Numerical CFD comparison of Lillgrund employing RANS

EERA DeepWind 2014

Deep sea offshore wind power
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WindSim AS

- Established in 1993
- WindSim - World class software launched in 2003
- Ownership - Privately held company and venture backed
- Business areas
  - Software solutions, consulting services and training
    - Wind farm simulation and wind energy assessment
      - Entire wind farm lifecycle (pre/post construction)
      - Onshore and offshore

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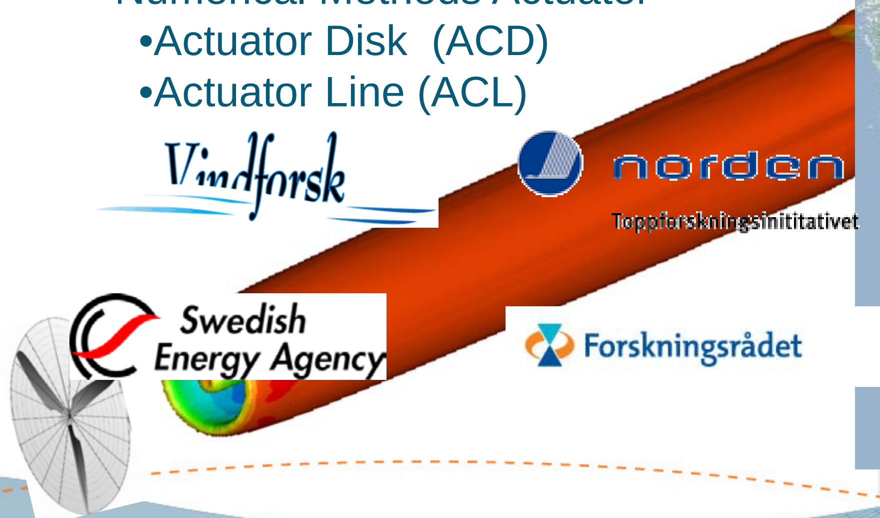
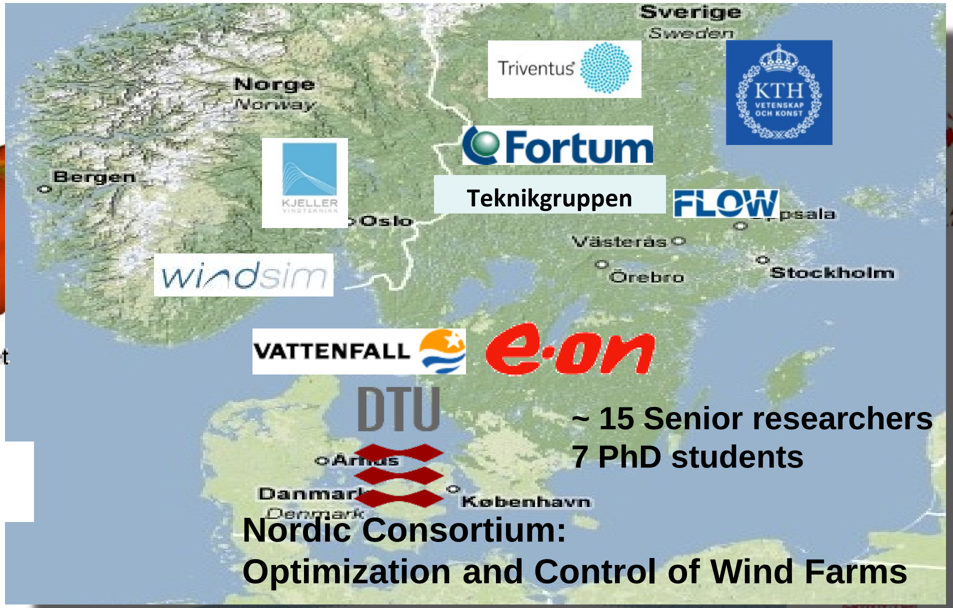
Research

