Development of operational forecasting for icing and wind power at cold climate sites

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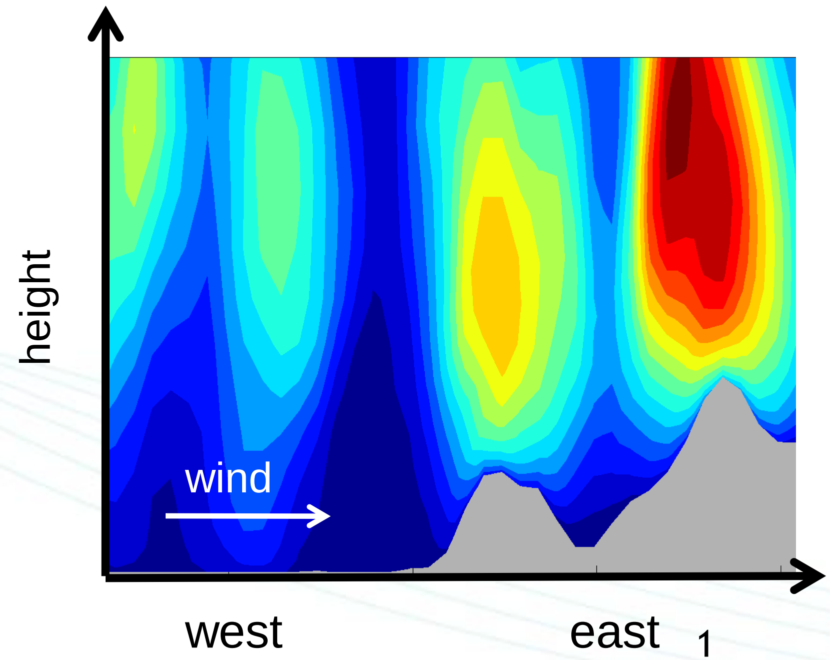
Icing conditions

- 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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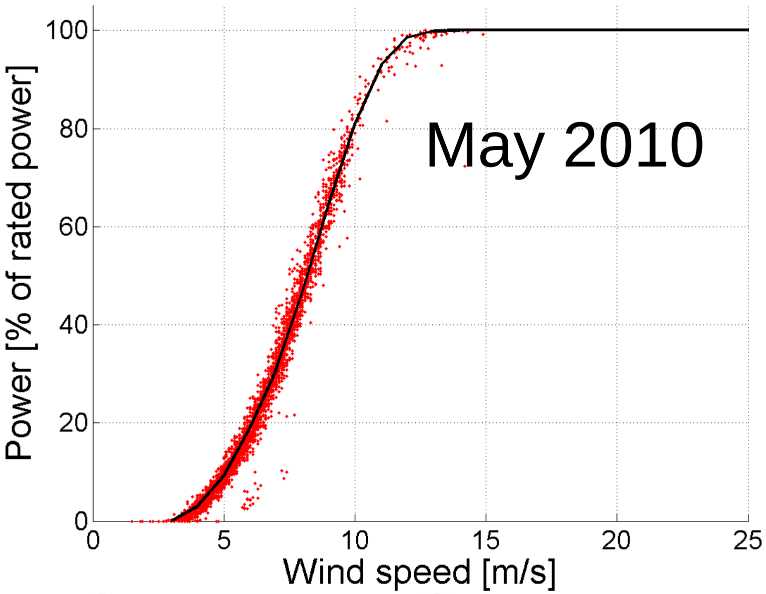
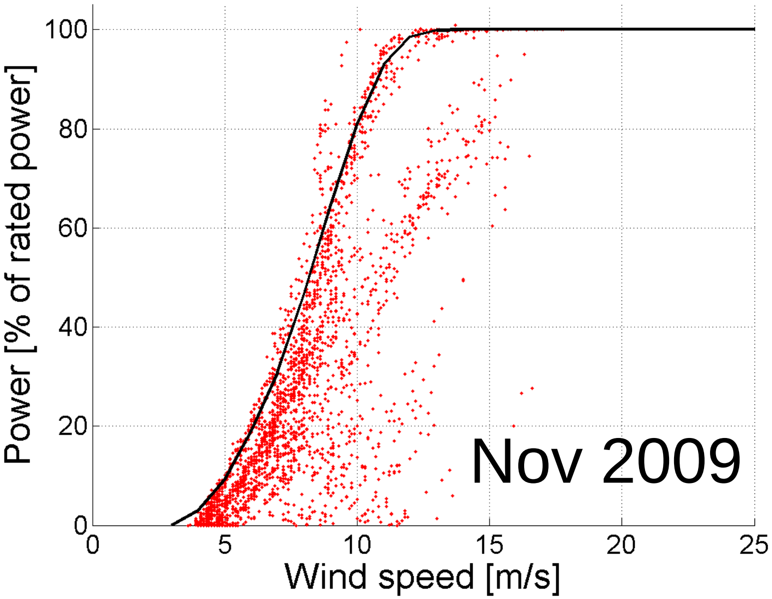
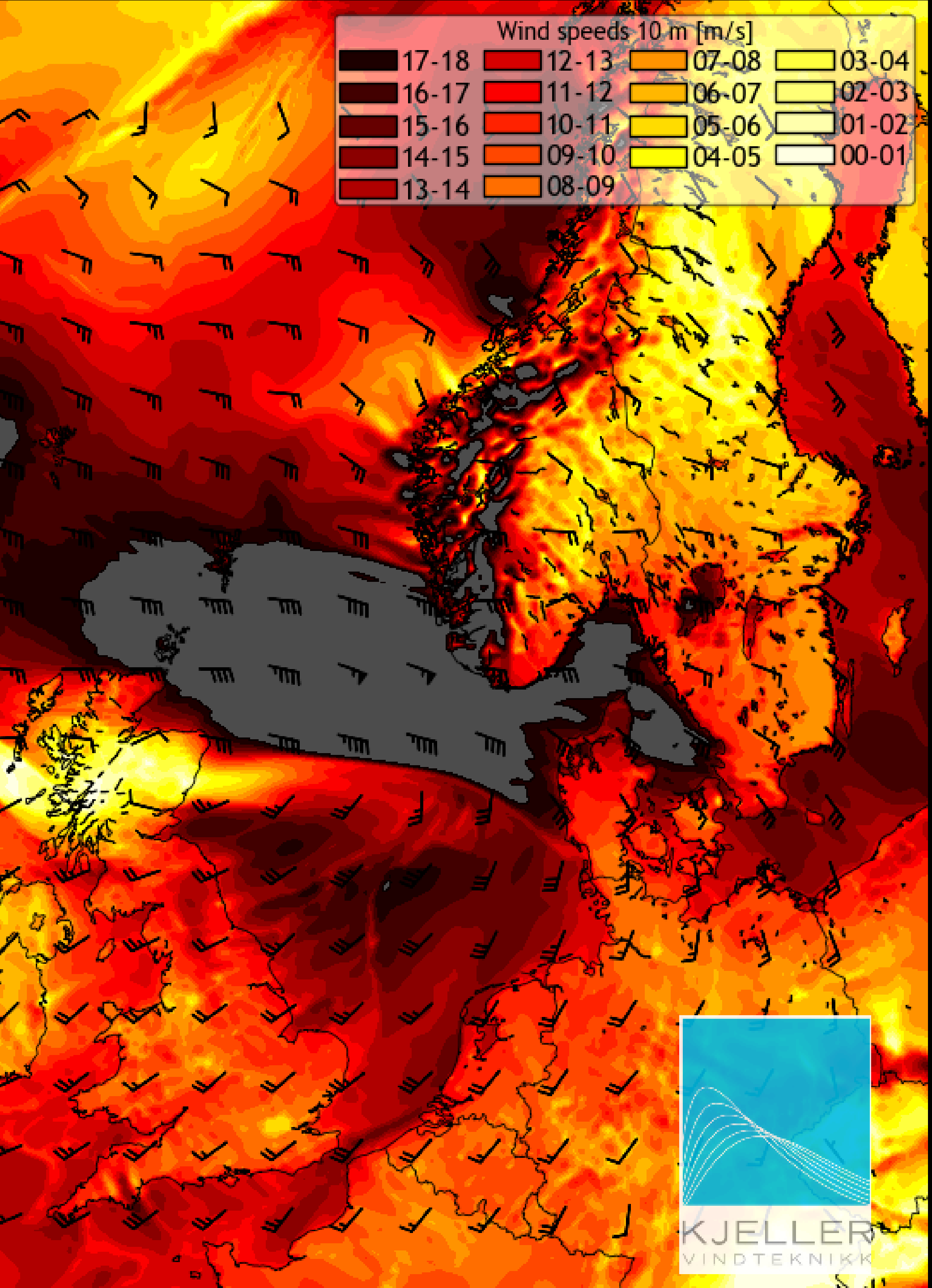
How does icing influence wind energy production?







