# Analysis of spatial and temporal variability in icing conditions and production losses due to icing using a new long-term icing climate database

Icewind

Top-level Research Initiative

WeatherTech

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# About WeatherTech

- Consultant firm based in Uppsala, Sweden

- Specialised in:

    - Mesoscale atmospheric modeling

    - Atmospheric icing

- Other services:

    - Energy forecasts

    - Dispersion

    - Sailing

- R&D:

    - National and international projects

# Introduction

Variability in icing conditions and production losses due to icing.

From observations and SCADA data we know:

- Large variability from season to season

- Large variability from site to site

- Large variability within a site

Only a limited data set available.

- Few icing seasons and few sites.

What can be learned from model data?
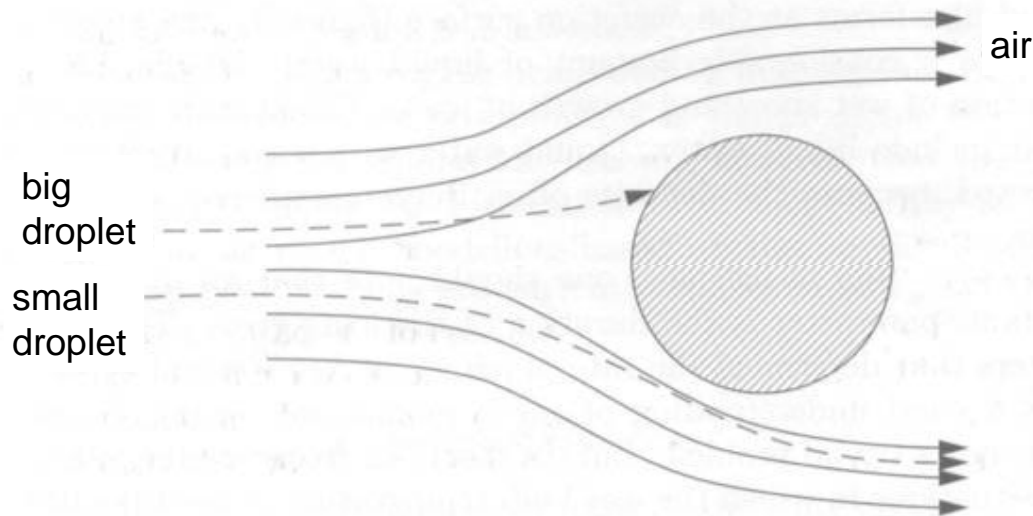
# Atmospheric modelling

- The Weather Research and Forecast (WRF) model

- Forcing: ERA Interim

- Period length / grid resolution:
    - 34 years / 9 and 3 km
    - 5 years / 1 km

- Hourly values:
    - Wind speed/direction
    - Temperature
    - Cloud condensates etc.

- Diagnostics:
    - Ice accretion
    - Ice load

3 km          1 km

9 km
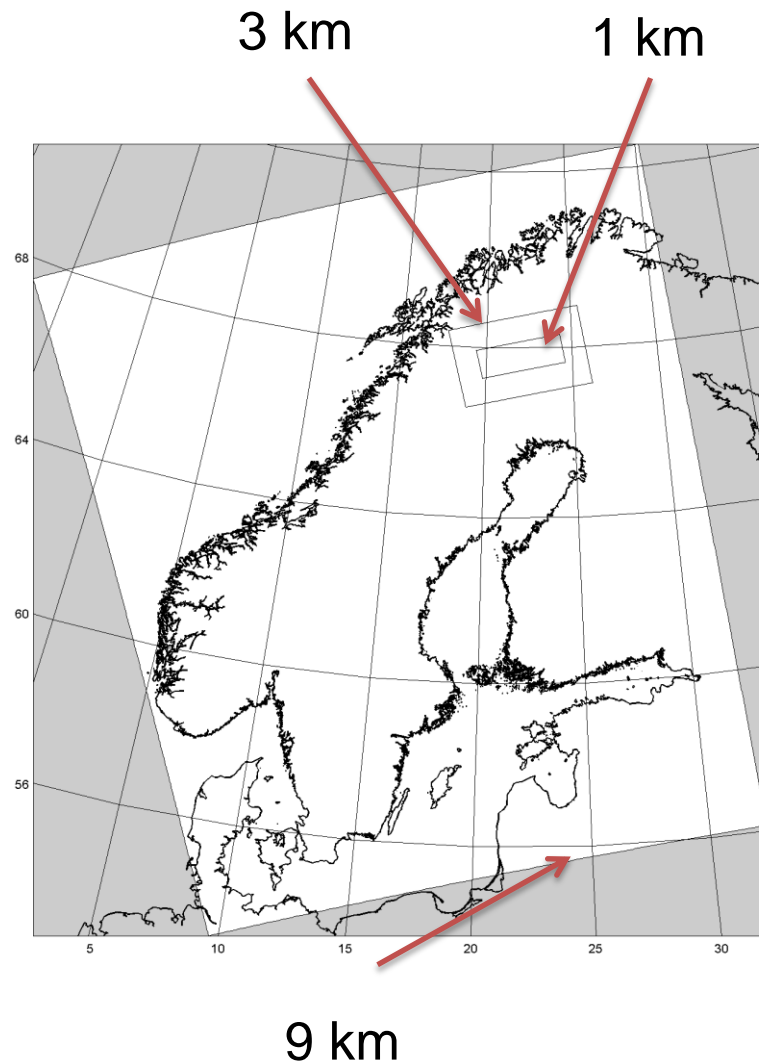
# Modelling ice accretion (ISO 12494)

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
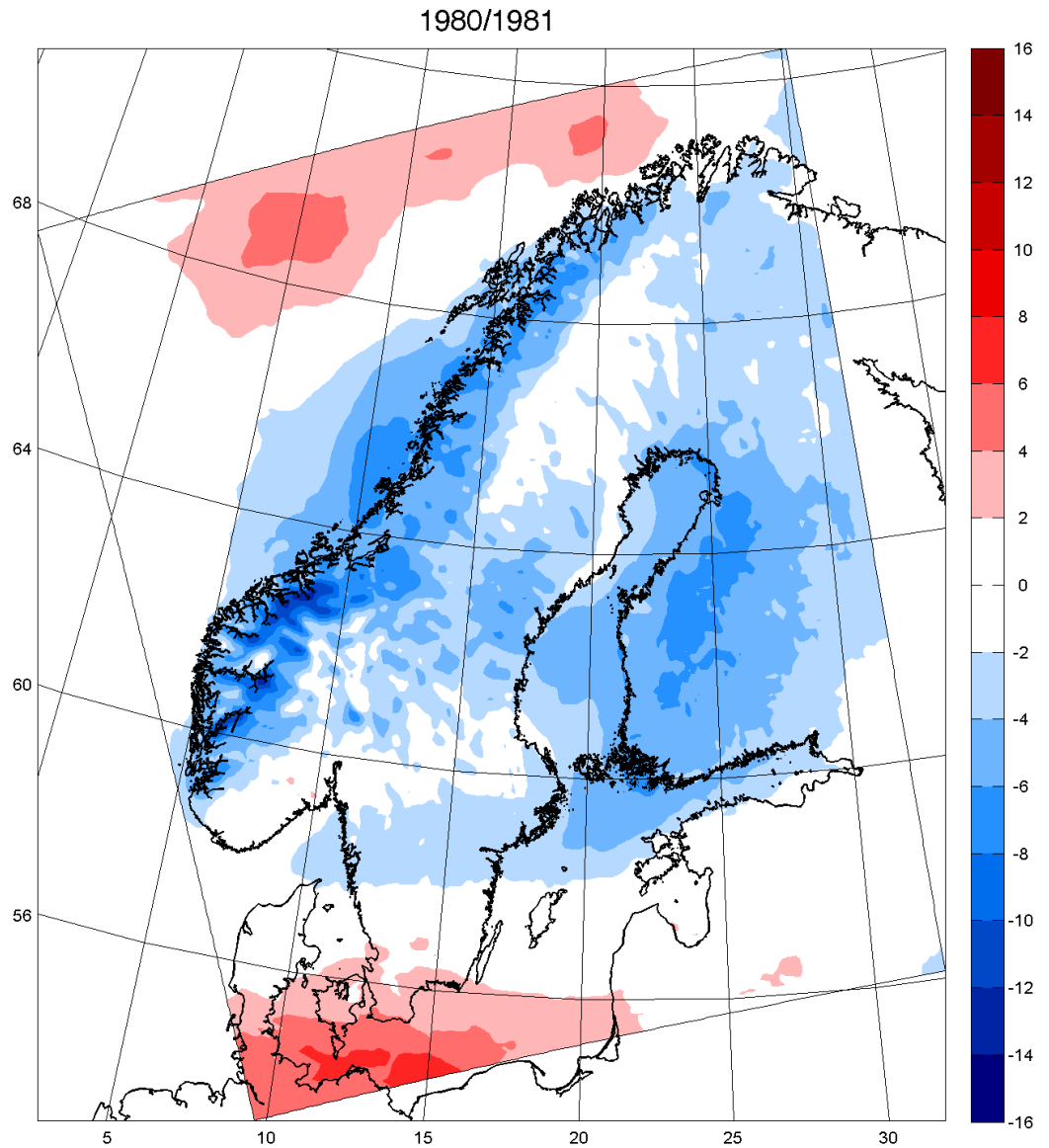- $\alpha_1$ collision efficiency
- $\alpha_2$ sticking efficiency
- $\alpha_3$ accretion efficiency

