

Farm efficiency and power matrices based on CFD simulations and comparison with measurements

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Supervisor

Coordination

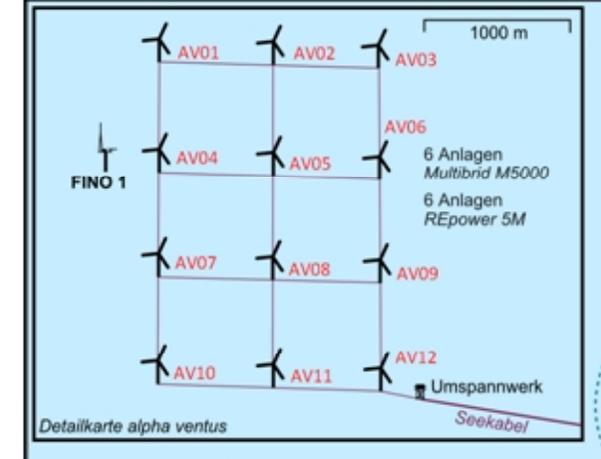
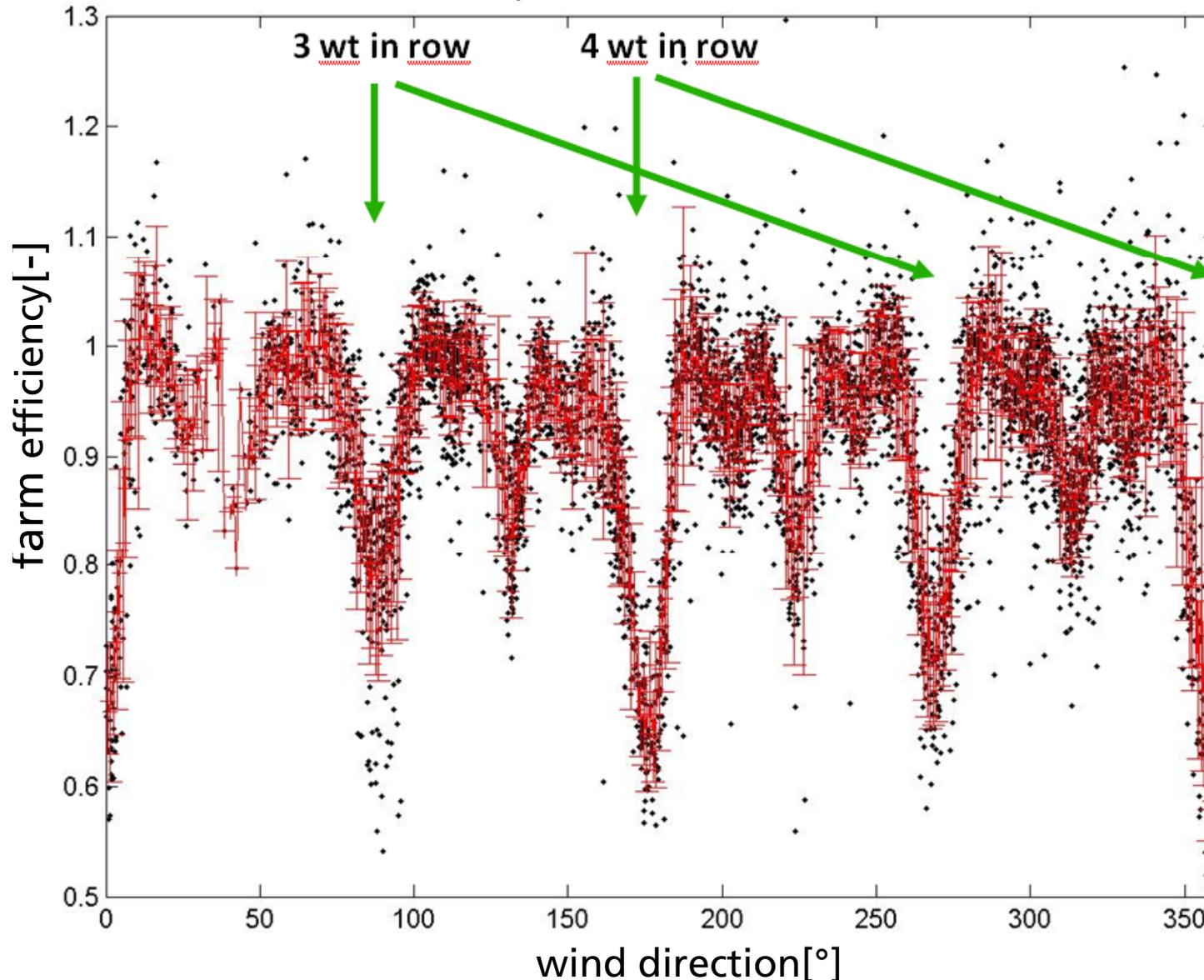
Farm efficiency and power matrices based on CFD simulations and comparison with measurements

- Motivation
- Power matrices
- Influence of different parameters on power matrices



