Icing map of Sweden

Øyvind Byrkjedal
Kjeller Vindteknikk
oyvind.byrkjedal@vindteknikk.no

Winterwind, Östersund, 12.02.2013

Icing map for Sweden available from

www.vindteknikk.no

Icing Map for Sweden

KJELLER
VINDTEKNIKK

Number of icing hours (dM>10g/hr) per year. Average of 2000-2011 100 m above ground level

|	
	0 - 50
	51 - 100
	101 - 200
	201 - 300
	301 - 500
	501 - 1 000
	1 001 -

# Outline

- 1. Icing atlas methodology
    - background
    - meso scale modelling
    - Icing calculations
    - height corrections
    - long term correction
    - verification
- 2. Applications of the icing atlas

KJELLER
VINDTEKNIKK

Icing conditions

- Temperatures below freezing
- cloud or fog containing small water droplets
- Something to freeze to
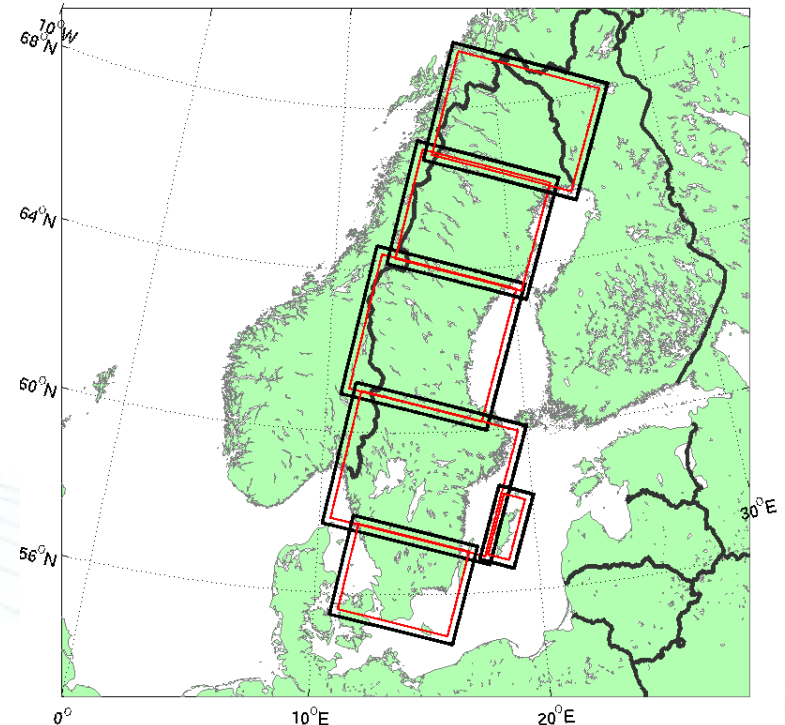
→ in-cloud icing
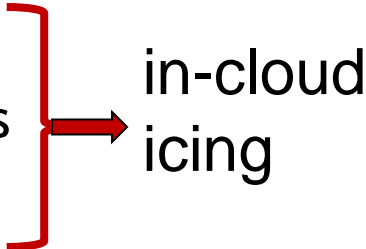
- Lifting of airmasses

