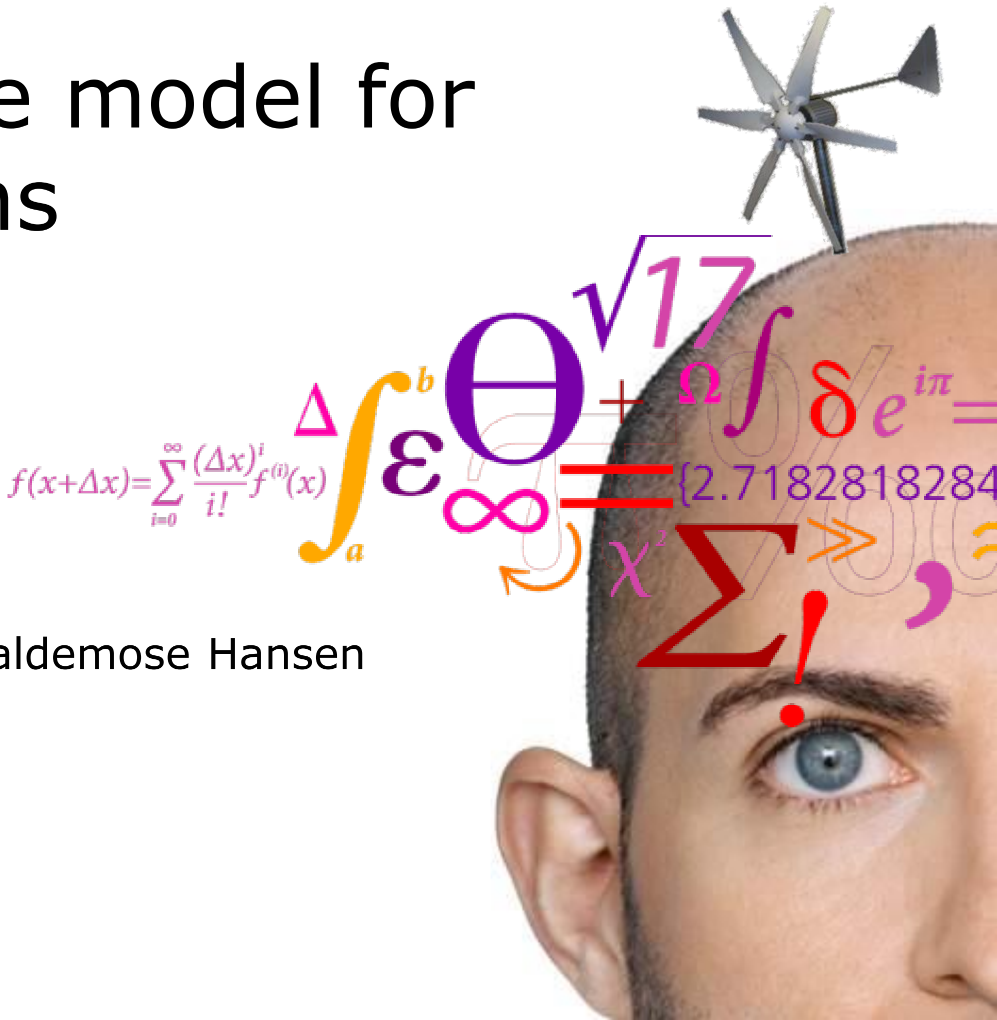
Fuga

- Validating a wake model for offshore wind farms



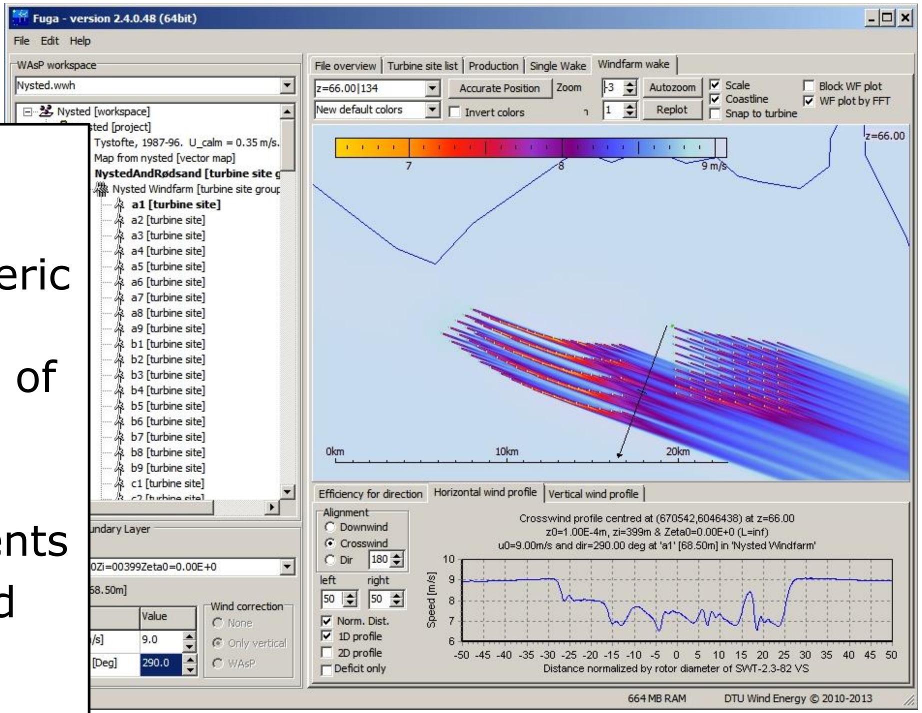
Søren Ott, Morten Nielsen & Kurt Shaldemose Hansen

Outline

- What is Fuga?
- Model validation: which assumptions are tested?
- Met data interpretation: Is it important?
- Simple models for the impact of large scales
- Illustrated with Fuga tests
- Conclusions

Fuga – features*

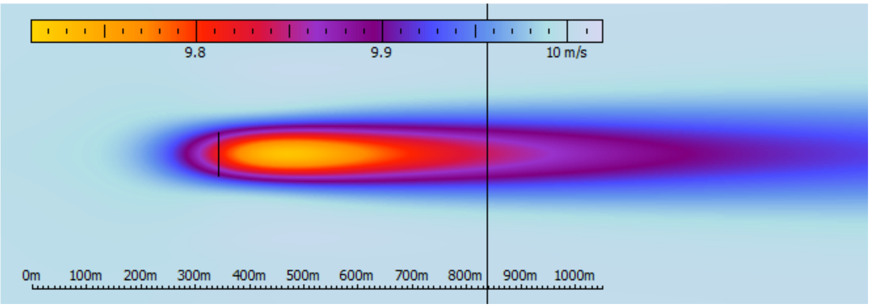
- Solves linearized RANS equations
- Latest version incorporates: atmospheric stability, meandering, effects of non-stationarity and spatial de-correlation of the flow field.
- No computational grid, no numerical diffusion, no spurious pressure gradients
- Integration with WAsP: import of wind climate and turbine data.
- Fast, mixed-spectral solver:
  - 10^6 times faster than conventional RANS!
  - 10^8 to 10^{10} times faster than LES!

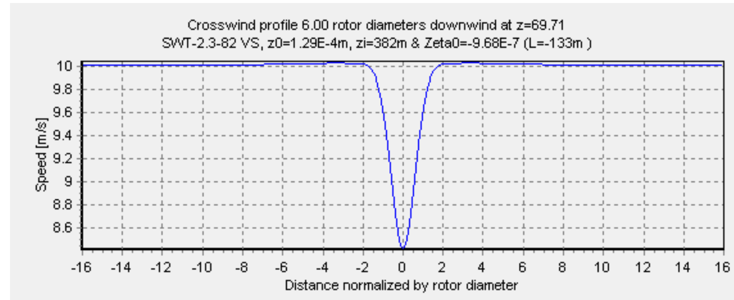


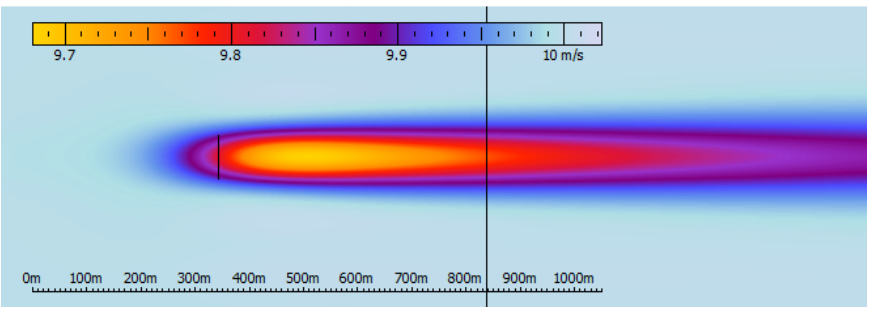
Fuga development partly sponsored by CARBON TRUST

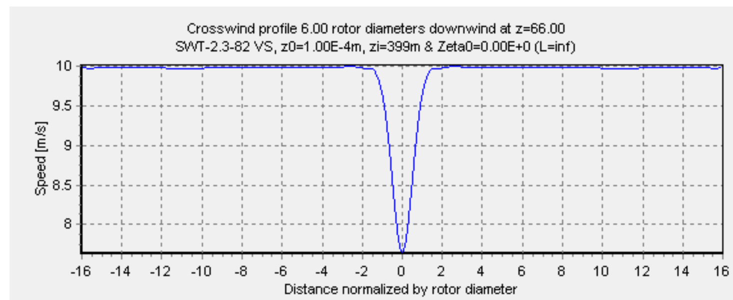
*Søren Ott, Jacob Berg and Morten Nielsen: 'Linearised CFD Models for Wakes', Risoe-R-1772(EN), 2011

