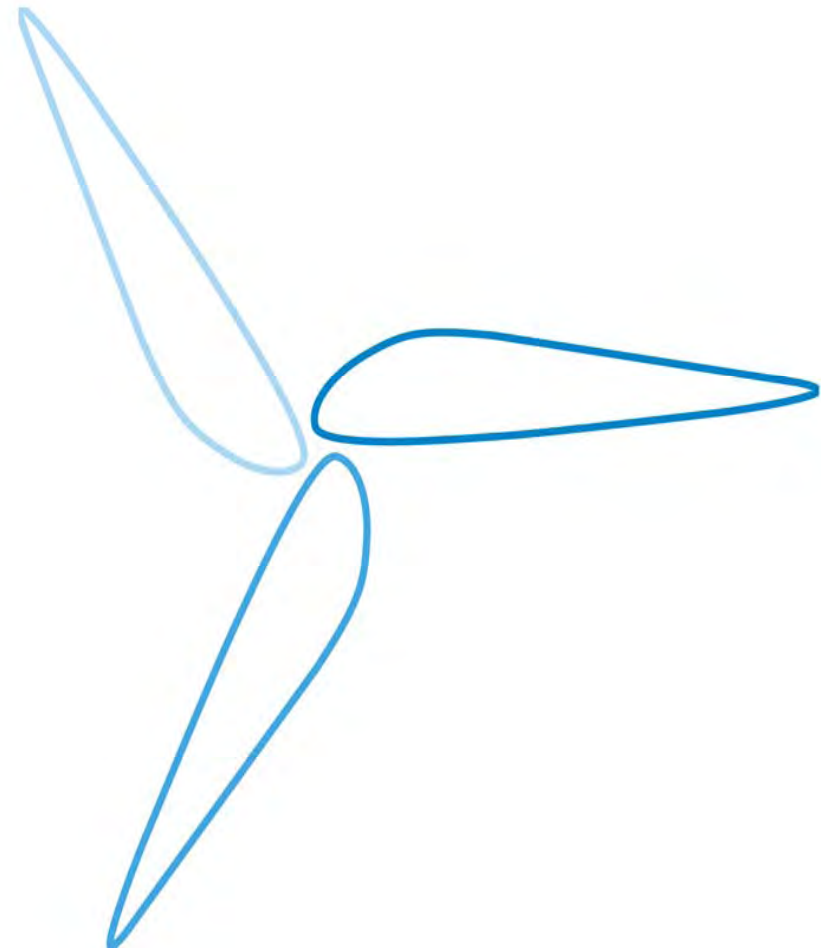


Wake Meandering Modeling for Wind Turbine Loading and Performance

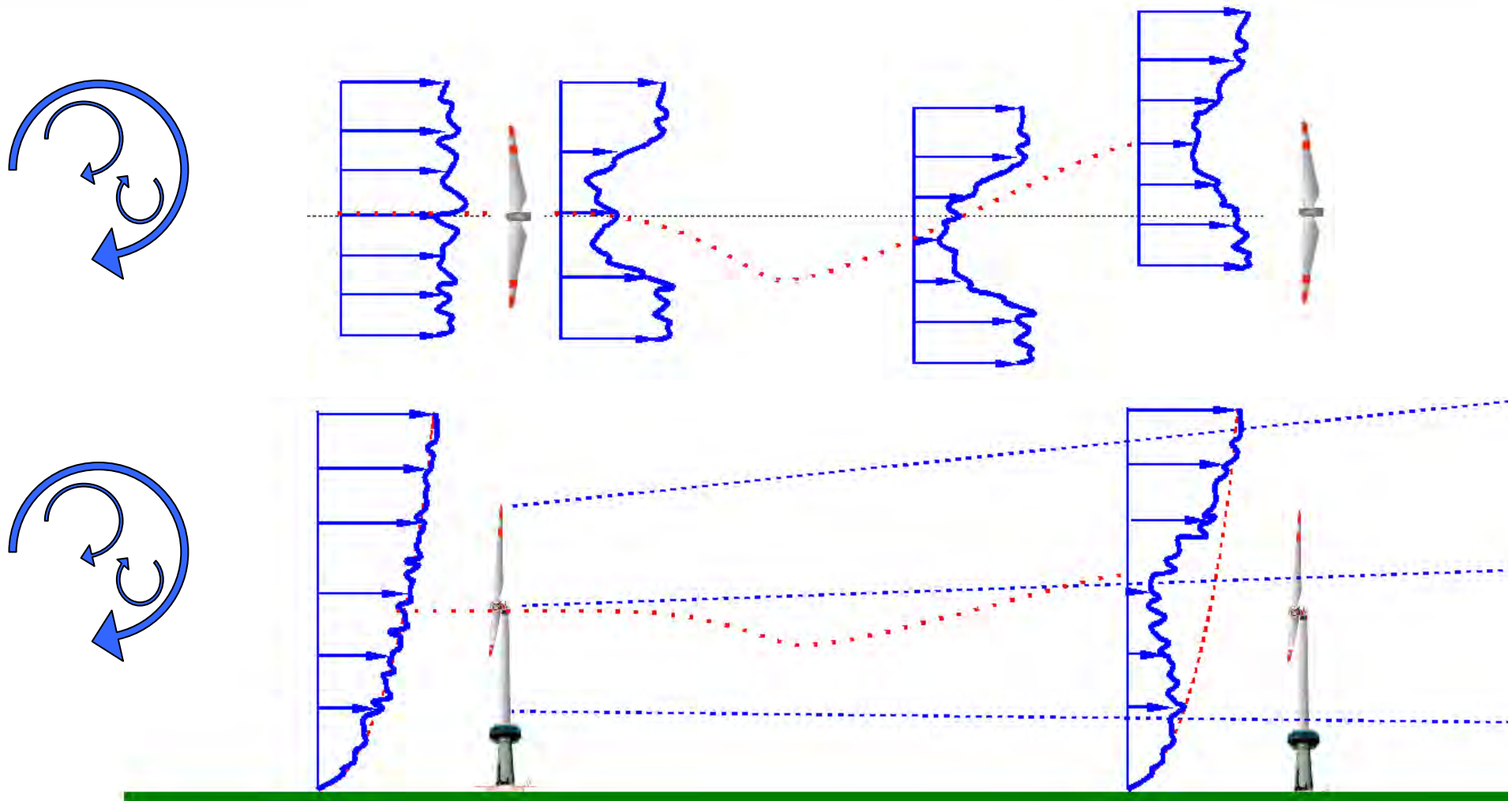
Juan-José Trujillo and Martin Kühn
Endowed Chair of Wind Energy
Universität Stuttgart, Germany



