

Experiences from studies of icing and production losses due to icing in OX2's wind pilot project



WeatherTech

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IWAIS
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About WeatherTech

- Consultant firm based in Uppsala, Sweden
- Specialised in:
 - Mesoscale atmospheric modelling
 - Atmospheric icing
- Other services:
 - Energy forecasts
 - Dispersion
 - Sailing
- R&D:
 - National and international projects



OX2's wind pilot project

Large-scale, cost-effective wind energy development in icing climates

- Funded by the Swedish Energy Agency
- 2008 – 2015
- 8 MEuro

WeatherTech one of the participants



WeatherTech

Production losses due to icing

Cloud water droplets
& $T < 0$



Accretion of ice on
turbine blade



Reduced efficiency
of turbine

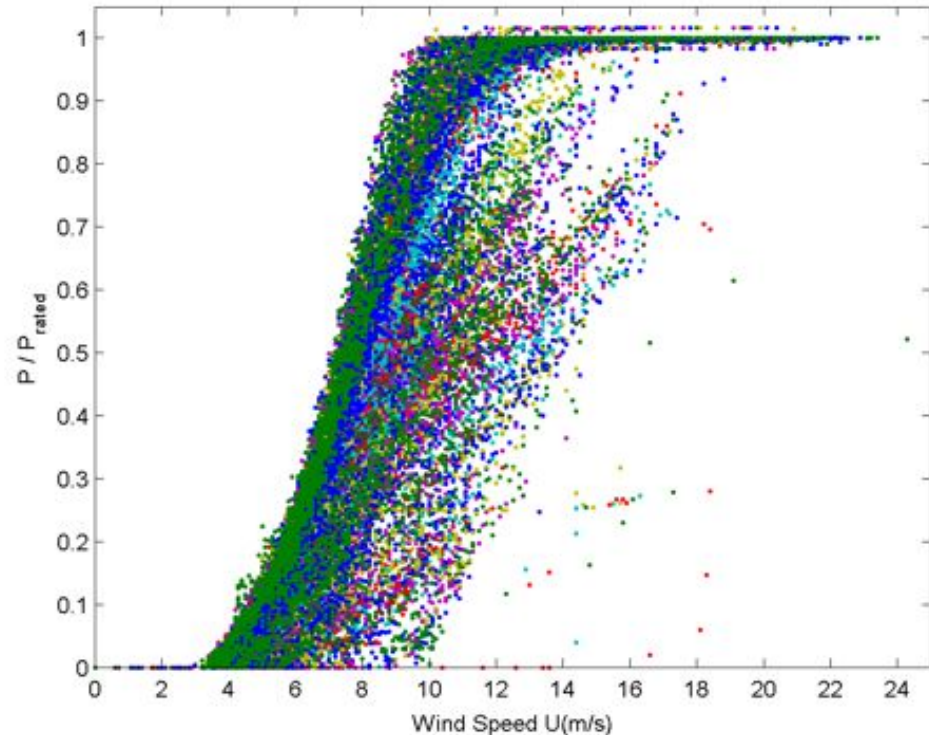


Photo: Kent Larsson, ABVEE

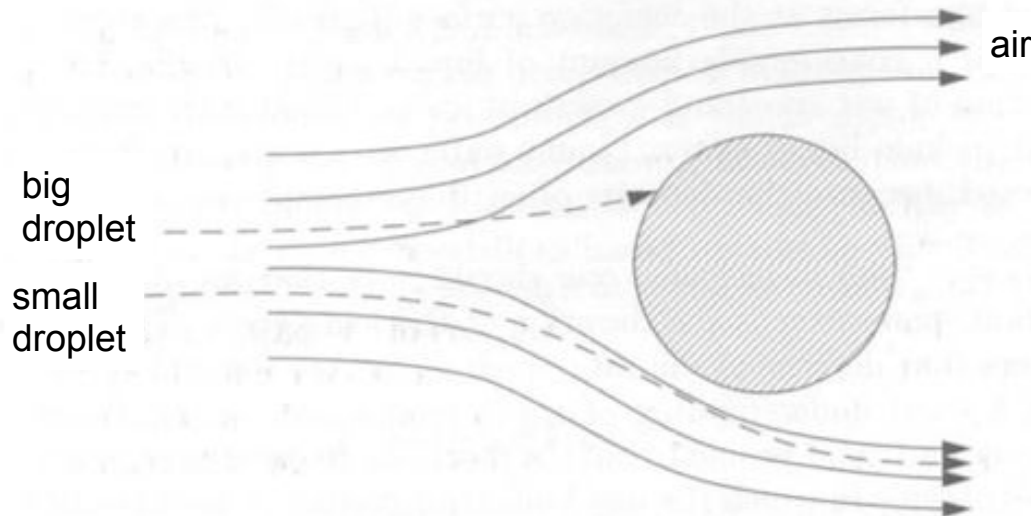
Model development

- Ice accretion model
- Production loss due to icing => WICE
- WICE add-ons/application

Modelling ice accretion (ISO 12494)

Ice growth rate on a cylinder:

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



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

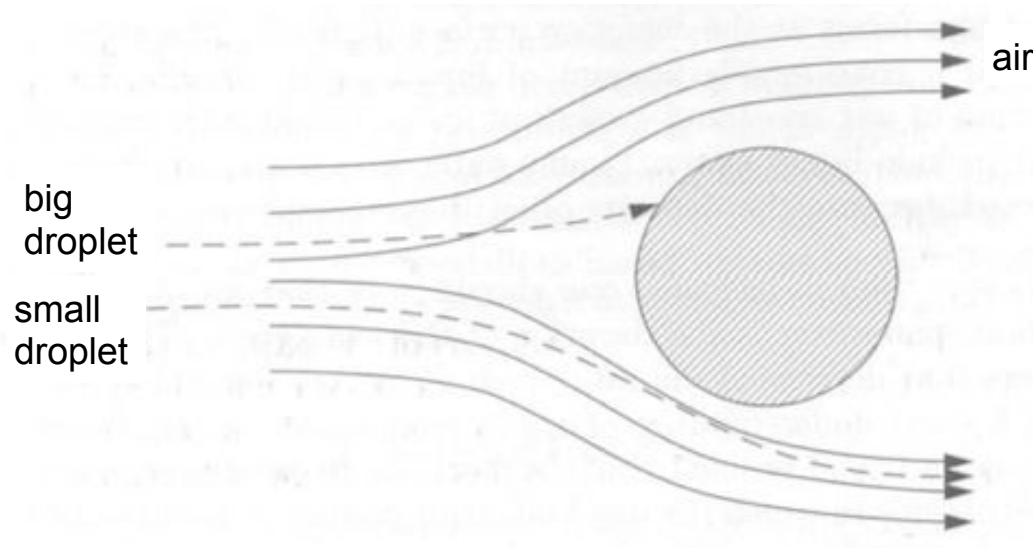
Active icing/icing hour:

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

Modelling ice load

A modified version of the accretion model:

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



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

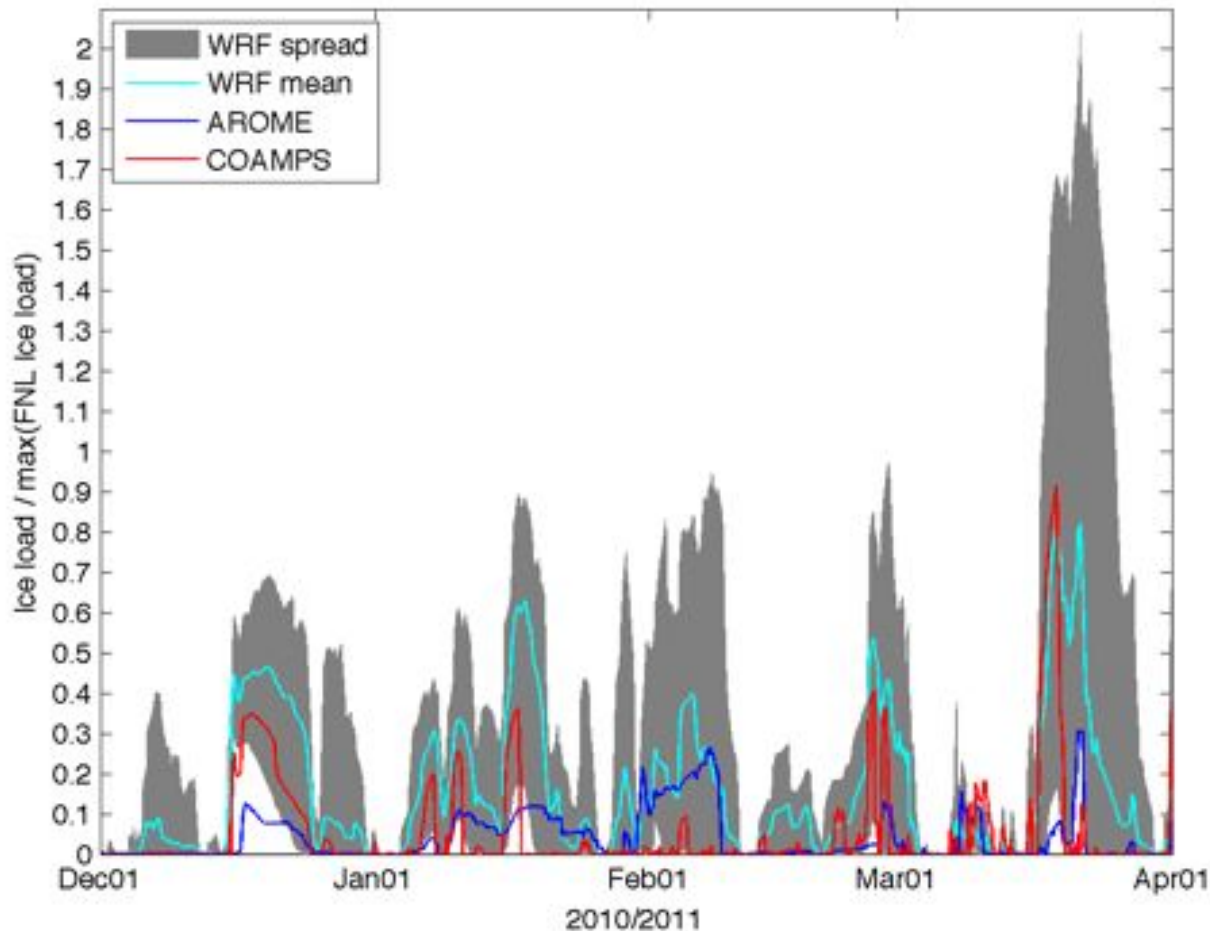
Melting when $T > 0^\circ\text{C}$

- energy balance

Sublimation when $T < 0^\circ\text{C}$

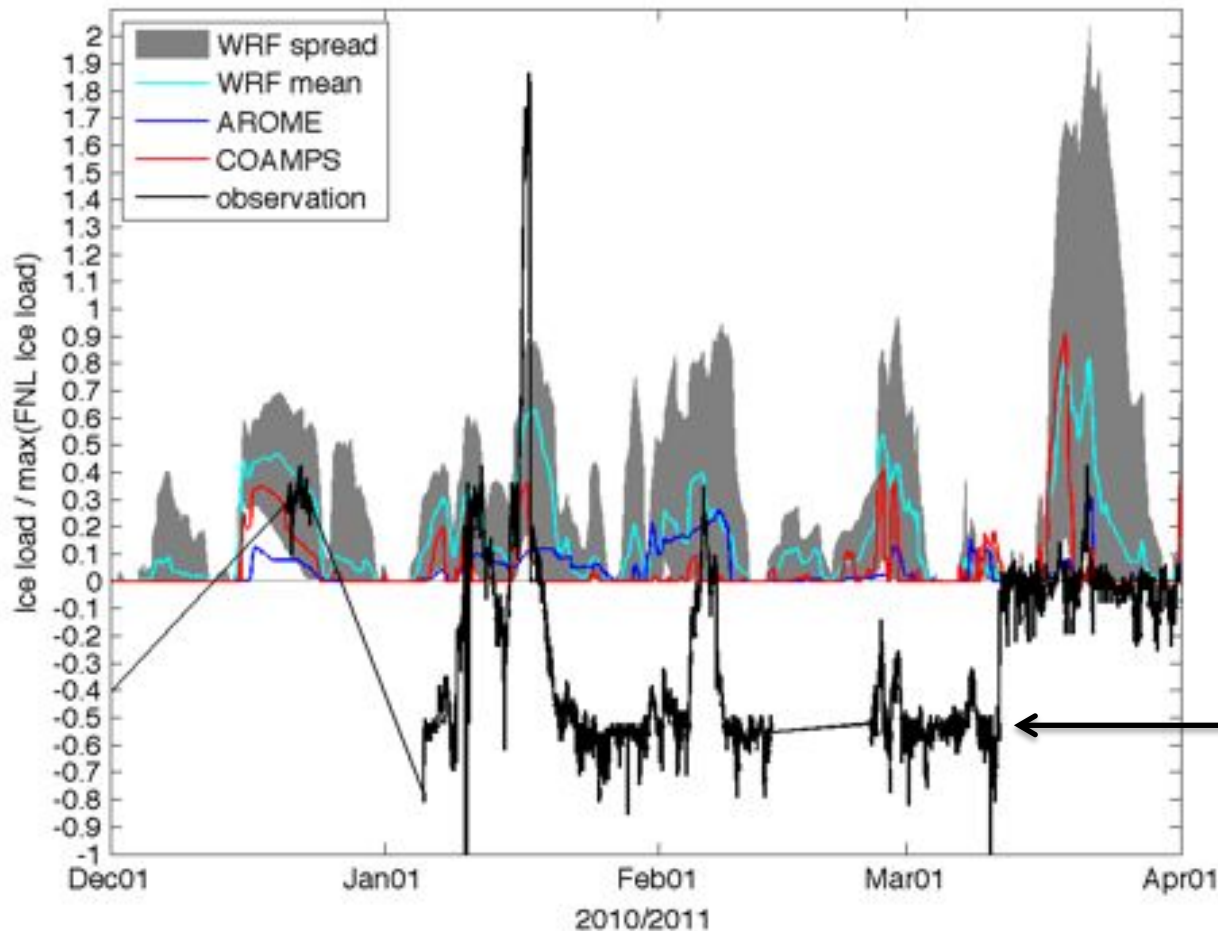
- Transition from ice to vapour

Modelled ice load – AROME, COAMPS, WRF spread



Results from
Vindforsk V-313,
Wind power in
cold climates,
funded by the
Swedish Energy
Agency

Ice load – AROME, COAMPS, WRF spread, obs



Results from Vindforsk V-313, Wind power in cold climates, funded by the Swedish Energy Agency

