Operational forecasting of icing and wind power at cold climate sites

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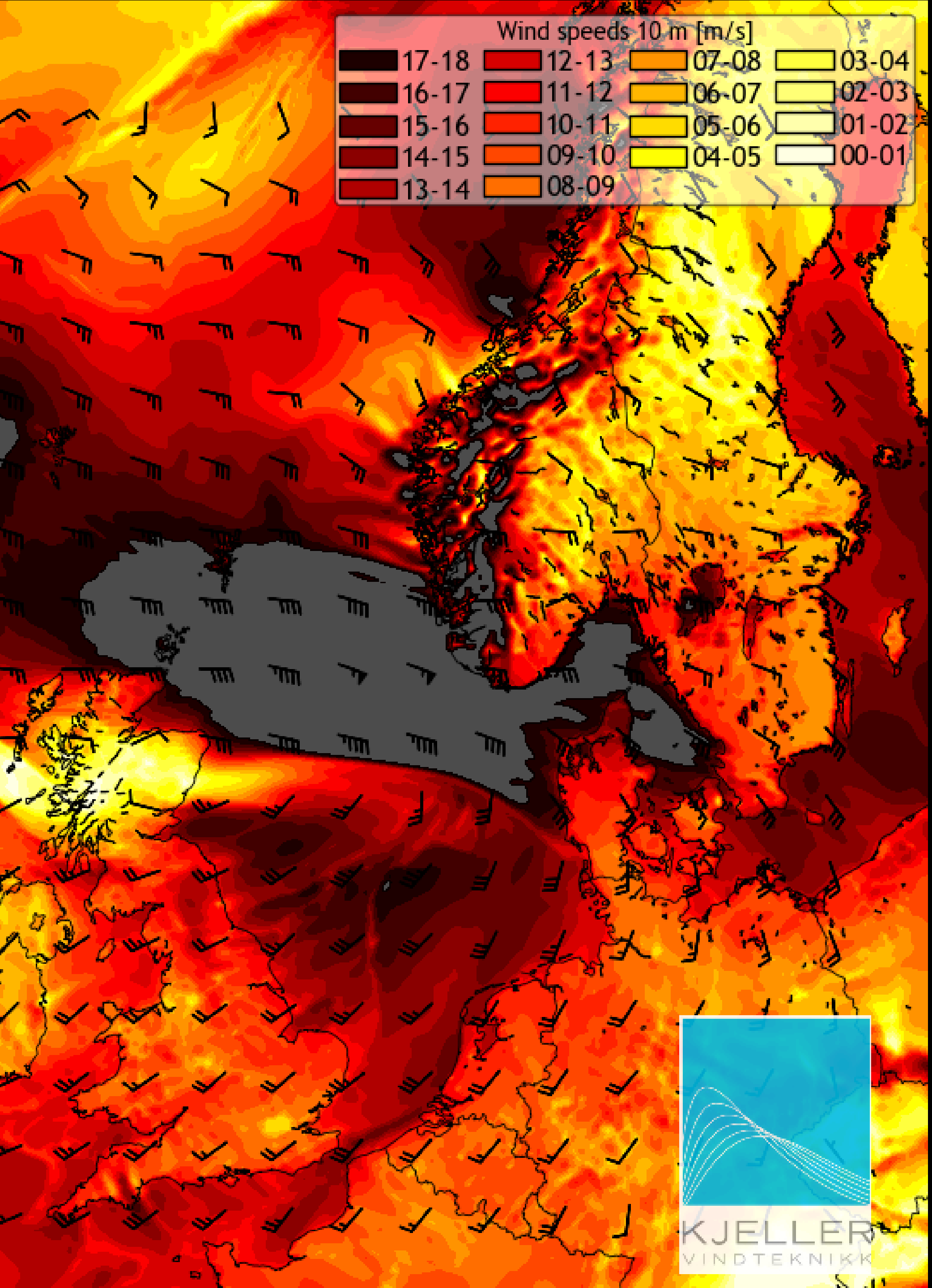
Power forecasts



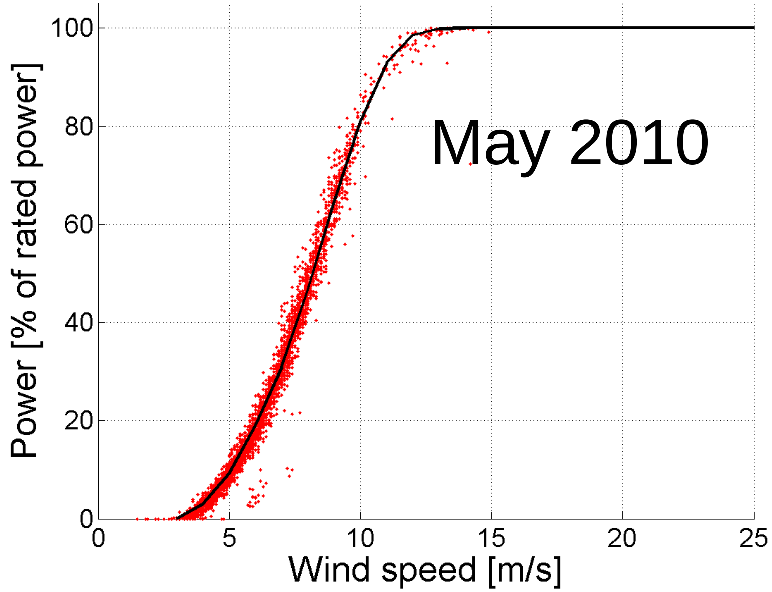
- WRF simulations at 6km x 6km resolution
- 4 times daily
- GFS 48 hour forecasts