Operational forecasting

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

Forecasting of icing - motivation

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

- **Monitoring of exposed power lines**
  - Avoid damages

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Calculation of in-cloud icing

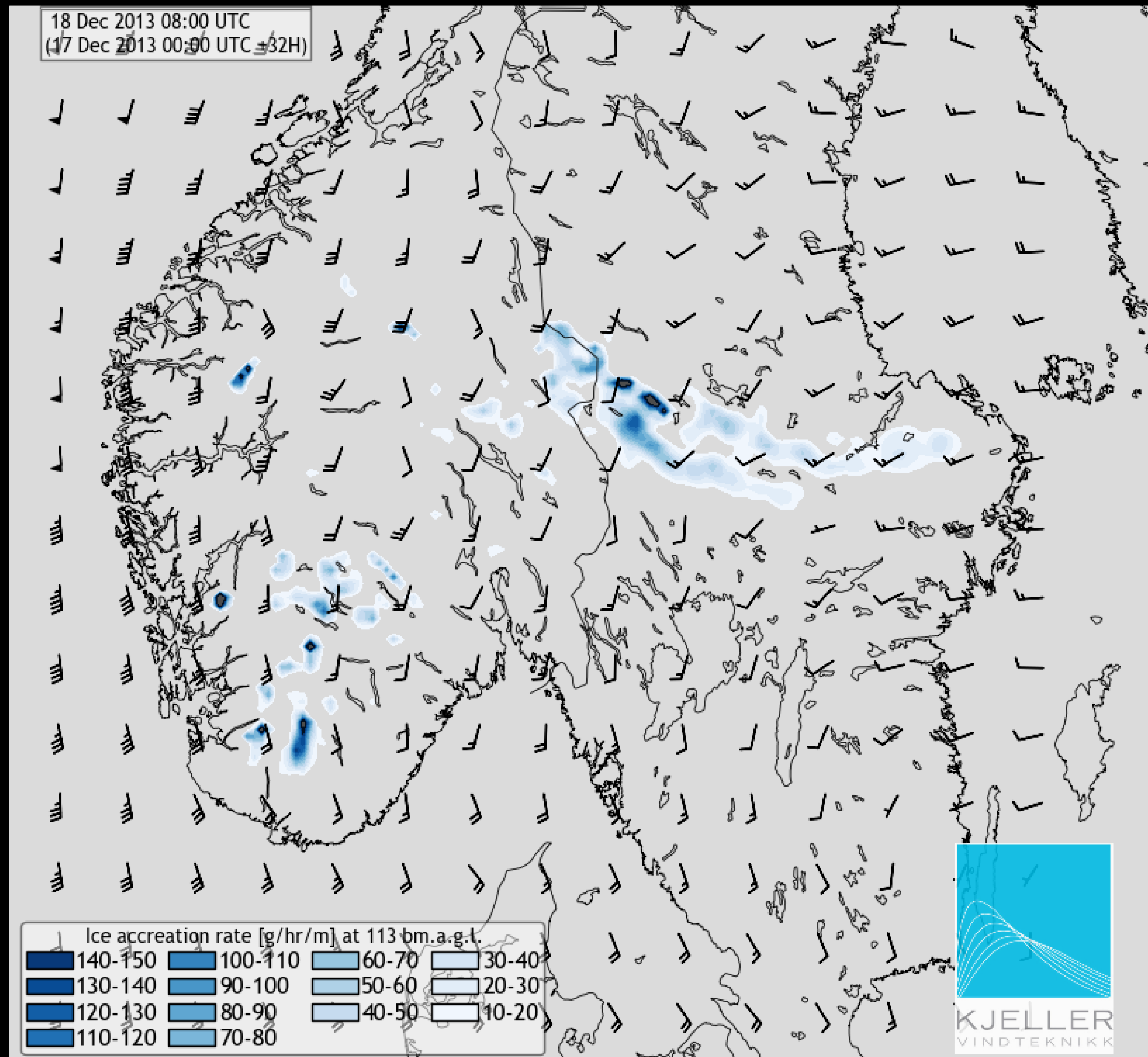
Forecast parameters:

- Icing intensity
- Ice loads
- Ice shedding episodes
- Wind energy

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

According to ISO12494

Forecasting – icing intensity

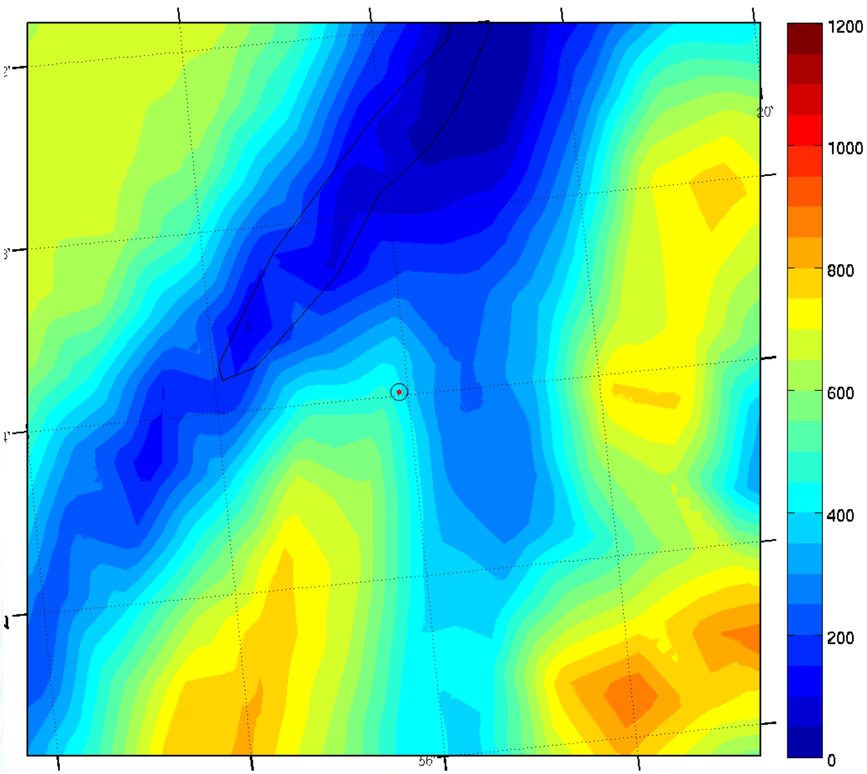


Topography

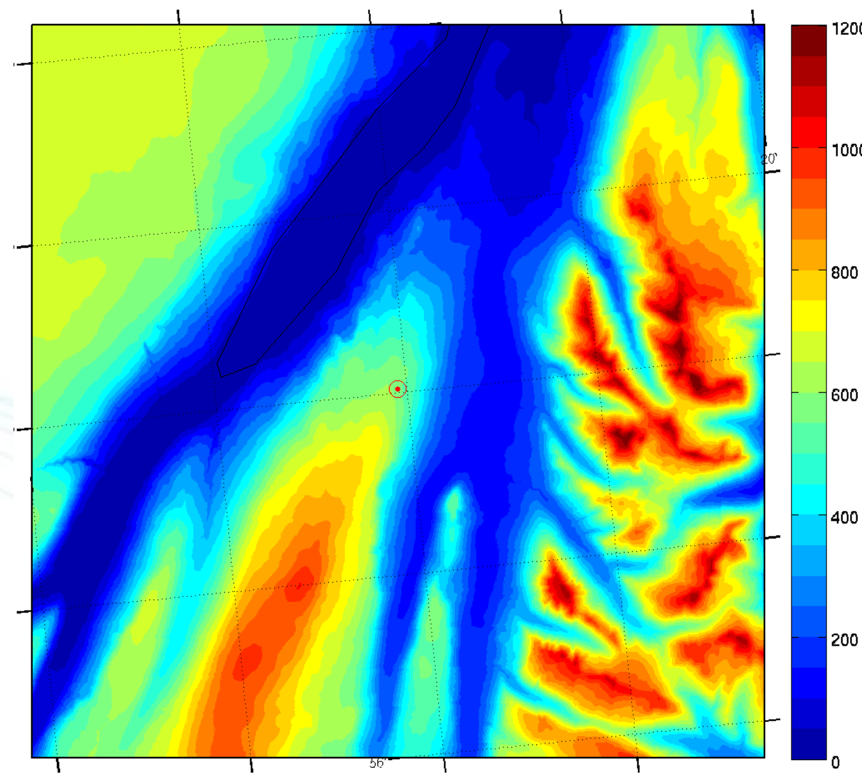
The terrain is smoothed in the coarse model resolution:

- The orographic lifting of the air masses will be too small
- The coarse model will therefore underestimate the icing on hills