air

big droplet

small droplet

**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
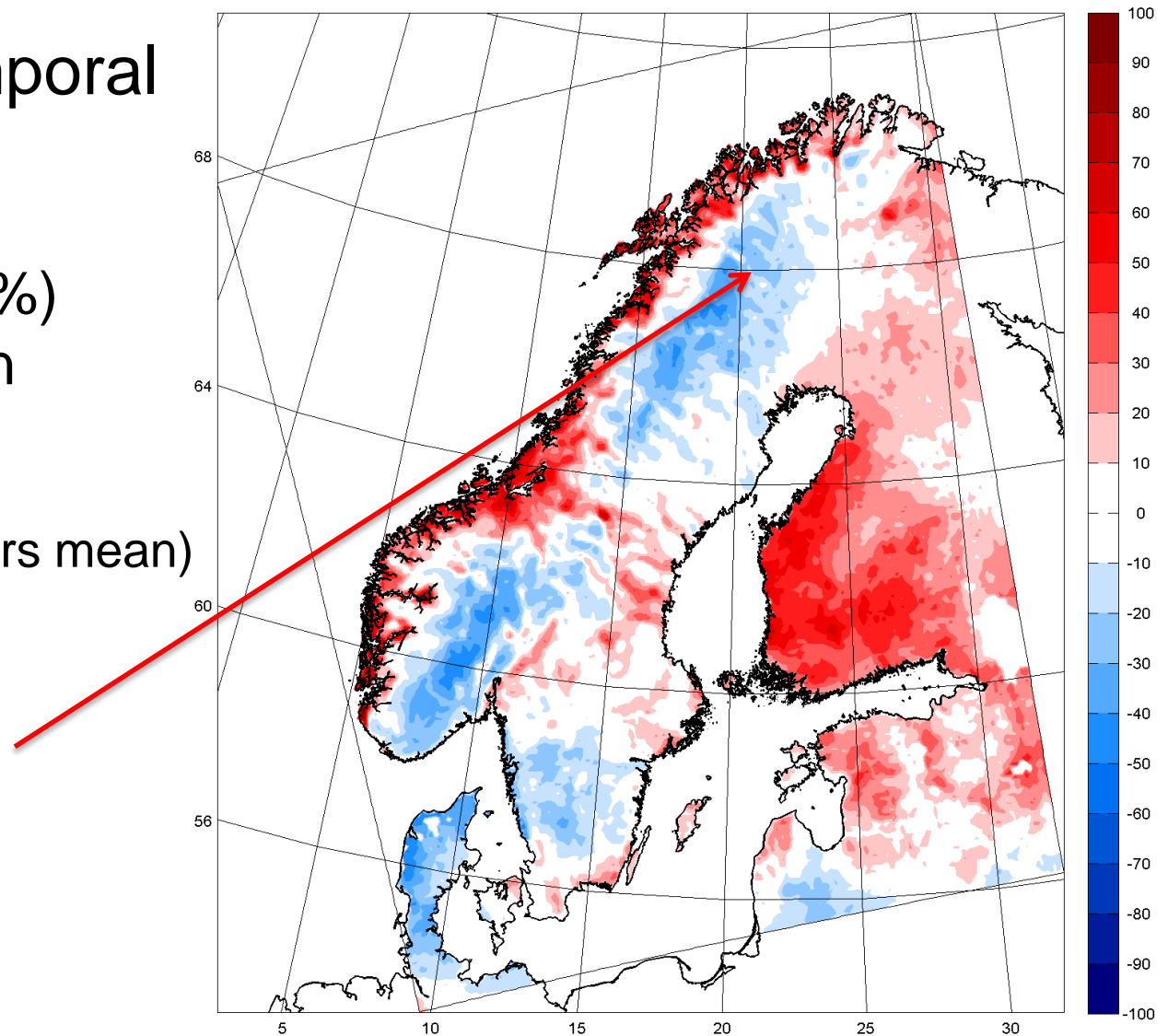at 120m

(+/-16% from 34 years mean)



