TOWARDS A HIGH-RESOLUTION ICING CLIMATOLOGY IN SWEDEN

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***Abstract**:* Due to a high rate of expansion of wind power in cold climate conditions there is an increased demand of a high resolution icing climatology in Sweden. A project that will address this issue was started 2009. This is joint project between the Swedish Meteorological and Hydrological Institute (SMHI), Uppsala University and Weathertech Scandinavia. Re-analysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) together with nested runs of high resolution mesoscale models will be used to produce this climatology. Measurements of ice load will be used to validate the model results.

1. INTRODUCTION

Wind power production in cold climates can suffer a lot from icing so it is of great interest to know what the icing conditions will be at selected sites. Previous studies has shown that in order to estimate icing conditions over areas of complex topography, the numerical models used, has to be run at very high resolution, down to about one kilometre. At the moment it is not feasible to run such high resolution models on an area the size of Sweden for longer time periods, e.g. 30 years. Instead some method for choosing representative periods has to be developed. For this, different weather classification algorithms will be applied to the re-analysis data.

2. RESULTS AND DISCUSSION

The ERA-interim [1] re-analysis data from ECMWF consists of global analysis of surface and atmospheric weather parameters ranging from 1989 until today with a 6-hour time resolution. The horizontal scale is about 80 km. So far the Lamb [2] weather classification method has been tested on this dataset in order to find representative months. Analysis of mean sea level pressure is used to classify the weather situations. The ERA-interim data has also been used to calculate ice loads, using the Makkonen formula as described in [3], and preliminary comparisons with observations of ice load at some sites in the northern part of Sweden show that the timing of icing events is well described but not the levels of the load.

Three different high resolution mesoscale models have been run in a number of configurations during the icing season 2009/2010. The models are: COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) [4], AROME (Applications of Research to Operations at MEsoscale) [5] and WRF (Weather Research and Forecasting model) [6]. Output from the model runs has been used to calculate ice load with the Makkonen formula. A comparison with the observational ice loads shows that most of time the model runs with highest horizontal resolution performs best. Figure 1 shows one example of a comparison between modelled (AROME) and observed ice load.

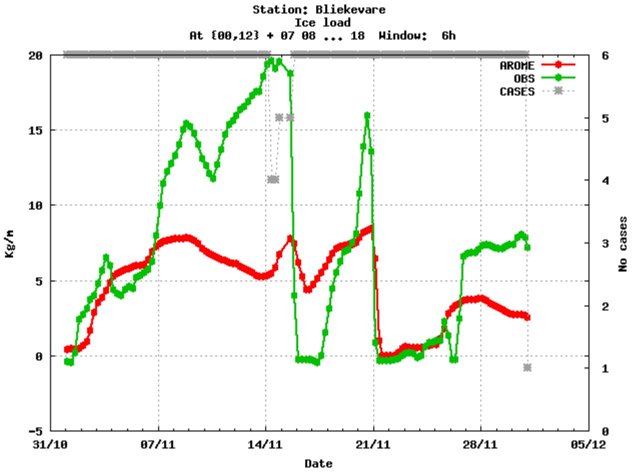

Figure 1: Observed (green) and modelled (red) ice load in kg/m for Bliekevare November 2009.

3. CONCLUSION

Initial tests have shown that it is possible to simulate icing events rather well with high resolution mesoscale models. There are still some uncertainties on the icing severity but there is a clear signal that the models need to be run with highest possible resolution.

4. REFERENCES

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***Abstract*— A project was started in 2009 in Sweden with the aim to develop a high resolution icing climatology. There is a high rate of expansion on wind power especially in the northern part of Sweden where the icing problems are significant. The project is funded by the Swedish Energy Agency and it is a joint effort between the Swedish Meteorological and Hydrological Institute (SMHI), Uppsala University and Weathertech Scandinavia. Output from high resolution numerical weather prediction models together with an ice accretion model will be used to calculate icing conditions. Since we are not able to run such high resolution models over an area the size of Sweden for longer time periods, e.g. 30 years, some methods for selecting representative shorter time periods has to be developed. For this re-analysis data from European Centre for Medium-Range Weather Forecasts (ECMWF) will be used. A small net of ice accretion observation stations has been established in Sweden. Data from these stations will be used to validate the high resolution model performance.**

