VALIDATION OF ICING MEASUREMENTS

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Abstract— Icing has become an area of increased interest for wind power since the development of new turbine parks sometimes are located where there is a risk of icing. There is a need for reliable measurements before establishing a park to assess the icing risk. An important part of understanding icing is to have access to good and accurate data. It is important to stress the need for accurate data since it will provide a basis for future research and also can be a basis for prospecting for a new wind turbine park, an inaccuracy in the data could have severe consequences.

There are many instruments for measuring ice loads today on the market and it is vital that these instruments are accurate. To investigate the accuracy of the data available in the Vindforsk project in situ measurements have been compared to modeled data for icing events in Sweden during the winter season 2009-2010. The in situ measurements have been compared with ice load both modeled with COAMPS (Coupled Ocean/ Atmosphere Mesoscale Prediction System) and in situ meteorological parameters.

Using in situ meteorological parameters for modeling ice load show promise, as does using a mesoscale model. Though further investigation is needed since the modeled ice load is underestimated.

The work presented is an ongoing project in which ice load data are being validated - calling the attention to the need for more measurement sites and validation. This need cannot be stressed enough, without trustworthy data many issues with icing will be left unaddressed.

1. INTRODUCTION

With the expansion of wind power in cold climate the issue of atmospheric icing becomes an important parameter for prospectors. Though this parameter is not as well understood as the other parameters that effect wind turbines. To understand the effect of icing Vindforsk has a project which will measure icing and this will hopefully lead to a mapping of icing risk in Sweden.

The ice load will be modeled with the equation developed by Makkonen, [1], 错误！未找到引用源。. To calculate the cloud water content used in the equation the results from 错误！未找到引用源。 will be used.

In this study the measured ice will be compared to ice loads modeled from COAMPS data and in situ measured data. To the authors' knowledge the modeling of icing from in situ measurements is a novel approach. The aim of this is to see how well the model capture the icing events.

2. RESULTS AND DISCUSSION

The results show some promise for the method of calculating the ice load from the in situ measured meteorological parameters. The modeled results capture the dynamics of the icing events quite well, although the ice load is quite underestimated. The same is true for using a NWP for modeling icing, see Fig. 1.

There are many possible explanations for this. One is that the icing events chosen in this study could have been caused by other forms of icing than in-cloud icing which the modeled used don't capture. In this study to ice load have been studied, but perhaps more interesting the study would be the accretion rate of the ice. This could perhaps give a more correct view of the icing events.

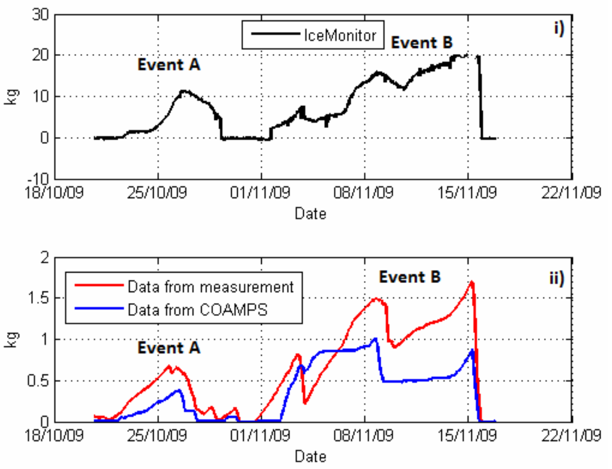

Figure 1: Icing event at Bliekevare winter 2009-2010, note that the y-axis scale is different in i) and ii)

3. CONCLUSION

The method of using in situ measurements for estimating the ice load show some promise. This method, as well as modeling the ice load form COAMPS data, gives a good agreement of the dynamics in the icing events, but the ice load is underestimated. This method will need more investigation and evaluation but could perhaps be used as a compliment to in situ measurements of icing.