→ condensation
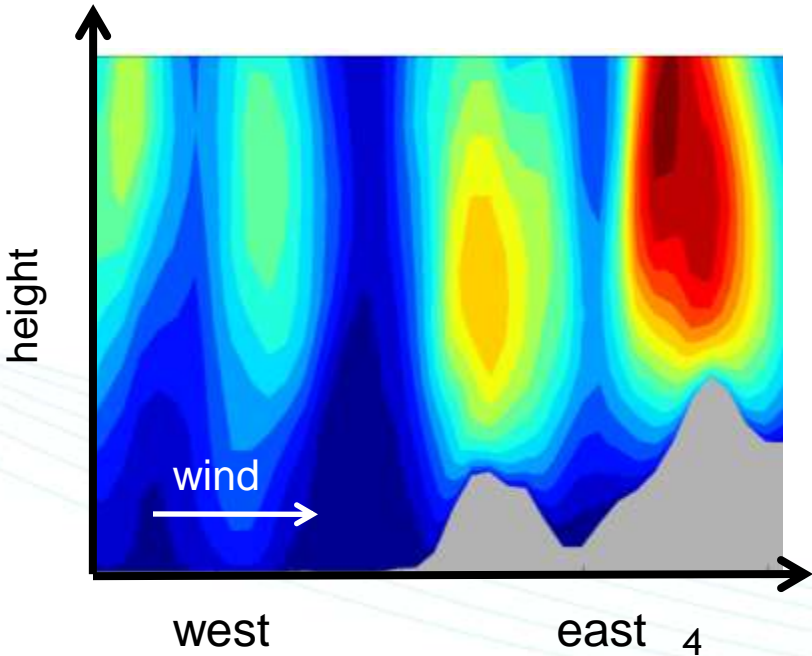
Mesoscale model

- WRF – Weather Research and Forecasting
  - The model describes the atmosphere dynamics (wind, temperature and humidity), and includes physical description of radiation, cloud formation, precipitation, snow, surface processes, etc.
  - The model performes calculations in the time domain

- Model resolution:
  - 1km x 1km
- Simulations for two winter seasons:
  - 01.10.2009 -30.04.2011

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, $\alpha_1 = f(V,d,D)$

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

α_3 - accretion efficiency, $\alpha_3 = f(V,d,w,T,e,D,\alpha_1)$

w – cloud liquid water content

A – collision area, perpendicular to flow

V – Wind speed

KJELLER
VINDTEKNIKK

Calculation of in-cloud icing

Definition of icing hours:

- meteorological icing
- number of hours with dM/dt > 10 g/hr

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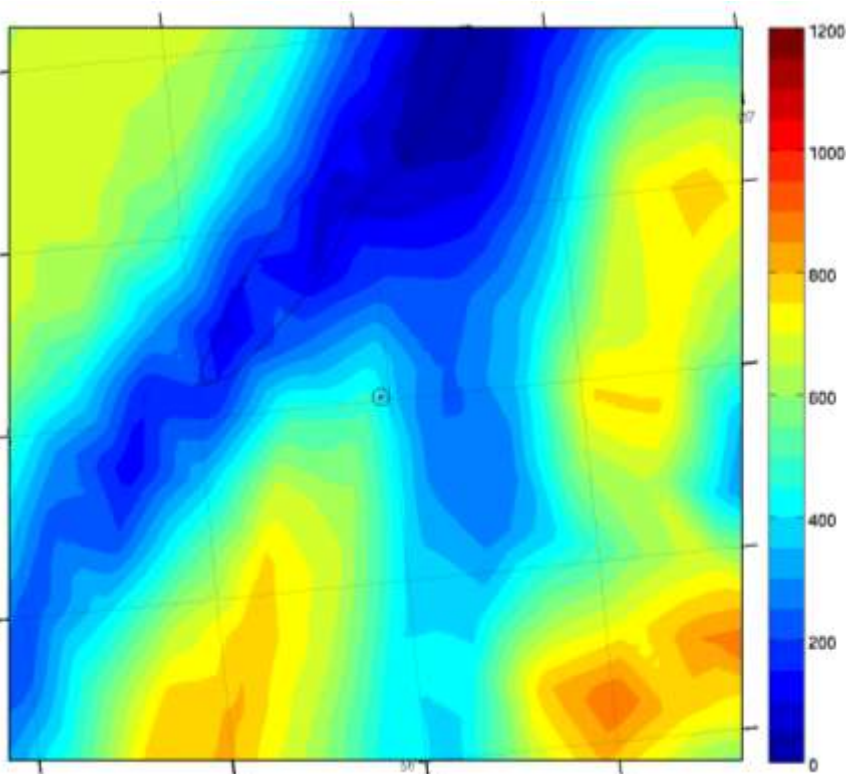

