Estimation of Production Losses Due to Icing –

Development of methods for site assessment and forecasting

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Outline

- Problem description
- Atmospheric modelling
- Ice accretion modelling
- Estimating production losses – Version 1.0
- Estimating production losses – Version 2.0
- Estimating production losses – Version 3.0
  - Adjusted makkonen model
  - Site assessment
  - Forecasting
- Results

Production loss due to icing

Cloud water droplets & T< 0

↓

Accretion of ice on turbine blade

↓

Reduced efficiency of turbine

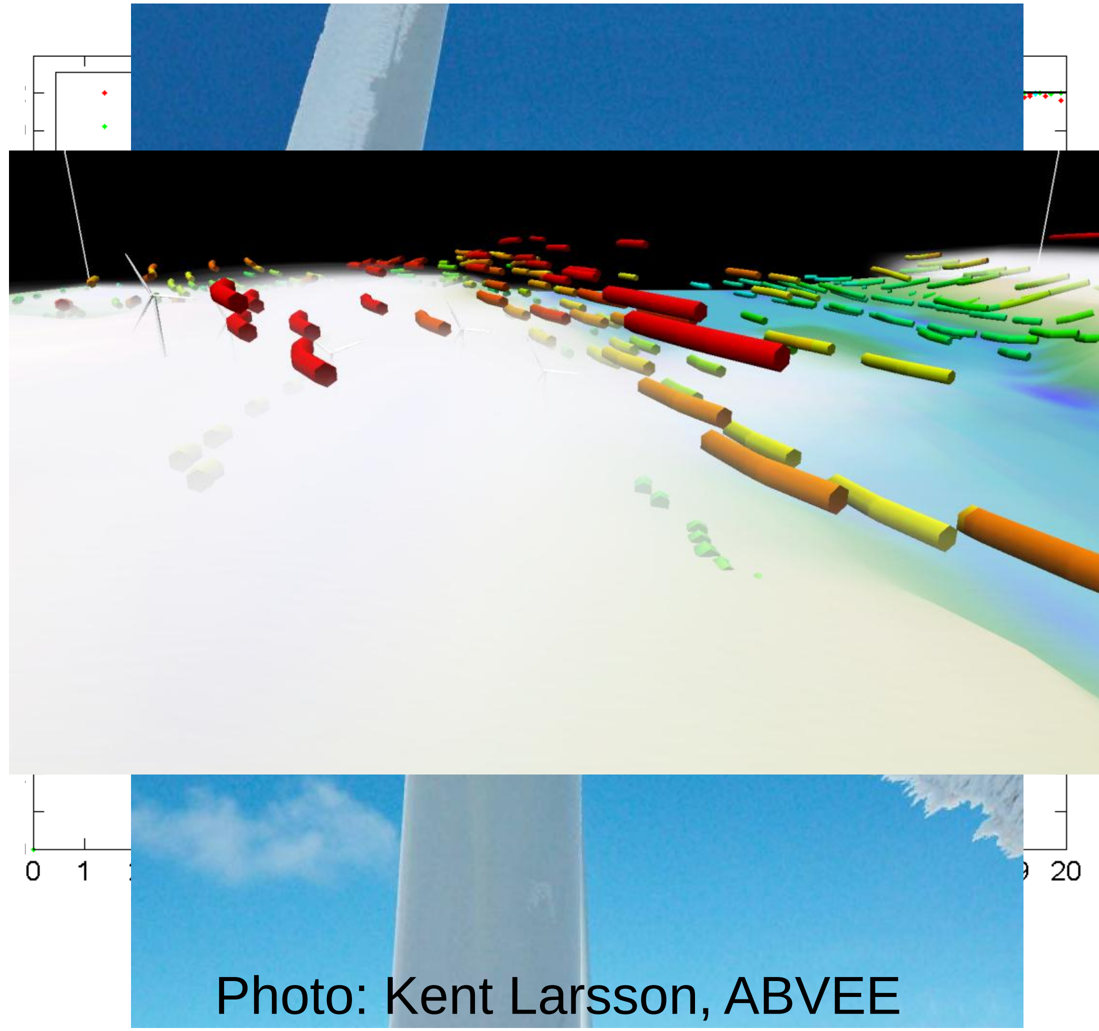
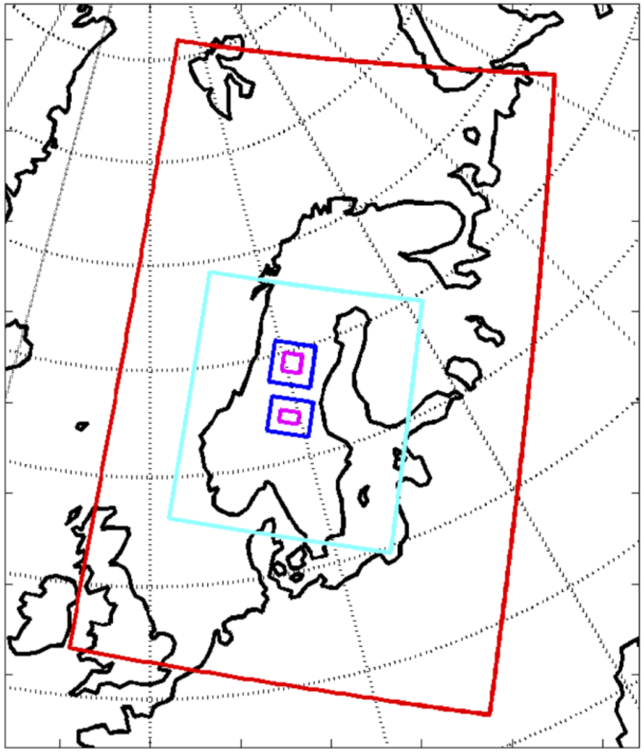


