Verification of Icing-model, in Finland.

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***Abstract*: Icing-model used at FMI gets its input from the numerical weather prediction model AROME. The AROME uses traditional observations in verification and assimilation purposes. However, the absence of daily icing measurements makes the verification of Icing-model challenging. In this paper we present the methods and results of the verification of Icing-model.**

Keywords: icing, modelling, verification, icing rate

ABBREVIATIONS

LWC	*Liquid Water Content*
MVD	*Median Volume Diameter*
FMI	*Finnish Meteorological Institute*
NWP	*Numerical Weather Prediction*
CLW	*Cloud Liquid Water*
agl.	*Above ground level*

I. INTRODUCTION

Icing causes many difficulties to wind energy and creates challenges to operators. Financial loss can be expected at the electricity markets, when the promised electricity amount is not produced. Detailed day-a-head icing forecasts could provide help to this situation by enabling better power production estimates.

In our study we use combined modelling system. The post-processing tool Icing-model gets the input from numerical weather prediction (NWP) model AROME [1]. AROME uses many different kinds of observations in assimilation, from satellites to ground observations. AROME is also used as the operational weather forecasting model at Finnish meteorological institute (FMI). However, measuring of atmospheric icing is not part of FMI's daily routine. Due to this the amount of icing measurements available is quite limited. Yet, there are some observations from different field campaigns. And more or less regular daily measurements are made at Puijo measurement station.

The lack of operational icing measurement data made us to perform sensitivity tests to understand how the Icing-model behaves. In this work we present the results from observation comparison and sensitivity tests. The results of sensitivity test are presented as hours of active icing per month, which corresponds to frequency of the events. This is due to the fact that we were interested on how large is the uncertainty in the results of Finnish Icing Atlas, published by FMI.

II. OBSERVATIONS AND MODELLING METHODS

A. Observations

We collected five different types of icing measurements from FMI's observation archives for three sites to validate our Icing-model. The observations available were from Puijo (continental area in Eastern-Finland) and Luosto (Lapland) measurement stations. In addition to FMI measurements, data from one wind turbine site at Riutunkari (west coastal are) was also used.

From Puijo we had data from Labkotec's LID-3300IP and Vaisala's FD12P instruments. The Vaisala FD12P instrument is not actually icing measurement instrument, but a visibility sensor. Together with temperature measurement and wind speed we used the correlation relation defined by Hirvonen et al. [2].

Labkotec data was also available from Riutunkari wind farm provided by Labkotec Oy. LID-3300IP instrument gives ON-OFF type of information if it is icy or not.

From Luosto we had two different types of measurements. ON-OFF data from Rosemount instrument and mass measurements form Combitech IceMonitor.

With AROME we created weather datasets to cover the periods from which we had observations. These dataset were post-processed by Icing-model. We tested each site and the observations from each instrument separately against the model results.

B. Icing-model

The input for the Icing-model is taken from NWP model AROME. From the AROME we get wind speed, temperature and liquid water content. AROME has advanced microphysics scheme in which it is able to divide hydrometeors into five categories: rain, snow, graupel, cloud water and cloud ice. In our setup only liquid water content (rain and cloud water) is used in icing calculations.

AROME has a 3D-Var assimilation system, in which it uses wide spread of different kind of observations. The horizontal grid-size of AROME is 2.5 km with 60 levels in vertical. Consequently, the icing results are calculated for whole Finland by using the same resolution.

The Icing-model was developed for climatological applications such as for creating the new Finnish Icing Atlas. The Icing-model is based on physics described in ISO Standard 19494 [1], so called Makkonen model. In this method ice is accumulated over standard cylinder. It takes into account the surface area *A* seen by the wind *V*, *LWC* and three coefficients. These coefficients describe sticking, collision and accretion efficiencies. The icing rate is:

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

In addition to *LWC*, the Icing-model needs to know the cloud particle number concentration. In our work we use constant value 100 cm^{-3}. From literature we discovered that ~70 cm^{-3} responds to clean marine air [4] and 300 cm^{-3} to forested area [5]. It is clear that constant value is not the best option for all conditions. Therefore, we performed sensitivity test to evaluate magnitude of possible errors due to constant number concentration approach.

