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Wind power in cold climates

Vindforsk project V-131

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V-313 Wind power in cold climates

Goals:
Increase certainty in estimating production in areas with icing.

Especially to determine methods to produce a climatological ice map for Sweden on 1 km^2 resolution.

The project is a collaboration between:

Uppsala University – Dep. of Earth Sciences (meteorology)

Hans Bergström, Petra Thorsson

Weathertech Scandinavia

Stefan Söderberg

SMHI

Per Undén, Esbjörn Olsson, Ulf Andræ, Björn Stensen

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What do we mean by an ”icing climatology”?

A mapping of icing should give answers to questions as:

- **How often icing occurs**
- **How long the icing persists**
- **How large the amounts of ice are**

The most important questions may be:

- **How often do active icing occur?**
- **How is the production affected?**

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An icing climatology could be based upon todays NWP models (Numerical Weather Prediction) or upon meteorological observations.

Data from weather models (NWP)

or

Data from meteorological observations

Model of ice load (Makkonen)

$$\frac{dM}{dt} = E \cdot w \cdot V \cdot D - Q$$

Modelled ice load

Comparisons with observations of ice load

dM/dt=**ice growth** (M = ismassa, t = tid)
E = **accretion efficiency**
w = **liquid water content**
V = **wind speed**
D = **diameter**
Q = melting, sublimation

Gives ice growth on a 0.5 m long cylinder with 30 mm diameter.

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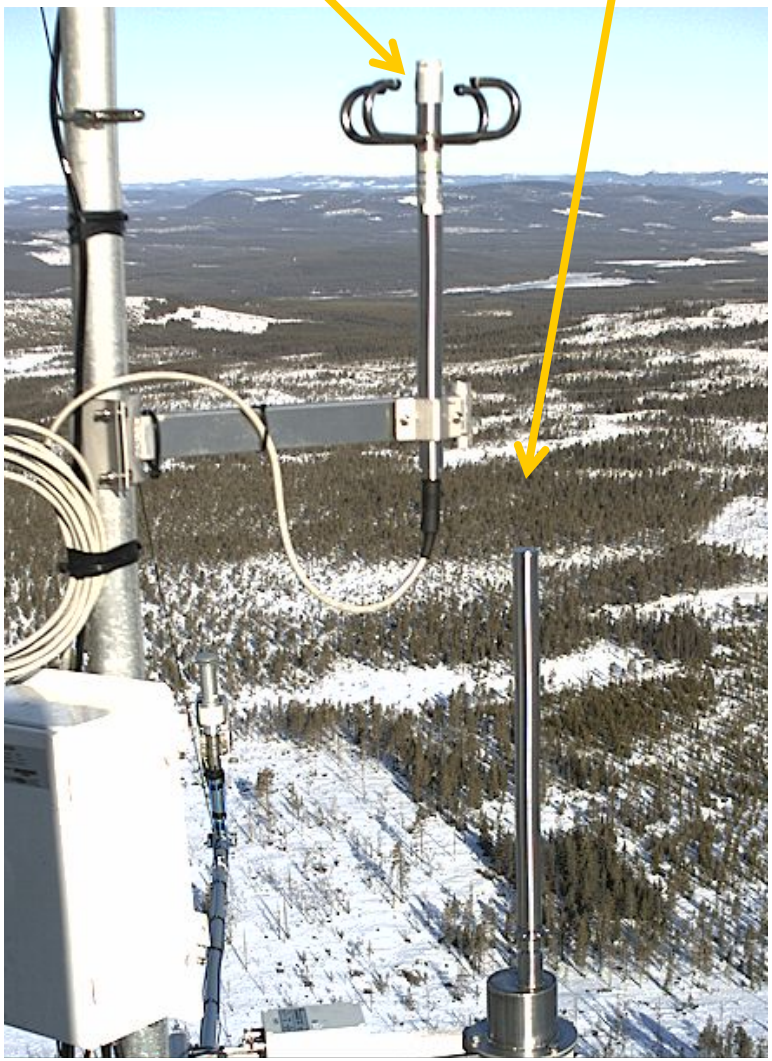
Icing measurements – camera and HoloOptics IceMonitor (’rotating’ cylinder)

(O2-Vindkompaniet)



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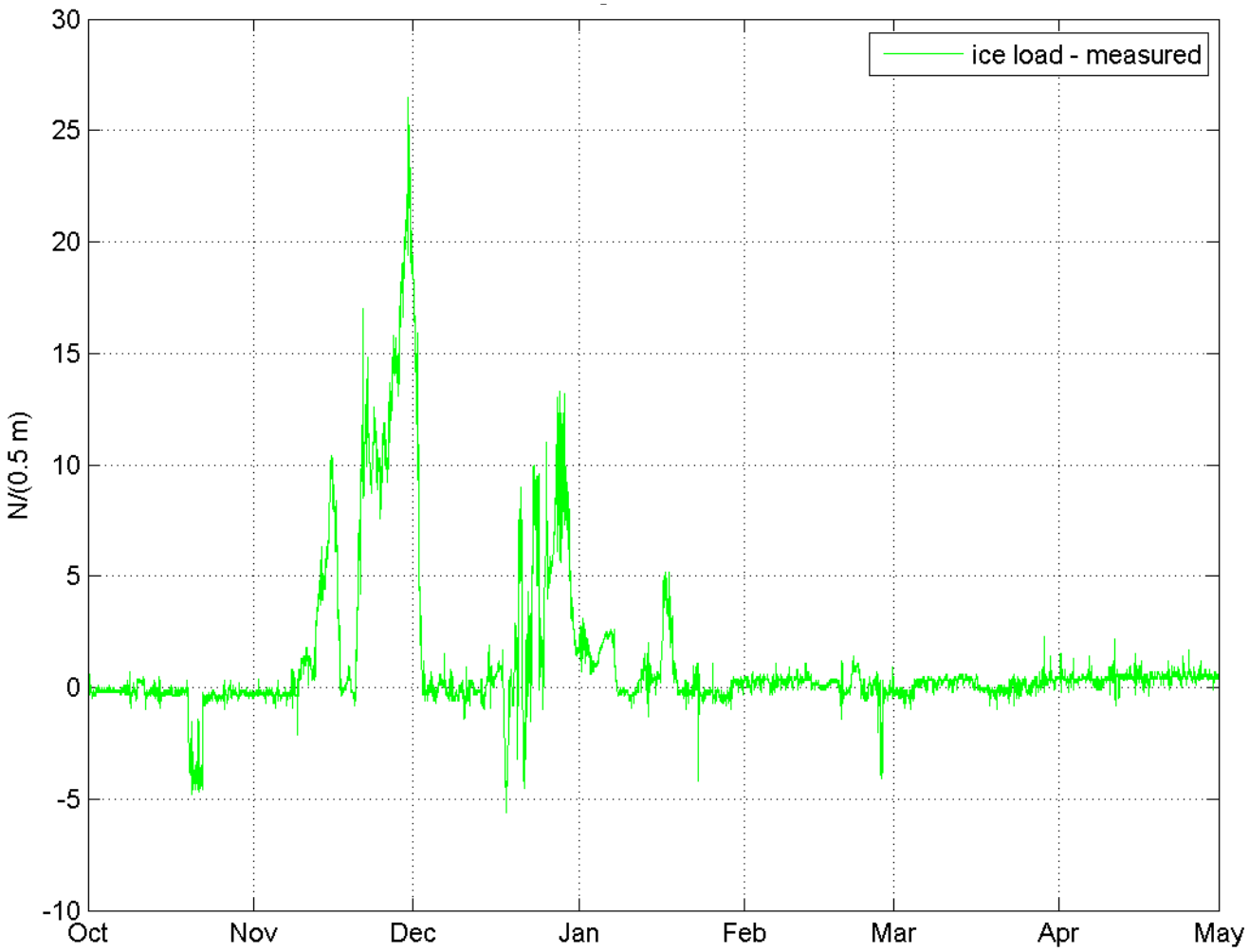
Measured ice load



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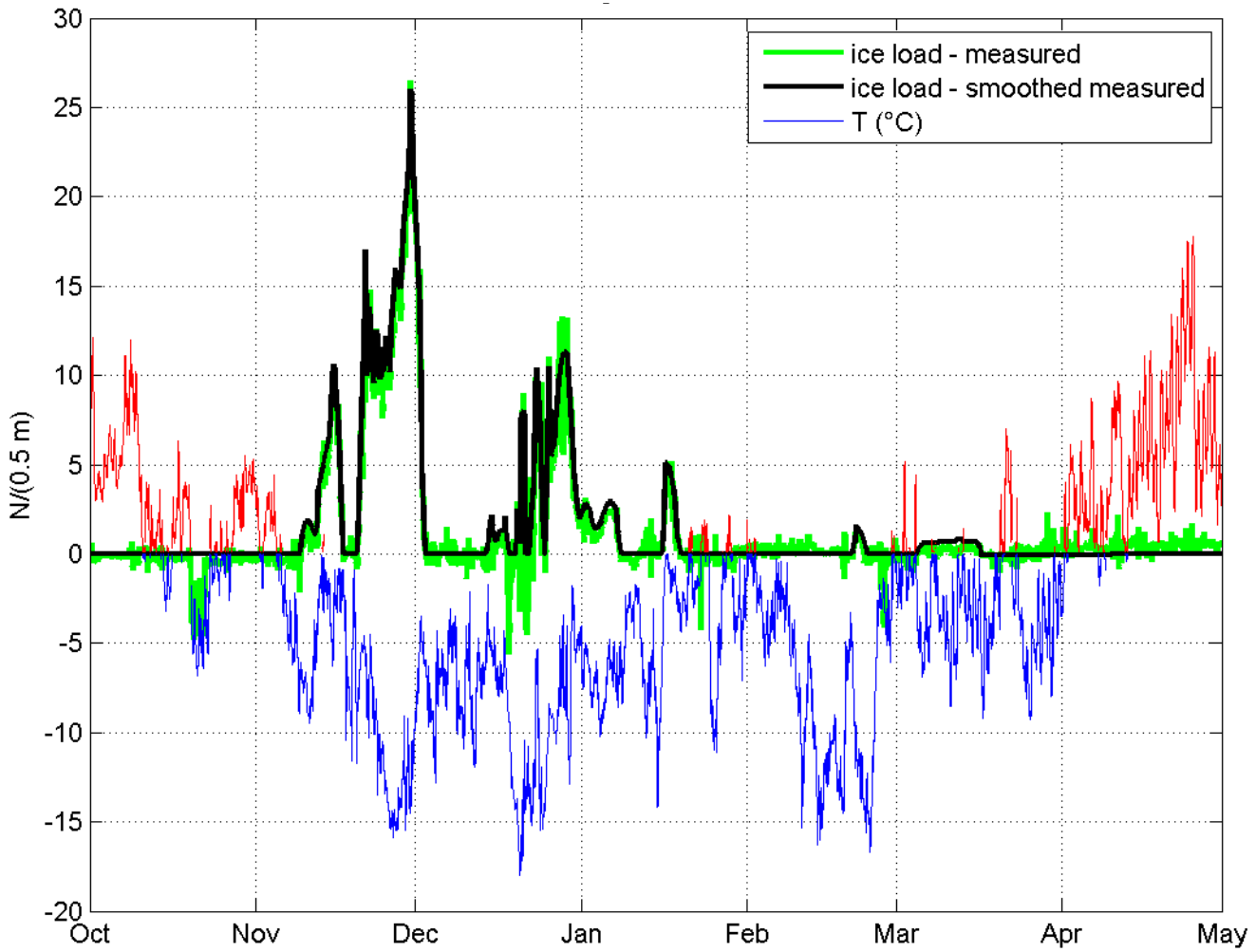
Measured ice load – needs filtering



