Content WP4+5

- Complex terrain, forest
- Complex terrain, topography & stability
- Wakes
- Torque conference

Complex terrain, forest:
Generation of accurate forest parameters for CFD flow models

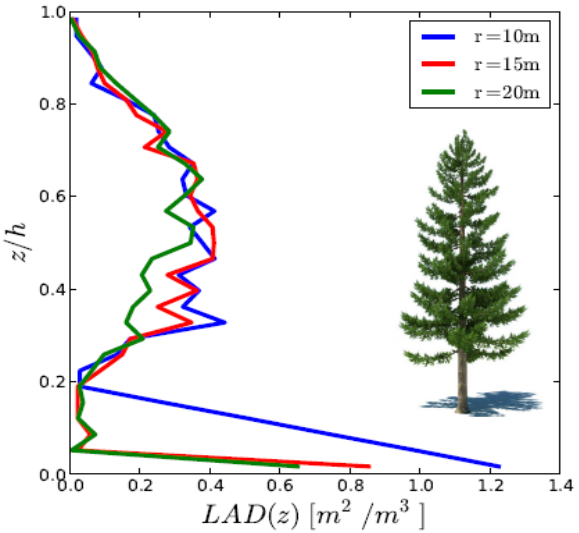
Context

- Modification of RANS $k - \epsilon$ equations to account for forest effects

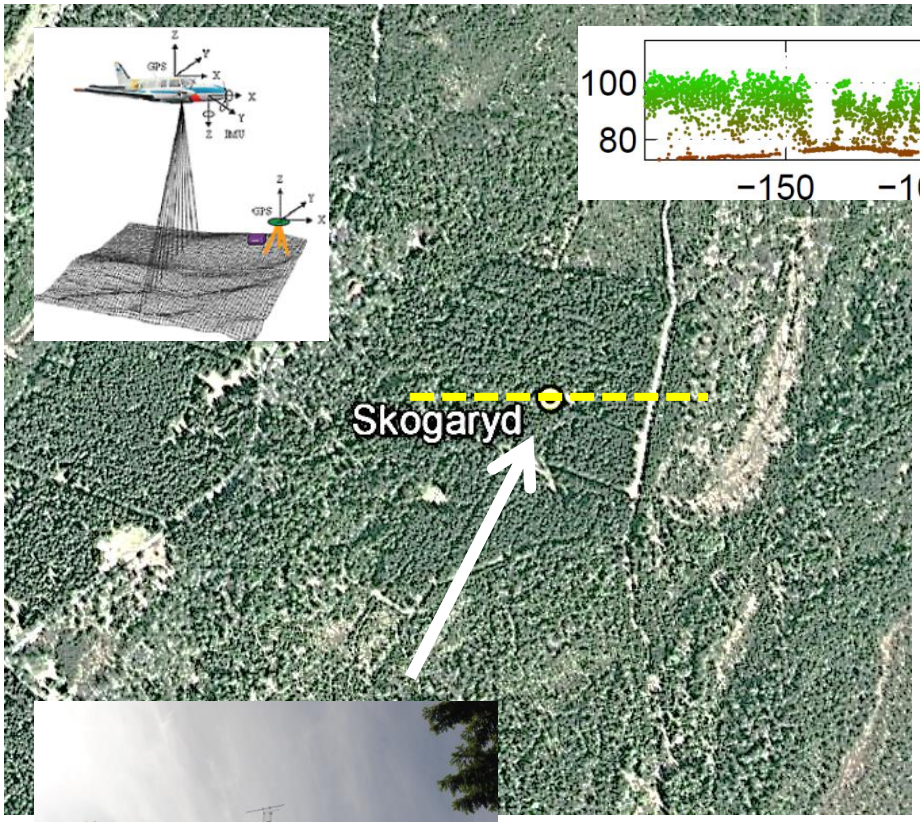
Canopy model: [Sogachev, 2009]

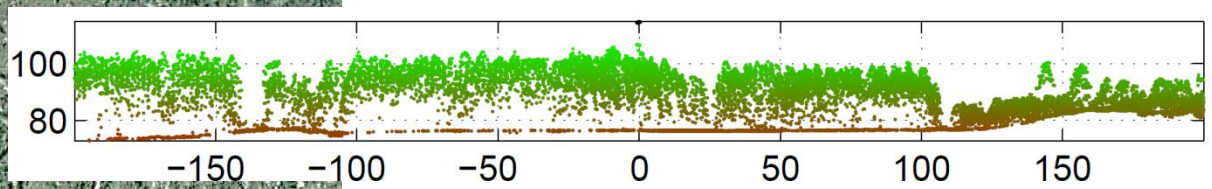
Momentum:

$$\frac{\partial u_i}{\partial t} = \ldots - C_d LAD(z) u_i |U|$$



Aerial lidar scans (ALS) from Skogaryd, Sweden

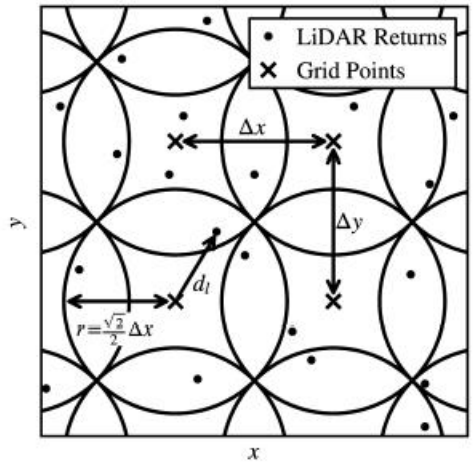


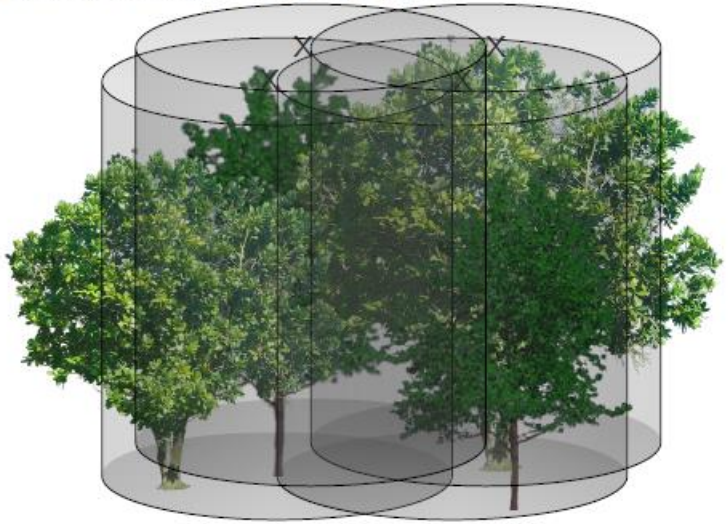


- The (x,y,z) coordinates of the lidar reflections form a point cloud.
- These raw data are used to generate the new Swedish elevation model.
- Such data are increasingly available.

