



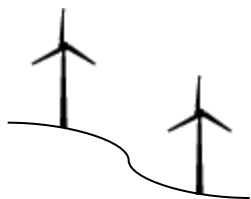
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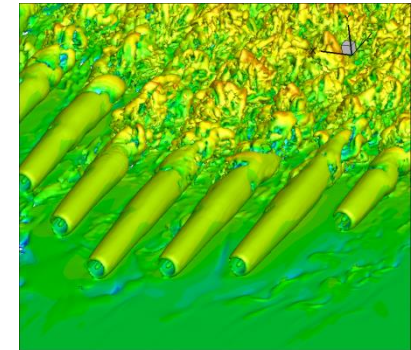
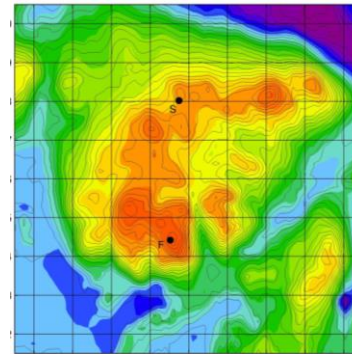
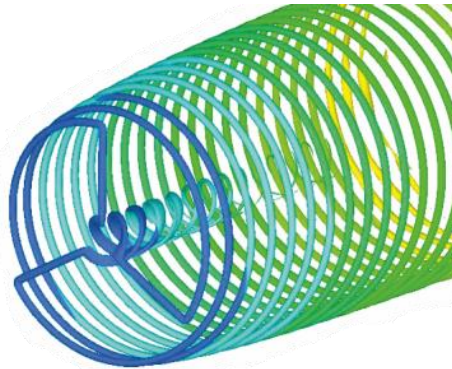
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Impact of ice in large wind farms

-

Swedish participation in ICEWIND



Stefan Ivanell

Head of Section, Wind Energy UU Campus Gotland

and

Director StandUp for Wind

In collaboration with

Stefan Söderberg, Ola Eriksson & Magnus Baltscheffsky



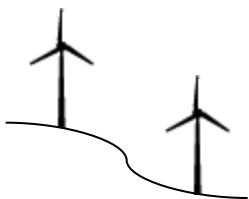
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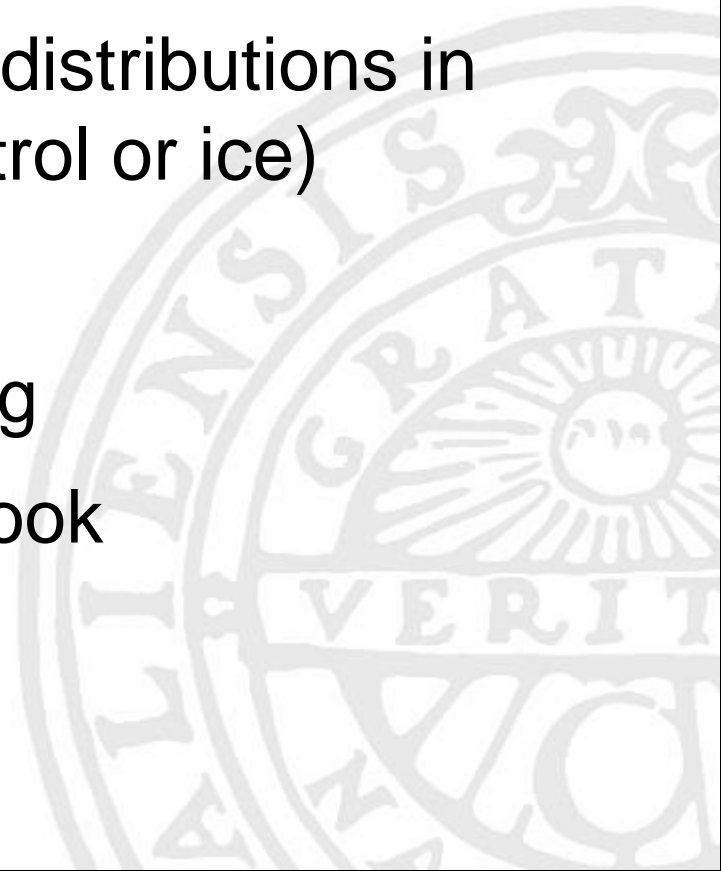
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Outlook

- Contributions to ICEWIND
- Research Focus and Methods
- Production and Load distributions in wind farms (from control or ice)
- Farm-farm interaction
- Local Mapping of Icing
- Conclusions and outlook





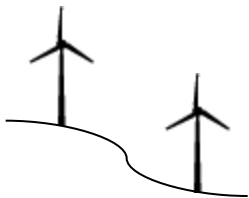
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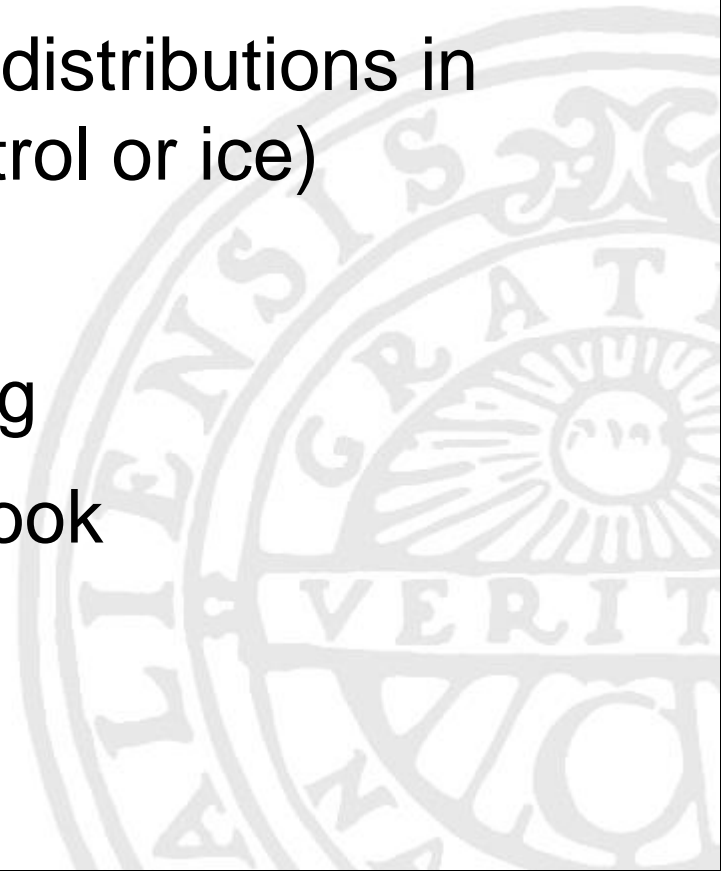
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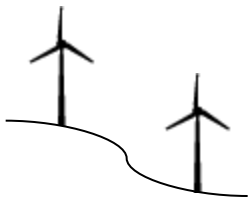
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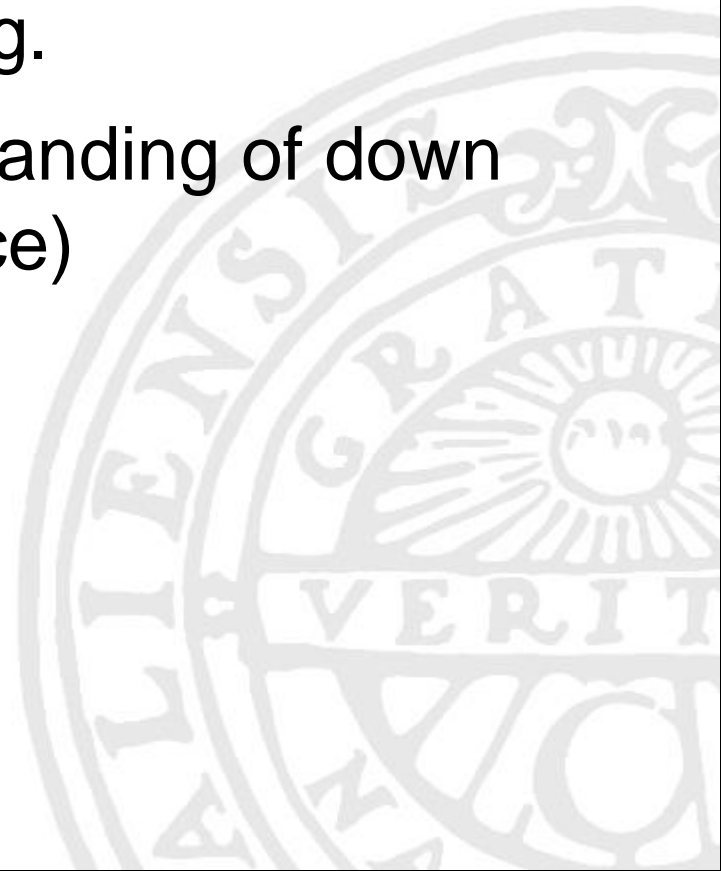
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Contributions to ICEWIND

- Local Mapping of Icing
- Initial aim to link Lift and Drag to different levels of icing.
- Fundamental understanding of down rating (by control or ice)
- Farm-farm interaction





