



(Large Scale) Meandering in Wind Farms

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(Large Scale) Meandering in Wind Farms.

S J Andersen, J N Sørensen, R F Mikkelsen

November 13, 2015

Overview

- 1 Motivation
- 2 Methodology
- 3 Simulations
- 4 Results - Flow Characteristics
- 5 Results - Power Production
- 6 Results - Loads
- 7 Conclusions and Discussion

Motivation

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Motivation



Wake effects in Horns Rev 1. Photographer Christian Steiness.

As the size of wind farms continue to grow, there is an increasing demand for understanding and predicting wake effects.

The importance of wake effects are basically related to:

- Decreased production
- Increased loads.

Meandering or low frequency undulations have been attributed to arise from several different phenomena:

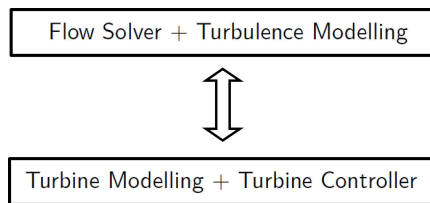
- Atmospheric turbulence(Larsen et al., DWM).
- Instability of the hub vortex(lungo et al., 2013).
- Rotating helical vortex core(Okulov et al., 2014).
- Strouhal (Medici et al., 2006).
- Turbine spacing(Andersen et al., 2012).

This work presents preliminary results of LES of very large wind farms aimed at elucidating on meandering and its effects in very large wind farms.

Methodology

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Modelling a Wind Turbine and its Wake



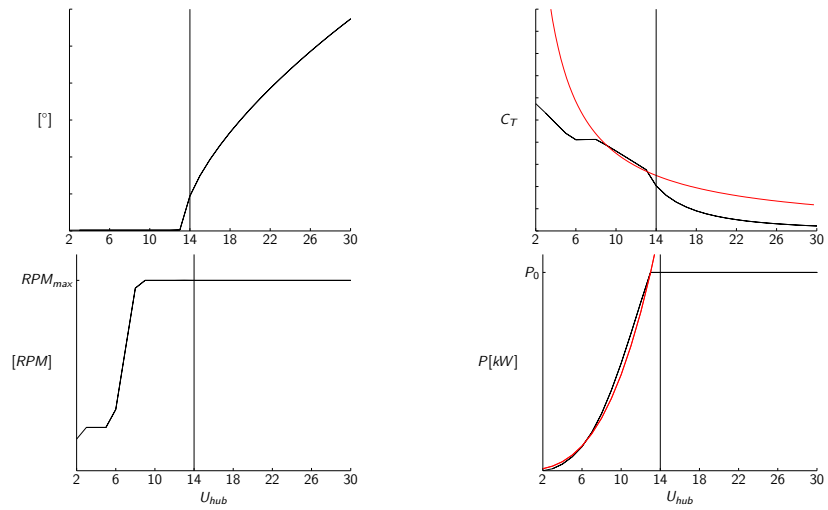
Fully coupled LES and aero-elastic codes.

NM80 Turbine



- NM80.
- $R = 40m$.
- $U_{rated} = 14m/s$.
- $P_{rated} = 2.75MW$.
- Variable speed P-controller and PI-pitch angle controller.

Turbine Controller



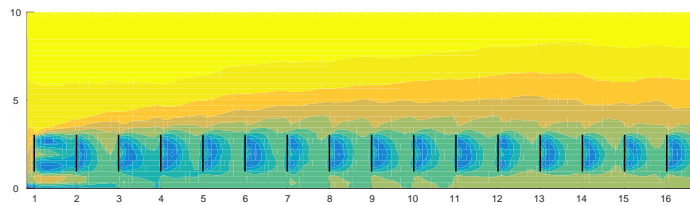
Simulations

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60 mins of real time, 10 min averages shifted by 1 min(not statistically independent)

Table : Overview of simulations.