- From research on wake instabilities to simulations of complete wind farms
- Behavior of wakes and wake-turbine interactions
- Applied research on farm optimization
- Numerical Methods Actuator
  - •Actuator Disk (ACD)
  - •Actuator Line (ACL)



Education

- 1 Year Master program on campus in: Wind Power Project Management
- 11 Distance courses in Wind Power



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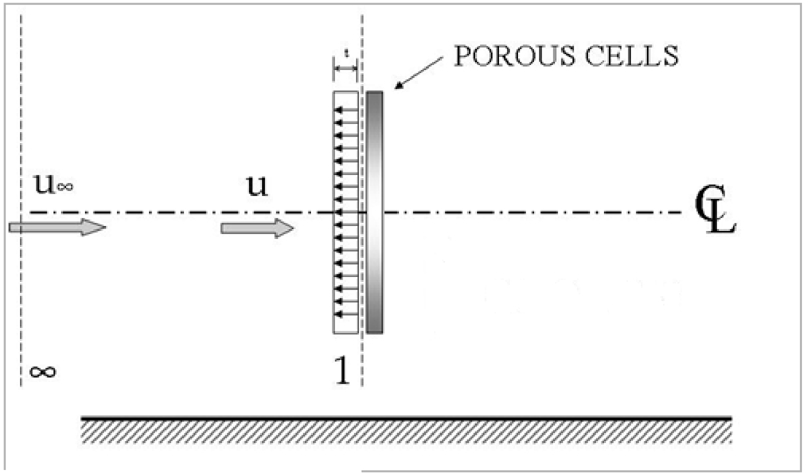
Actuator Disc Concept

The thrust, momentum sink for the axial flow, is supposed evenly distributed on the swept area (uniform pressure drop)



By definition axial induction factor

$$a_i = \frac{u_{\infty i} - u_{1i}}{u_{\infty i}} \quad (1)$$

Betz's theory

$$a_i = \frac{1}{2}\left(1 - \sqrt{1 - C_{T,i}}\right) \quad (2)$$

$$t_i = C_T \frac{1}{2} \rho u_\infty^2 area_i$$

$$\Rightarrow t_i = C_{T,i}(u_{1,i}) \frac{1}{2} \rho \left(\frac{u_{1,i}}{1 - a_i(u_{1,i})} \right)^2 area_i \quad (3)$$

$$T \approx \sum_i t_i$$

Uniform : $t = T / A = C_T \frac{1}{2} \rho u_\infty^2$

Polynomial : $t(\mathrm{r}) = C_1 + C_2 r^2 + C_3 r^4$

Lillgrund Offshore Wind Farm

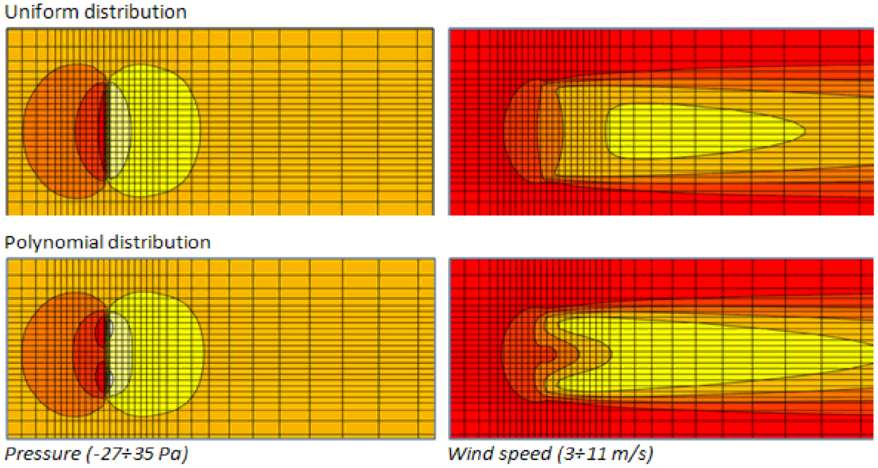
- Located in Øresund consisting of 48 wind turbines (Siemens SWT-2.3-93)
- The presence of shallow waters caused the layout of the wind farm to have regular array with missing turbines (recovery holes).
- Very close inter-row spacing (3.3xD and 4.3xD)