1980/1981

# Spatial and temporal variability

Icing hour Index (%)
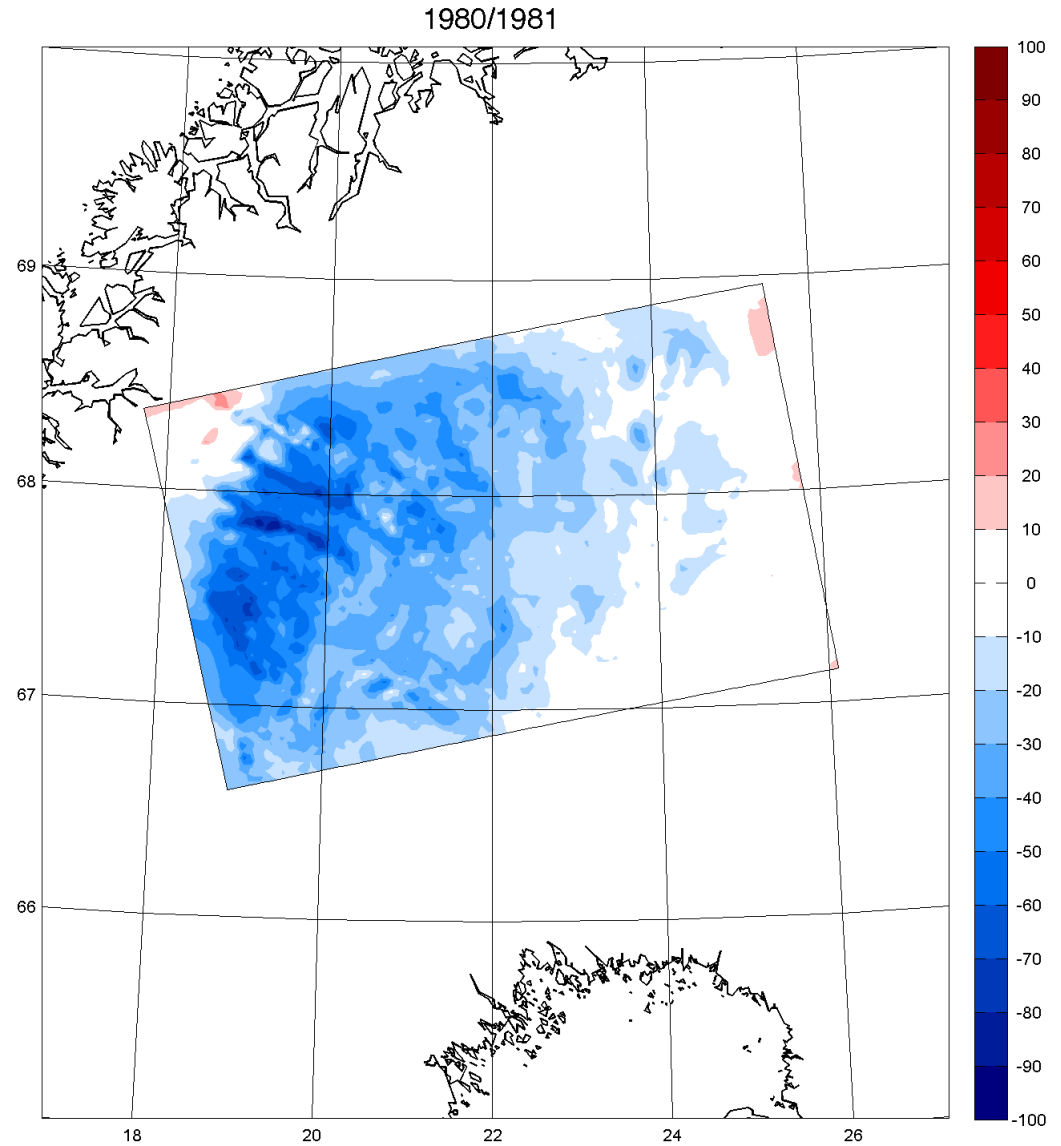Seasonal variation
at 120m

(+/-100% from 34 years mean)

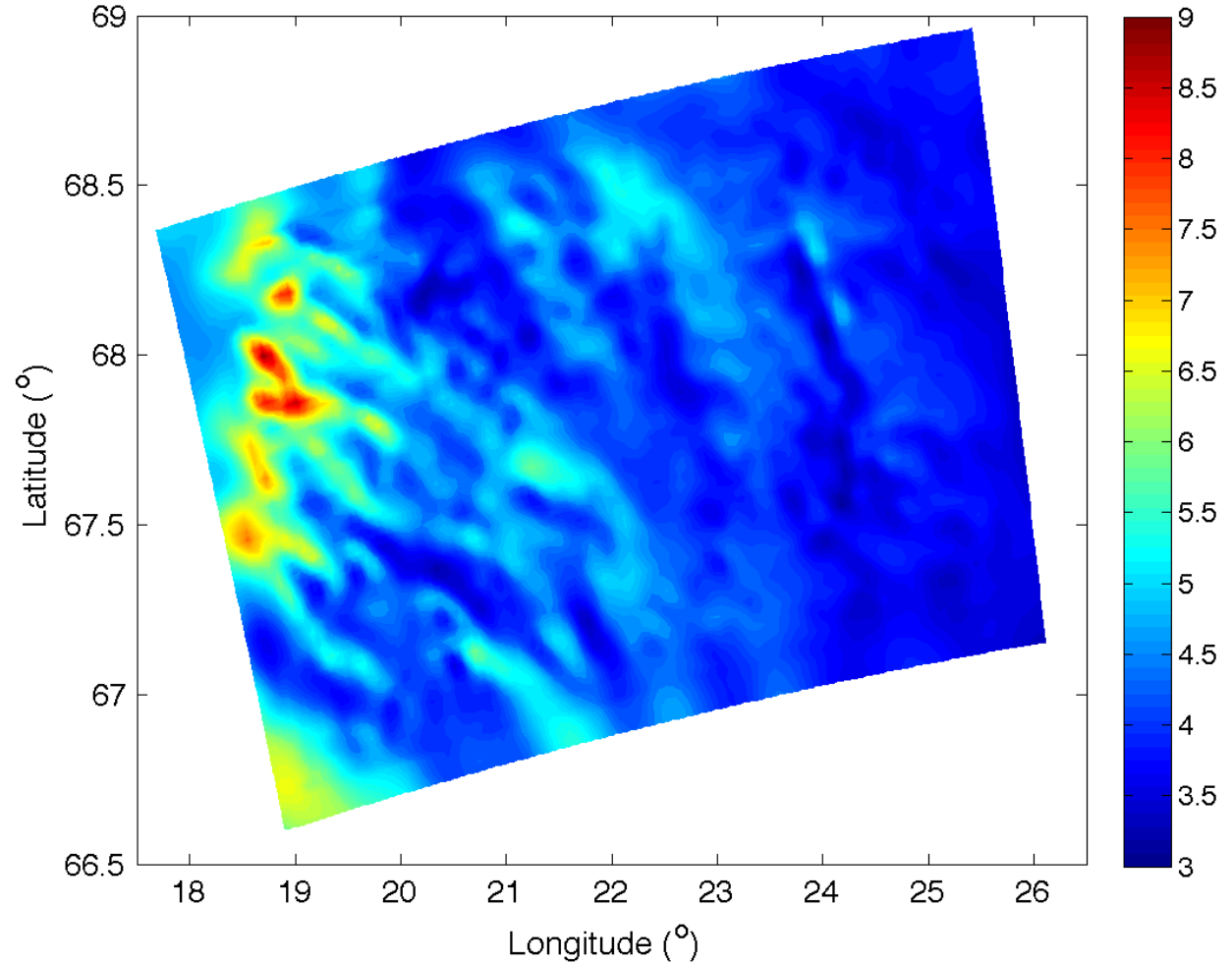On a finer scale



1980/1981

# Spatial and temporal variability

Icing hour Index (%)
Seasonal variation
at 120m

(+/-100% from 34 years mean)