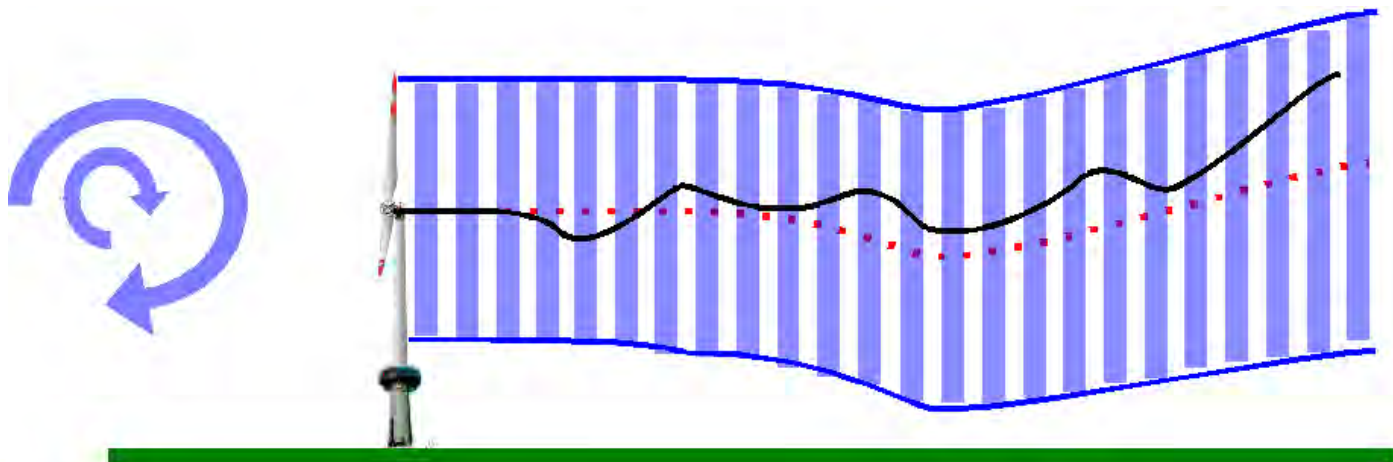
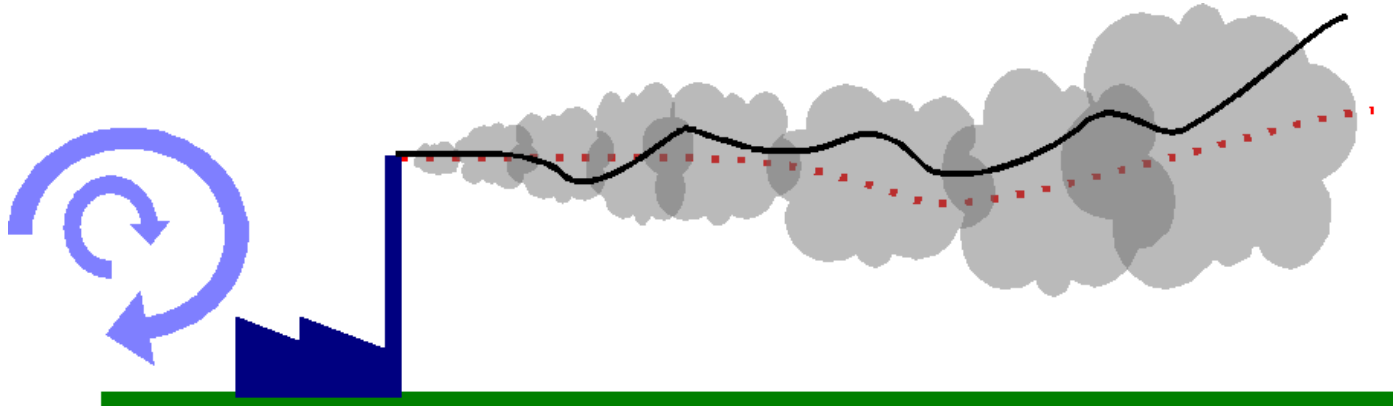
Outline

- Motivation and Scope
- Engineering model
- New stochastic model
- Preliminary simulation results
- Comments

How does the far wake behaves?



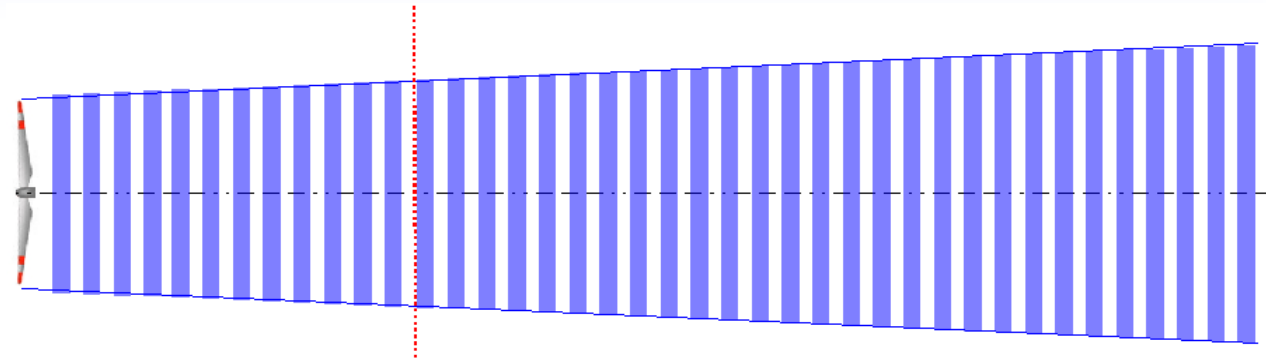
Main assumption: Wind turbine wake meanders similar to passive tracers