WRF model:
3km x 3km resolution



Terrainmodel:
50 m x 50 m resolution

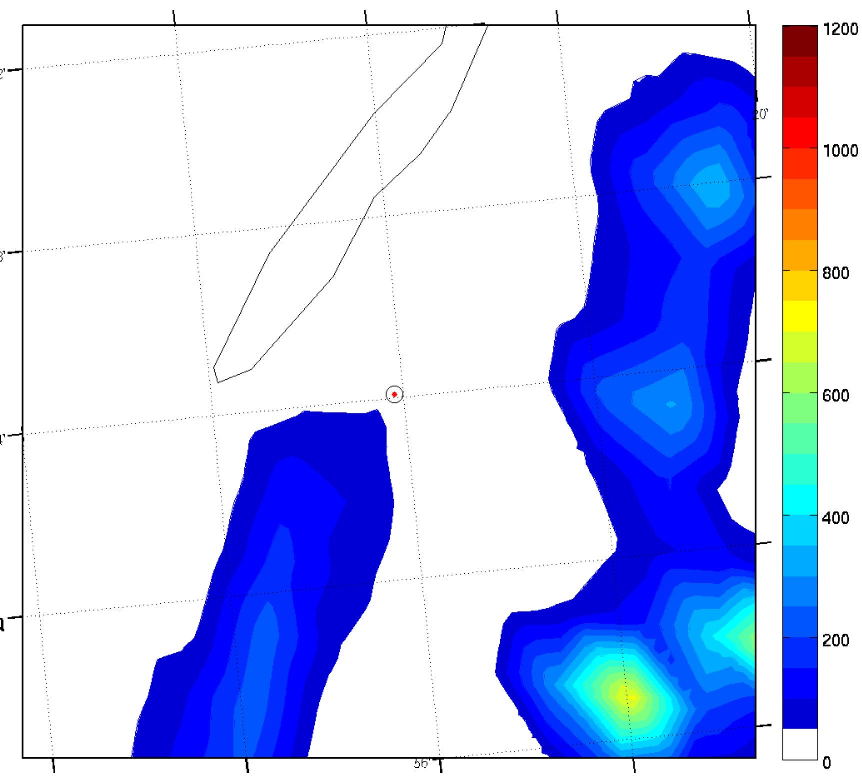


Height adjustment

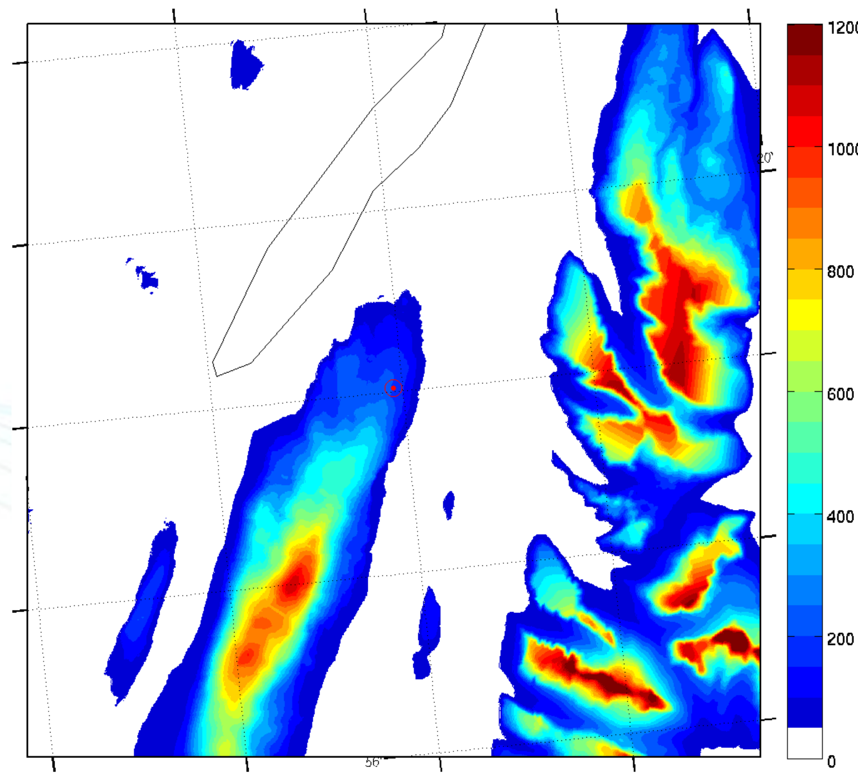
Height adjustment routine:

- Forced lifting of the air masses from the coarse smoothed terrain to the height in the terrain model
- Icing hours per year with 50 m x 50 m resolution.

WRF model:
3 km x 3km resolution



WRF model:
With height adjustment

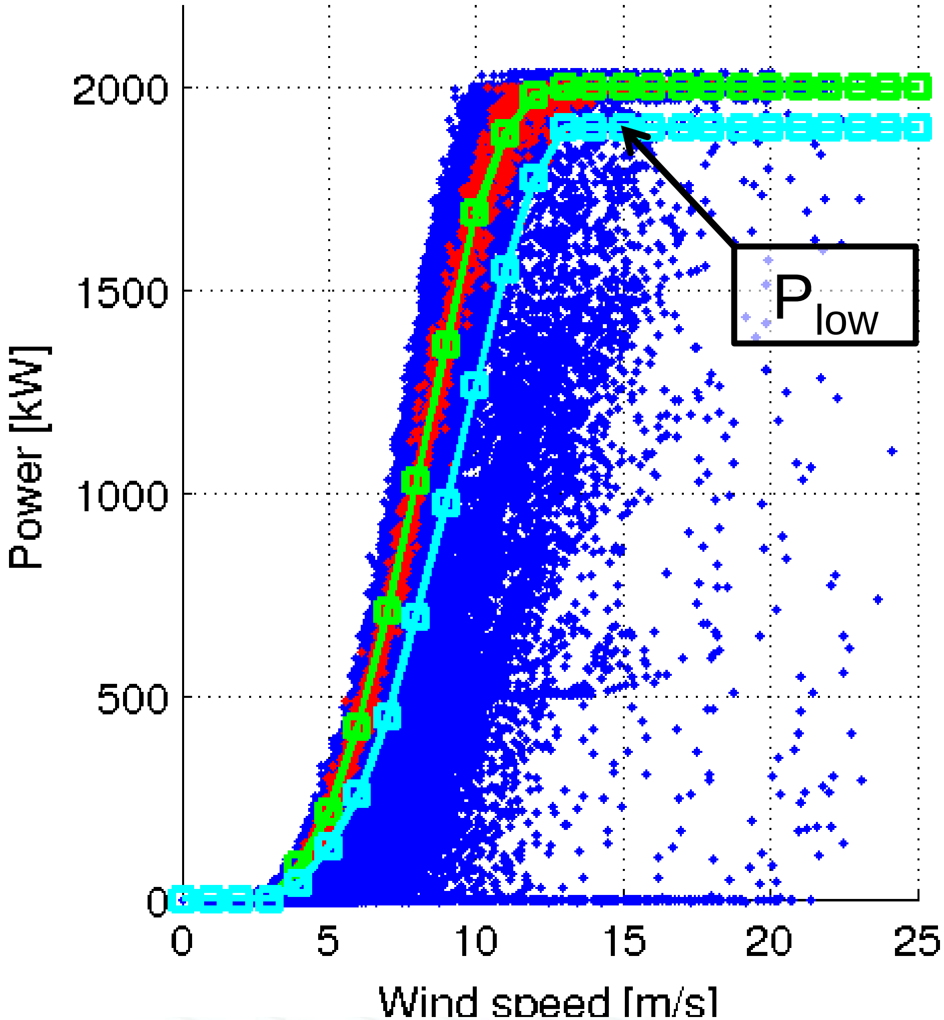


Validation of icing forecasts

Identification of icing from SCADA data

- Data available form four wind farms:
  - Power
  - Nacelle wind speed
  - Nacelle wind direction
  - Temperature
  - Operational state
  - 10 minute frequency
  - More than 2 years of data from each wind farm