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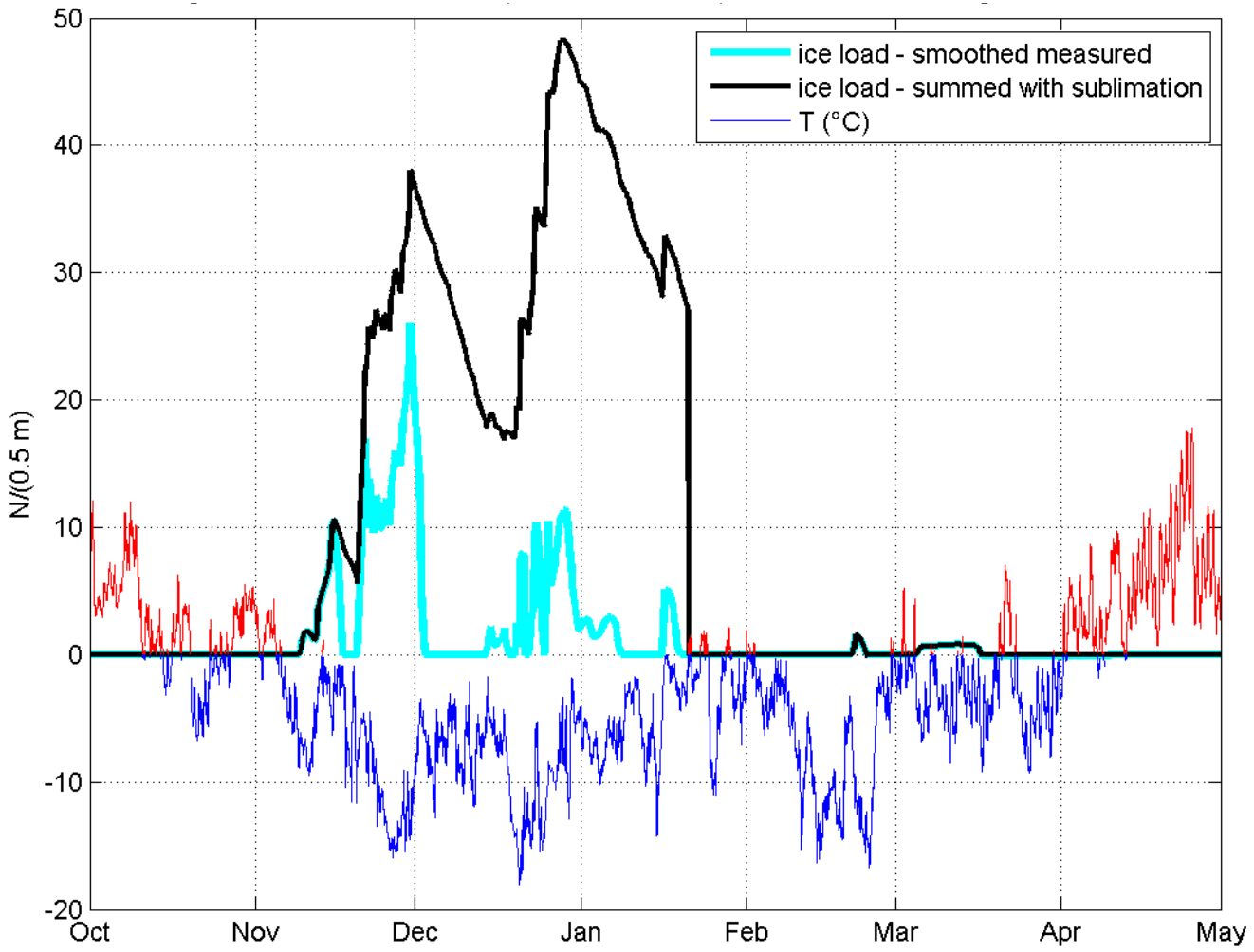
Measured ice load – needs filtering – handling of ice drop.

Thus not at all straightforward to use the icing measurements.



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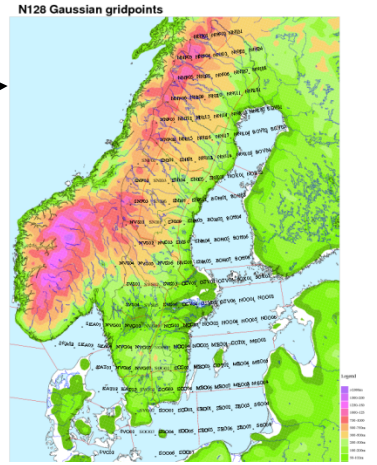
Models used:

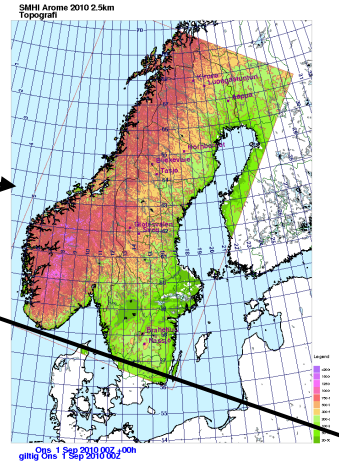
ECMWF ERA-interim
(~80 km)

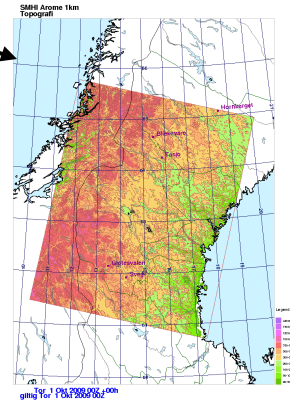
AROME
(1 / 2.5 km)

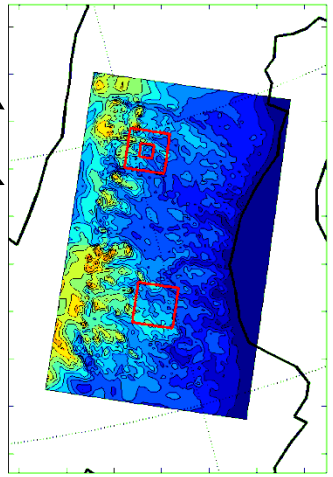
COAMPS
(1 / 3 / 9 km)

WRF
(1 / 3 / 9 km)









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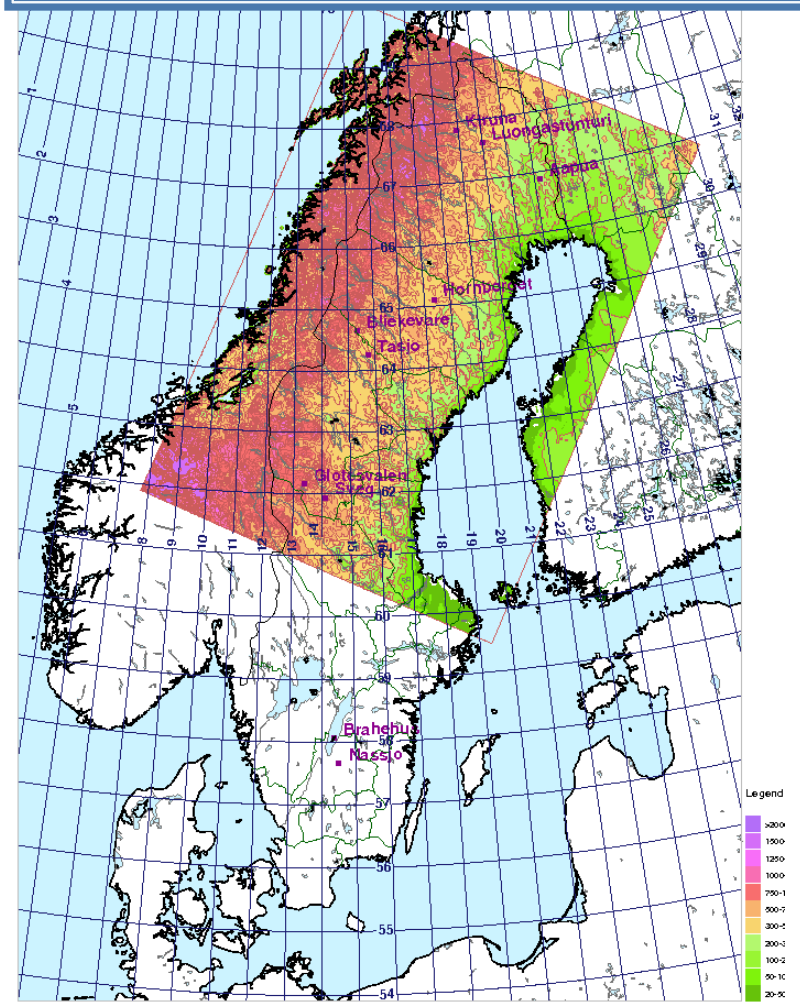
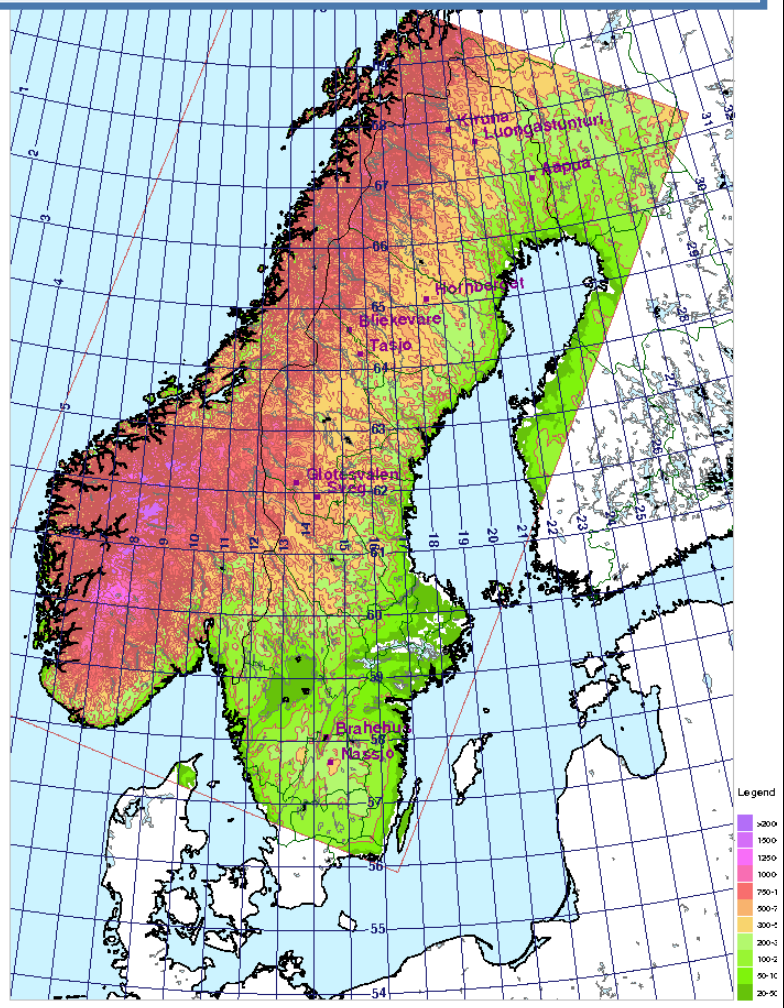
Model domains – AROME: Outer mesh forced by ECMWF