From point cloud to a forest description adapted for CFD # 1

1. Local binning **algorithm** for generating a **forest grid**:

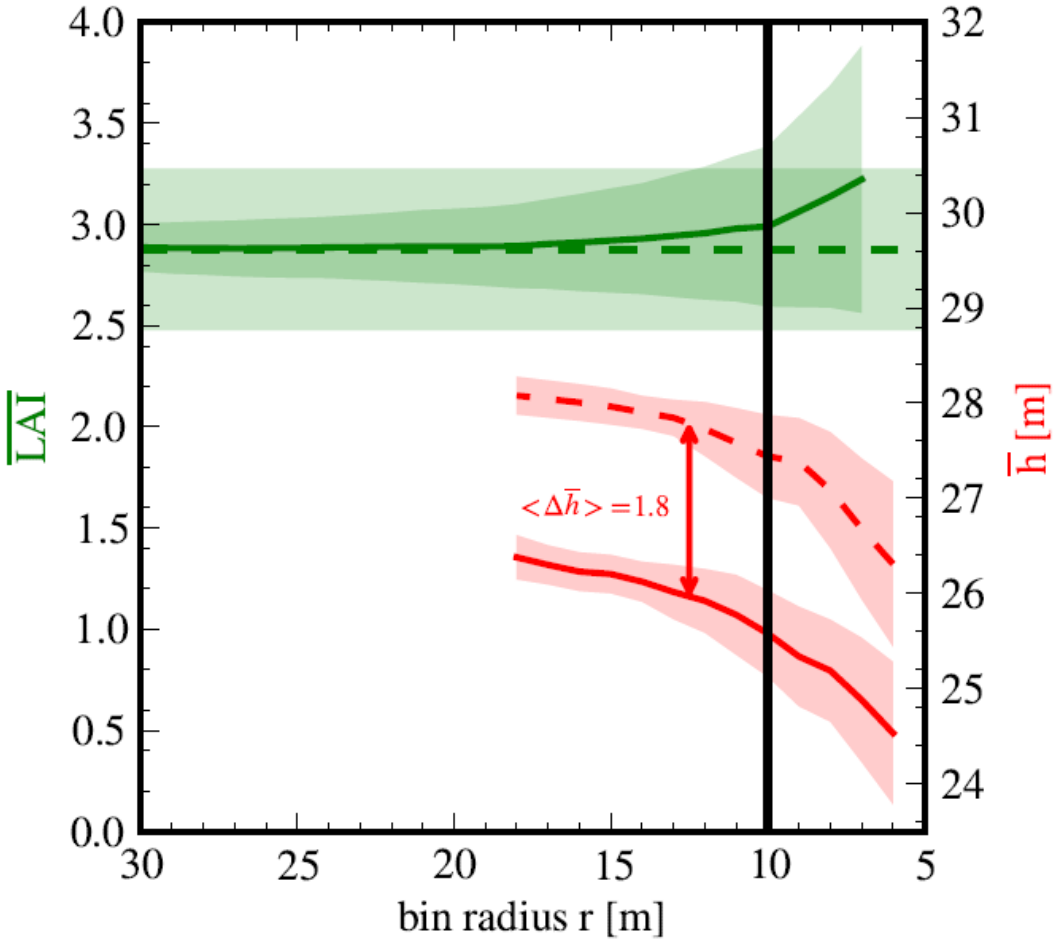




2. **Computation** of the 3D discrete LAD values by applying light radiation theory inside canopies.

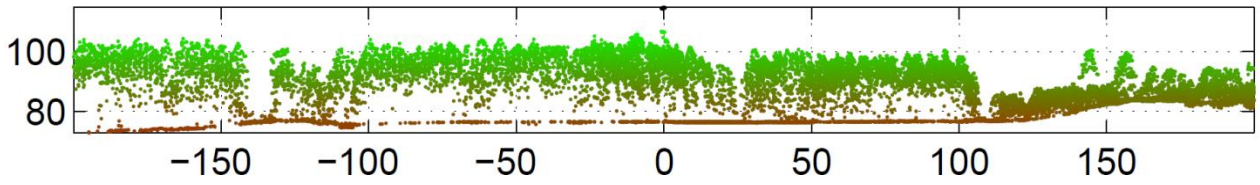
Comparison to ground-based measurements in a 90 x 90m area (Gothenburg University)

$$LAI = \int_0^z LAD\, dz$$

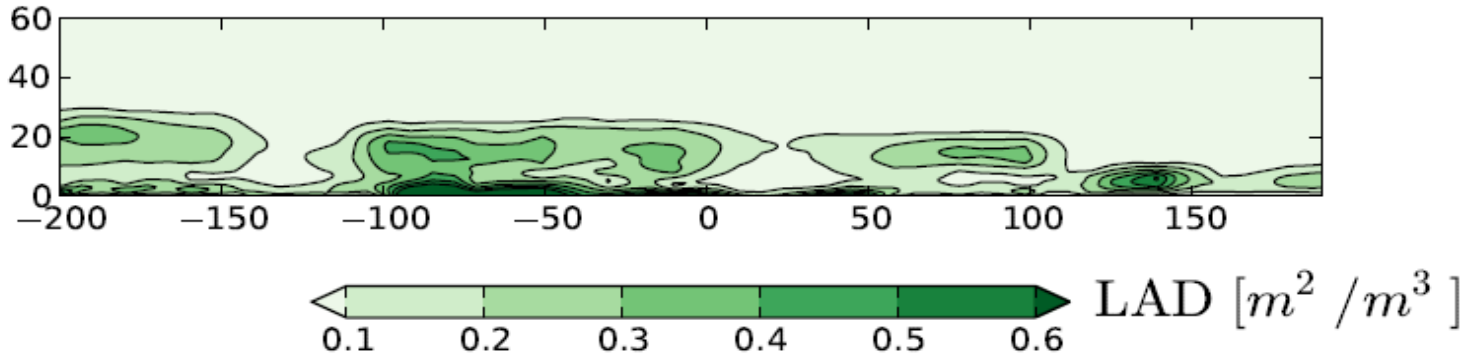


Full line: ALS
Dashed line: in-situ
(PCA LiCor/ Vertex)