IceMonitor

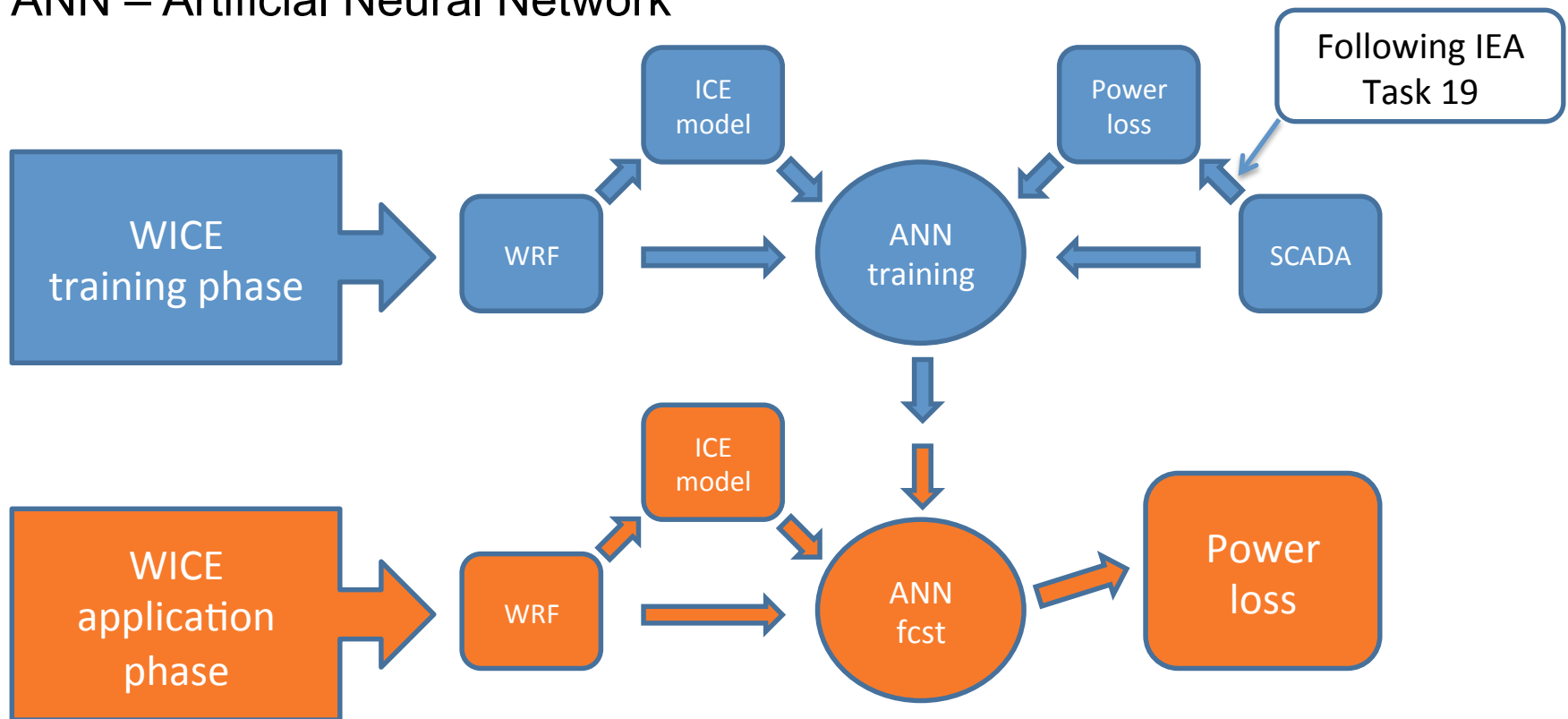
Model development

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- WICE add-ons/application

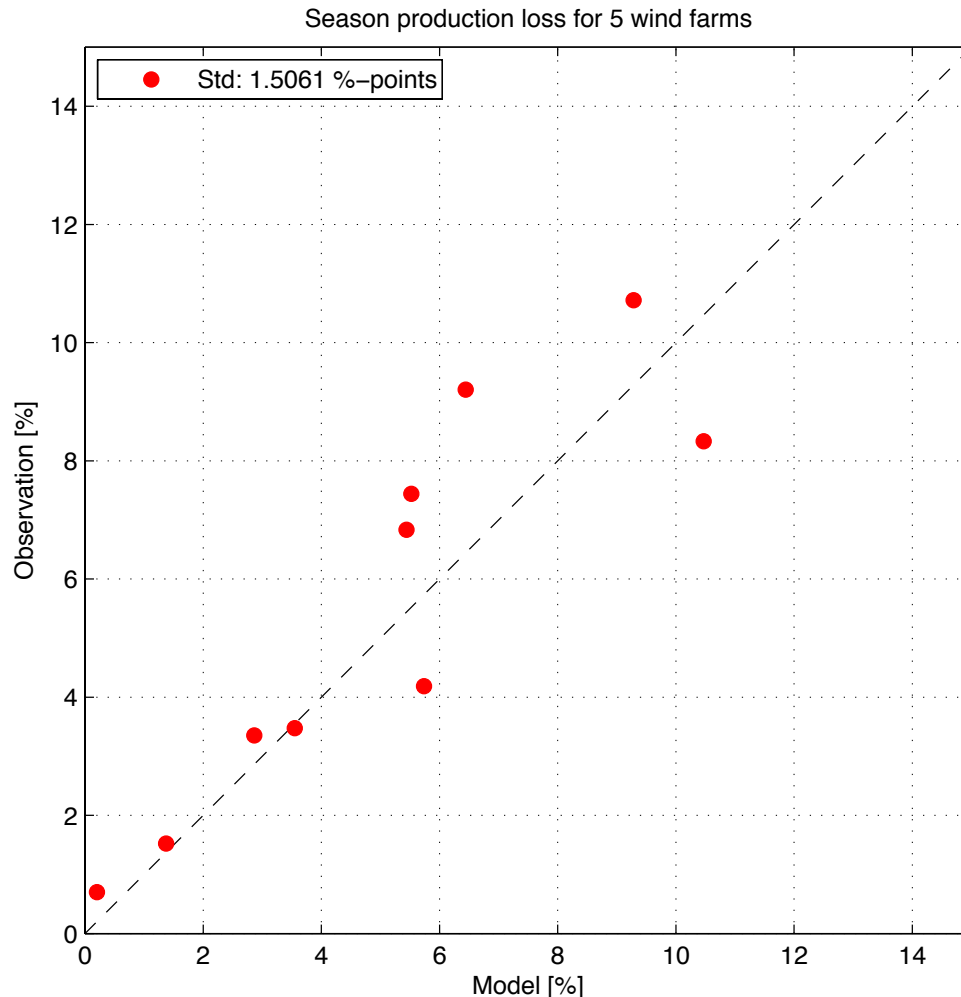
Production loss model - WICE

A combination of physical and statistical modelling

ANN – Artificial Neural Network



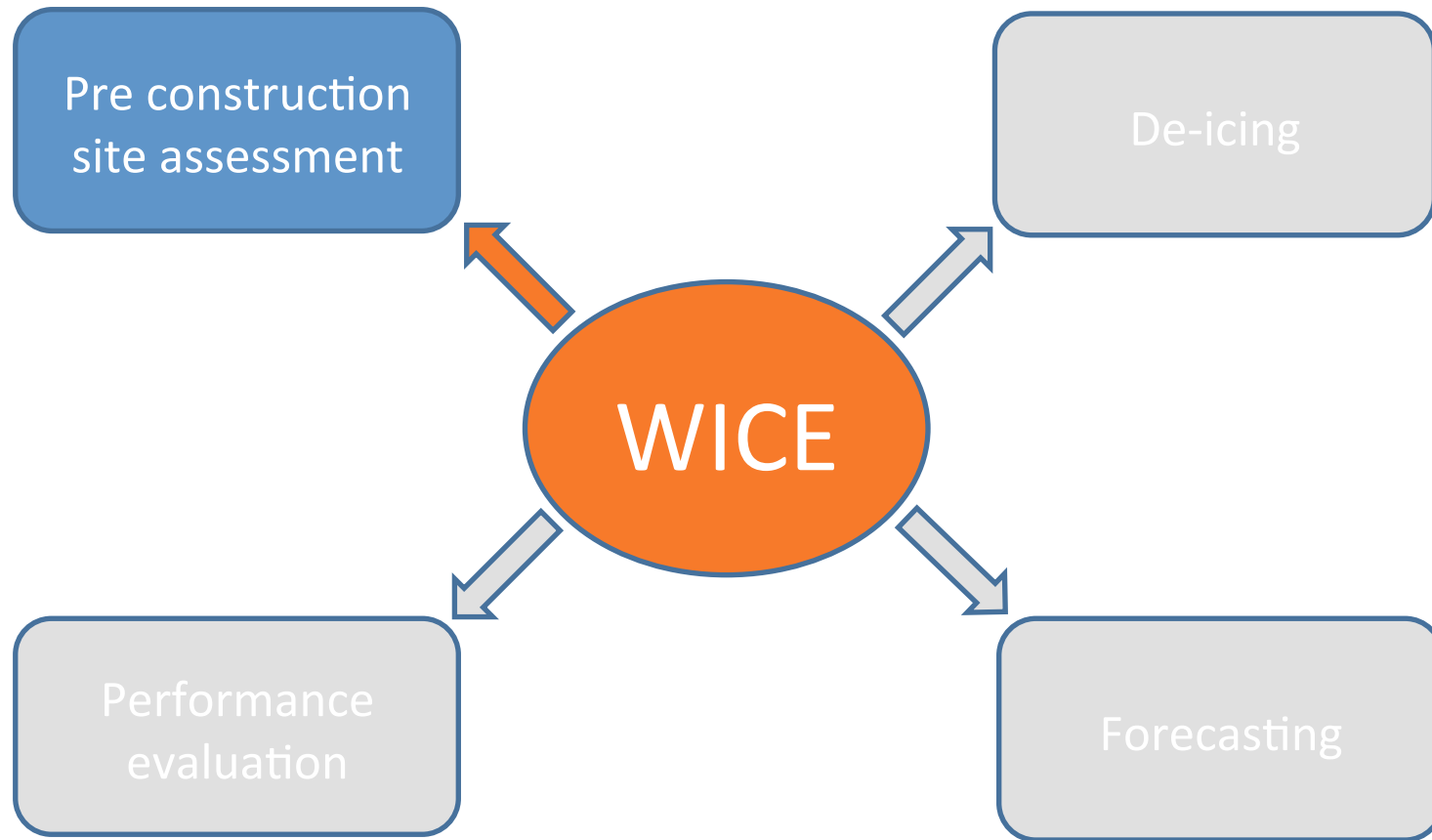
Production loss model evaluation



On-going work

Data from new wind farms and seasons are continuously added to the training and evaluation data sets.