Motivation

Farm efficiency of alpha ventus, $v=[6;12 \text{ m/s}]$

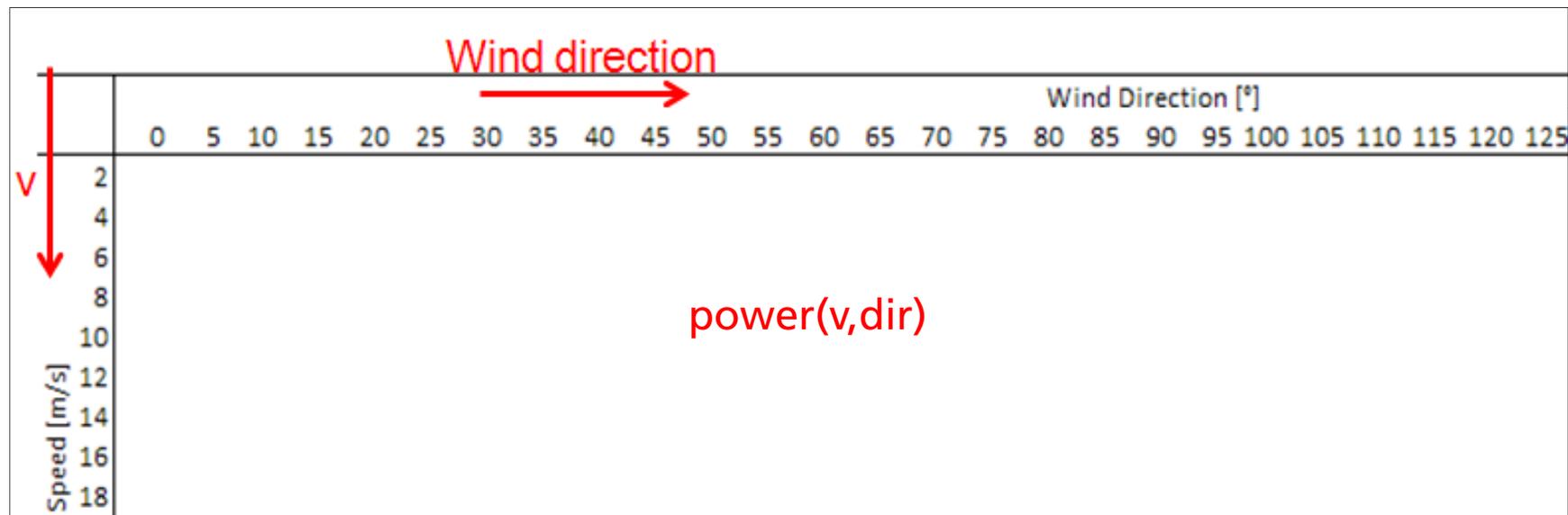


- Farm efficiency shows distinct wind farm axis
- At some wind directions all wt's are in free flow
- -> It is necessary to consider the directional dependency



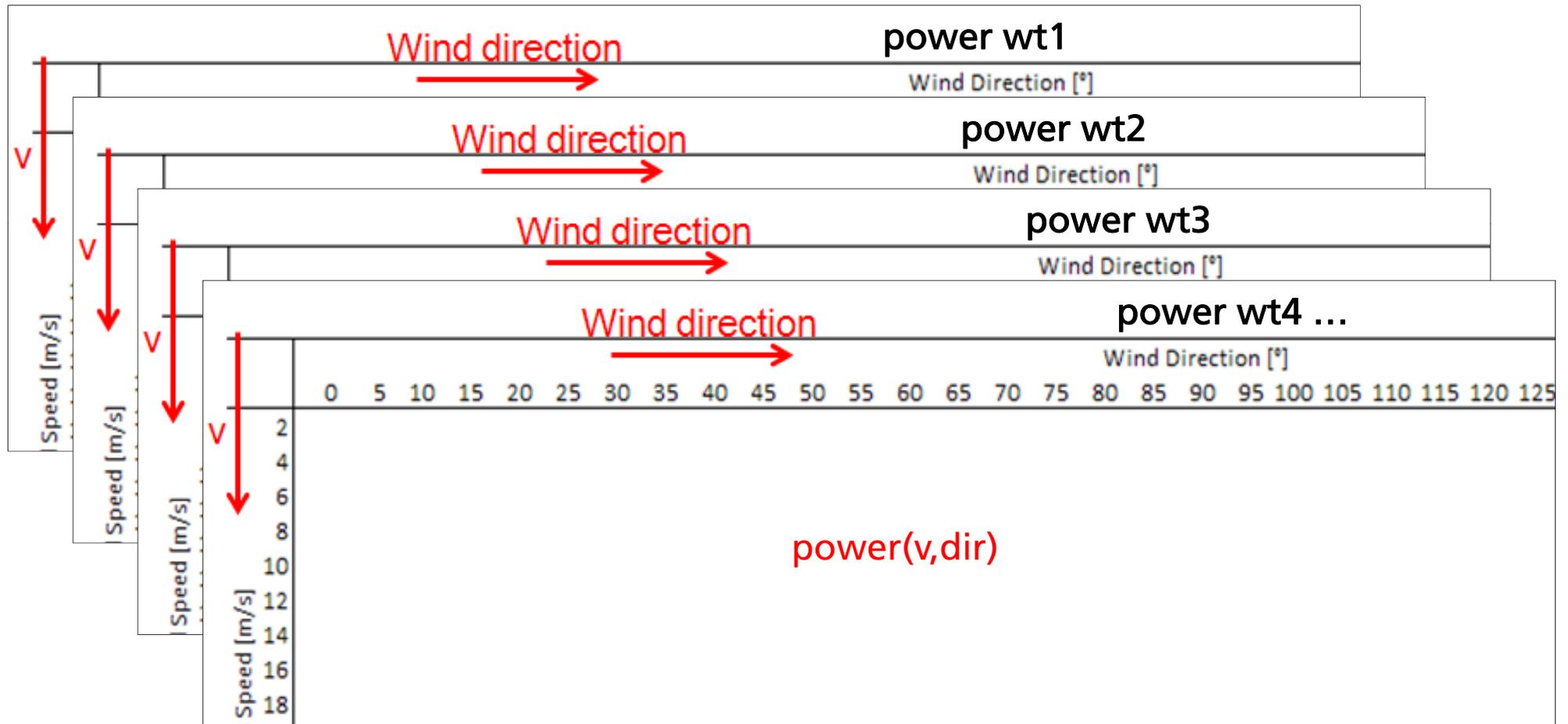
Power Matrices

- Power Matrix: power output dependent on wind speed and direction (and additional parameters)