4. REFERENCES

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Keywords - Icing measurements, ice load, data verification, modeling of icing

I. INTRODUCTION

For developers of wind power in cold climate icing is one of the risks facing a project. Thus understanding icing is an important part of making cold climate wind power projects bankable. A valuable tool for the wind power companies would be the ability to forecast icing correctly. Though, to be able to produce an accurate icing forecast the data used to develop the forecast must first be verified. During the winter season of 2009-2010 there are many occurrences in the icing data that has lead to a questioning of the validity of the data. Examples of this will be discussed in 错误！未找到引用源。. To the authors' knowledge there exist no records of modeled ice loads being verified against icing instruments besides, wind tunnel experiments against, in situ measurements. In this paper data of ice loads from two sites in Sweden from the winter of 2009-2010 have been studied in an effort to verify them. The in situ measurements of ice loads will be compared with modeled ice loads and ice loads calculated using measurements of other meteorological parameters, such as temperature and wind speed. The focus of this study will be how well the model captures the icing events.

The ice load will be calculated from the in situ measurements of standard meteorological parameters, which to the authors knowledge is a novel approach. To get an estimate of the validity of the ice load a simplified way of calculating the median total cloud water content of the atmosphere will be used. The calculated median total cloud water content will be used to model the ice load for two sites in Sweden where icing measurements are conducted. This will be compared to modeled ice load from COAMPS (Coupled Ocean/ Atmosphere Mesoscale Prediction System). This will serve as a first test of the method of calculating ice load from in situ measured meteorological parameters. If this approach is successful it will need further development.

II. SITES AND INSTRUMENTATION

The in situ measurements available in this project consist of several sites mostly located in the northern part of Sweden. During the winter 2009-2010 a few sites were operational, and it is from these stations different icing events have been chosen in this study.

A. Sites

Two sites have been chosen from the winter of 2009-2010, Aapua and Bliekevare, in which successful ice load measurements were made that winter season.

Aapua is located 20 kilometers west from the Swedish-Finnish border. Bliekevare is located on a hill near the Norwegian-Swedish border approximately 60 kilometers west of the town Dorotea.

B. Instrumentation

At both sites there is a meteorological mast. In addition to measuring meteorological parameters each mast is also equipped with an IceMonitor, a 0.5 long rotating rod with a 0.03 m diameter, such as specified by ISO 12494 [1]. The IceMonitor have an accuracy of ±50 g . The rod is allowed to rotate freely when ice is accreted on the instrument, the rotation is caused by the wind. The support is heated to +1 °C 错误！未找到引用源。. An example of the instrumentation of the sites can be seen in 错误！未找到引用源。.

Figure 1: An example of instrumentation set up.

There are some problems with the data from the IceMonitor during this winter season. Examples of this is that the ice load during some periods is negative and that there are some periods where there are many erroneous values during this season. There are many possible explanations for why this happens. One reason could be that the instrument rod gets stuck when freezing and cannot rotate properly. An important thing to note is that the ice load during one icing event exceeded the maximum level of the instrument, 100 $\frac{N}{0.5m}$ or approximately 20 $\frac{kg}{1m}$. An example of this can be seen in 错误！未找到引用源。(Event B) around the 15th of November 2009. Another problem is that the zero level is not always located at 0, but varies during this season, which most clearly can be seen in 错误！未找到引用源。. This have been explained as a drift in the zero level that manually has to be adjusted. These are a few examples of why the work of verifying the data is important.

III. MODELING OF ICING

A. *Using Numerical Weather Prediction models for modeling of icing*

The modeling of icing is done with a numerical weather prediction (NWP) model. The potential of using NWPs for making forecasts of icing conditions have been shown [3]. Though, many studies of modeling ice loads with NWPs are carried out assuming that the ice load given by the icing instruments are correct. The results in [3] were that a NWP could be used to predict icing, though there still are problems with predicting the actual load. Another problem with using a NWP would be that the model smoothes out the topography.

For this study COAMPS was used.