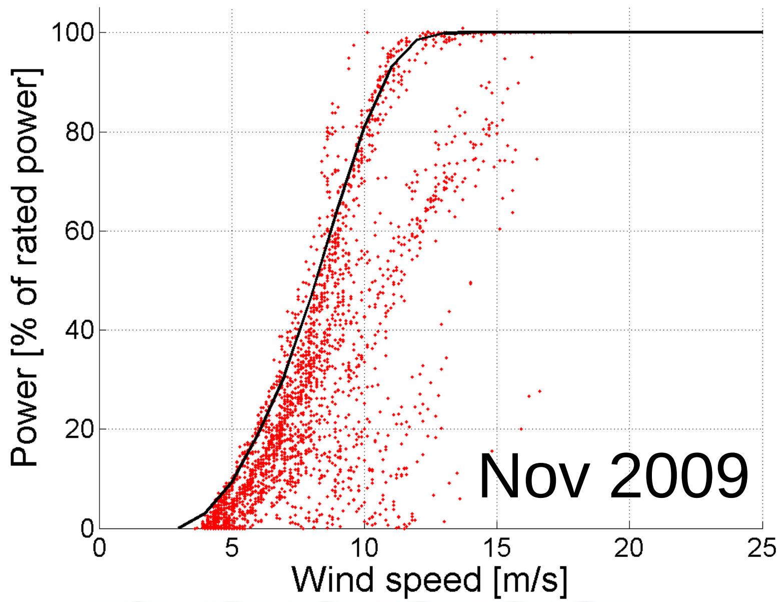


Forecasting of icing

The aim is to know **when** icing will occur:

- Power trading
- Blade heating systems:
  - Start the heating before icing starts
  - Avoid unnecessary stops during heating
- Risks of ice throw / ice fall
  - Planning of maintainance
  - Public safety





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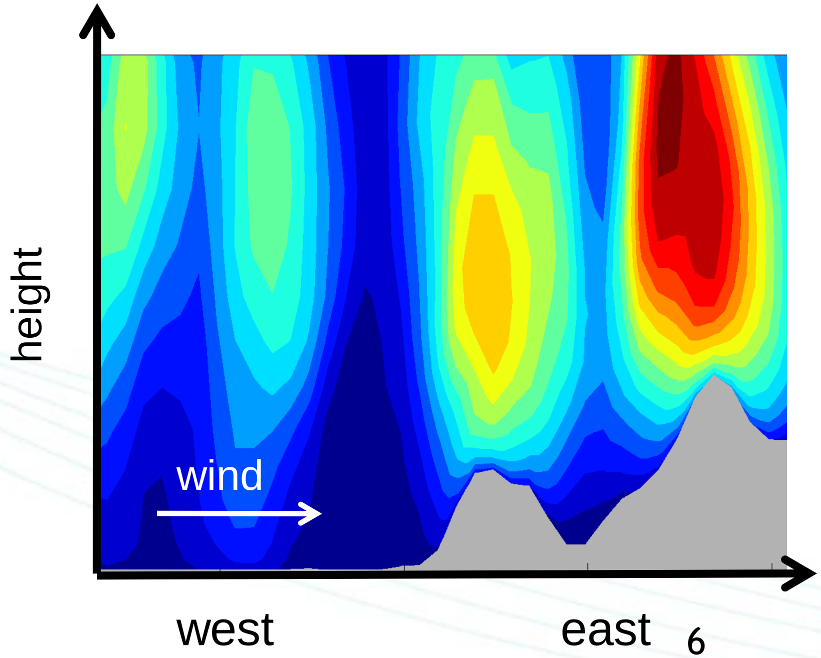
Icing conditions

- Temperatures below freezing
- cloud or fog containing small water droplets
- Something to freeze to

→ in-cloud icing

- Lifting of airmasses

→ condensation



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Calculation of in-cloud icing

- Icing intensity calculated according to ISO 12494:

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

α_1- collision efficiency, α_1=f(V,d,D)

α_2- sticking efficiency, $\alpha_2 \approx 1$

α_3- accretion efficiency, α_3= f(V,d,w,T,e,D,α_1)

w – cloud liquid water content

A – collision area, perpendicular to flow

V – Wind speed

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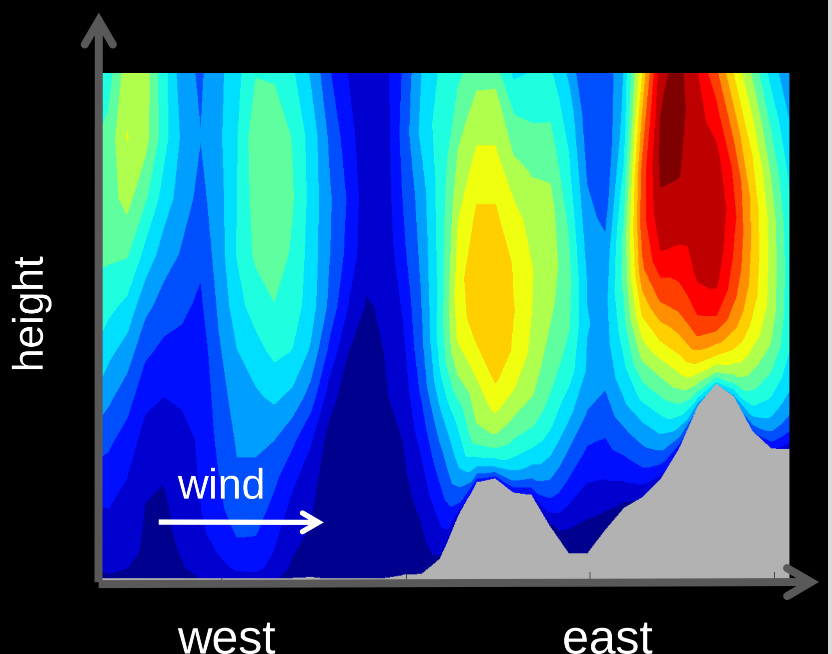
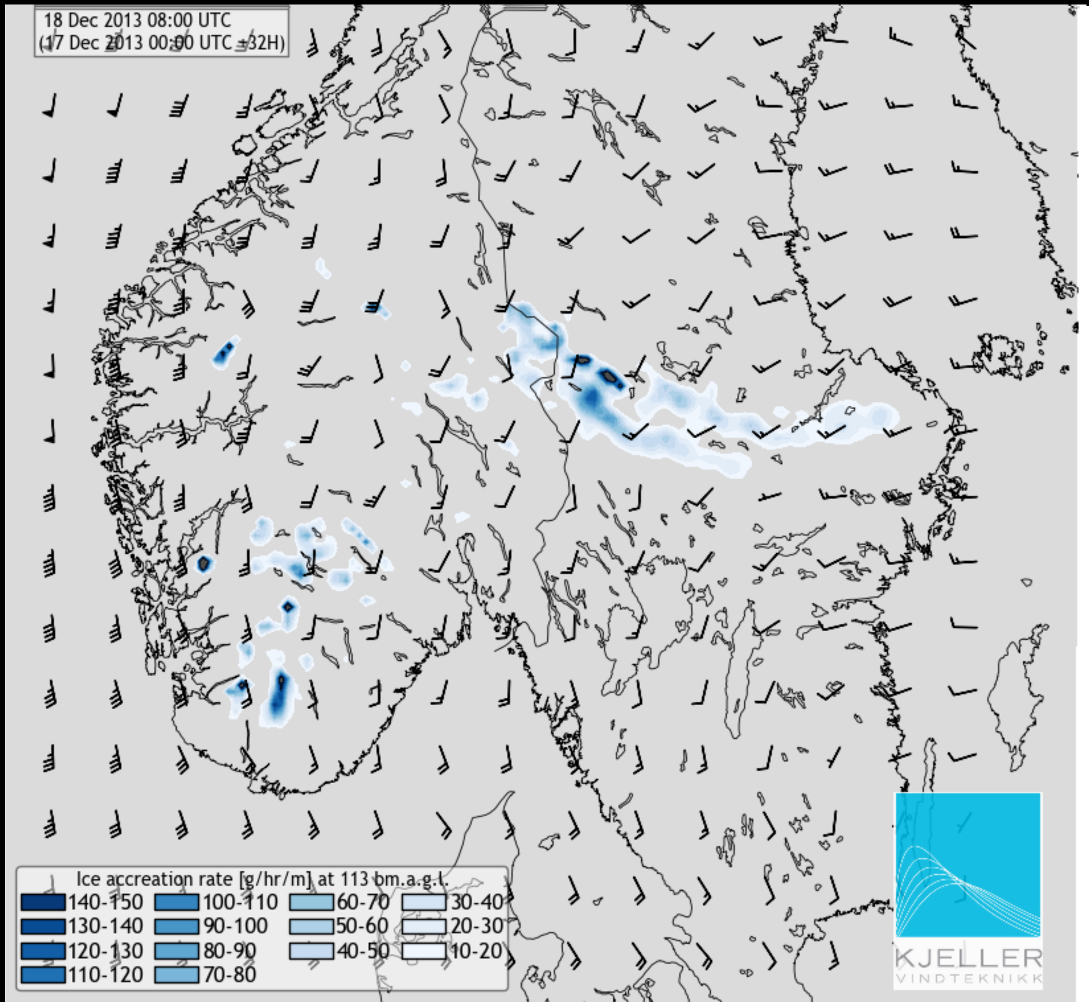
Forecasting – icing intensity

