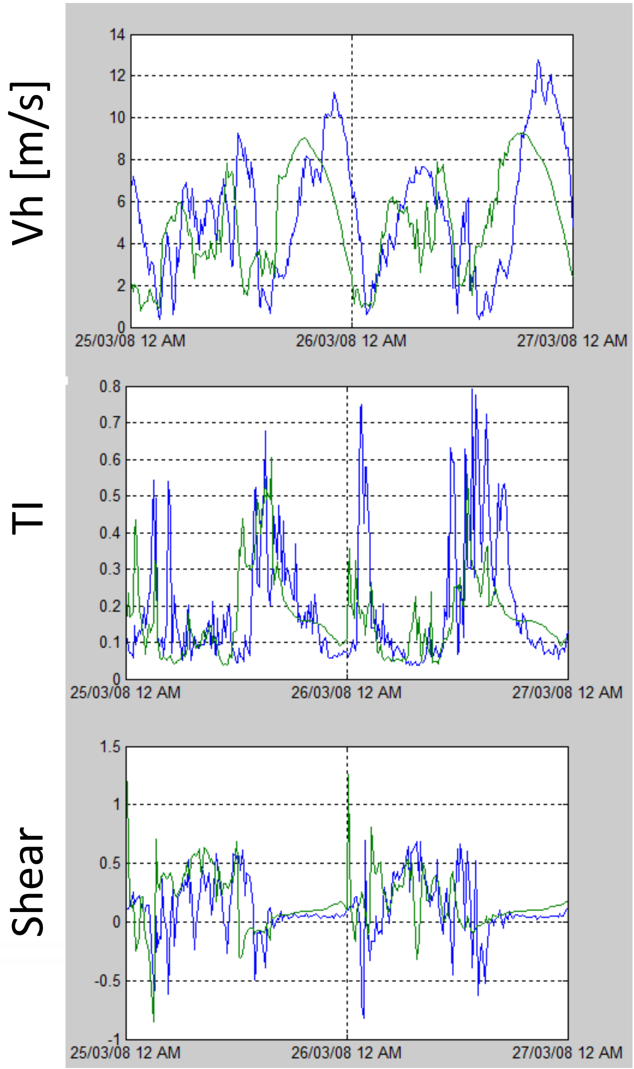
# EXAMPLE OUTPUT – NEGATIVE SHEAR




(Note that measurements are over a year, while computations are meant to represent one full year)

# EXAMPLE OUTPUT – TIME SERIES




The model is able to reproduce diurnal patterns observed for thermally-driven flow



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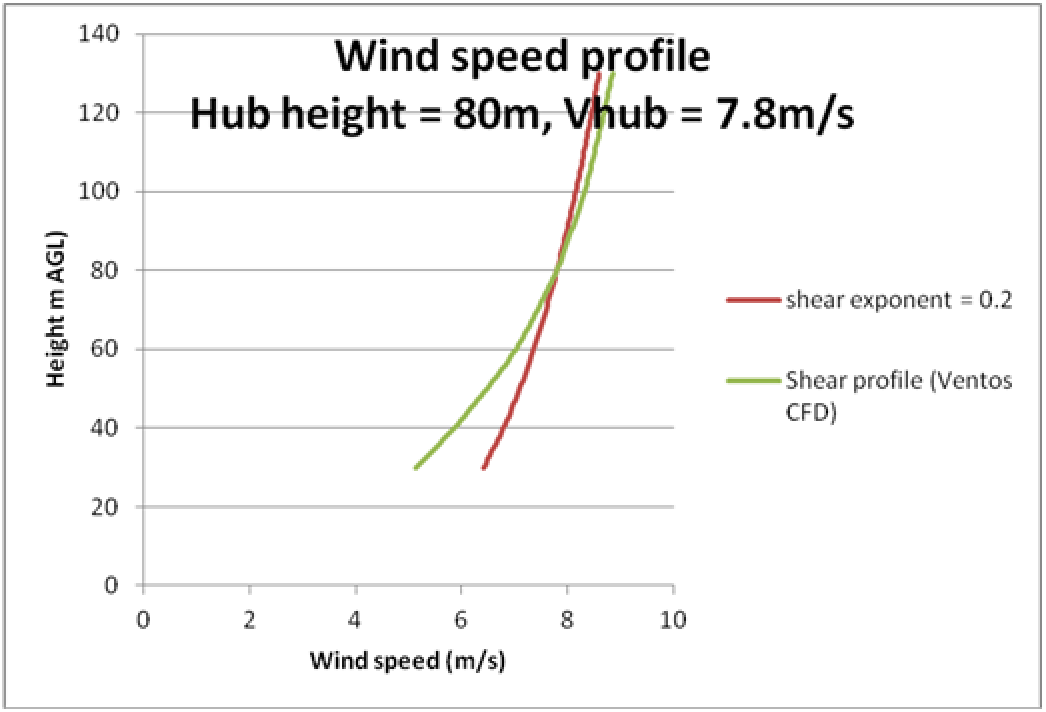
# EXAMPLE OUTPUT – TIME SERIES