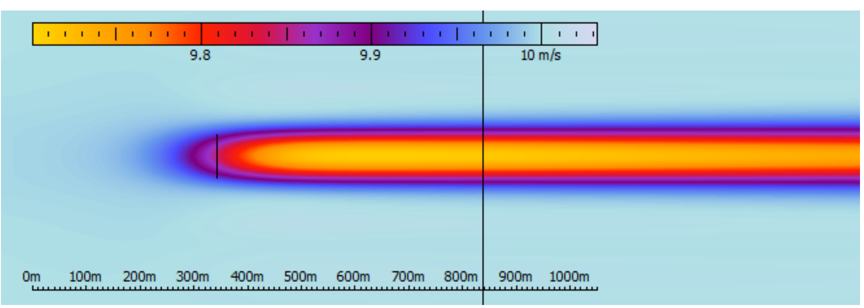
Variable atmospheric stability – horizontal profiles

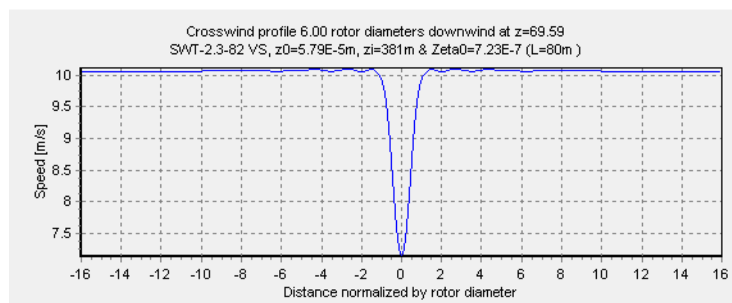




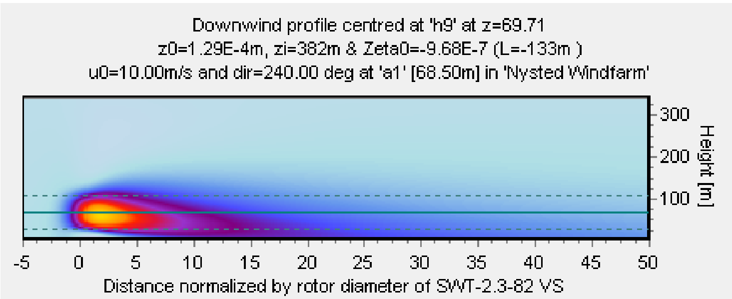


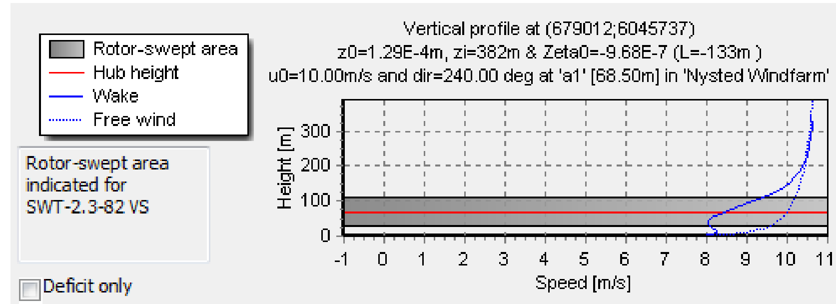


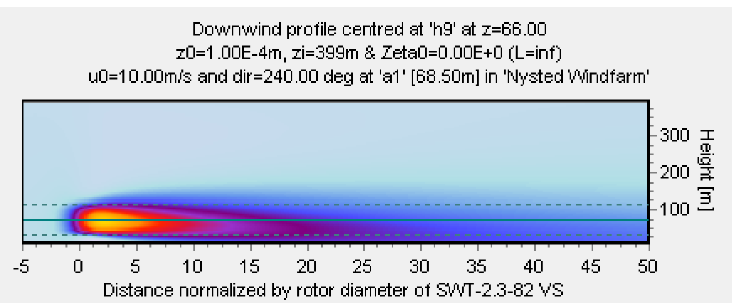


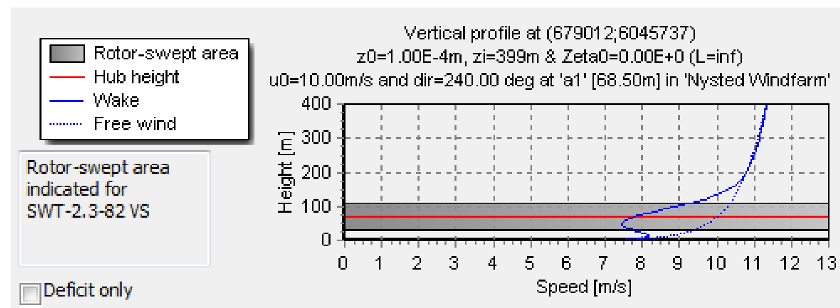


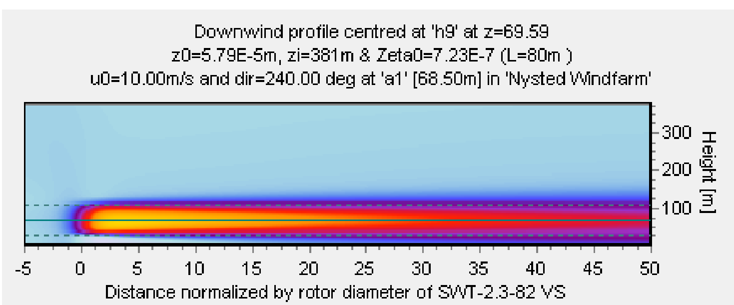
Variable atmospheric stability – vertical profiles