WICE - Applications



Pre construction site assessment

Objectives for icing climate study

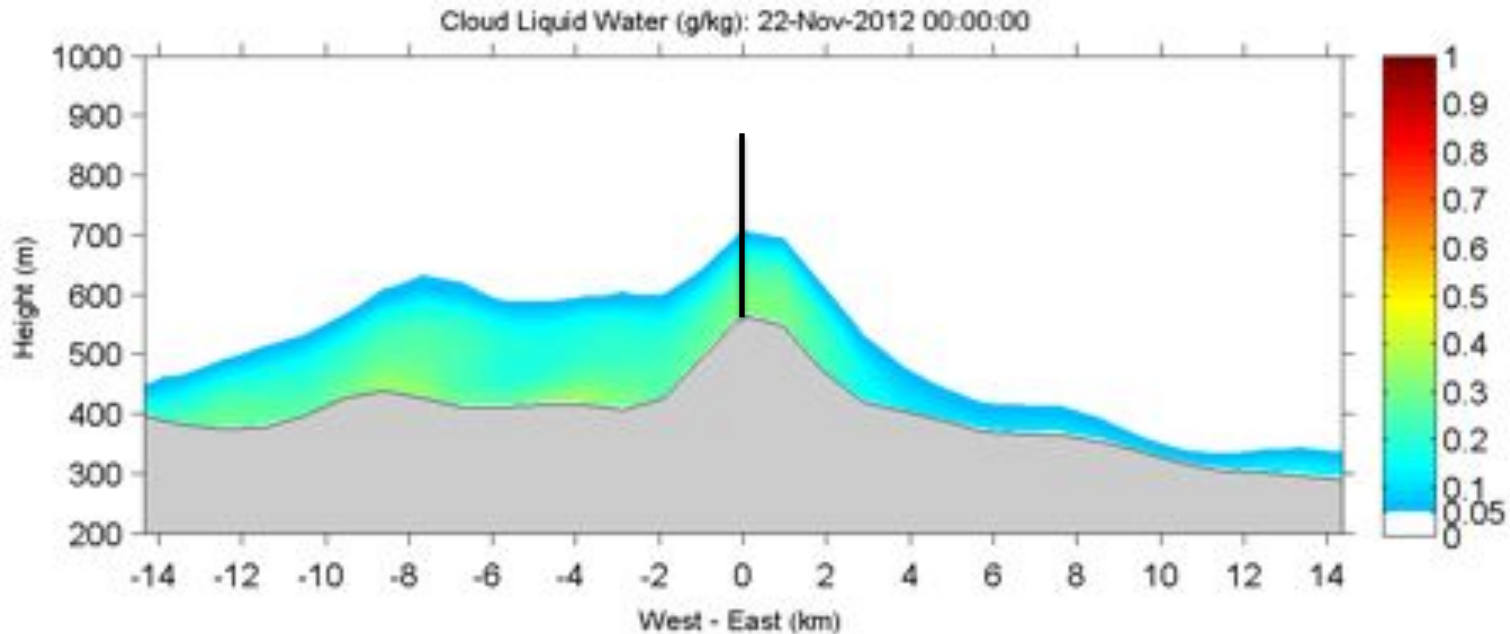
Long term site specific estimates of:

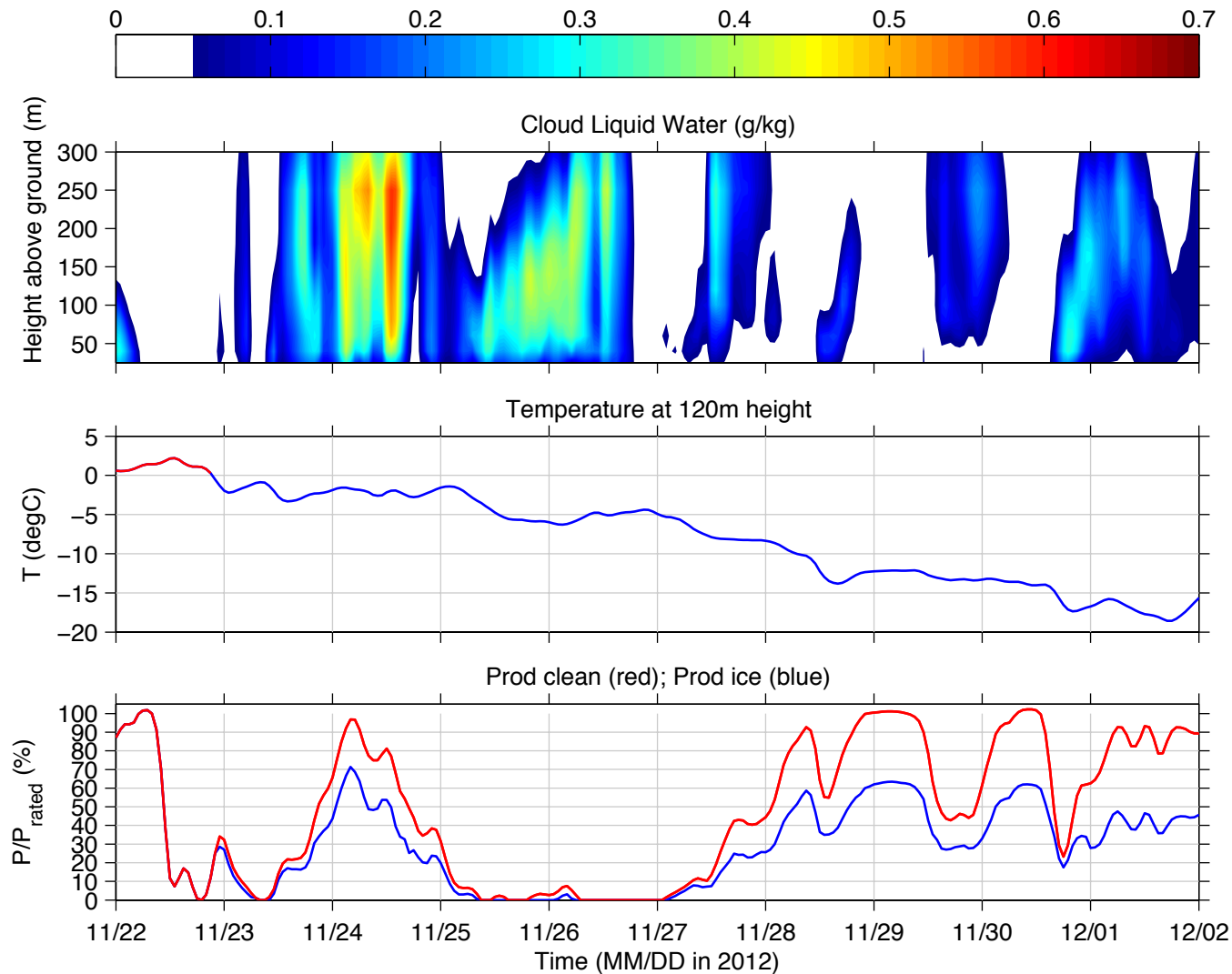
- Icing hours and iceload.
- Production and production loss.

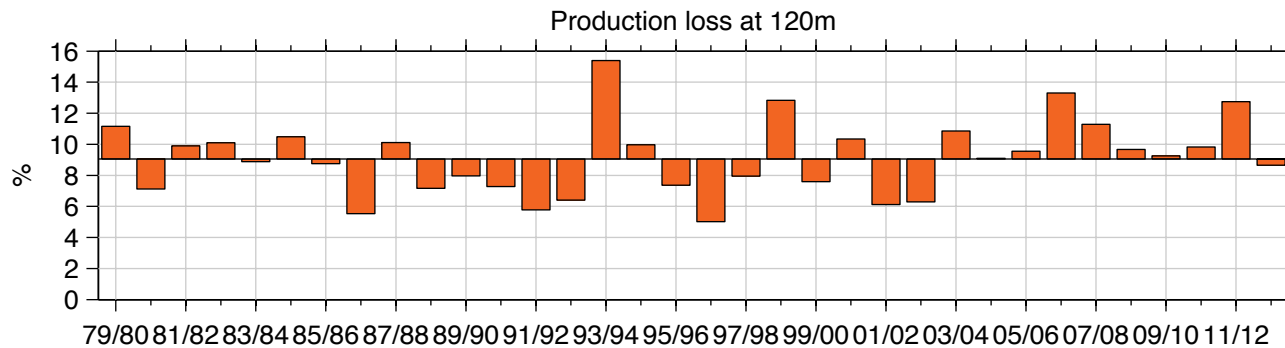
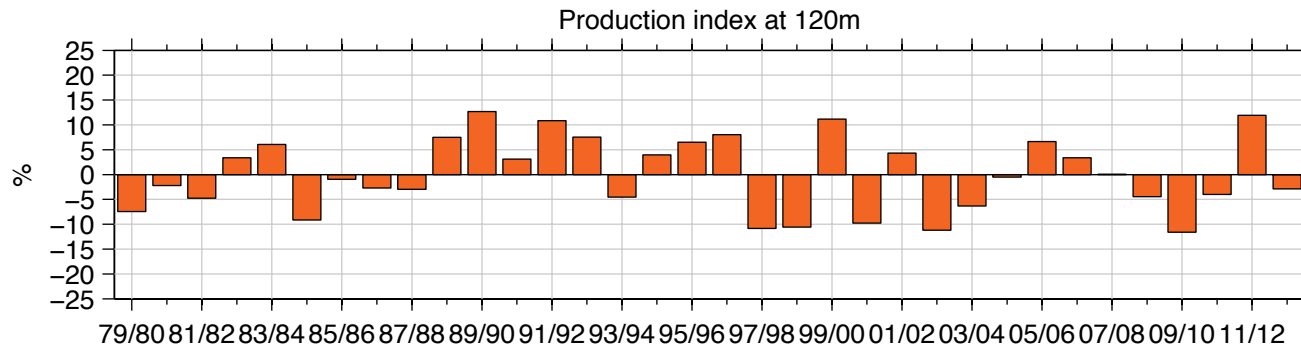
1. WRF high-resolution model runs covering 1 year.
2. Ice accretion model.
3. WICE.
4. Long term correction using 30+ yrs WRF 9km resolution.