3% difference in energy flux

# CONCLUSIONS

- CFD enables detailed flow characterization
  - **Additional outputs are merely used for site suitability**
  - **Time-dependant simulations could be used further**
  - **Multidimensional power curves  should improve accuracy of EYA**

- Coupled CFD generate virtual mast time series
  - **More accurate analyses** (stability, mast independent)
  - **Next level EYA, with PC(Time, Vh, TI, Shear, IA, Density)**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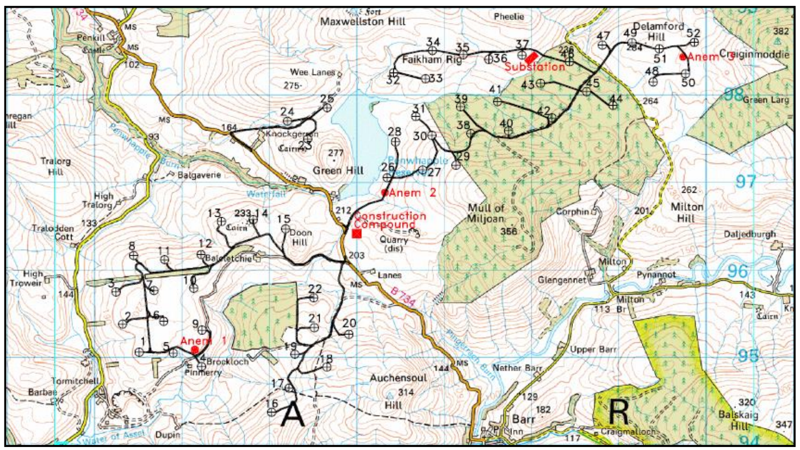
Contact : oisinb@naturalpower.com