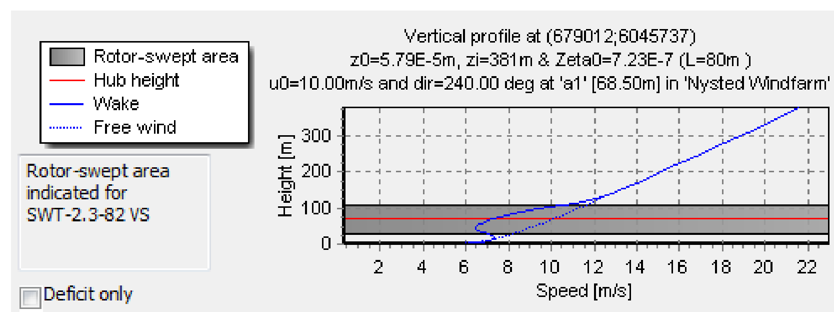




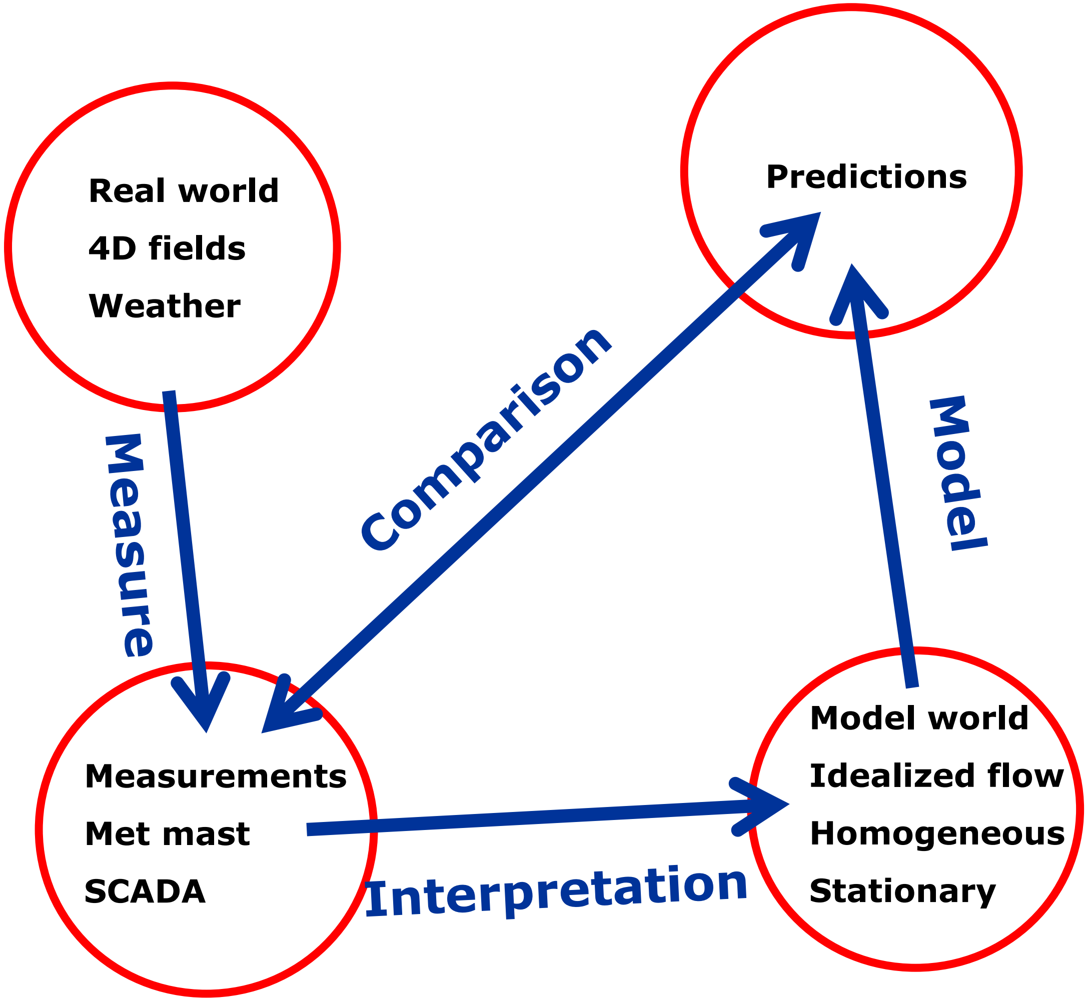








Model testing and assumptions



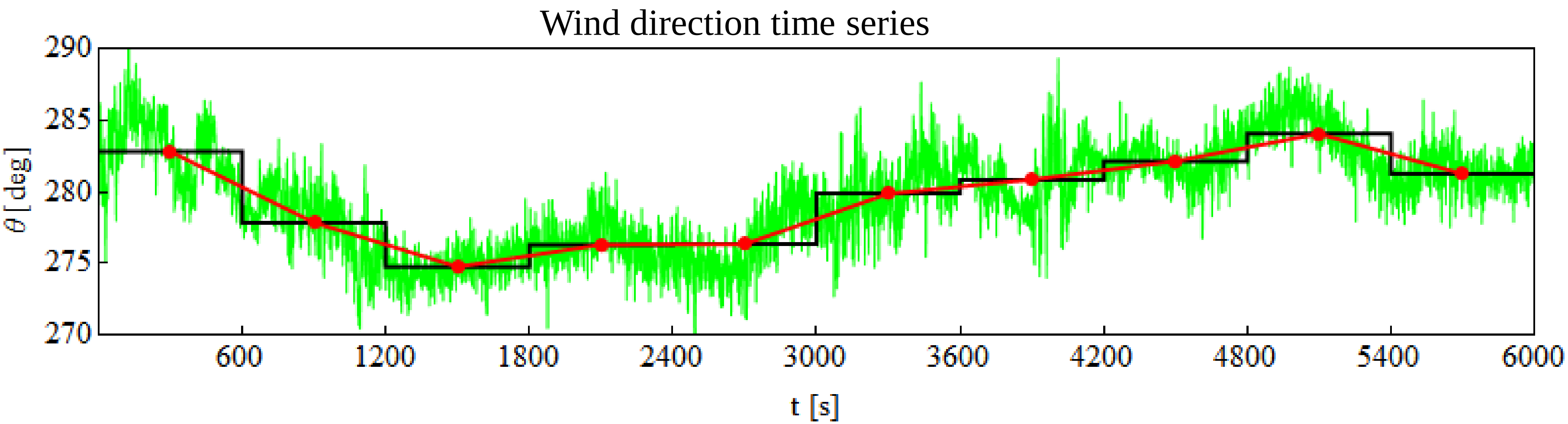
Two layers of assumptions:

1) interpretation of data in terms of an idealized 'model world'
2) Flow model assumptions

Controlled experiments test only one assumption at a time!

Is data interpretation important?

Two different interpretations of met data



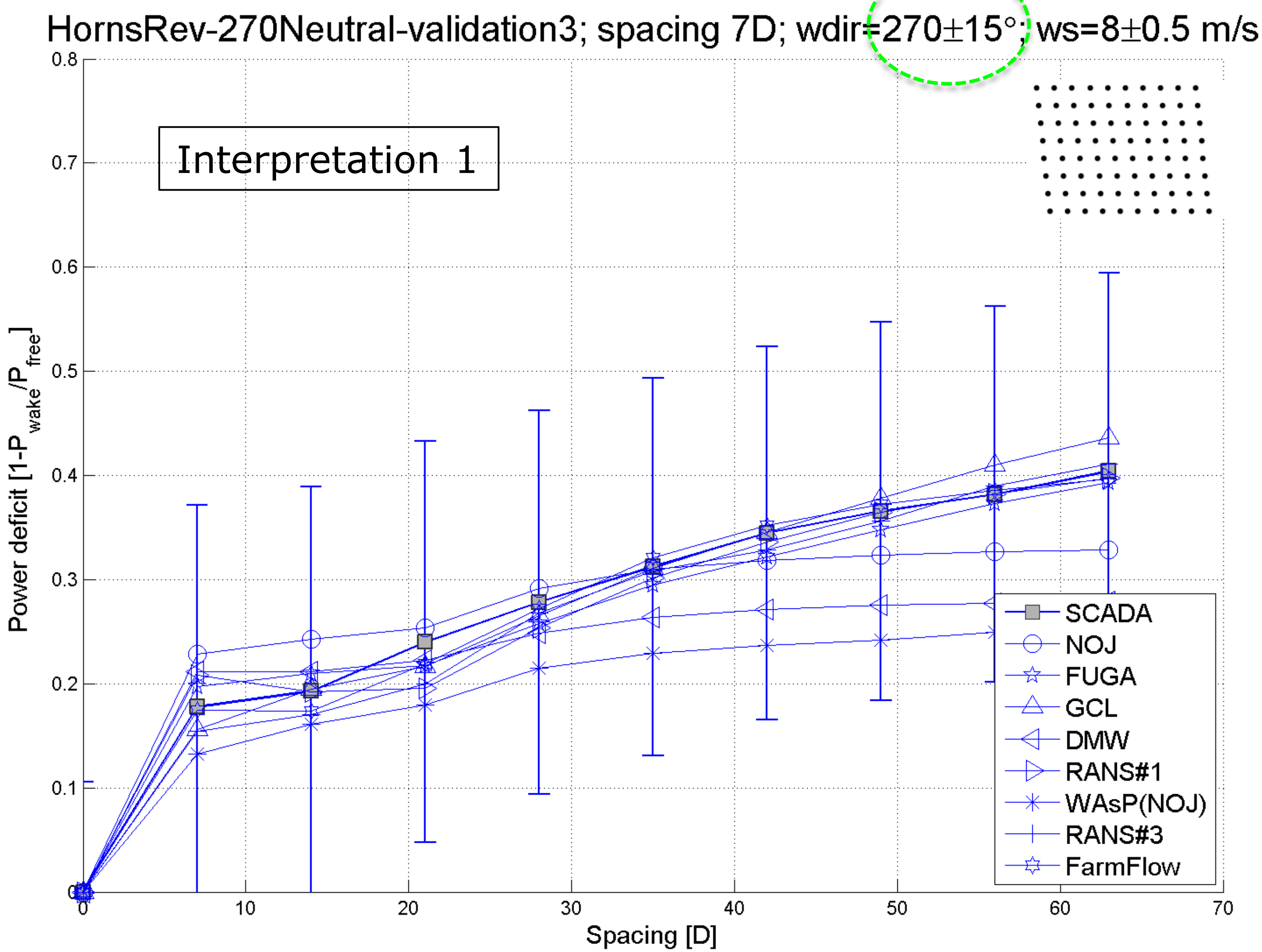
Wind direction measurements

Ten minutes average wind direction

Interpretation 1: each ten minutes period can be regarded as a piece of a stationary time series with mean = ten minutes average. *We only need to simulate the measured mean direction*.

Interpretation 2: the mean value changes following the red curve. The deviation from the red curve is statistically stationary. *We need to simulate a range of directions for each measure mean direction.*