Source: Vattenfall

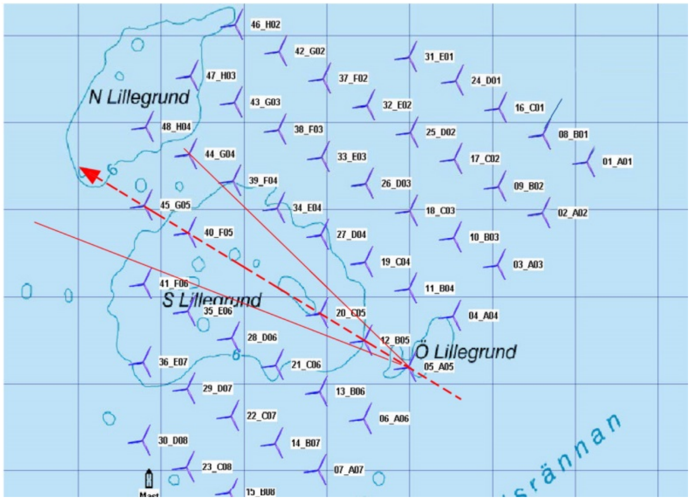
- The maximum peak loss occurs for the second turbine in the row and is, for inter row spacing of 4.4xD, typically 70%, and for row spacing of 3.3xD, typically 80%.(Dahlberg, 2009)
- The turbine production efficiency rate for the entire wind farm has been found to be 67% if only below rated wind speeds are considered. (Dahlberg, 2009)

