Modelling Icing on Power Lines at the Ålvikfjellet Test Span (Norway) Using High-Resolution Climate Model Data

Andreas Dobler[1], Julia Lutz[1], Bjørn Egil Nygaard[2], Harold Mc Innes[1], Jan Erik Haugen[1]

[1] *Norwegian Meteorological Institute, Norway*
[2] *Kjeller Vindteknikk AS, Norway*

andreas.dobler@met.no

Abstract— **Icing on a test span located at Ålvikfjellet in the Norwegian mountains has been modelled using data from high-resolution (2.5 km) climate model simulations covering the years 2005-2016. The modelling follows the ISO 12494 standard on atmospheric icing of structures and uses 10-meter wind speed, cloud liquid water content at the lowest model level, surface pressure and 2-meter temperature as input from the climate model. Calculated ice loads show a low sensitivity to variations in wind speed and pressure, a moderate sensitivity for cloud liquid water content and a high sensitivity for temperature.**

The comparison with three winters of observations at the test span shows that the icing model is able to reproduce icing at daily and longer time scales. Inclusion of a melting assumption in the icing model shows good results. Using the climate model data, maps of icing estimates are provided for the whole Norwegian mainland at a resolution of 2.5 km covering the years 2005-2016.

Keywords— ***Icing modelling, Icing on power lines, Norway, High-resolution climate model, Model evaluation***

I. Introduction

In the mountainous regions of Norway, icing on power lines is a severe hazard as power lines are exposed to strong winds and ice from supercooled cloud droplets. In some places the ice load can reach up to hundreds of kg/m and damage the infrastructure [1]. The aim of this work is to provide a reliable tool to model icing on power lines by using output from a high-resolution regional climate model. We are focussing on the development and evaluation of the icing model at a specific location, namely the Ålvikfjellet test site near the Hardangerfjord in the southwest of Norway [2]. Modelling icing at the test site location enables us to compare the results with actual measurements and thus conduct a quality study of the proposed icing model. Thereafter, the icing model can be applied to provide icing maps for the whole of Norway in recent years using the same set-up. Once the icing model has been evaluated, it can also be used to analyse the impact of climate change and provide future projection of ice loads in Norway [3].

II. Study Area, Data and Methodology

A. Study Area

The Ålvikfjellet test site is located north of the Hardangerfjord at 1090 m above sea level (see Figure 1) and was established in November 2014. In addition to measuring wind speed, wind direction and air temperature, it provides the ice load on the actual power line along with the ice load on an 80 m test span making our modelling results comparable to observed ice loads.

Fig. 1 Location of the Ålvikfjellet test site (© OpenStreetMap contributors, see https://www.openstreetmap.org/copyright).

B. Data

The icing model is run using the output from a high-resolution regional climate model. In this case we use simulations from the HCLIM-AROME model, with a spatial resolution of 2.5 km x 2.5 km covering the Norwegian mainland [4]. The data of the nearest grid point to the location of the Ålvikfjellet test site is used as input for the icing model.

The icing model requires the following variables: 10 m wind speed, cloud liquid water content at the lowest model level, surface air pressure and 2 m air temperature. The HCLIM-AROME simulations cover the years 2005-2016 and are forced with ERA-Interim data [5].

To compare the icing model results with observations, we use the ice load measurements from the Ålvikfjellet test site. These measurements are available from November 2014 until the present day. However, we use only the time period 2014-2016 as this is the overlapping period with the climate model data. Thus, we have in total only two and a half winters to analyse.

The observations are available in time steps of ten minutes while the model data is hourly. However, since the HCLIM-AROME simulations have been done without spectral nudging and data assimilation, model results and observations are not completely synchronised, resulting in low temporal correlations on short time scales. To reduce this asynchrony, daily values are used in the presented analysis. As heavy icing is happening on time scales of several days, the effect of reducing the temporal resolution on the maximum icing values is small (not shown).

C. Methodology

The icing model used in this study follows the ISO 12494 standard [6]. It is described in detail in [2]. It is based on the following equation

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 CLW \upsilon A,$$

where the icing rate (*dM/dt*) on a 1-meter cylinder is the product of the efficiency factors α_1, α_2 and α_3 (varying between 0 and 1), the cloud liquid water content *CLW*, the droplet collision speed υ and the cross-sectional area *A* of the power line (relative to the direction of the particle velocity vector υ). For each time step, the modelling starts with the calculation of the median volume diameter as a function of the mass concentration of particles (i.e., the liquid water content) and the droplet concentration (set to 100 droplets per cm^3 in our model). This is followed by the calculation of the collision efficiency (α_1) and droplet collision speed depending on the median volume diameter, wind speed, air density and the cylinder diameter (initialised at 3 cm). Note that in our icing model α_1 is calculated only for small cloud droplets. Larger drops and particles (i.e. drizzle and wet snow) have a collision efficiency equal to one, assuming that the impinging structure is of a "normal" size (e.g., with a diameter below 1 m). In the next step, the accretion efficiency (α_3) is calculated based on air temperature, wind speed, air pressure, air density, mass concentration of particles, the cylinder diameter and the efficiency factors α_1 and α_2, where the sticking efficiency α_2 is set to one. Finally, the resulting icing intensity is added to the current ice load, and the new cylinder diameter is derived from the accumulated ice load, before moving on to the next time step.