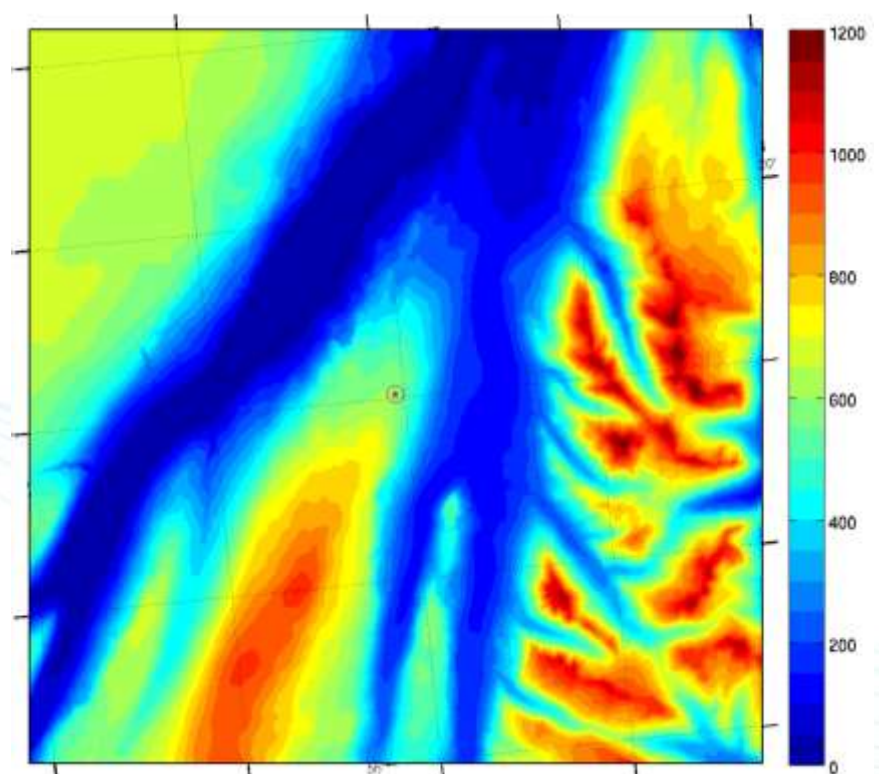KJELLER
VINDTEKNIKK

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:
1 km x 1km resolution

Terrainmodel:
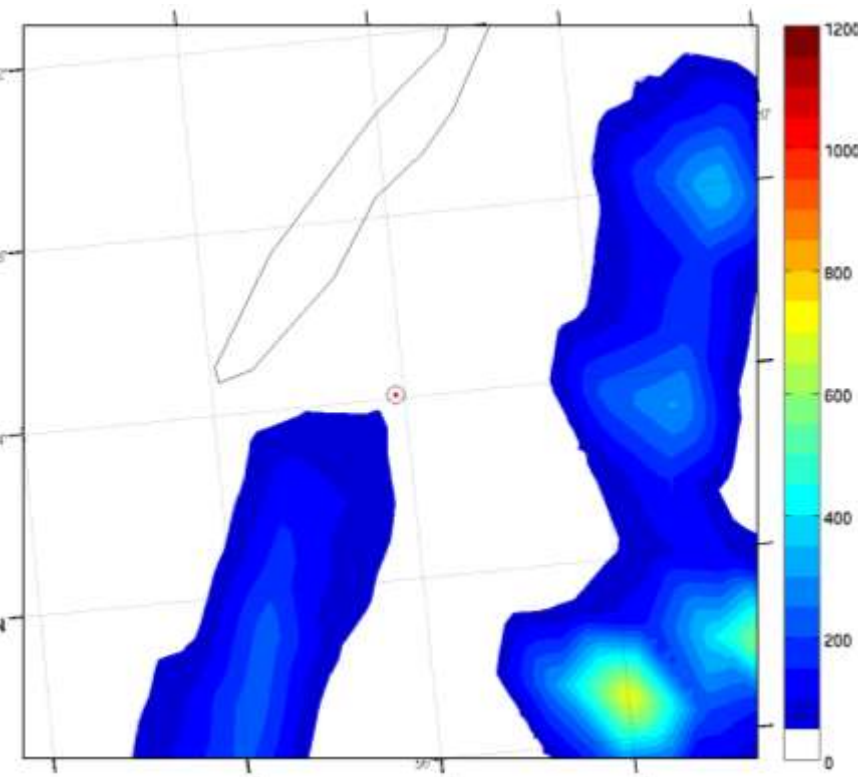**50 m x 50 m resolution**
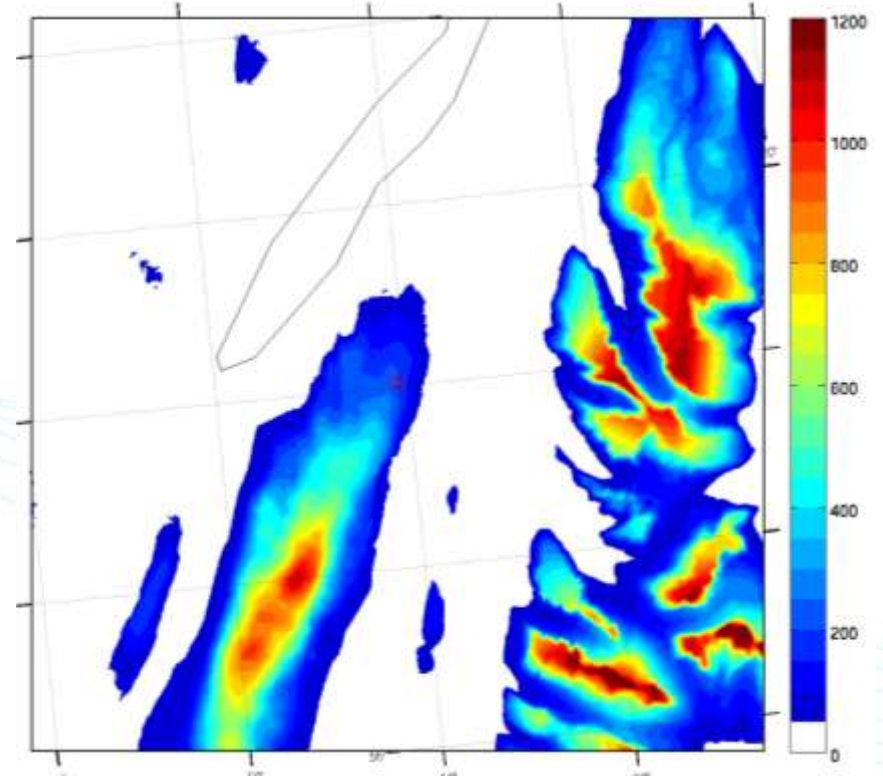
Height adjustment