- Identification of icing
  - Davis et al. (2015)
  - P10 treshold curve
  - Time constraint
  - Temperature constraints



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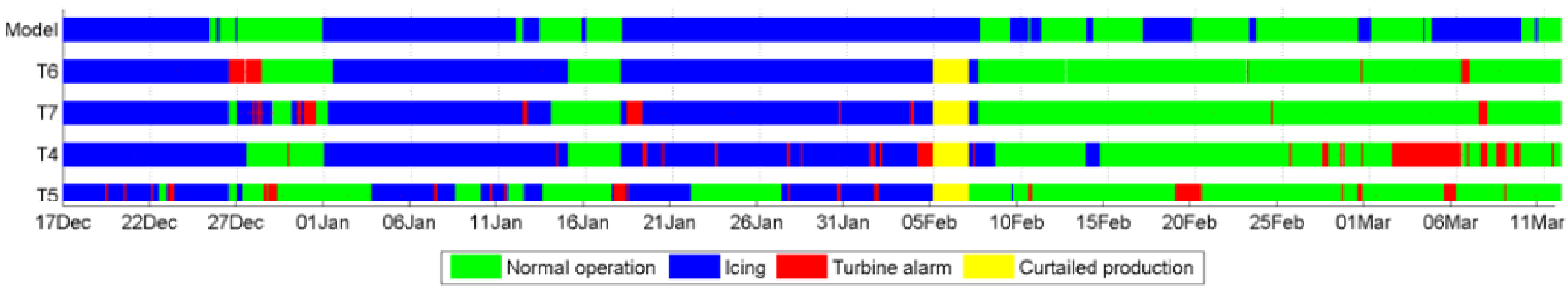
Identification of icing from SCADA data

- Icing flagged for each turbine and for the model:
  - Green: normal operation
  - Blue: icing identified
  - Red: Turbine alarm
  - Yellow: Curtailed production



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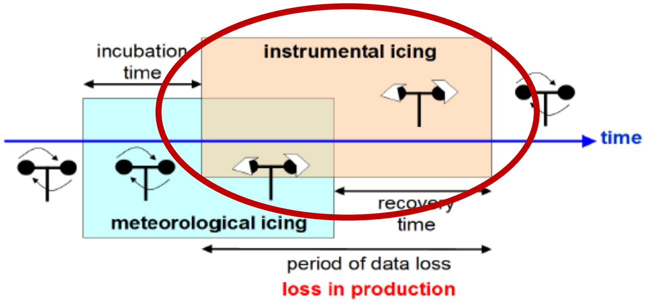
Validation of instrumental icing periods

- The periods with observed instrumental icing compared to modelled periods with instrumental icing for 4 wind power sites in Sweden:
  - Site A, B, C, D
- Differences in ice shedding from model and observations



	A	B	C	D
Ratio of time when ice is detected	22 %	9 %	10 %	13 %
Probability of detection	74 %	82 %	79 %	63 %
Probability of false alarm	6 %	7 %	6 %	5%

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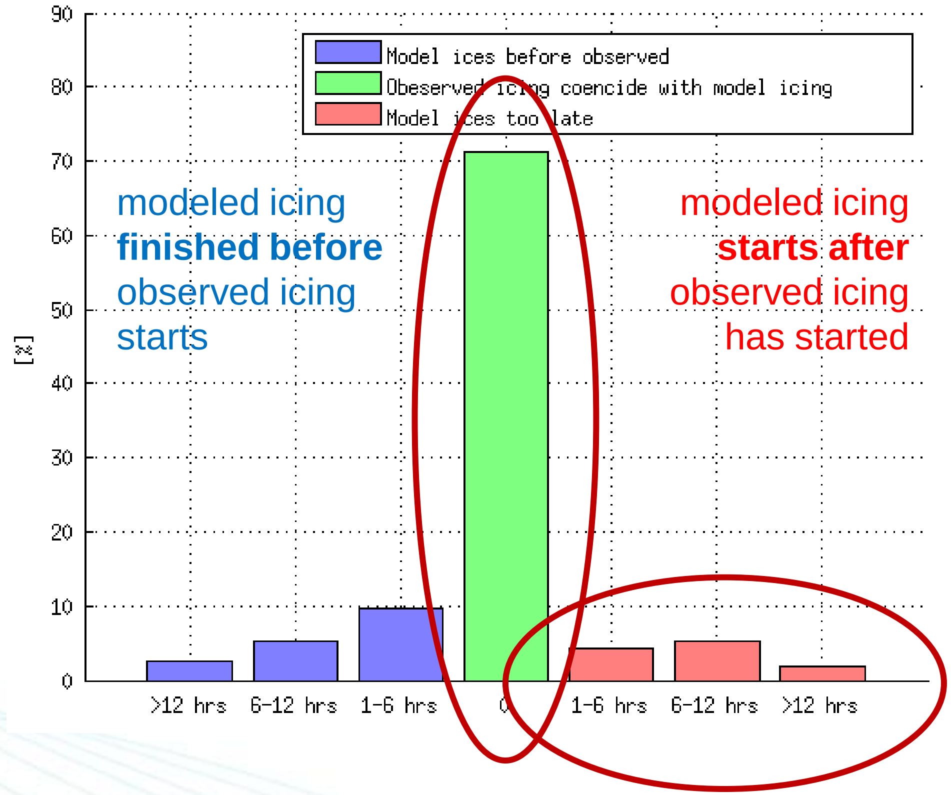
Validation of meteorological icing - Timing