During the loop, the modelled ice load is reset to zero after each winter (on 1. April to be exact). This improves the simulation of total ice mass significantly, as otherwise the cylinder diameter is constantly growing throughout the simulation, resulting in a very large collision object and thus immense icing intensities.

Since icing on power lines in reality is usually not accumulated over the whole winter, but ice is melting or falling off during periods with mild weather, we also account for melting in our icing model. Therefore, the accumulated ice load is reset to 0 if

$$\left(\sum_{i=t-2}^{i=t} T_i | T_i > 0°C \right) > 3\ °C,$$

where *t* is the actual time step, i.e., the sum of positive temperatures on three consecutive days is more than 3 °C. This happens for example when T_{t-2}=-5 °C, T_{t-1}=-5 °C and T_t=3.5 °C or when T_{t-2}=1 °C, T_{t-1}=2 °C and T_t=1 °C. To show the impact of this assumption, we present icing simulation results with and without the melting condition.

III. Results and Discussion

A. Ålvikfjellet Test Site

Figure 2 demonstrates the modelled and observed ice load growth at the Ålvikfjellet test site. The winter months for the overlapping period of model data and observations (2014-2016) are shown. The icing model performs very well towards the end of each winter. However, it tends to underestimate the observed ice load growth in the beginning of each winter. The correlation between the model and observations for the whole time period amounts to 0.4. Generally, we conclude that the icing model is able to reproduce the observed ice load growth on daily or longer scale.

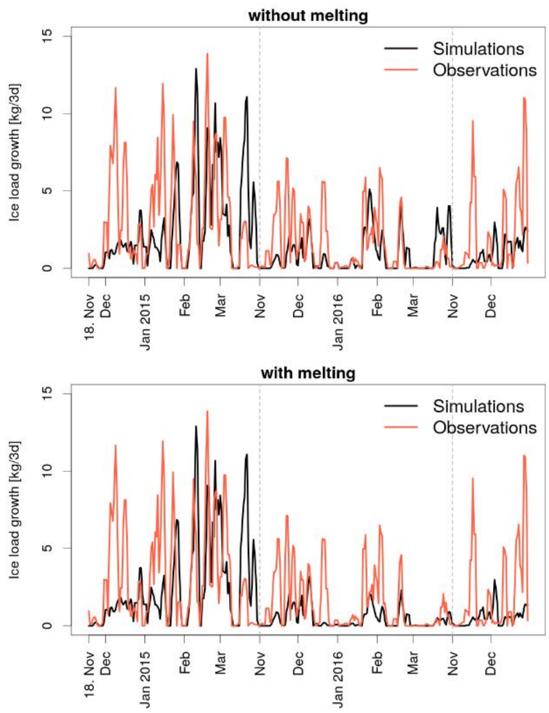

Fig. 2 Modelled (black) and observed (red) ice load growth at the Ålvikfjellet test site for the winter months 2014-2016. The running sums over 72 hours are shown for simulations without (top) and with (bottom) assumption of ice melting.

To analyse the sensitivity of the icing model on the different input variables, we have used several combinations of different data sets. This revealed that the calculated icing shows a low sensitivity to variations in wind speed and pressure and a moderate sensitivity for cloud liquid water content. The highest sensitivity was found for air temperature.

Figure 2 also shows that including melting in the model has only a small effect on the ice load growth at this specific location. For the accumulated ice loads, the impact of melting is more pronounced (Figure 3). In the second and third winter, melting provides a clear improvement in the simulations. However, the first winter is not affected at all, as there is no case when the melting criteria is fulfilled. Thus, ice loads are accumulating throughout the whole winter period reaching values of almost 120 kg. This highlights that, while the simulation of icing may yield accurate results, especially on shorter terms, continuous simulations of accumulated ice loads covering several months should always be considered as an indication of the maximum possibly accumulated ice loads. While some improvements can already be made by including a melting criteria, adding further processes could be beneficial, like for instance the probability of ice falling off depending on the accumulated weight or prevailing wind speed.