Wake meandering modelling

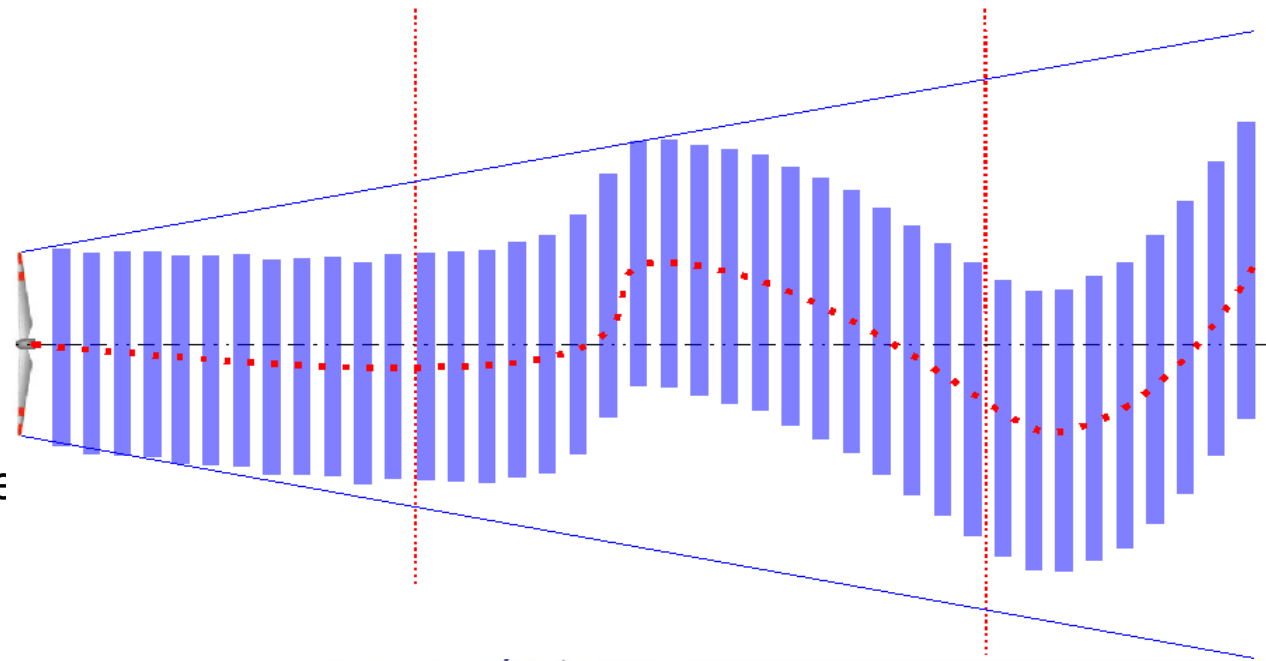
Stationary wake

Without effect of large scale atmospheric turbulence



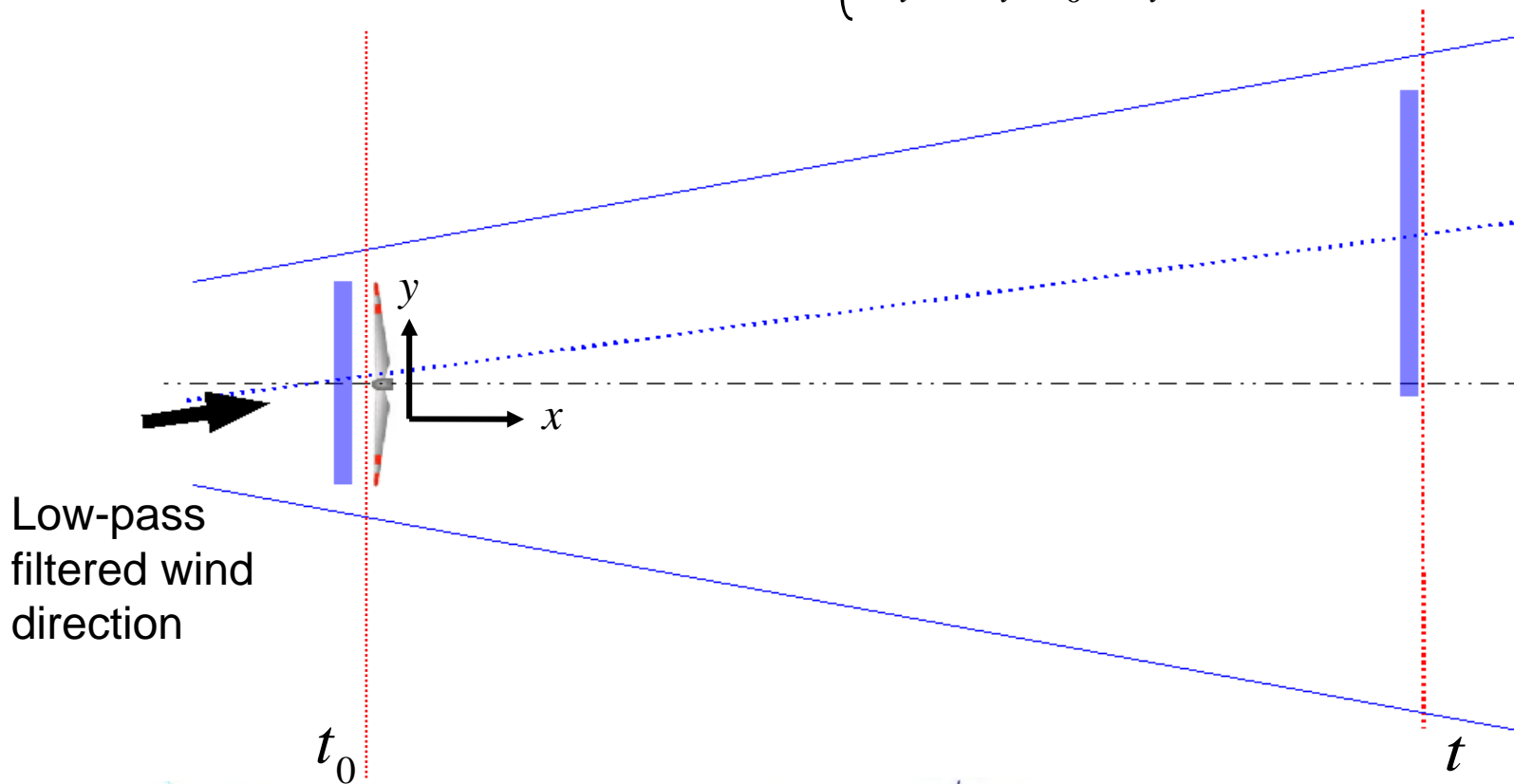
Meandering wake

Wake meandering driven mainly by turbulence in the atmosphere with scales larger than the rotor size