I. INTRODUCTION

Earlier studies [1] on this topic has shown that the models need to be run at a resolution around one kilometer in order to accurately describe cloud processes in the lower part of the atmosphere in areas of varying topography. It is not feasible today to run such high resolution models on an area the size of Sweden for longer time periods. So instead, we in some way, for the high resolution runs, have to choose time periods that in some sense represent climatology. It can be whole months or whole winter seasons. Data from the ECMWF ERA-interim re-analysis [2] project will be used to decide what time periods to run with high resolution. This database consists of both surface and atmospheric analysis ranging from 1989 until today. Different methods for automatic weather type classification will be applied on this data to find the appropriate time periods. Using ERA-interim analysis as initial data and boundary conditions, higher resolution models will be run in a nested configuration for the chosen periods. Hopefully it will be possible to cover the whole of Sweden with a one-kilometer grid in the innermost domain. A small net of ice measuring stations has been built in Sweden, 3 sites last winter, will be 11 sites this coming winter. Comparisons of ice loads calculated from ERA-interim data, with the measurements from last winter, show that the timing of the icing events is rather well described but the amount of ice is often underestimated. This indicates that the ERA-interim data will serve as a good foundation for the icing climatology. The mesoscale high-resolution simulations that have been run for the last winter season also show some promising results. We are able to reproduce the timing of the icing events but there are some uncertainties in level of ice accretion.

II. TOOLS

A. Observations

A small net of icing measurement stations was established in the northern part of Sweden for the winter season 2009/2010. The main ice load measuring instrument on these stations is the Ice Monitor manufactured by SAAB Security. This instrument collects the ice on 0.5 meter vertically mounted rotating cylinder and the collected ice is constantly weighed. An optical sensor from Holooptics has also been used, this sensor at the moment only measures ice yes/no, and we do not get any accumulations. Apart from icing also standard meteorological parameters as wind speed, wind direction, pressure, temperature and humidity are measured. The sensors are mounted either on a wind power plant or a telecommunication tower. We had three sites online during the last winter, and this winter so far, two more stations have been established and another six are being deployed. To some of the sites measurements of visibility and cloud base are added to the above mentioned parameters. Figure 1 shows the Ice Monitor (bottom) and Holooptics (top) from the Sveg measurement site.

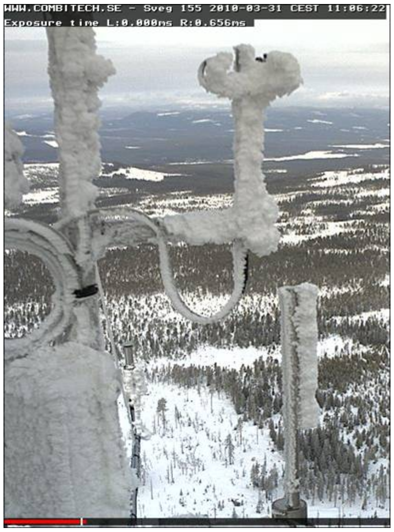

Figure 1. Ice Monitor (bottom) and Holooptics (top) ice measuring devices with some ice accretion on them.

B. *Ice accretion model*

The output from the mesoscale model runs is used to calculate ice loads utilizing a cylindrical ice accretion model often referred to as the "Makkonen model" [3]. Inputs for this model are temperature, wind speed, super cooled liquid water content and median volume droplet size (MVD). The latter is not possible to get from the present models so a constant value has to be prescribed. Time series of the atmospheric parameters, can be extracted from our model runs with a one hour time resolution and put in to the accretion model and as output we get an ice load time series that can be compared to the observations. Despite the high resolution of the models we still lack some topographic detail so the mountain tops in the models are in most cases below the real tops. To compensate for this height difference the model data (temperature and specific humidity) are lifted adiabatically to the height of the observations. In this process condensation can occur, if so, the condensed water is added to the model liquid water before it goes in to the accretion calculation.

C. *ERA-interim*

The ECMWF ERA-interim re-analysis data covers the whole globe from 1989 until today with a 6 hour time resolution. The horizontal resolution is about 80 kilometers and there are 60 vertical levels in the atmosphere. Every possible weather parameter both on the surface and in the free atmosphere is included in the database. The project will use this data in two different ways; first it will used to find the representative icing periods that will be run with high resolution, secondly it will also serve as initial conditions and lateral boundaries for the high resolution runs.