Grid resolution: 2.5 x 2.5 km^2

Winter season 2009/10



Winter season 2010/11 and 2011/12



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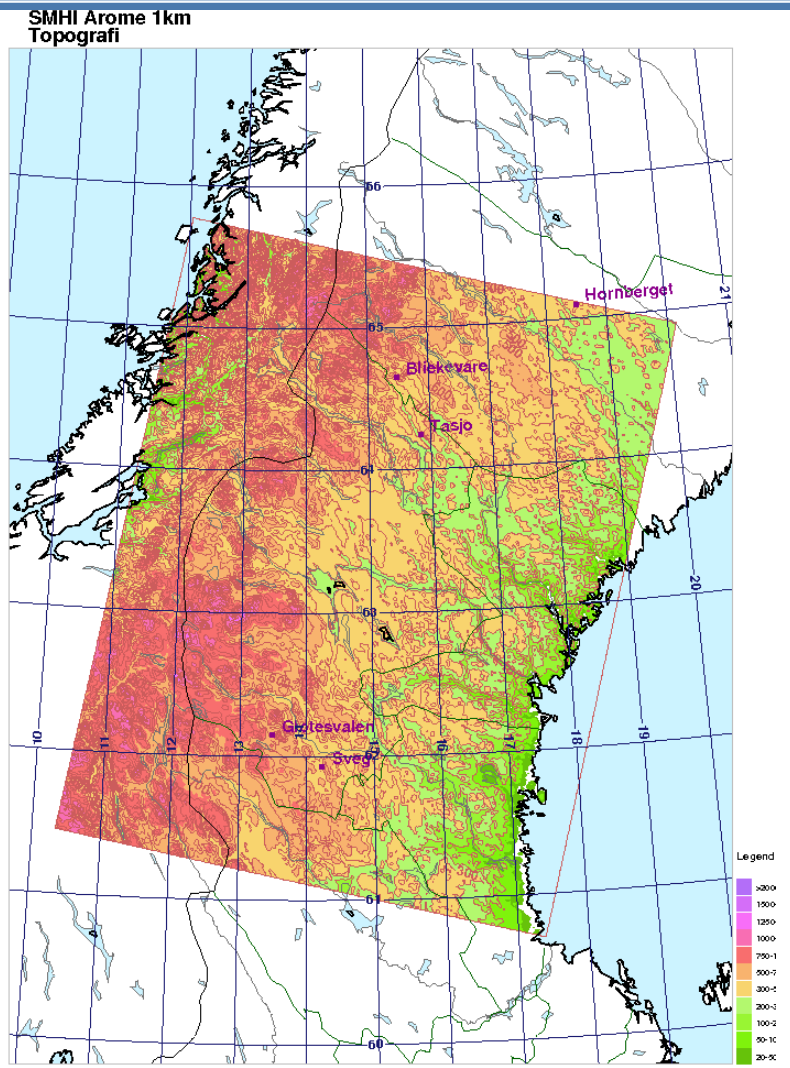
Model domains – AROME: Outer mesh forced by ECMWF

Grid resolution: 1x1 km^2
Winter season 2010/11



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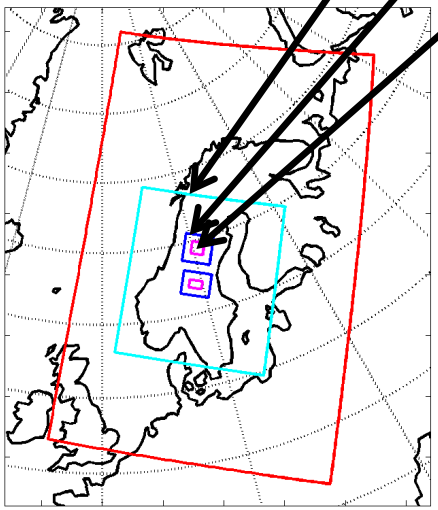
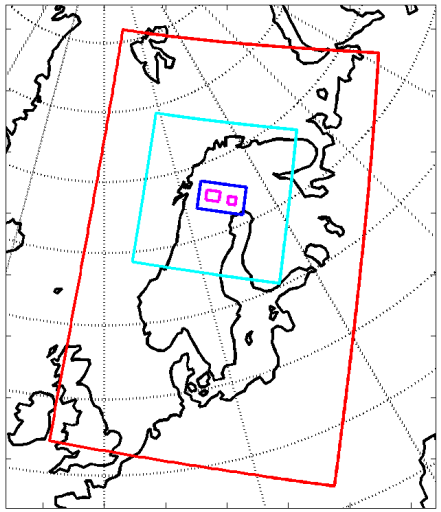
Model domains – COAMPS/WRF: Outer mesh forced by GFS

Grid resolutions: 9x9, 3x3, 1x1 km^2

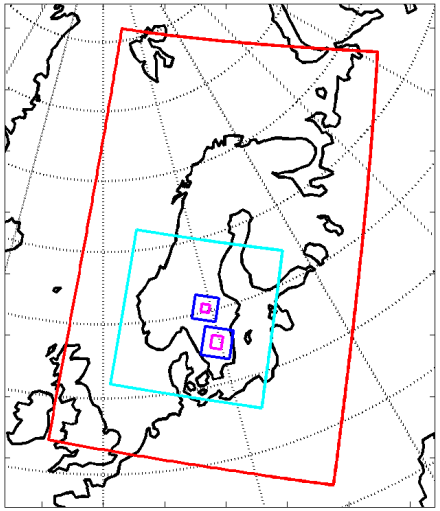
Bliekevare/Tåsjö
Glötesvålen/Sveg



Kiruna/Luongastunturi/Sjisjka
Aapua



Röberg
Brahehus/Nässjö



COAMPS: Winter seasons 2009/2010 (all but Röberg), 2010/2011, and 2011/2012.

WRF: Sensitivity tests oct-dec 2009.
Winter seasons 2010/2011 and 2011/2012.

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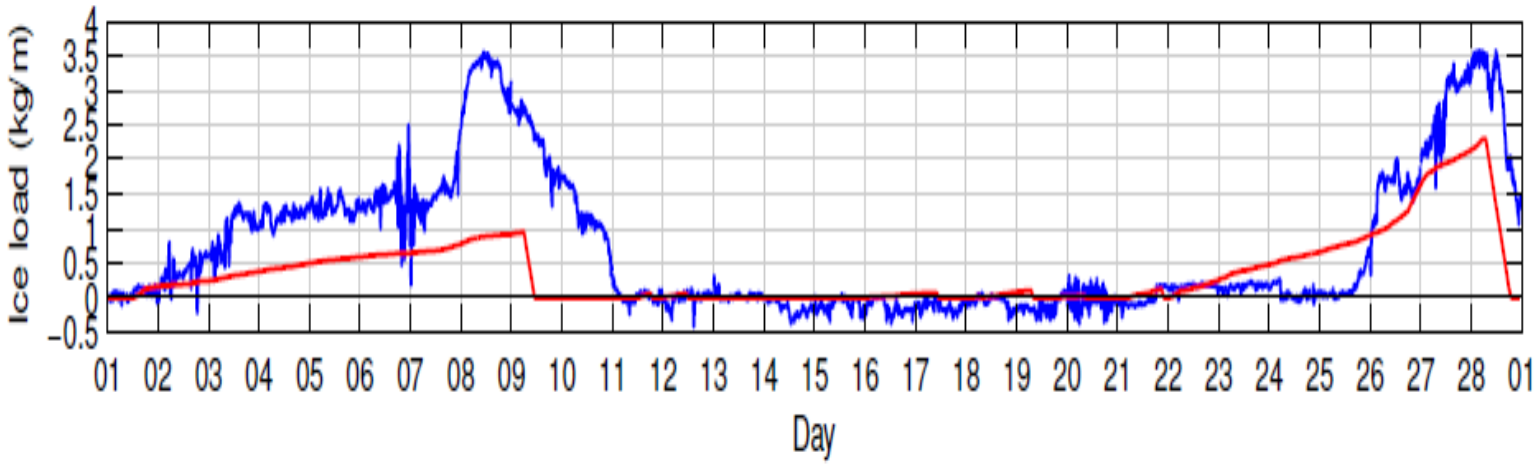
Icing modelling - what do we know today?

Experience so far from V-313:

- Models catch the icing events
- But sometimes large differences between modelled and measured ice amounts
- Measuring ice loads very difficult



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Icing climatology:

We could have done this today – but the results would depend on which model is used and the model resolution.

We want to learn more to get more reliable results

...

and how shall the icing climatology be done.

Two problems to balance:

- The need for period length to get a representative estimate of the climate
- The need for resolution to get a result accurately reproducing the geographical variations

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Icing climatology:

What others have done

Finish Wind Atlas – 48 months at 2.5 km
Finish icing climate – the same as for wind –
Kjeller icing atlas – one year at 1 km

Our options

Two choices:

•A long period (30 years) is dynamically modelled using low resolution (9 km?) – the results are then dowscaled to desired resolution (1 km).

•A limited number of periods (totally ~1 year) is modelled with high resolution – the periods are chosen to be representative for the icing cimate.
Could possibly be based upon ”Lamb’s weather type”.
Results weighted together to get the climatology.

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Icing climatology:

Dynamical model runs for the whole country

Example:

- AROME with 2.5 km resolution ~ 1 h / day on 48 processors
- 1 km resolution 8 times more (2x2x2) 8-12 h
- 30 years takes 10-15 years to run!

Unrealistic – although computers will have more power after a few years but still.....

If chosen using a coarser resolution – need for downscaling.