B. *Icing model*

The so called Makkonen formula for calculating the ice growth was used [4];

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 W_l v A , \qquad (1)$$

where M is the mass, t is time, α_1 , α_2 and α_3 are the collision, sticking and accretion efficiencies, W_l is the liquid water content, v is the particle velocity and A is the cross sectional area of the object subjected to icing. The collision, sticking and accretion efficiencies are also known as correction factors [4].

Important to note in (1) is that even though it is meant to calculate the icing rate, what the equation really calculates is the accretion rate. The accretion can contain liquid water in the ice and the equation does not distinguish between liquid or solid water [5].

C. *Calculation of the cloud water content*

To be able to model the ice load based on the in situ meteorological measurements the water content must be known. This parameter is not measured at the sites used in this study. As this is a first evaluation of the method of calculating the ice load, a simplified approach will be taken. There are certain assumptions made in this approach, which have been deemed valid for a first test. The first assumption made is that the liquid water content in (1) can be substituted with the cloud water content. The second assumption is that the median total cloud water content could be used to approximate the cloud water content.

The median total cloud water content is calculated in the following way according to [6]:

, (2)

where W_m is the median total cloud water content in and T is the temperature [°C].

IV. RESULTS

The results shows good agreement in the shape of the accretion as can be seen in 错误！未找到引用源。, but of course, not all of the complexity of the icing events can be captured by either model, since the ice load is subjected to falloffs from the IceMonitor. Also the modeled results shows that the models underestimates the icing. The focus of this study will be how well the model captures the icing events. Important to note in the figure is that the y-axis is different in i) and ii) in both Fig. 2 and Fig. 3.

The icing events that have been studied have been chosen for the fact that these periods can be said to represent typical icing event in Sweden and that these periods have few erroneous values in them.

A. Results from the Bliekevare site

At Bliekevare one time period was chosen for this study, containing several icing event that took place in late October/ early November 2009. During the period several icing events took place, which included accretion, melting and ice falloffs. As can be seen in 错误！未找到引用源。 i) (see Event A) there is a first icing event taking place in October where there first is an accretion followed by a period of melting and later a falloff of the ice. The second icing event, Event B in 错误！未找到引用源。 i), is more substantial and during this event the ice load exceeds the maximum measureable level of the instrument. This icing period contains several accretion and melting phases as well as two events where the ice falls off see 错误！未找到引用源。 i).

As can be seen from 错误！未找到引用源。 ii) the data modeled from the in situ measurements can capture the icing events, even though there are some underestimation of the total ice load. But the melting occurrences are captured quite well during the later icing event. Also seen in 错误！未找到引用源。 ii) the COAMPS data set also captures the icing events quite well, though the ice load is somewhat underestimated.

B. Results from the Aapua site

Also for the Aapua site an icing event during late October/ early November was chosen. During this period an icing event took place during which there was a period of accretion and a period where the ice melts/ falls off the IceMonitor, Event A in 错误！未找到引用源。 i). This is followed by smaller icing events, Event B 错误！未找到引用源。i). The measured ice from Aapua shows some signal noises in the data. Seen in 错误！未找到引用源。 Event A there are some spikes in the data. The reason for these are unknown, but one explanation could be freezing of the support for the IceMonitor.

The modeled in situ ice load underestimates the ice load during this period seen in Fig. 3 ii), but the accretion of ice from the in situ meteorological measurements stops about the same time as the measured ice load. The ice load modeled from COAMPS data also underestimates the measured ice load, but seems to capture the dynamics of the event well. The ice load modeled with COAMPS also capture some of the minor icing events after the first one, although not the timing of the events.

V. DISCUSSION

A. Evaluation of the modeled ice load compared to the measurements of ice load

Both methods for calculating the ice loads show promising results, but there are some issues that will need to be addressed to be able to get more than an estimation. Over all the results from both Aapua and Bliekevare show some promise for the modeling of icing from the in situ measurements.