Power Matrices

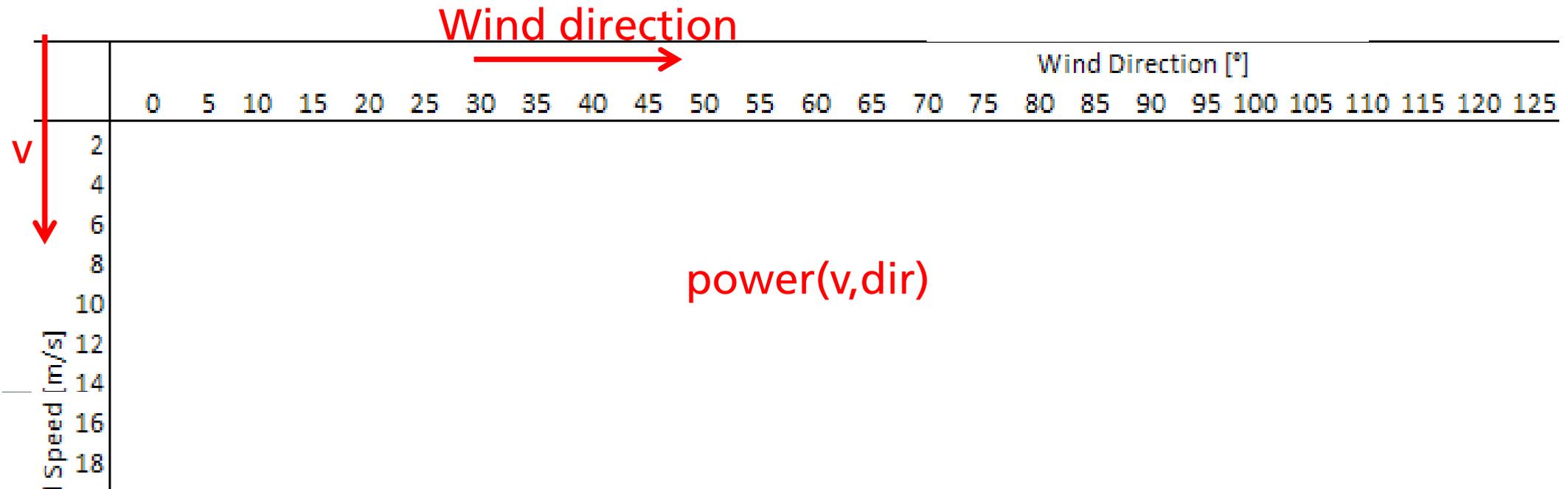
- Power Matrices for each wind turbine in wind farm



Power Matrices

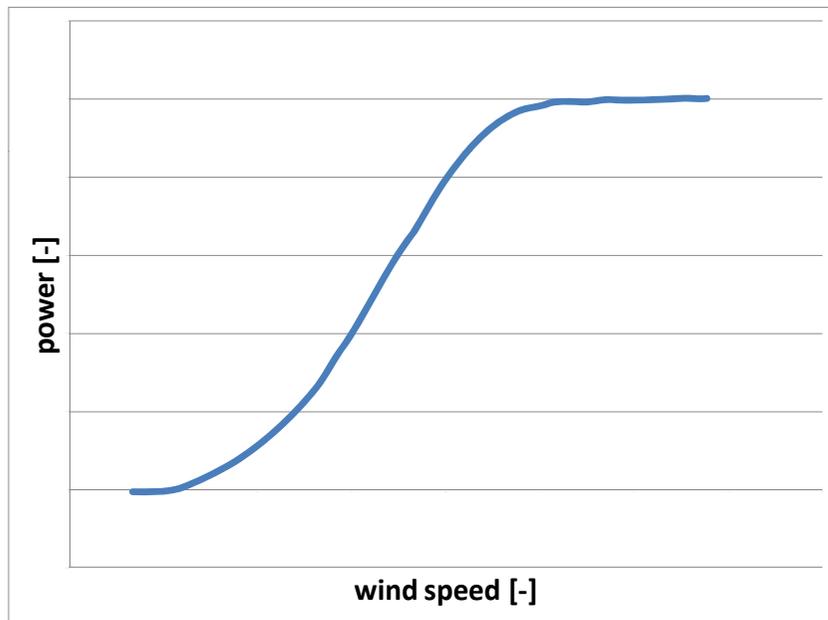
- applications:
 - monitoring of the power output
 - guarantee agreements,
 - forecasting,
 - wind farm performance over a certain period

input data for application:
wind from measurements (mast, Lidar, calibrated nacelle anemometer) or numerical weather models
+ additional data: air density, stability, ...