Application of WICE

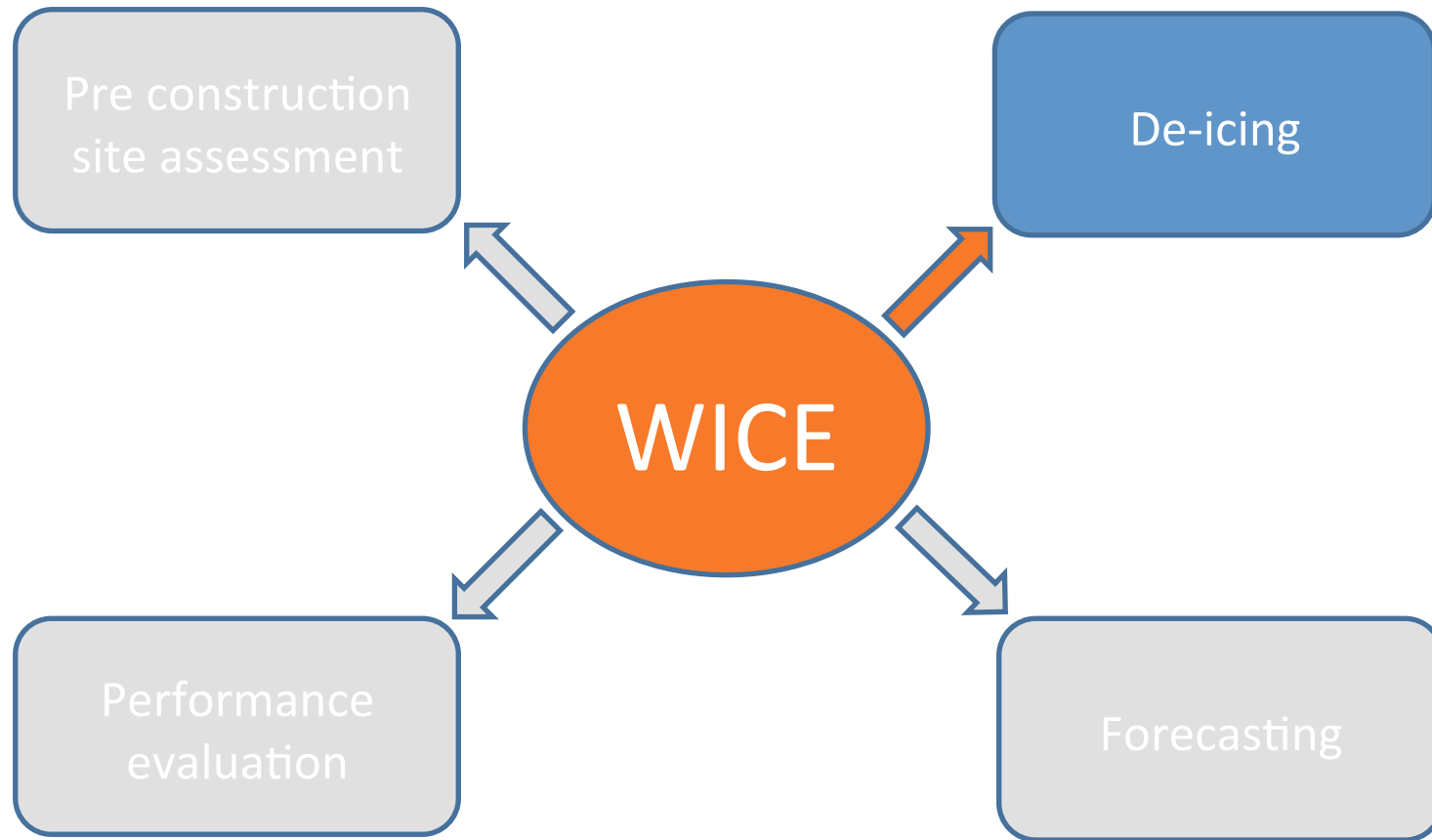




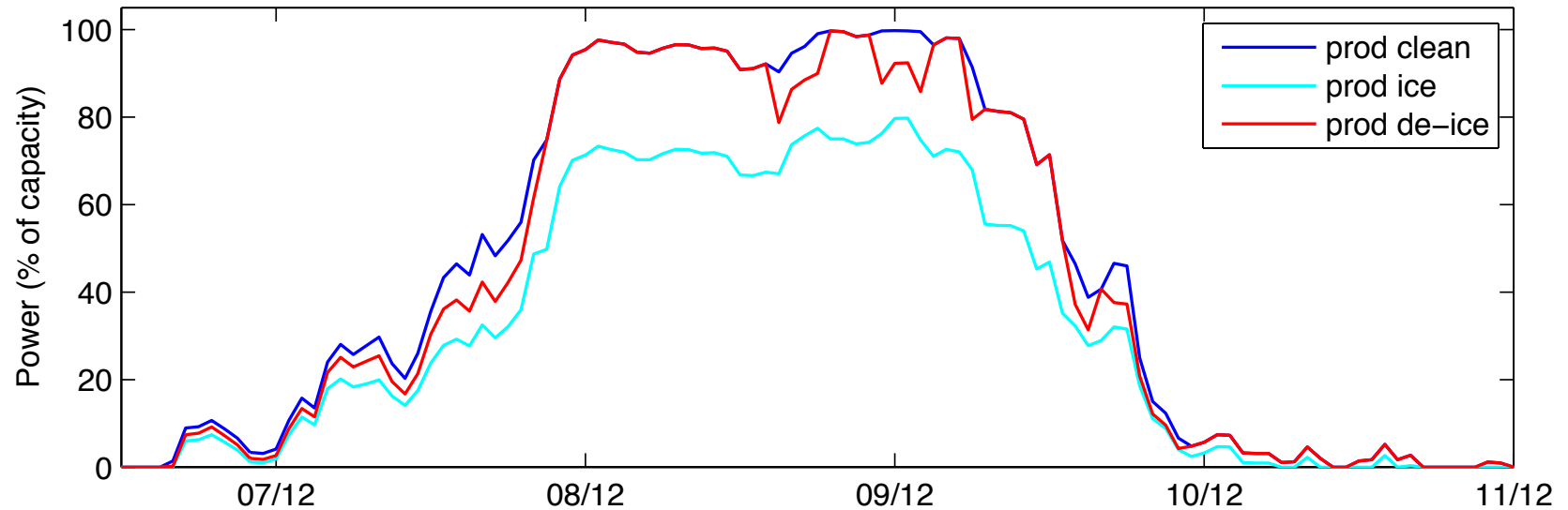


Mean ploss	Max ploss	Min ploss	Std ploss
(%)	(%)	(%)	(%)
9.1	15.4	5.0	2.4

WICE - Applications

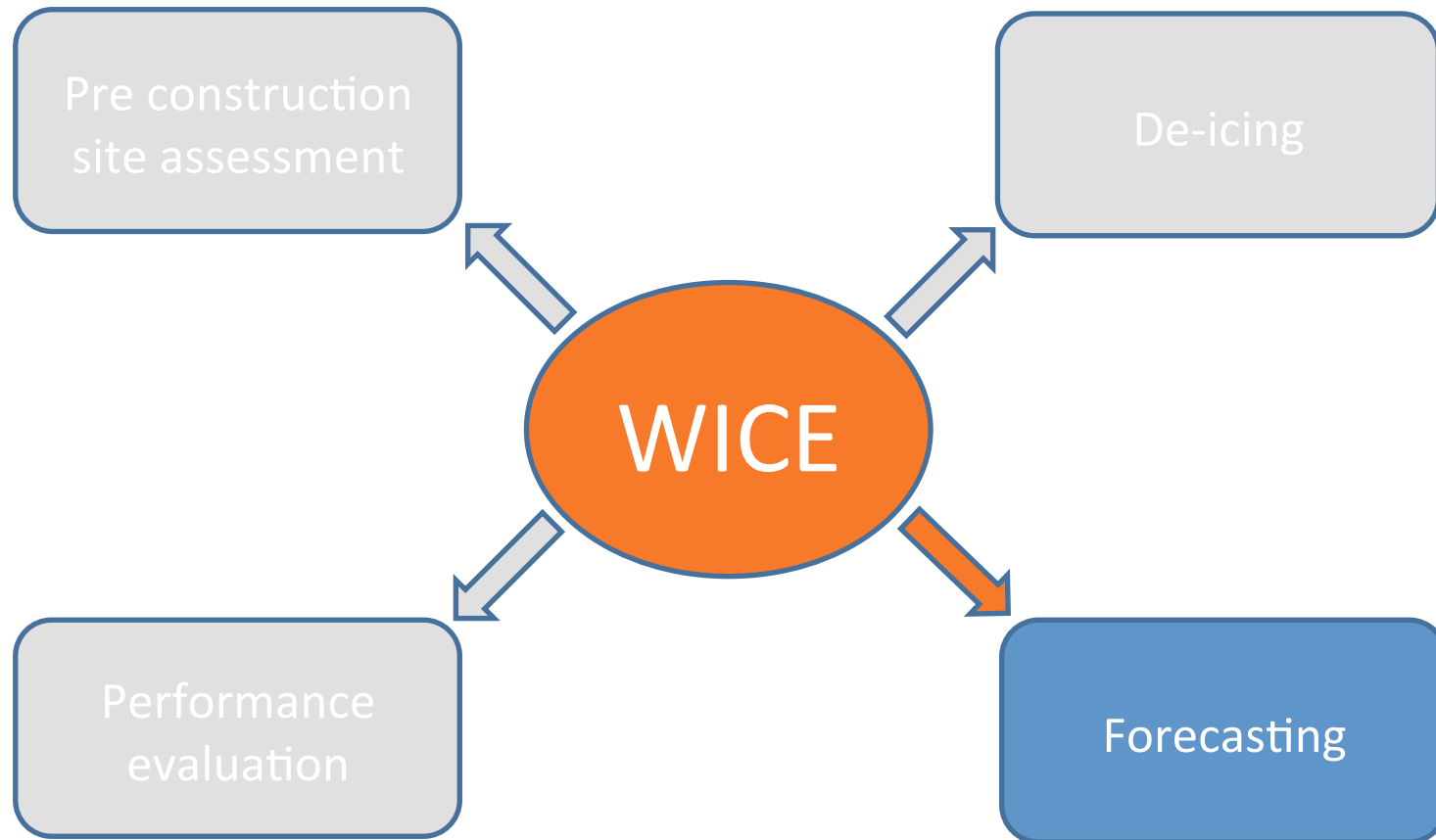


De-icing model



De-ice case	Temperature limit °C	Detection	Prod_loss in operation %	Prod_loss stopped %
-	-		9.9	
5	none	P_loss 5%	2.0	10.3
6	none	P_loss 10%	2.3	7.4
7	none	P_loss 15%	2.6	5.9
8	none	P_loss 20%	3.2	4.5