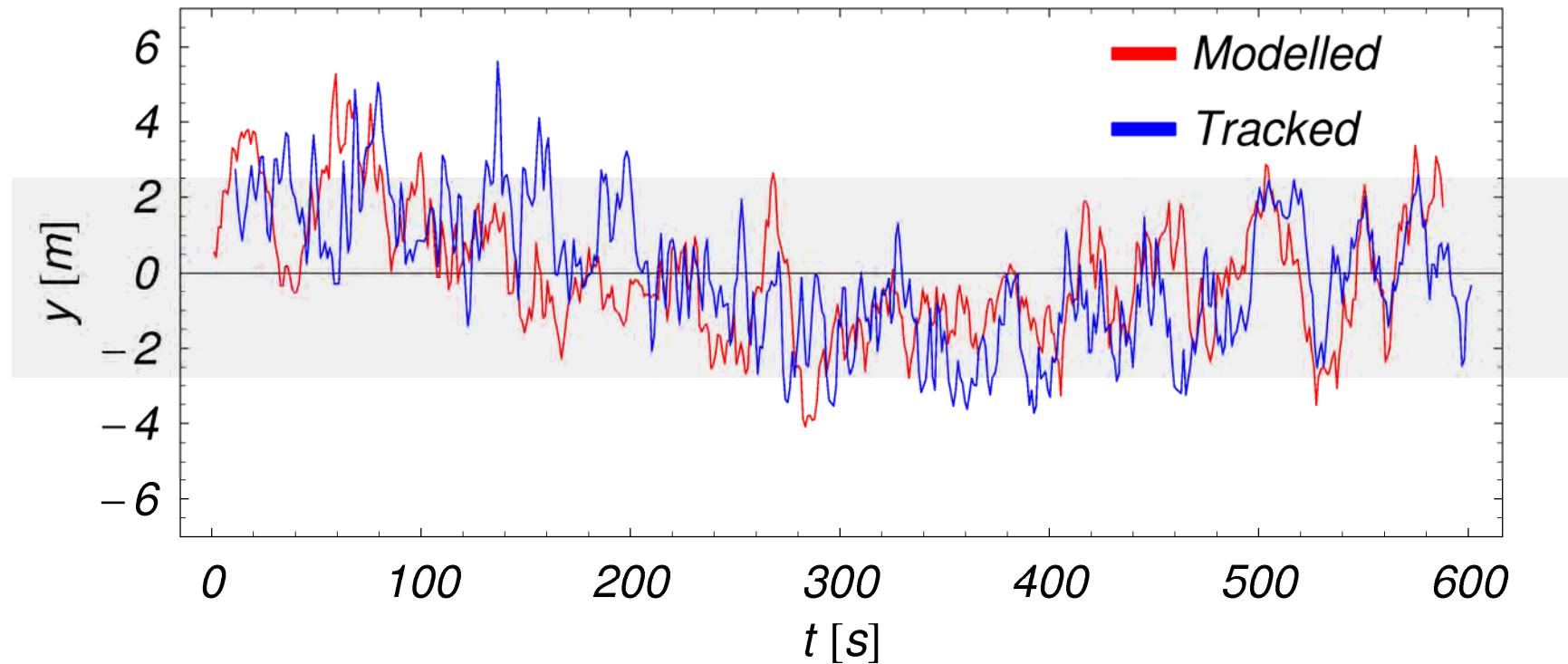
Wake disk position estimation

Position of disk i at time t $\begin{cases} x_i = \bar{u} \cdot t_i \\ y_i = v_i(t_0) \cdot t_i \end{cases}$



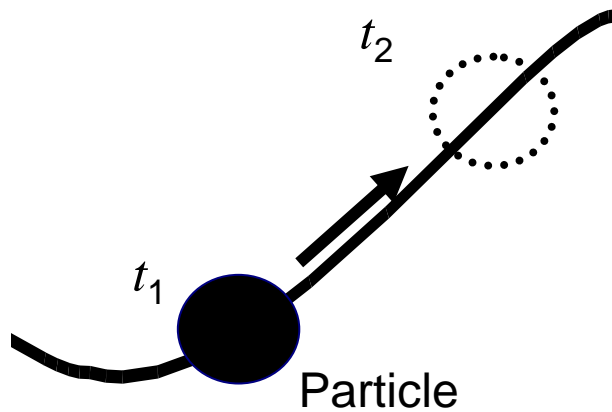
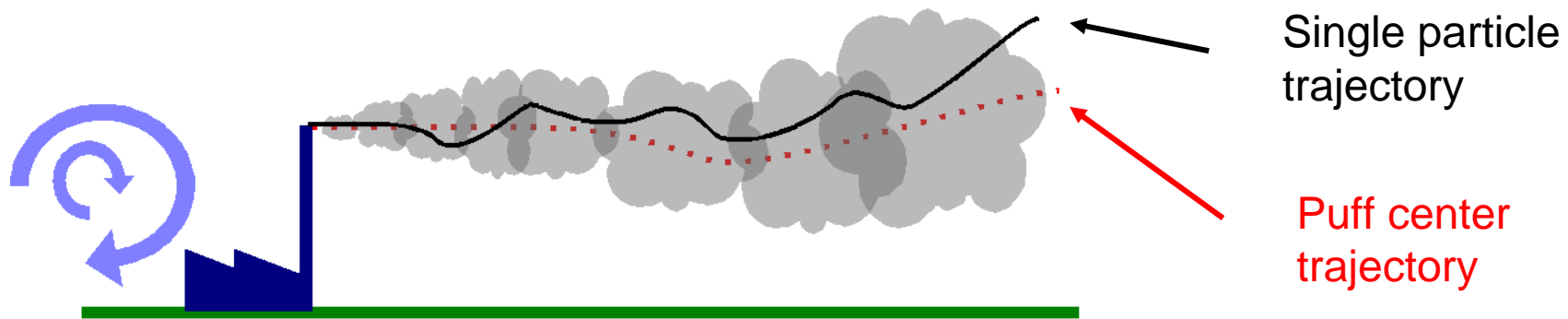
Modelled and tracked wake meandering at 4D