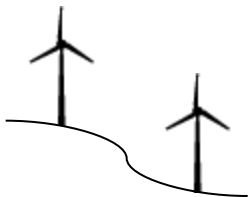
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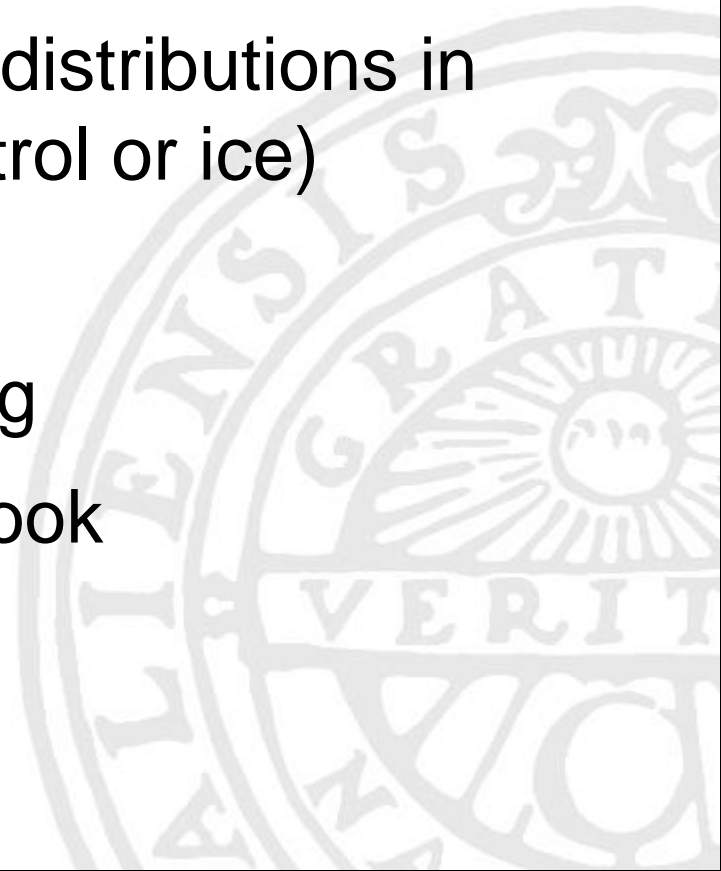
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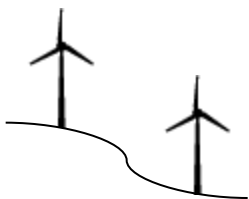
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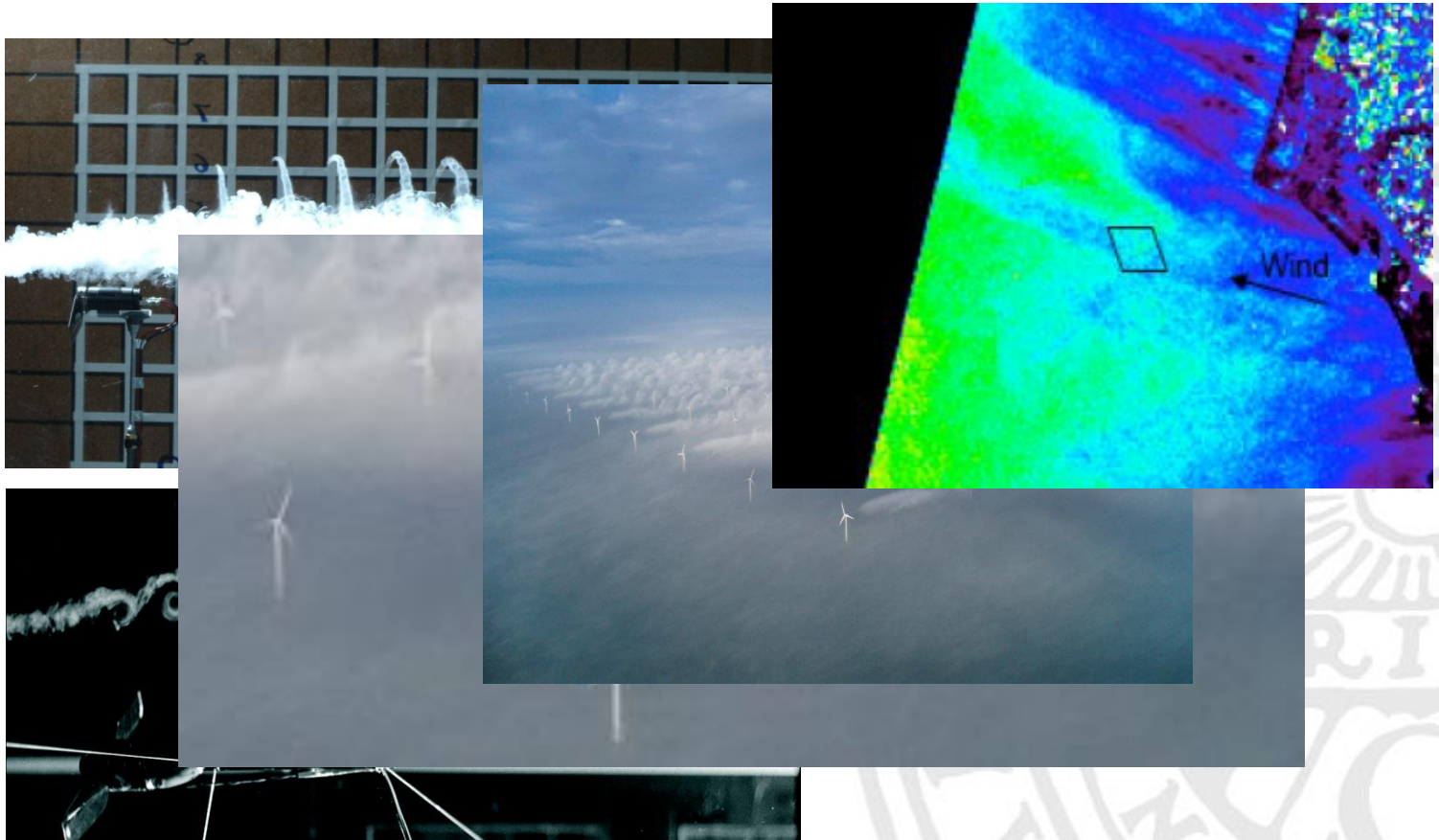
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Research focus;
from fundamental understanding to applied methods.

- Wake vortices interact and roll up during breakdown process
- Break down to large-scale turbulence and mixing
- Interaction in large wind farms
- Farm-farm interaction





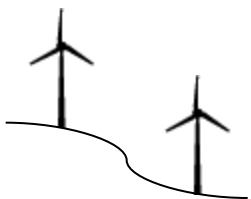
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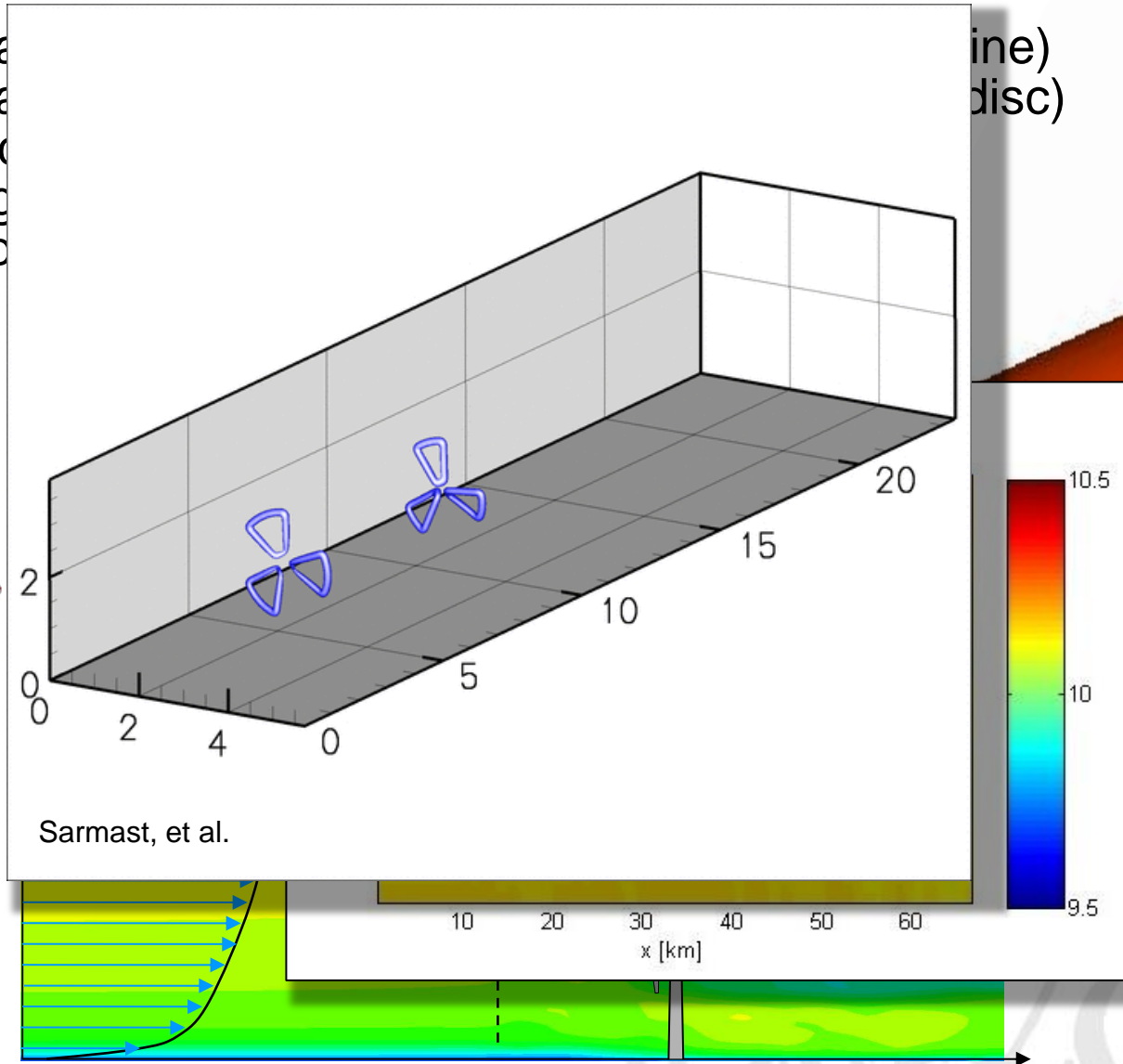
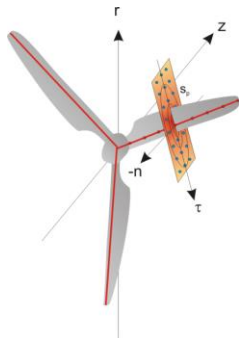
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Research methods; from ACL to Mesoscale.