Photo: Kent Larsson, ABVEE

Atmospheric modelling

- WRF model
- Both forecast and hindcast mode
- High resolution ($1x1km^2$)
- Meteorological parameters:
  - Wind speed/direction
  - Temperature
  - Pressure
  - Cloud condensates

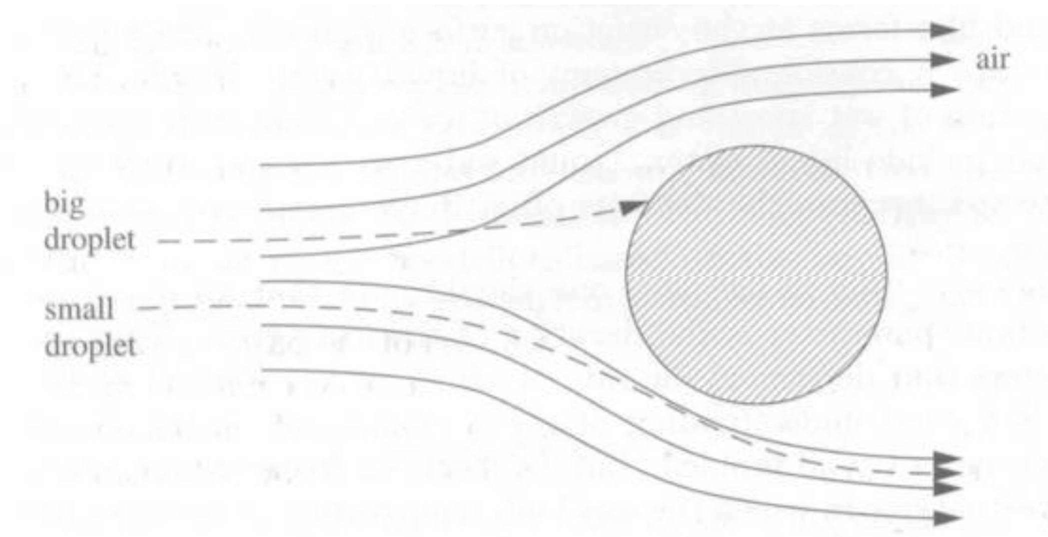
Example of model domains



Modelling ice accretion

A modified version of the "Makkonen model"

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



Assume a rotating cylinder

Growth

- α_1 collision efficiency
- α_2 sticking efficiency
- α_3 accretion efficiency
- wAV water flux