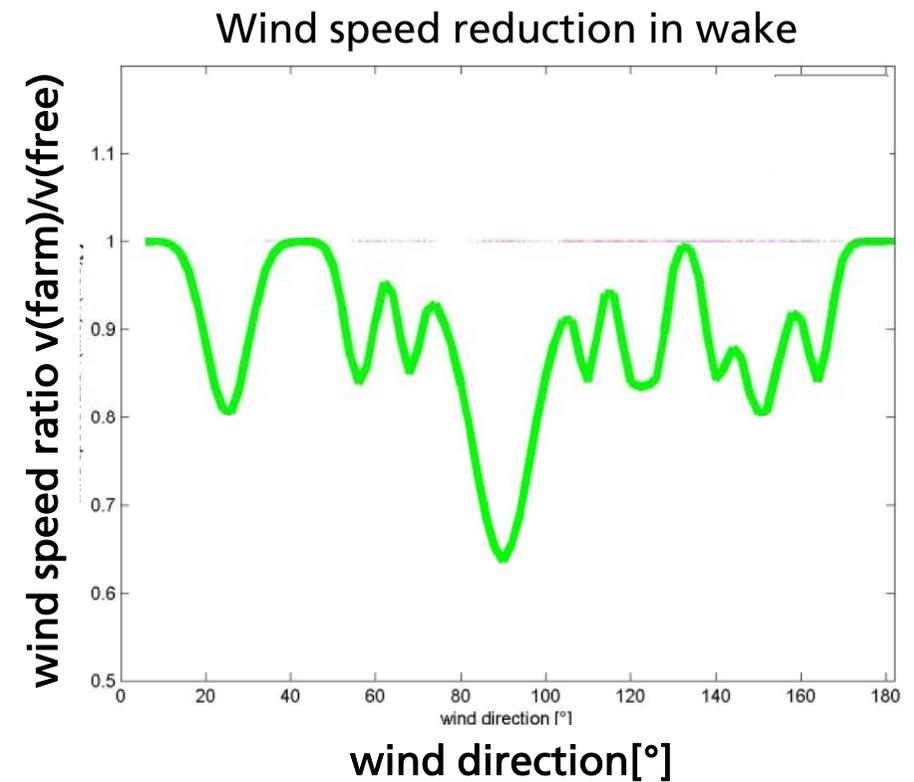


Power Matrices

- Combination of power curve + wake

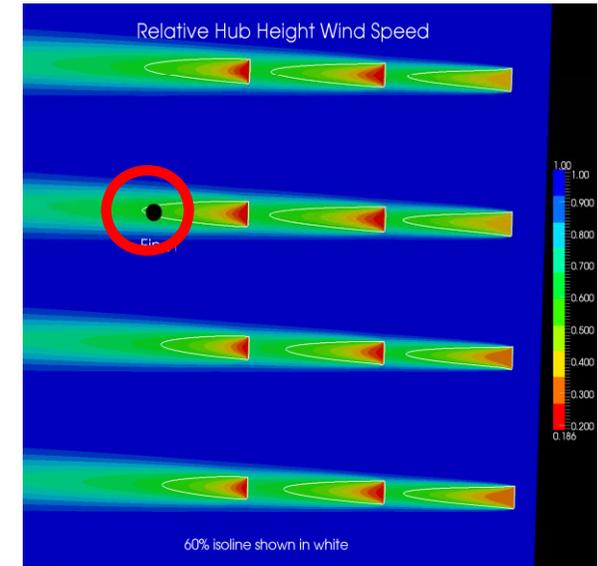
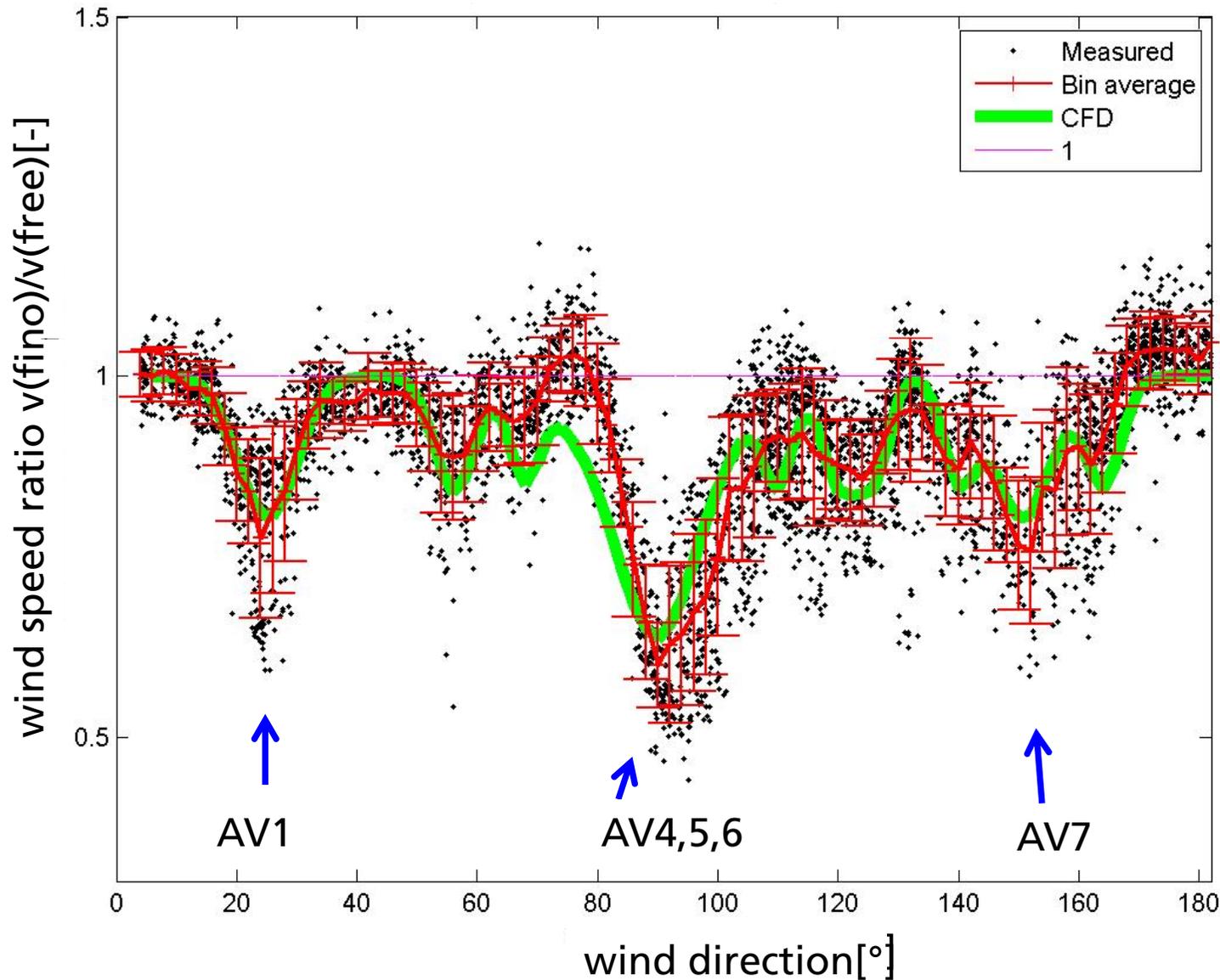


+

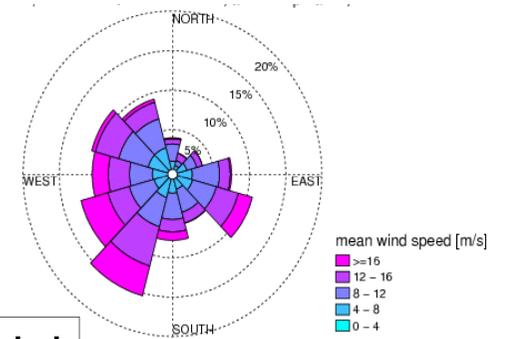


Wake at FINO1 (Measurement vs. CFD)