Flow cases, part 1- wide inflow sector

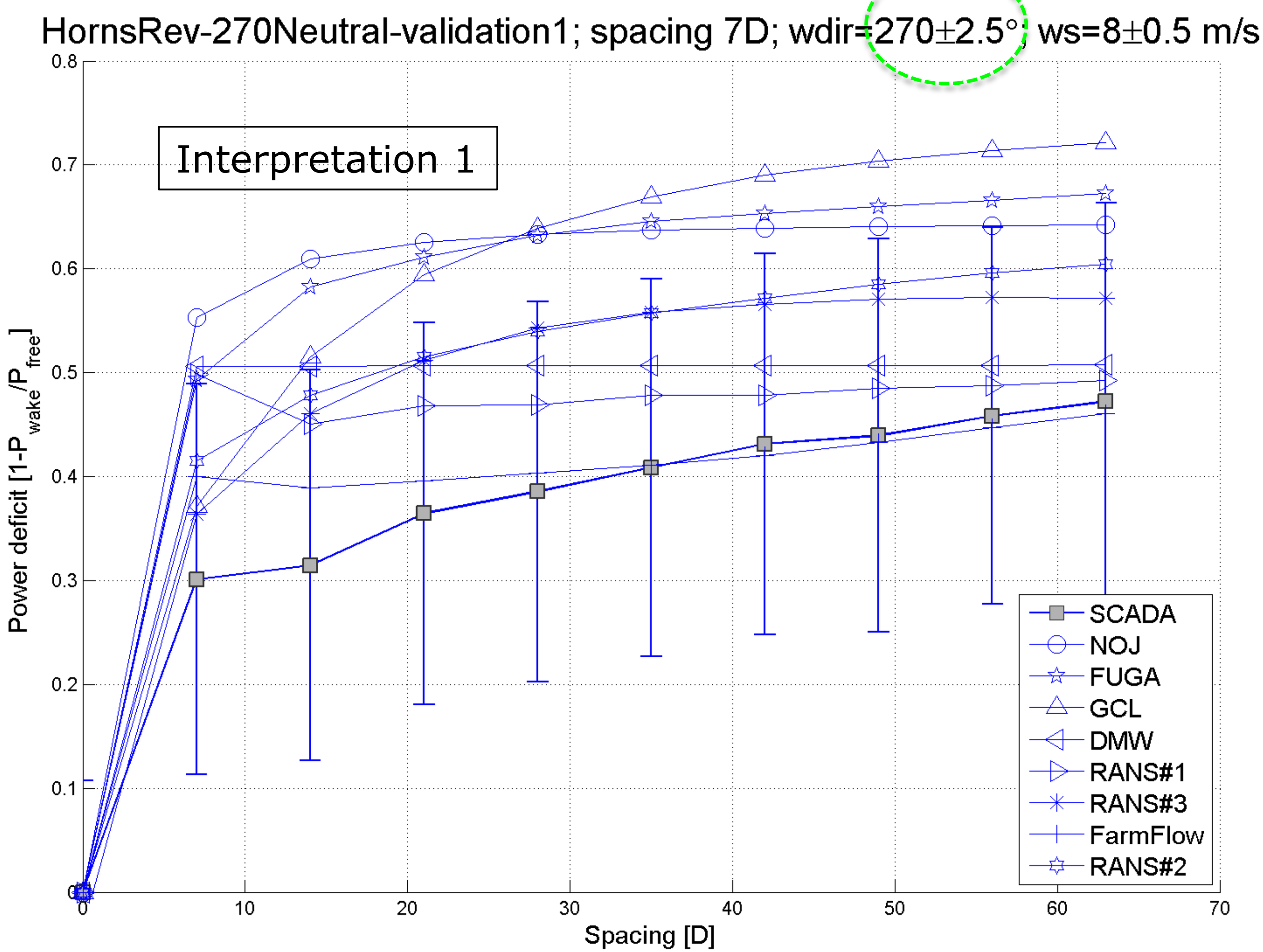


Thanks to Kurt S. Hansen for this slide

/ksh

Flow cases, part 1 – narrow inflow sector

Thanks to Kurt S. Hansen for this slide



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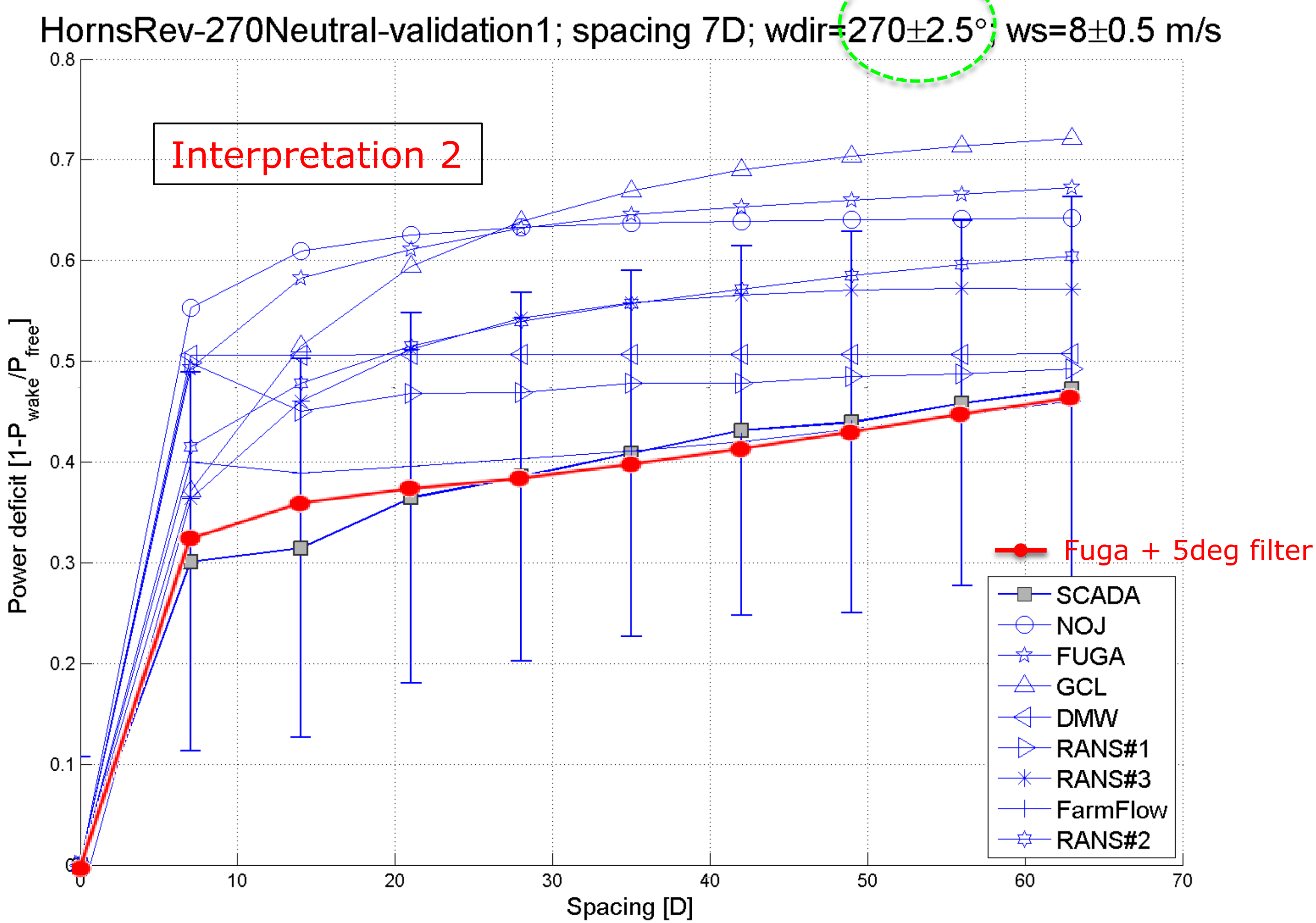
Flow cases, part 1 – narrow inflow sector



Thanks to Kurt S. Hansen for this slide

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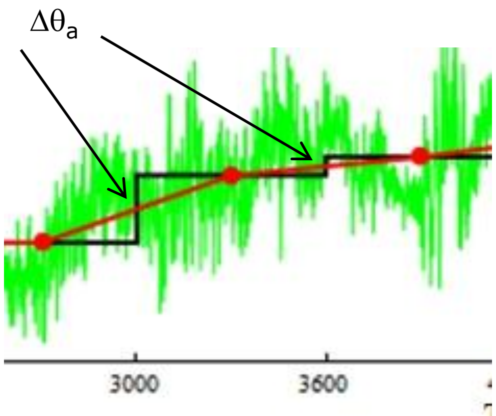
Effect of ‘drifting’ wind direction can be estimated from data

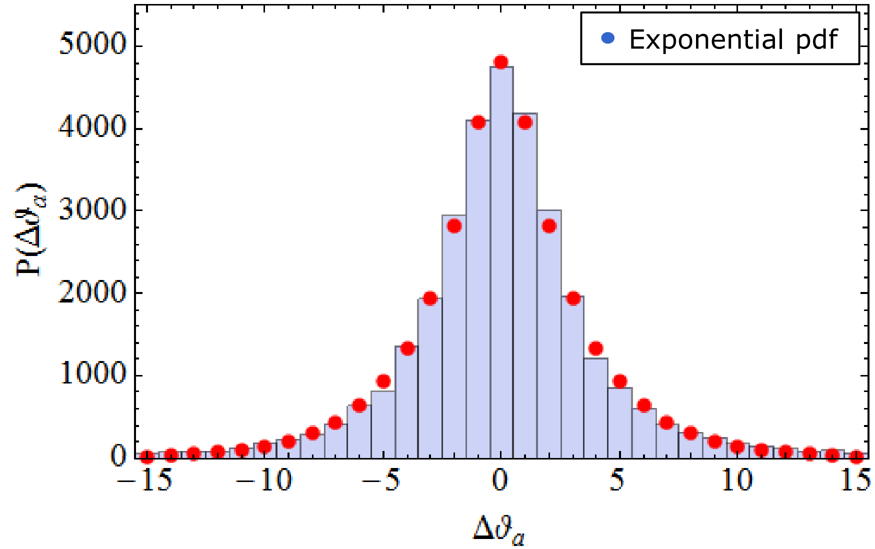
- $\Delta\theta_a$ = Difference of two consecutive ten minutes averages of the wind direction

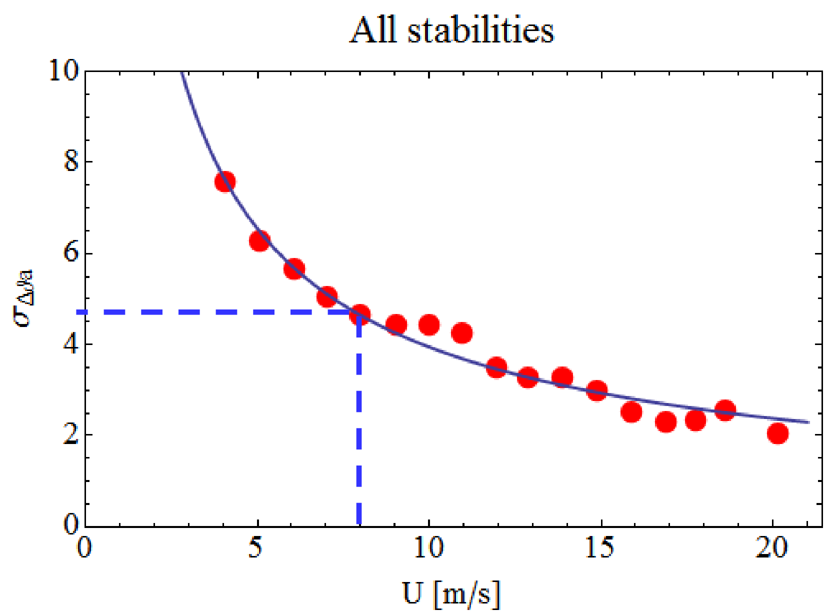


- Width $\sigma_{\Delta\theta a} = \langle(\Delta\theta_a)^2\rangle^{1/2}$

- $\sigma_{\Delta\theta a}$ can be obtained from 10 minutes averages.

Horns Rev 1 met mast data

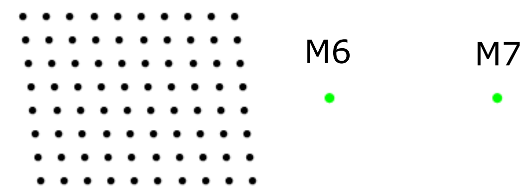


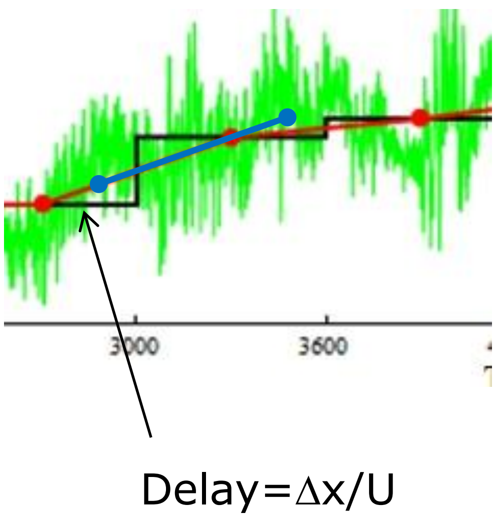


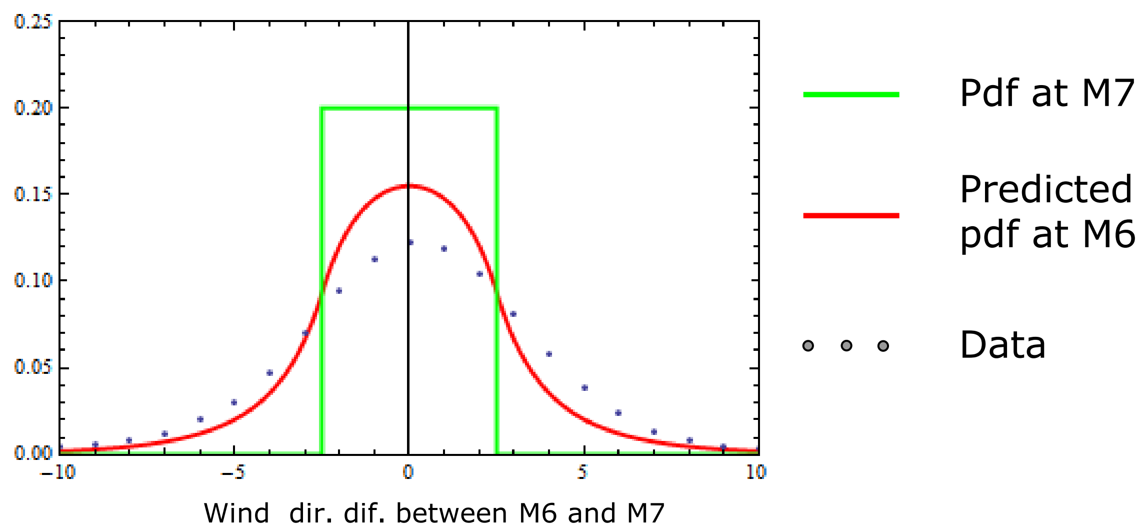
Spatial de-correlations of wind direction

Problem: wind direction at met mast ≠ wind directions at the turbines.