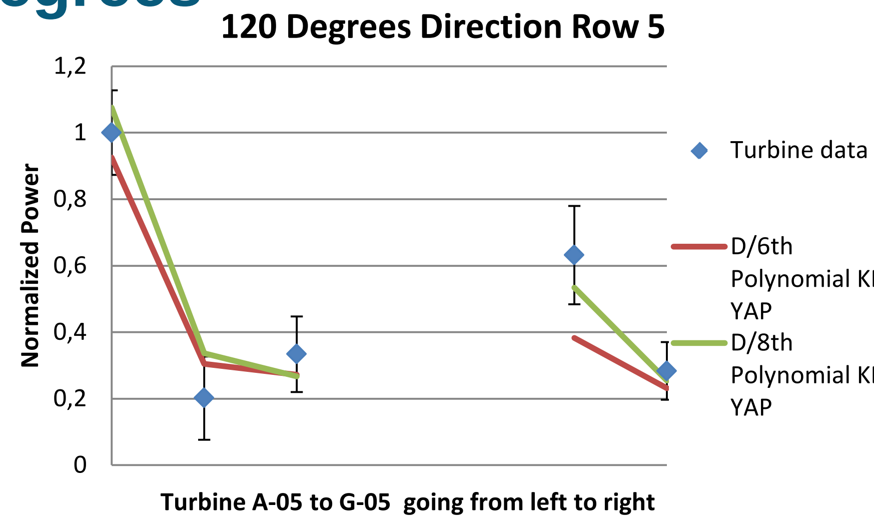
Different Parameters Analysed

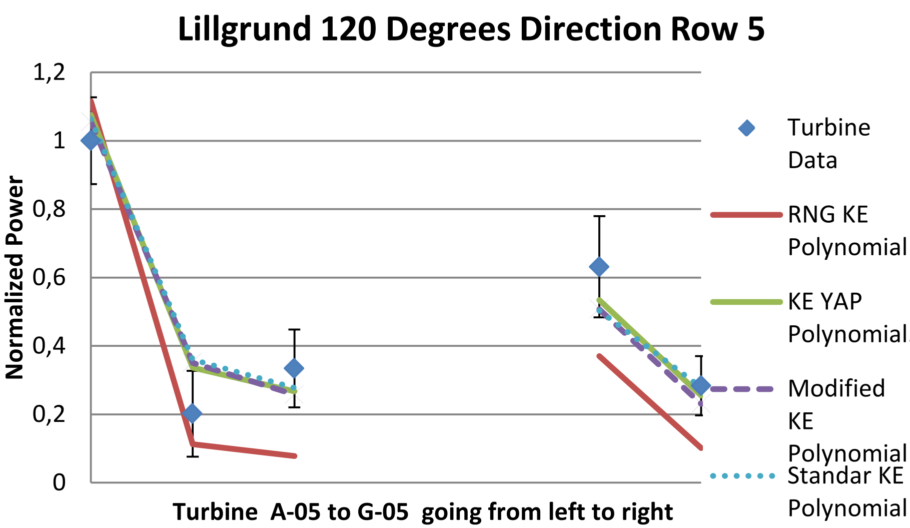
- Grid sensitivity study
  - D/6 (approximately 15.3 m)
  - D/8 (approximately 11.5 m)
- Main Inflow angles
  - 120 degrees, TI=7,8
  - 222 degrees , TI=5,6
  - 300 degrees , TI=6,0
- Axial thrust distributions
  - Uniform
  - Polynomial
- Turbulence closure models
  - Standard k-epsilon,
  - Modified k-epsilon
  - K-epsilon with YAP correction
  - RNG k-epsilon