Height adjustment routine:

- Forced lifting of the air masses from the coarse smoothed terrain to the height in the terrain model
- Icing atlas with 50 m x 50 m resolution.
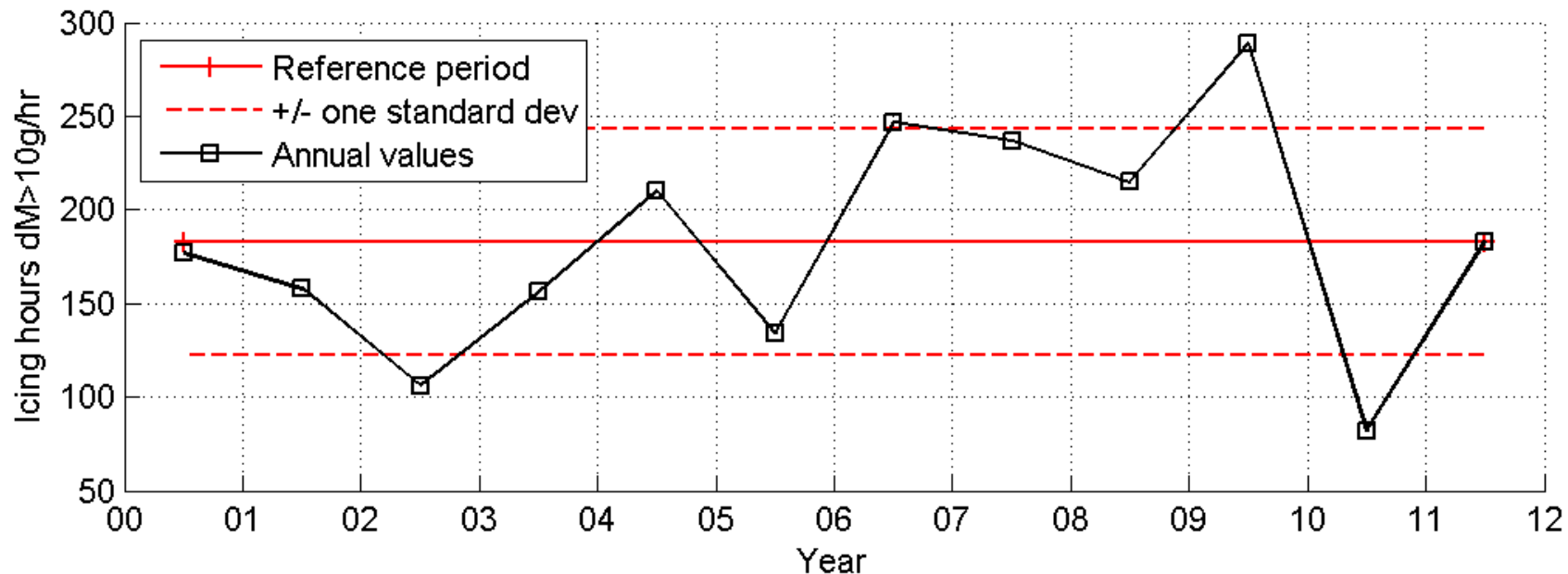
WRF model:
1 km x 1km resolution