From point cloud to a forest description adapted for CFD # 2

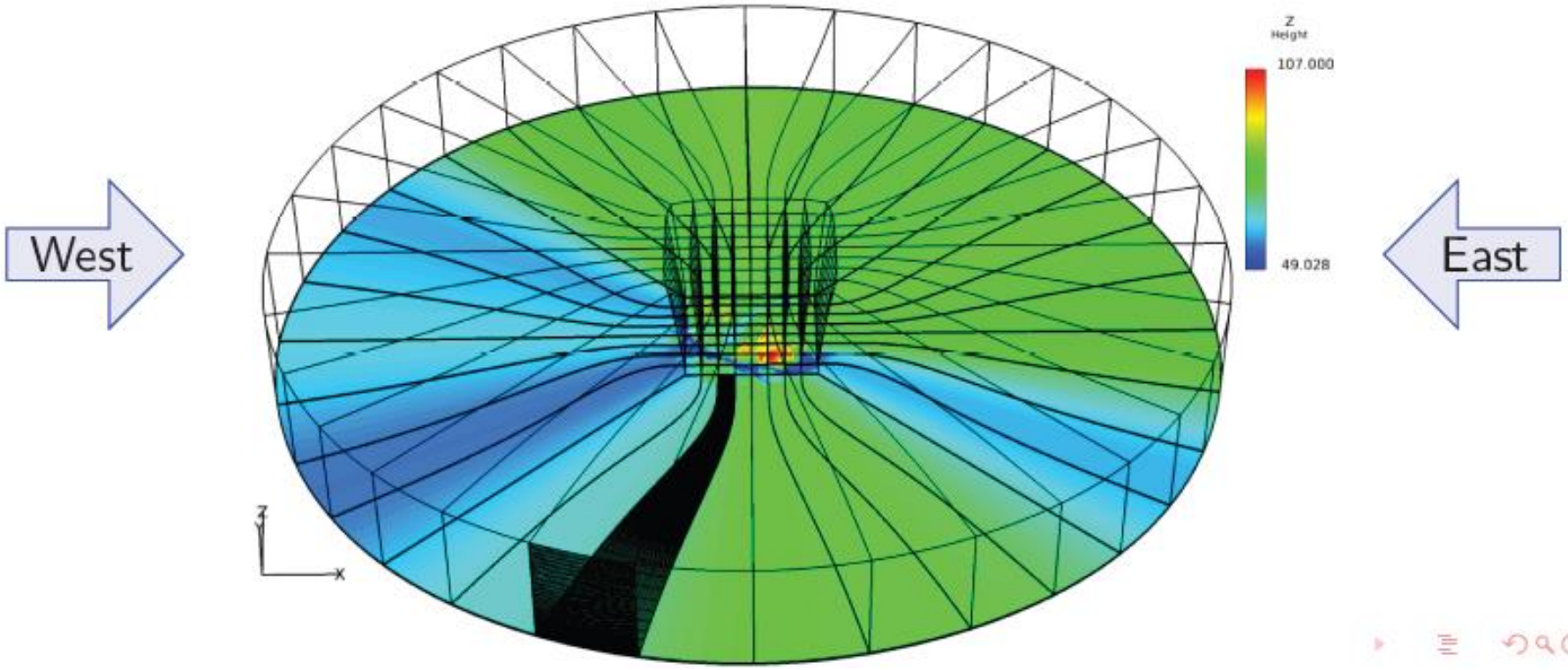


Subtraction of surface grid

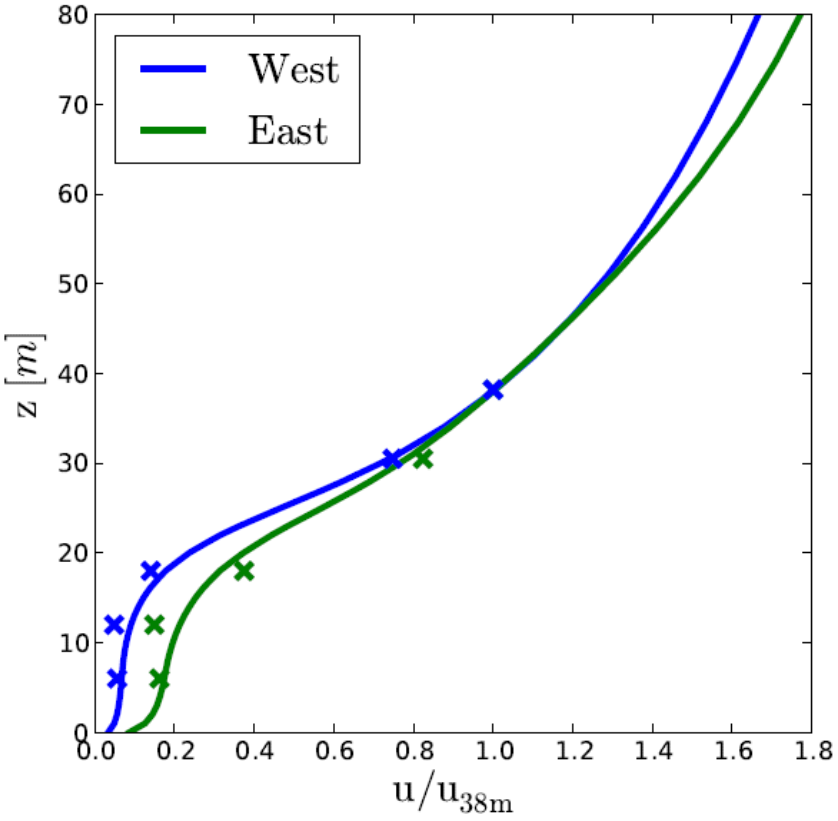


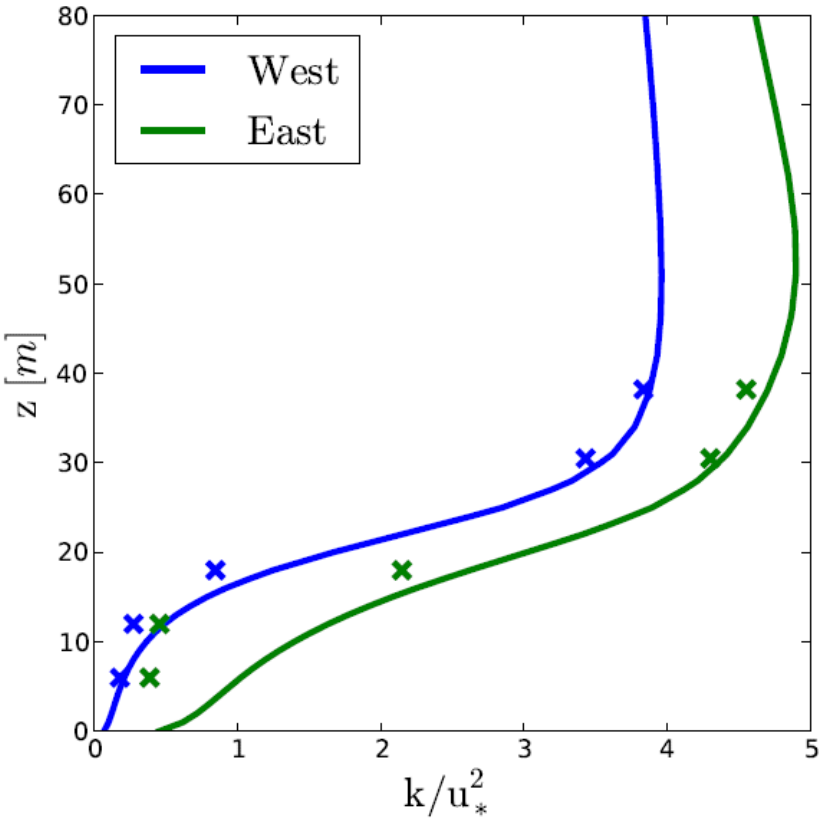
CFD model

- Finite-volume flow solver EllipSys3D [Michelsen, 1982, Sørensen, 1995]
- $k - \epsilon$ model + diffusive terms [Sogachev, 2012]
- $\tau = cst$, steady-state, neutral, no Coriolis force
- Computational grid: $10m$ resolution / ≈ 22 million cells

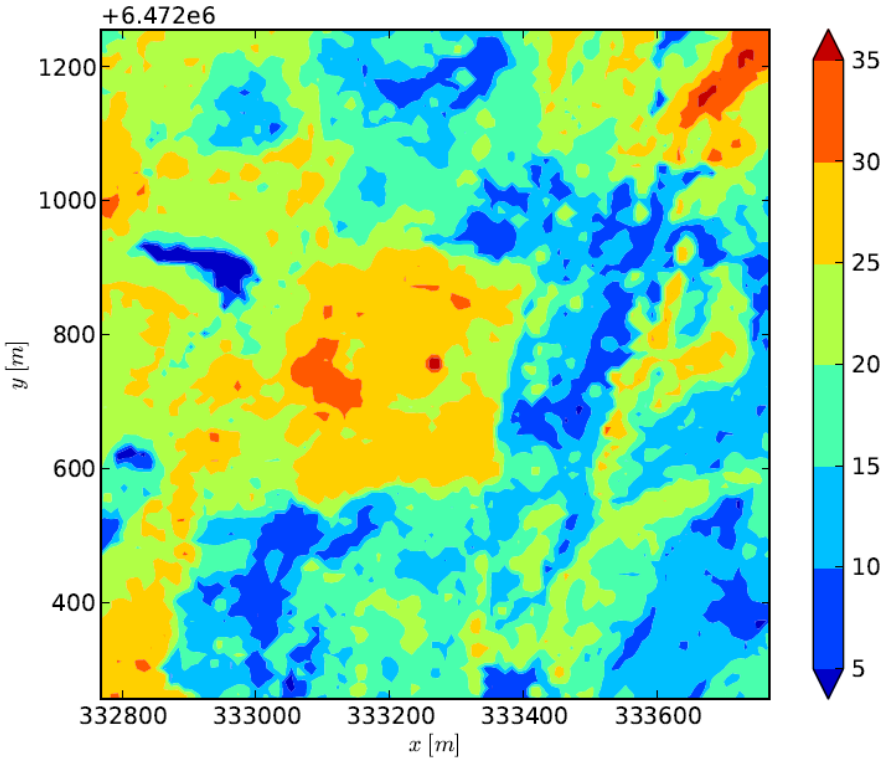


Model-measurement comparison @ 38m tall tower

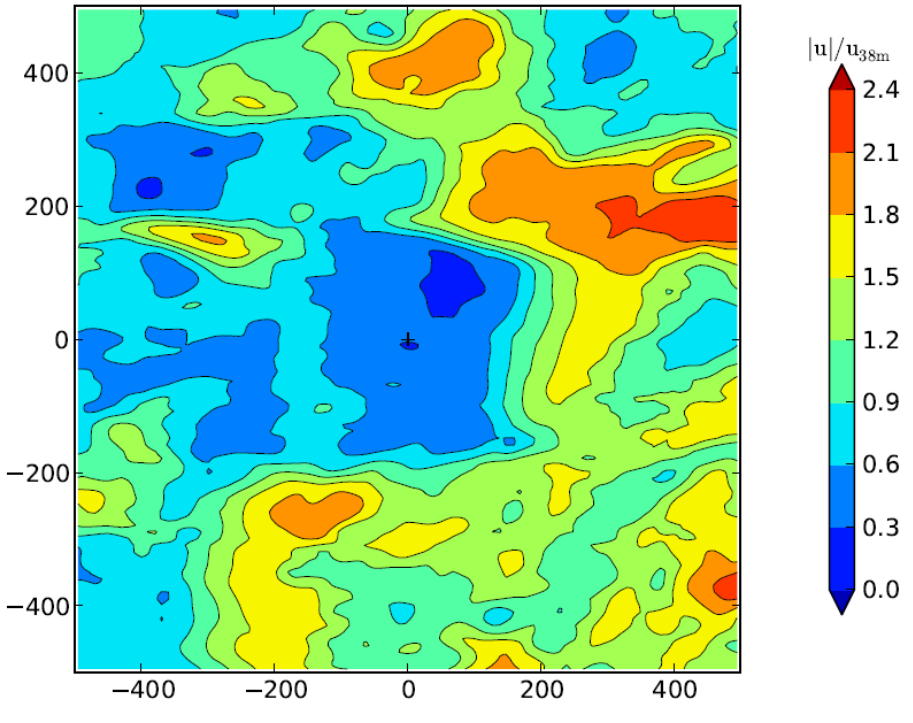




The ALS-based input allows us to study the variation of the near-surface flow in heterogeneous forests with a higher degree of realism.