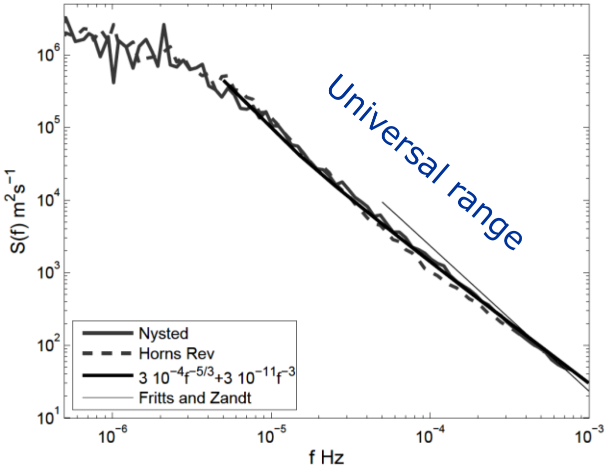
This uncertainty can be estimated using Taylors hypothesis:



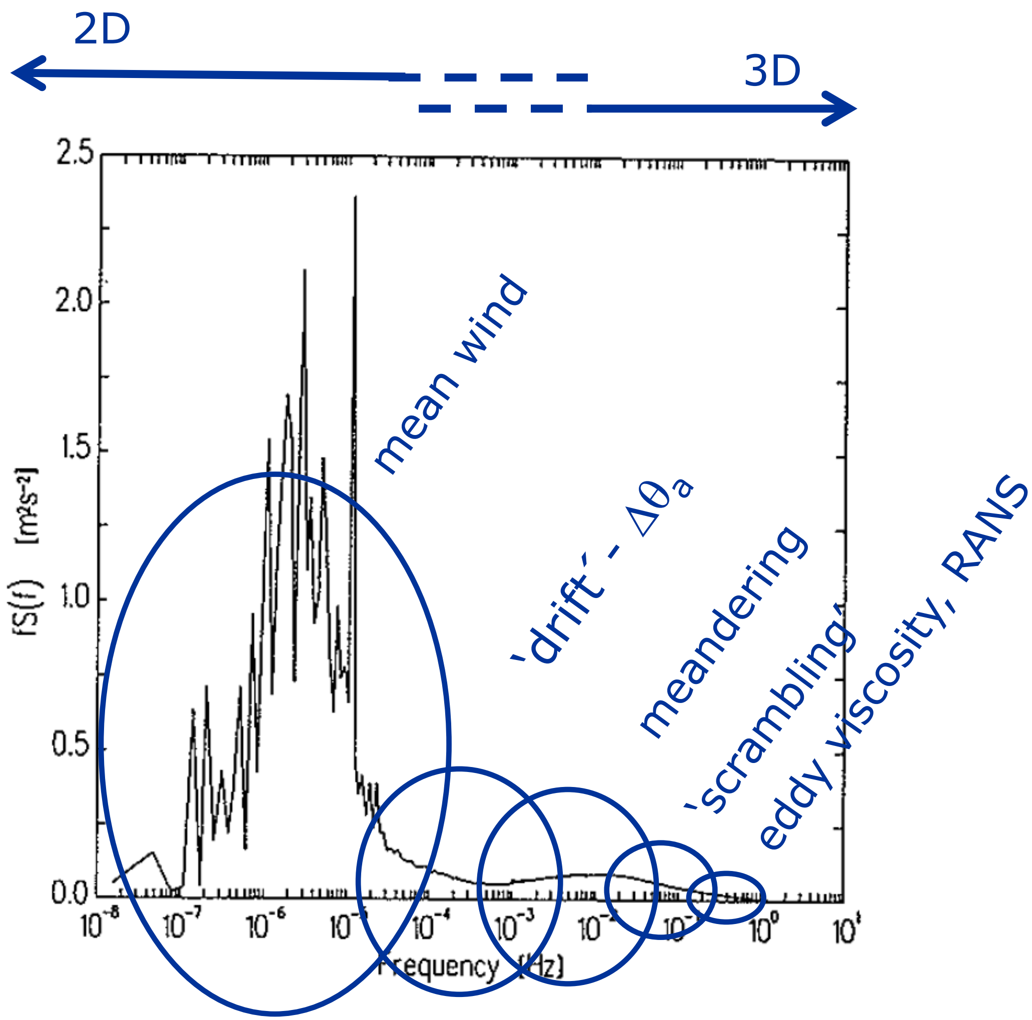




Spectral regimes



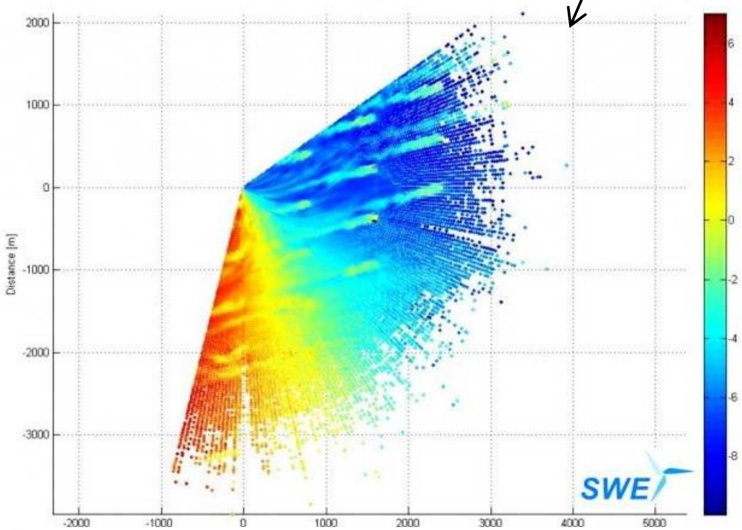
Larsén, Vincent & Larsen 2011

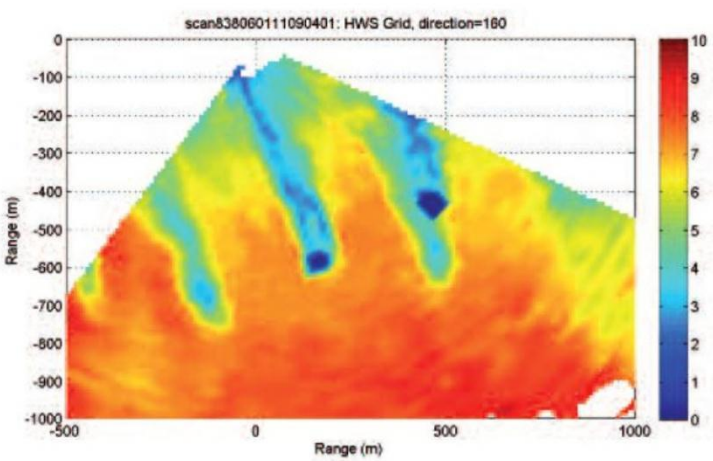


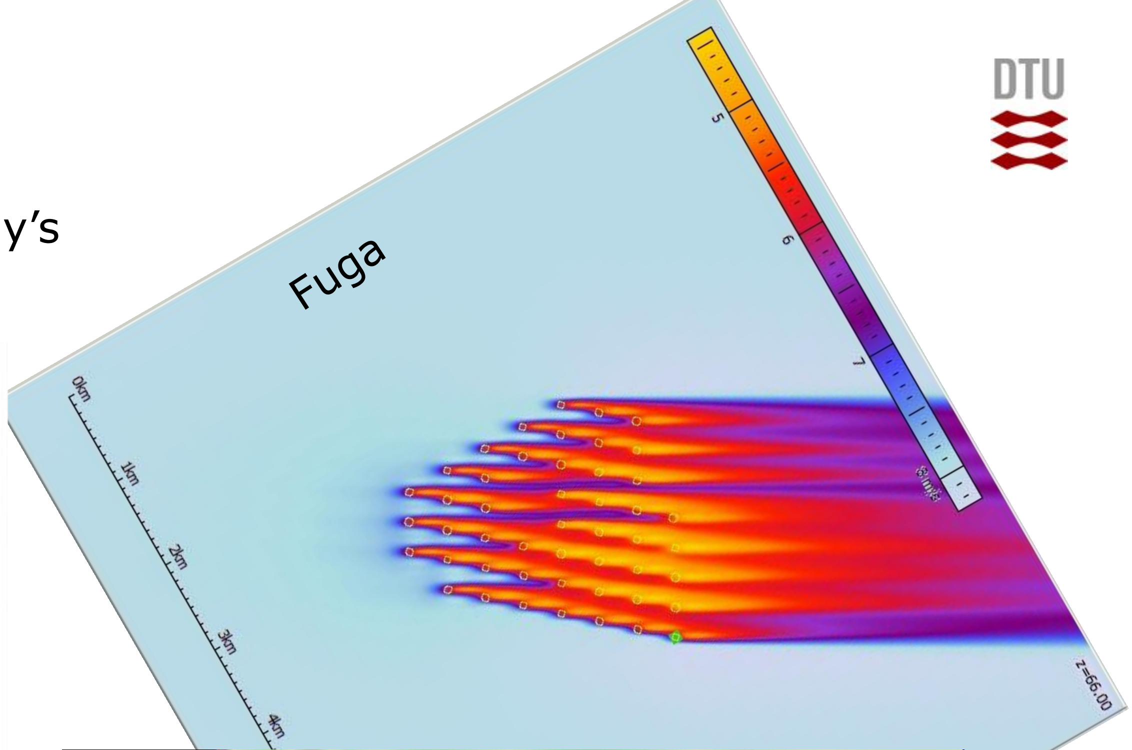