- Actua
- Actua
- Presc
- Pre-g
- Coup



(line)
(disc)



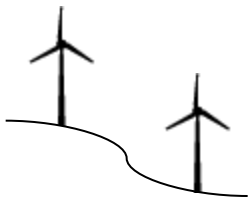
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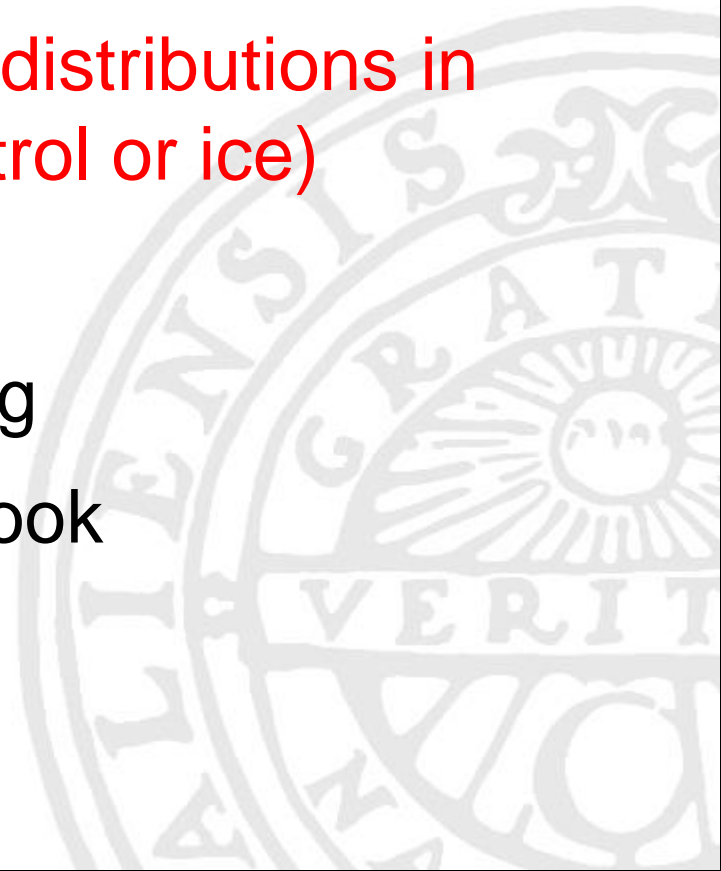
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Production Simulations of Lillgrund

Excellent agreement of production

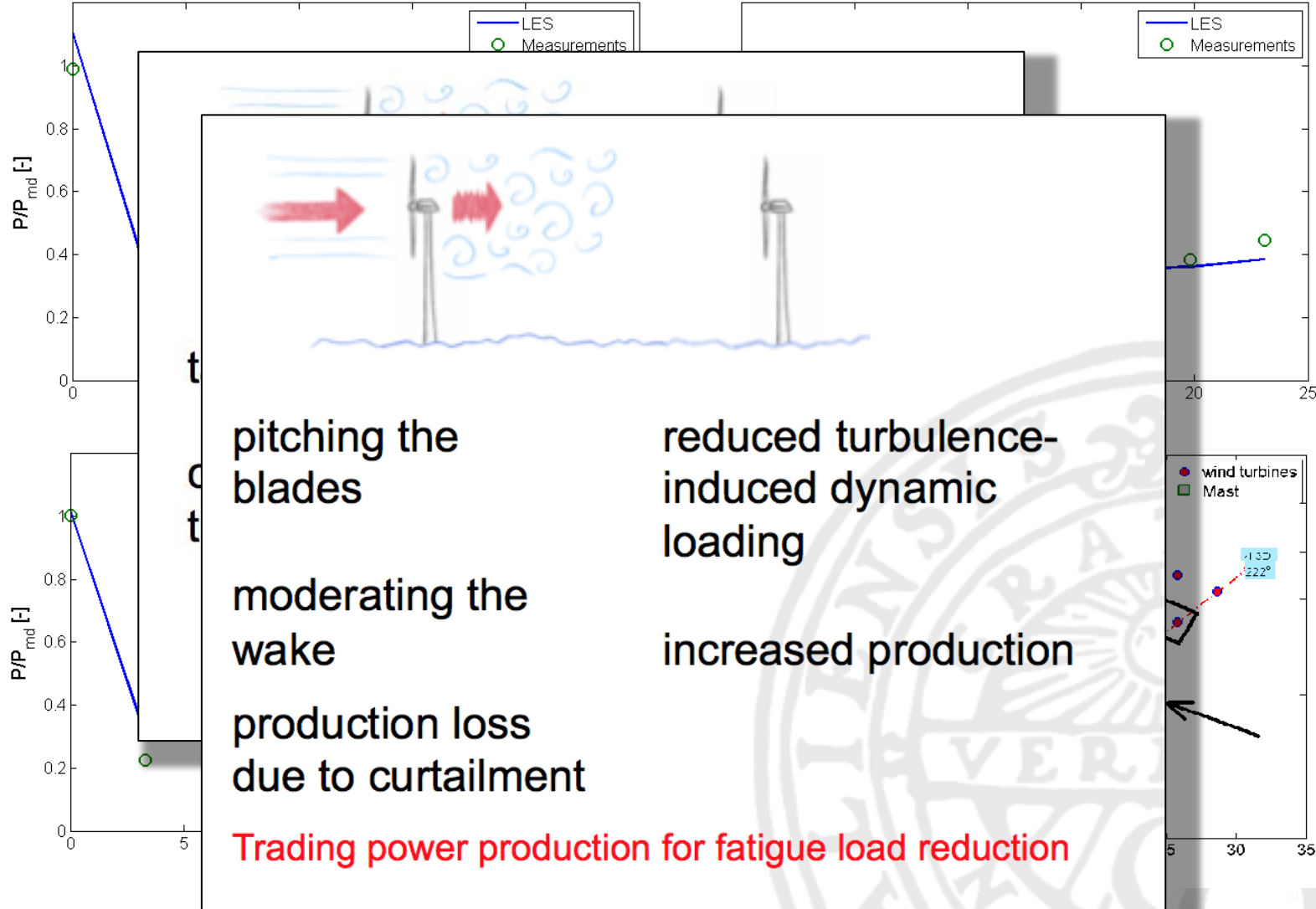
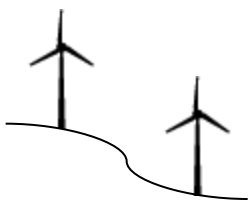
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Derating of first row of turbines