Melting when T > 0 °C

- energy balance

Sublimation when T < 0 °C

- transition from ice to vapour

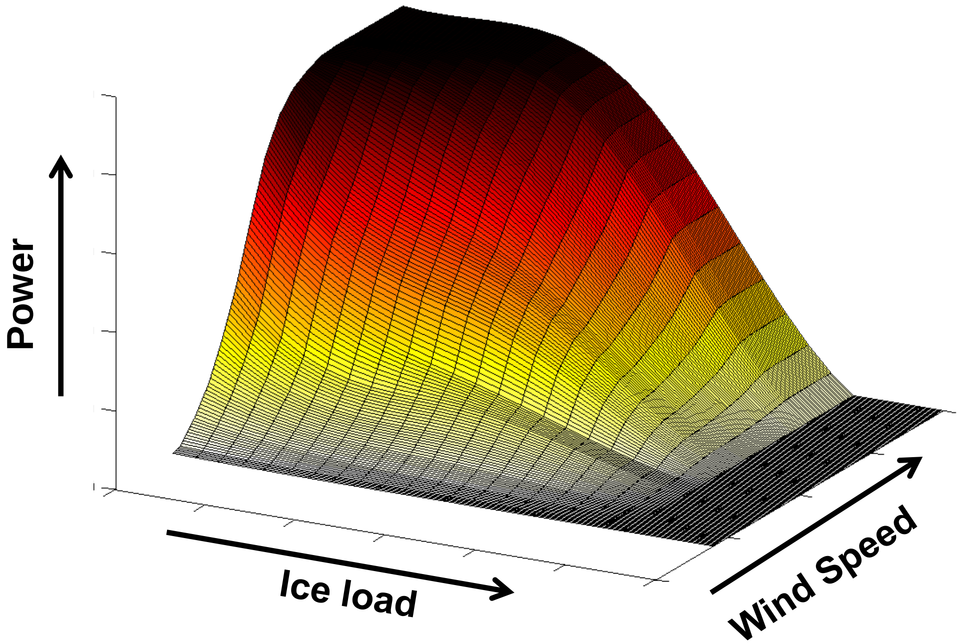
dM/dt = F(wind, temperature, pressure, LWC, droplet size distribution)

Production loss estimates I

3D power curves

Power production as a function of wind speed and ice load.

Power curves derived from wind farm production and ice load measurements.



Production loss often underestimated.

Production loss estimates II

3D power loss curves

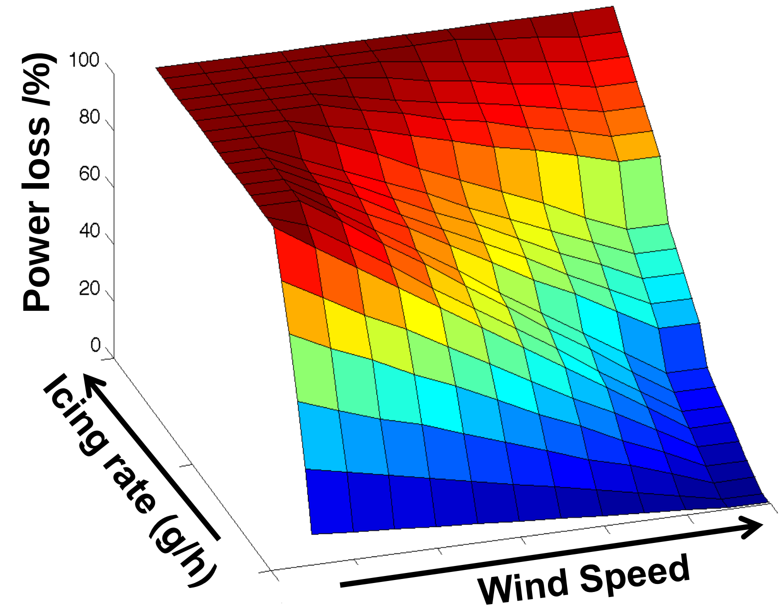
Active icing: Power loss as a function of wind speed and icing rate.

Passive icing: Power loss as a function of wind speed and ice load.

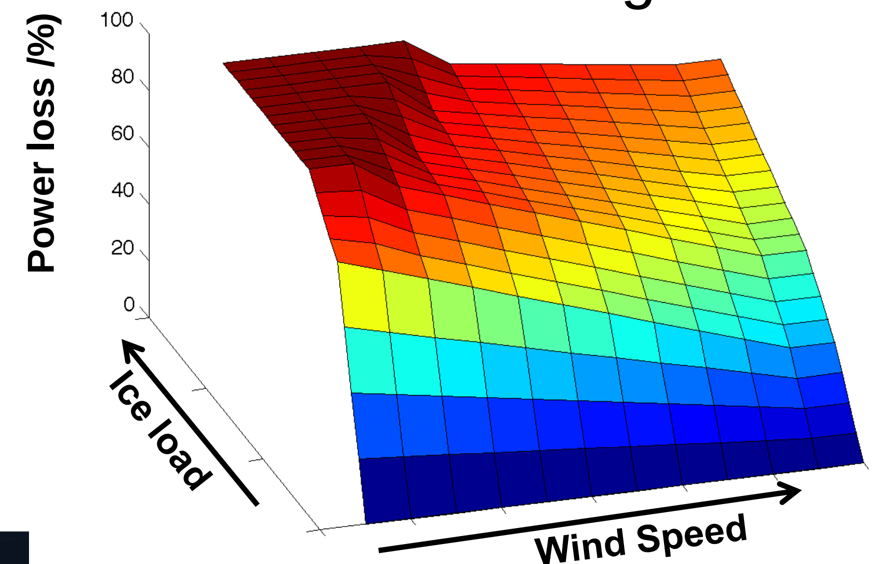
Derived from observations and mesoscale model data.