Courtney & Troen 1990

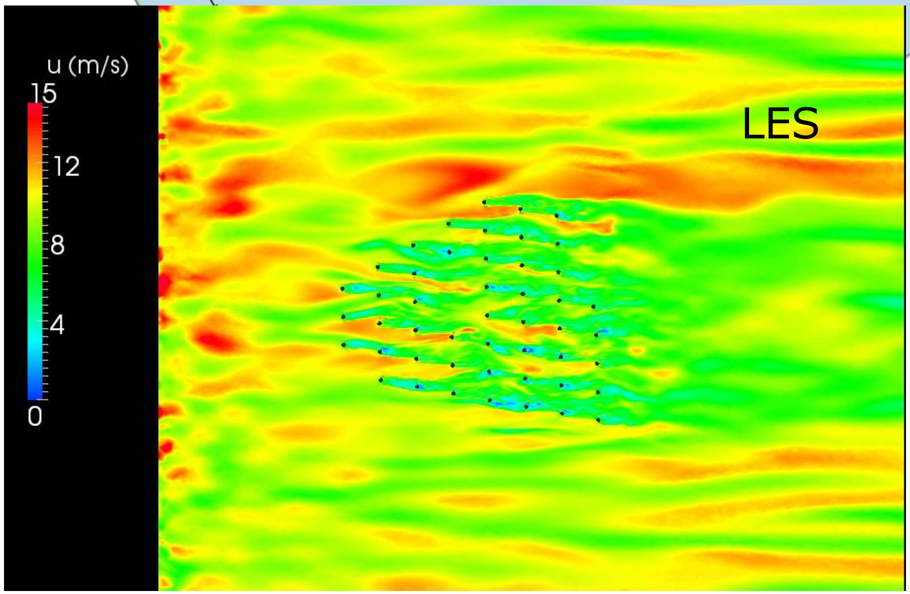
Meandering

Measurements with SgurrEnergy's Galion Lidar.









Creech et al.(2013): *High-resolution CFD modelling of Lillgrund Wind farm*, RE&PQJ, 11

Lillgrund wind farm

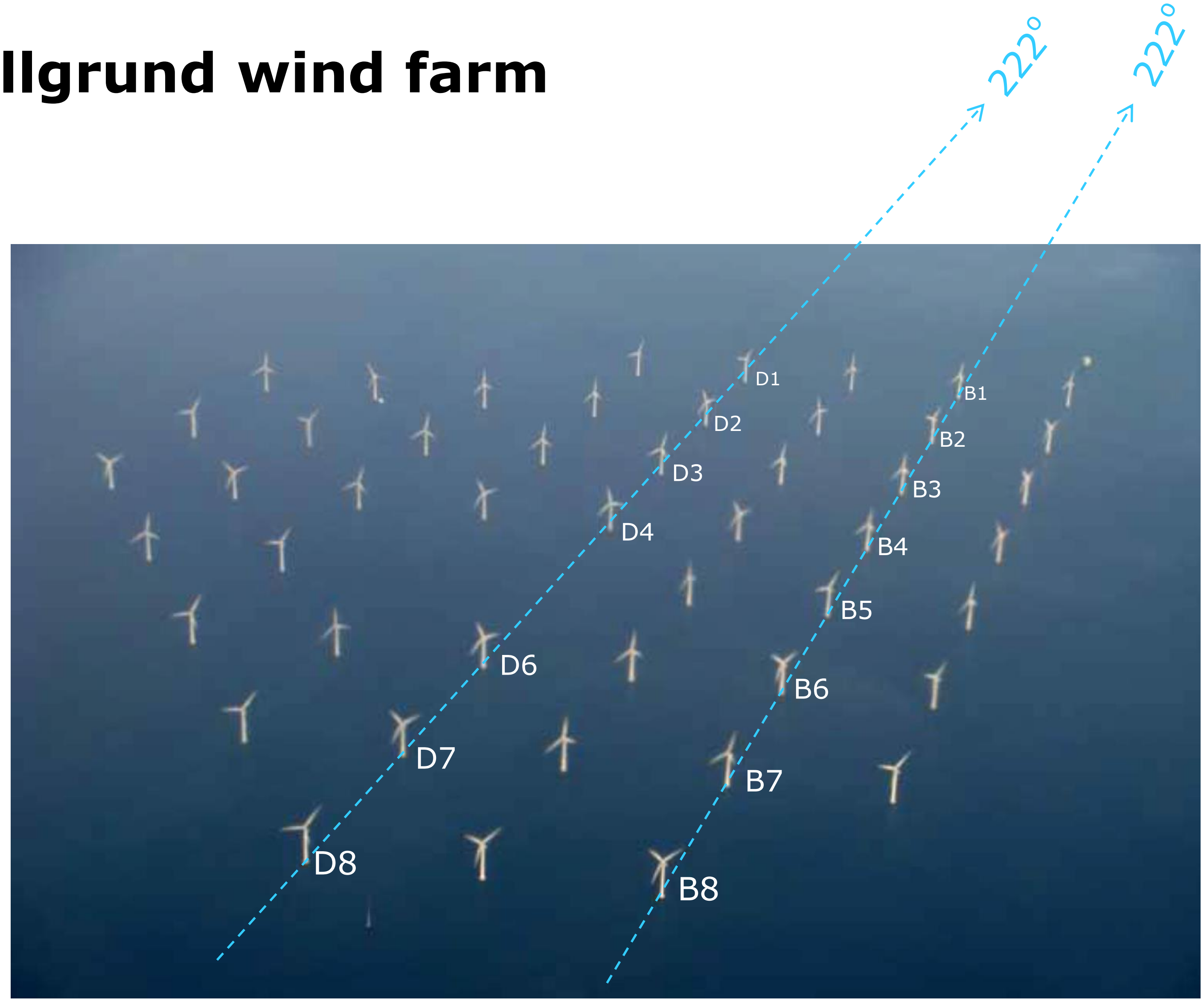
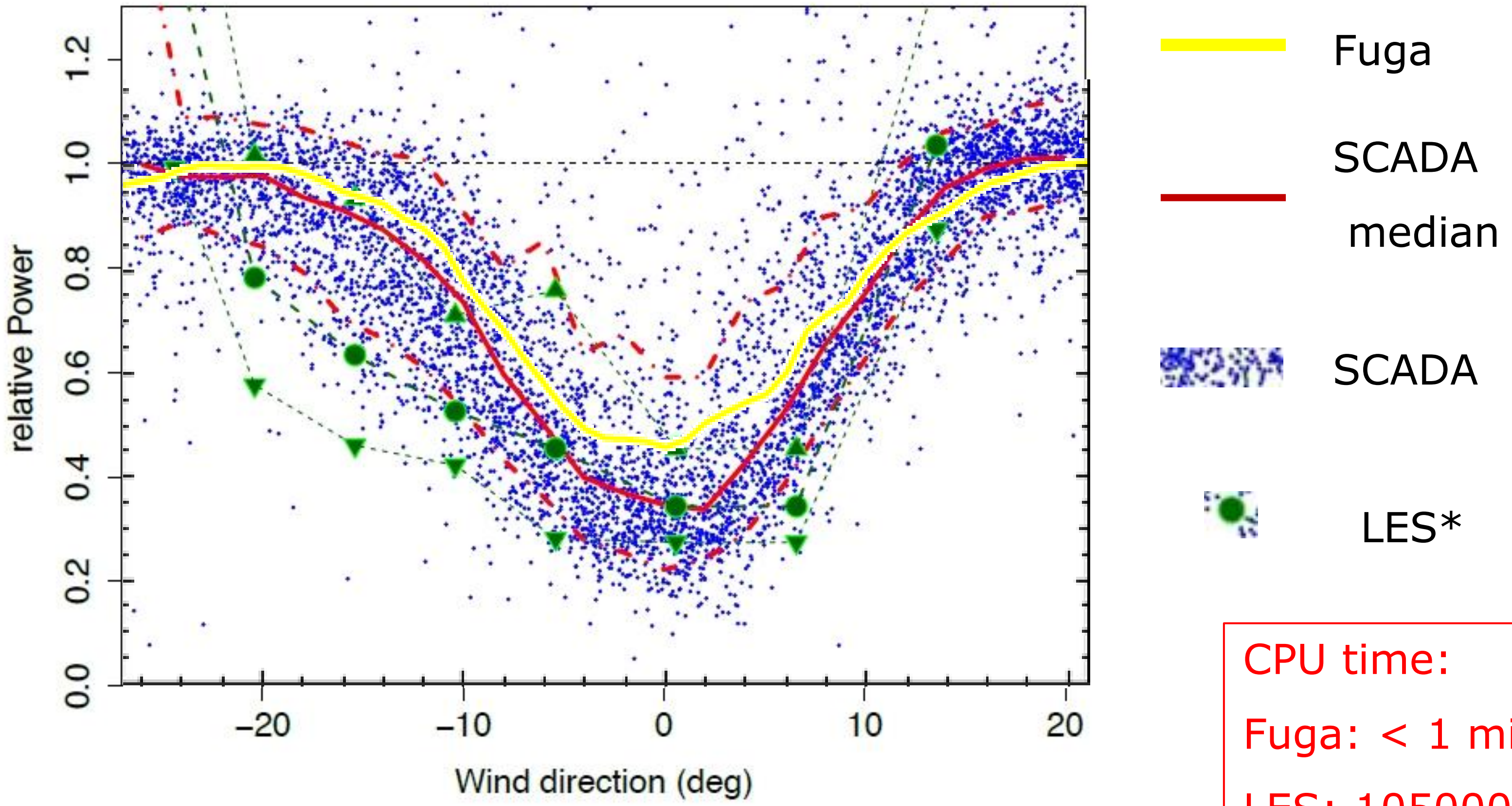