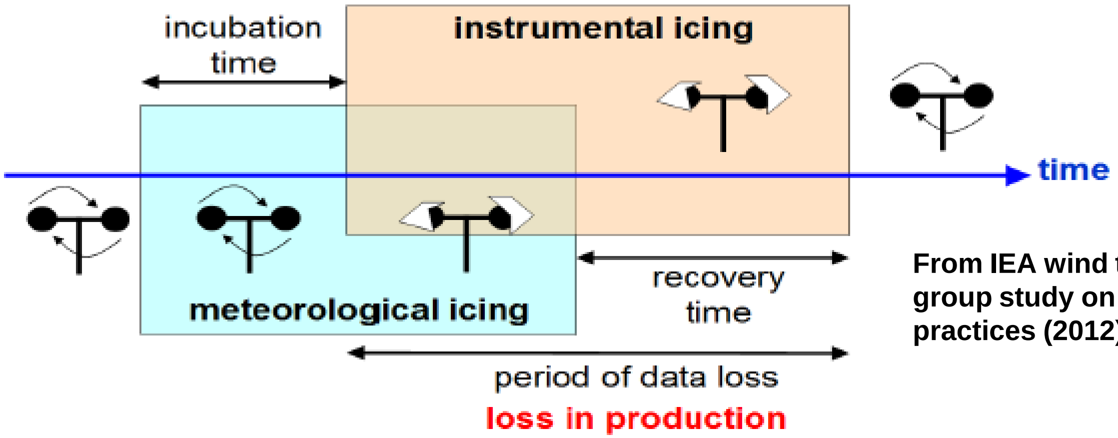
- Hourly values of icing intensity
- Accumulated ice loads



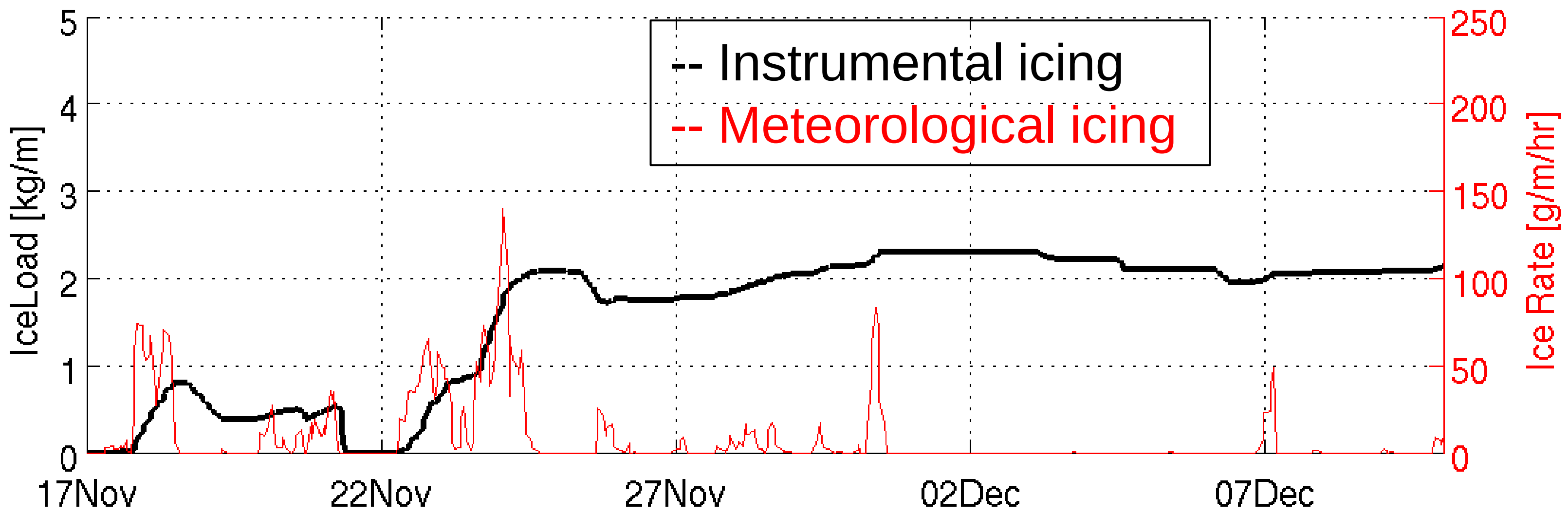


Validation of icing forecasts

Meteorological icing vs instrumental icing



From IEA wind task 19: Expert group study on recommended practices (2012)