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Icing climatology:

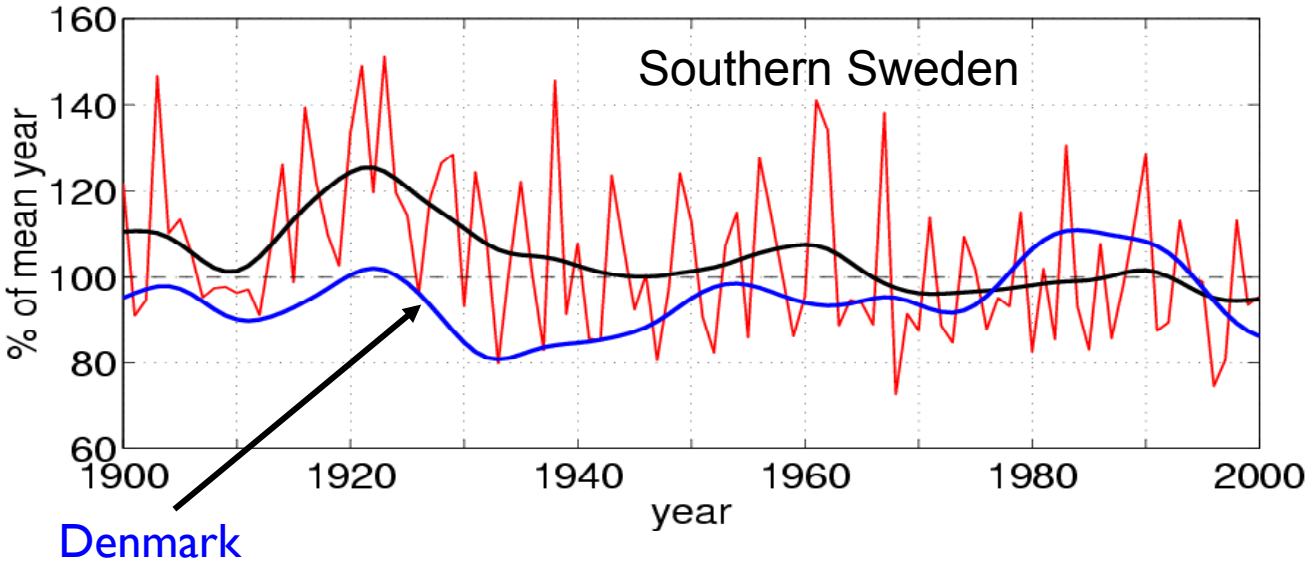
Do we really need 30 years?

To illustrate this compare with observed variations of the energy content of the wind.

Varies between 70 % and 150 % on an annual basis (red).

Even 30 year averages varies with at least ±10 % around a long time average (black, blue).

Probably not smaller variability regarding the icing climate.



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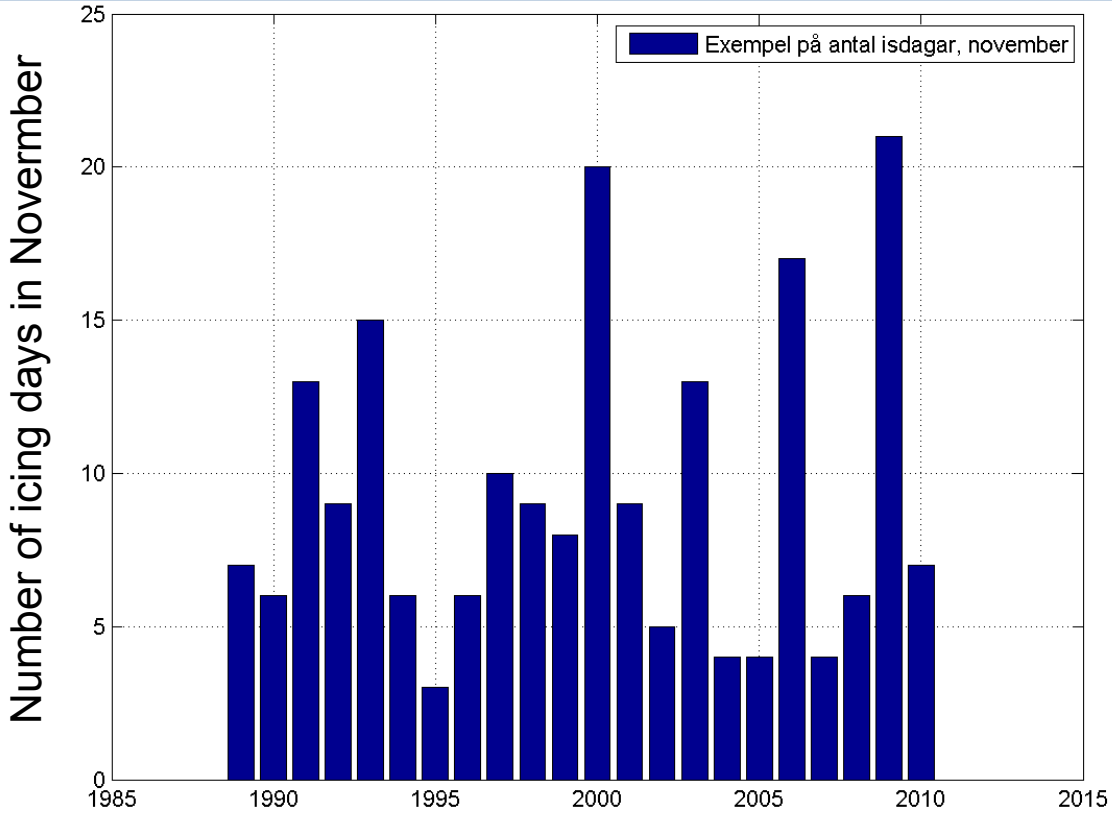
Icing climatology: Example of icing variability

Variations regarding icing climate could be illustrated by the following example: Icing days in November according to ERA Interim data varies between 33 % and 230 % as compared to the 22 year average 1989-2010 average.

How representative is a single year? Or 10 or 30 years?



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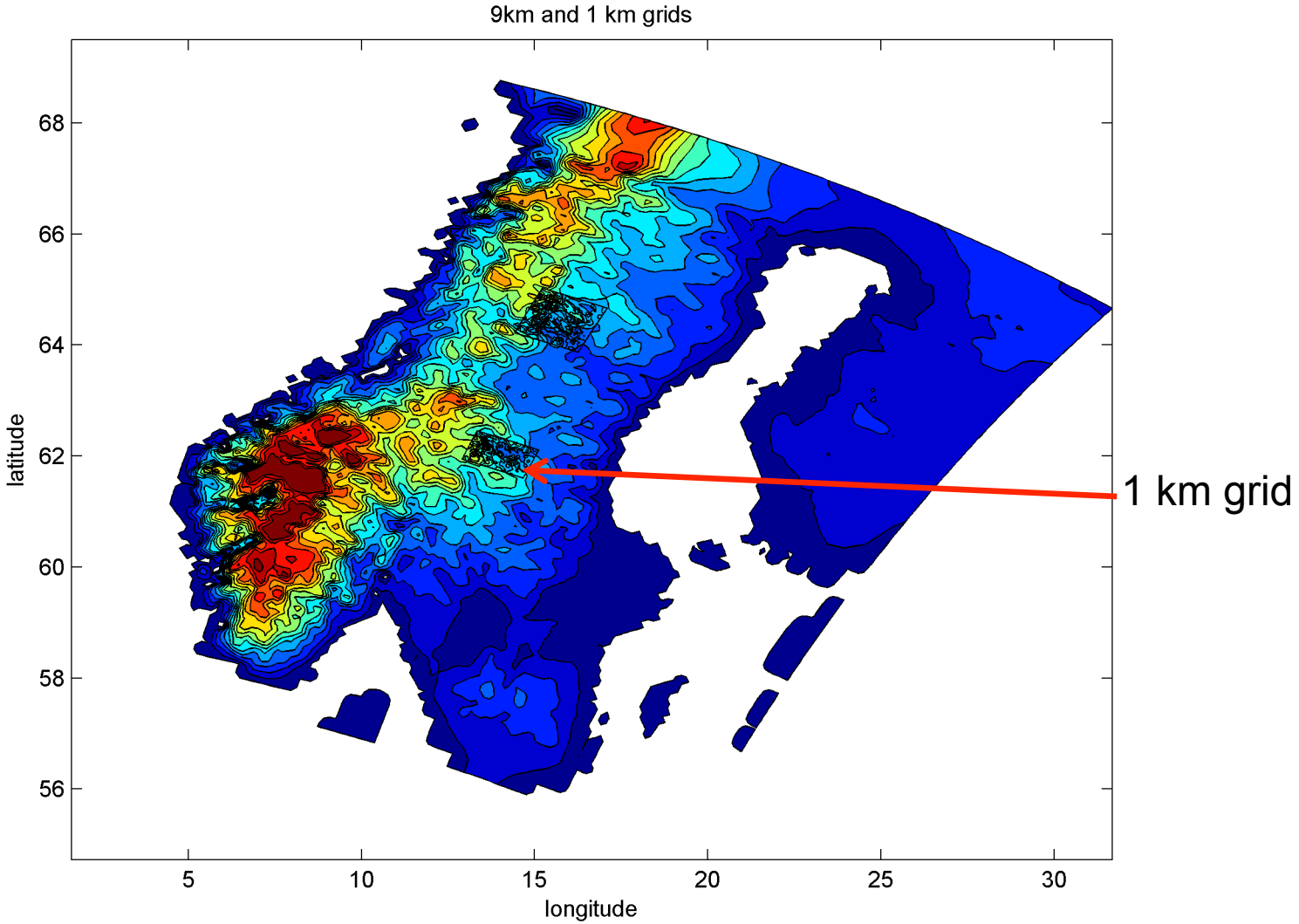
Icing climatology: Downscaling

An example using WRF data from 1 month at 9 and 1 km resolutions.