Photo by Kurt's wife

D7 being shadowed by D8



CPU time:

Fuga: < 1 minute

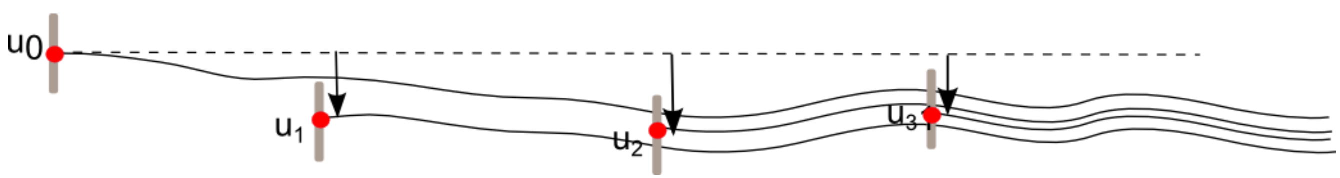
LES: 105000 hours

*Creech et al.(2013): *High-resolution CFD modelling of Lillgrund Wind farm,* RE&PQJ, 11

Stochastic meandering

The model says:

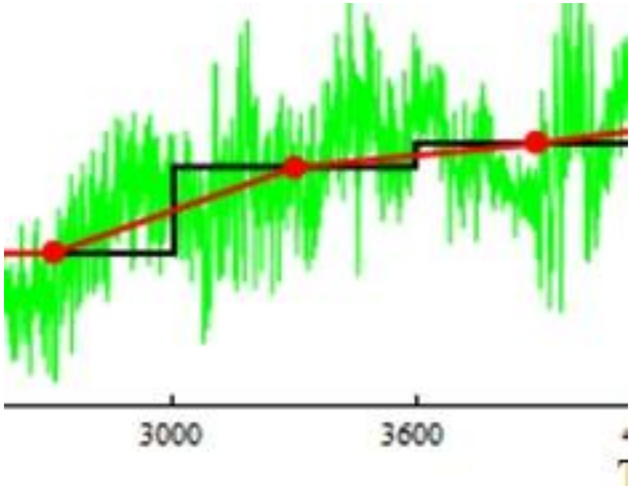
But something like this is more realistic:



Meandering model

Simulating *U*-*U*

1) Make spectra of the difference between the green and the red curves.
2) Fit to the Mann model spectra*
3) Make tracer particle diffusion in Mann turbulence field using the spectra
4) Compute Lagrangian velocity auto-correlation function
5) Fit a model to it

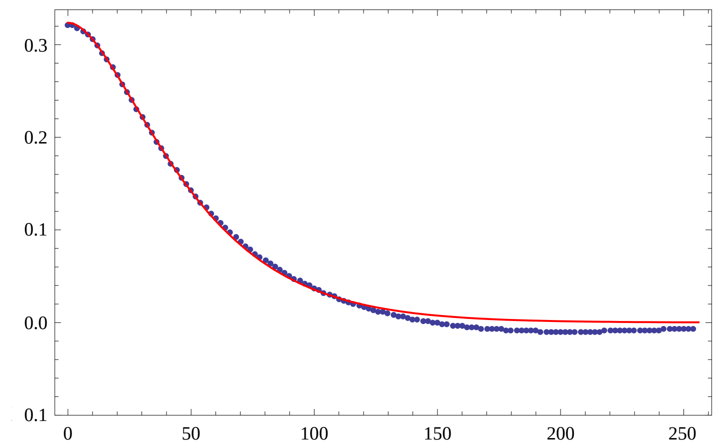


* Peña, Gryning & Mann (2010): On the length-scale of the wind profile, *Q. J. R. Meteorol. Soc.* 136: 2119–2131

A model for turbulent diffusion in Mann turbulence

Fitting the Lagrangian velocity auto-correlation function:

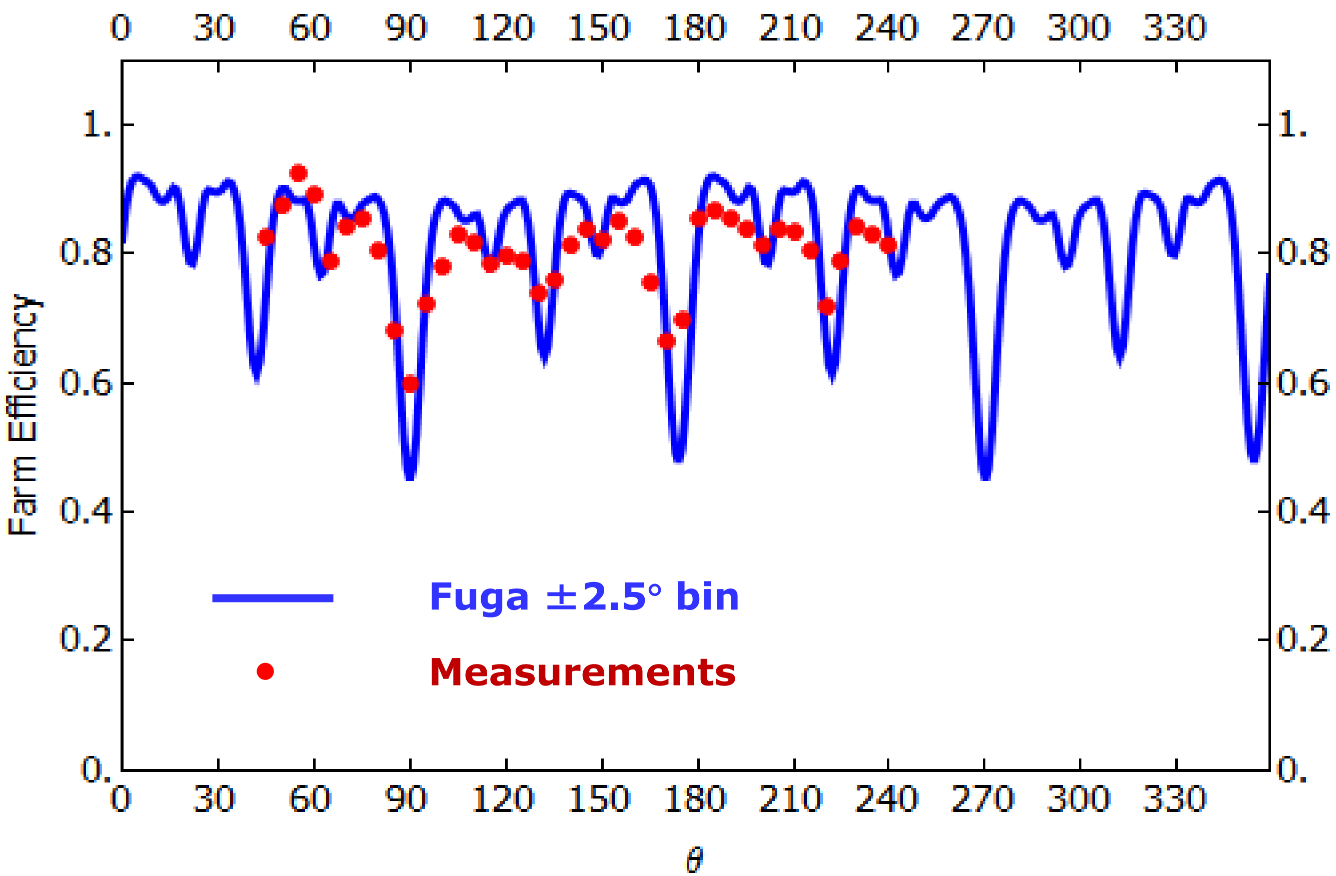
$$\langle v(t+\tau)\ v(t)\rangle = \sigma^2(1+\lambda\tau)e^{-\lambda\tau}$$



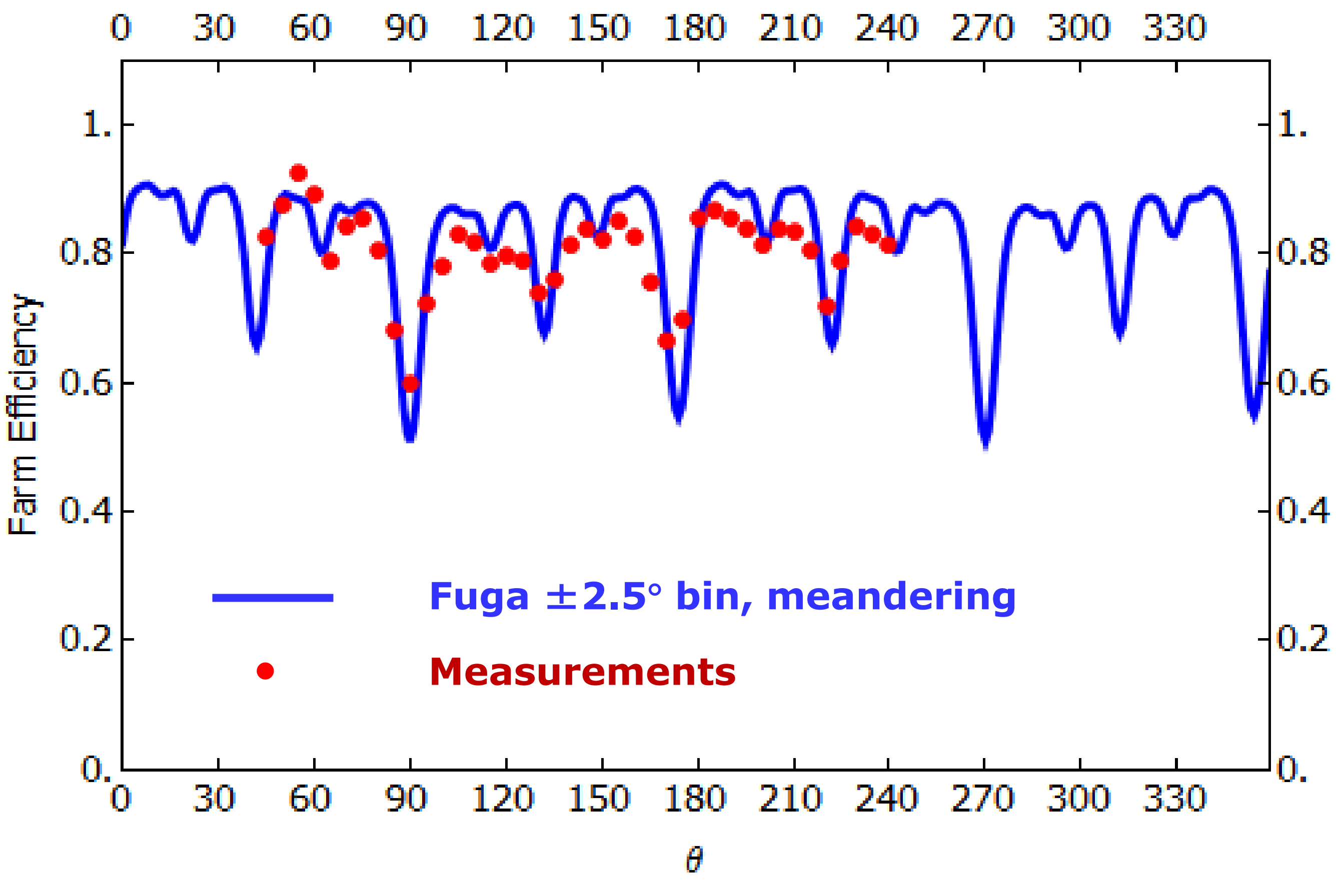
This model says: the acceleration is an Ornstein-Uhlenbeck process.