Improvement but still under-estimated production loss.

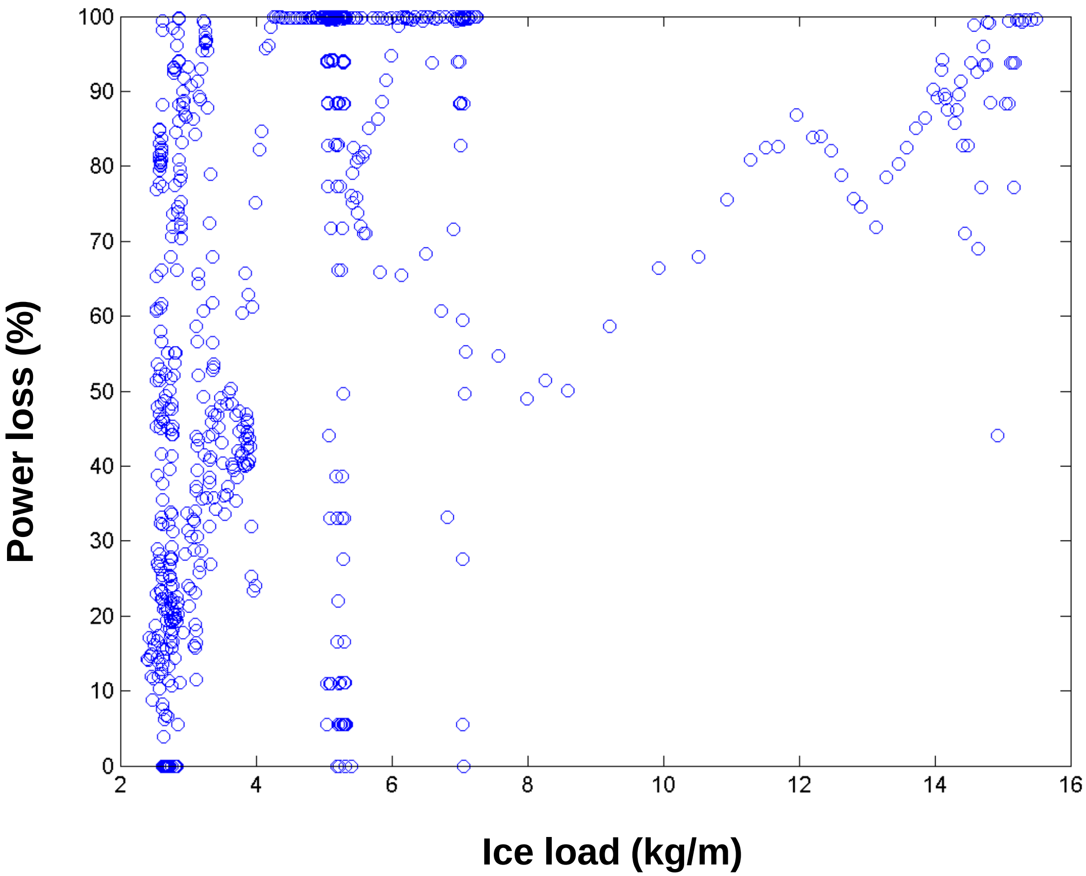
Active icing



Passive icing



Is ice load on a cylinder a good proxy for production losses?



Production loss estimates III

- **Multidimensional power loss functions**

- Observed production loss – Best truth!
- Search for explanatory variables
- Derived from turbine data and mesoscale model data.

Production loss estimates III – Adjusted Makkonen model

- Look at cloud water flux profile over rotor disk
- Ice accretion on area representative of blade
- Use relative wind speed seen by blade
- Adjust sublimation to better represent new surface area

Production loss estimates III – Site assessment

Goal:

Estimate long term effects from icing on monthly and annual power production

Requires:

- Generic production loss model
  1. Independent of site and farm layout
  2. Preferably work reasonably for different turbine types