C. *Sensitivity tests*

We tested how sensitive the Icing-model itself is for the input it gets from the weather model. Input variables such as wind speed, temperature, liquid water content and cloud particle number concentration were perturbed in order to see the effects of these parameters. The motivation for this was to understand the effect on icing results if we mis-forecast the parameter. The test period is February 2006. Monthly mean values of icing intensity were calculated and compared to original Icing Atlas results.

The perturbations are following:

- Temperature by ±2˚C, the average temperature bias of AROME during Wind Atlas.
- Wind speed by ±2m/s, average difference between calm and windy month during Wind Atlas.
- Liquid water content by ±20%, if water content is wrongly divided between different water phases.
- Cloud particle concentration by ±30%, and even with 300 cm^{-3}.

III. RESULTS

D. *Observation comparison*

According to Icing-model observation comparison the Icing-model has the skill to detect icing events (Fig. **1**). However, the ability to estimate accumulated ice mass is very poor (Fig. **2**). The model results did not seem to be greatly dependent on used instrument. However, we trusted the Puijo and Luosto observations more, because from these stations we had maintenance information available.

From Figure **1** we see that the modelled and observed temperatures are very close to each other, during the test period November 2005. We can recognize that modelling error in 23rd of November is due to temperature error in the NWP-model. In the observations the temperature is below zero, but the model is just above 0˚C. This is why the Icing-model does not produce ice. The other modelling error can be identified during 18th of November. In this case the NWP-model predicts the temperature right, but does not have CLW to produce ice. Altogether it seems that the Icing-model is very sensitive to temperature and CLW input from NWP-model.

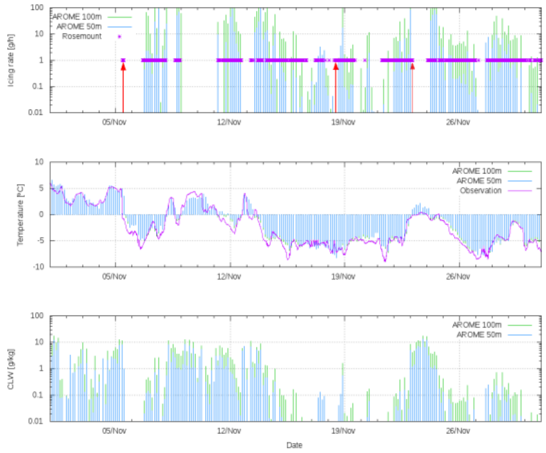

Figure 1. Luosto observations against model results, in November 2005. At the upper panel icing observations with purple stars and icing intensity from the model with green and blue respect to 100m and 50m heights. At the middle panel observed temperature (purple) and modelled temperature (green and blue). At lower panel cloud liquid water in the Icing-model.

In figure **2** we show example of the ice mass comparison from Luosto. We can see that the start of the ice mass accumulation is quite accurately simulated. However, the mis-forecasted temperature in the model launches melting almost four hours too early even if there would be enough liquid water available. The amount of ice mass is also far too low.

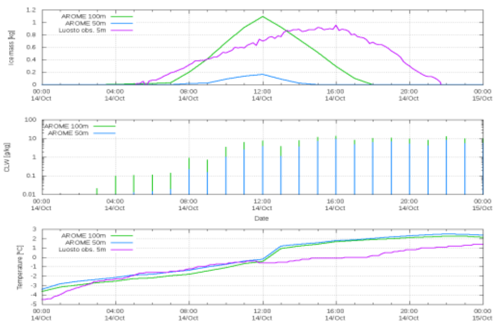

Figure 2. Ice mass observation comparison from Luosto measurement station in 14th of October 2007. At top panel ice mass. In the middle panel CLW content by the Icing-model. At lower panel: temperature. Purple values are presenting the observations from 5m height. And the green and blue are presenting the Icing-model results respect to 100m and 50m heights.