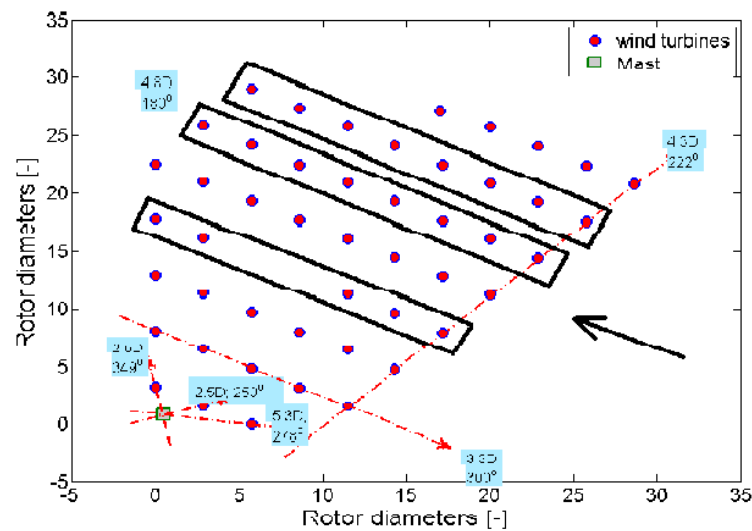
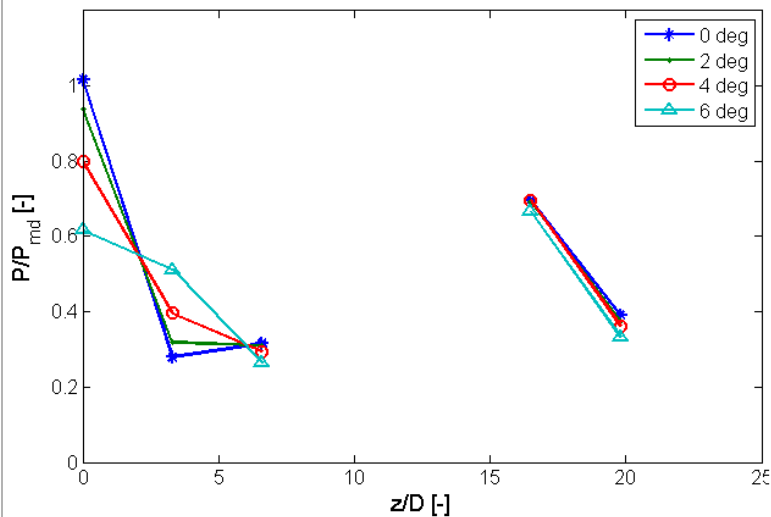
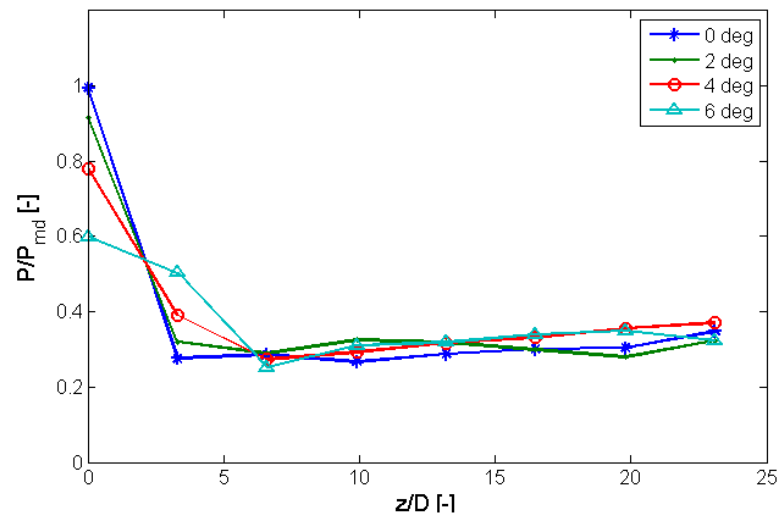
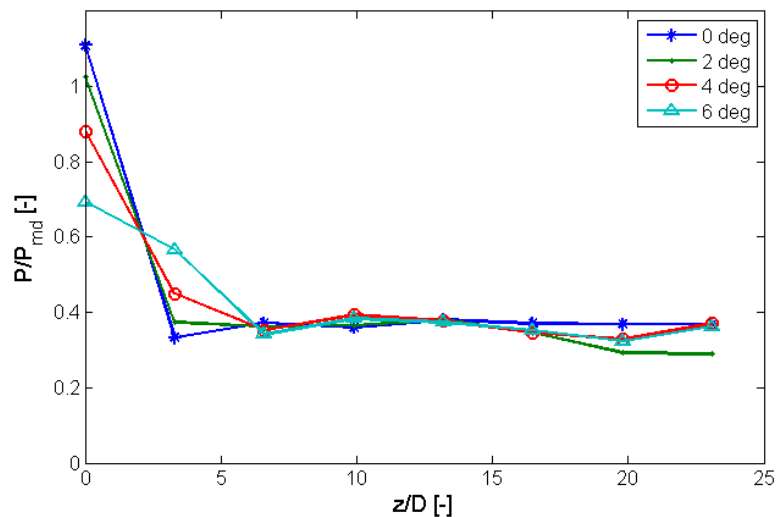
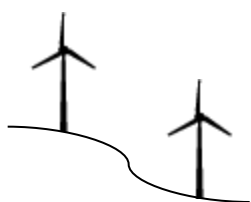
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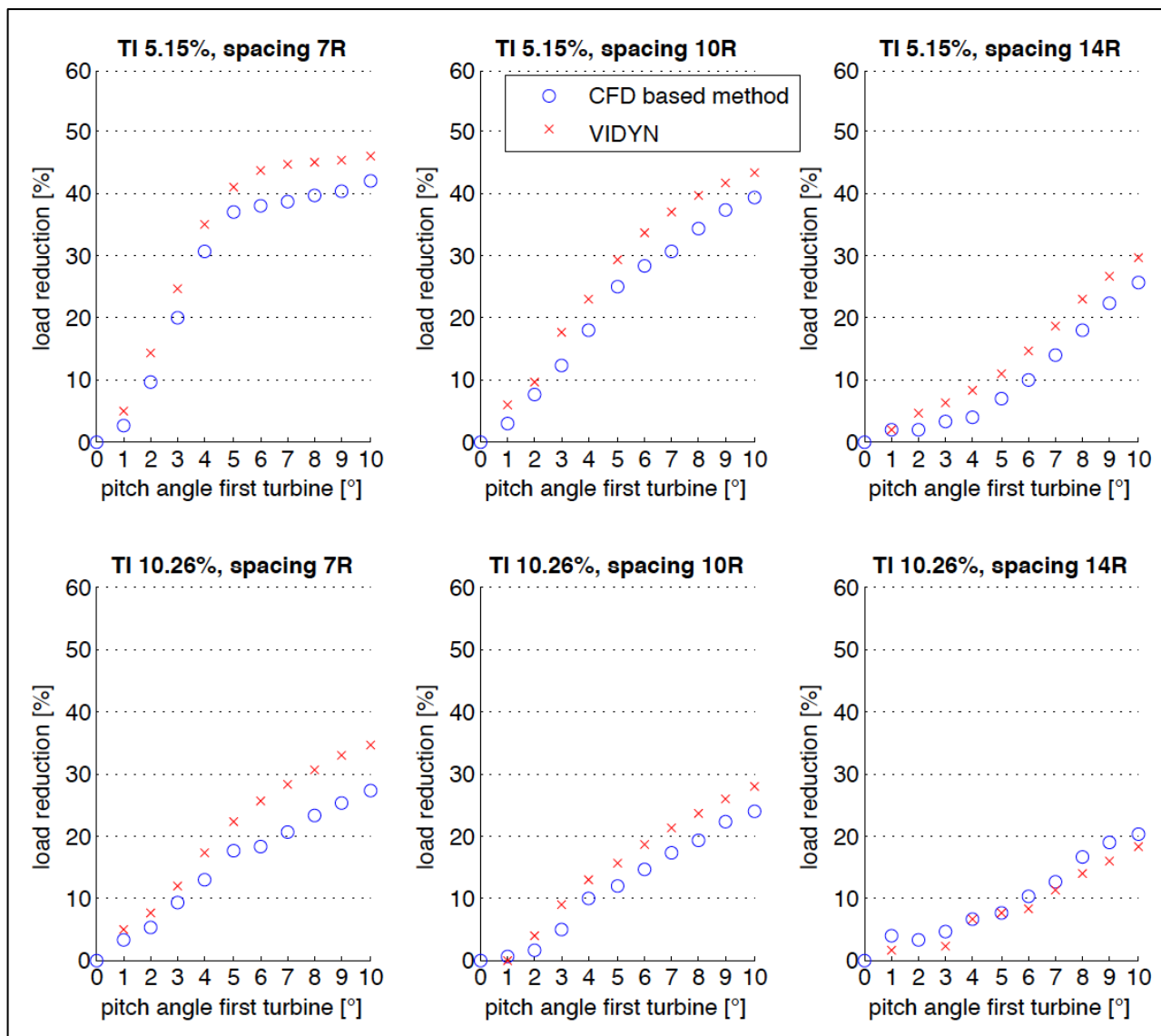
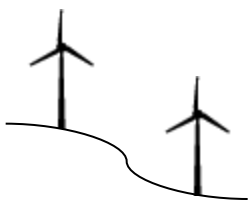
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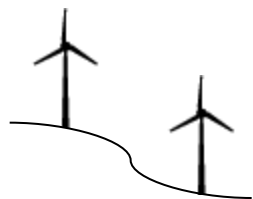
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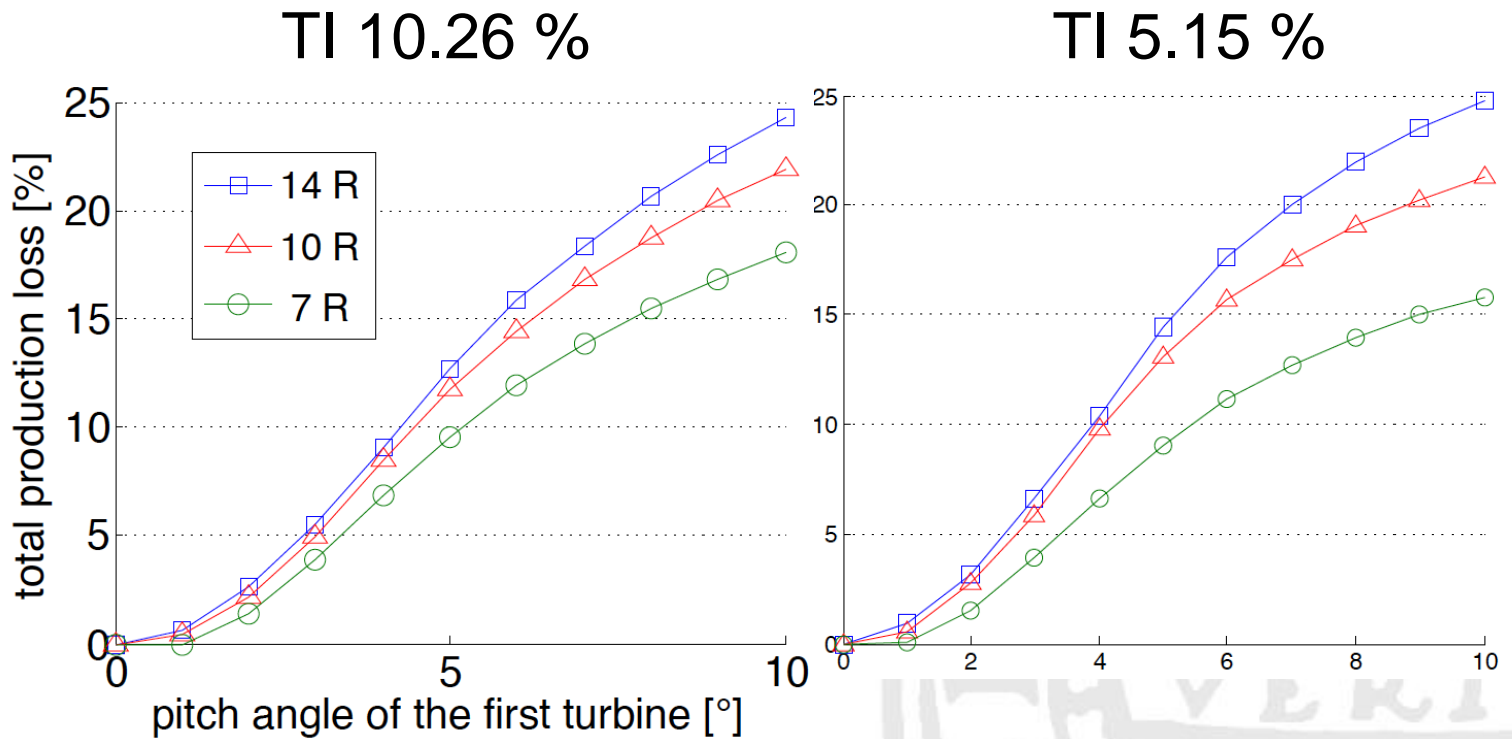
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Total production loss due to curtailment





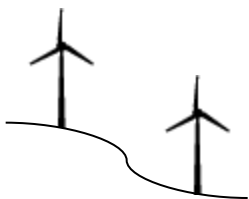
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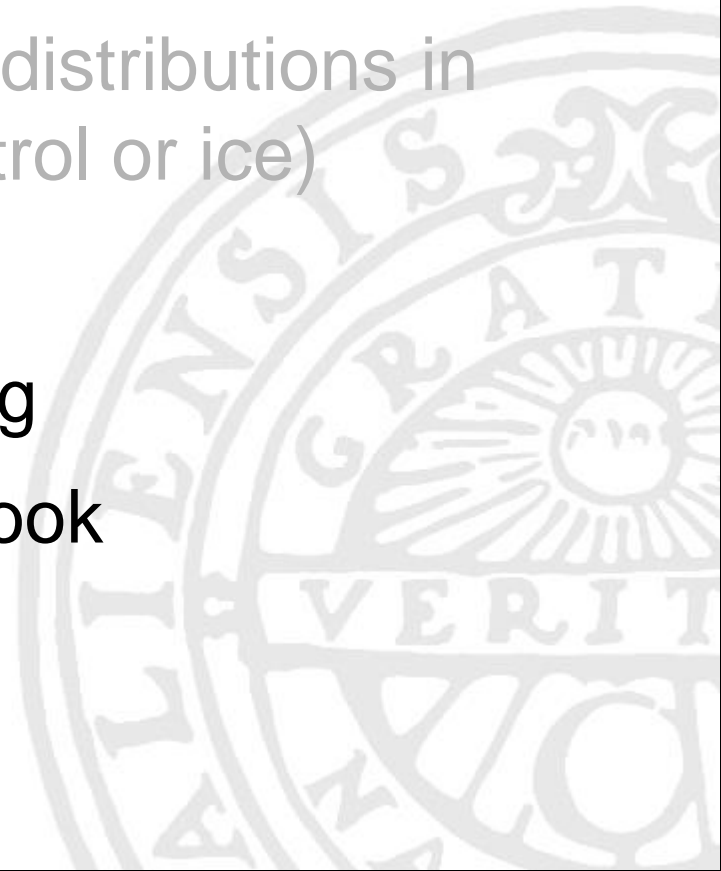
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Farm-Farm interaction