- 70 % of the observed icing episodes starts when the model indicates meteorological icing



	A	B	C	D
Number of icing episodes	109	57	115	27
Probability of detection	67 %	70 %	71 %	70 %

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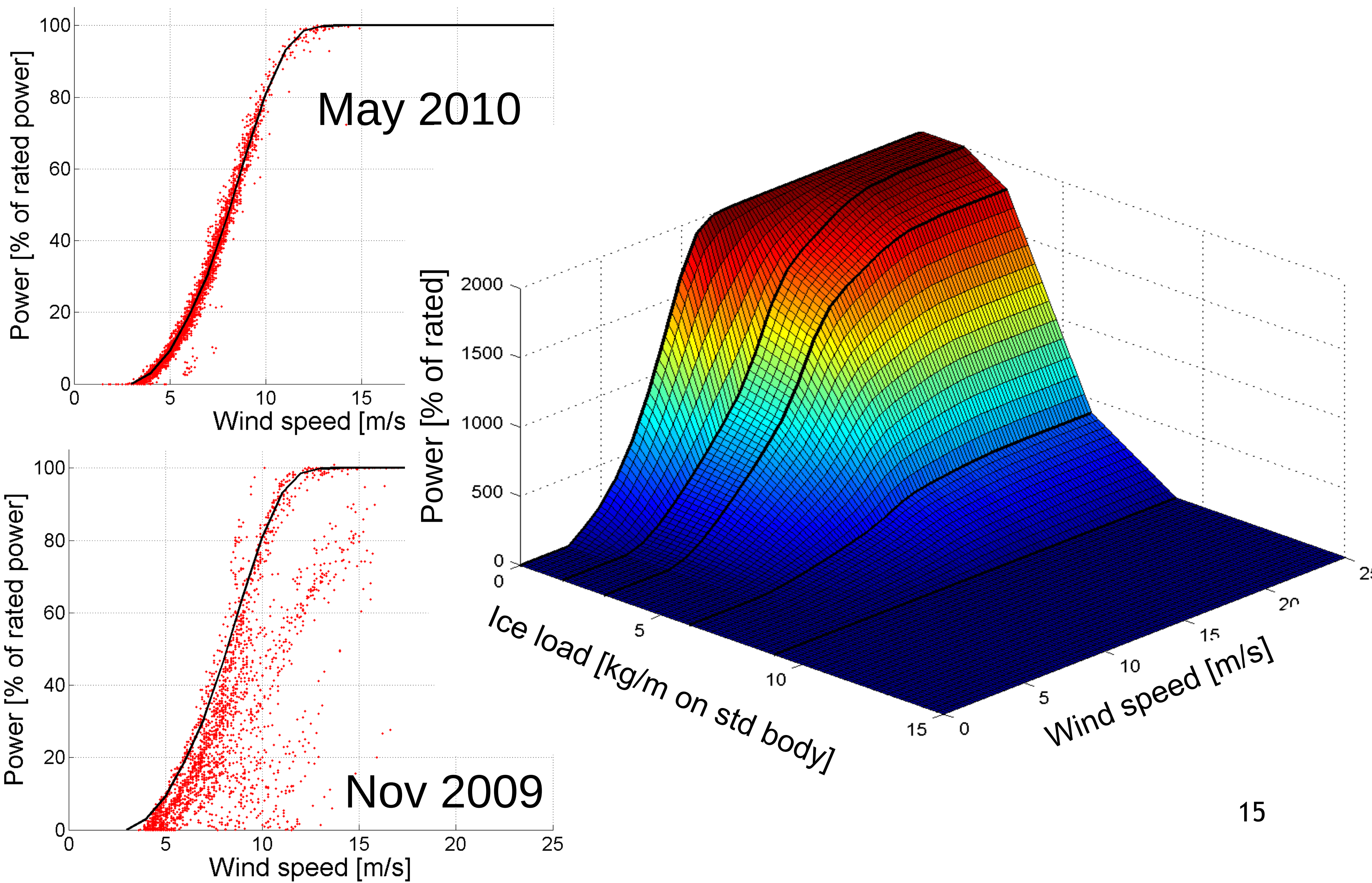
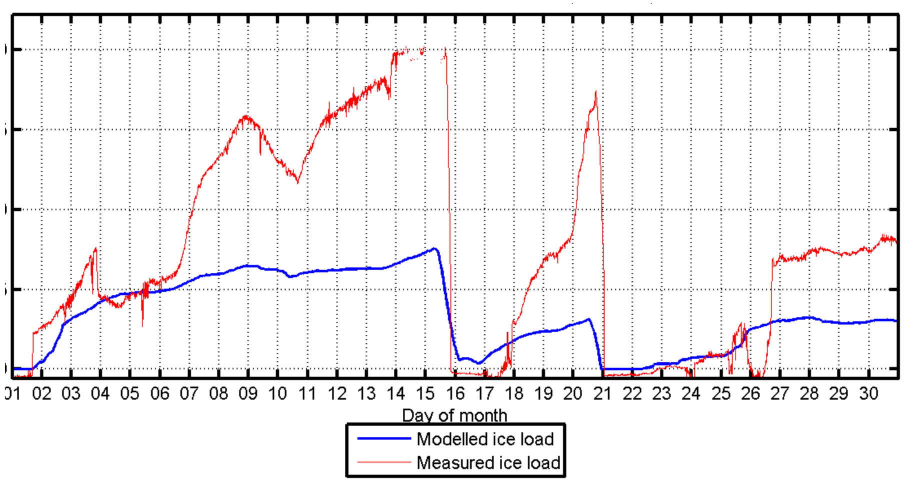
Energy forecasts for wind power

IceLoss - Forecasting of power losses



Estimating production loss

Ice load:
model (blue)
observed (red)