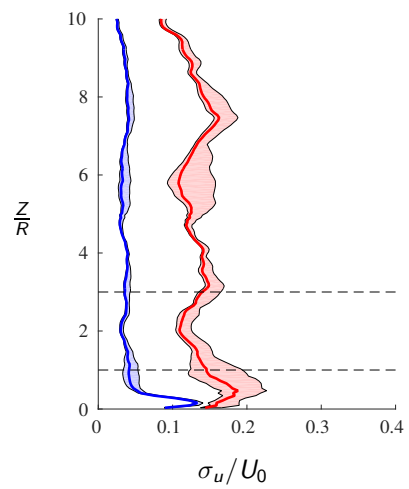
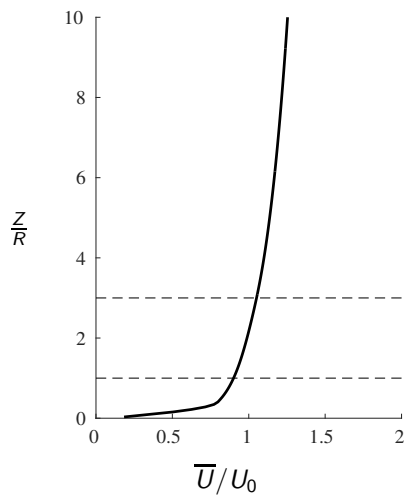
Name	U_0	TI	Spacing
s12u8ti0	8m/s	0%	12R × 20R
s12u8ti3	8m/s	3%	12R × 20R
s12u8ti15	8m/s	15%	12R × 20R
s12u15ti15	15m/s	15%	12R × 20R
s20u8ti15	8m/s	15%	20R × 20R



Remember color coding

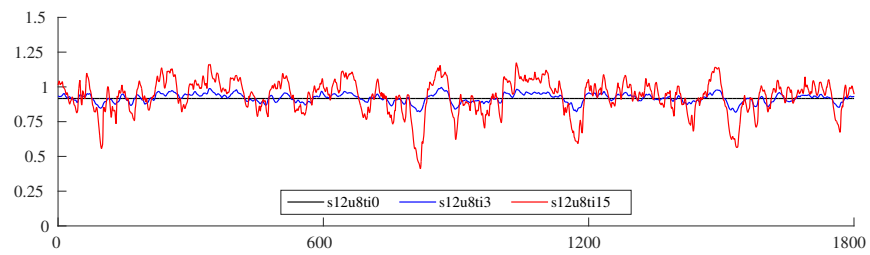
Inflow Conditions:

Shear exponent: $\alpha_{PBL} = 0.14$.



Inflow Conditions:

Same Mann turbulence applied with different forcing. Streamwise velocity 1R upstream 1st turbine.

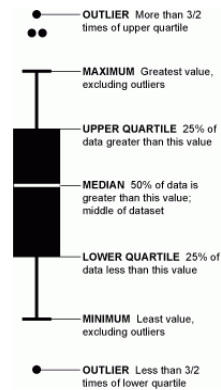


Results

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Box Plots explained

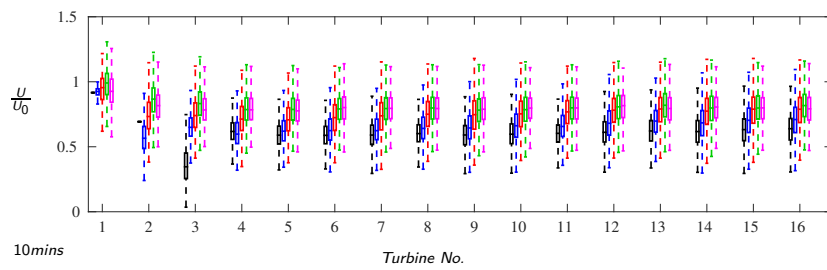
- Compact way to show distribution of data.
- Box made up of first, second (median), and third quartile.
- Maximum and minimum extend would correspond to 99.3% coverage for normally distributed data.
- Outliers excluded in this context.



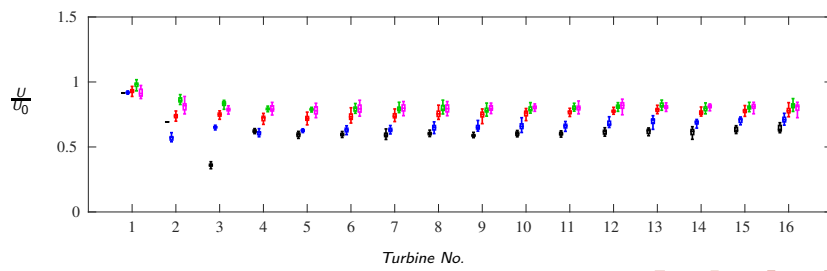
<http://informationandvisualization.de/blog/box-plot>

Velocity distributions:

Instantaneous(1Hz)