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Horns Rev 1



0km 5km

Horns Rev 2

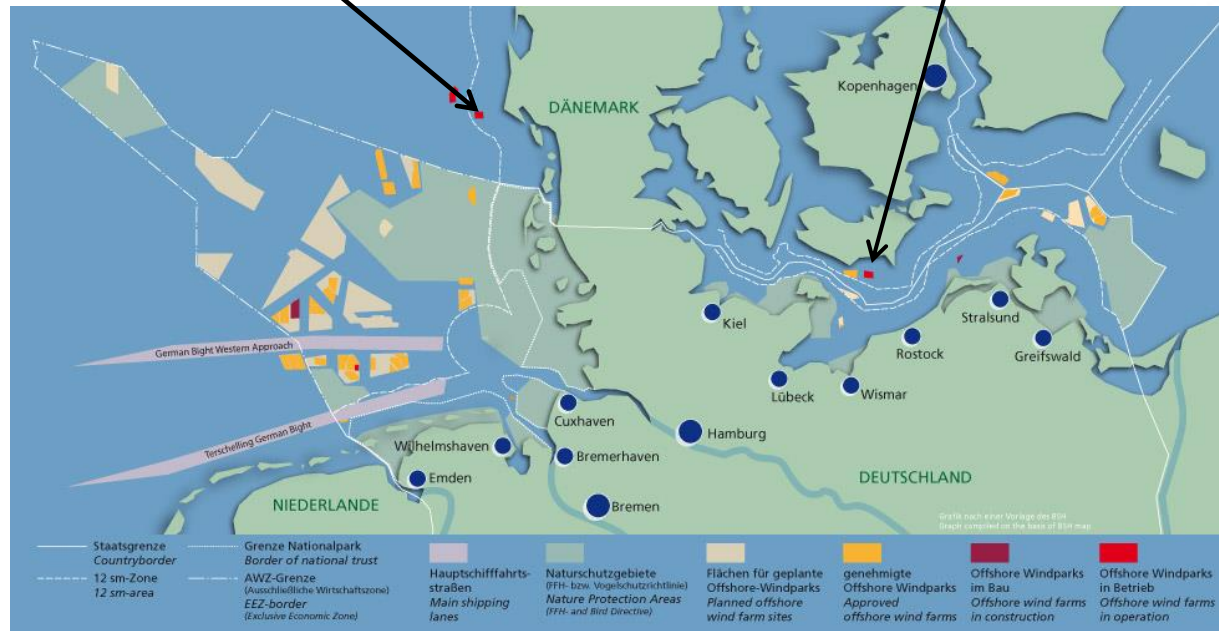
Rødsand 2



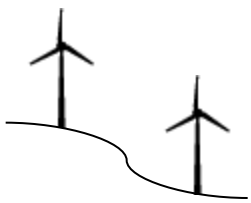
Rødsand 1



0km 5km 10km



<http://www.southbaltic-offshore.eu/regions-germany.html>, 2013-10-06





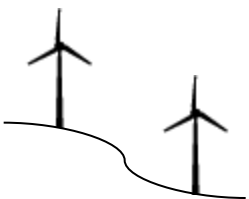
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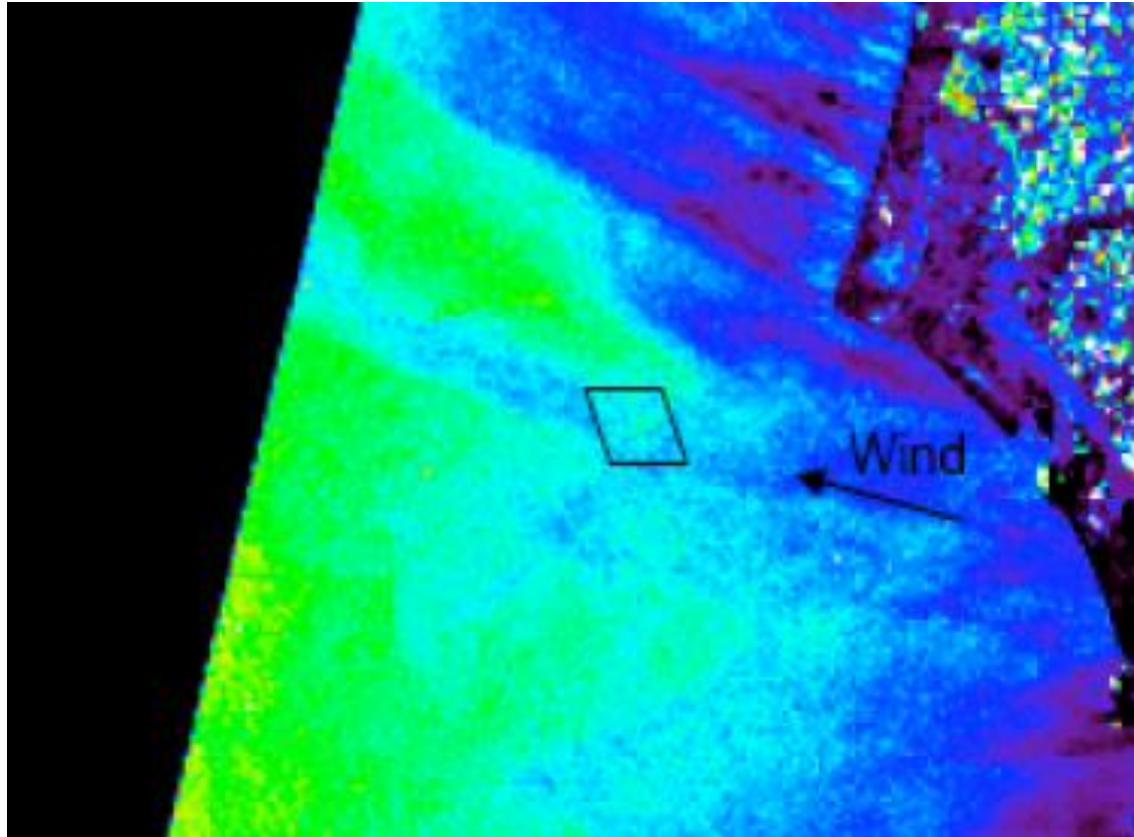
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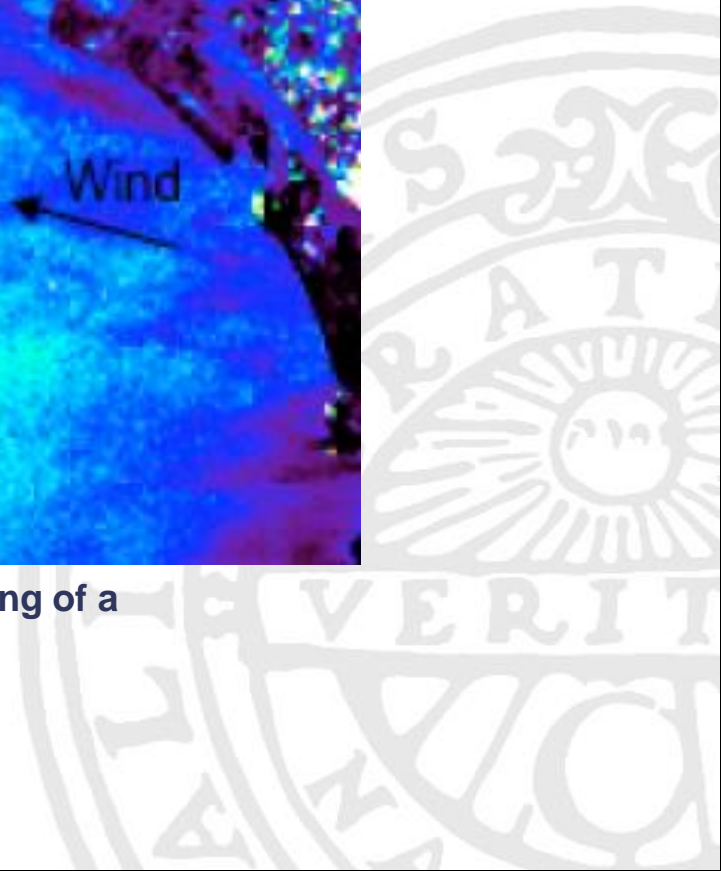
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Farm-Farm interaction



[Sten Frandsen, Kurt Hansen et.al., **The making of a 2nd generation wind farm model**]





Measurements from Horns Rev

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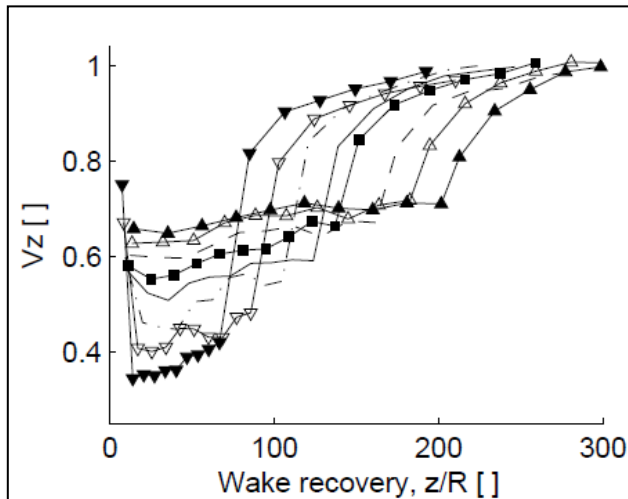
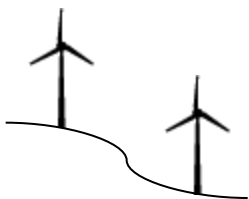


Figure 13. Wake recovery.

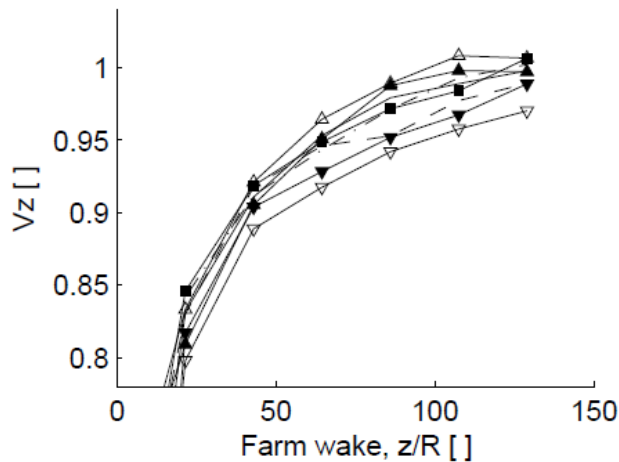


Figure 15. Wake recovery, farm wake.

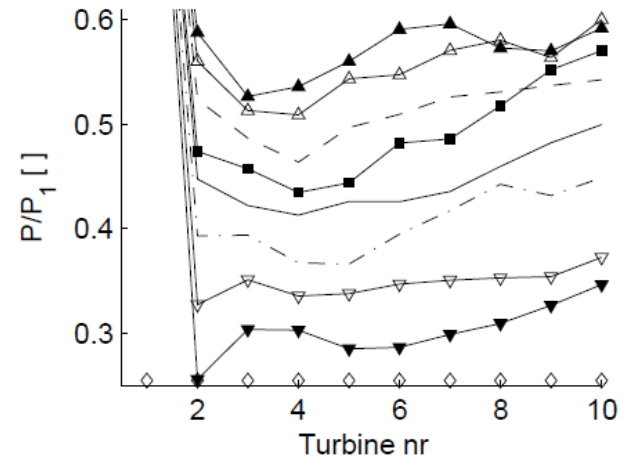


Figure 14. Relative production, turbine 2-10

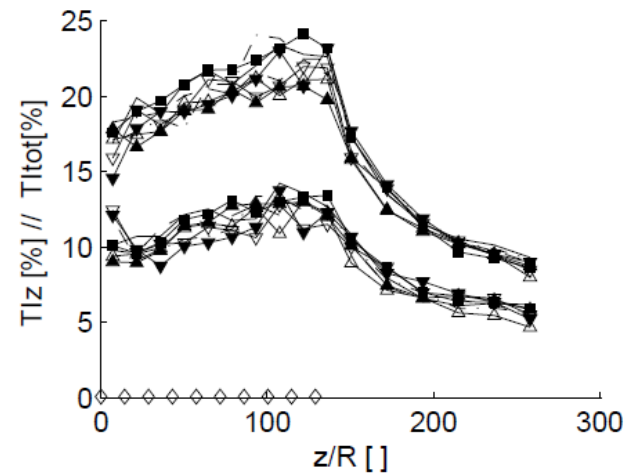


Figure 16. Turbulence intensity.