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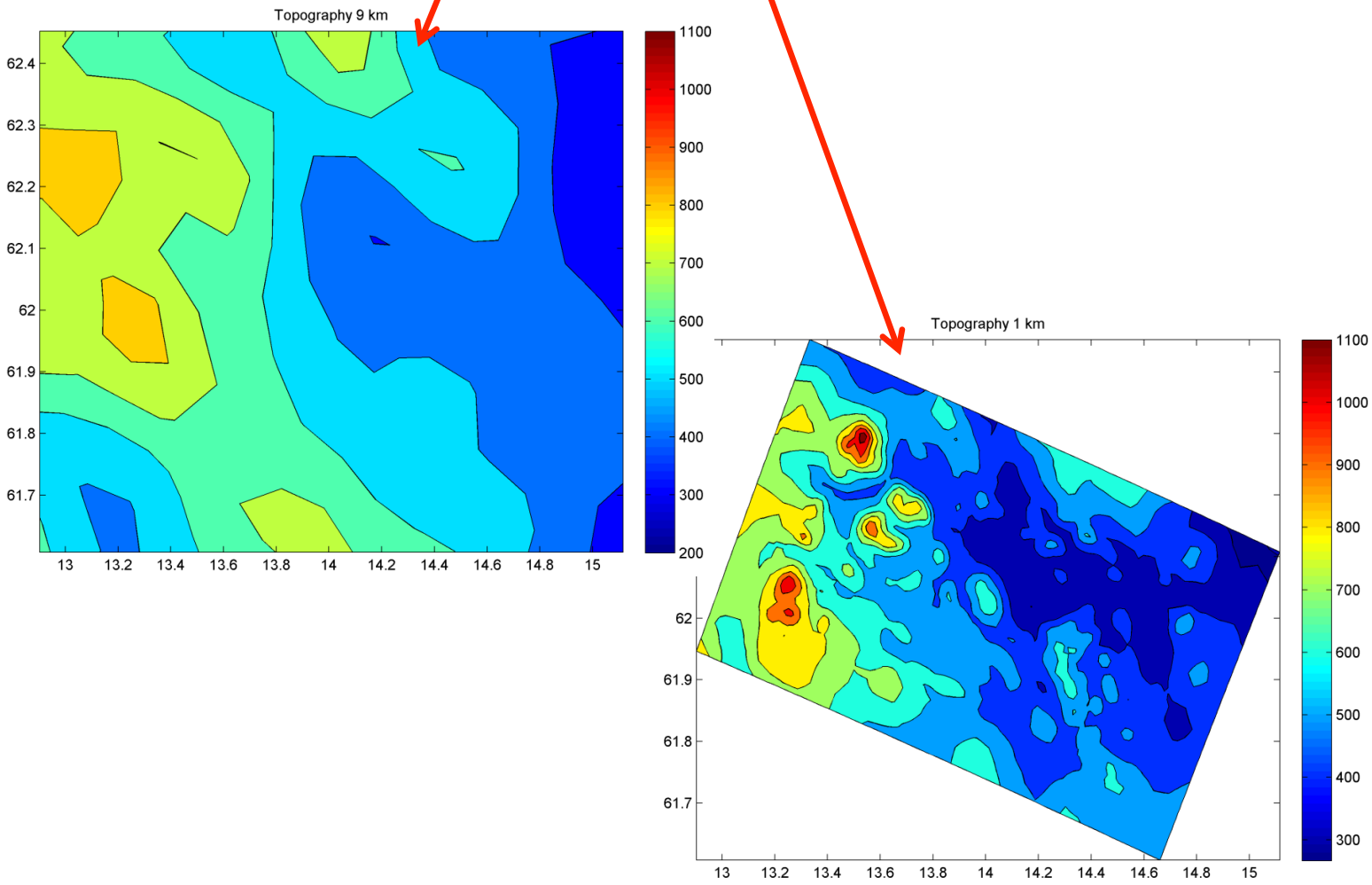
Icing climatology: Downscaling

WRF topography at 9 km and 1 km resolutions.



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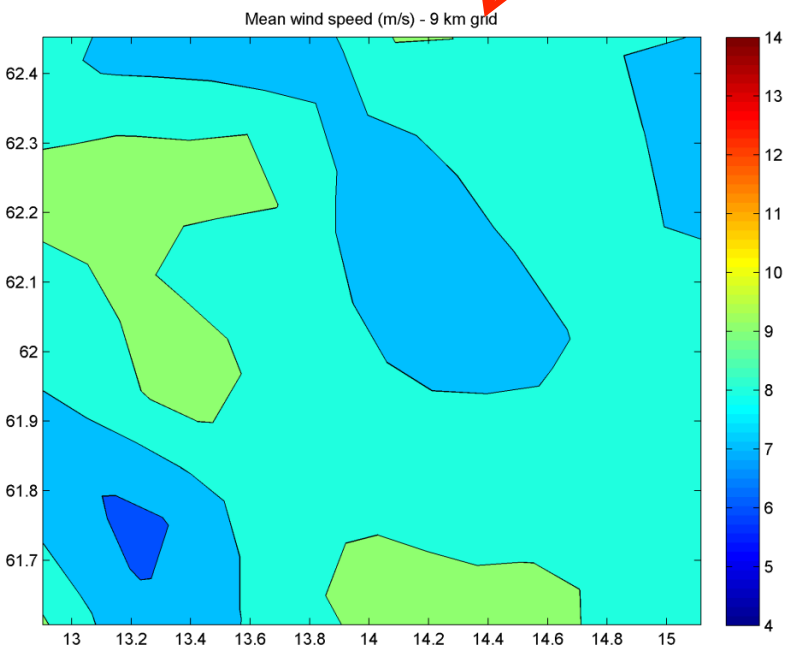
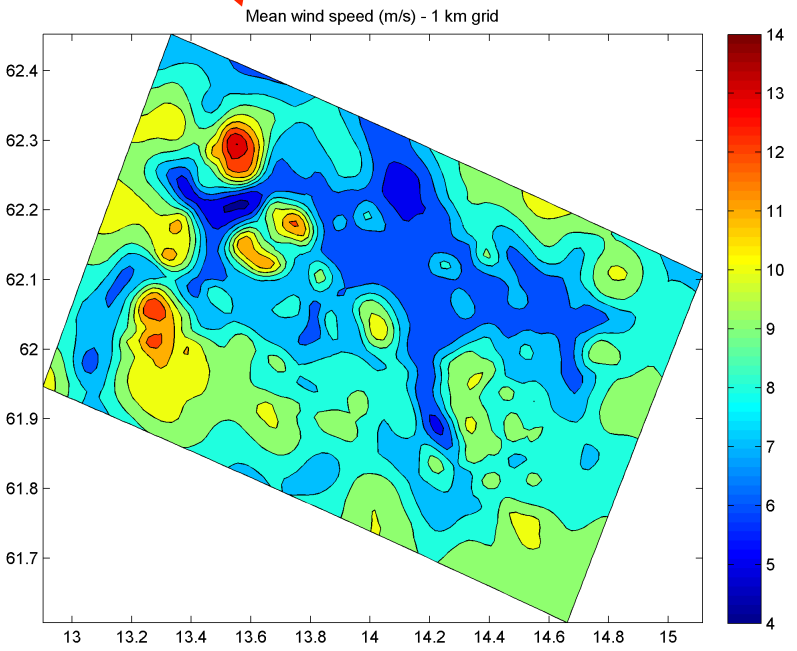
Icing climatology: Downscaling

WRF mean wind speed at 9 km and 1 km resolutions.





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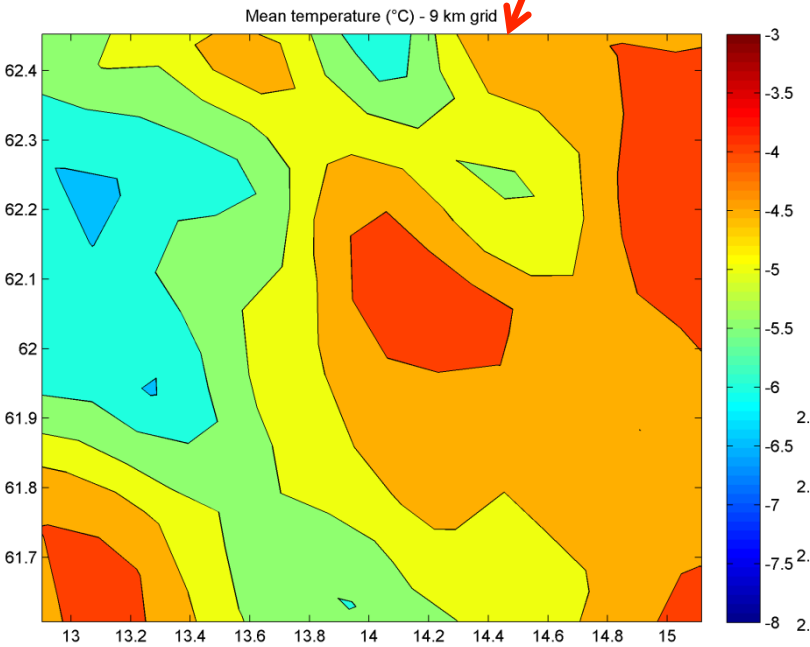
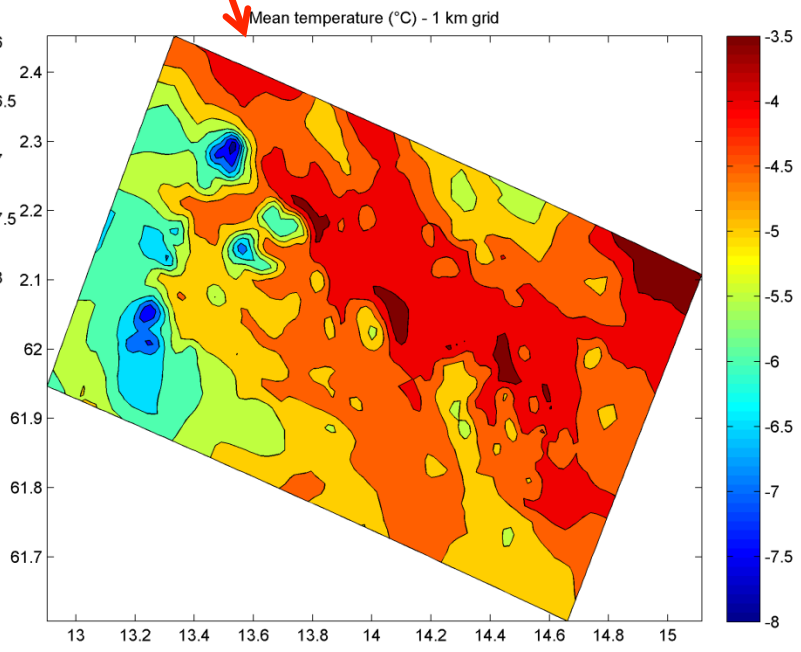
Icing climatology: Downscaling

WRF temperature at 9 km and 1 km resolutions.