WRF model:
With height adjustment
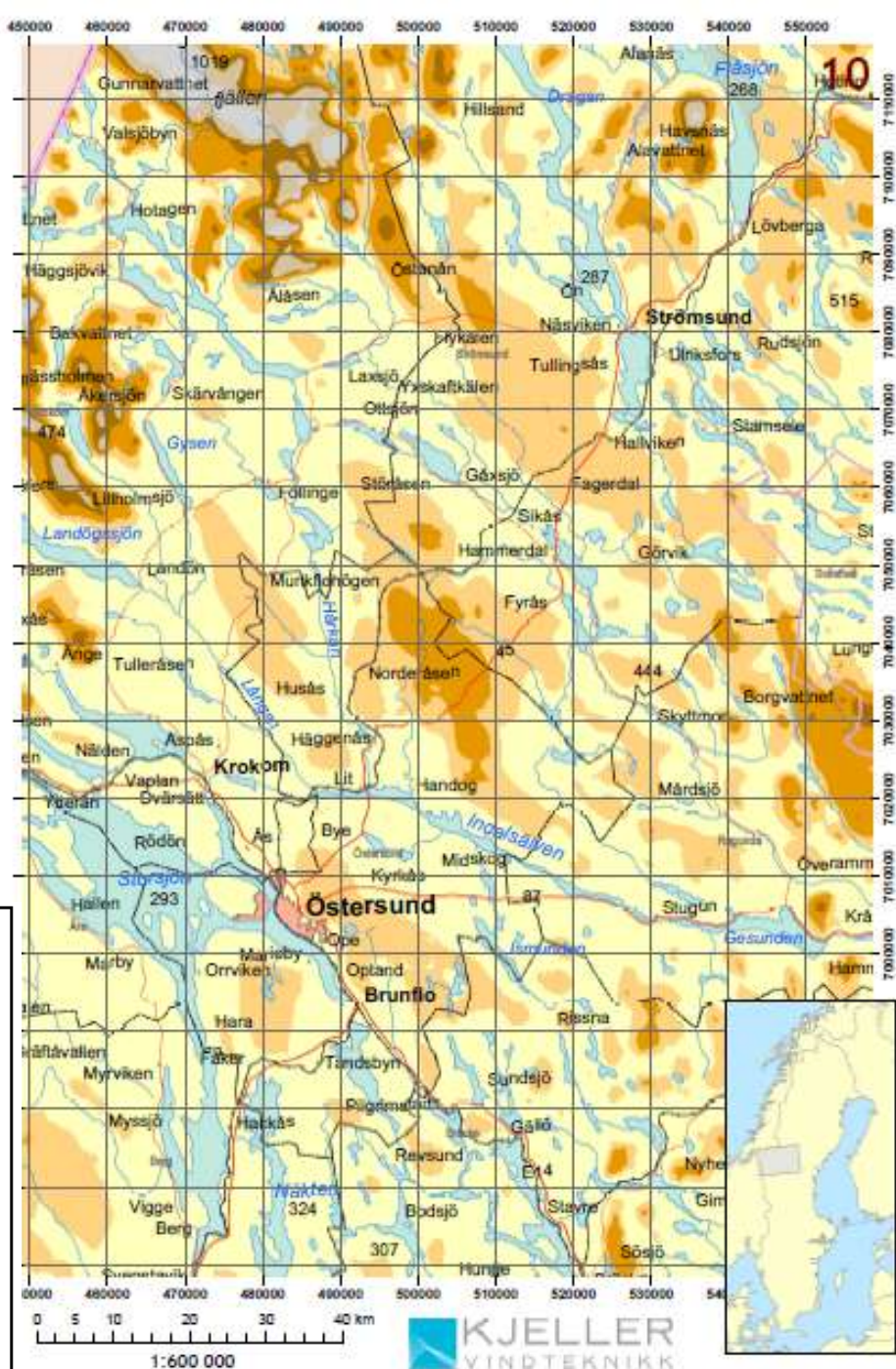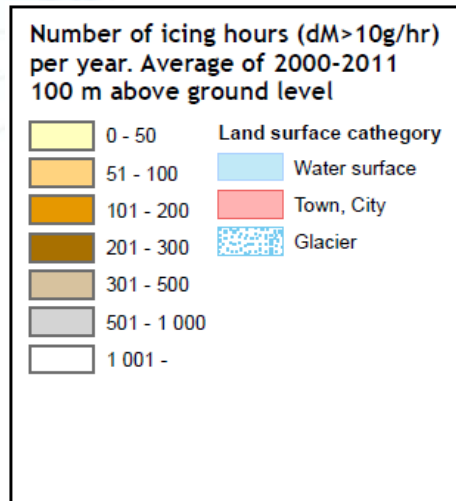
Long term correction