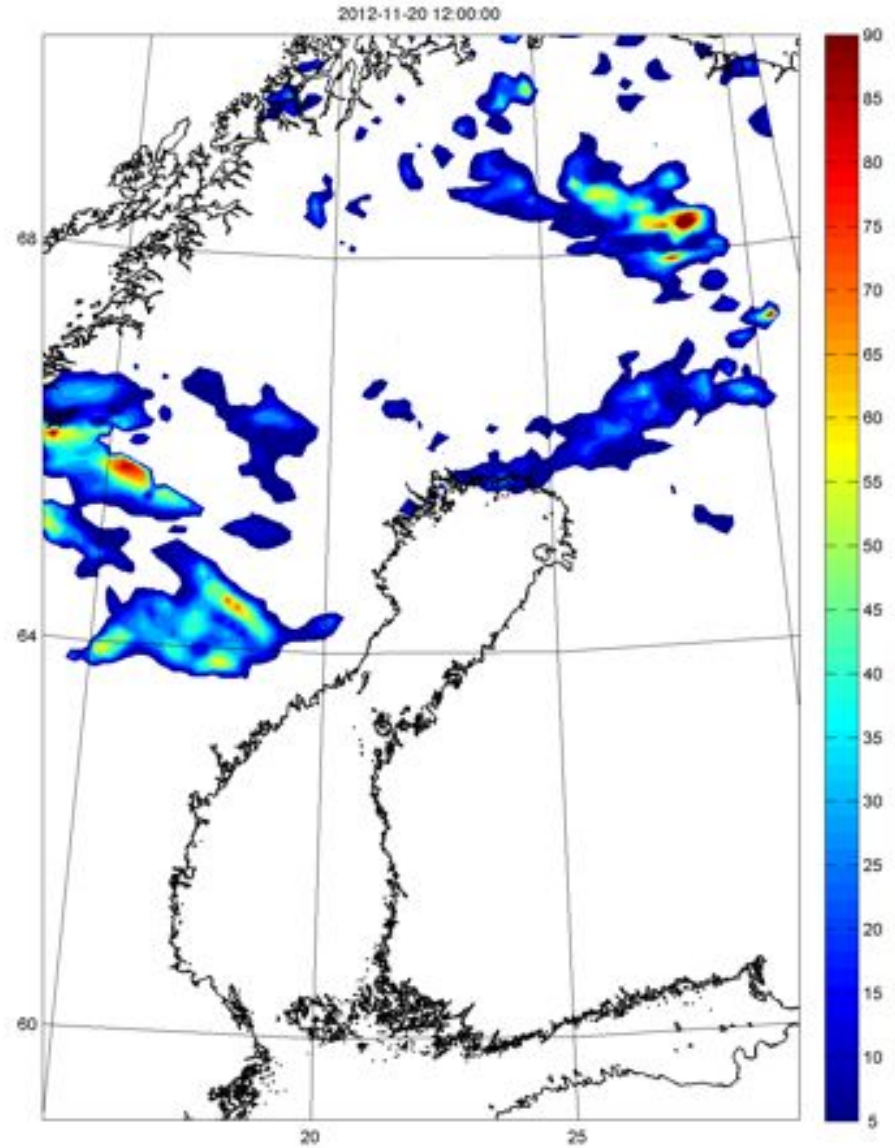
WICE - Applications



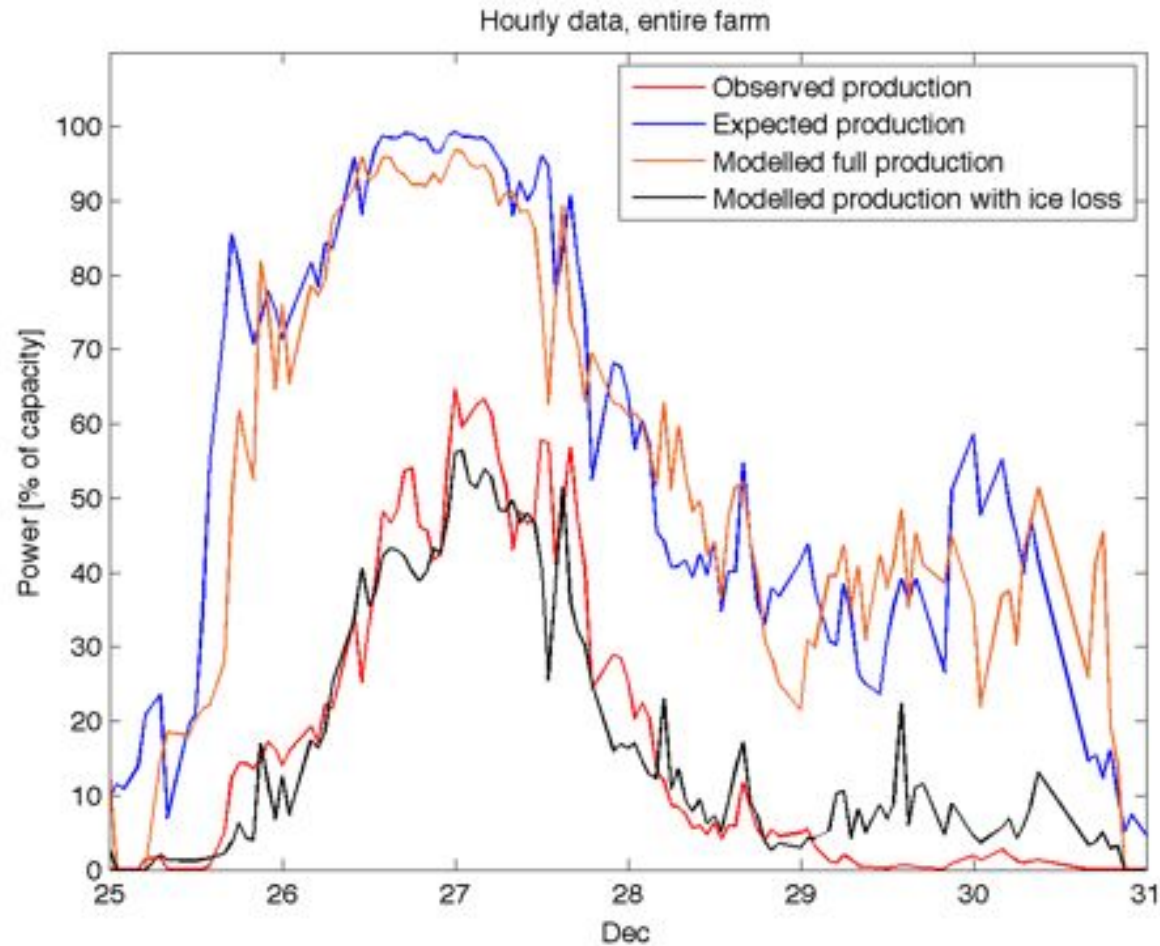
Icing rate forecast

Icing rate (g/hour)
Hourly variation
at 120m

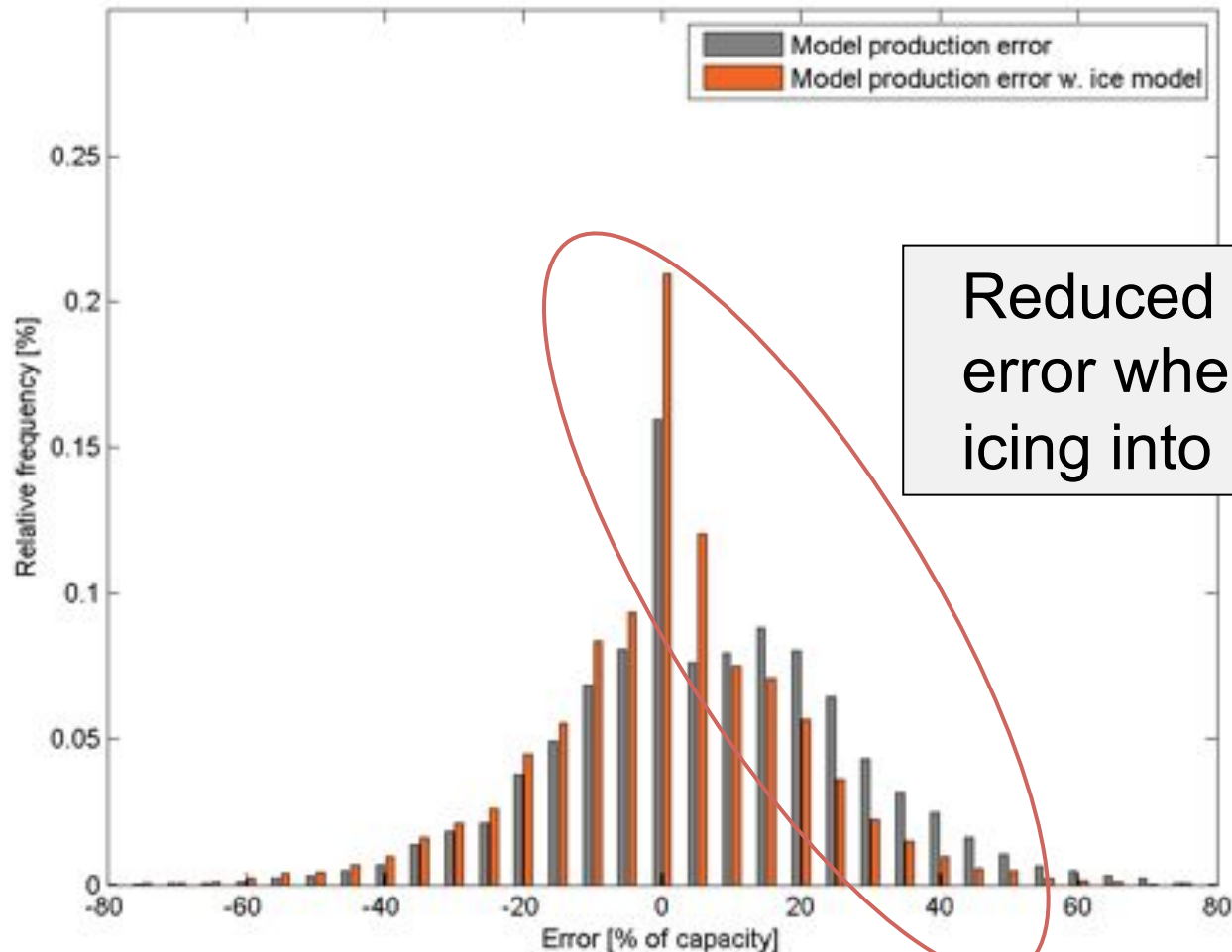
(5-90 g/hour)