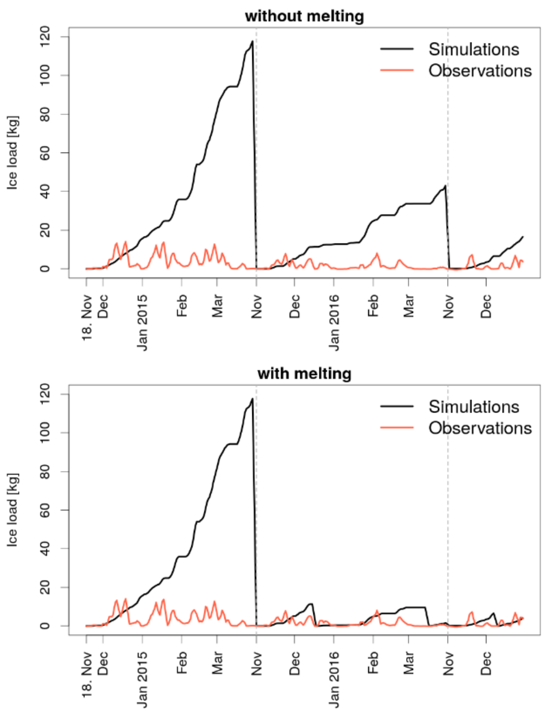

Fig. 3 Modelled (black) and observed (red) ice load at the Ålvikfjellet test site for the winter months 2014-2016. The running means over 72 hours are shown for simulations without (top) and with (bottom) assumption of ice melting.

B. Modelling Ice Loads for Norway

Our results above show that the icing model, at least to a certain degree, is able to reproduce the observed icing at the test site. Thus, ice loads for the complete regional climate model domain and available time period (2005-2016) have been calculated. The area includes the whole Norwegian mainland and large parts of Sweden (see Figure 4). The land area covers about 350’000 km² at a resolution of 2.5 km.

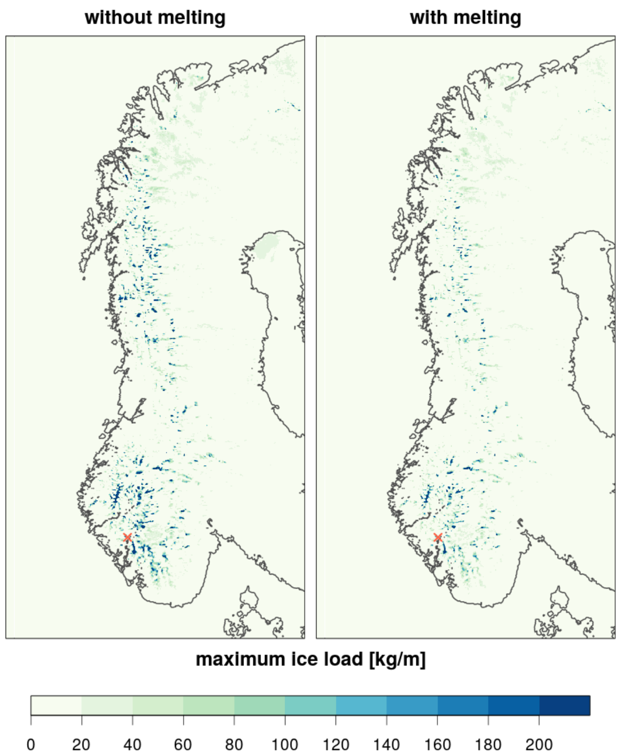

Fig. 4 Simulated absolute maximum ice load [kg/m] for the years 2005-2016 without (left) and with (right) assumption of ice melting. All values above 200 kg/m are shown with the same colour. The location of Ålvikfjellet is marked with a red cross.

Figure 4 shows the absolute maximum of the simulated ice load. The fine scale resolution illustrates that the icing is limited to single points, especially in mountainous regions in the southwestern and central parts of Norway. Both, the simulation with melting during mild weather periods and the simulation without melting are shown. As can be seen, in the simulation without melting, maximum ice loads of more than 200 kg/m are more common. However, one should keep in mind that also the simulations with melting do not include any other process for ice to be removed, and ice loads may still sum up to very high amounts during one winter.

Figure 5 shows the same as Fig. 4 zooming in on the area around Ålvikfjellet. The 1000 m above sea level contour line illustrates how icing is correlated with altitude. Note that the elevation is taken from the regional climate model and the height of the grid box including Ålvikfjellet is 929 m.a.s.l., while the actual height of the test span is 1090 m.a.s.l. The figure also shows that, as expected, the simulation with melting shows lower maximum values than the simulation without melting in most of the areas.

The simulations with melting compare well with results for maximum ice load simulations around Ålvikfjellet given in [7] showing similar amounts and spatial variability, including the pronounced maximum at Folgefonna (located southeast of Ålvikfjellet).