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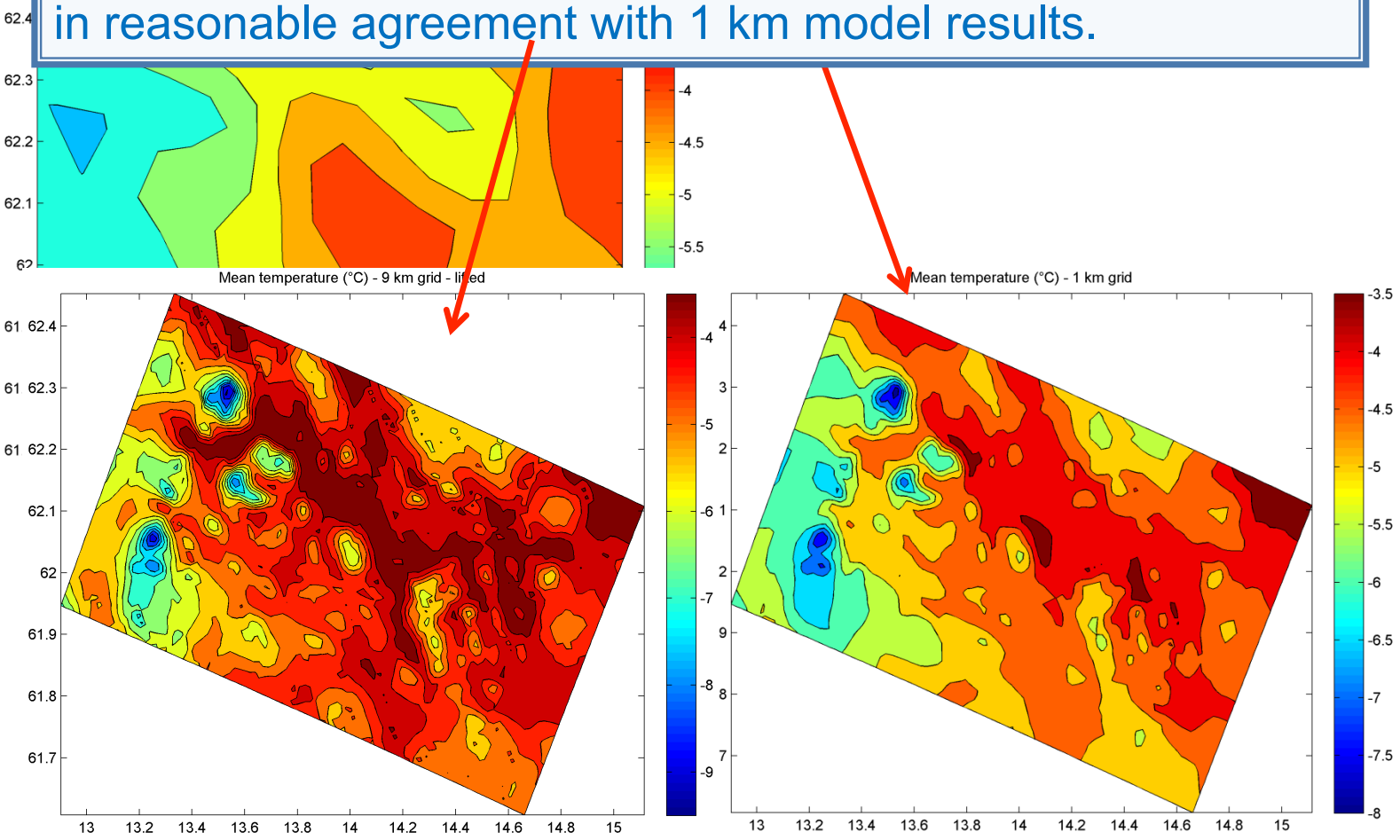
Icing climatology: Downscaling

WRF temperature at 9 km and 1 km resolutions.

Lifting of 9 km temperature according to difference between 9 km and 1 km topography will give a new 1 km temperature – in reasonable agreement with 1 km model results.



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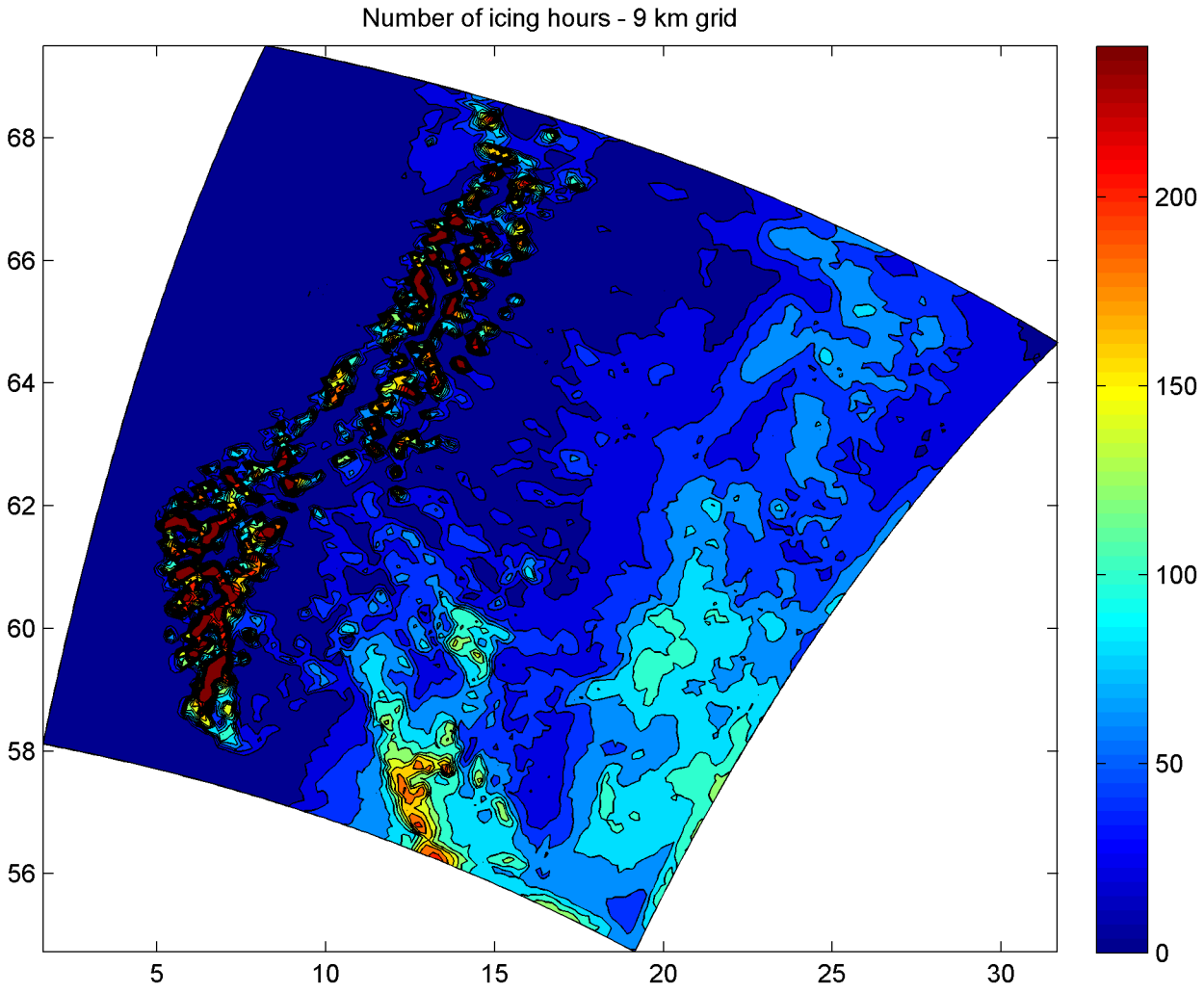
Icing climatology: Downscaling

WRF icing hours at 9 km resolution.



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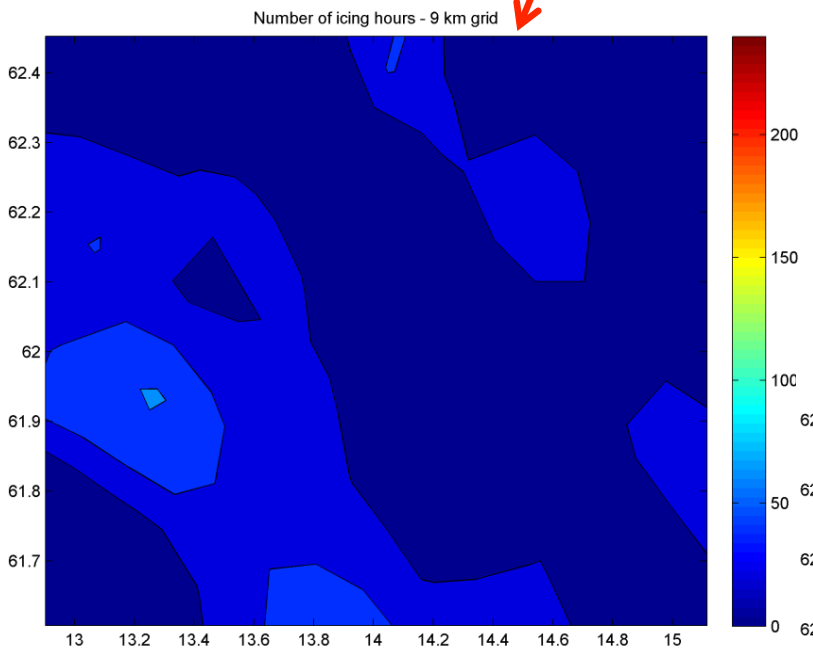
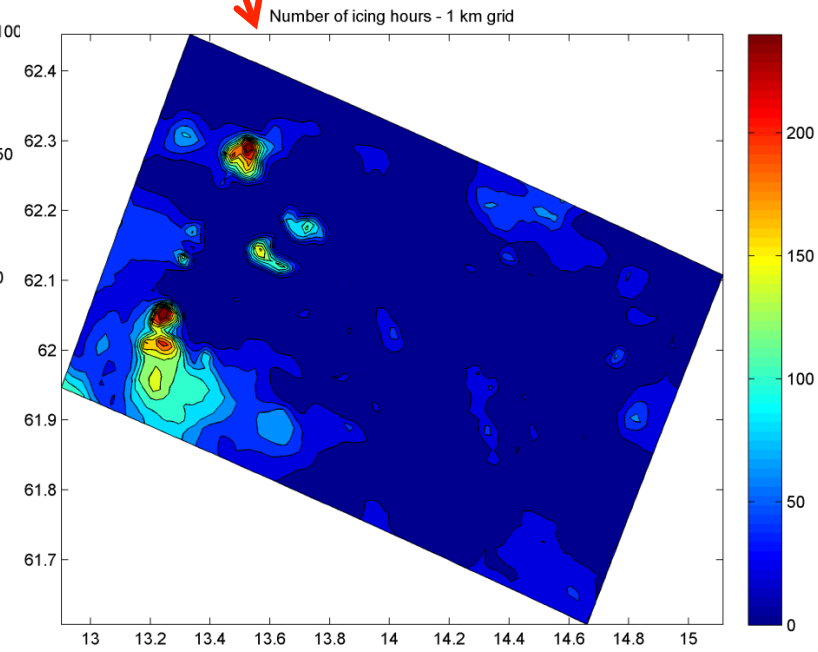
Icing climatology: Downscaling

WRF icing hours at 9 km and 1 km resolutions.