There seems to be an underestimation of the modeled ice load regardless of the method used. And of course not all of

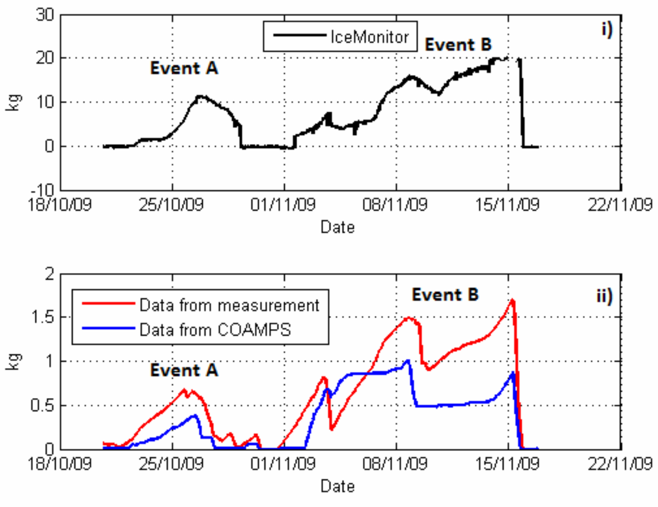

Figure 3: Icing event at Bliekevare, note the scale on the y-axis

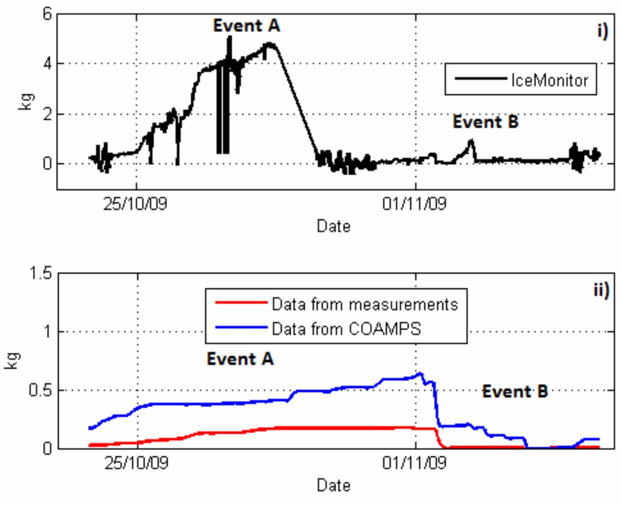

Figure 3: Icing event at Aapua, note the y-axis scale

the dynamics of an icing event can be modeled correctly, such as the falloff of ice. But overall the growth and melting periods are captured well.

B. Evaluation of the calculation of the cloud water for the in situ modeling of ice load

The calculation of cloud water content will have to be further improved. In this study only a simple estimation was used. In using (2) there are some approximations made that are believed not to be correct in these circumstances. For instance (2) gives cloud water content always, regardless if there is an in cloud icing event ongoing or not. To further develop this method one would need to have a greater understanding of when to calculate the cloud water. A first step towards this could be to calculate the cloud base or using the relative humidity as a check for possible clouds. But as a first result this method bodes well as a compliment to icing measurements. But with further refinement the method could very well serve as a useful complement to an icing instrument.

C. Suggestions to improve the calculation of icing

Of course the cloud water content used in this study was very simplified and this method needs further improvements.

Another improvement that can be done would be to look at the icing rate instead of the total ice load. Perhaps icing rate would be estimated more correctly when using (1). It would also be interesting to study the synoptic weather charts for the icing events investigated. This could be done as a compliment to using (1), as the ice accretion in (1) only comes from in cloud icing, not precipitation icing, which would cause an underestimation of the ice load.

Though the need for correct measurements of icing is needed. It would be optimal to increase the number of sites that measure icing and equip these sites with dependable instruments. It would also be beneficial that these sites are often checked manually. Of course this could be a problem, since the sites often are located in areas where it for practical reasons is hard to visit often, but a camera could be a solution for the most inhospitable sites.

In conclusion the result looks promising for calculating the ice load from measured meteorological parameters, but further investigation is needed. But there is a need for further validation of the measured data as well in the modeled ice load.

ACKNOWLEDGEMENTS

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