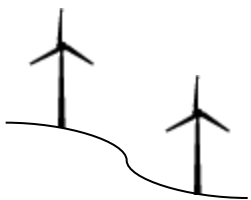
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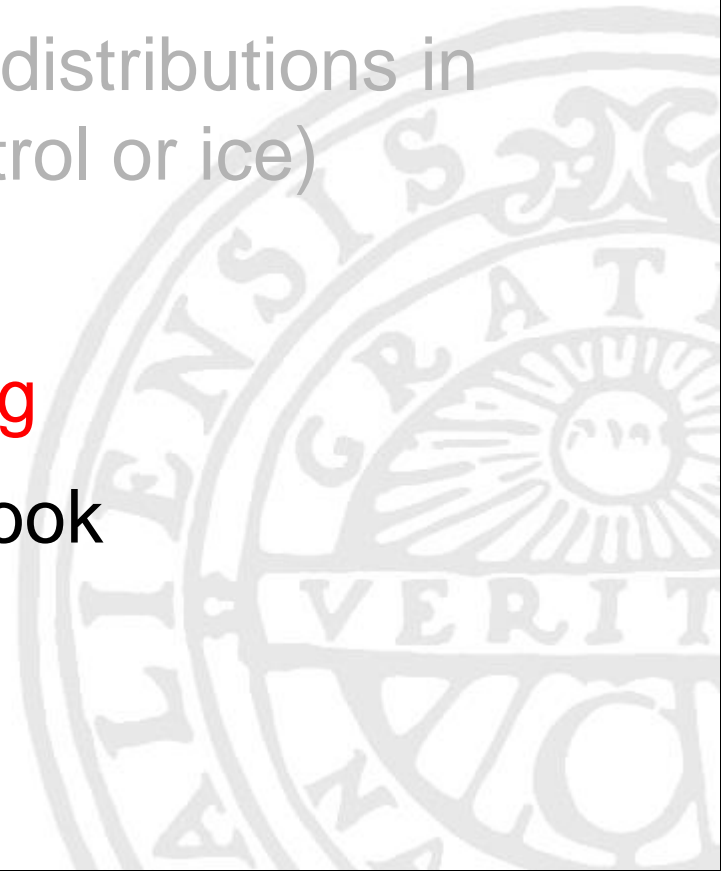
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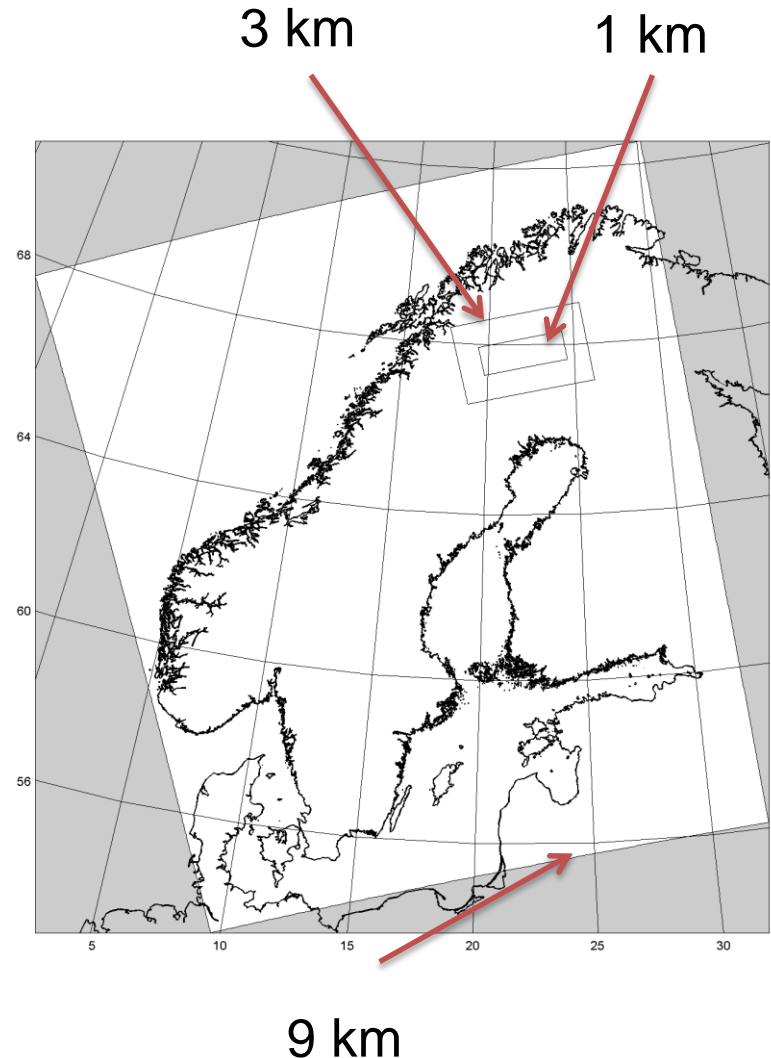
Local mapping of icing – IceWind WP1

- Objective:
 - Study the ice accretion at 5 sites in Sweden and Finland
 - Produce hourly time series for up to 33 years.
 - Cloud condensates etc.
- Tools:
 - Mesoscale atmospheric model
 - Diagnostic model for ice accretion



Atmospheric modelling

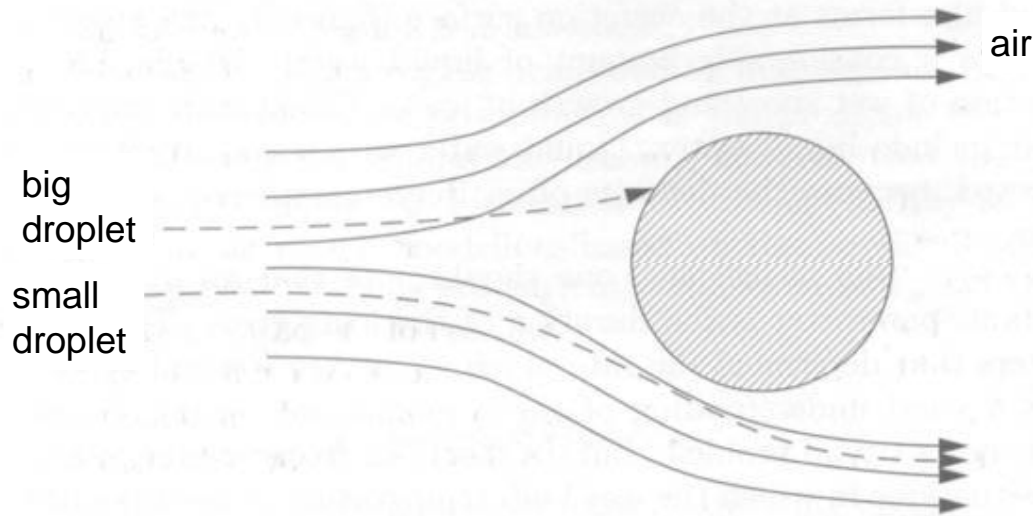
- The Weather Research and Forecast (WRF) model
- Forcing: ERA Interim
- Period length / grid resolution:
 - 33 years / 9 and 3 km
 - 5 years / 1 km
- Hourly values:
 - Wind speed/direction
 - Temperature
 - Cloud condensates etc.



Modelling ice accretion (ISO 12494)

Ice growth rate on a cylinder:

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 w * A * \vec{V}$$



Where

- w is the liquid water content
- A is the cross-sectional area of the object
- V is the wind speed
- α_1 collision efficiency
- α_2 sticking efficiency
- α_3 accretion efficiency

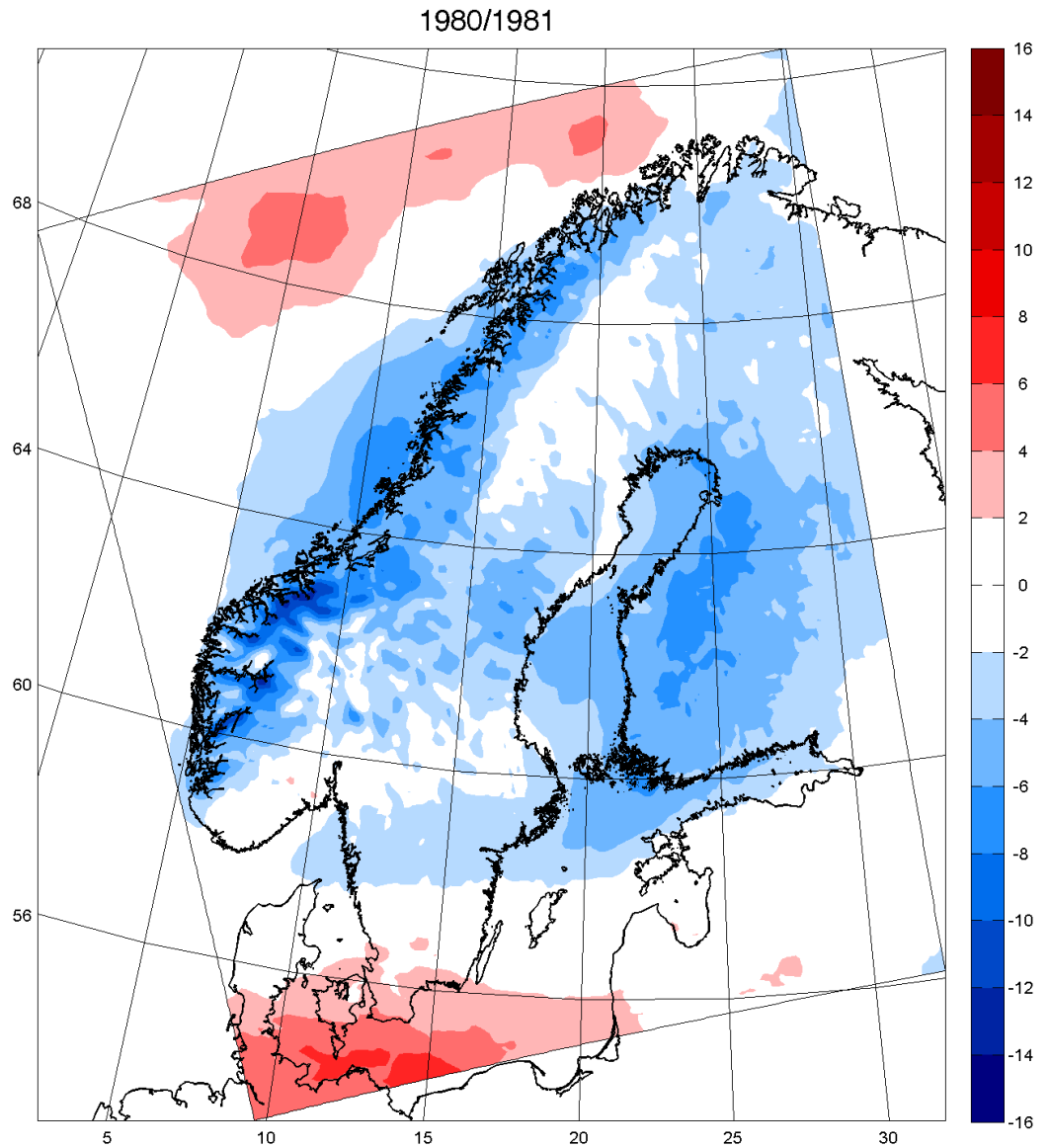
Active icing/icing hour:

Ice growth > 10g/h
on a 1 m tall cylinder 3 cm
in diameter.