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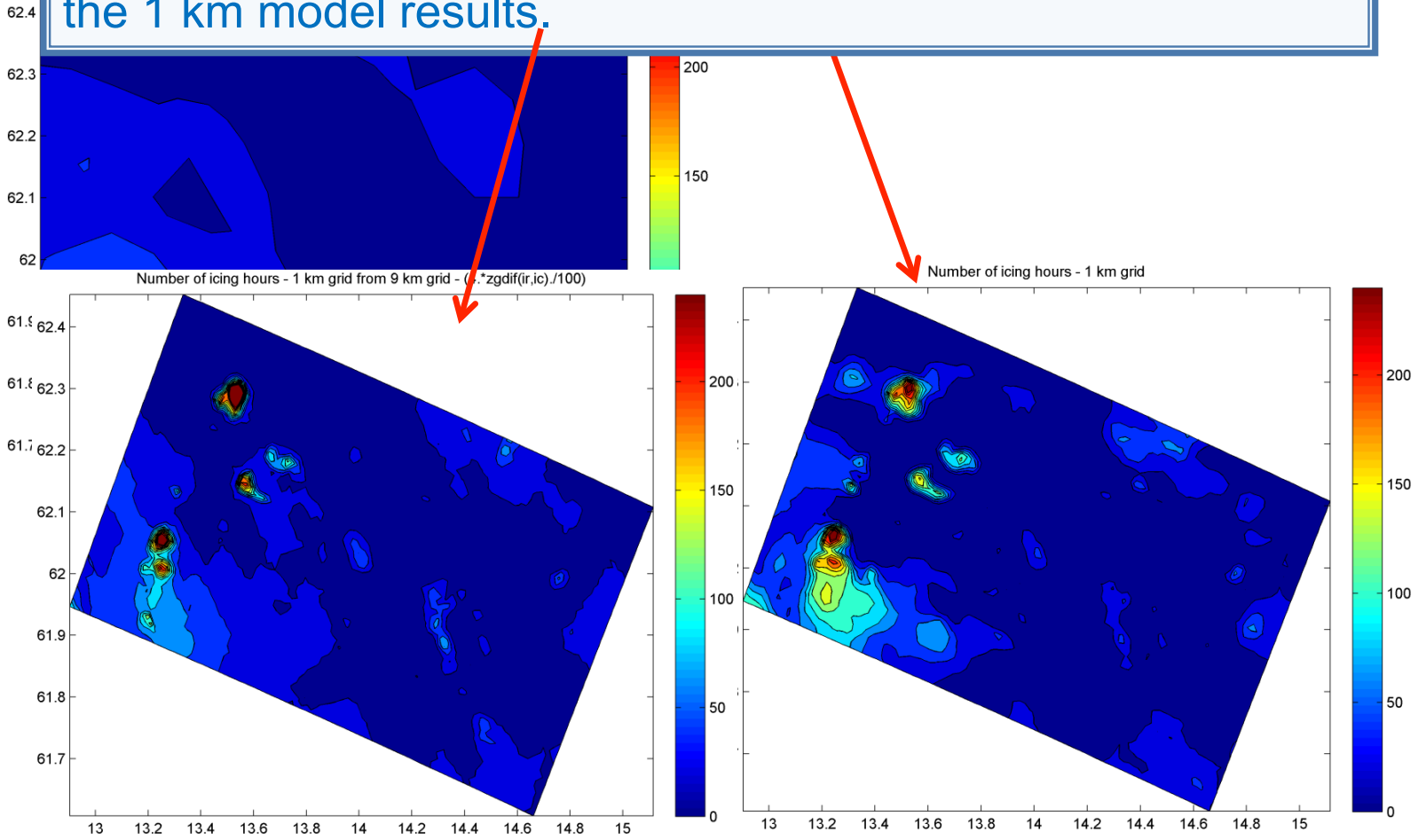
Icing climatology: Downscaling

WRF icing hours at 9 km and 1 km resolutions.

Lifting and adding supersaturated water to the liquid water content results in icing hours in reasonable agreement with the 1 km model results.



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Icing climatology:

Downscaling possibel to use – we may loose accuracy as regards local terrain response but we gain accuracy as regards climatological representativity.

Alternative:

Model representative periods wih high resolution?

Using some classification to find typical months ...

.....

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Using the Lamb classification

- Used by Professor H. H. Lamb for the British Isles
- Sorts into 27 classes based on direction of flow and pressure (cyclonic or anti-cyclonic) (8 direction types, 2 pressure types, 16 hybrid classes and 1 undefined)

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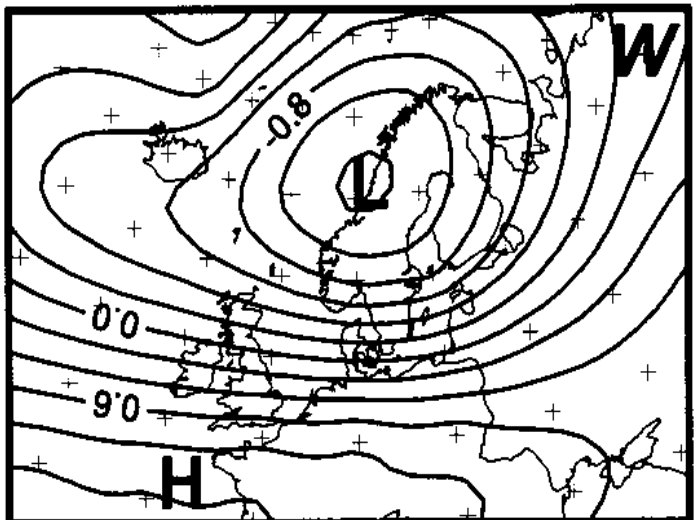
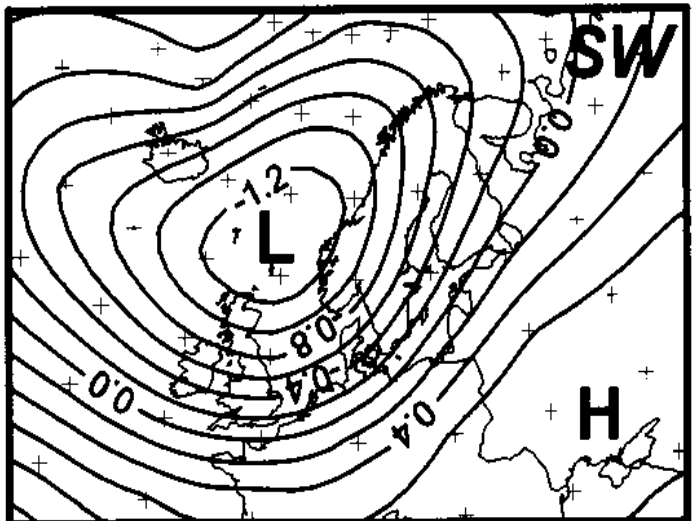
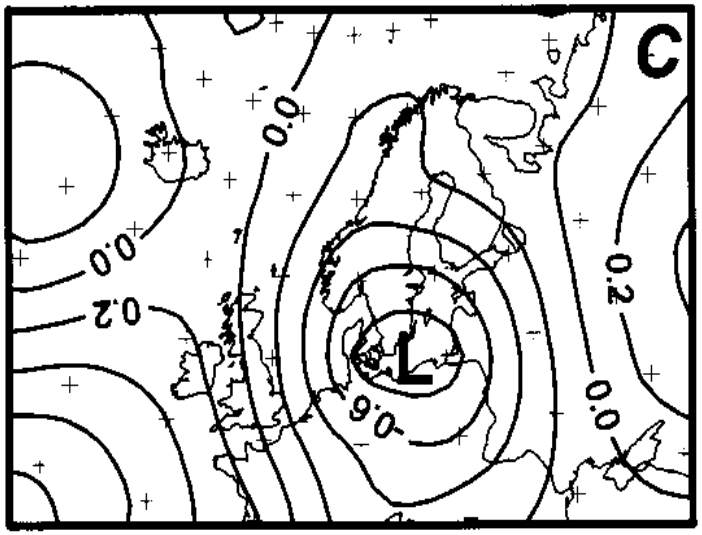
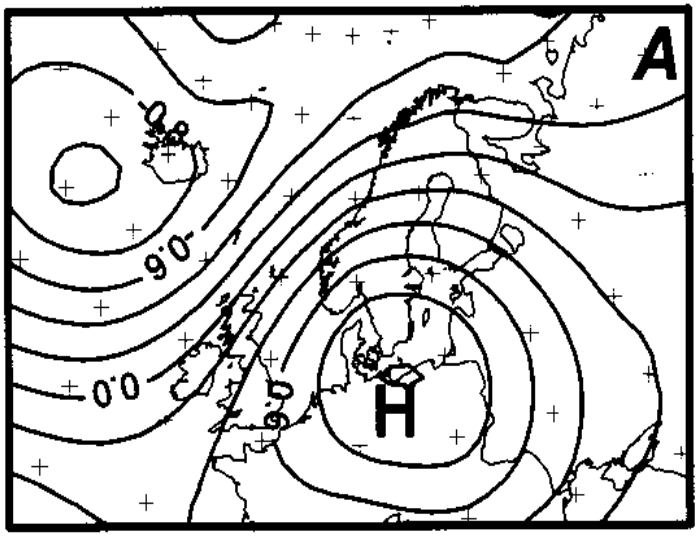
Examples of Lamb classes









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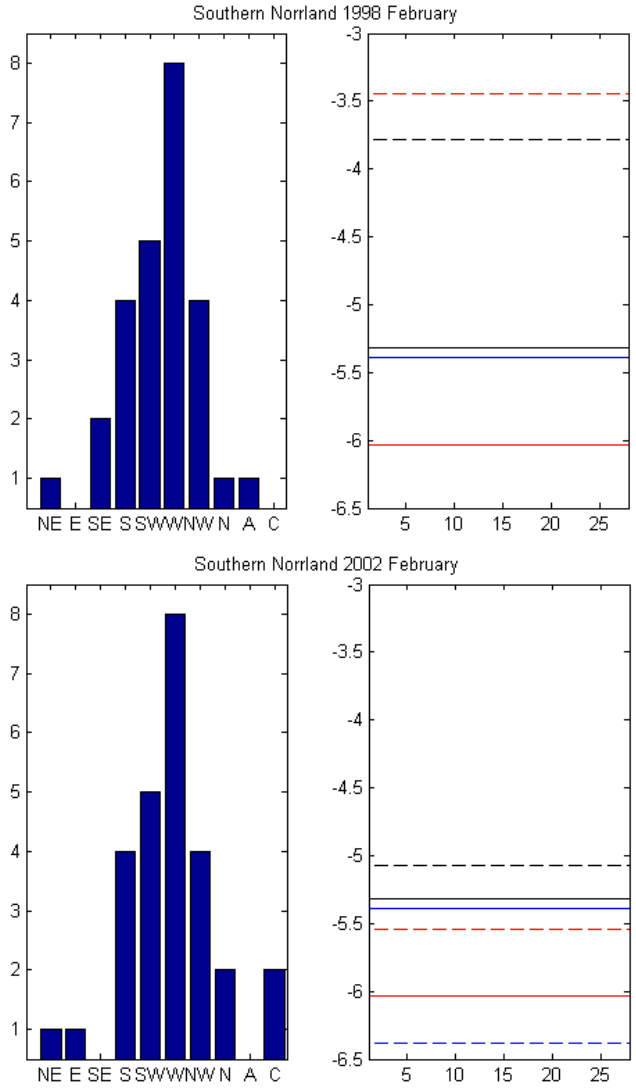
Using Lamb classification to create an icing climatology