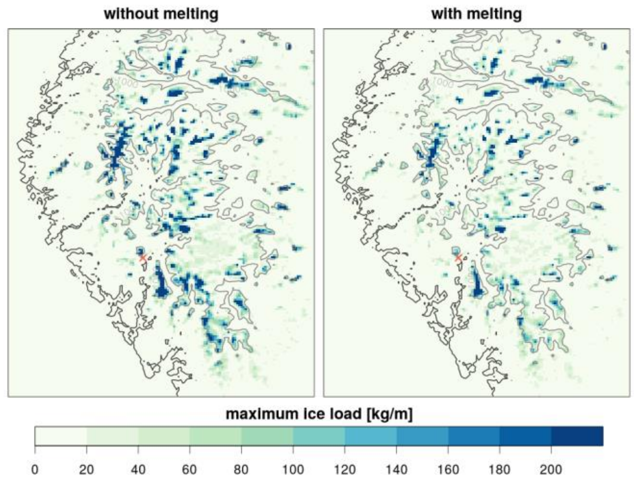

Fig. 5 Simulated absolute maximum ice load [kg/m] for southwestern Norway for the years 2005-2016 without (left) and with (right) assumption of ice melting. All values above 200 kg/m are shown with the same colour. The location of Ålvikfjellet is marked with a red cross and the grey line shows 1000 m.a.s.l.

IV. Summary and Conclusions

In this study we have used an icing model to simulate the ice loads at the Ålvikfjellet test site in southwestern Norway. To evaluate the icing model, we have compared the simulated ice loads to observed ice loads available from the test site. We conclude that the icing model works well and is able to reproduce the observed icing on daily and longer time scales.

Thus, the icing model has been applied to data from the regional climate model HCLIM-AROME for the period 2005-2016. The resulting ice load data set covers the Norwegian mainland and also a large part of Sweden with a resolution of 2.5 km. In general, the icing simulations look physically reasonable and correlate well with the altitude. To improve the icing simulations covering several years, we have included melting of ice during mild weather periods in the icing model. A comparison between icing simulations with and without melting shows that, as expected, the simulations with melting provide lower ice loads. Although the inclusion of melting shows only a slight improvement at the Ålvikfjellet test site, agreement with other ice load simulations for western Norway, and generally more realistic ice load values, indicate an added value. The inclusion of further processes to remove ice could further improve the long term simulations, for instance ice falling off due to heavy weights or strong winds.

We expect the data to be of use for further impact studies and that it can also be used as a reference data set for future icing studies. The simulated daily ice loads (with and without melting) are available as NetCDF files at

http://thredds.met.no/thredds/catalog/metusers/andreasd/WISLINE-Collection/ERAInterim_HCLIM_NORWAY-2.5km/icing/catalog.html.

Acknowledgments

This work has been carried out within the WISLINE project funded by the Research Council of Norway. Computational and storage resources for the HCLIM-AROME simulations have been provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) and UNINETT Sigma2 – the National Infrastructure for High Performance Computing and Data Storage in Norway. Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org. The complete HCLIM-AROME model data set is freely available at http://thredds.met.no/thredds/catalog/metusers/andreasd/WISLINE-Collection/ERAInterim_HCLIM_NORWAY-2.5km/catalog.html.

References

[1] B. E. Nygaard, Ø. Byrkjedal, E. Iversen, M. Fredbo and H. Ágústsson, "Development of a reliable modelling system for the calculation of rime ice loads on overhead transmission lines," Proceedings – Int. Workshop on Atmospheric Icing of Structures IWAIS 2017.

[2] L. Makkonen, "Models for the growth of rime, glaze, icicles and wet snow on structures," *Philos. T. Roy. Soc. A*, vol. 358(1776), pp. 2913-2939, 2000, doi: 10.1098/rsta.2000.0690.

[3] J. Lutz, A. Dobler, B. E. Nygaard, H. McInnes, and J. E. Haugen, "Future Projections of Icing on Power Lines over Norway," *Proceedings – Int. Workshop on Atmospheric Icing of Structures IWAIS 2019*, submitted.

[4] A. Crespi, C. Lussana, M. Brunetti, A. Dobler, M. Maugeri, and O.E. Tveito, "High-resolution monthly precipitation climatologies over Norway (1981-2010): Joining numerical model data sets and in situ observations," *Int. J. Climatol*., vol. 39(4), pp. 2057-2070, 2018, doi: 10.1002/joc.5933.

[5] D. P. Dee, S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae et al., "The ERA-Interim reanalysis: Configuration and performance of the data assimilation system," *Q. J. Roy. Meteor. Soc.*, vol. 137(656), pp. 553-597, 2011, doi: 10.1002/qj.828.

[6] ISO, "Atmospheric icing of structures," ISO 12494, Geneva, Switzerland, 2001.

[7] K. Ingvaldsen, "Atmospheric icing in a changing climate – Impact of higher boundary temperatures on simulations of atmospheric ice accretion on structures during the 2015-2016 icing winter in West-Norway," M. Geo. Sci. thesis, University of Oslo, Norway, 2017.