Gridded tree heights around 38m tower



10m wind speed from RANS simulations for the same area

Complex terrain, topography:

- Comparison of EllipSys3D and OpenFoam
- Tilman Koblitz PhD thesis on stability and flow in complex terrain
- Julia Lange PhD thesis started in March: Analysis and physical flow modeling of Bolund. Planned stay at WindEEE
- 2014: Attempting LES of Bolund with NCAR's pseudo-spectral code (Jacob Berg, Dalibor Cavar)

Conclusions

- Mesh Generation
    - HypGrid (HG) – Developed for EllipSys3D, works in OpenFOAM with certain adjustments.
    - SnappyHexMesh (SHM) – has reasonable capability and flexibility for ABL flows, but very difficult to use. Especially grid layers near the ground difficult (in many cases impossible) to make.
- Accuracy
    - Very good general agreement between OpenFOAM and EllipSys3D.
    - Askervein case – runs on identical grid gave almost identical results, both regarding the speed up and TKE.
- Computational time
    - EllipSys3D is app. 2-6 times faster in obtaining results of similar level of accuracy on grids of similar size, utilizing the EllipSys3D default grid sequencing procedure
    - OpenFOAM SHM based computations found to be 3.5-7 times faster (Askervein case) and 1.8-9.8 times faster (Bolund case) then HG based calculations

Benakalahalli

Stability and complex terrain

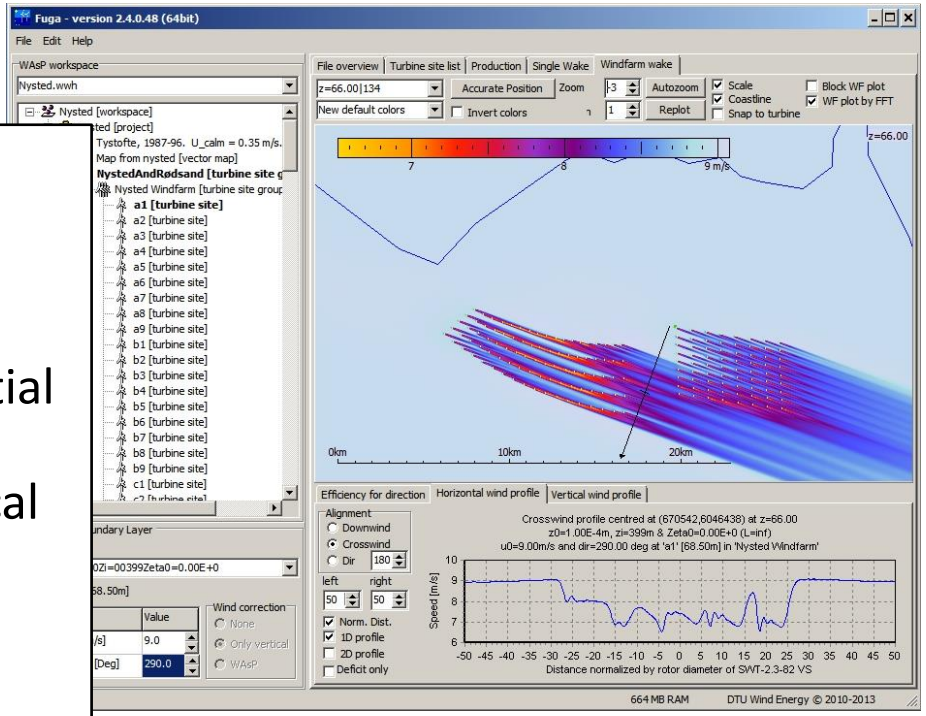
- Stability effects and Coriolis force implemented in EllipSys3D
- Improvements in predicting the airflow over Benakalahalli during non-neutral conditions

Stability and turbulence

- PhD thesis by Abhijit Chougule

Wakes

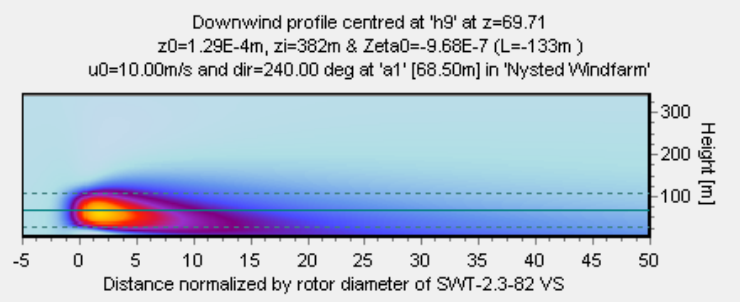
Fuga – features*

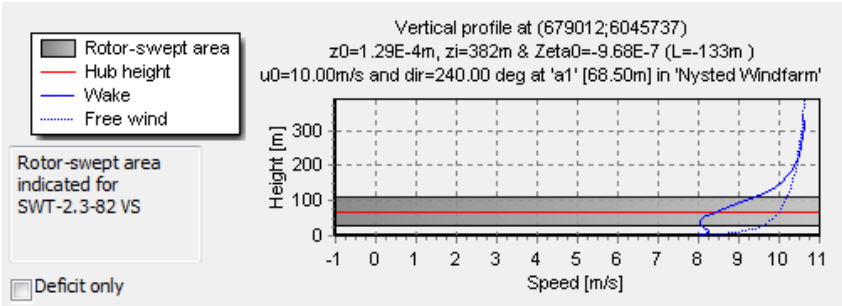


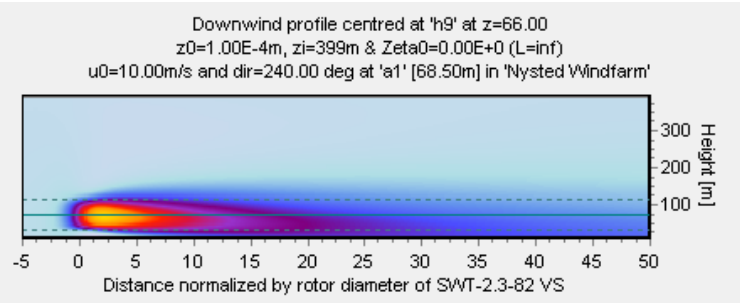
- Solves linearized RANS equations
- Latest version incorporates: atmospheric stability, meandering, effects of non-stationarity and spatial de-correlation of the flow field.
- No computational grid, no numerical diffusion, no spurious pressure gradients
- Integration with WAsP: import of wind climate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

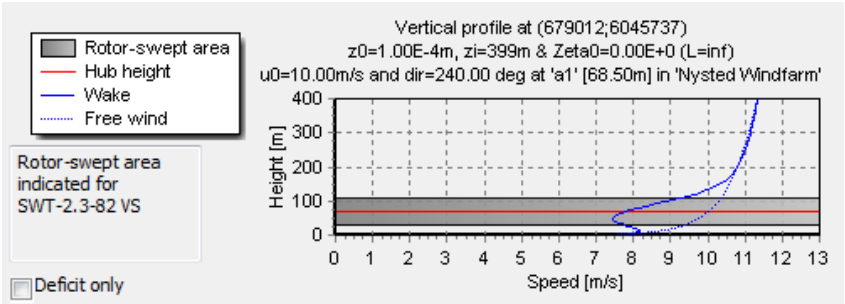
*Søren Ott, Jacob Berg and Morten Nielsen: 'Linearised CFD Models for Wakes', Risoe-R-1772(EN), 2011

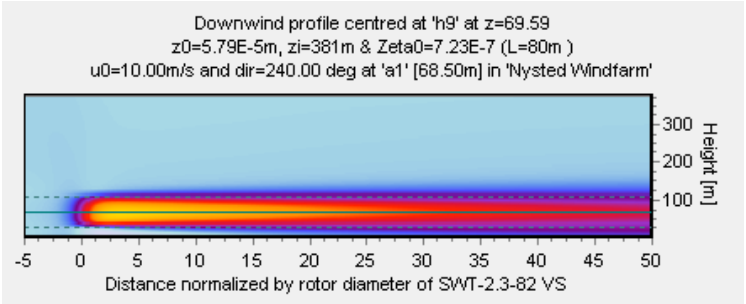
Variable atmospheric stability – vertical profiles