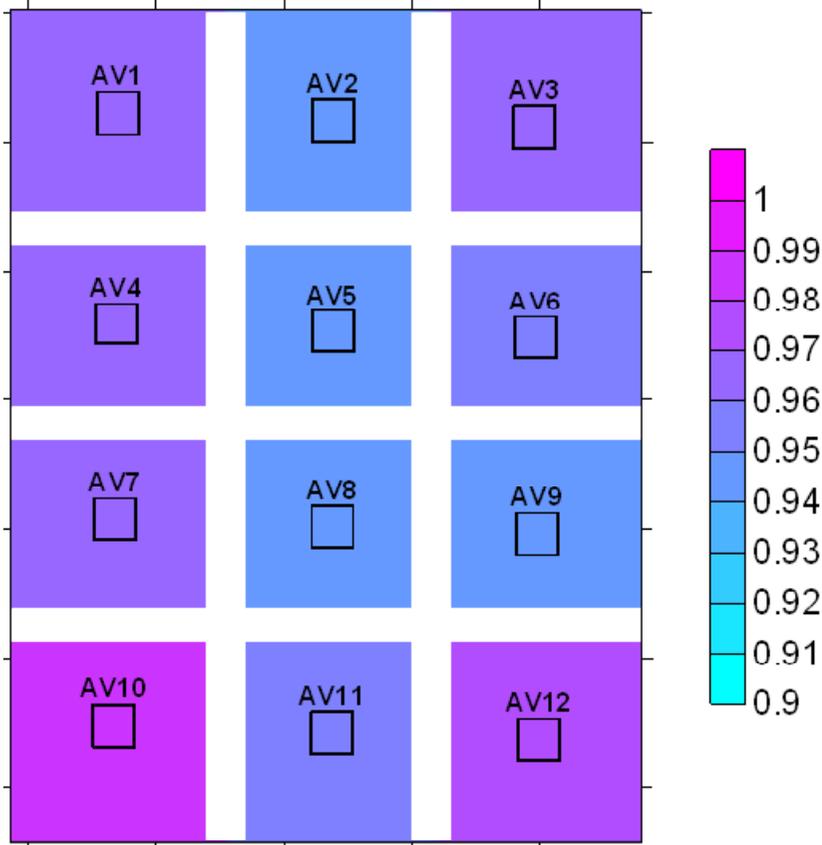
wind speed reduction, free wind speed $v=[10;14 \text{ m/s}]$



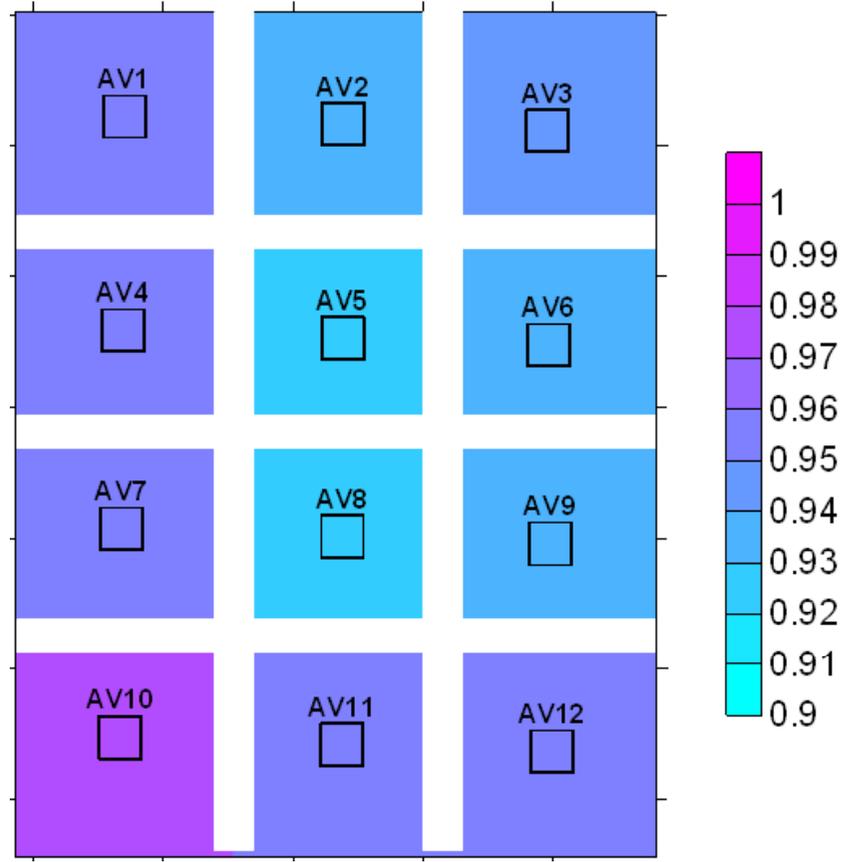
Farm Efficiency (Measurement vs. CFD)



Measurement



CFD Wake Model



Power Matrix

How good is the accuracy? → Has been tested with data of alpha ventus.