Some preliminary tests have been done to find the representative periods using an automatic version of the Lamb [4] weather classification. In this classification daily mean low resolution analysis of mean sea level pressure is used to classify the weather situation. Analyzing the relation between the geostrophic wind and the vorticity for the pressure field gives as a result a weather class that can either be a low pressure, high pressure or one of eight dominating wind directions. There are also 16 hybrid classes that are a combination of low/high pressure and wind direction. The classification has been done for three different parts of Sweden, northern, middle and southern part. Mean values of weather class distribution for each area and each winter month has been calculated and also which month that has been closest to this mean distribution. These months could then be candidates for high resolution simulations. It is not clear however if this the optimal way to choose, further studies will follow.

The ERA-data has also been used for some ice accretion tests. Data from the gridpoints closest to the ice observation stations is fed in to ice accretion model and the output can then be compared to the observed values. Figure 2 shows an example of such a comparison from Bliekevare for the last quarter of 2009. This was a rather intense icing period with high loads, up to 20 kg/m. We are not able to reproduce this high ice load with the ERA-data but the timing of the events seems to be caught quite well. Some melting episodes are missed in ERA because of too cold temperatures. There seems to be some strange fluctuations in the measured ice load at the end of the period that indicates some uncertainties in the performance of the Ice Monitor.

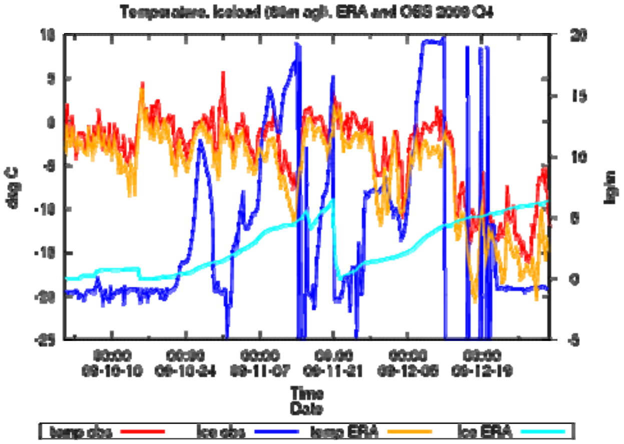

Figure 2. ERA ice load (light blue), observed ice load (dark blue) in kilogram/meter. ERA temperature (orange), observed temperature (red) in deg. C. The site is Bliekevare.

D. *Mesoscale models*

Three different high-resolution mesoscale models have been used so far in this project. They are COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) [5], WRF (Weather Research and Forecast model) [6] and AROME (Applications of Research to Operations at MEsoscale) [7]. The horizontal resolution used in the innermost domains has been between 0.4 and 2.5 kilometers and they have all been run with non-hydrostatic dynamics. They all have very advanced parameterizations of turbulence and cloud processes, essential for near ground cloud simulations. All three microphysical schemes keeps track of five different cloud species, cloud water, cloud ice, rain, snow and graupel. Figure 3 shows the model setup for the COAMPS and WRF runs. The outer domain has 36 kilometer horizontal resolution, then it goes from 12 to 4 and finally 1.3 kilometers. Some tests has also been done with COAMPS on 0.4 kilometers resolution nested in the most northern 1.3 kilometer domain.