Modelled transversal meandering based on metmast
in wake and assuming wake as passive advecting disks



Puff-Particle-Model

Puff trajectories estimated with a single particle Lagrangian model

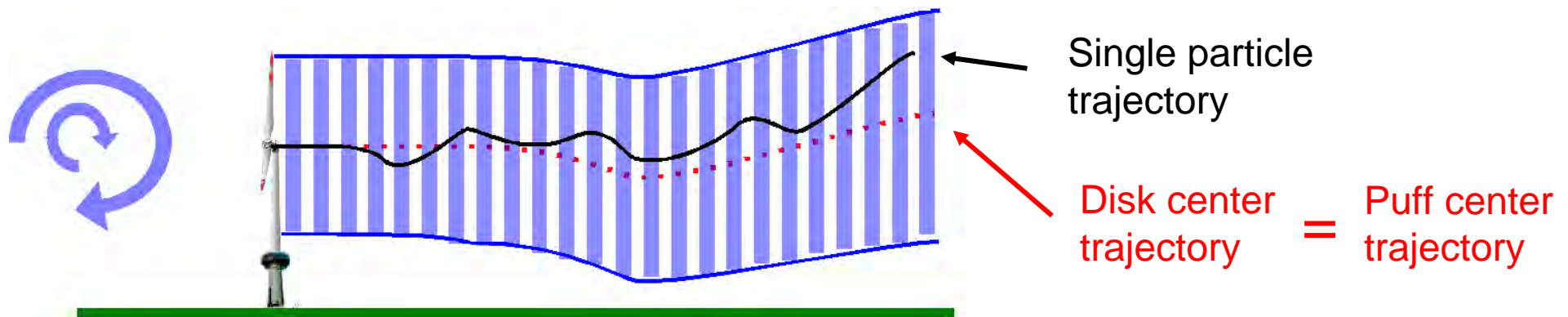


$$d\mathbf{u} = \underbrace{\mathbf{a}dt}_{\text{Correlated}} + \underbrace{\mathbf{b}d\zeta}_{\text{Random}}$$

$$\mathbf{x} = \mathbf{u}dt$$

Disk-Particle Model

Disk trajectories estimated with a single particle Lagrangian model



Superposition of two independent problems

Meandering is estimated with a Puff-Particle approach (filtered particle trajectories)

Internal wake flow is calculated in a classical way without meandering (e.g. modified Ainslie)

Model implementation

- *Finite differences* $\Delta \mathbf{u} = \mathbf{a}\Delta t + \mathbf{b}\Delta \zeta$ and $\mathbf{x} = \mathbf{u}\Delta t$
- *Initial conditions* ($\mathbf{x}_o, \mathbf{u}_o$)
 - Inflow conditions at wind turbine hub height
- *Model variables a and b*
 - Based on the approach of Rotach et al. 1998
 - 3D trajectories
 - Neutral to fully convective boundary layer
- *Boundary layer scaling*
 - Mean wind shear and Turbulence statistics
- *Meandering estimation with a low pass filter on particle wind speeds*

Preliminary results: Lateral movement

Particle trajectories estimated with a single particle Lagrangian model

Stability

intermediate between fully convective and neutral

Particles 100

Initial conditions

$$x_o = 0\text{m}$$

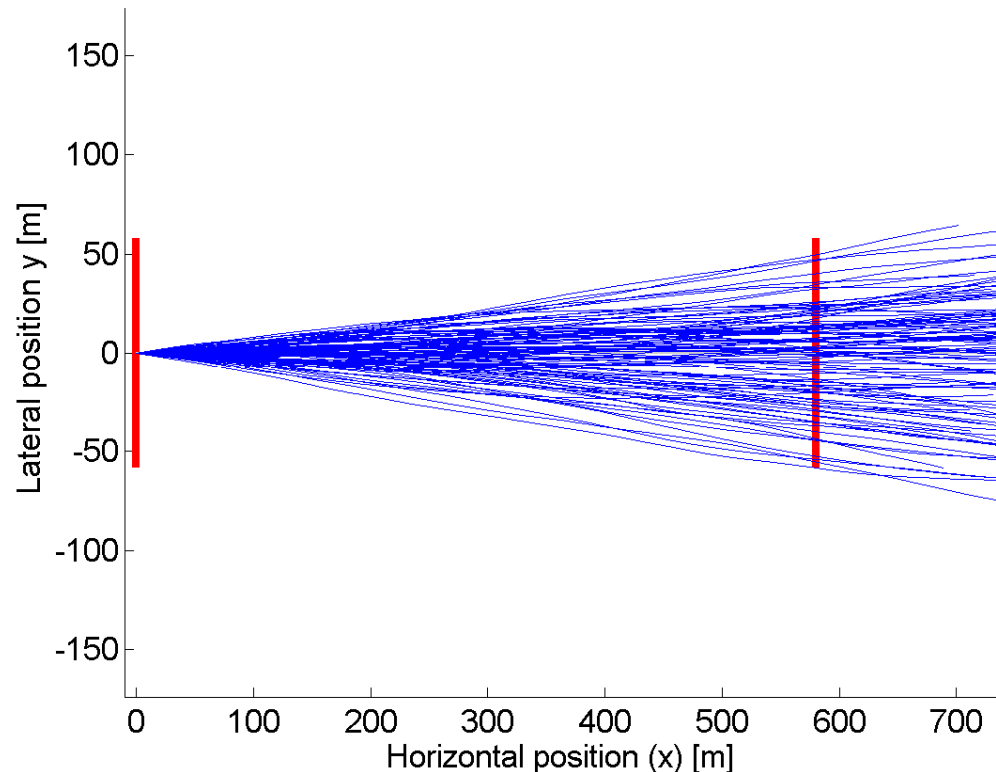
$$y_o = 0\text{m}$$

$$z_o = 102\text{m}$$

$$u_o \sim 5.5\text{m/s}$$

$$v_o : \text{random with } \sigma_v$$

$$w_o : \text{random with } \sigma_w$$



Second wind turbine at 5D downstream ($D = 116\text{m}$)