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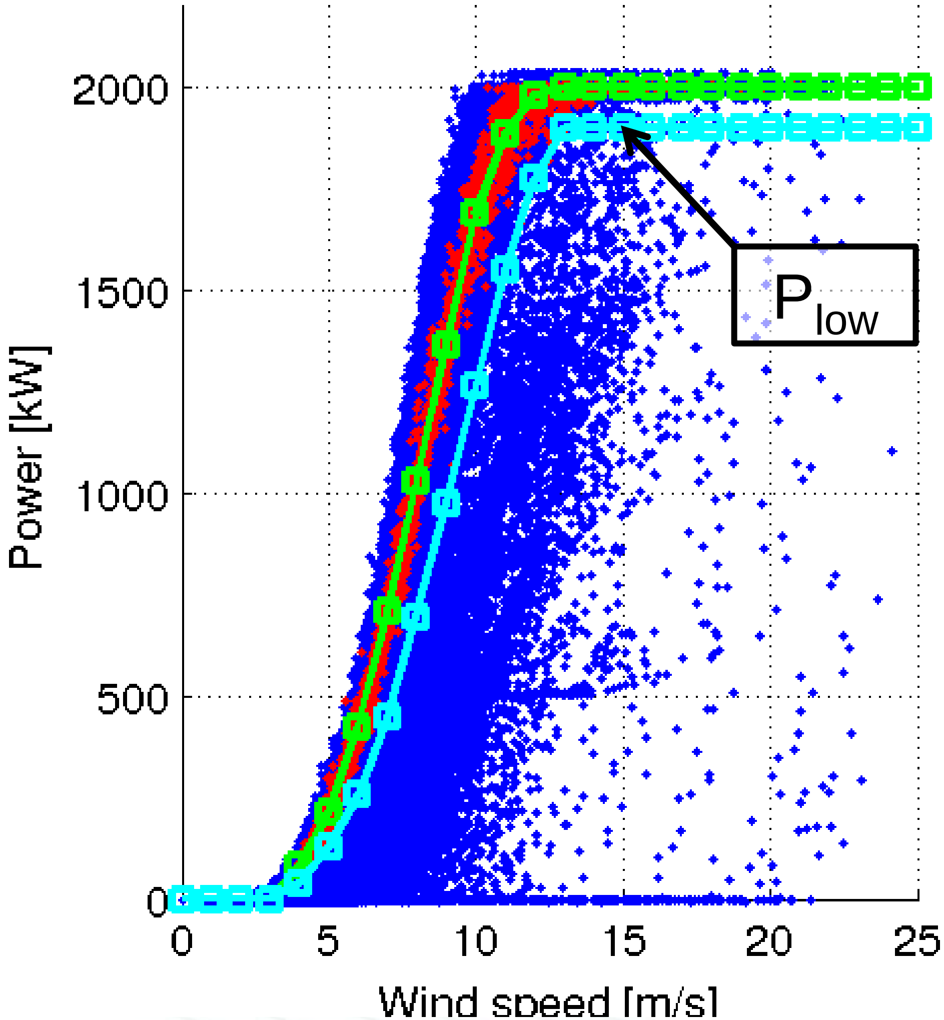
Observation data

- Data from one wind farm:
  - 10 minute frequency
  - power, nacelle wind speeds, temperature, turbine alarms
- Identification of icing from power data:
  - Temperature treshold: T<+2 ºC
  - Power treshold: $P < P_{low}$
- Definition of icing periods:
  - Icing identified for 3 or more turbines
  - Duration of minimum 12 hrs
  - Aggregated to 20% power loss or more



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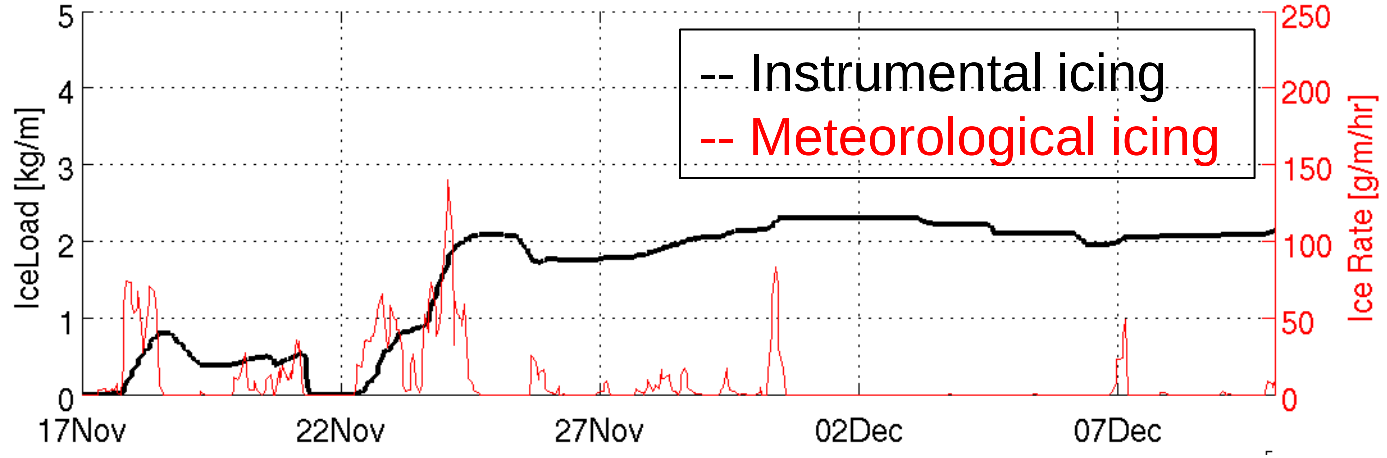
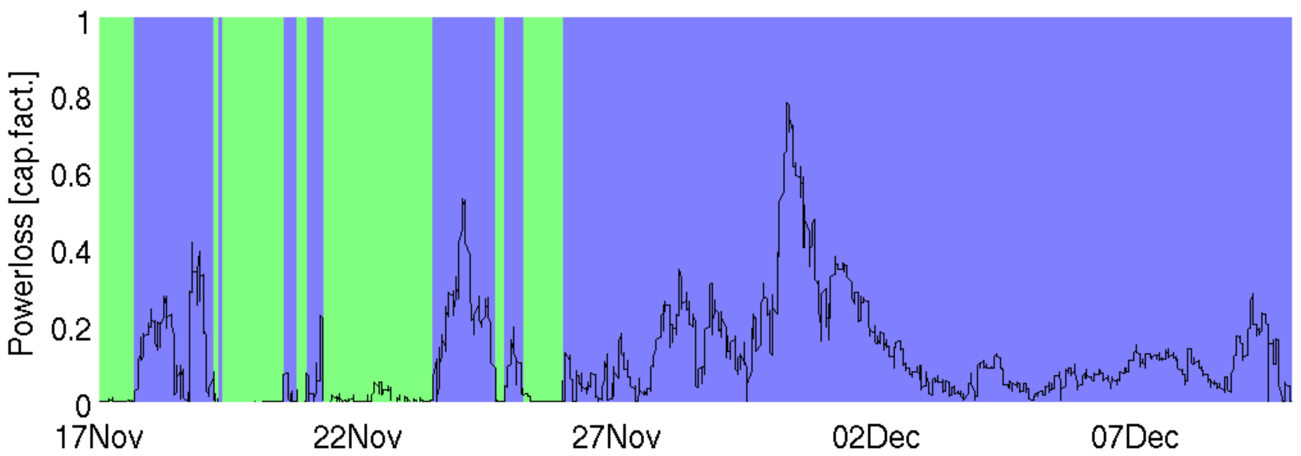
Power loss during periods with instrumental icing