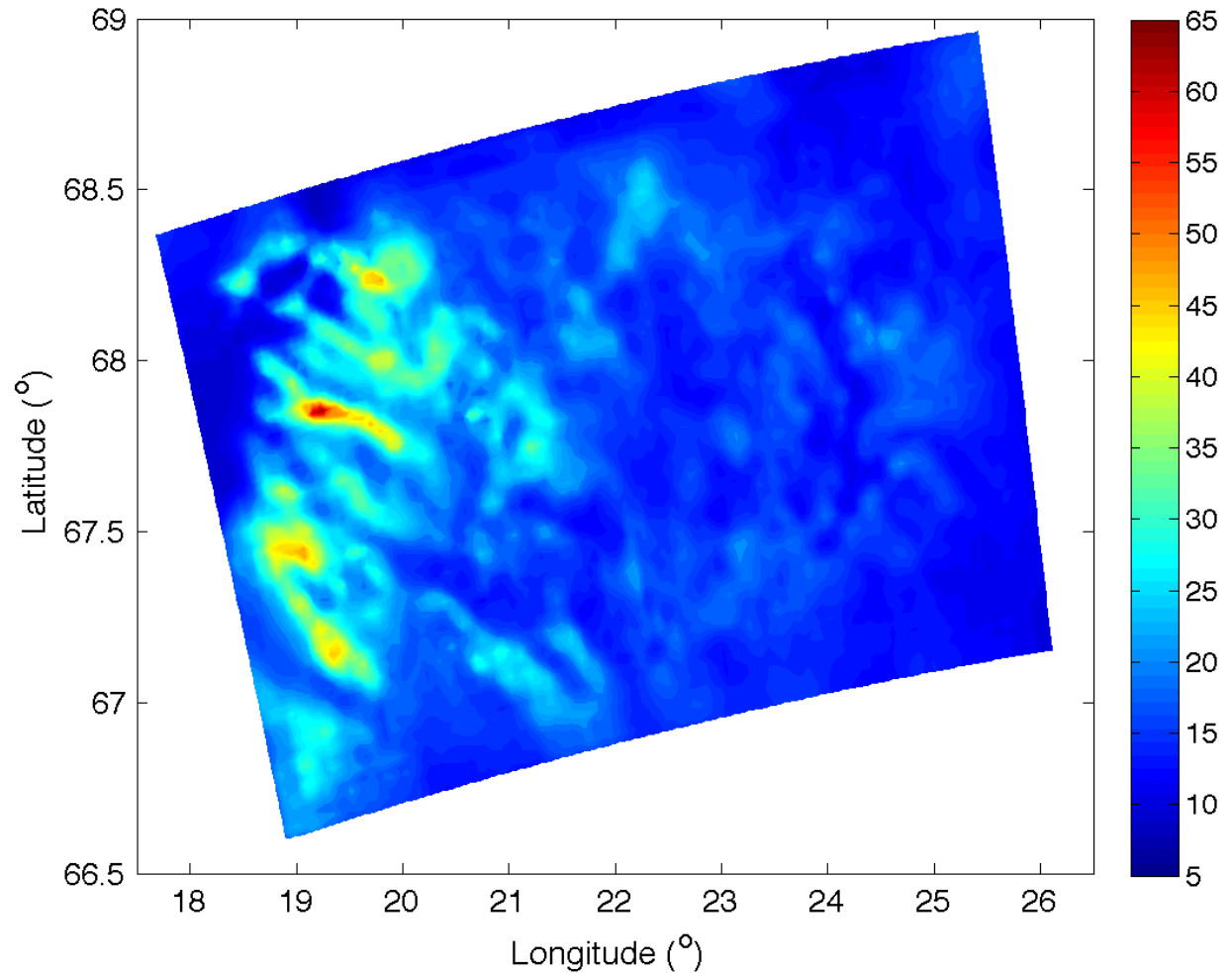

1980/1981

# Spatial and temporal variability

**Wind speed** variability coefficient, stddev/mean, at 120m (%)

# Spatial and temporal variability

**Icing hour** variability coefficient, stddev/mean, at 120m (%)

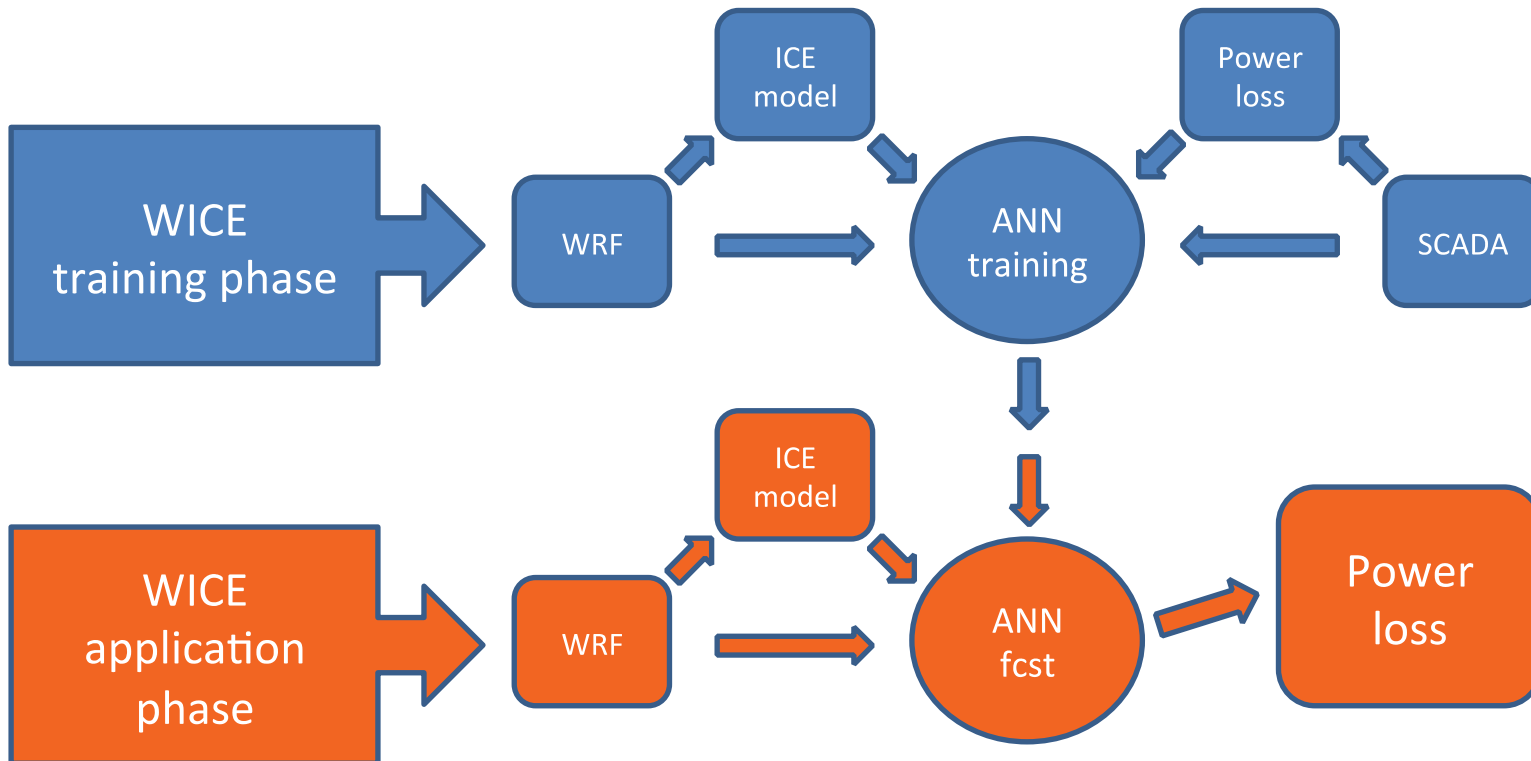An order of magnitude larger than for wind speed

# Production loss model - WICE

Includes:

- a physical module for modelling ice accretion and ice removal on a simplified wind turbine blade

- a statistical module that relates the modelled ice and properties of the atmosphere to turbine performance