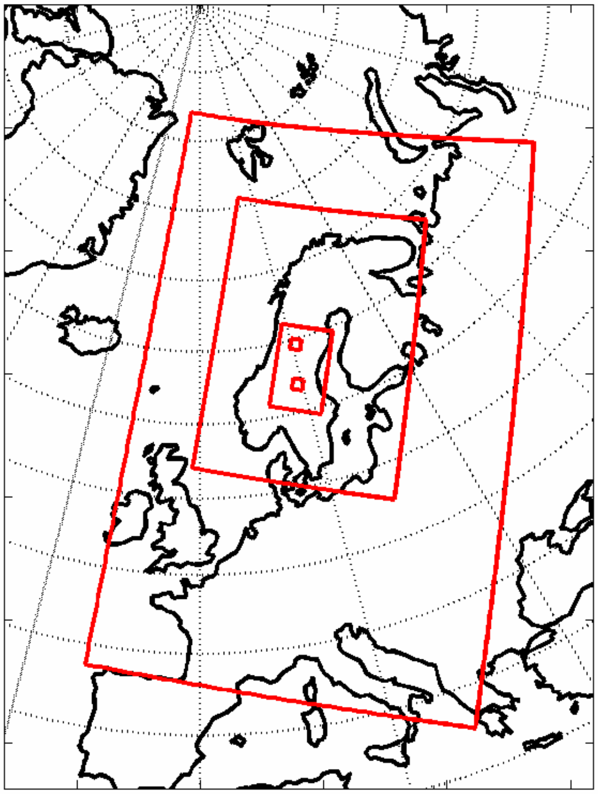

Figure 3. Model domains for COAMPS and WRF, the outermost are 36 kilometer resolution, then 12, 4 and 1.3 kilometers

The American Global Forecasting System (GFS) model with 0.5 degrees horizontal resolution has been used for initial conditions and lateral boundaries for the outer domain. COAMPS and WRF has been run with 40 vertical levels, with 14 of them below 540 meter.

Figure 4 shows the domain for the AROME simulations at 2.5 kilometers horizontal resolution. For lateral boundaries and initial conditions the operational SMHI Hirlam model with 0.05 degrees resolution has been used. AROME simulations have been run with 65 vertical levels, 15 levels below 540 meter.

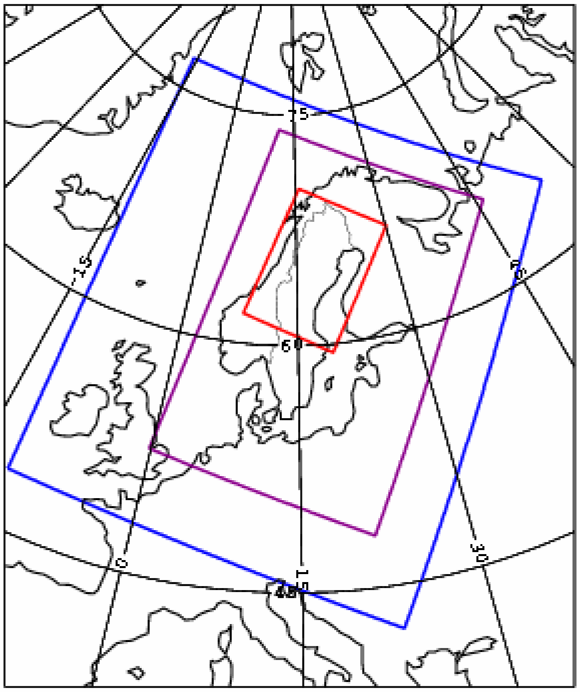

Figure 4. Model domain for AROME (red), SMHI Hirlam model with 0.05 degrees resolution (purple) and SMHI Hirlam with 0.1 degrees resolution (blue).

III. RESULTS

The result for the weather classification analysis of the ERA-interim data is shown in table 1. It shows for each winter month, October to March, and each part of the country, which year that the distribution of the weather classes was closest to the mean distribution for the whole time period.

Month	Northern	Middle	Southern
October	1996	1999	2003
November	2003	1996	2008
December	1997	1989	1989
January	2007	1991	1994
February	1997	1997	1999
March	1995	1996	2003

TABLE 1. WEATHER CLASSIFICATION RESULT

As can be seen from figure 2 there were some very interesting icing episodes during the autumn 2009. For the last week of October output from the three models has been studied for the site Bliekevare. Figures 5-7 shows time series of temperature, cloud water, cloud ice, rain, snow, graupel, sum of all condensates and computed ice load for COAMPS (1.3 km), WRF(1.3 km) and AROME (2.5 km) respectively. This is done without the adiabatic lifting described above. There are some differences between the models. WRF seems to produce more cloud particles than

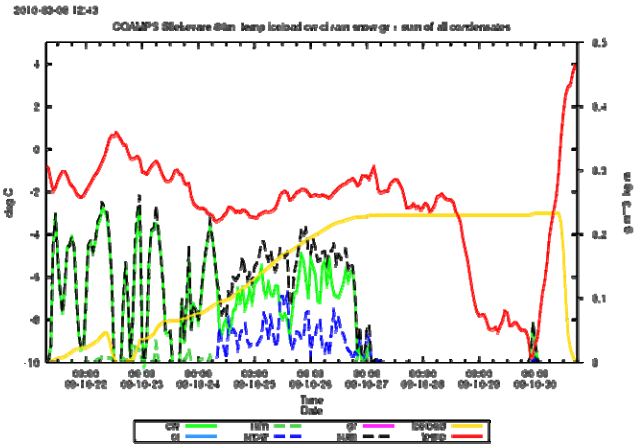

Figure 5. Time series COAMPS last week of October 2009 for Bliekevare. Temperature deg C (red). Cloud water (green), cloud ice (blue), rain (dashed green), snow (dashed blue), graupel (purple), sum of all condensates (dashed black). All these in grams/m**3. Ice load (yellow) kilograms/meter.