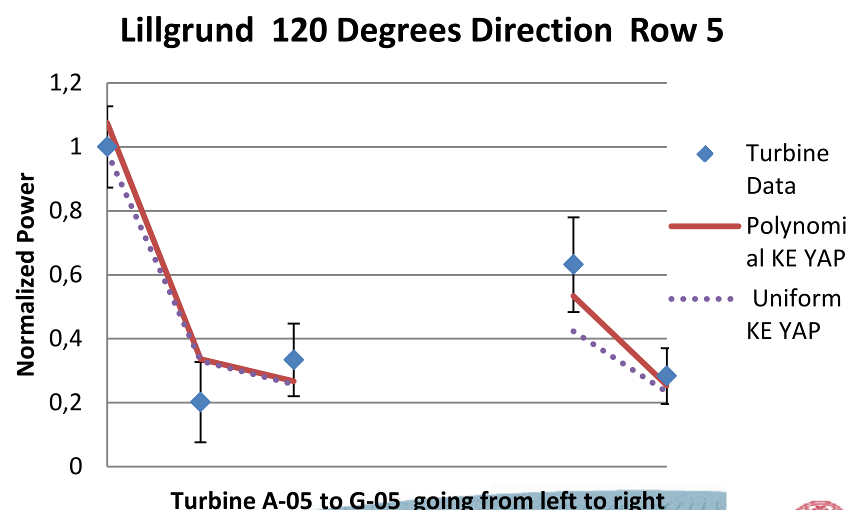


Lillgrund Row 5 120 ± 2,5 degrees









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