- WRF simulations with high resolution (1km) is only carried out for two winters (2009/2010 and 2010/2011)
- The variability in icing is large from one year to the next.
- A long term correction has been applied using icing data from a 4 km x 4 km simulation

Icing map for Sweden:

- 50 m x 50 m resolution

- Average number of icing hours per year

- Based on the period 2000-2011

www.vindteknikk.no

Number of icing hours (dM>10g/hr) per year. Average of 2000-2011 100 m above ground level

Color	Range
	0 - 50
	51 - 100
	101 - 200
	201 - 300
	301 - 500
	501 - 1 000
	1 001 -

Land surface cathegory

Color	Category
	Water surface
	Town, City
	Glacier

1:600 000

Verification

- No systematical verification has been carried out (yet!)
- Model calculations has been compared to observed ice loades at several Swedish sites through a wind pilot project funded by Energimyndigheten:
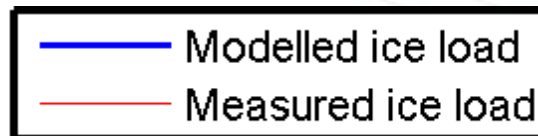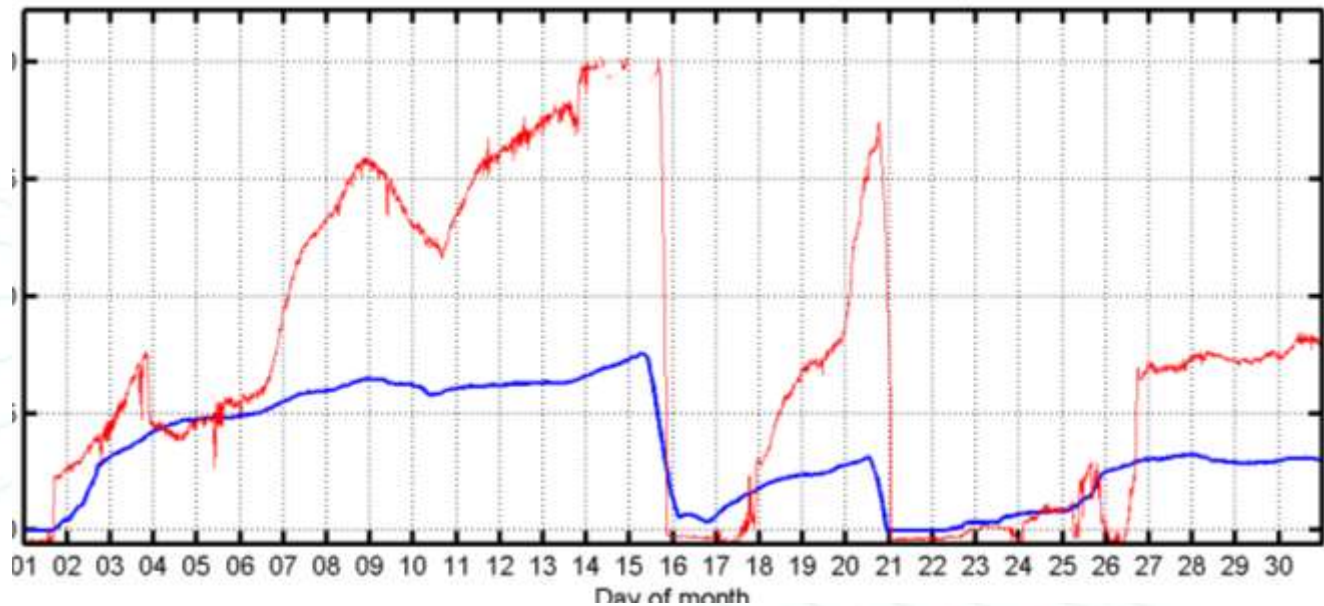
Verification

- The model is good at describing:
  - timing of ice accumulation
  - timing of sublimation and melting
- The model has a tendency of underestimating large ice loads
- Uncertainty also for the observations.