Spatial and temporal variability

Wind Index (%)
Seasonal variation
at 120m

($\pm 16\%$ from 33 years mean)



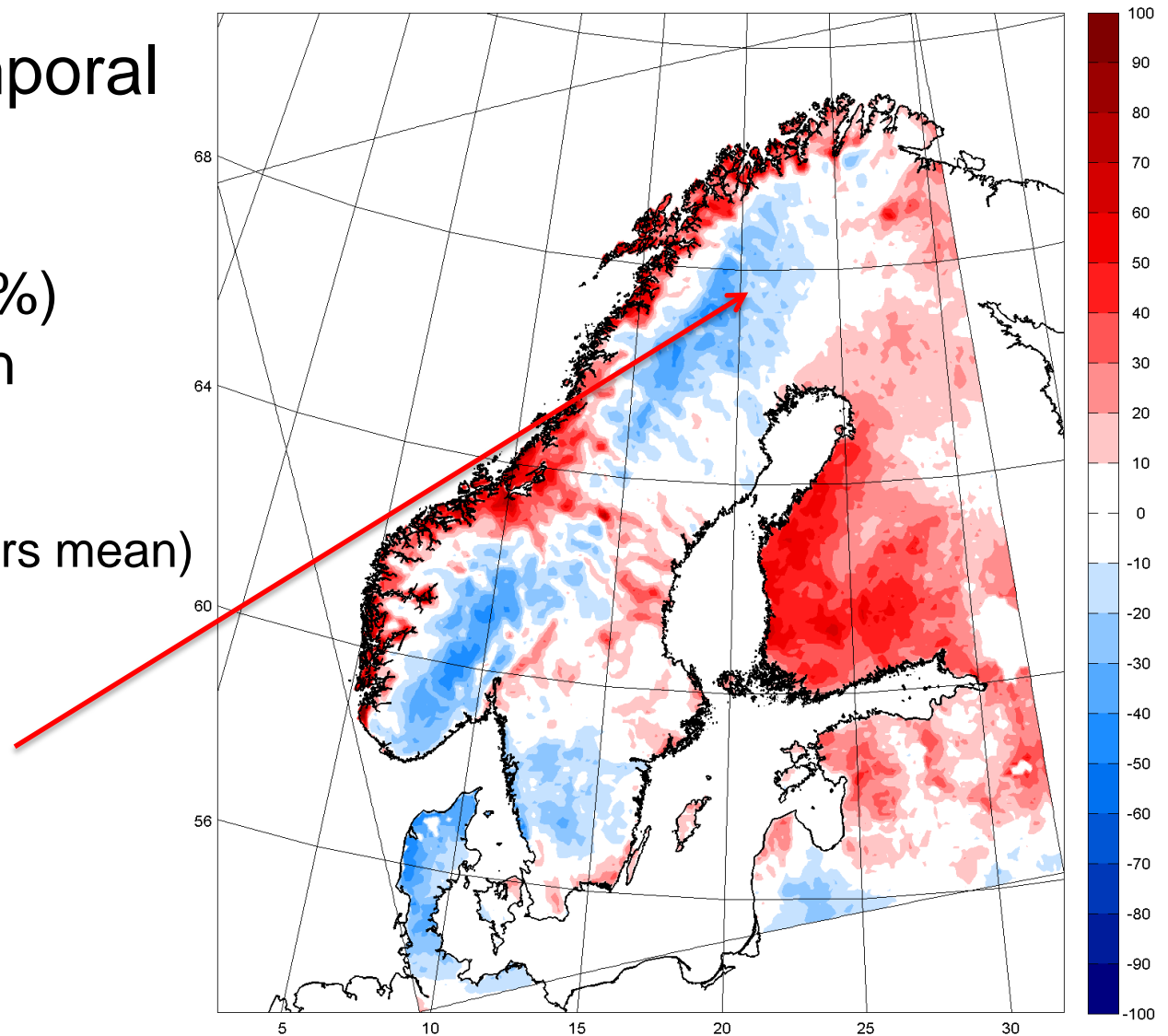
1980/1981

Spatial and temporal variability

Icing hour Index (%)
Seasonal variation
at 120m

(+/-100% from 33 years mean)

On a finer scale

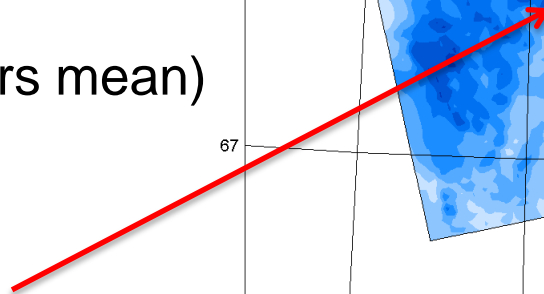


Spatial and temporal variability

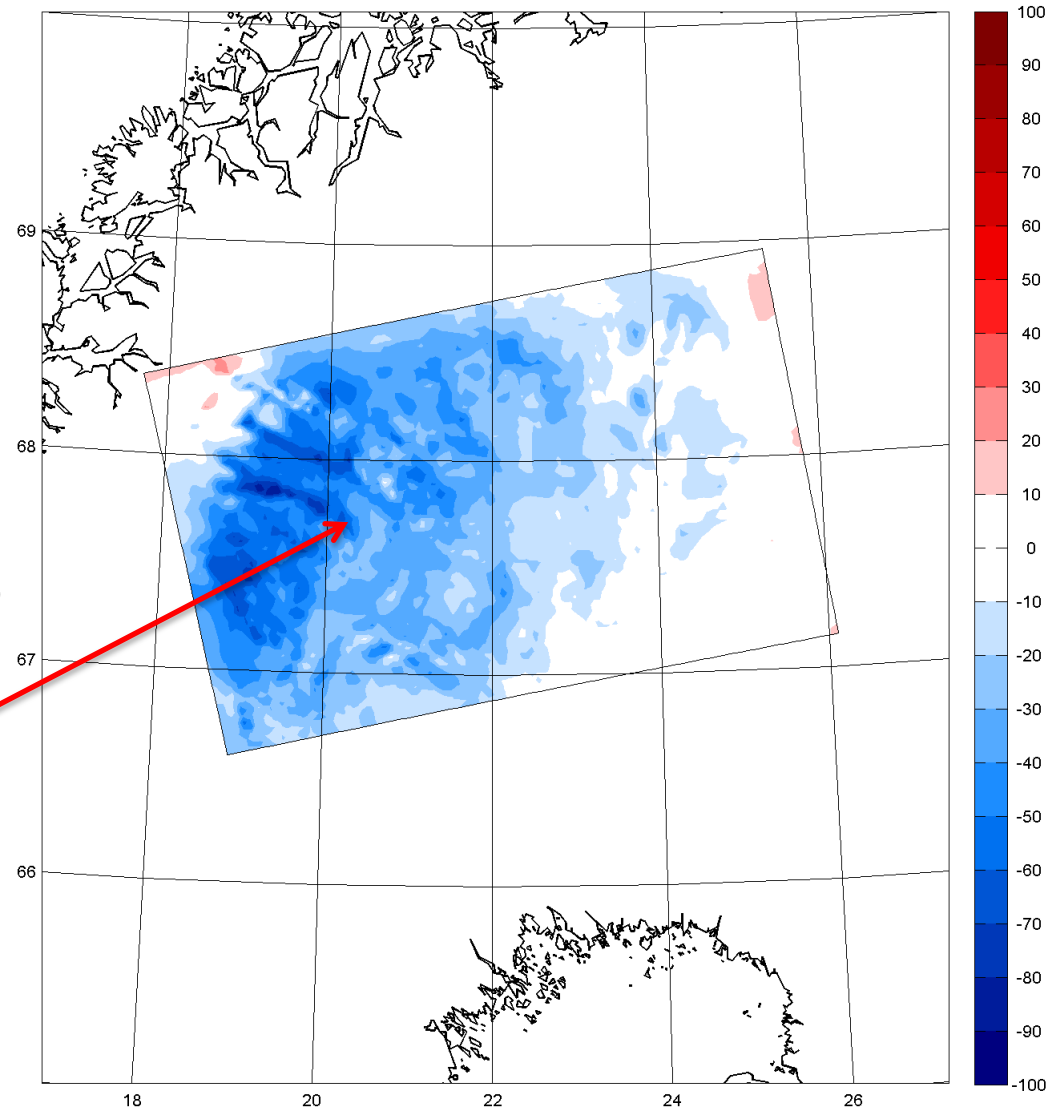
Icing hour Index (%)
Seasonal variation
at 120m

(+/-100% from 33 years mean)