Production loss estimates III – Forecast

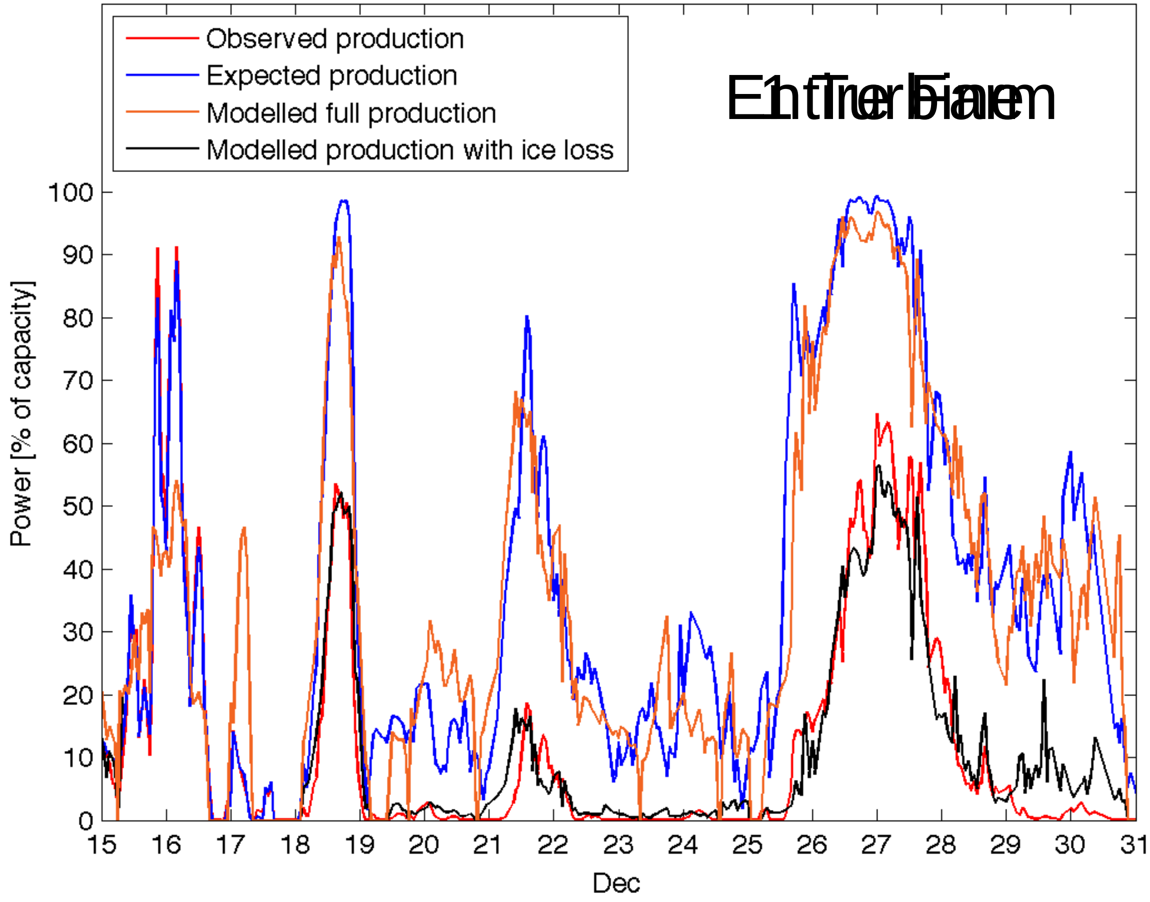
Goal:

Include effects from icing in hourly power production forecasts

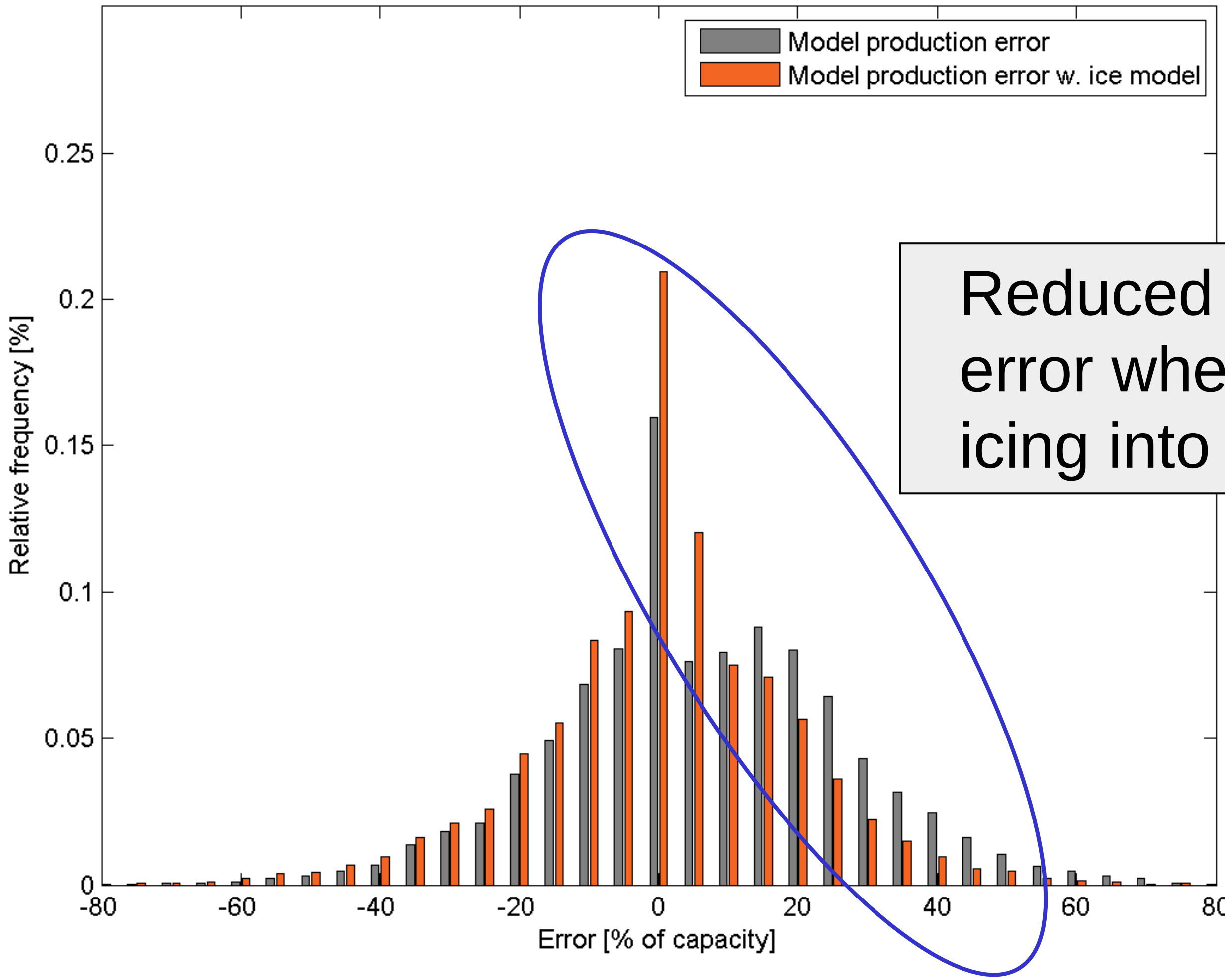
Requires:

- Specific production loss model
  1. Individual empirical function for each turbine
  2. Takes local site features into account
  3. Includes wake effects