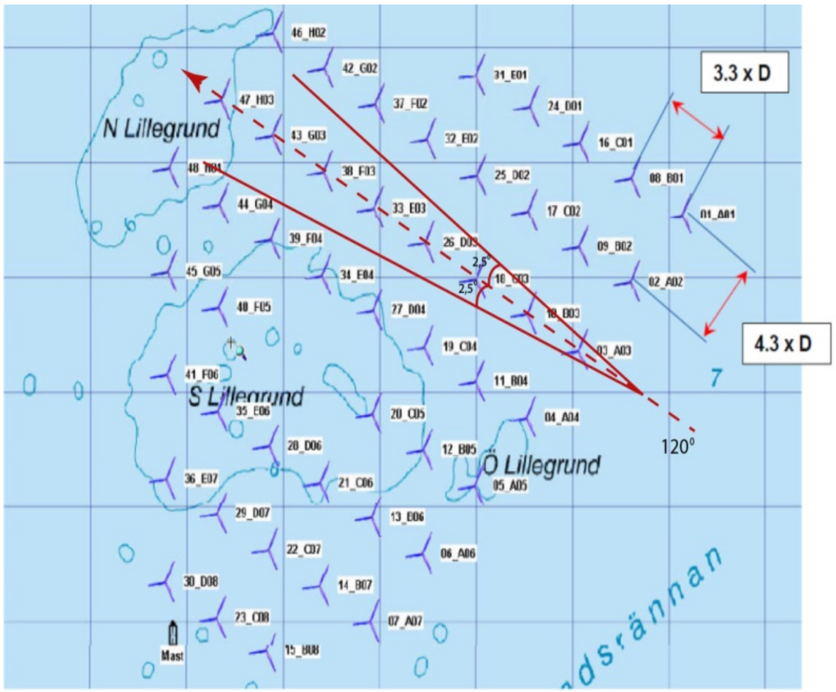
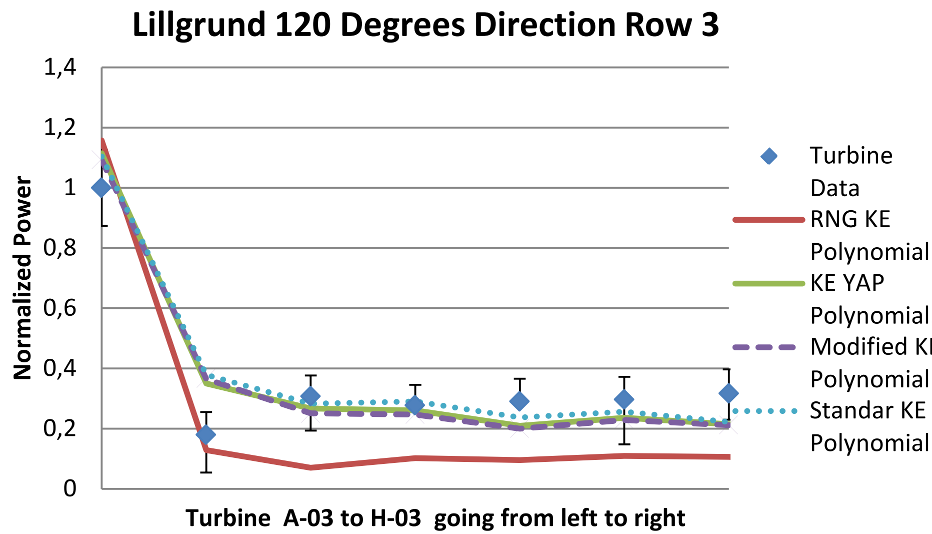
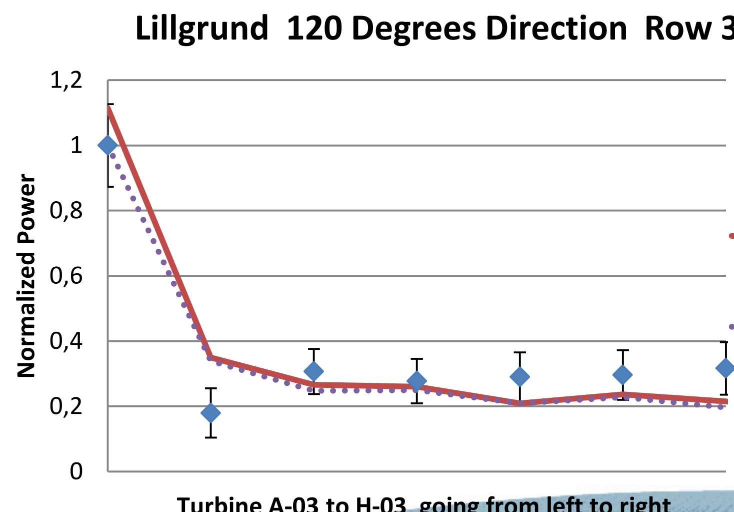
Lillgrund Row 3 120 ± 2,5 degrees