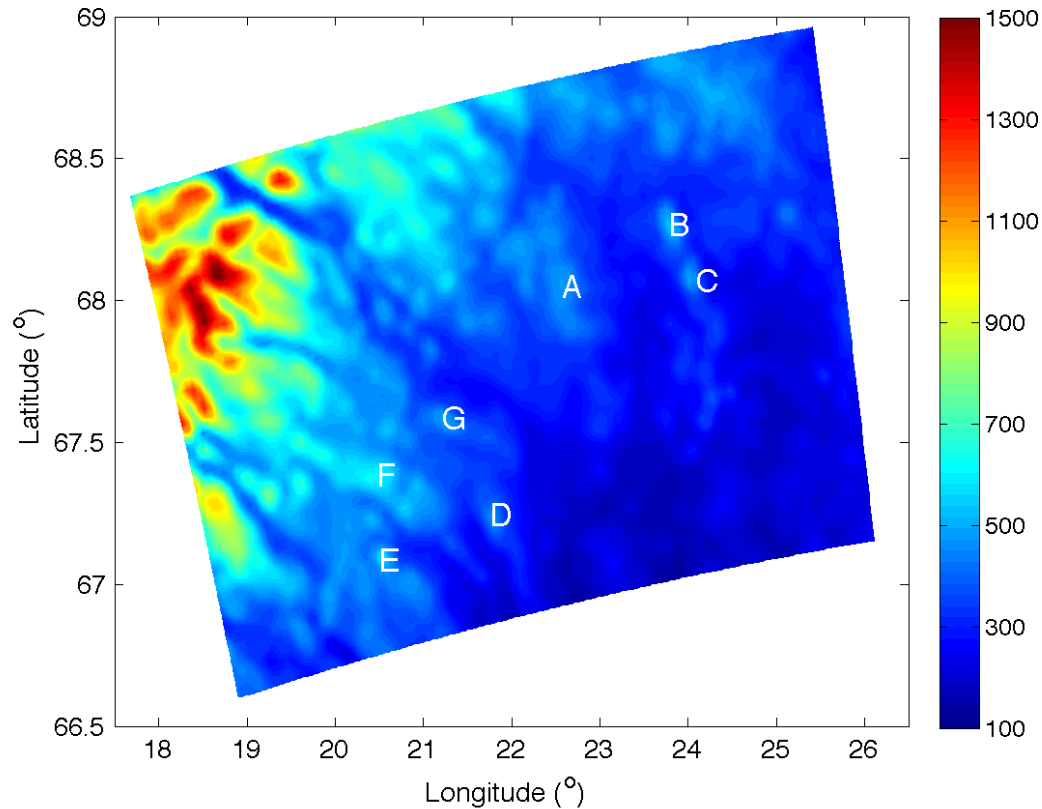# Production loss model - WICE

Conceptual description of WICE

# Production loss model evaluation



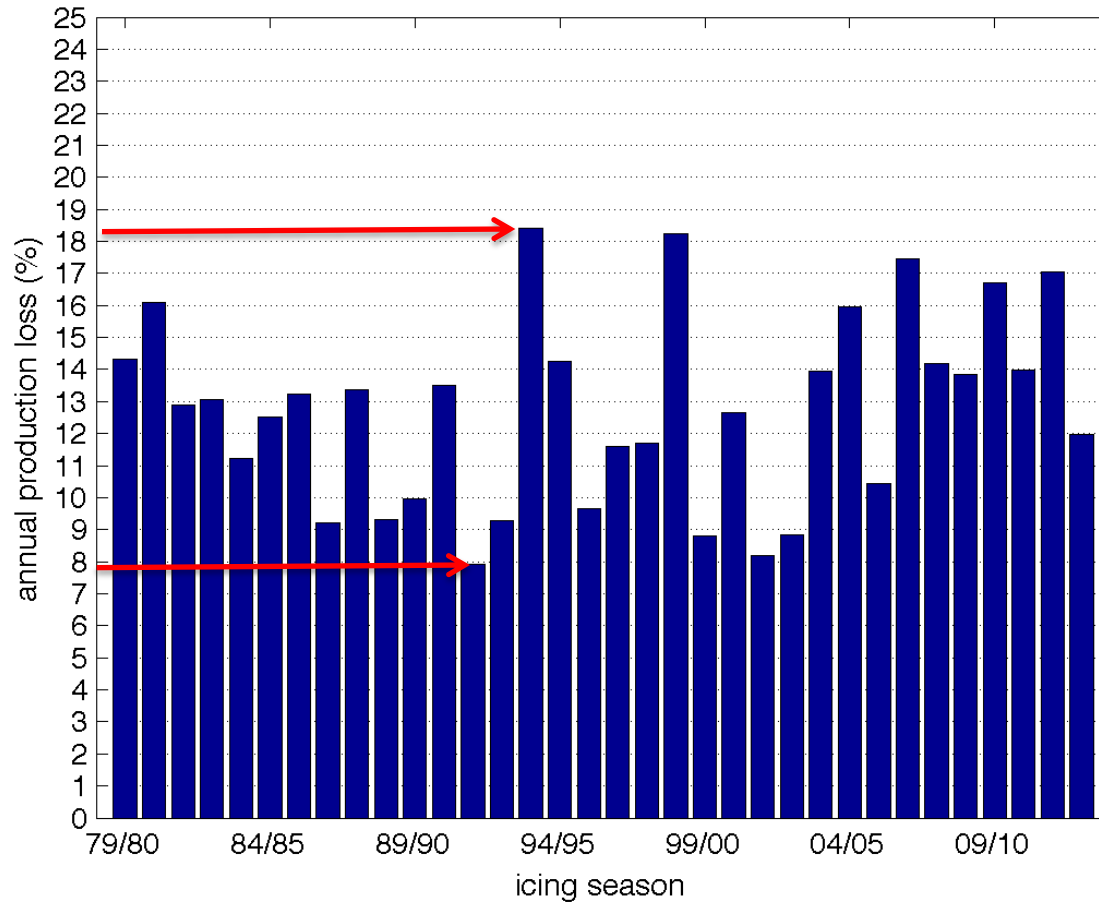Season production loss for 5 wind farms
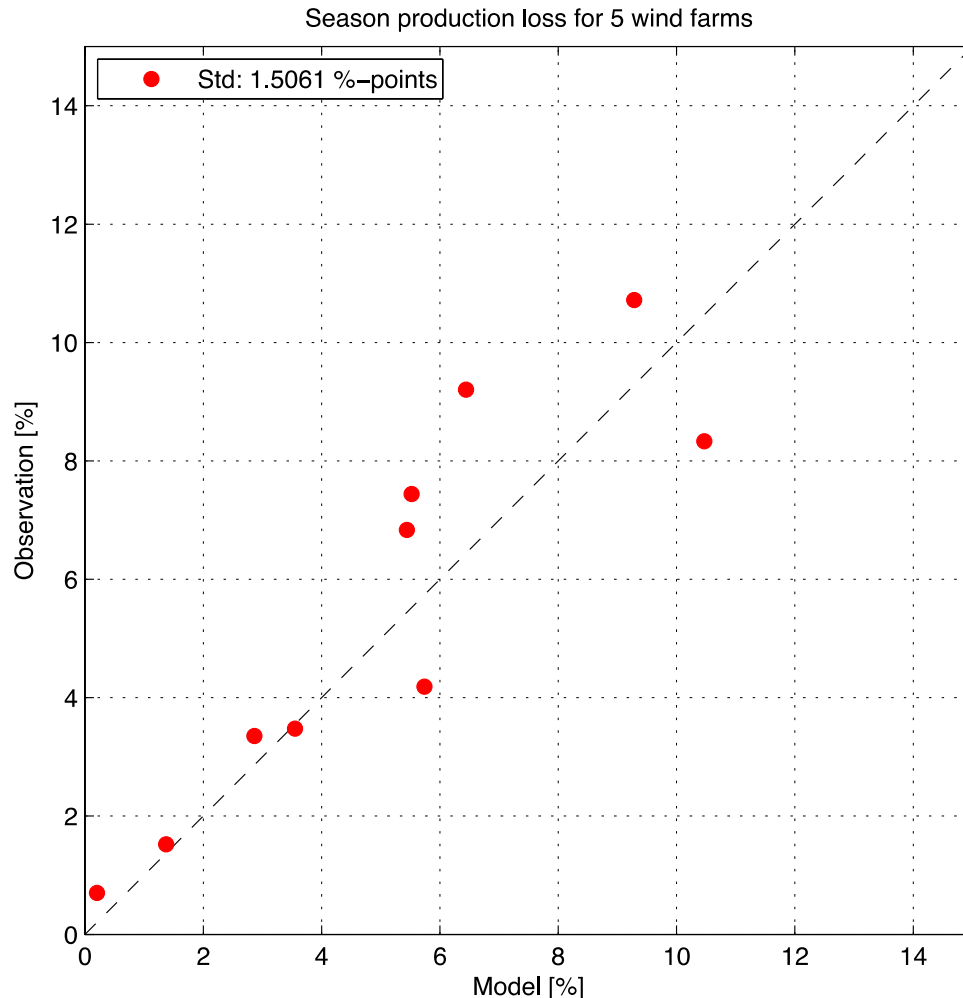
Ongoing work