Preliminary results: Lateral movement

Particle trajectories estimated with a single particle Lagrangian model

Stability

intermediate between fully convective and neutral

Particles 20

Initial conditions

$$x_o = 0\text{m}$$

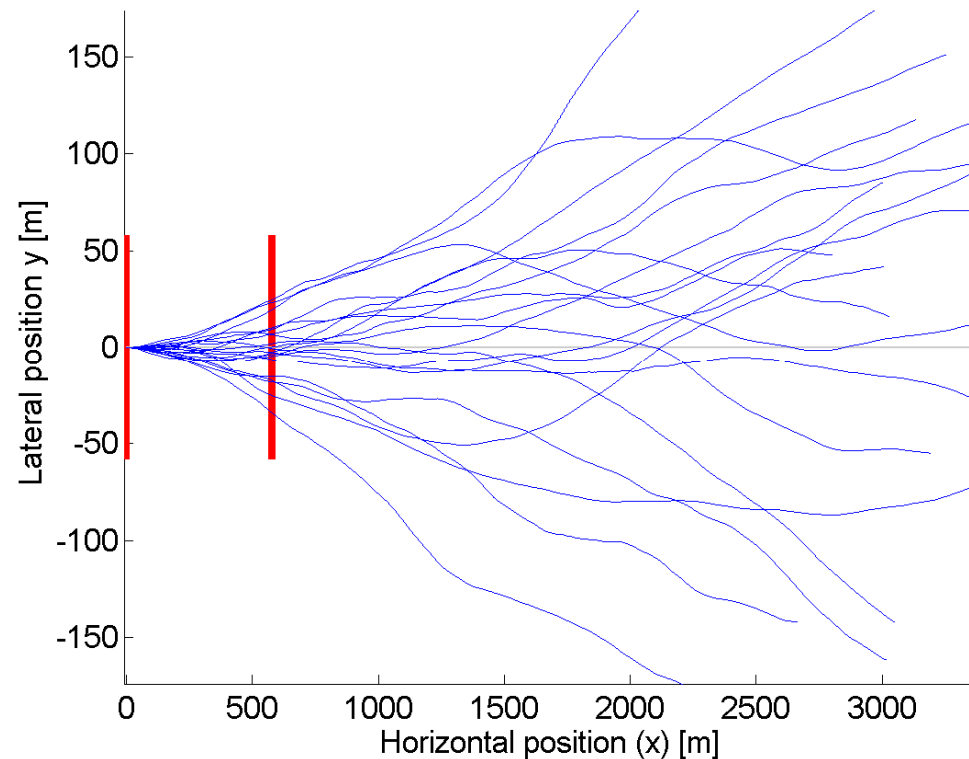
$$y_o = 0\text{m}$$

$$z_o = 102\text{m}$$

$$u_o \sim 5.5\text{m/s}$$

$$v_o : \text{random with } \sigma_v$$

$$w_o : \text{random with } \sigma_w$$



Second wind turbine at 5D downstream ($D = 116\text{m}$)

Preliminary results: Vertical movement

Particle trajectories estimated with a single particle Lagrangian model

Stability

intermediate between fully convective and neutral

Particles 100

Initial conditions

$$x_o = 0\text{m}$$

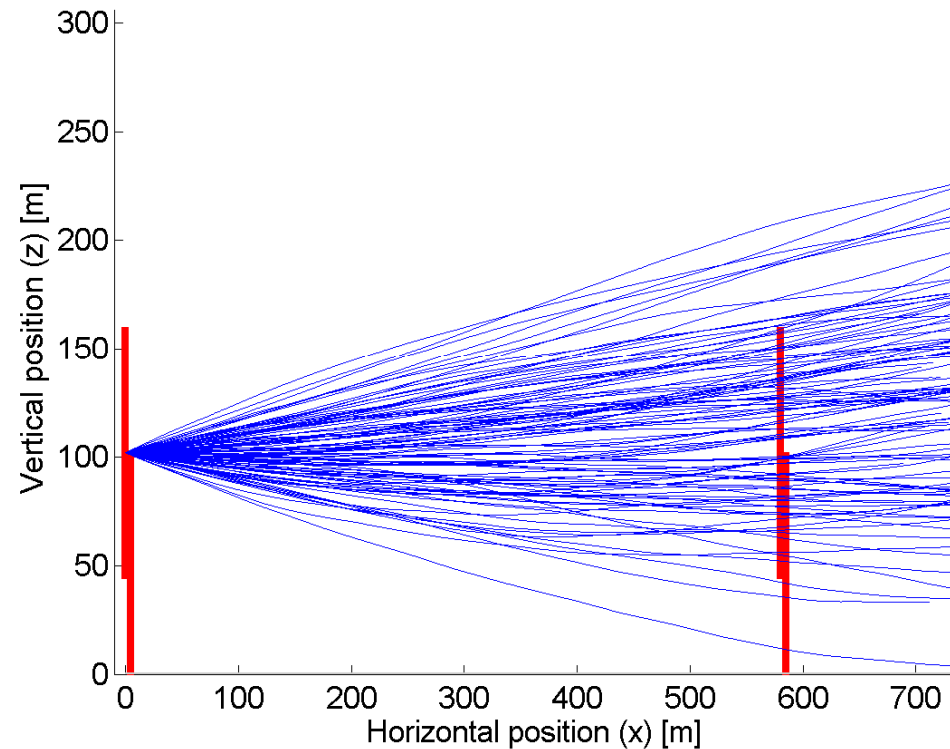
$$y_o = 0\text{m}$$

$$z_o = 102\text{m}$$

$$u_o \sim 5.5\text{m/s}$$

$$v_o : \text{random with } \sigma_v$$

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Second wind turbine at 5D downstream (D = 116m)