Modeled icing



Observed icing and power loss



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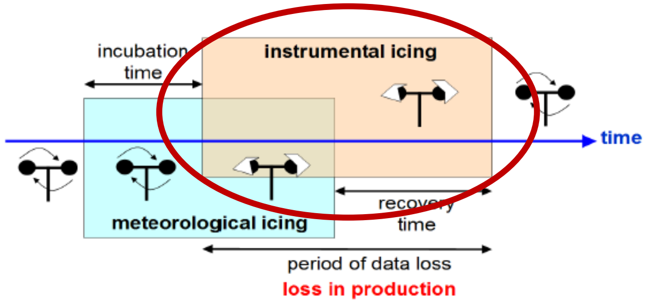
Validation of instrumental icing

- The periods with observed instrumental icing compared to modelled periods with instrumental icing.



- 75 % of the time when the model inicates instrumental icing ice is also identified from the power data.

- 33% of the cases when icing influences the power, is not identified as icing by the model

		Observations	
		iced	ice free
Modeled	iced	14 %	5%
	ice free	7 %	74 %

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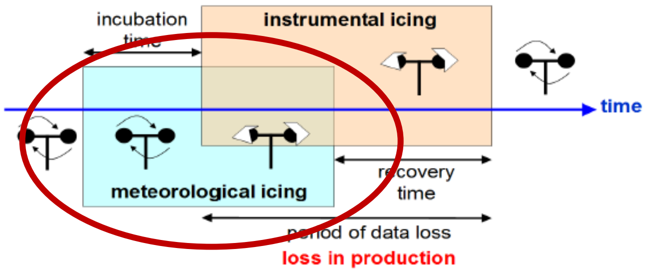
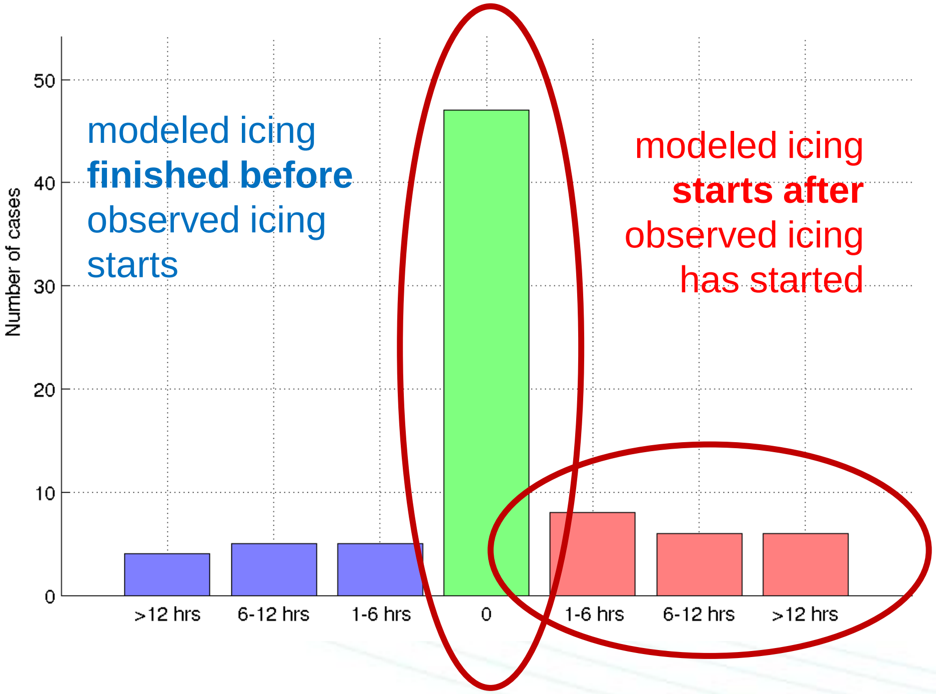
Validation of meteorological icing - Timing

- 60 % of the observed icing episodes starts when the model indicates meteorological icing

- Timing challenge:
  - In 25 % of the cases the model forecasted the icing too late
  - Time shift of the results gives improved timing of icing for this site

- False alarm rate:
  - 45 % of the modelled meterological icing events did not show as reduced power output from the wind farm