Production loss:
model (blue)
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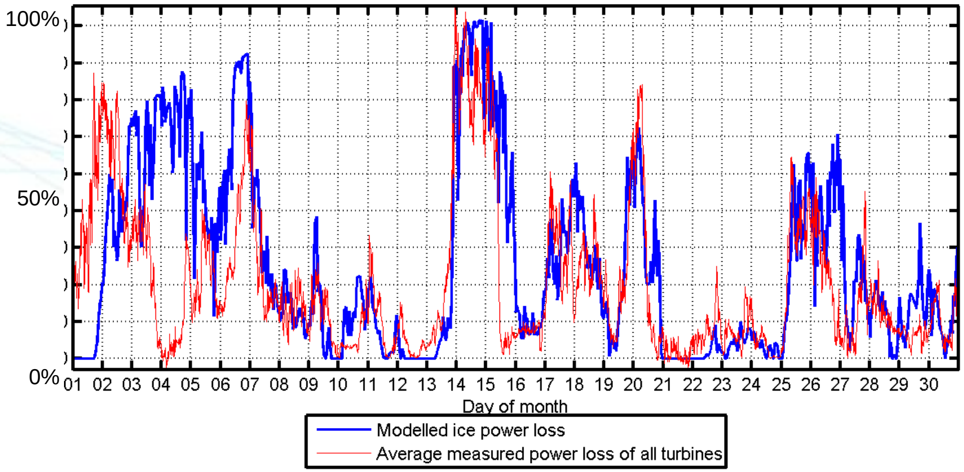

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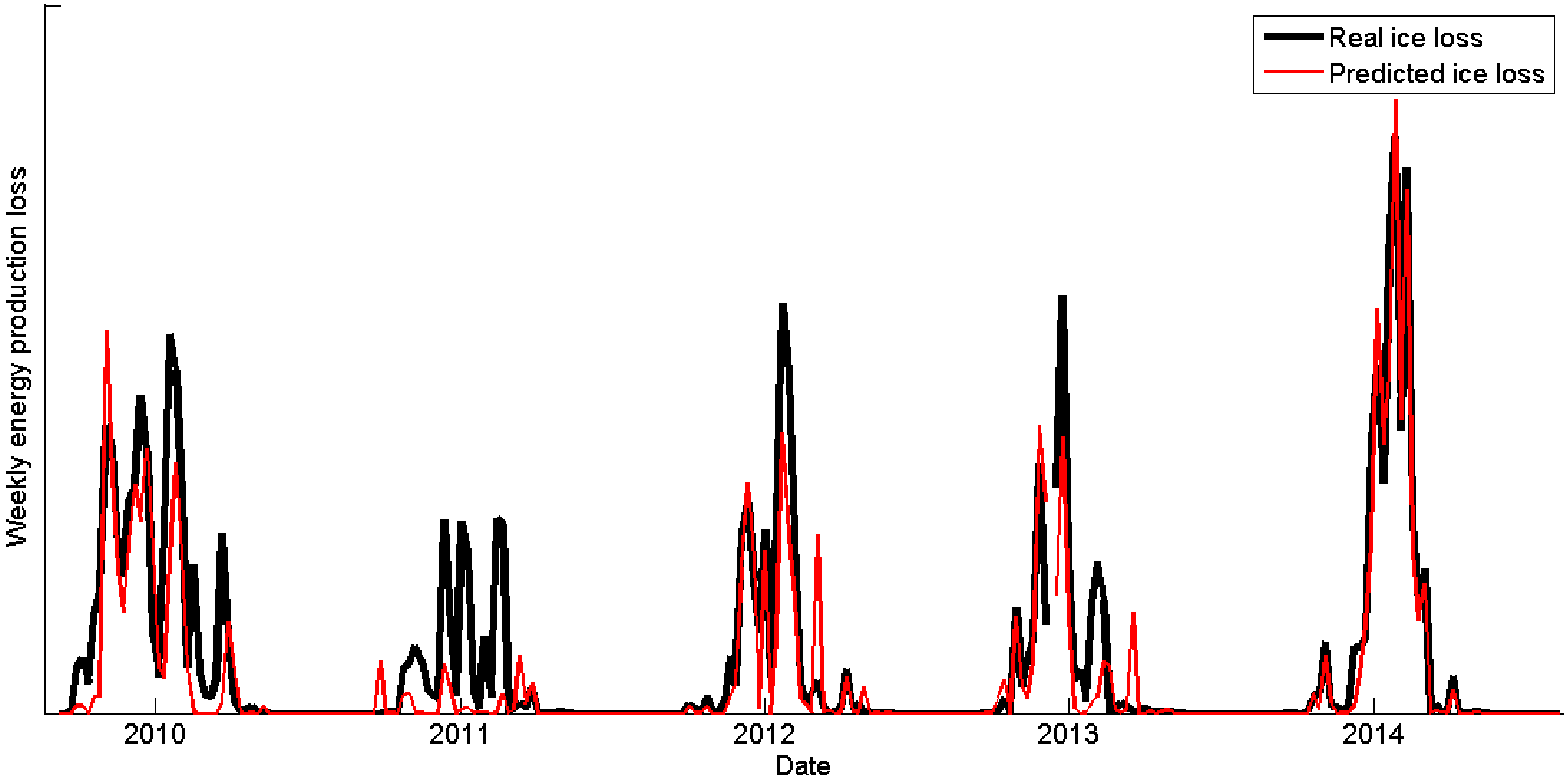
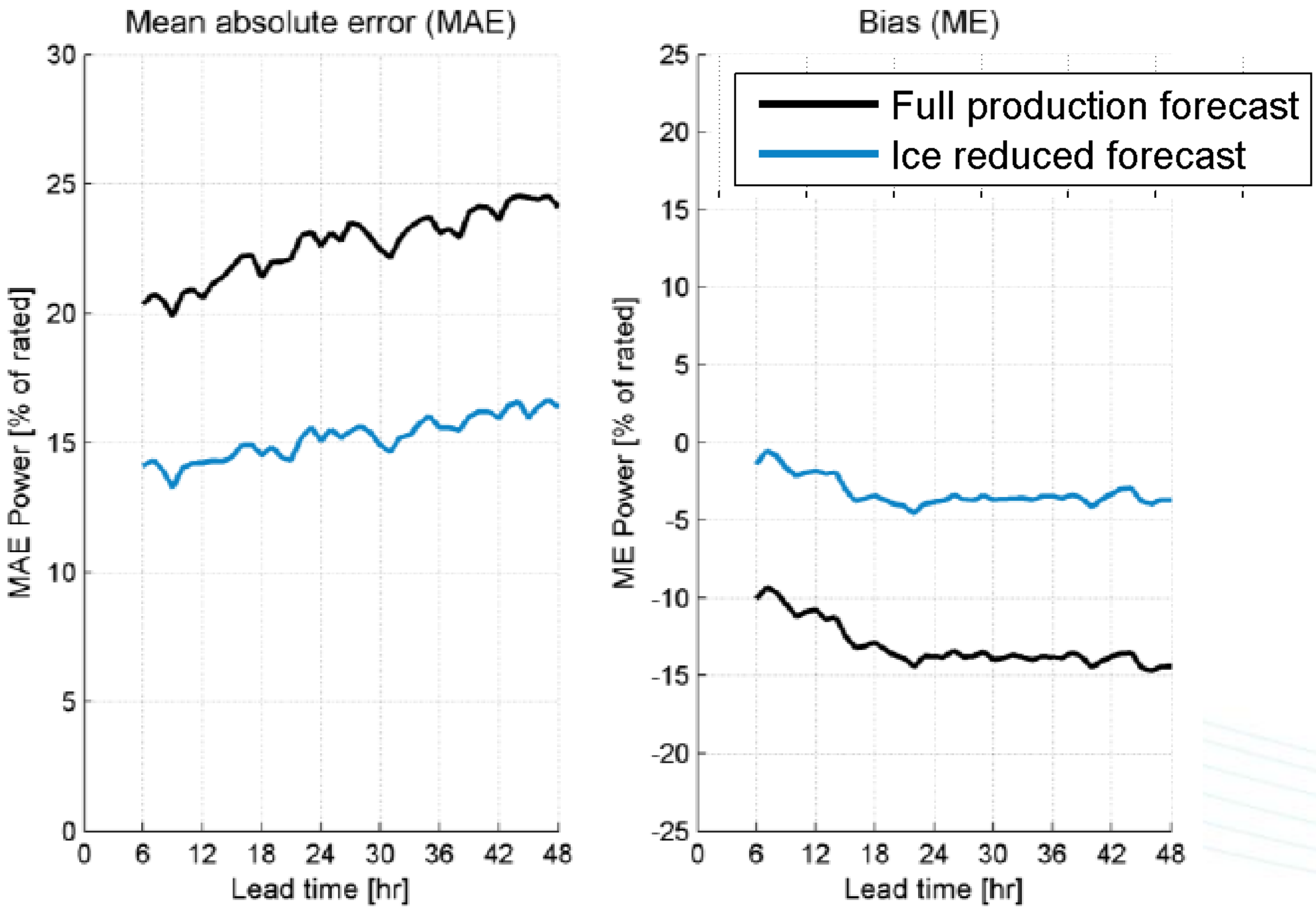
Modelled vs observed production losses