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

# Example sites A-G



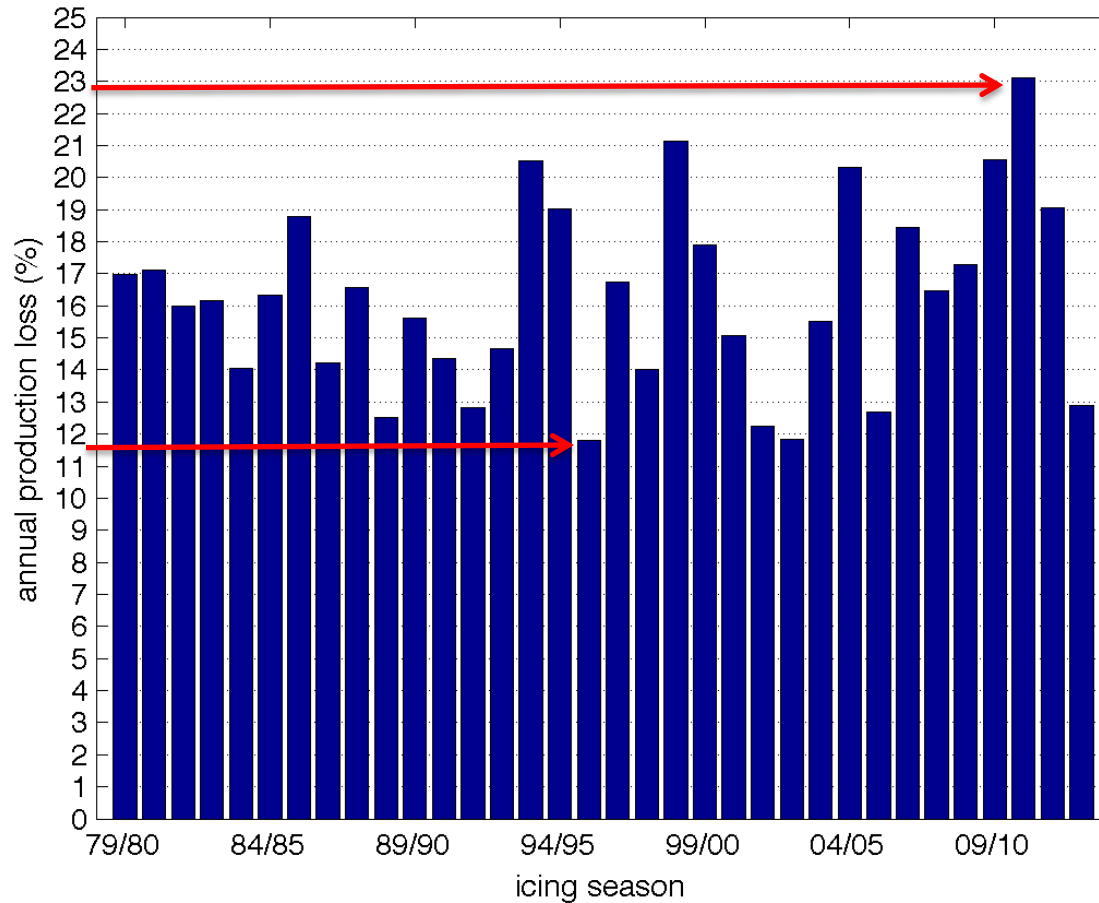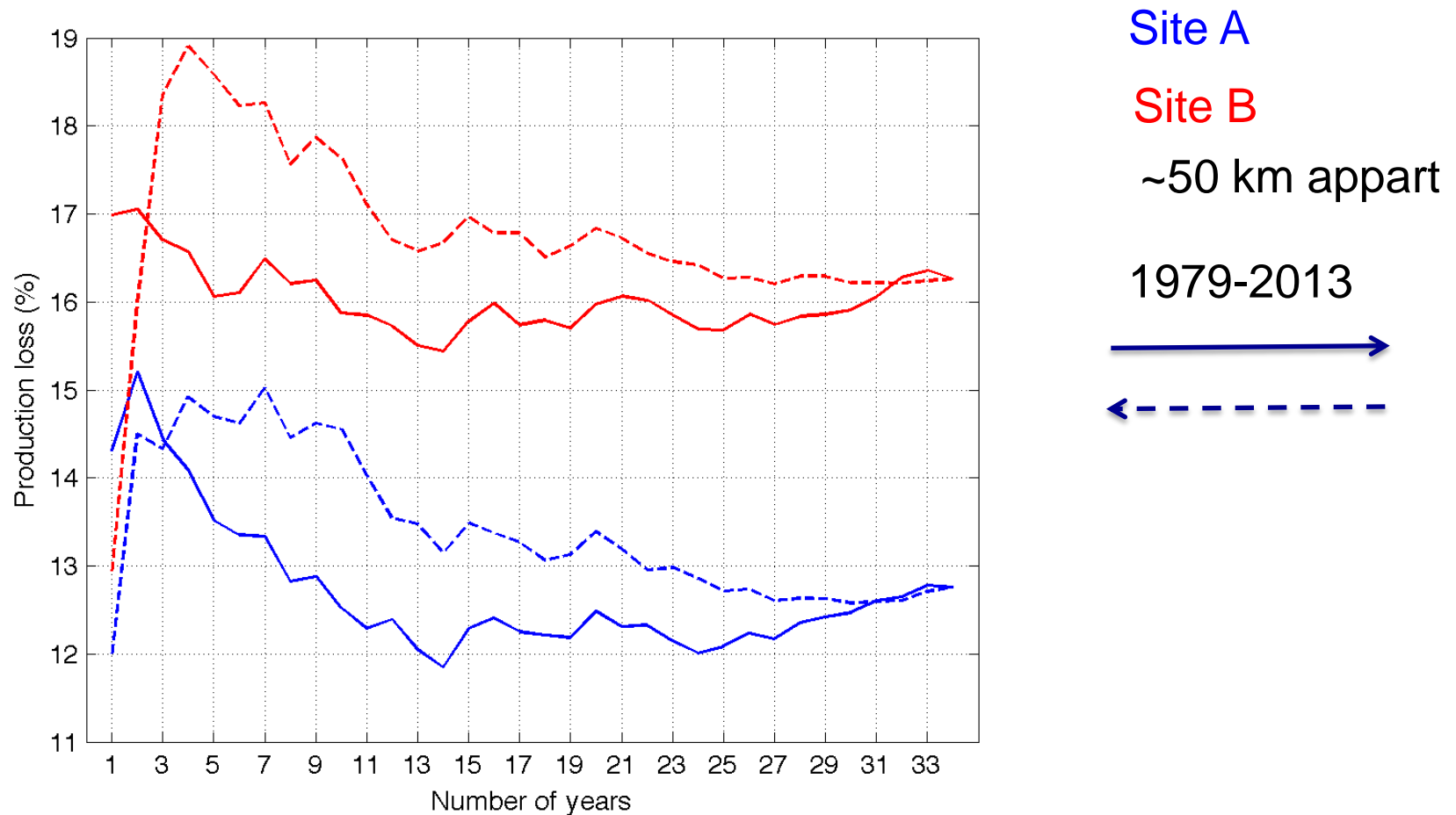| Site | Terrain elevation (m) | Long term production loss (%) |
|---|---|---|
| A | 485 | 12.8 |
| B | 535 | 16.3 |
| C | 445 | 13.3 |
| D | 455 | 12.1 |
| E | 550 | 10.7 |
| F | 616 | 11.6 |
| G | 505 | 9.2 |

