Future Projections of Icing on Power Lines over Norway

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Abstract— **Icing on power lines can be a huge problem in some parts of Norway. There are several studies that deal with present icing conditions. However, future projections of icing on power lines, especially for large areas, are lacking. The aim of this work is to fill this knowledge gap and to estimate future icing trends for Norway, but the analysis covers also a large part of the Scandinavian Peninsula.**

We have used the EURO-CORDEX simulations to run an icing model following the ISO 12494 standard on atmospheric icing of structures. As the EURO-CORDEX simulations do not provide cloud liquid water (CLW) content, which is crucial for modelling atmospheric icing, we have developed a model to estimate CLW with the available variables from the EURO-CORDEX simulations. A comparison with model data including CLW provides good results. To consider realistic conditions, the icing model has been extended by melting of ice after several days with temperatures above or around 0°C.

The final results show that the ice amounts depend on the chosen regional model, rather than on the driving general circulation model. Further, the results indicate a significant decrease of maximum ice loads on power lines in the southwestern parts of Norway that are nowadays prone to atmospheric icing. Northern parts of Norway however, seem to undergo a significant increase in ice loads: Being too cold for icing in the present climate, they are getting warmer in the future and will therefore favour icing conditions.

Keywords— ***Icing on power lines, Icing modelling, Climate change, Future projections, Norway***

I. Introduction

Forming from supercooled cloud droplets, icing can occasionally cause severe damage to infrastructure. Especially power lines in mountainous areas of Norway are affected, where ice loads on conductors may reach several tens or even hundreds of kg/m (e.g., [1]). Simultaneous occurrence of strong winds and heavy ice loads increases the risk of failure even more. There are several studies that deal with present icing conditions and events (e.g., [2] – [4]). However, future projections of icing on power lines, especially for large areas, are lacking. This study aims to fill this knowledge gap and to estimate future icing trends for Norway and a large part of the Scandinavian Peninsula.

The icing model we use has already been tested for Norway (see [5]) and proves to reproduce observed ice loads on power lines satisfactorily. In this work, regional climate model (RCM) simulations from the EURO-CORDEX initiative (see [6]) serve as input for the icing model. As the EURO-CORDEX simulations do not provide cloud liquid water (CLW) content, which is needed for modelling atmospheric icing, we have developed a model to estimate CLW with the variables available from the EURO-CORDEX simulations.

II. Data and Methodology

A. Data

To estimate past and future icing conditions, we have used the output from eleven EURO-CORDEX simulations (see Table I) covering a historical period (1971-2000) and a future period (2071-2100) following the RCP8.5 greenhouse gas scenario. The ensemble consists of four regional climate models (RCMs) and six driving global climate models (GCMs). We have used daily data for near surface temperature, relative and specific humidity, surface pressure and 10-meter wind speed on the original 0.11° grid (approx. 12 km). For this study, the domain was restricted to Norway and further parts of the Scandinavian Peninsula. As shown in [6], the simulations generally overestimate precipitation sums in northern and northeastern Europe, but are able to reproduce seasonal mean values and variabilities.

TABLE I. Model Names, Associated Institutes and Driving GCMs (for Details, see [7])

RCM	Institute	Driving GCMs
RCA4	SMHI	CNRM-CM5, EC-EARTH_r12, IPSL-CM5A-MR, HadGEM-2ES, MPI-ESM-LR
HIRHAM5	DMI	EC-EARTH_r3, HadGEM2-ES, NorESM1-M
RACMO22E	KNMI	EC-EARTH_r1, EC-EARTH_r12, HadGEM2-ES

B. Methodology

The icing model used in this study follows the ISO 12494 standard (see [8]) and is described in detail in [1]. Basically, it follows the equation

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

where icing (dM/dt) on a 1-meter vertical cylinder is the product of the efficiency factors α_1, α_2 and α_3, the cloud liquid water content CLW, the droplet collision speed υ and the cross-sectional area A of the cylinder. The efficiency factors vary between 0 and 1. α_1 denotes the collision efficiency of the particles, α_2 represents the sticking efficiency and α_3 the efficiency of accretion.

Since in reality, icing on power lines is normally not accumulated over the whole winter without 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 the positive temperatures of three consecutive days is greater than 3 °C. This applies for example to the values T_{t-2}=-5 °C, T_{t-1}=-5 °C and T_t=3.5 °C or to the values T_{t-2}=1 °C, T_{t-1}=2 °C and T_t=1 °C.

As the cloud liquid water content is not directly available from the EURO-CORDEX simulations, we have developed a model to estimate CLW using the variables available from the EURO-CORDEX simulations. Following [9] and [10], we are basically mimicking a very simple cloud microphysics scheme, where *CLW* is a function of relative humidity *(RH*), air temperature (T) and specific humidity (q):

$$CLW_{sim} = f_{RH}\, f_T\, q\, f_{spec}$$

The variables f_{RH}, f_T and f_{spec} denote three factors that are dependent on temperature and relative humidity. f_{RH} estimates the cloudiness in the model based on the relative humidity. It is 0 below the critical relative humidity of 90 % and increases linearly to 1 at a relative humidity of 100 %. f_T also varies between 0 and 1 and estimates the liquid water fraction based on the temperature. It is 0 below a temperature of -15 °C and increases linearly to 1 until a temperature of 0 °C and above. Finally, $q * f_{spec}$ is an estimation of the water content, where f_{spec} is set constant to the difference between 1 and the critical relative humidity (i.e., 0.1).