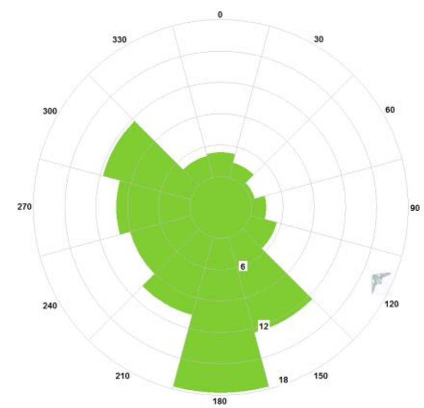
# ADDITIONAL SLIDES

# CASE STUDY 1 – SITE CHARACTERISTICS

- **Complex, forested site**
- **Underproduction**




Site topography and forestry map




On site wind rose



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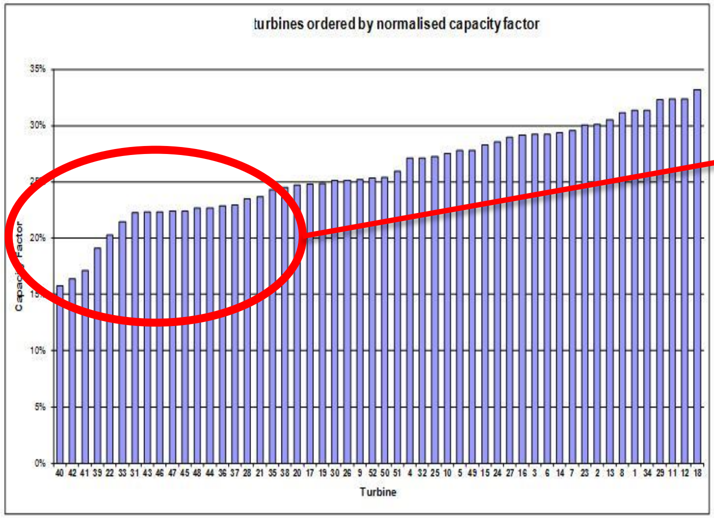
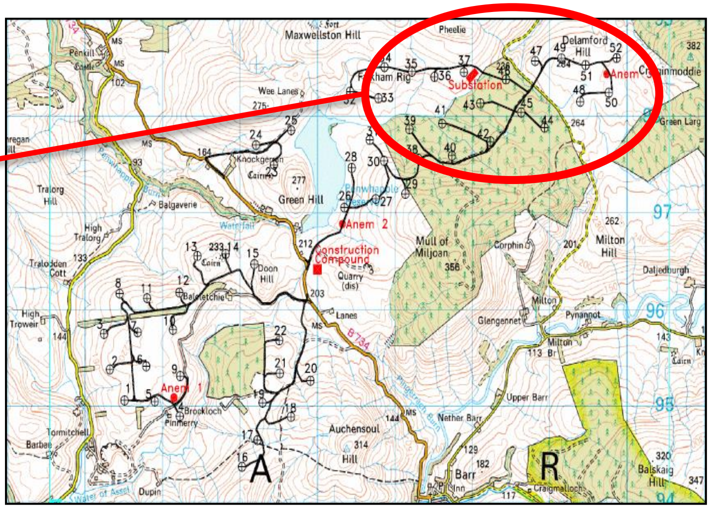
# CASE STUDY 1 – OBSERVED UNDERPERFORMANCE

- **Most turbines showing low capacity factors are located next to the forest**




Capacity factor per turbine

Site topography and forestry map



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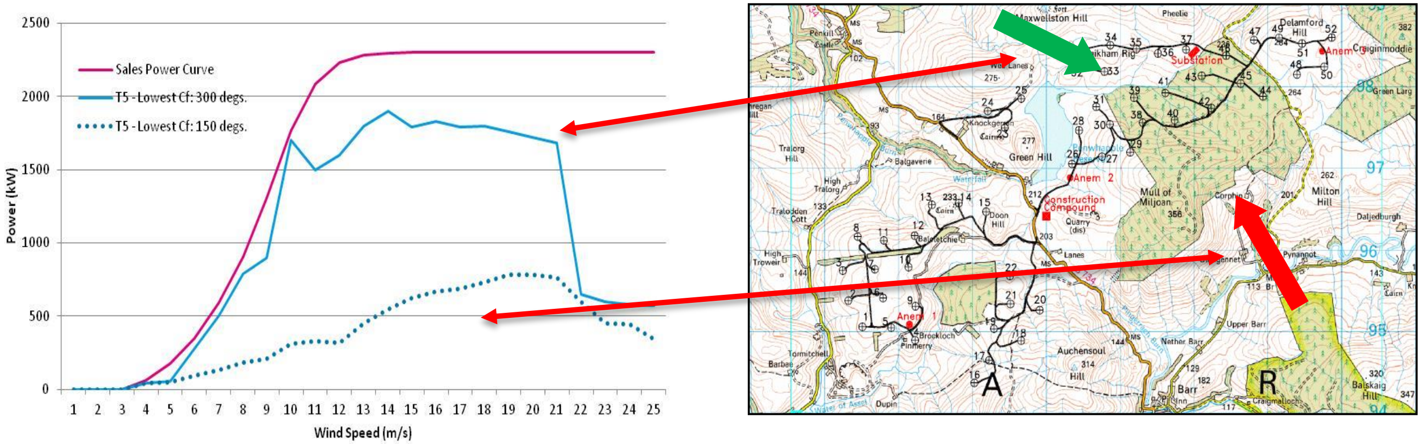
# CASE STUDY 1 – OBSERVED UNDERPERFORMANCE

- **Underperforming turbines are shown to be performing properly in some wind directions (300), but not in other (150)**