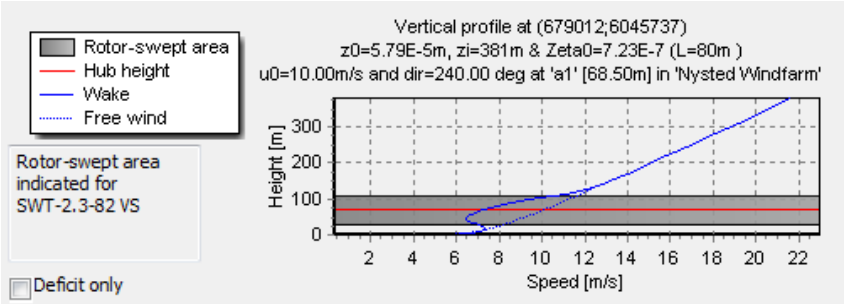




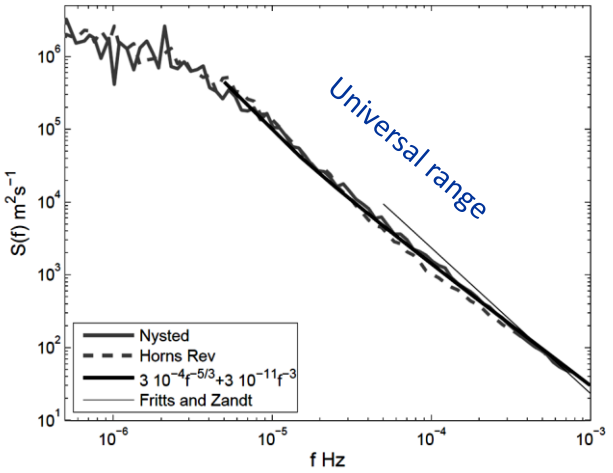




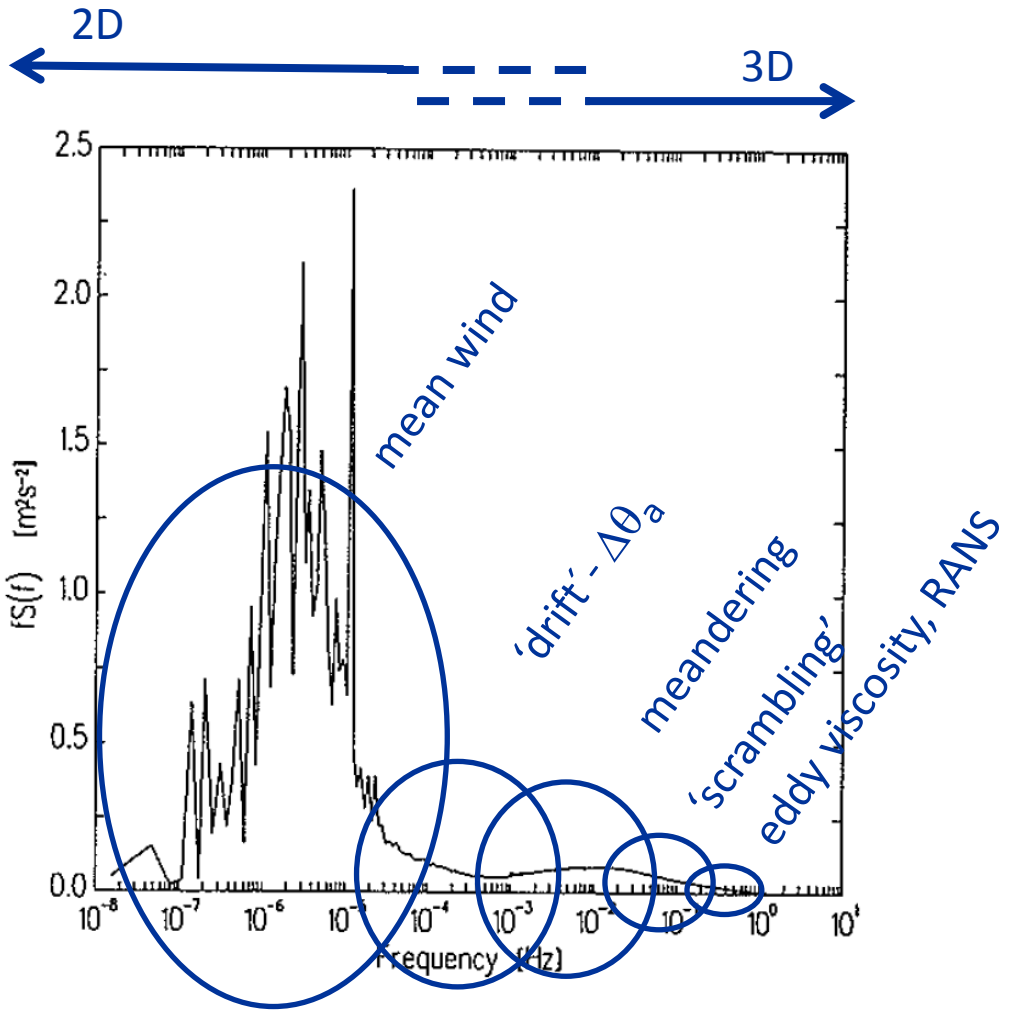




Spectral regimes



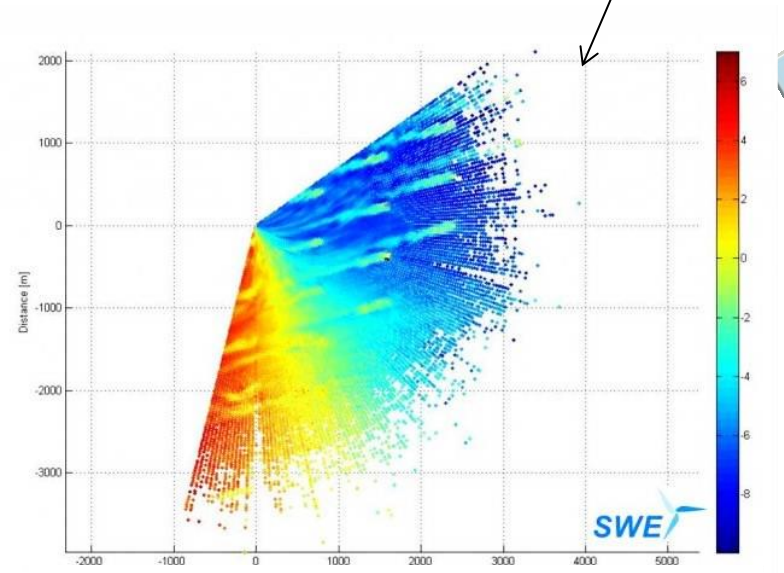
Larsén, Vincent & Larsen 2011

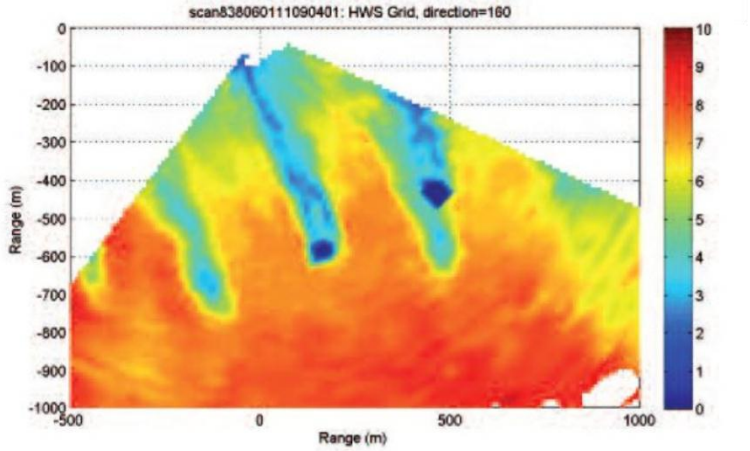


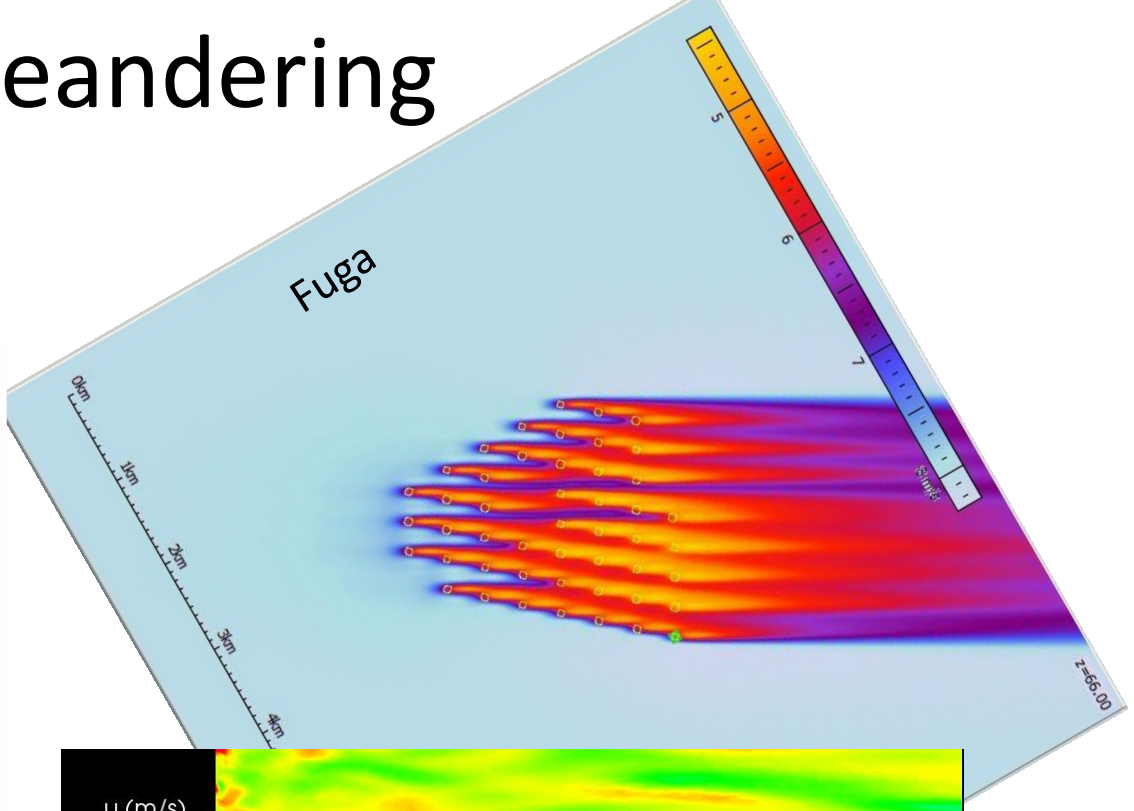
Courtney & Troen 1990

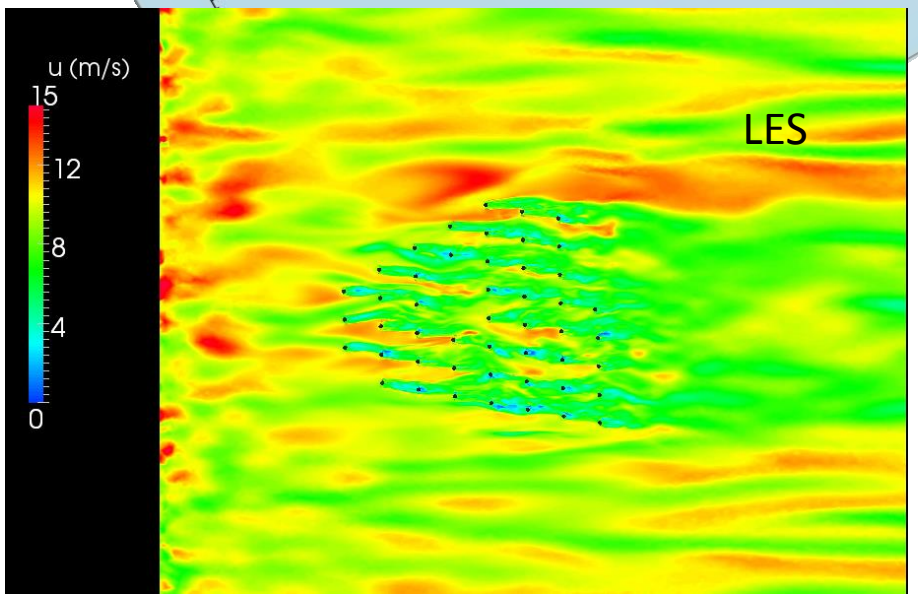
Meandering

Measurements with SgurrEnergy's Galion Lidar.