Preliminary results: Vertical movement

Particle trajectories estimated with a single particle Lagrangian model

Stability

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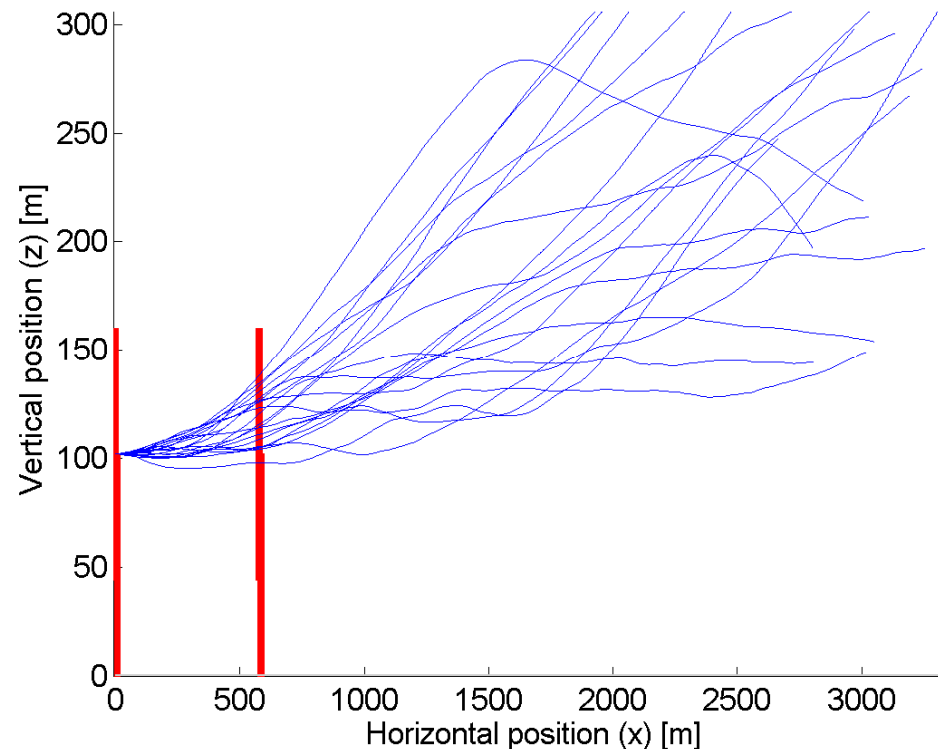
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$$v_o : \text{random with } \sigma_v$$

$$w_o : \text{random with } \sigma_w$$



Second wind turbine at 5D downstream ($D = 116\text{m}$)

Horizontal wake profiles at hub-height

Nacelle frame of reference

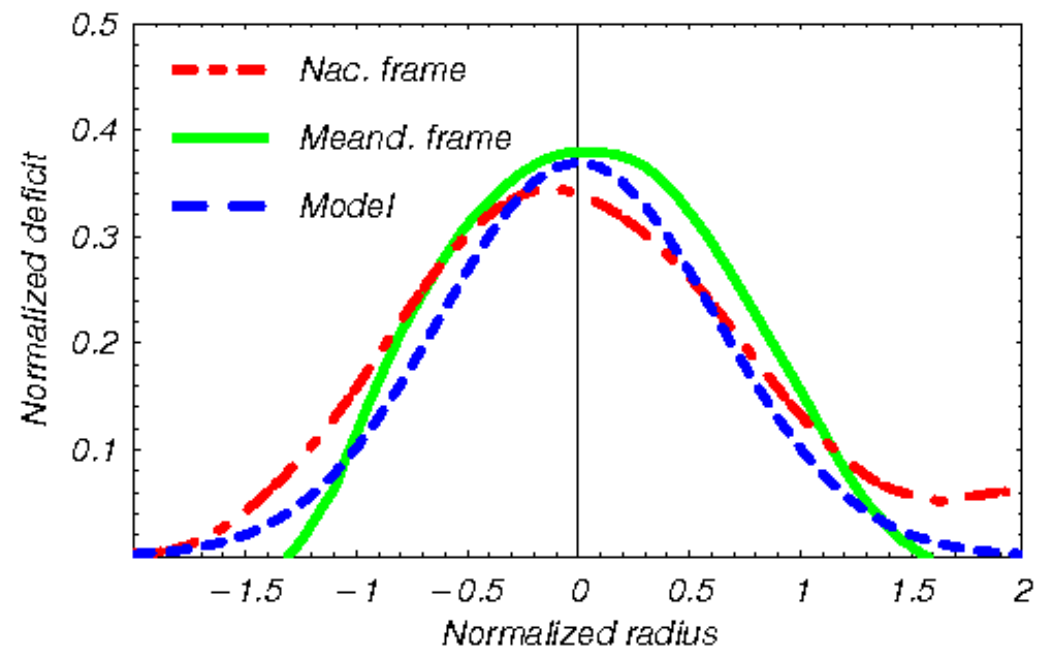
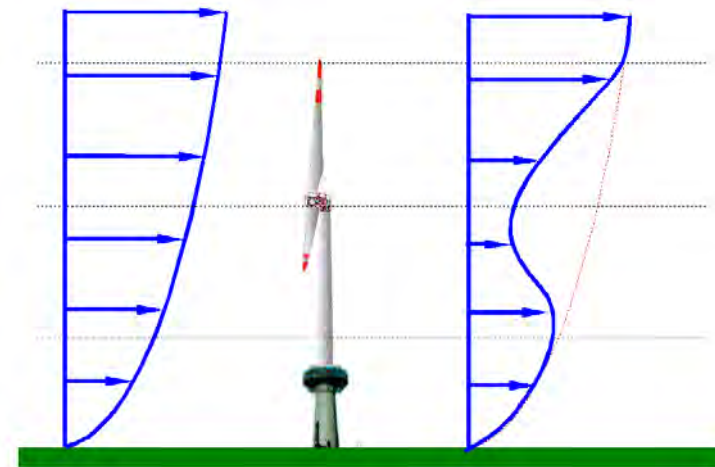
Average without meandering correction