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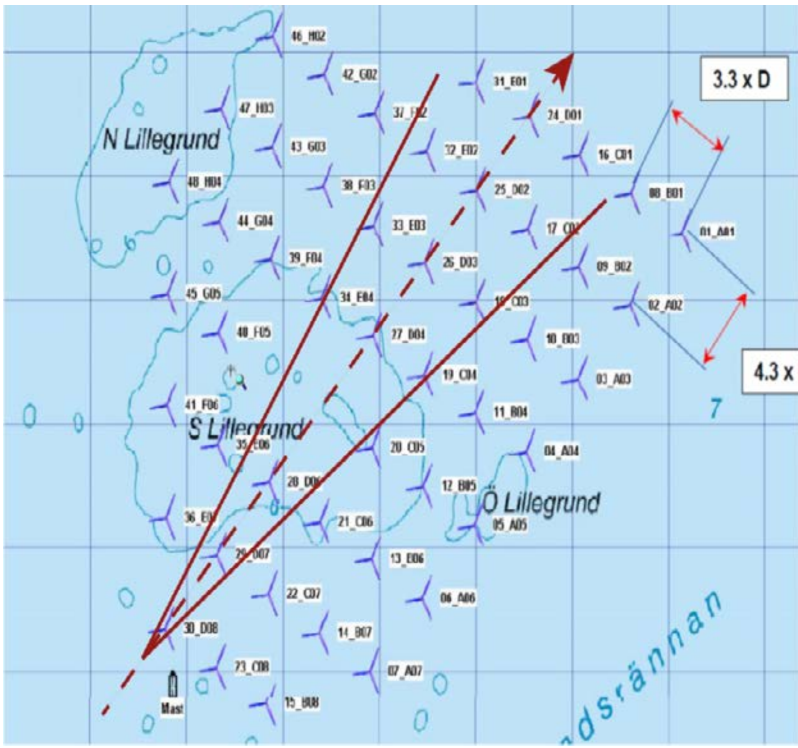
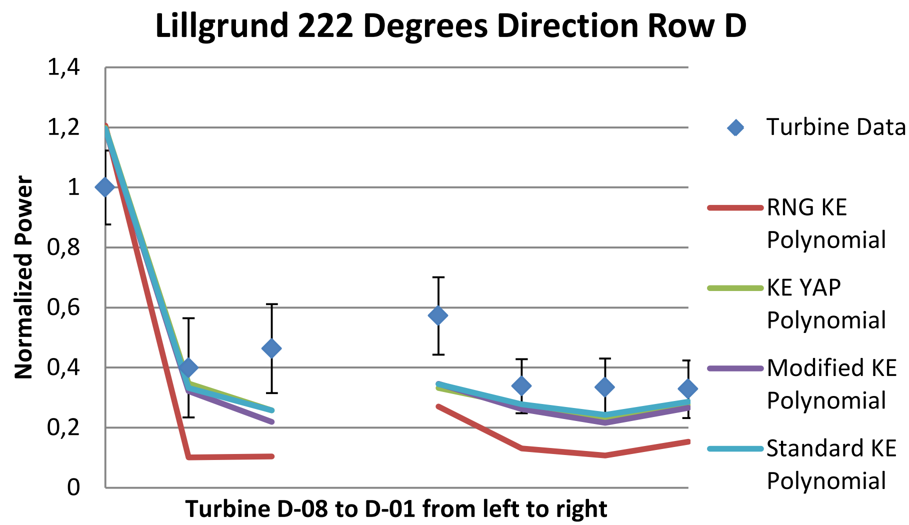
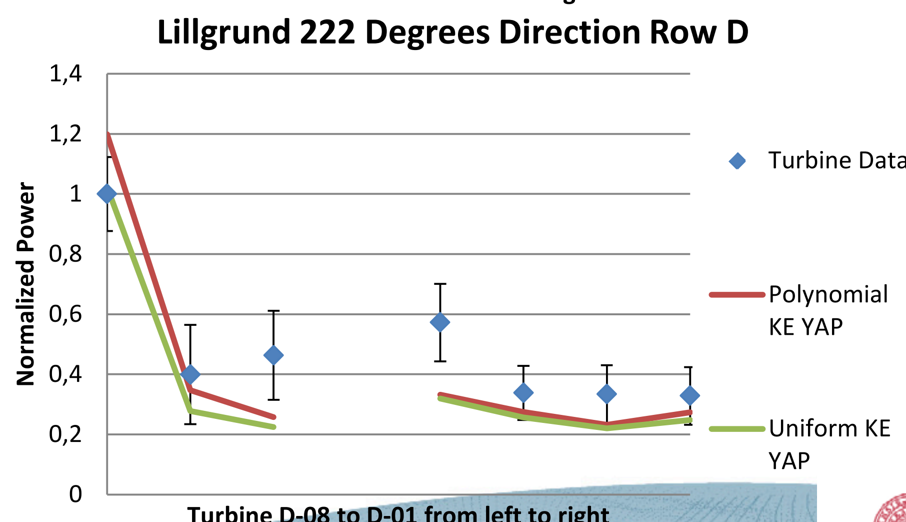
Lillgrund Row D 222 ± 2,5 degrees