Results

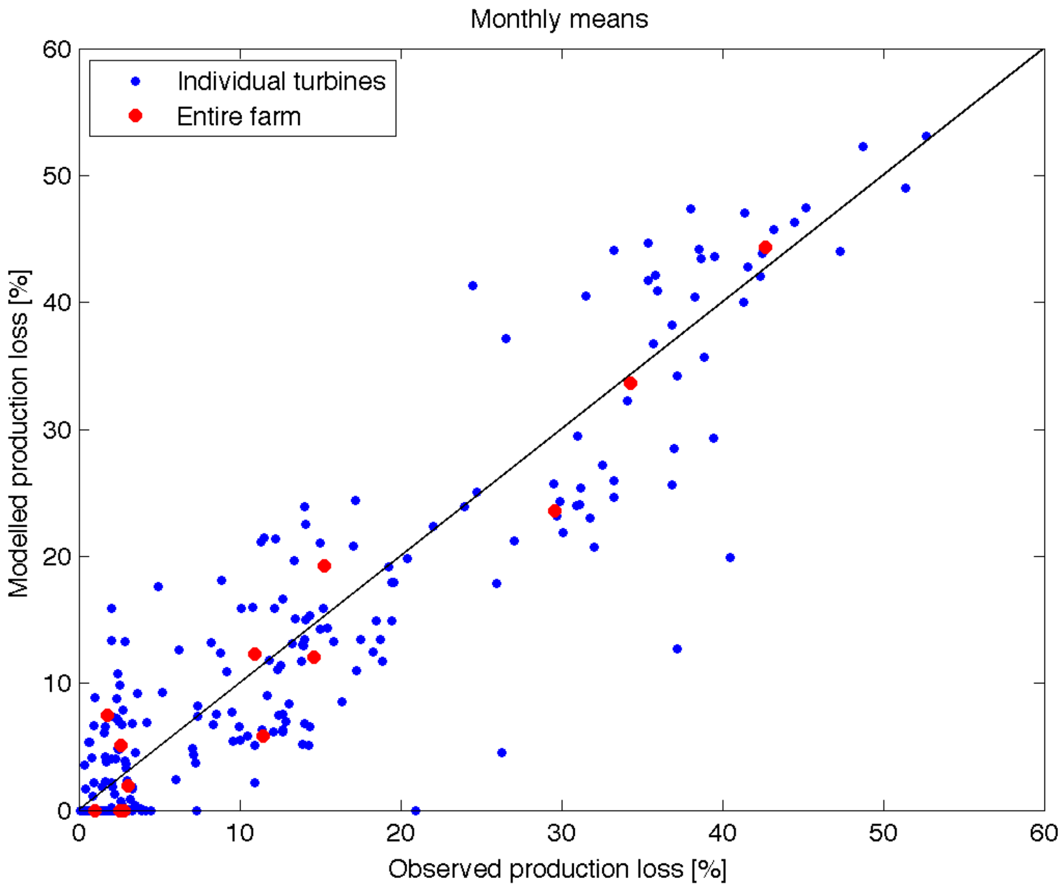

Observed production
Expected production
Modelled full production
Modelled production with ice loss
Power [% of capacity]
0
10
20
30
40
50
60
70
80
90
100
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
Dec

Results



Reduced forecast error when taking icing into account.

Results

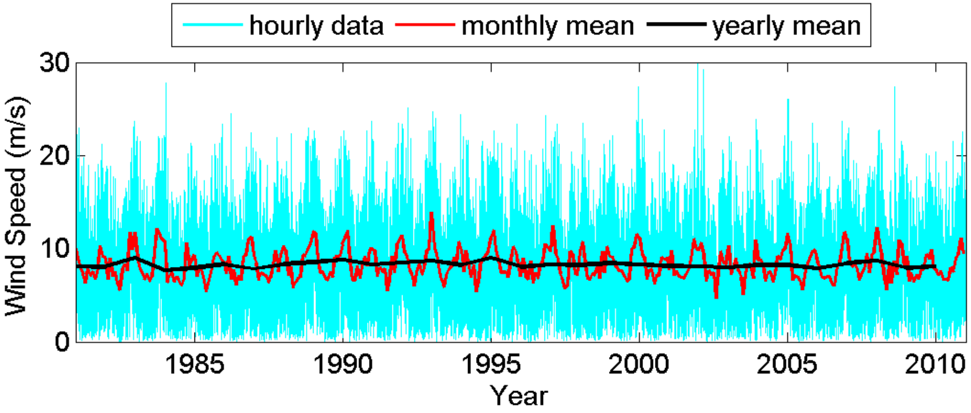


Monthly power losses (%)		
Obs	Model	YYYYMM
3	0	201009
15	19	201012
11	12	201101
34	34	201102
2	7	201103
3	2	201104
3	0	201109
1	0	201110
11	6	201111
30	24	201112
43	44	201201
15	12	201202
3	5	201203

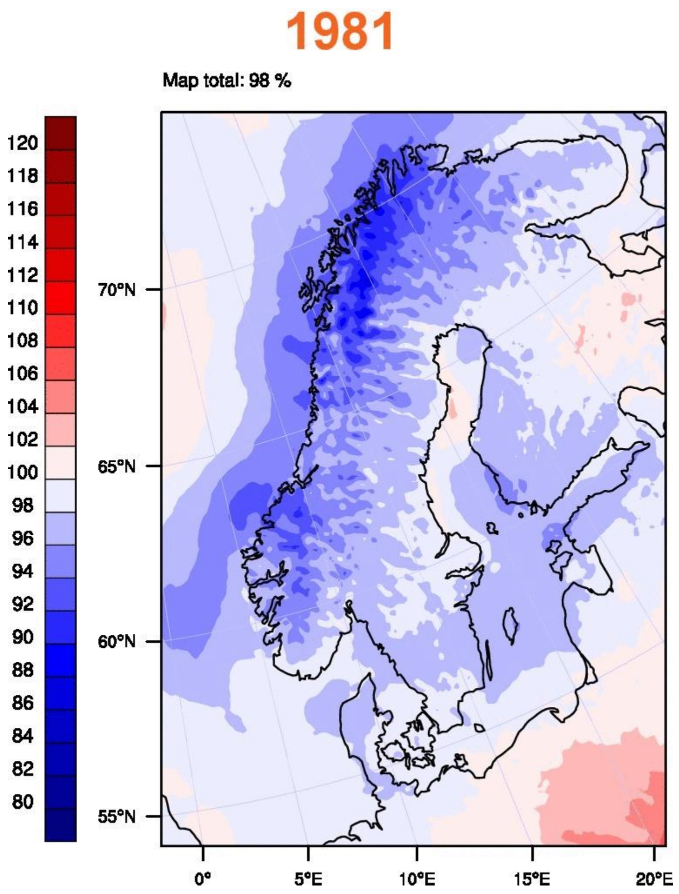
Icing climate

Long-Term Reference

30+ years of hourly values of wind speed, temperature, cloud water etc. from WRF runs on a 9x9 km^2 model grid.