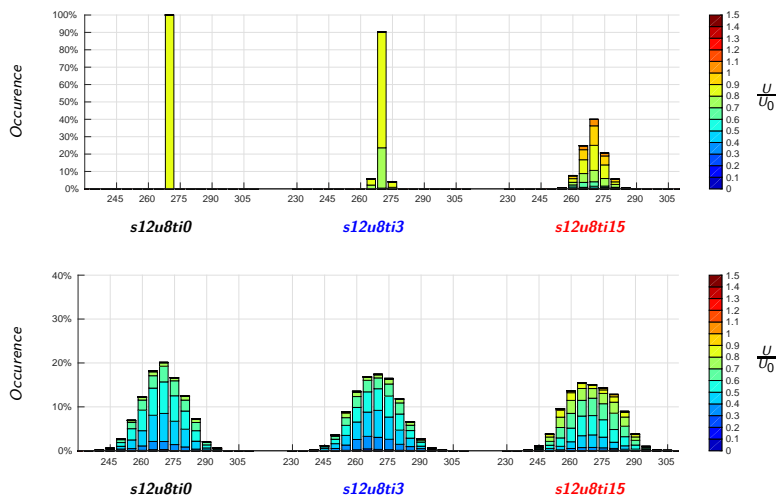


10mins



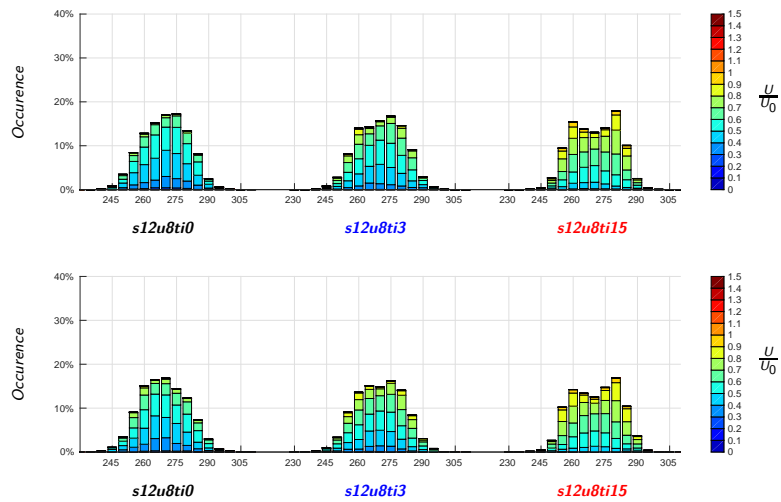
Directional Variability:

Inflow to 1st and 4th turbine



Directional Variability:

Inflow to 11th and 12th turbine

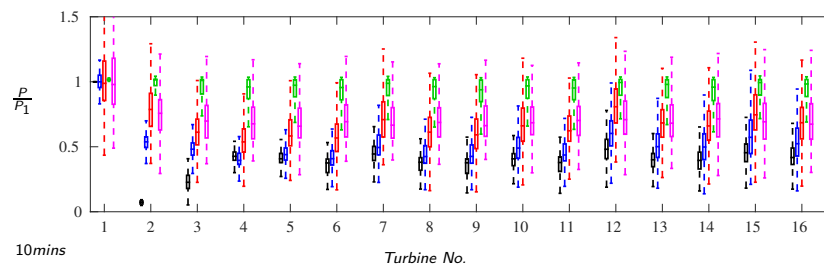


Results

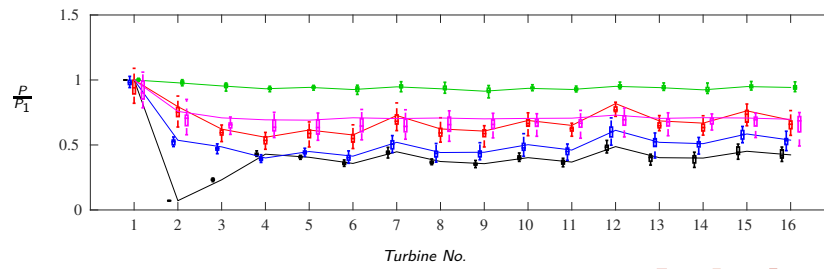
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Power productions:

Instantaneous(1Hz)

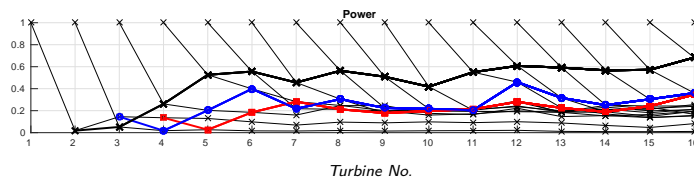


10mins

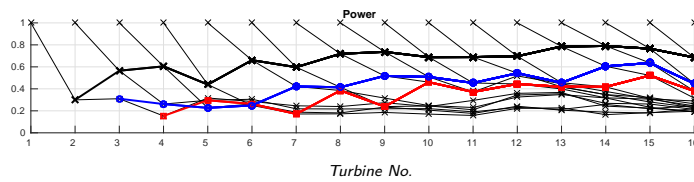


Correlation between different turbines:

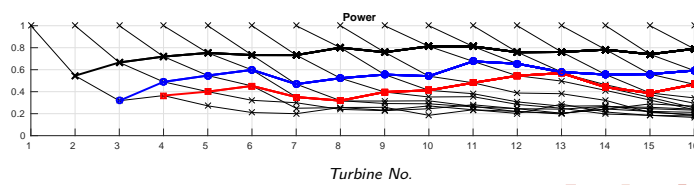
$TI = 0\%$



$TI = 3\%$



$TI = 15\%$

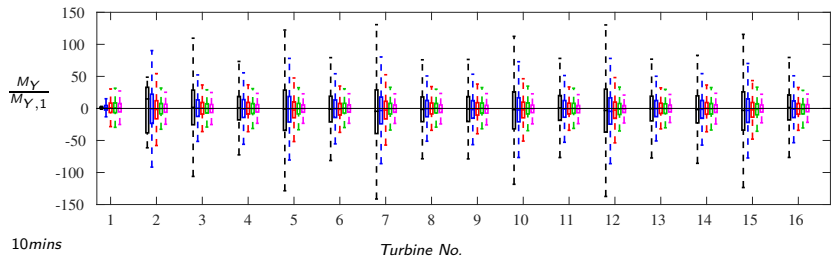


Results

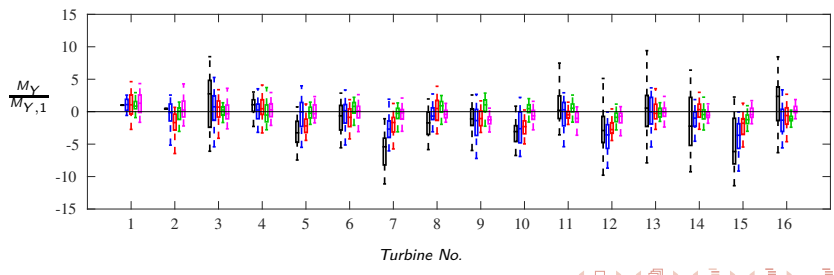
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Yaw moments:

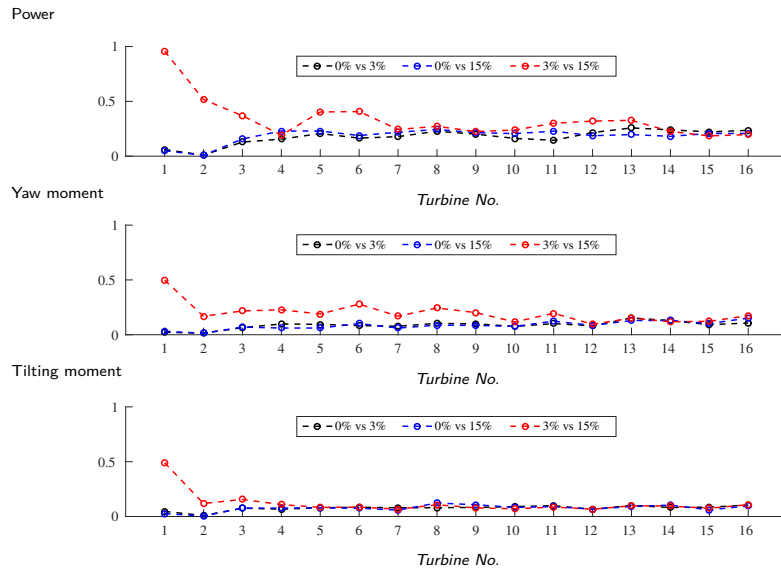
Instantaneous(1Hz)



10mins



Correlation between simulations:



Conclusions and Discussion

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Conclusions and Discussion

- Converged velocity after about 4th turbine.
- Time and directional variability of LES comparable with measurements?
- Increased correlation further into the farm indicates self-organised motion.
- Atmospheric turbulence seems to assist/increase the self-organised motion.
- Self-organised motion or large scales are inherent, but dependent on spacing and/or C_T .
- DWM assumption is questionable further into the farm.
- Certain turbines produce significantly more, but also experience higher loads, irrespective of turbulence intensity.

Thanks for your attention.