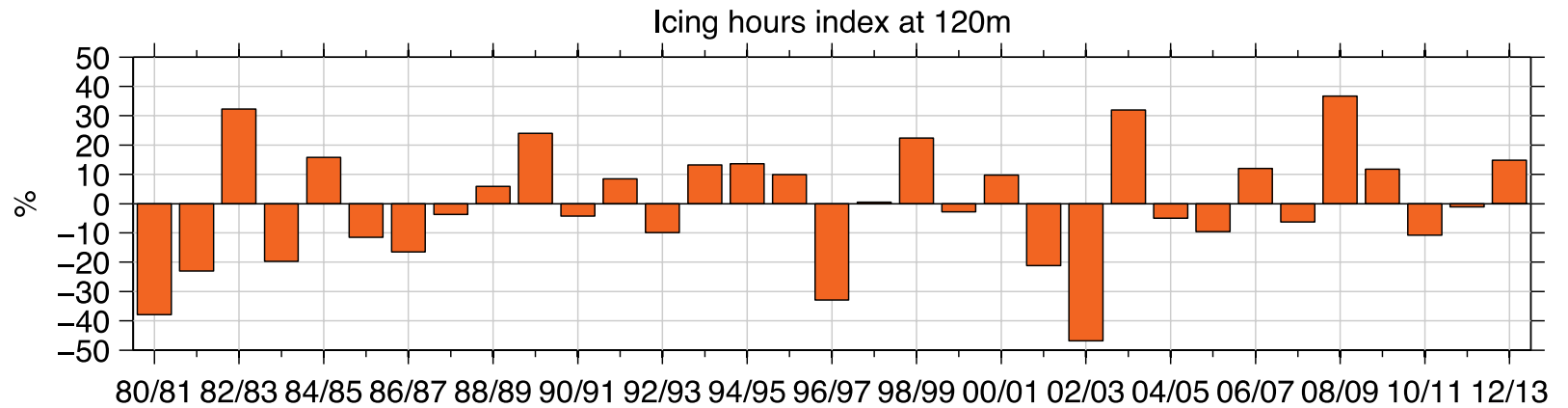
Sjisjka



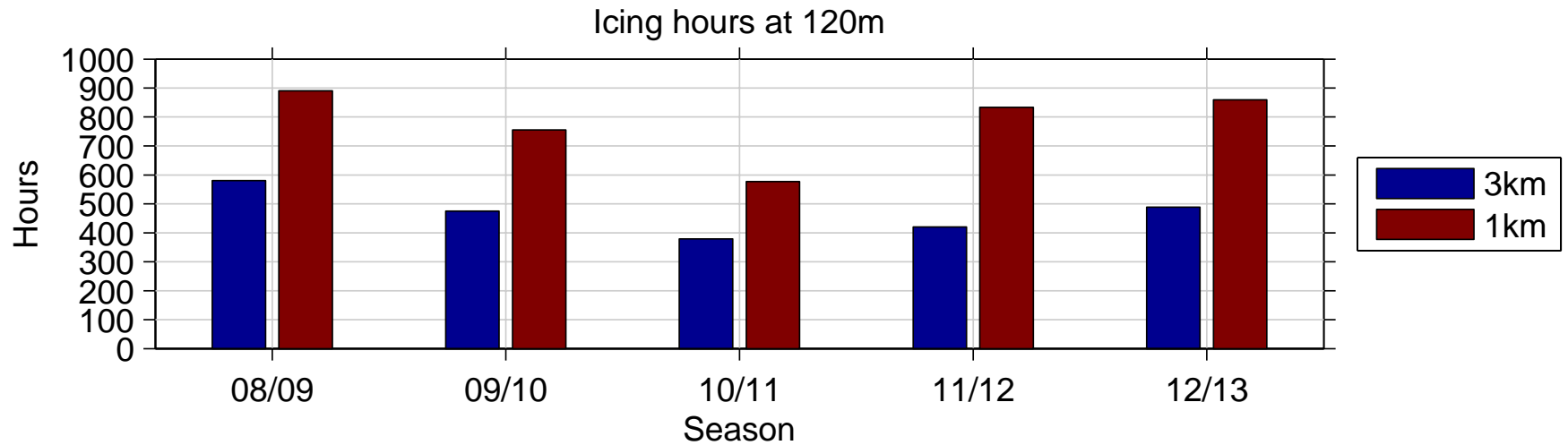
1980/1981



Long-term variability - Sjisjka



Model grid resolution - Sjisjka





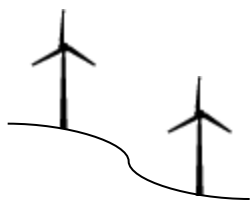
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Conclusions

- ACD-LES tools can be successfully used for production and load simulations related to inflow conditions.
- If L and D are known as a function of ice characteristics – the simulations can be done to estimate production losses and loads.
- A parametric study of Farm-Farm interaction has been performed; Turbulence intensity has large impact, Internal spacing has rather low impact on the wake recovery
- Methods to couple micro- and meso scale models are being developed. (Comparison, Lillgrund, Kjeller and UU)
- A local mapping of the icing climate in parts of northern Sweden and Finland has been carried out
- Large variability in icing conditions (Year to year, Site to site)
- High model grid resolution is needed to properly resolve local terrain features – clouds are typically heavily influenced by local terrain.



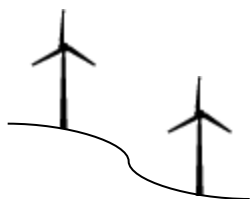
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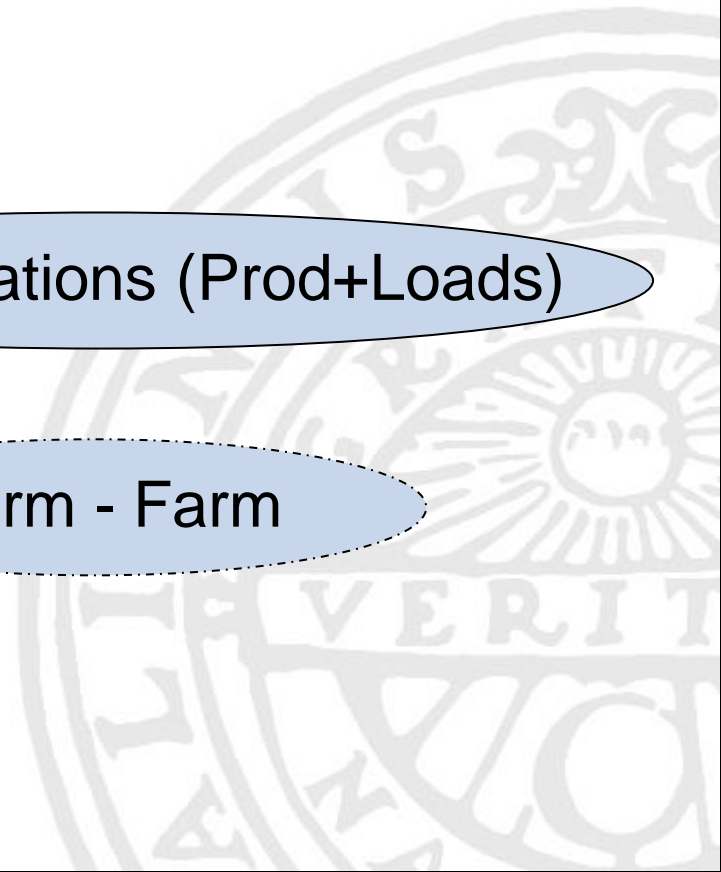
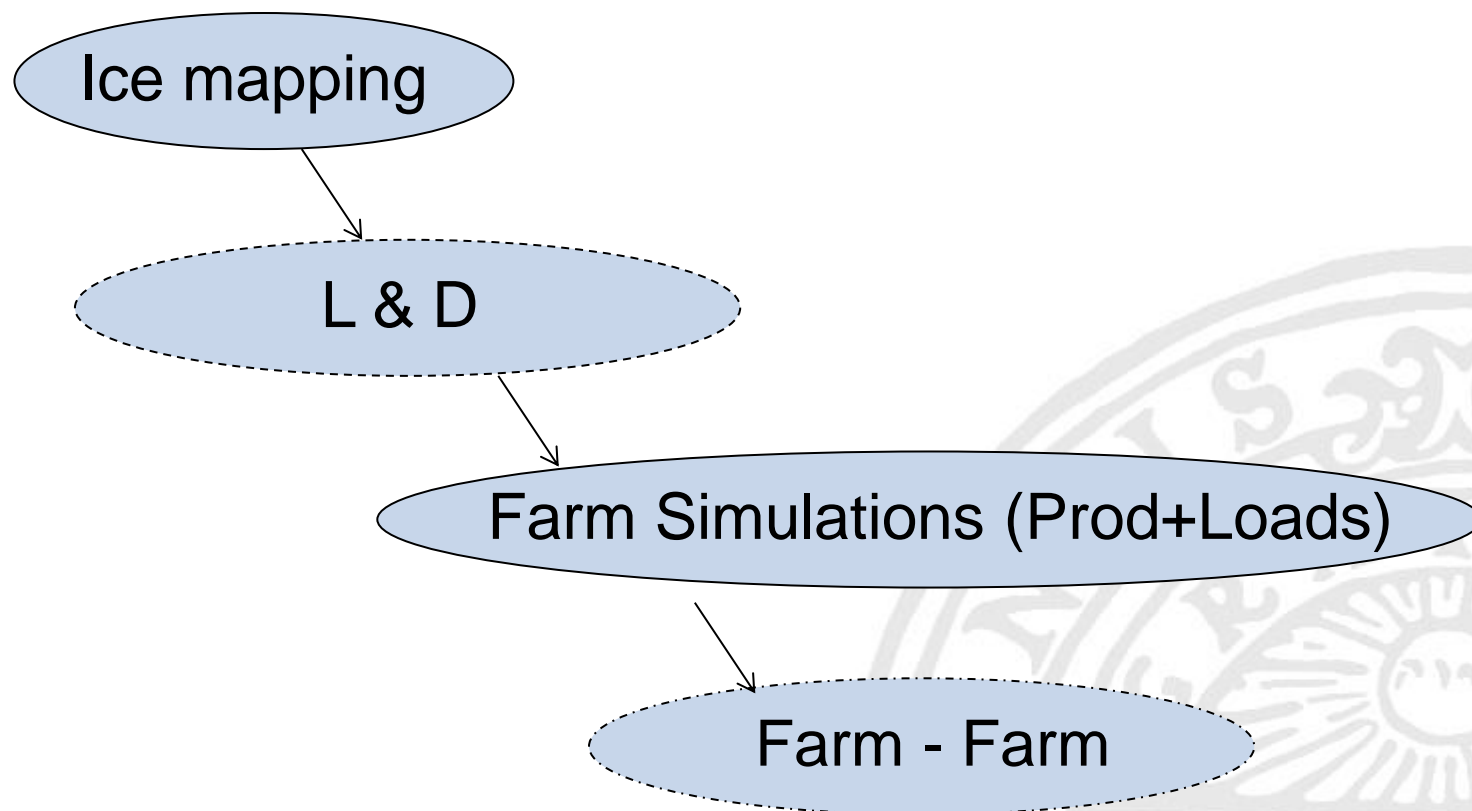
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Future challenges...



A photograph of a wind farm with several turbines scattered across a field. The sky is a bright, golden yellow, suggesting a sunrise or sunset. The turbines are dark silhouettes against the bright background.

**Thank you for your
attention!**

**www.ivanell.se
stefan.ivanell@geo.uu.se**