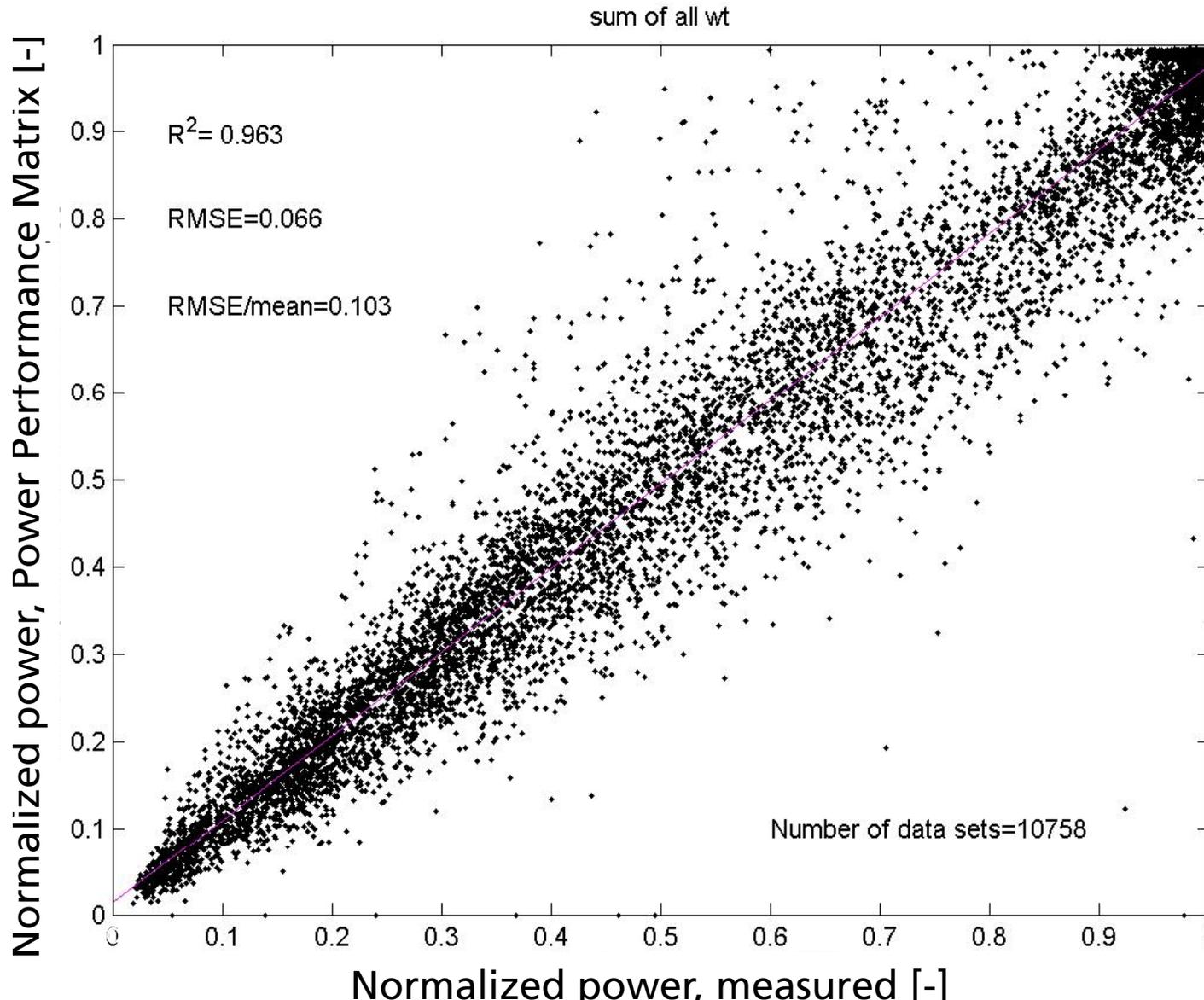
What are the dependencies on

- resolution in wind speed and wind direction
- atmospheric stability
- turbulence Intensity
- air density



Power Matrix (CFD vs Measurement)

How good is the accuracy?



$R^2=96.3\%$

RMSE=10.3% *

Bias=1.6% *

*of the average
power of this data set

Power curves gained
from production data
itself were used.