Wind index



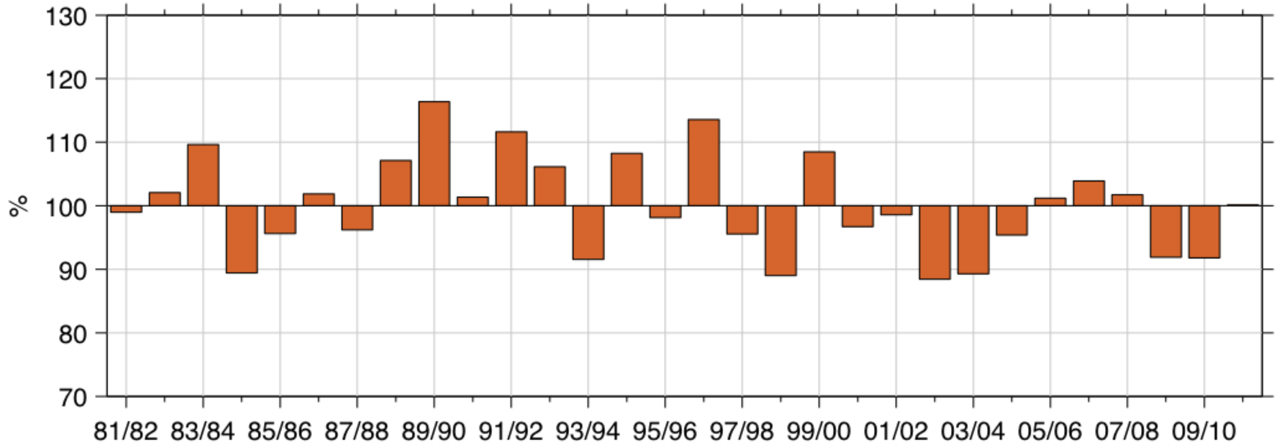
Icing climate

"Yearly" (May 1st – April 30th) deviations from 30-year mean

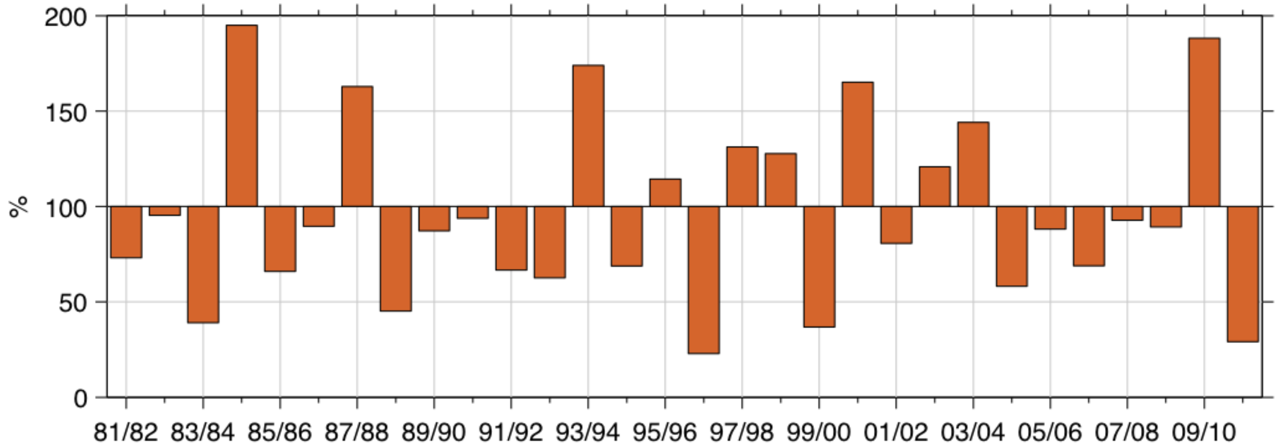
There is a substantial yearly variation in production and production losses.

Production losses in individual years can be twice as large as the long term mean.

Production index



Production loss index



Conclusions

- Ice load on cylinder may not be the best proxy for estimating production losses.
- The multidimensional power loss model looks promising for site assessment and forecasting.
- In icing climate studies, it is likely that some 20-30 years are needed to capture the variability in the icing climate.