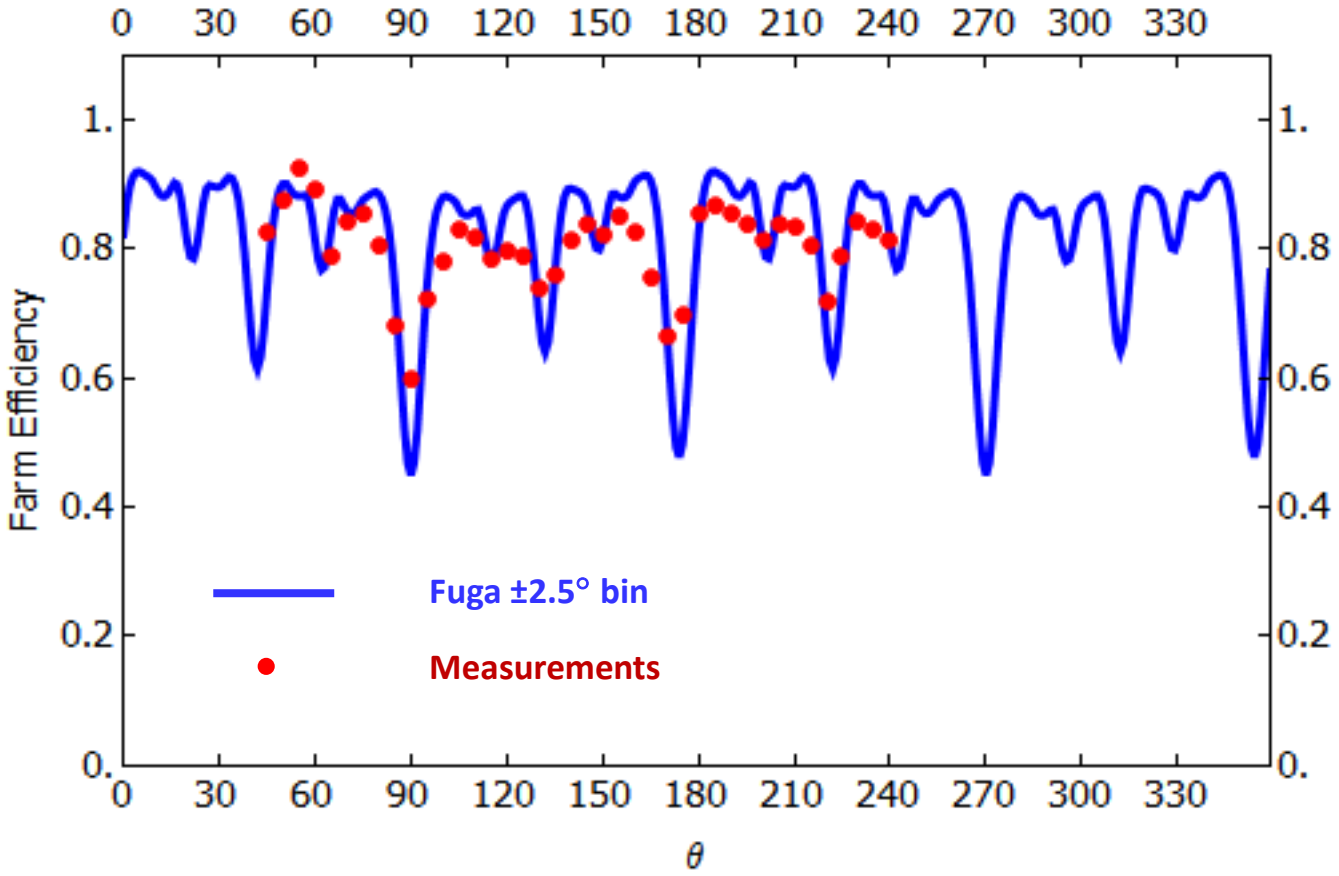




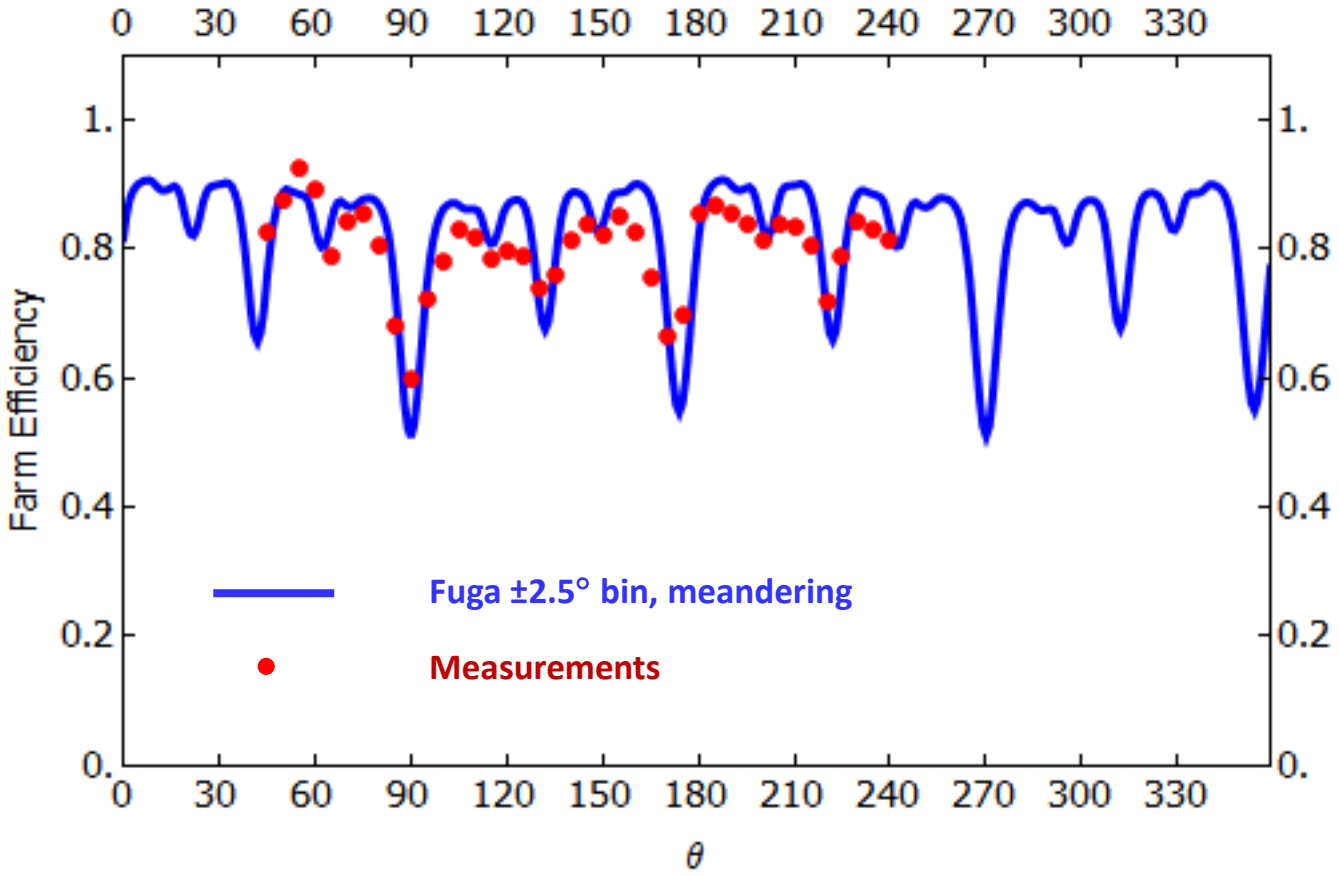


Creech et al.(2013): *High-resolution CFD modelling of Lillgrund Wind farm*, RE&PQJ, 11