Power Matrix

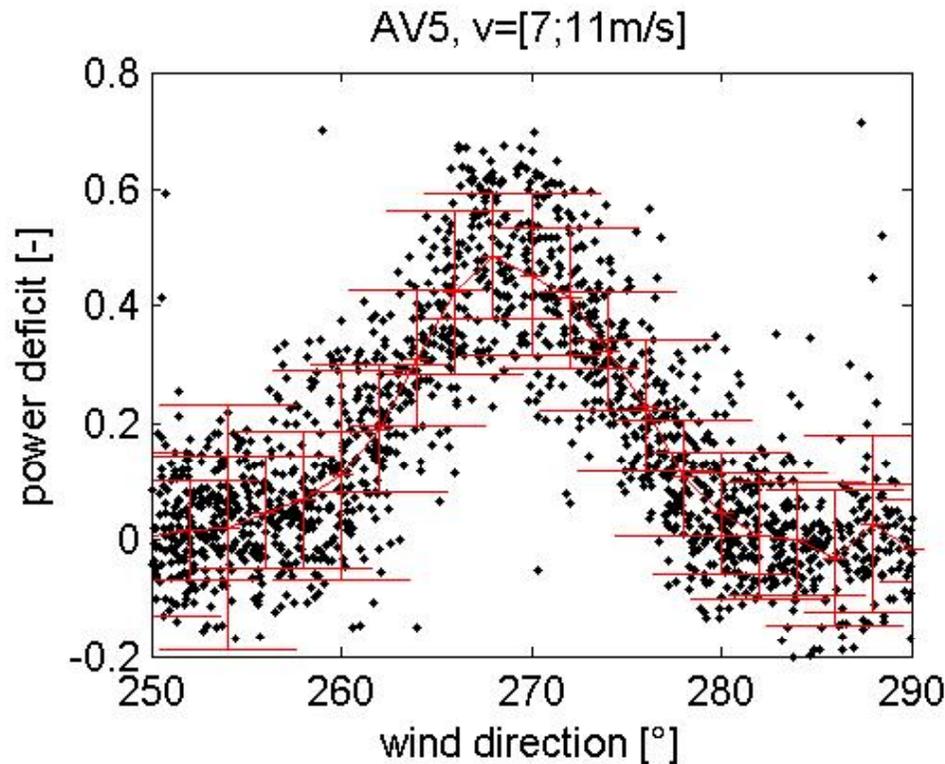
What are the dependencies on

- Resolution in wind speed and wind direction

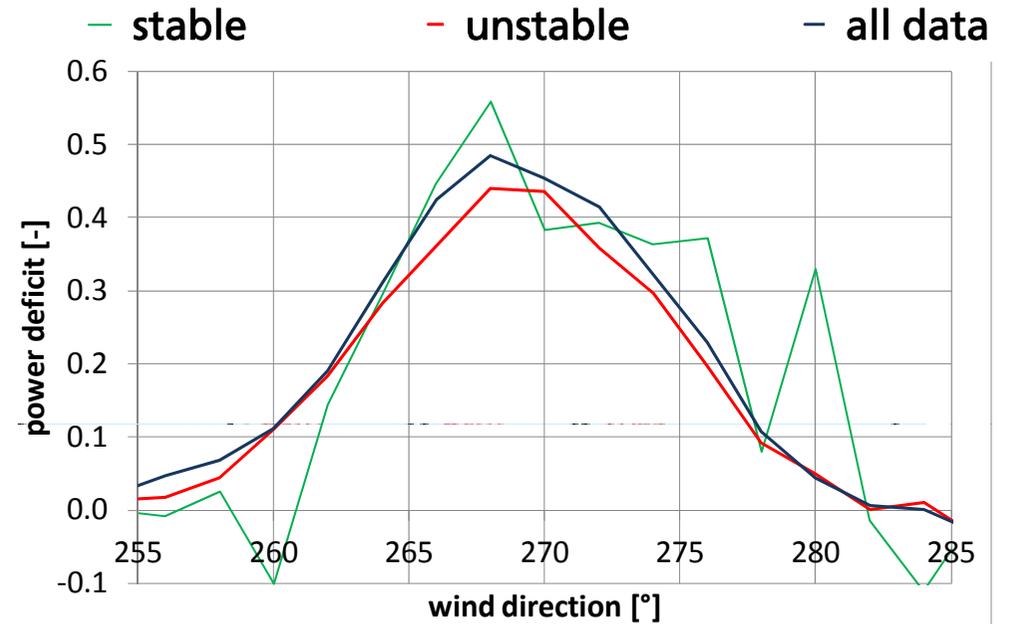
resolution		R ²	RMSE
in wind direction	in wind speed	[%]	[%]
5°	2 m/s	95.7	11.4
1°	1 m/s	96.3	10.3

Power Matrix

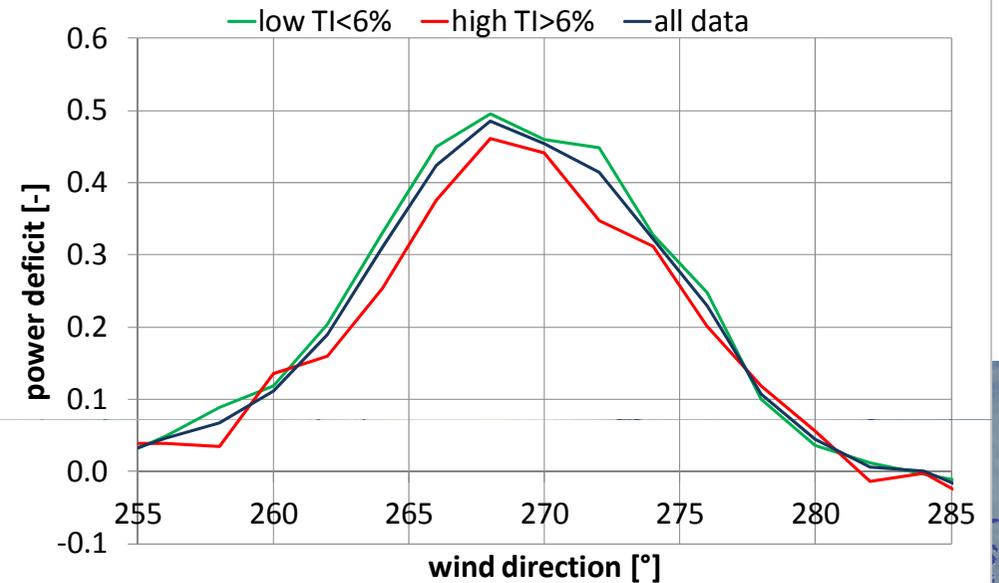
Dependency on atmospheric stability and turbulence intensity, observed power output in 7D