Wind turbine performance for a given wind direction



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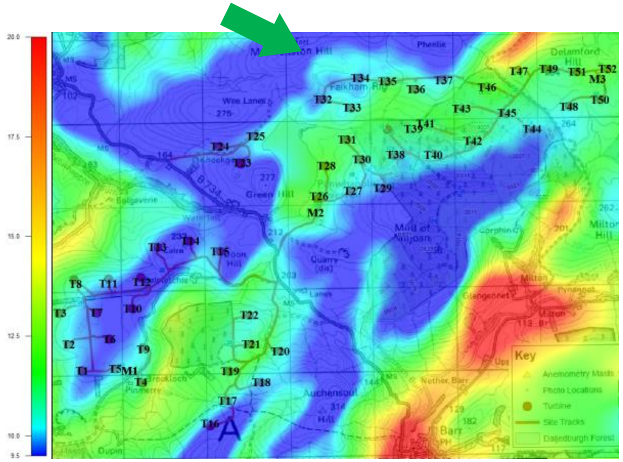
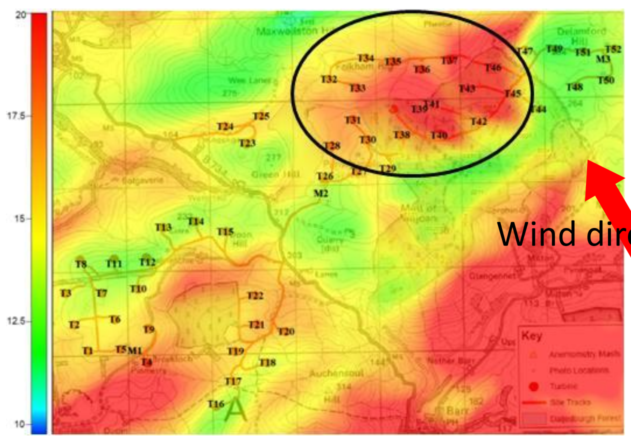
# CASE STUDY 1 – ADDED VALUE OF CFD

- **Underperformance is due to high turbulence/shear**
- **Impact on yield could be assessed through multidimensional power curves**

Wind direction



Turbulence (TI) map for 300 wind sector




Turbulence (TI) map for 150  wind sector



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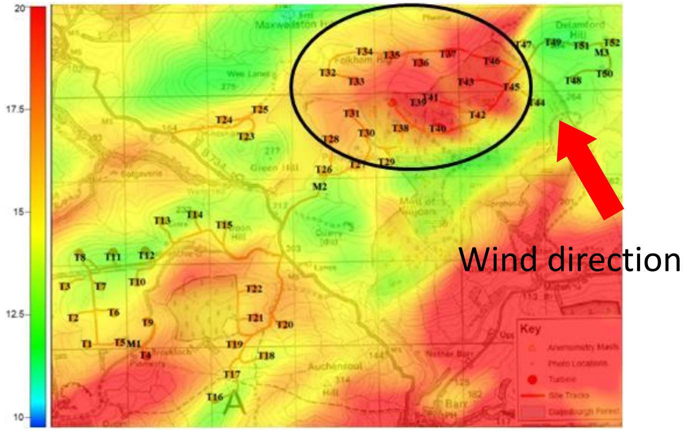
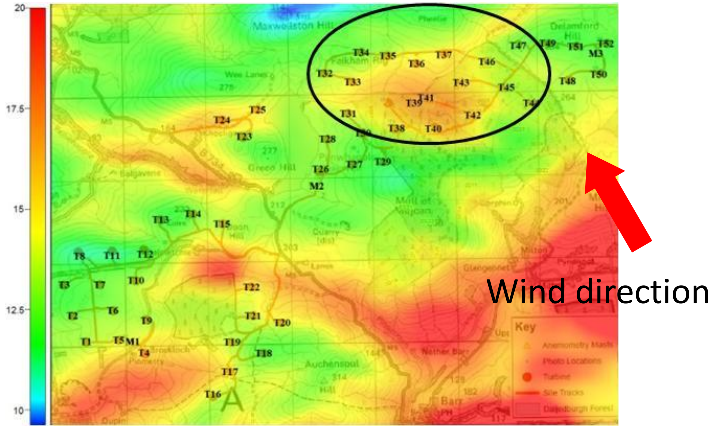
# CASE STUDY 1 – FUTURE FOREST SCENARIOS

- **Impact of tree growth/felling on flow can be assessed**
- **Impact on yield could be assessed through multidimensional power curves**




Turbulence (TI) map with the actual forestry




Turbulence (TI) map after forestry cuts (hypothetical scenario)



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