Forecasting of power production

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



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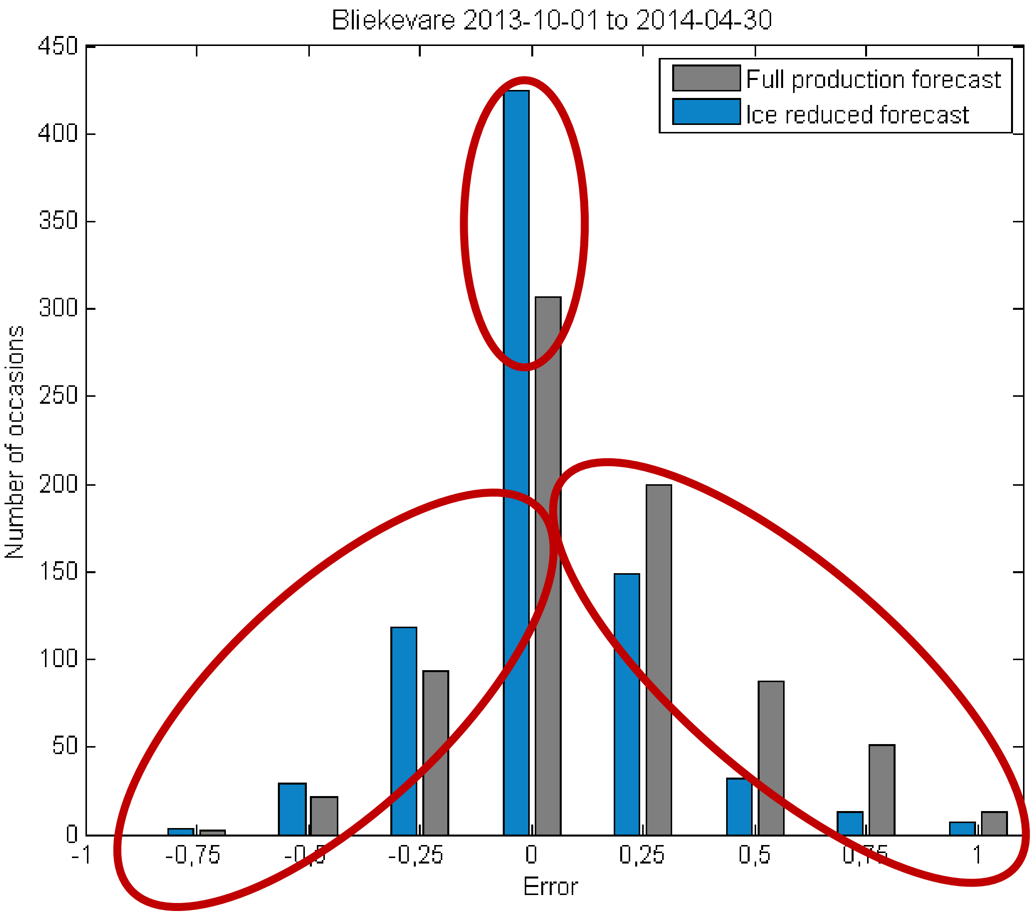
Forecasting of power



- 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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Summary

- We carry out forecasting of icing and energy production with the WRF model runniong operationally
  - Timing of icing periods are well modelled
  - The IceLoss model improves the energy forecasts

- Future work:
  - More realistic energy forecast by calulating icing on the turbine blade instead of a ISO cylinder
  - Validation of LWC contents
  - Continuos work on the modelling of ice accreation will continue in the projects FRonTLINES and WISLINE funded by the Norwegian Research Council and Statnett.

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Thank you for your attention!

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