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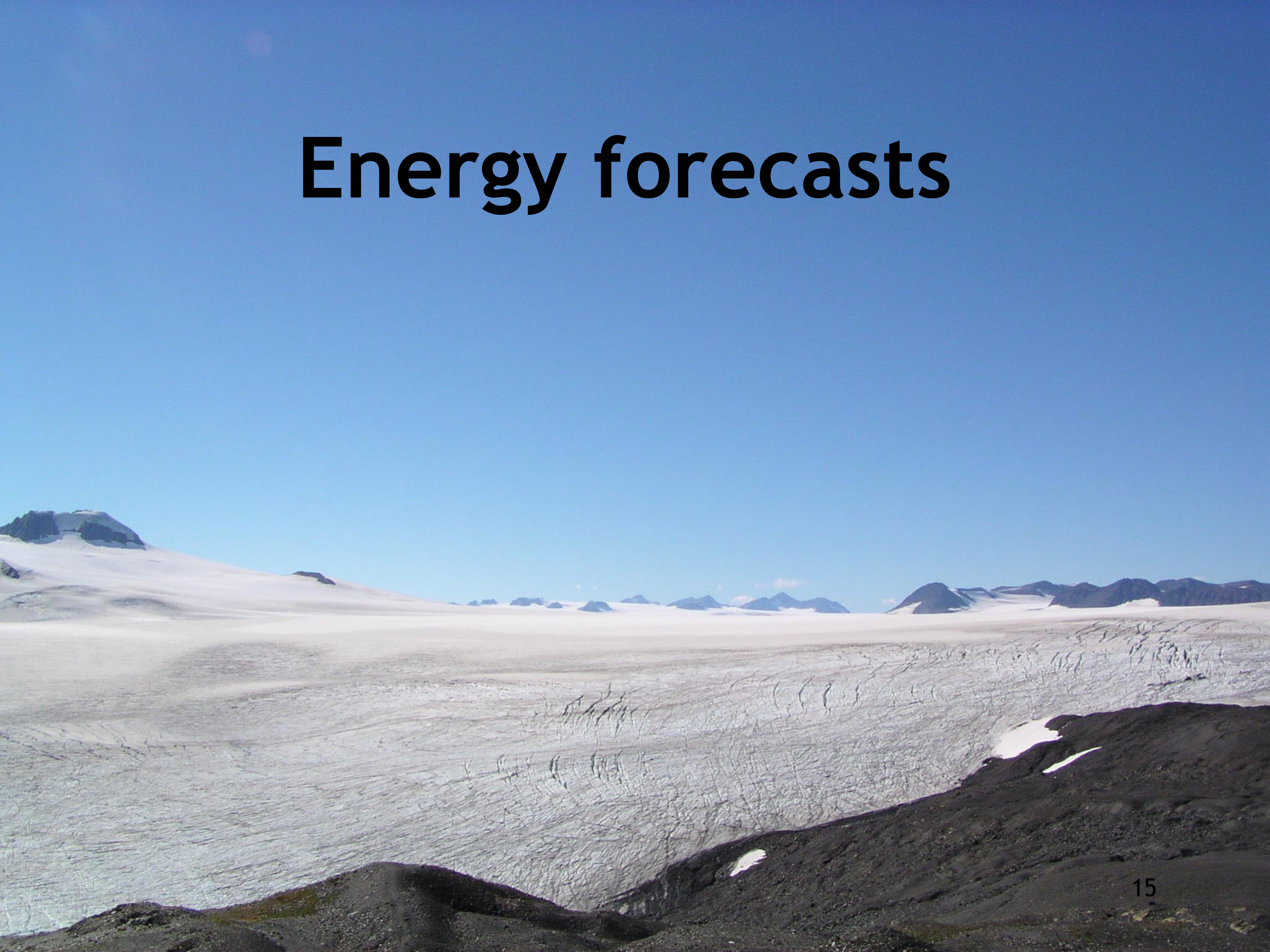
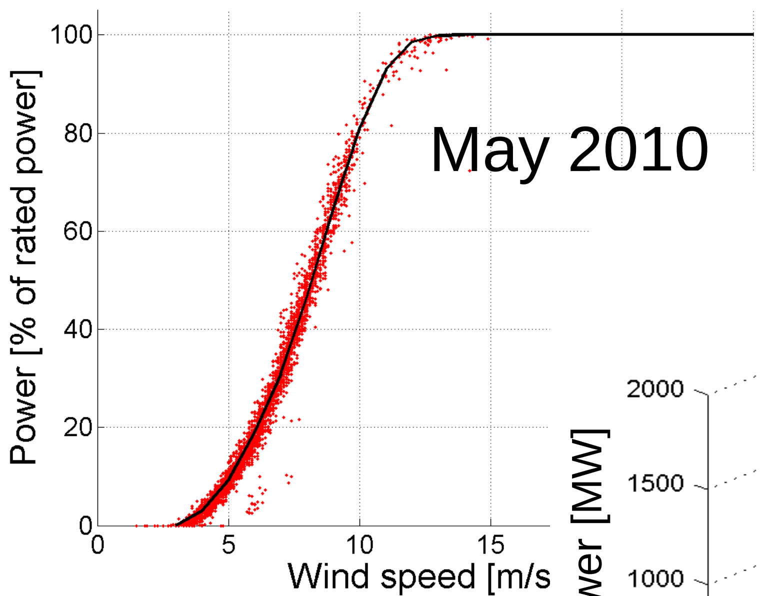