Production loss model evaluation

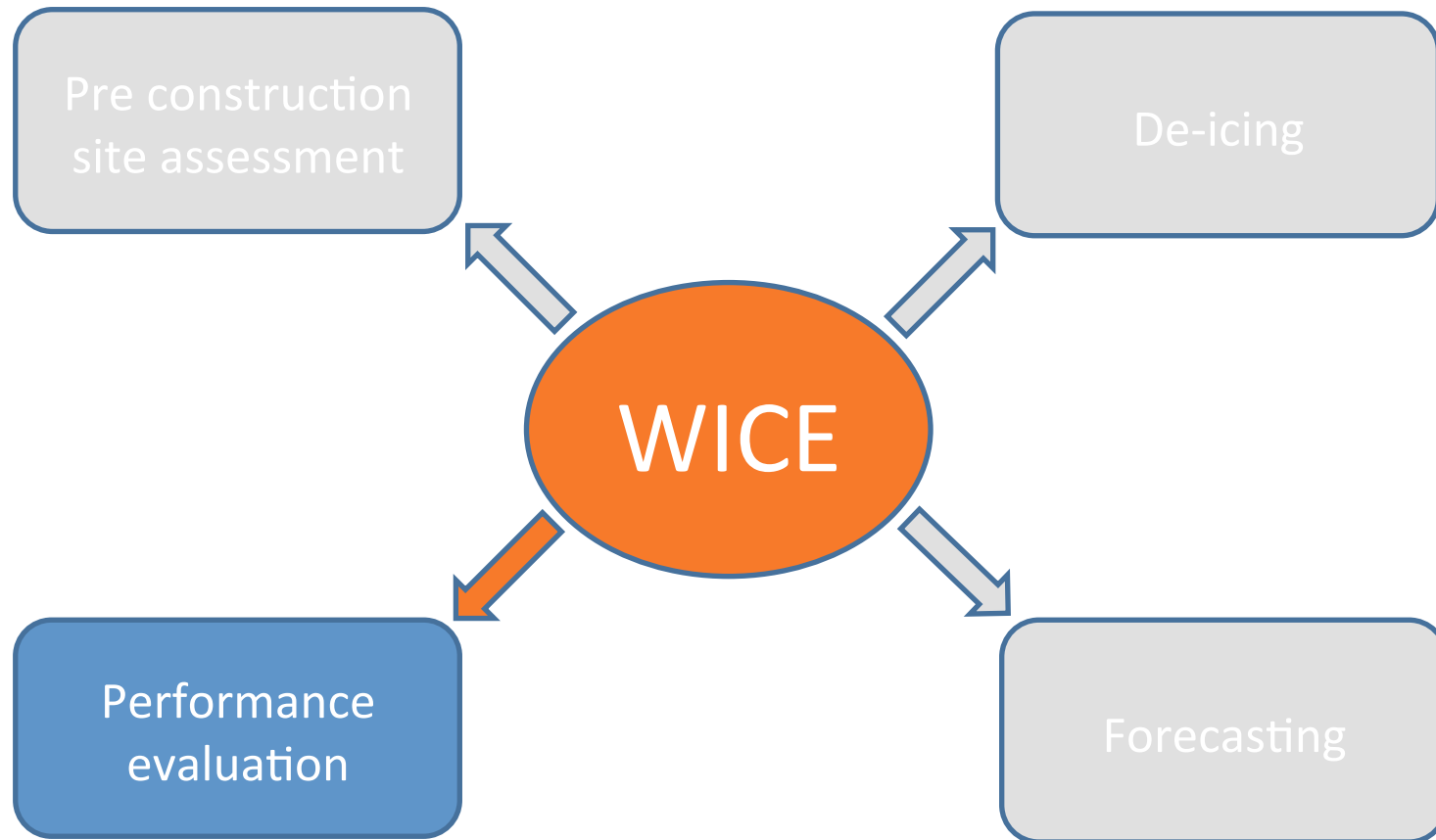


Production loss model evaluation



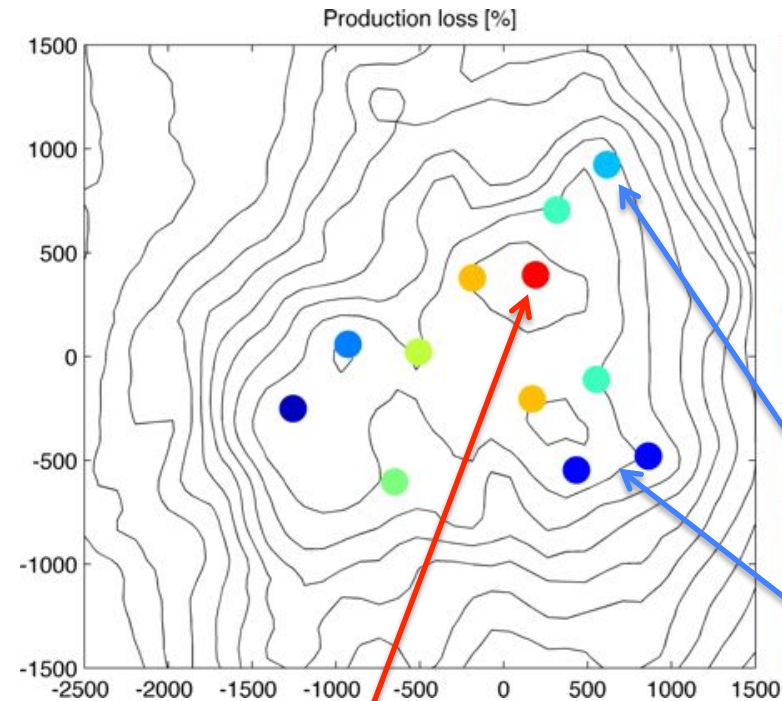
Reduced forecast error when taking icing into account.

WICE - Applications



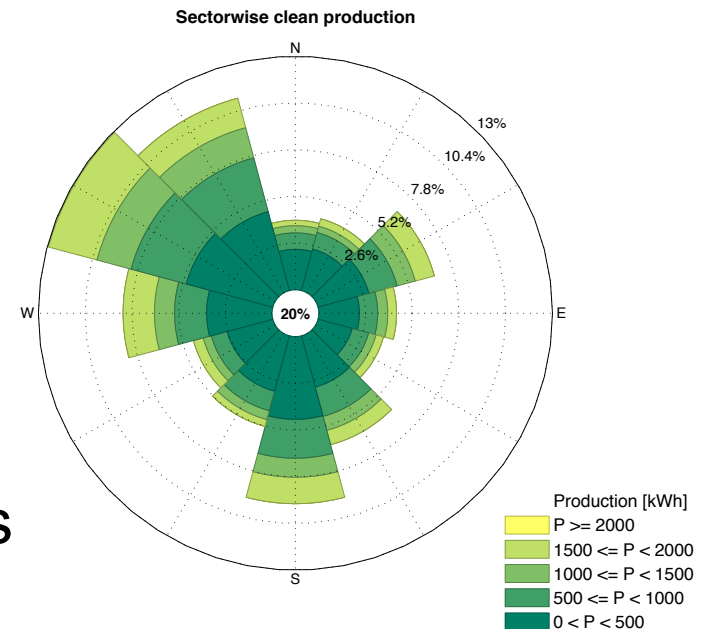
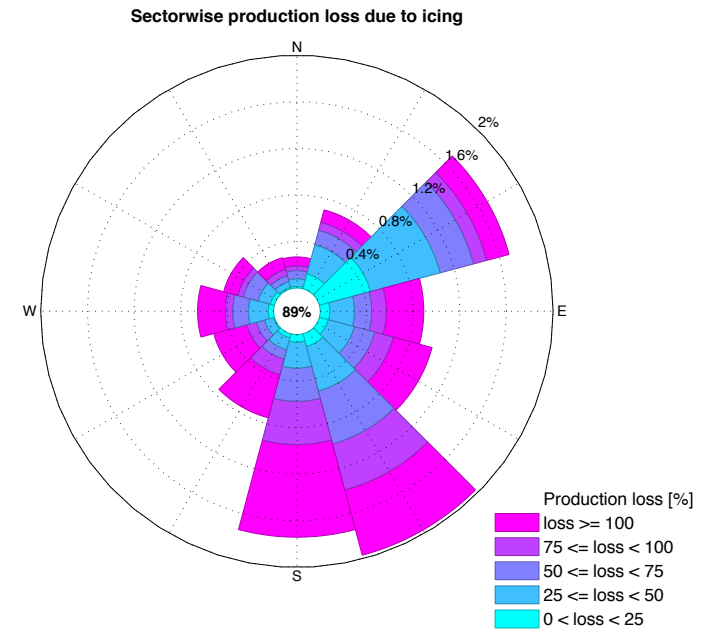
Variability within a site

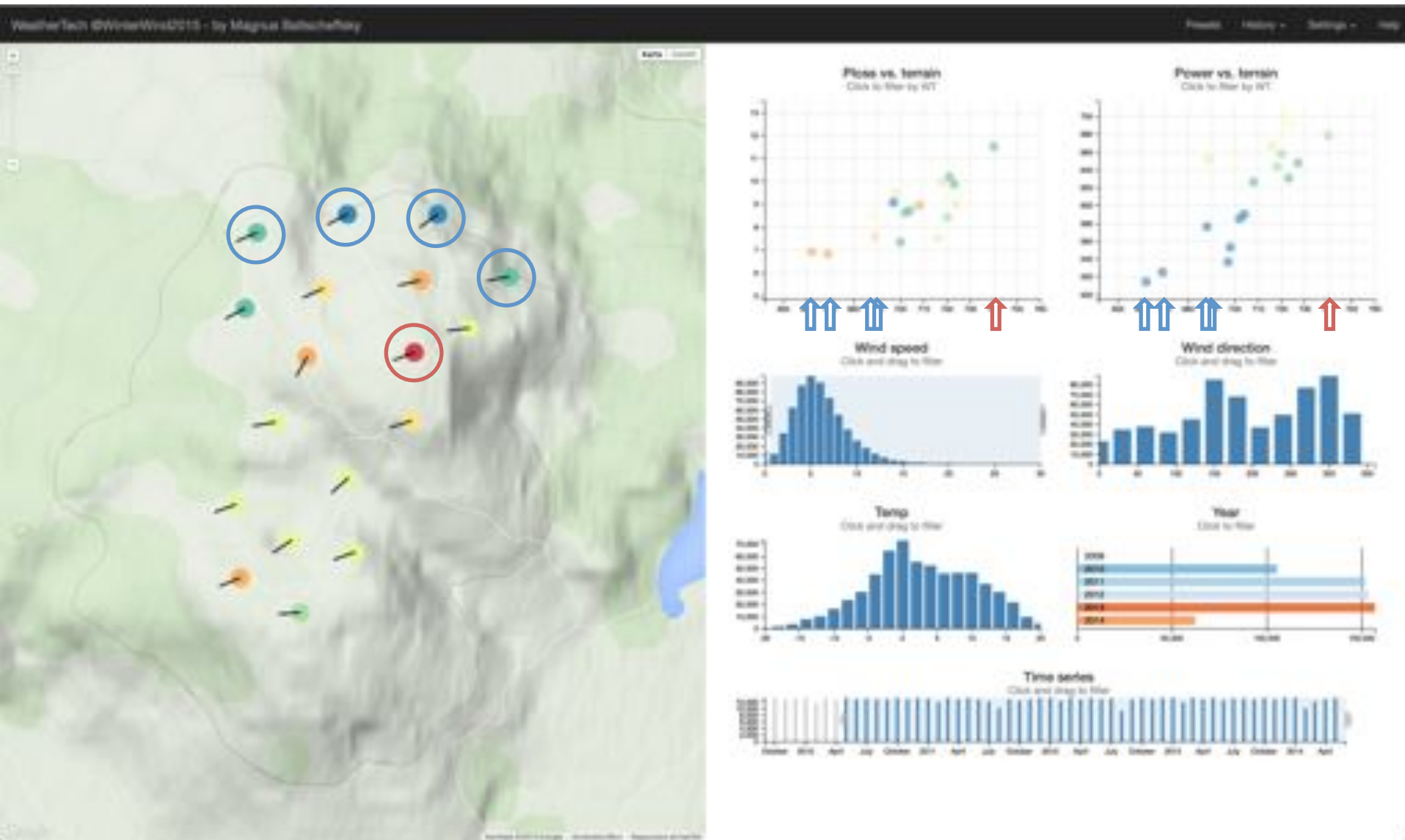
2010 - 2011 Scale: 4.9-9.1%



Large losses

Small losses





Summary

OX2's vindpilot project:

- Icing climate and production losses studied 2009-2015 at several sites in Sweden

Unique data set => WICE - Tool for:

- Site assessment and de-icing studies
- Forecasting
- Performance evaluation

On-going work

- Analysis of SCADA data from turbines with de-icing system
- Forecast evaluation projects