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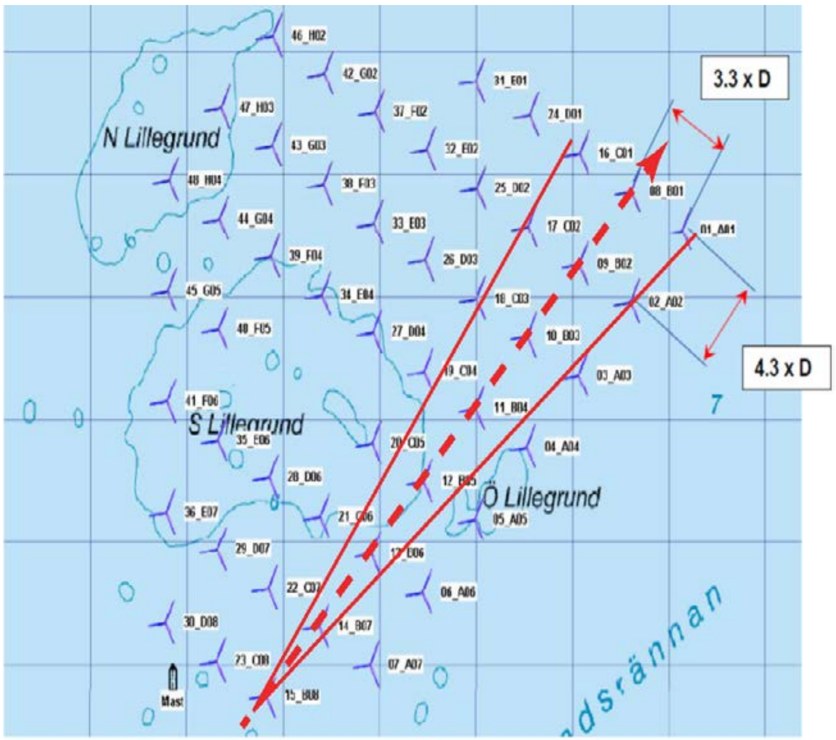
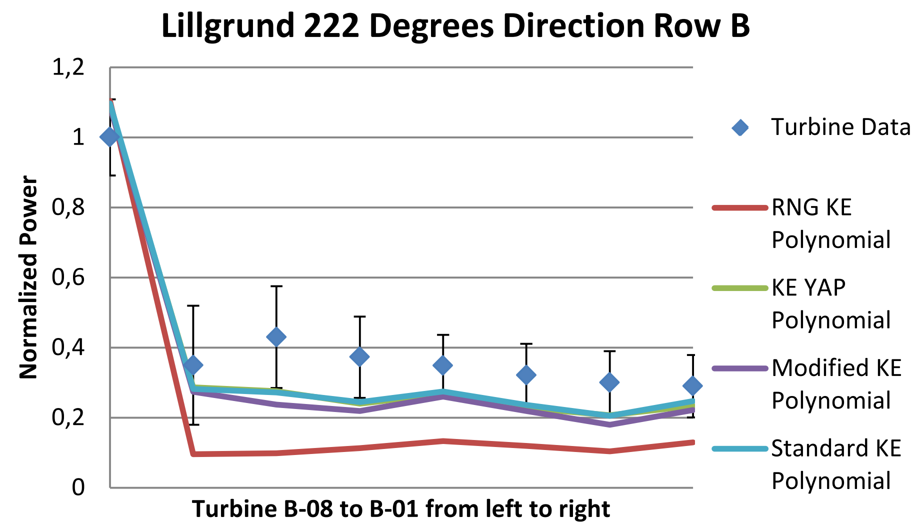
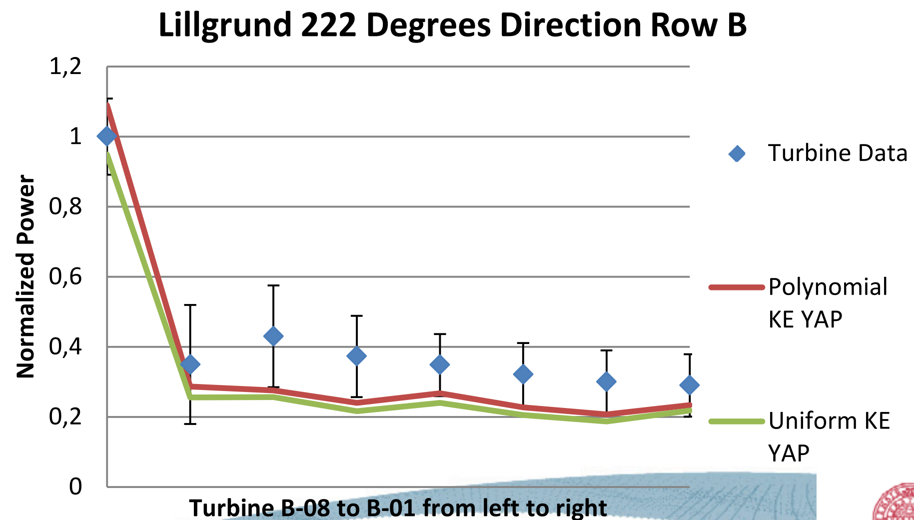
Lillgrund Row B 222 ± 2,5 degrees







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Summary

- Estimation capture the power production from wakes within the error bars of the experimental data.
- The results achieved using the higher resolution, D/8, outperform those obtained using the lower resolution simulation D/6.
- The polynomial distribution, by representing more accurately the thrust force distribution on the rotor, leads to results of higher accuracy in comparison to the uniform distribution.
- Good performance standard k-epsilon, modified k-epsilon and k-epsilon with YAP correction overestimate the power output of the second wind turbine in the row
- RNG k-epsilon captures in some cases the power production reduction in the second wind turbine but underestimates the following wind turbines of the row.

Future research

- Include additional analysis of the total amount of simulated result in further search for general trends.

- Moreover research will be directed on how to include meandering and swirl effects in the wake model used in this analysis.

- Finally studies with higher grid resolution will be conducted and comparison with analytical models and LES models will be conducted.

Acknowledgements

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