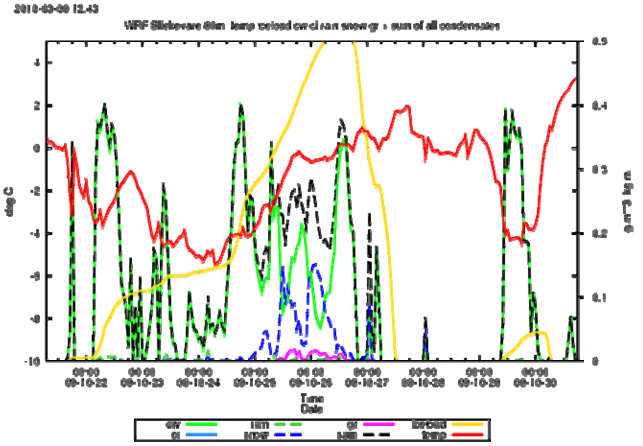

Figure 6. Time series WRF , same colors as figure 5.

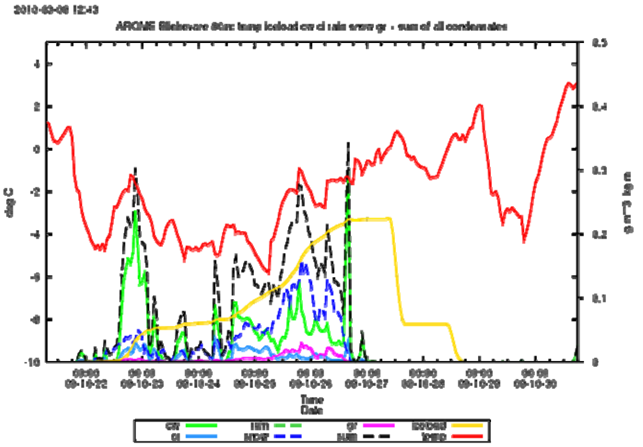

Figure 7. Time series AROME, same colors as figure 5.

the other two and that also reflects in the calculated ice load, where WRF has about twice as much as the others. There is no cloud ice to be seen in WRF and COAMPS, small amounts of cloud ice in AROME. No graupel in COAMPS, small amounts in the other two.

The observed ice load on the 27:th of October was a little above 10 kg/m, so all models are way off in this case. Adding the lifting to AROME (not shown) in this case will give an ice load of around 1 kg/m. Figure 8 shows, again for Bliekevare, a time series for November 2009 of observed and AROME simulated ice load. In this case lifting is added and we see that the model is able to produce quite large amounts of ice, but not as high as the 20 kg/m that was observed at the 15:th of November.

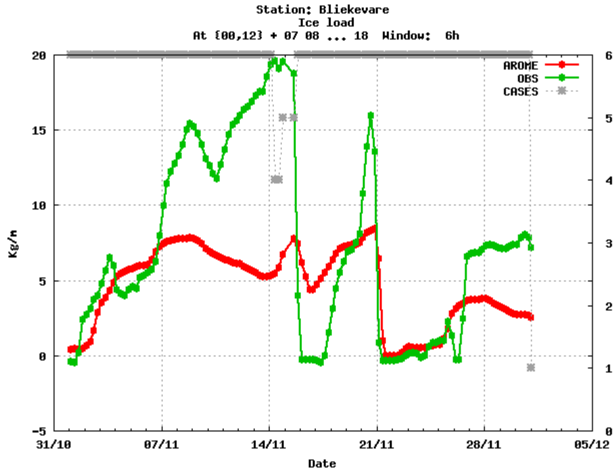

Figure 8. Time series November 2009 for Bliekevare. Observed ice load (green) kg/m, simulated ice load AROME (red) kg/m.