Applications of the icing atlas

- The geographical distribution of icing is described in the map

- Timeseries of icing and meterological parameters are also available.

Icing atlas applications

For development of new wind farms cold climate areas we recommend an analysis of the icing conditions:

- At which meteorological conditions can icing be expected at the site ?
- Analysis of the time series to estimate production losses at the site
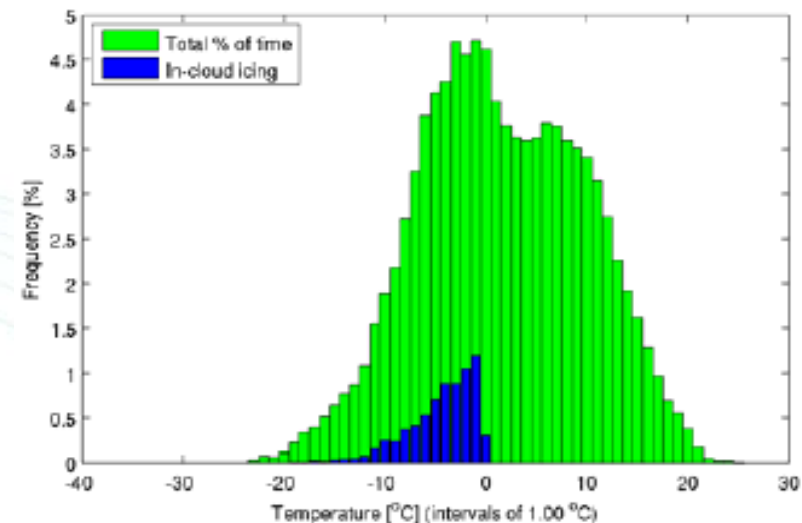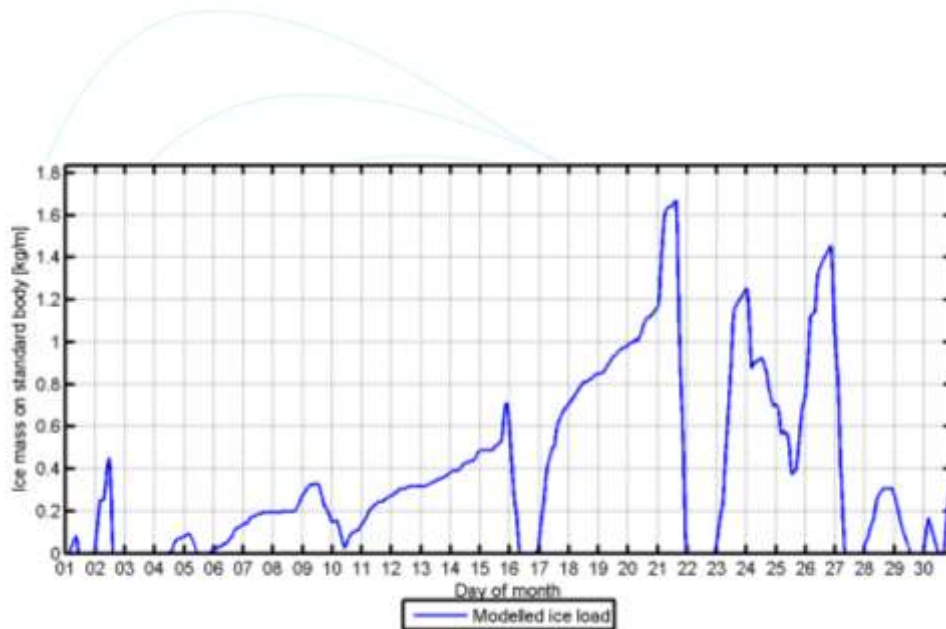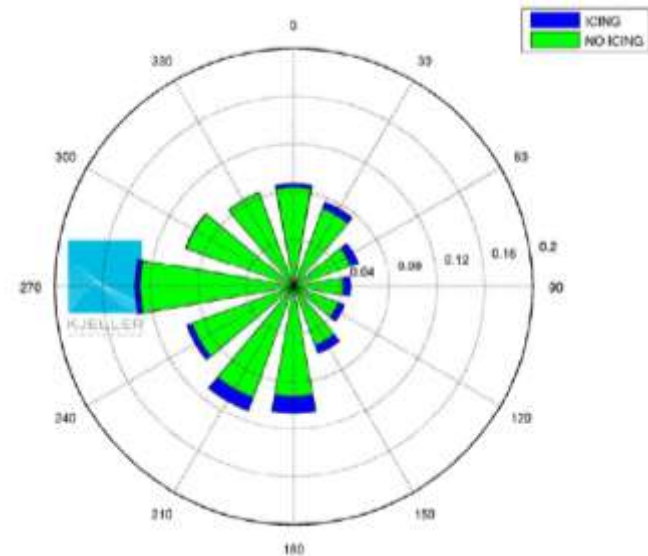
Icing atlas applications