# Annual production losses site A

# Annual production losses site B

# Cumulative mean production loss



Site A

Site B

~50 km appart

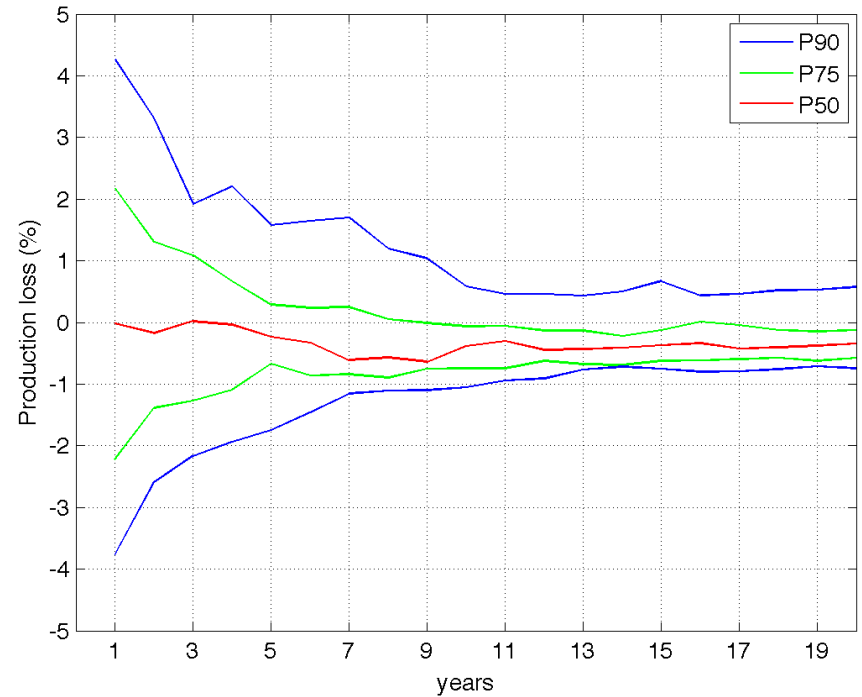1979-2013

# WeatherTech

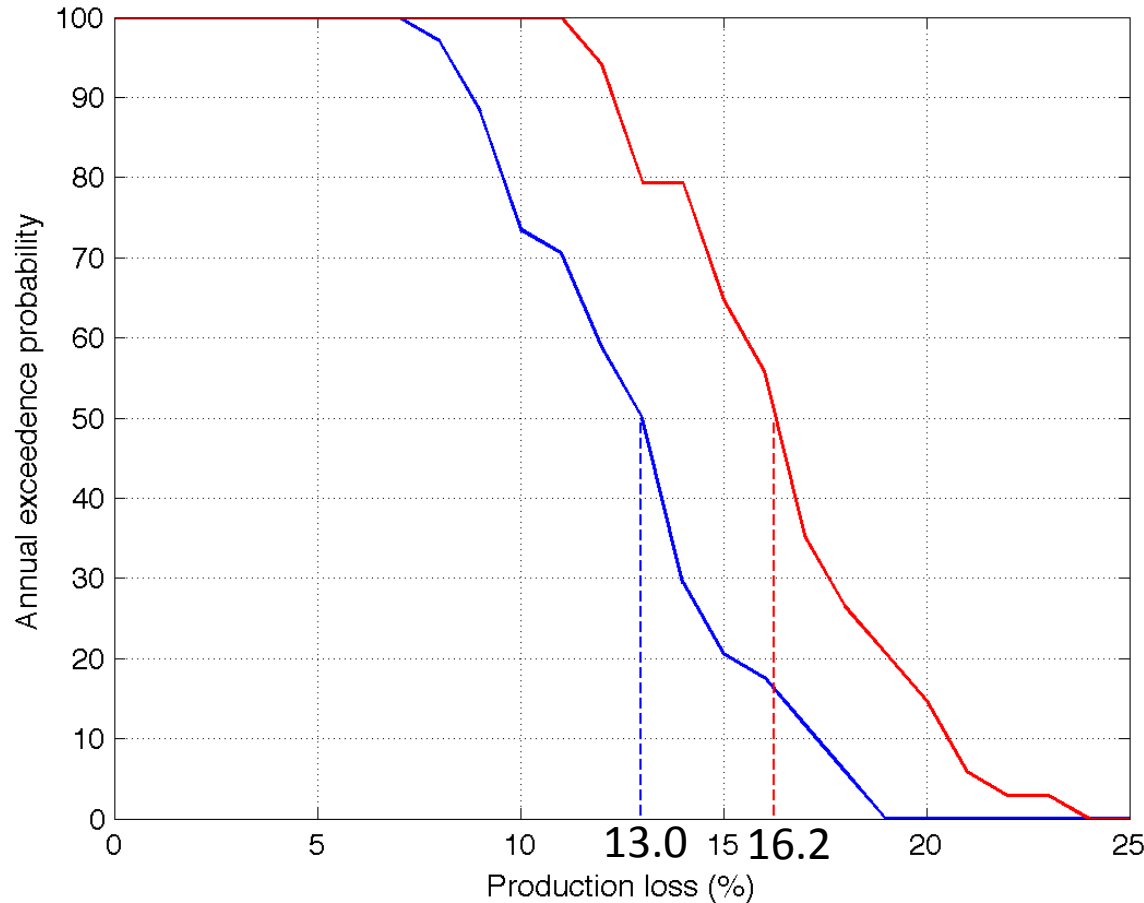# Error in production loss estimates

Site A
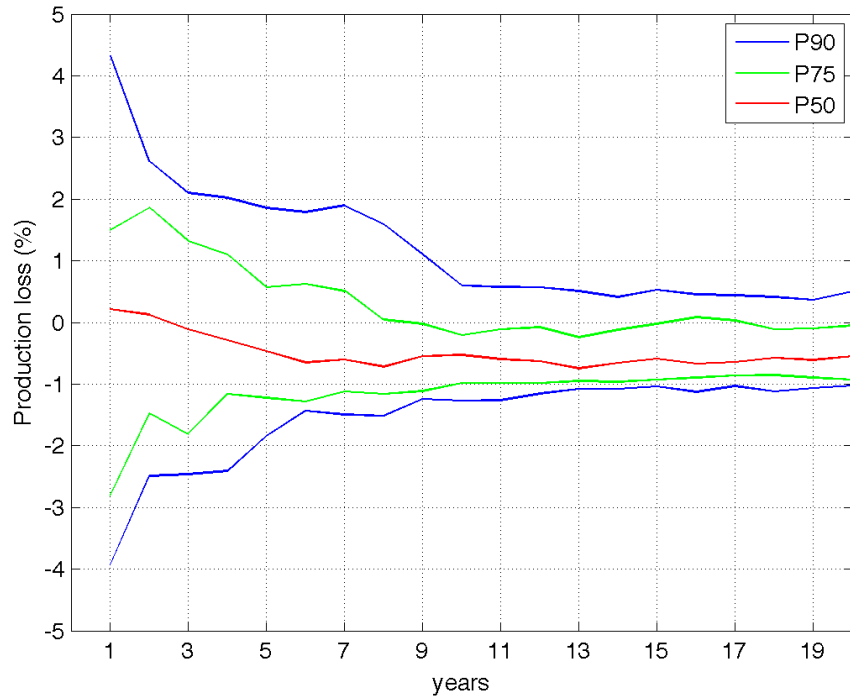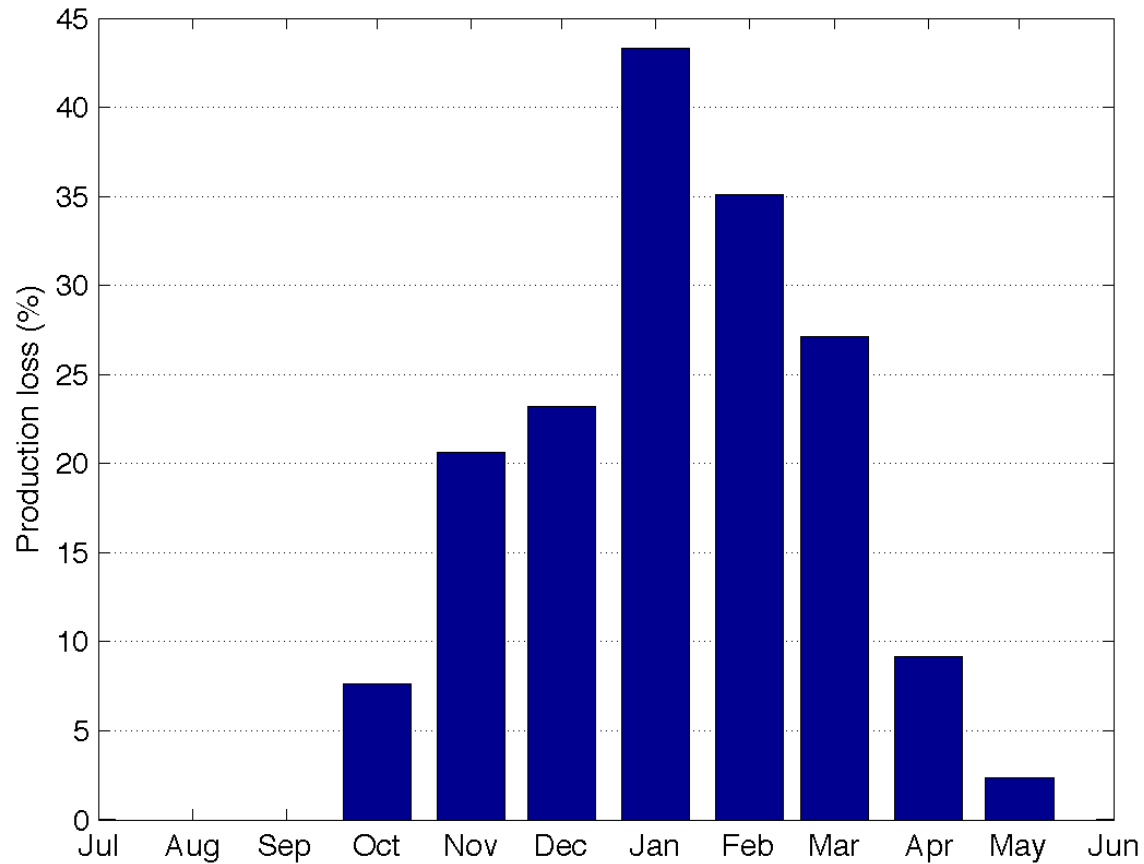
Site B

# Annual exceedance probability



Site A

Site B

~50 km appart

1979-2013

# Mean monthly production losses – Site B

# Mean monthly production losses – Site B

Q: Can observed production losses in Oct or Nov give a hint/early warning of the losses which can be expected over the entire icing season?