- It has been found that months with similar patterns in Lamb classification do not share the same distribution of temperature

Ten of the 27 Lamb classes (left hand side)
Solid lines: monthly mean temperature 1989-2008, dashed lines: monthly mean temperature during specific year. Red lines – Pajala, Black lines – Kvikkjokk, Blue lines - Arjeplog (right hand **side)**

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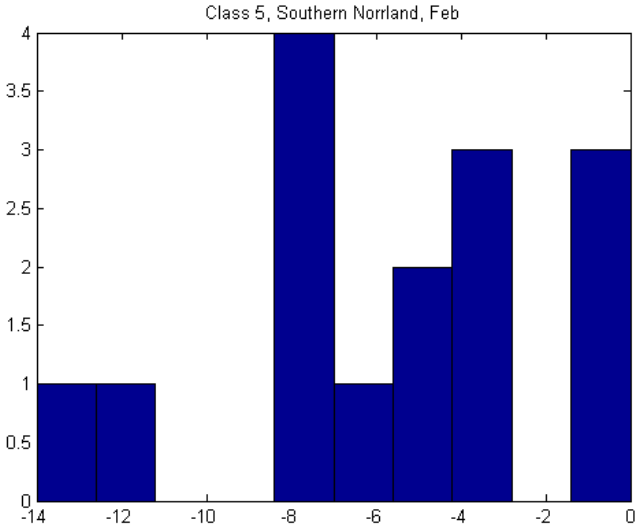

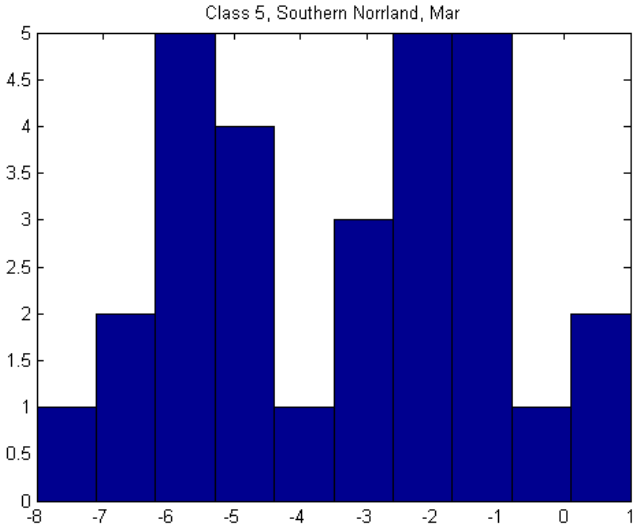

- Data from both SMHI stations and ERA suggests that to create a climatology of icing one needs to take more into account than just the class

Distribution of temperature in the SW class in Southern Norrland in February and March (three years). There is a noticeable spread in the temperature distribution

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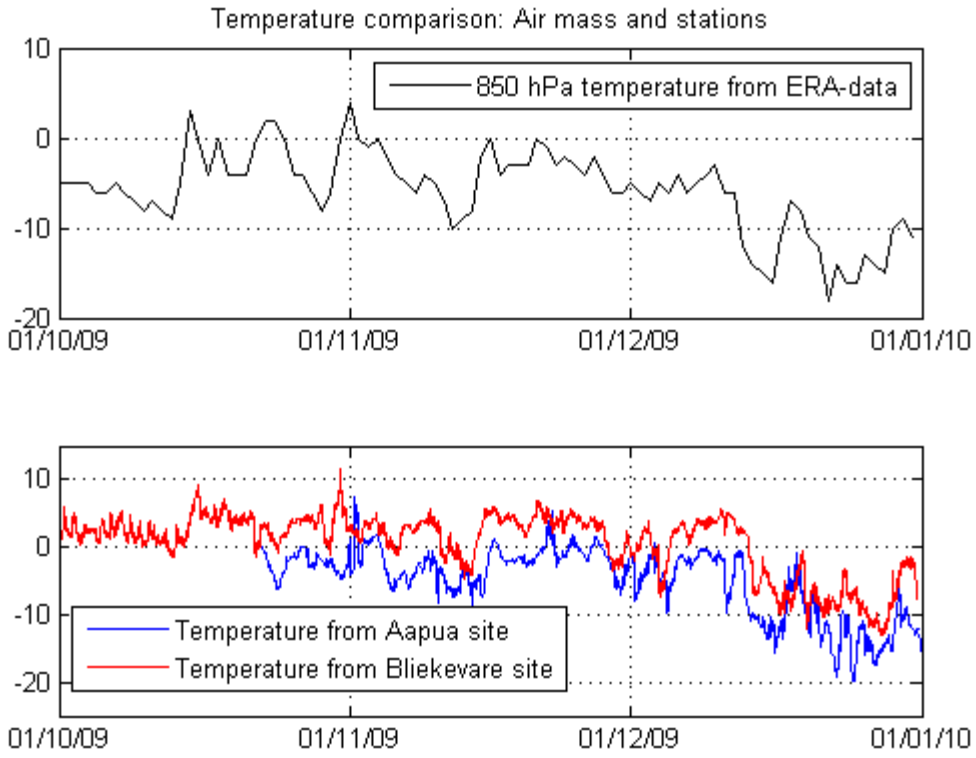
Using Lamb classification to create an icing climatology



Temperature from ERA data compared with temperature series from two measurement sits in Northern Sweden.

Temperature tendencies between air mass (above) and stations (below) show similar patterns

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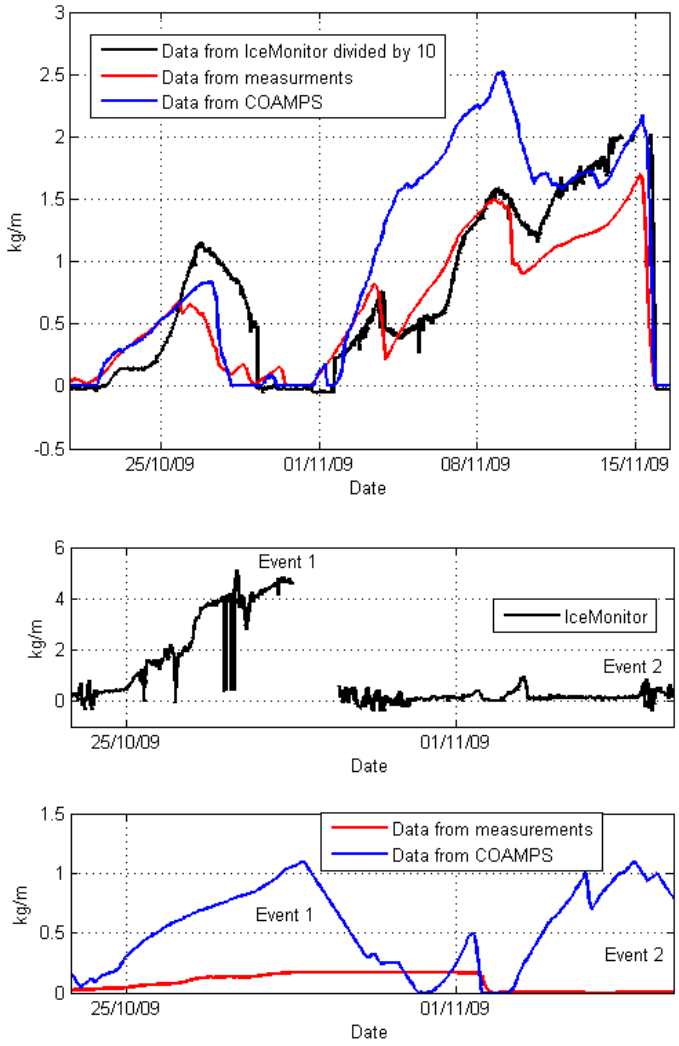
Could finding the most common wind direction for icing be of help?



Finding what classification is most common during an icing event could help create an icing climatology.

Figures
Above: Icing event from the Bliekevare site – black line: measurement. Red and blue lines: modelled ice load.
Below: Same as above but from the Aapua site

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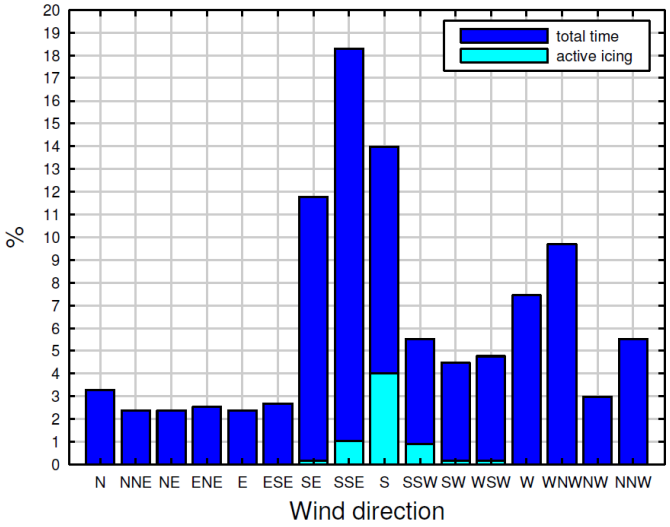

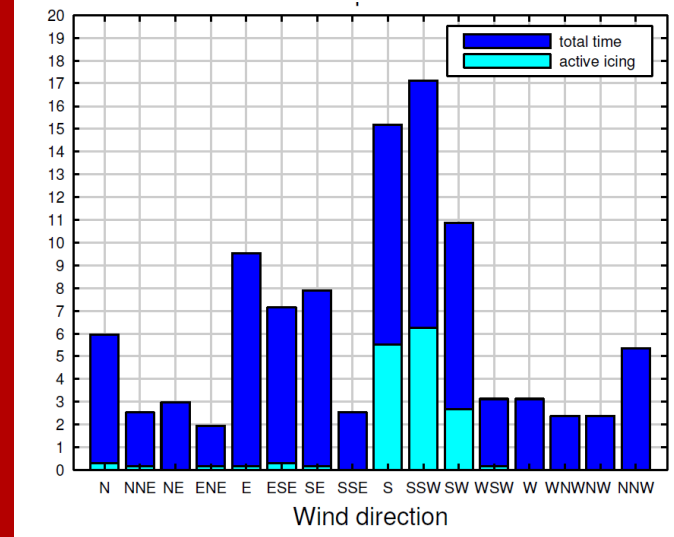

The most common wind directions for icing in the Bliekevare (above) and Aapua (below) sites seems to around south.

Figures
Above: Directions when there is an ice growth in the month of February 2011 Bliekevare site

Below: As above just the last week of February 2011 at Aapua site

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How can we move on with Lamb classification?

- A way to move forward?
  - Using the Lamb classification to find the classes with most icing
  - Using the geostrophic wind used to calculate classes in combination with temperature (either) from ERA or measurement sites to model icing
  - Combining the results into a climatology

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Thank you for your attention! Questions?

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