The simulations have continued for the current ice season 2010/2011. As indicated above new stations have been deployed and figure 10 shows time series of observed and simulated ice load from Glötesvålen. Here we compare simulations from COAMPS and AROME, adiabatic lifting included. In this case COAMPS does a god job on the first event, AROME only reach about half of the observed value.

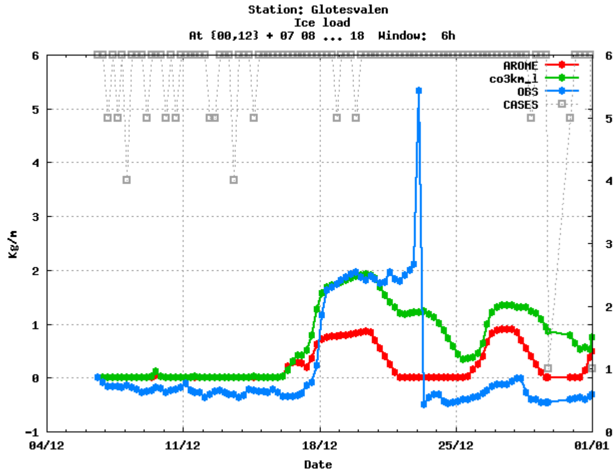

Figure 9. Time series for Glötesvålen december 2010. Observed ice load (blue) kg/m, simulated ice load AROME (green) kg/m and simulated ice load COAMPS (red) kg/m.

Finally to summarize the ice season 2009/2010 we present figure 10. In this all hourly values of ice accretion has been summarized from the AROME 2.5 kilometer simulations at 100 meters above the model terrain.

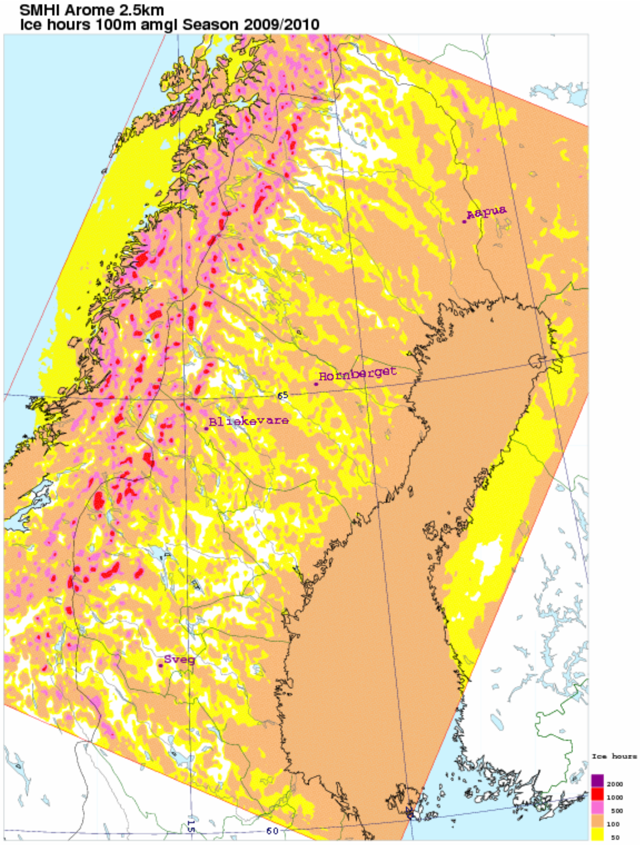

Figure 10. Map with number of hours when the hourly ice accretion has been greater than 5 grams/meter. White <50 hours, yellow 50-100 hours, orange 100-500 hours, purple 500-1000 hours and red > 1000 hours.

As expected we see a large correlation between icing and topography, but also rather big values for the coastal areas. This is probably due to a high frequency of east/northeasterly winds last winter.

IV. SUMMARY AND CONCLUSIONS

Work has begun to produce a high resolution icing climatology for Sweden. This is work in progress and no final result has been presented so far. The tools to produce this climatology have been tested within this project that will go on for two more years. We believe that state of the art high resolution mesoscale weather models are the most important tool. Experience so far, comparing modeled ice load to observations, shows that we need to run the models with a horizontal resolution around 1 kilometer. Since this kind of model runs are very computer demanding for large domains, we in some way need to choose representative time periods for those runs. The representative time periods will be selected using global re-analysis data.

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