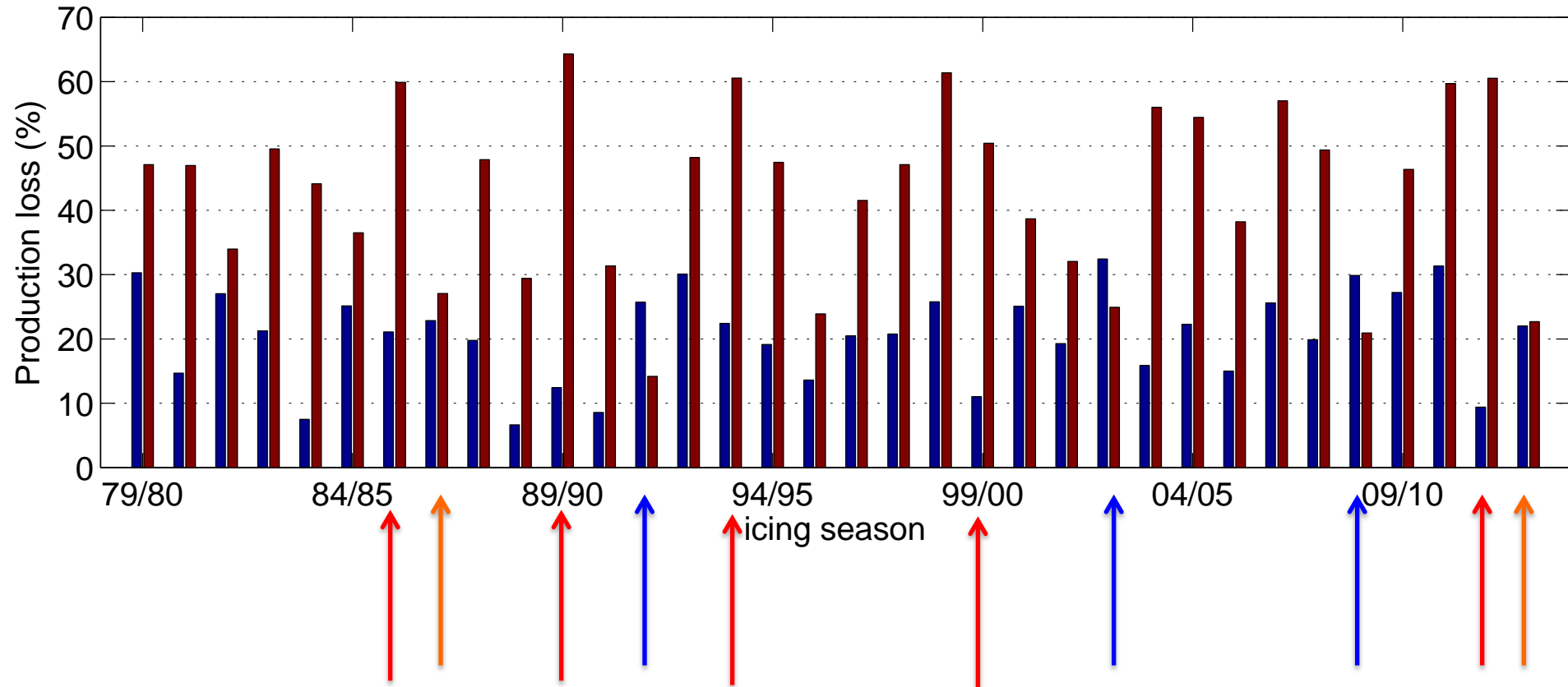
A: No! Only weak relations for Oct and Nov

| Month | Correlation coefficient |
|-------|-------------------------|
| Oct   | 0.32                    |
| Nov   | 0.26                    |

Monthly variability Site B – 34 Nov and Jan

# Summary

- Large variability in icing conditions and production losses from year to year and site to site.

- The variability coefficient for icing hours is an order of magnitude larger than for wind speed.

- Production losses is a function of terrain height, terrain height relative to surrounding terrain, proximity to open water etc.

**Thank you for your attention**

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