AV5 $v=[7;11\text{m/s}]$, stability



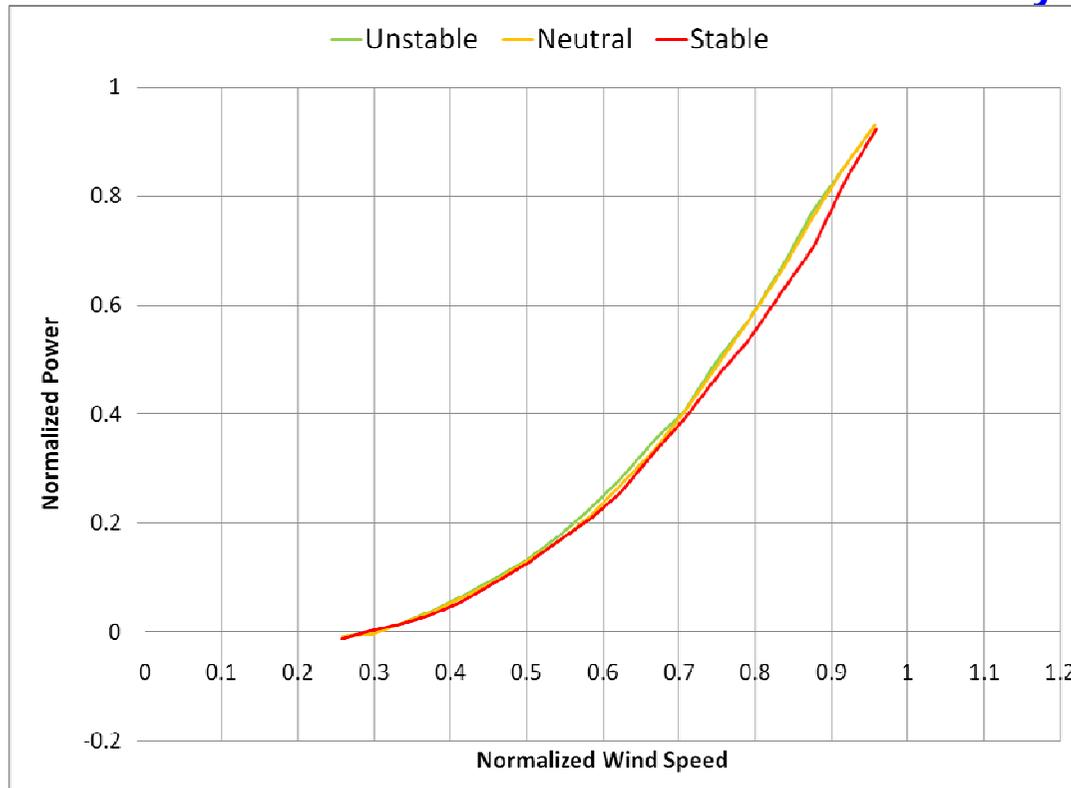
AV5 $v=[7;11\text{m/s}]$, turbulence



Power Matrix

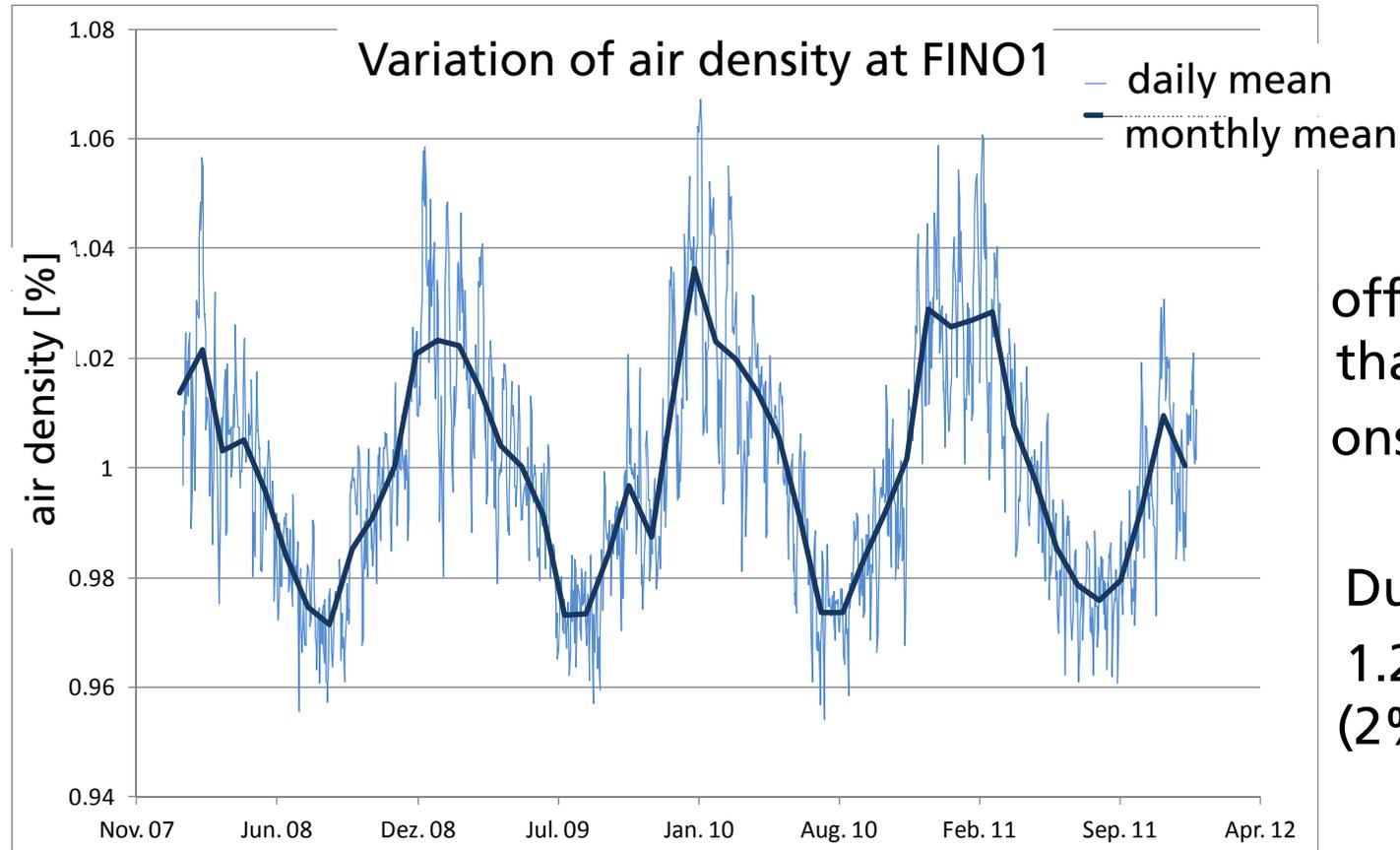
Atmospheric stability has a double effect on the power output offshore

1. Under stable conditions the power in respect to a hub height measurement (IEC power curve) is lower
2. Under stable conditions Farm efficiency in wake is lower



A. Bégué, T. Neumann, H. Mellinghoff, B Cañadillas: Influence of atmospheric stability on wind turbines (WT) power performance at Alpha Ventus offshore wind park, EOW 2011, Amsterdam.

Dependency on air density



offshore less variable
than
onshore,

During 2011:
1.239 kg/m³ +/- 0.027
(2% of mean)

Conclusions

- Farm efficiency and power matrices have been assessed from CFD wake model and compared with observed power output
- Sensitivity on parameters:
 - Air density: yes
 - Stability: yes
 - Turbulence intensity: yes
 - Resolution of CFD runs: $\Delta_{dir}=5^\circ$, $\Delta v=2\text{m/s}$ was acceptable
- Power matrices based on CFD simulations are a promising tool, can be useful for different applications



Thank you for your attention!

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