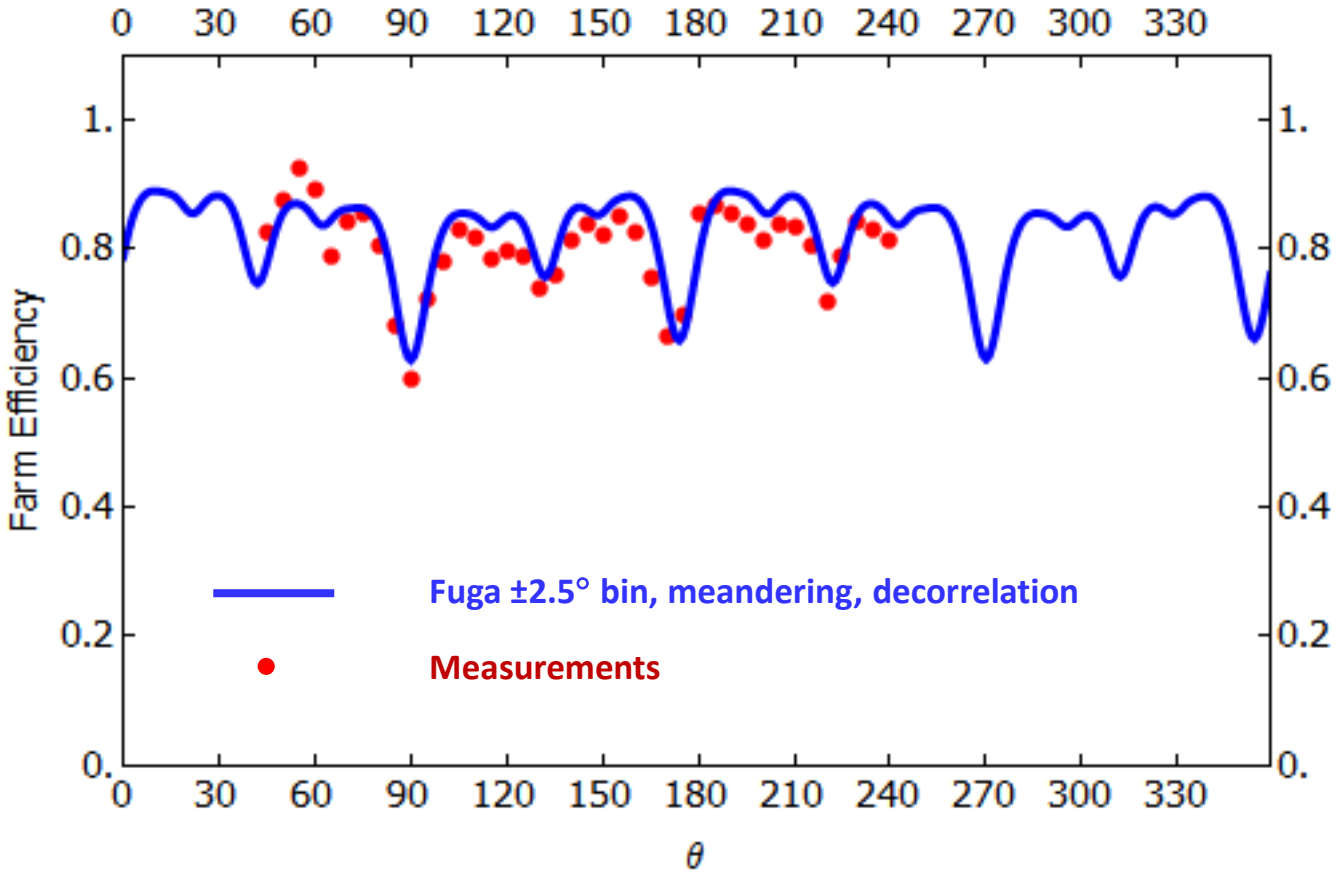
Validation – Horns Rev 1



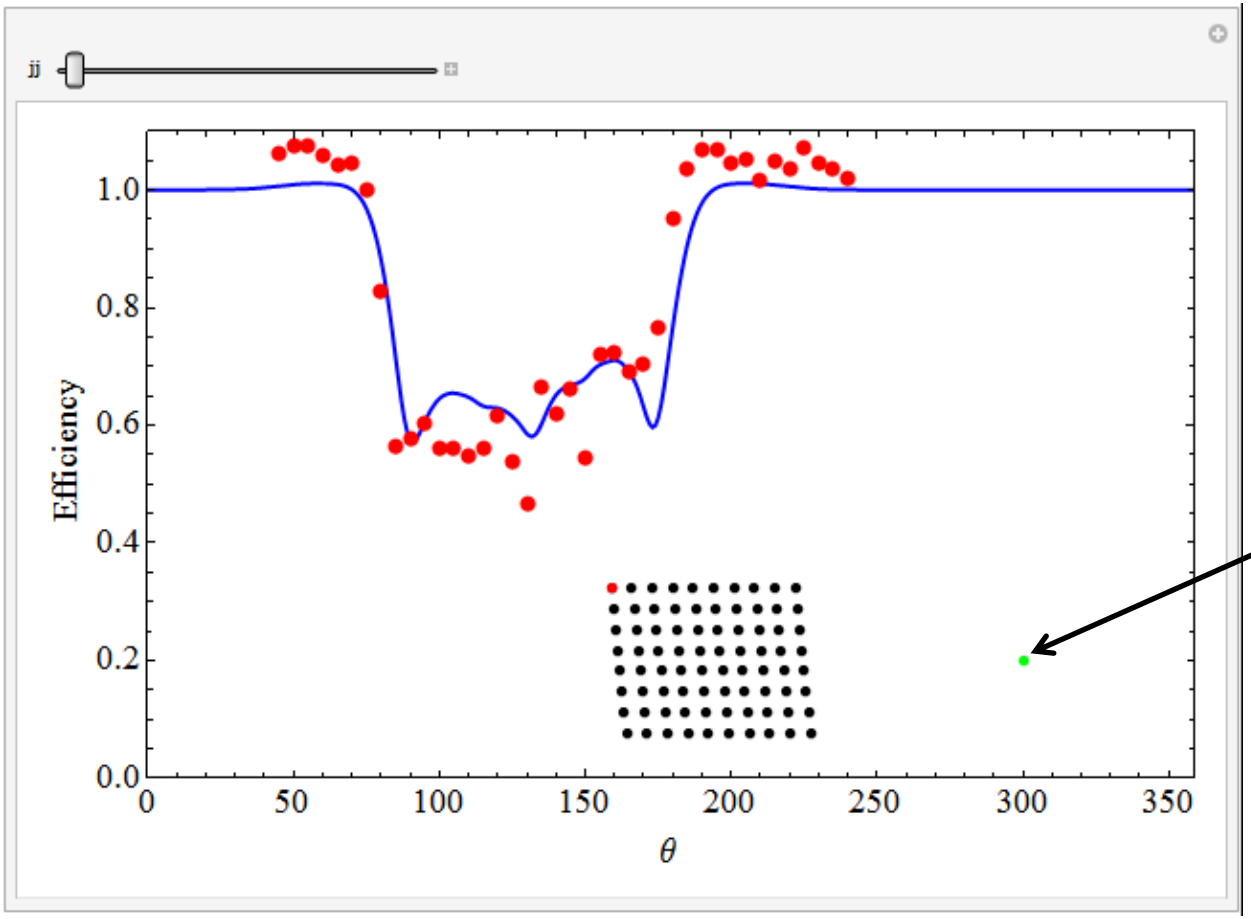
Validation – Horns Rev 1



Validation – Horns Rev 1



Horns Rev 1 – Efficiency for individual turbines



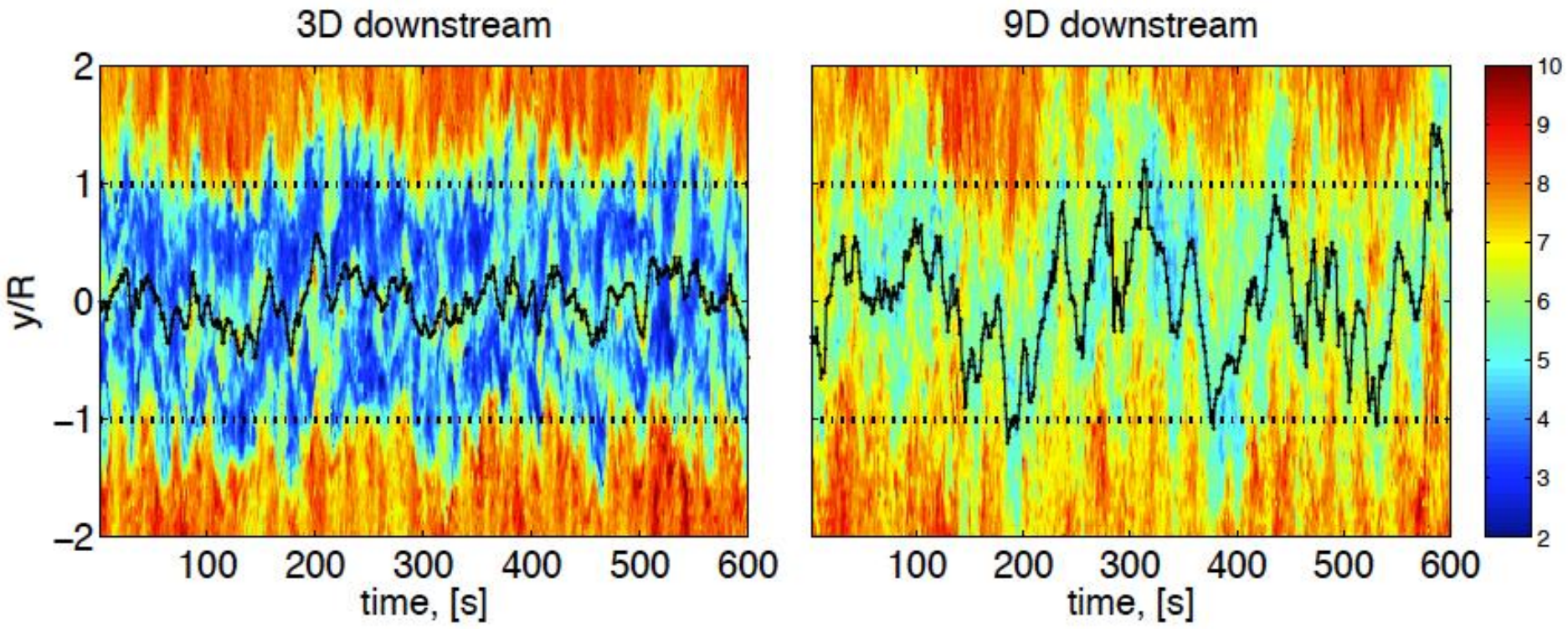
Met mast M7

Future work on Fuga

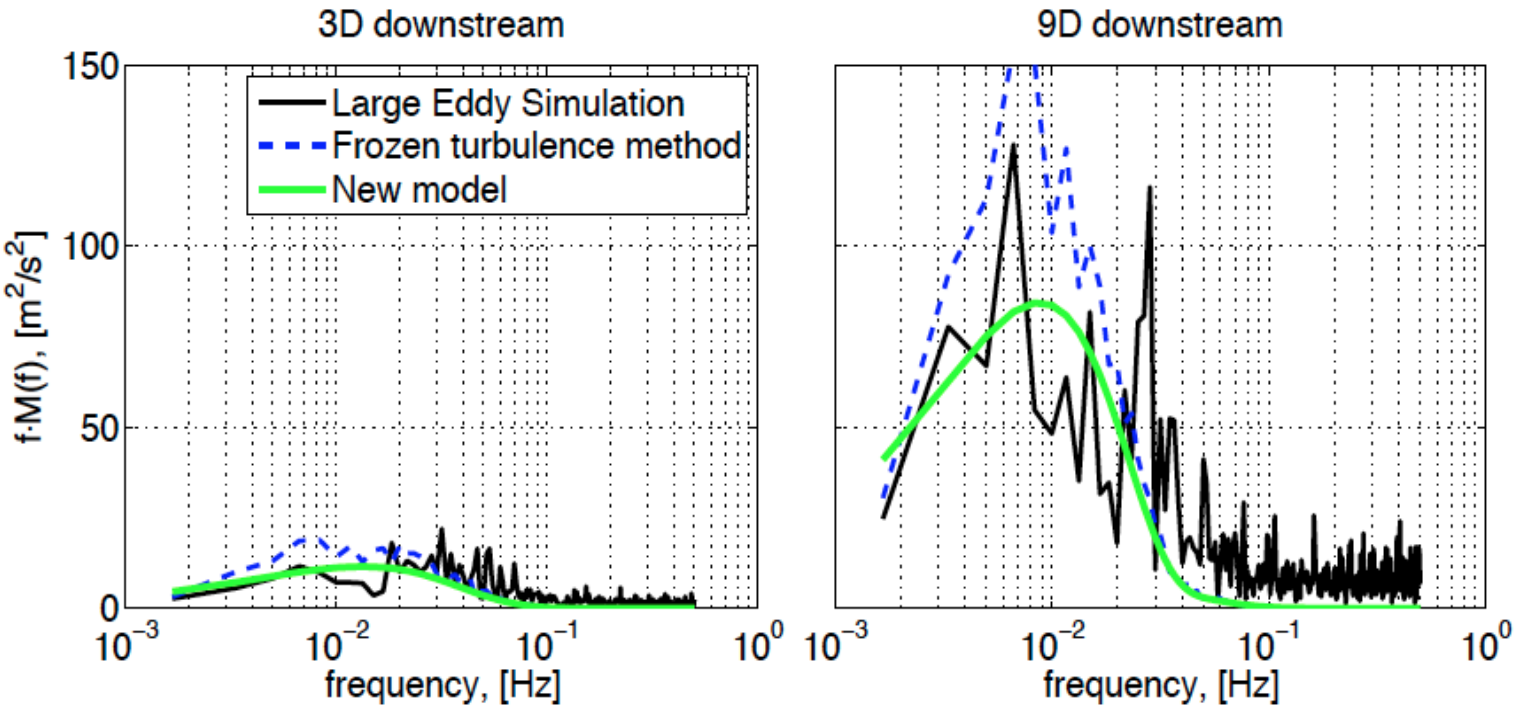
- Publication of model and results
- Release of model in WAsP

New wake meandering model

- PhD Martin de Maré



Spectra of deviation



The Science of Making Torque from Wind, June 18.-20. 2014

Torque

- Abstracts just called for
- Four accepted guest speakers
- Venue: DTU Campus, Lyngby
- Will use IoP for conference papers

- EAWE PhD seminar 2015 in DK