Meandering frame of reference

Average after alignment of all wind fields about the wake center

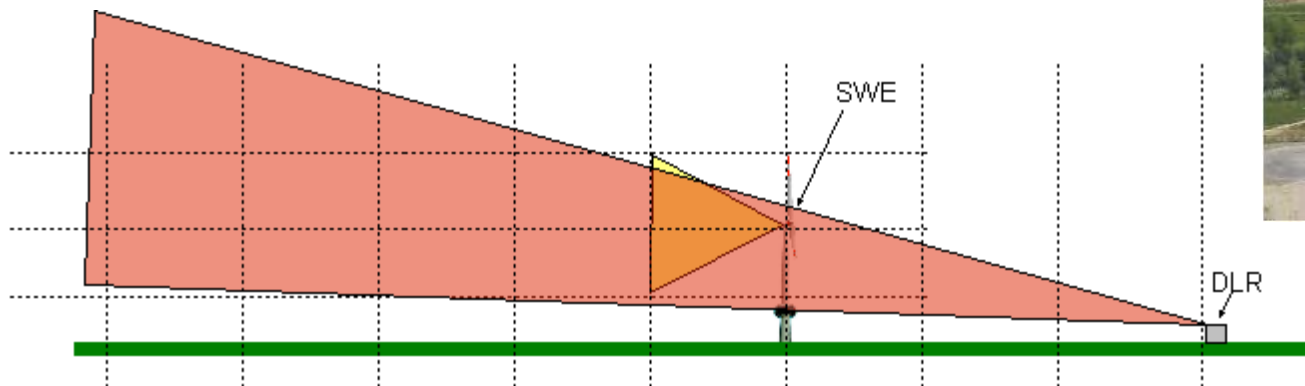
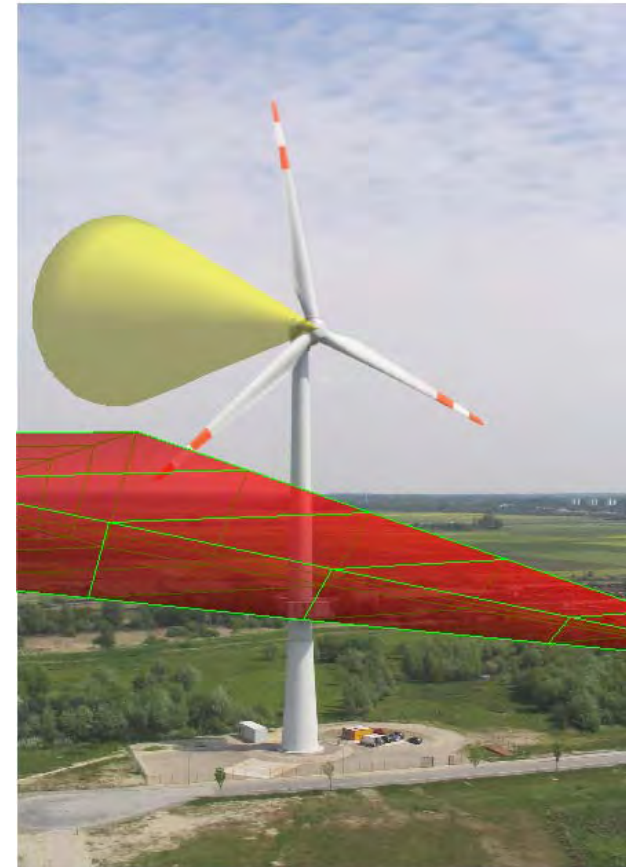
Model

Axisymmetric Ainslie model implemented in FLaP



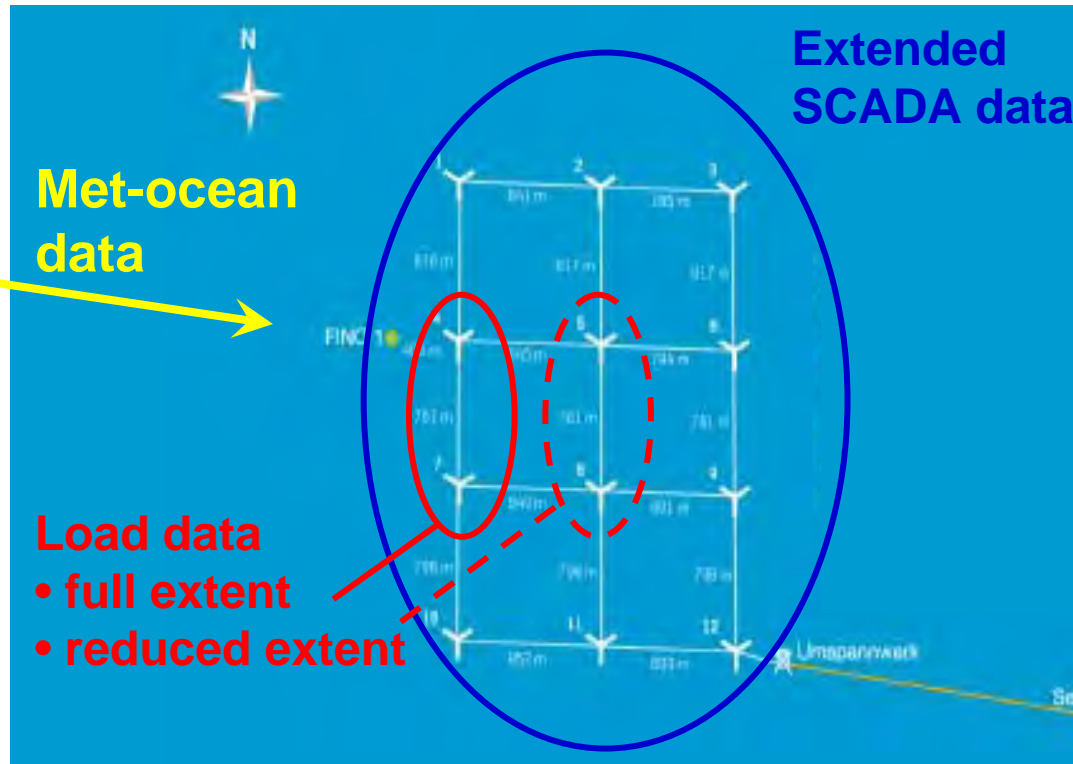
Outlook

- **Planned measurements:** in the wake of a 5MW wind turbine (Diam 116m) with two pulsed LiDARs (begin middle of April 2009)
 - **Near wake** : Short range LiDAR – SWE
 - **Far wake** : Long range LiDAR – DLR



OWEA-Project: “Verification of Offshore Wind Energy Converters”

- *Joint project with five work packages started Nov. 2007*
- Evaluation (not execution) of extensive measurements at “alpha ventus”



6 x REpower 5M with jacket



6 x Multibrid M5000 with tripod

[Source: DOTI, BMU, Multibrid, REpower]

Last comments

- Puff-Particle models seem plausible for estimating meandering of wind turbine wakes realistically
- Thorough validation of ist application has to be performed
- Atmospheric stability affects the accuracy of loading and performance models in onshore and offshore