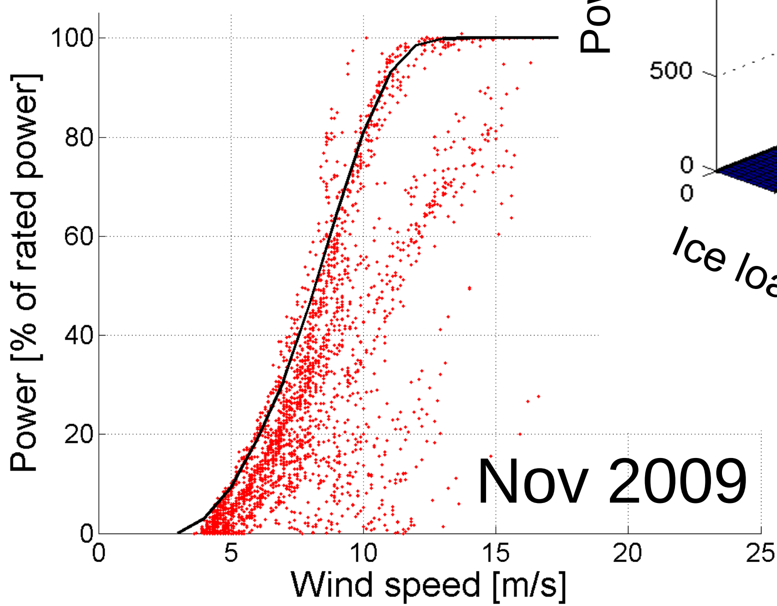
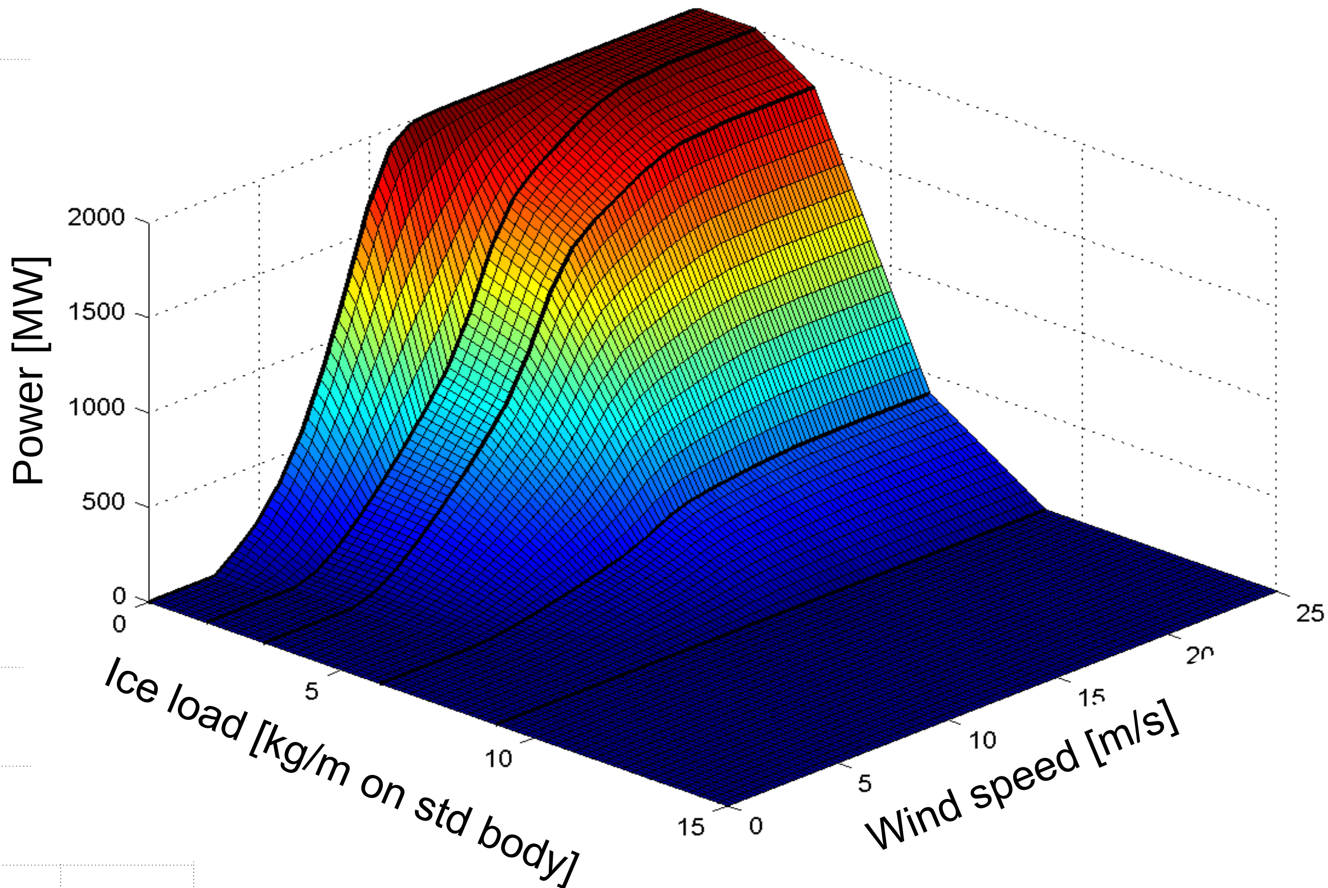
Energy forecasts