E. Results of sensitivity tests

The results are strongly dependent on how well the wind speed, temperature and liquid water content are forecasted. The results presented here are monthly mean values of hours of active icing. The original model results, to which we are comparing the test setup, is from Finnish Wind Atlas dataset.

Effects of temperature perturbations were as expected. Most radical changes are seen when the original temperature is close to zero degrees, like at coastal areas if the sea is not frozen. However, when the temperature is just below zero it seems not to have an effect on how much ice is accumulating. In Northern highland areas where the temperature can drop so low that the liquid water particles does not exist any longer the icing is reduced. From figure **3** we can see that by decreasing and increasing the temperature, the strongest effects are found on coastal areas and highlands. The most radical changes are seen at the south-west coastal areas, when temperature is increased by 2˚C. In this area the absolute values are already higher in original model run and rising of temperature causes significant reduction in monthly mean values.

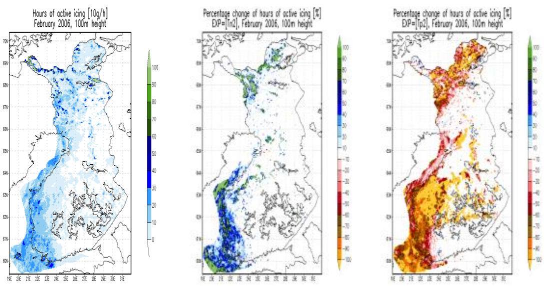

Figure 3. Effects of air temperature to hours of active icing during February 2006. On a left hand side: original model result. At the middle temperature decreased by 2˚C and on a right hand side temperature increased by 2˚C.

Perturbation of wind speed had largest relative changes [%] in the areas where the original values were small (from 0 to 10 hours per month). In these areas the changes were about 80-100%. However, the absolute changes in monthly mean values of icing were rather small. The modelled wind speed do not seem to have an effect on frequency of icing-events, but it has an effect on icing rate and how much ice is accumulated.

Changes in liquid water content has an effect on ice mass accumulation but not so much on when the accumulation is detected. Hence, the perturbation has a modest effect on hours of active icing. The largest changes are seen in the areas where the original values are small. Altogether the changes in absolute icing hours are small, when perturbing the liquid water content by 20%.

The Icing-model results were not sensitive to changes in cloud particle number concentration if the amount of LWC was kept as in original model run. In other words the droplet size distribution did not seem to have a great effect on ice mass or icing-rate, when studying the monthly averages.

IV. CONCLUSIONS

In general, the comparison between observations and icing-model results are very promising. However, the Icing-model has no or low skill to predict ice mass accumulation correctly. One problem in the ice mass comparison was that the observations were from 5m agl., but the lowest model level is at 30m height from the ground seen by the model. In Luosto's case the observations are made at top of a hill which cannot be seen by the weather model in such detail, causing a shift about 130m. Nevertheless, the Icing-model is suitable to predict the existence of icing events, but to estimate the severity of the event cannot be estimated accurately enough.

AROME is used as operational weather forecasting model at FMI. The daily verification results show that AROME has the skill to predict the temperature and the wind speed reliably. So the errors in icing results caused by temperature and wind speed should be in general rather small.

In the beginning of the study we were more concerned about the errors caused by LWC and cloud particle number concentration. Especially the cloud particle concentration raised some concerns, because we do not have tools to measure the concentration and create local maps. However, the sensitivity tests show that constant cloud particle number concentration assumption do not seem to cause significant error relative to other sources. However, predicting the clouds and the liquid water content temporally and spatially correctly still remains as challenge. For more accurate icing-forecasts we need to improve the microphysics in the NWP-model to cast clouds more accurately.

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