- IEA wind task 19 has defined 5 icing classes*:

Table 1: IEA Ice Classification

IEA Ice class	Meteorological icing	Instrumental icing	Production loss
	% of year	% of year	% of annual production
5	>10	>20	> 20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0 - 0.5

icing map

*Best practices for wind energy in cold climates – Resource assessment and site classification

KJELLER
VINDTEKNIKK

Icing atlas applications

- IEA wind task 19 has defined 5 icing classes*

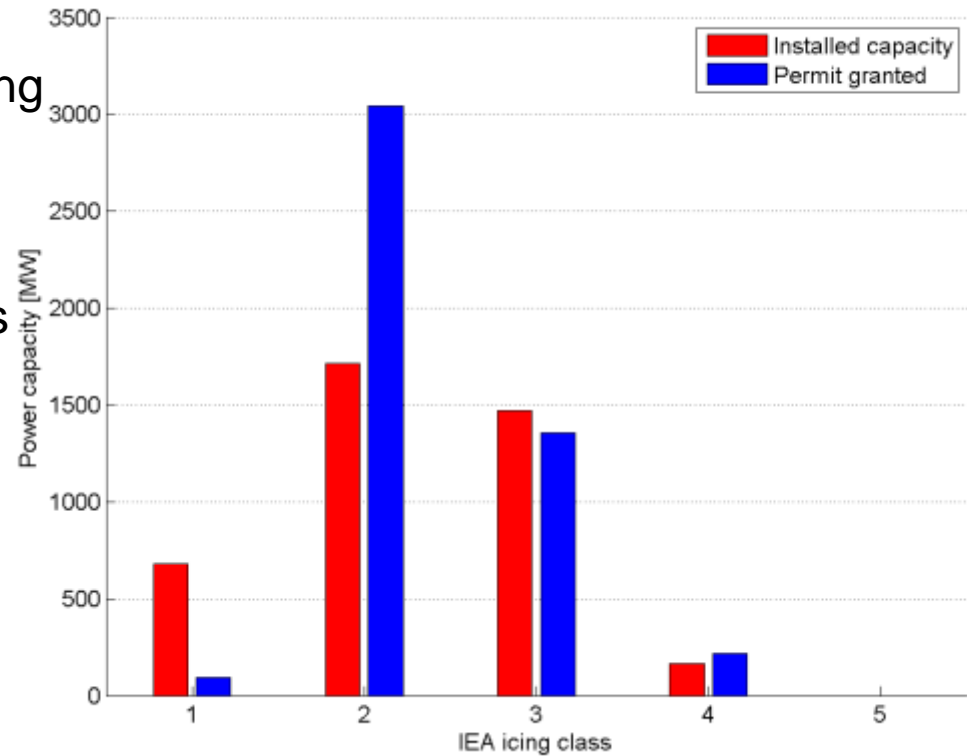- Most of the existing Swedish wind power plants** are located in class 2 or class 3 areas.

 *Best practices for wind energy in cold climates – Resource assessment and site classification
** Data from Energimyndigheten: www.vindlov.se

Table 1: IEA Ice Classification

IEA Ice class	Meteorological icing	Instrumental icing	Production loss
	% of year	% of year	% of annual production
5	>10	>20	> 20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0 - 0.5

KJELLER
VINDTEKNIKK

Summary

Icing map for Sweden:

- 50 m x 50 m resolution
- Average number of icing hours per year
- Based on the period 2000-2011

- Freely available from:

www.vindteknikk.no

Icing Map for Sweden

KJELLER
VINDTEKNIKK

Number of icing hours (dM>10g/hr) per year. Average of 2000-2011 100 m above ground level

- 0 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- 301 - 500
- 501 - 1 000
- 1 001 -

KJELLER
VINDTEKNIKK