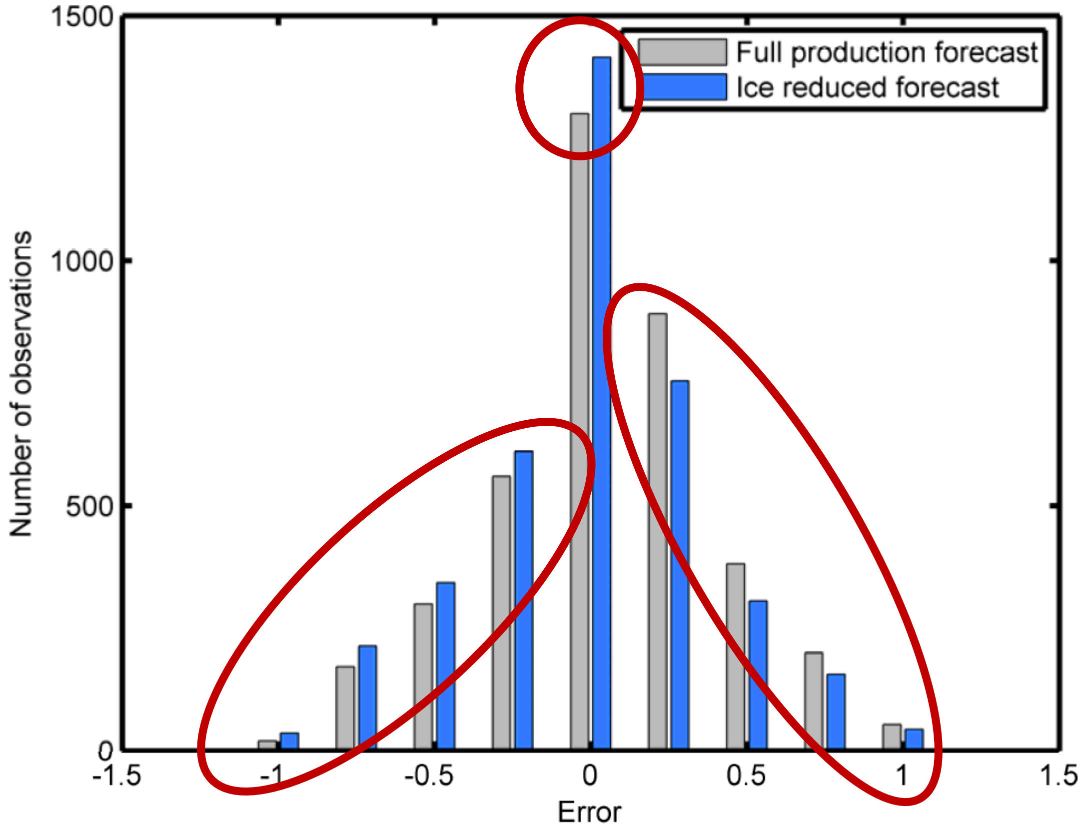
Forecasting of power losses







Forecasting of power



- Reduced number of cases with overprediction of power production in the forcast with icing
- Higher number of cases with error less than 12.5 % in the forcast with icing
- Higher number of cases with underprediction of the power production in the forecast with icing

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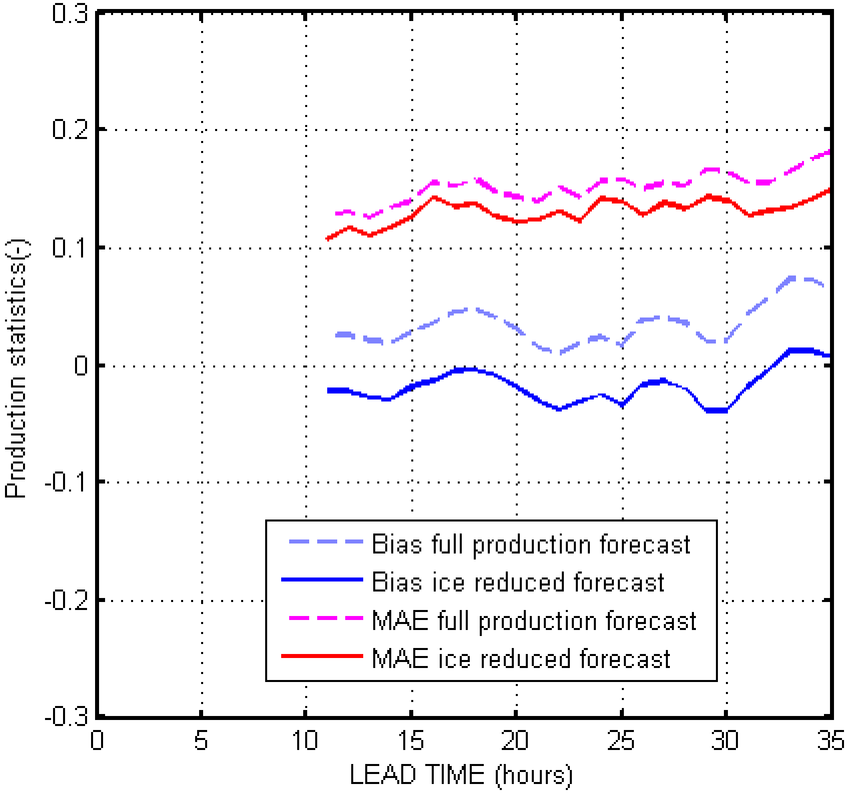
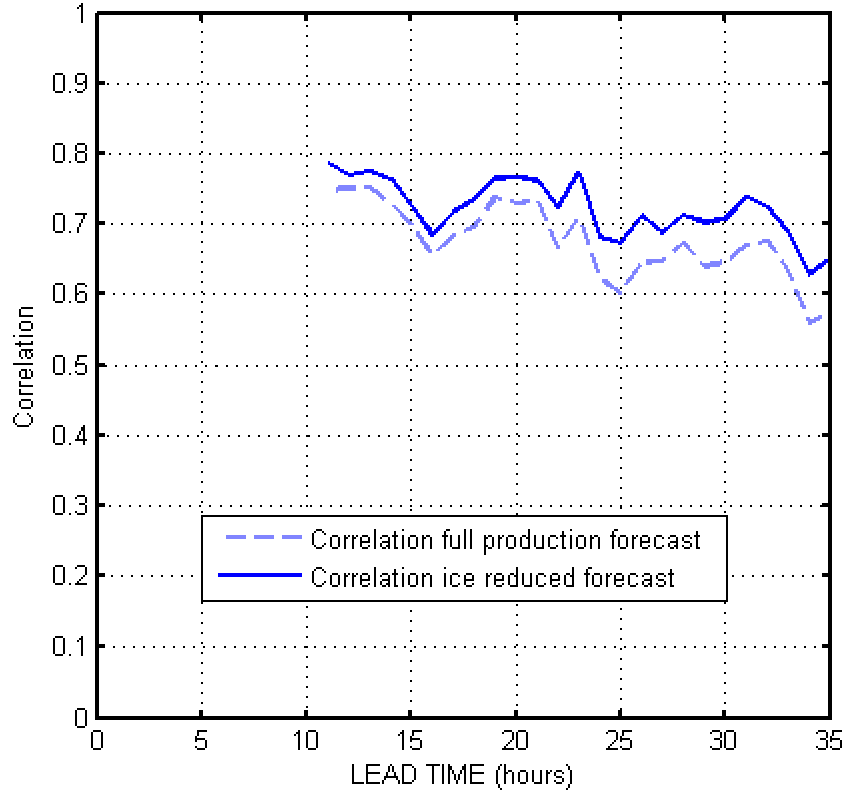
Forecasting of power production

- **Bias and mean absolute error** (MAE) in the forecasts are **reduced** when we include production losses due to icing (left figure)

- **Correlation** is **increased** when including icing in the forecasts (right figure)





Summary

- Gained experiences from operational forecasting of icing
- Validation of instrumental icing:
  - 75 % of the time when the model inicates instrumental icing ice is also identified from the power data.
  - 33% of the cases when icing influences the power, is not identified as icing by the model
- Validation of meterological icing:
  - 60 % of the observed icing episodes starts when the model indicates meteorological icing
- Validation of power forecasts:
  - General improvement of the power forecasts when the icing is included.

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Thank you for your attention!

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