Analytical solution in terms of stochastic numbers.

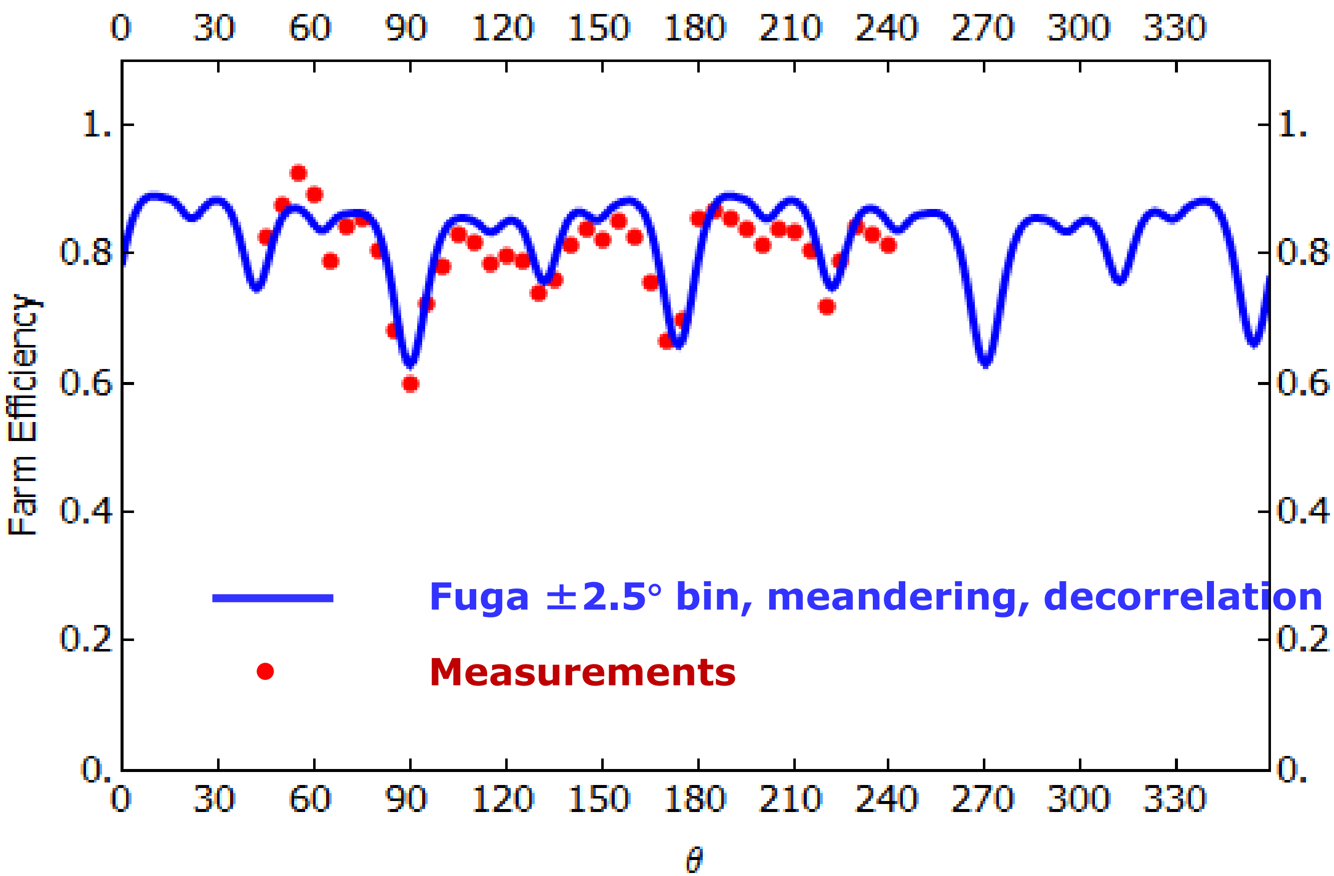
Validation – Horns Rev 1



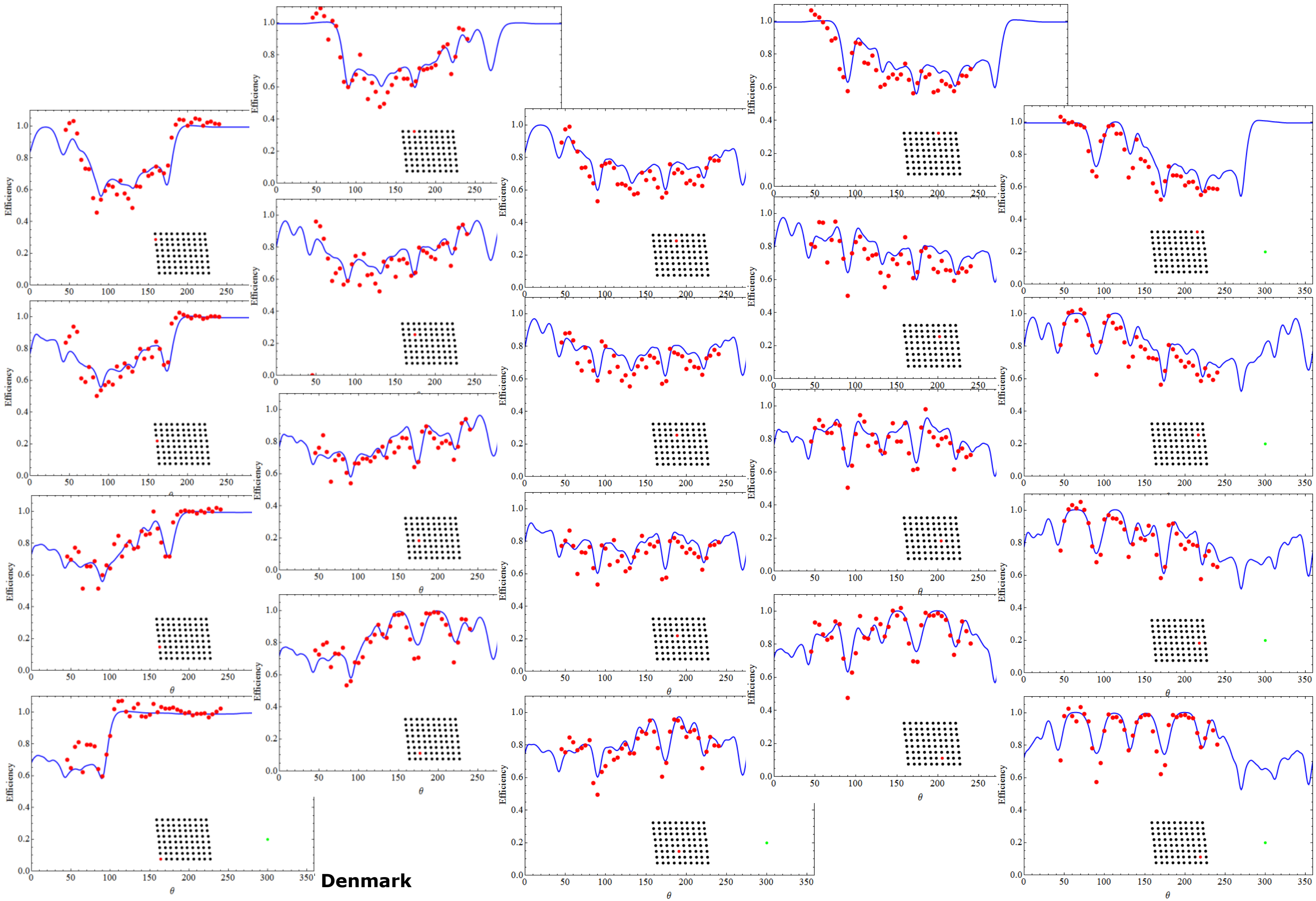
Validation – Horns Rev 1



Validation – Horns Rev 1



Horns Rev 1. Efficiency for individual turbines



Conclusions

- The interpretation of met data can have a profound impact on the results of validation exercises for offshore turbine wake models.
- The interpretation of met data can and should be backed up by on-site observations.
- Data for narrow bins around down-the-rows wind directions are the most uncertain.
- Sampling in very small wind direction bins introduces a large uncertainty because we don't really know what 'true' wind direction we should feed the models with.
- We need to know more about spatial and temporal wind field correlations across wind farms. The Doppler lidar is the key instrument.
- Fuga is fast and yields good results. It is a useful tool.