To test this model, we have compared CLW estimated from model output from a regional climate model simulation over Norway (see [5]) with CLW that is directly available from the model. The correlation between the two is 0.8, indicating that our model is able to estimate realistic CLW values.

III. Results and Discussion

To illustrate how the computed ice load depends on the different climate model combinations, Fig. 1 shows the time series of the simulated ice load from the individual EURO-CORDEX model combination and the ensemble mean for a grid point in southwestern Norway (Ålvikfjellet test site). It is obvious that the icing model is not sensitive to the large scale processes of the GCMs: the same GCM provides very different ice loads (compare for example all the plots with a light blue background), while the same RCM yields similar results for the different GCMs.

Figure 1 shows that the model HIRHAM5 results in the highest ice loads, while RCA4 provides the lowest ice loads. The reason for this are generally higher CLW estimates in the HIRHAM5 model (on average around 0.15 g/kg) compared to RCA4 (0.08 g/kg), combined with slightly lower temperatures (approx. -2.5 °C in HIRHAM5 compared to 0.5 °C in RCA4). The high CLW estimates in HIRHAM5 are due to a large fraction of days (more than 50 %) with relative humidity above 90 %, resulting in high f_{RH} estimates. For RCA4, the fraction of days with relative humidity above 90 % is about 40 %. RACMO22E lies in between the two other models, but generally closer to HIRHAM5.

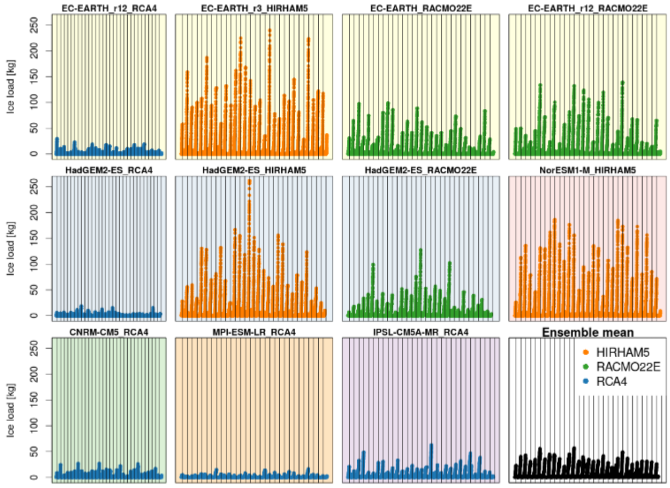

Fig. 1 Time series of the simulated ice load for the EURO-CORDEX simulations and the ensemble mean for a grid point in southwestern Norway for the years 1971-2000. Coloured points indicate the different regional climate model, while background colours show the forcing GCM.

Figure 2 shows the EURO-CORDEX ensemble mean of the absolute maximum ice load as well as the mean of the annual maximum ice loads for the years 1971-2000. Note that the actual maximum values are notedly higher than 200 kg/m, but the values are limited to 220 kg/m to point out the distribution for the lower values. As can be seen, the highest ice load values are located in the mountainous areas in southern and northern parts of Norway and northwestern parts of Sweden.

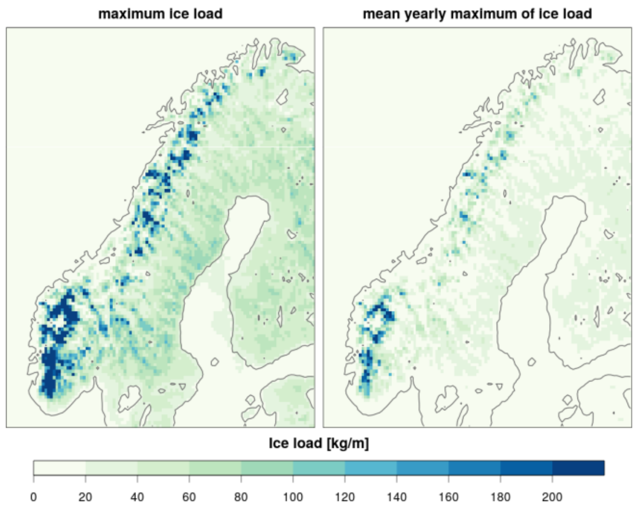

Fig. 2 Ensemble mean over all 11 EURO-CORDEX simulations for the maximum ice load (left) and the mean annual maximum ice load (right), both in kg/m. All values above 200 kg/m are shown with the same colour.

The differences of the absolute maximum ice load and the mean annual maximum ice load between the future (2071-2100) and the past (1971-2000) simulations are shown in Figure 3 and 4. There is an obvious pattern for both factors: a decrease of icing in southwestern parts of Norway and an increase of icing in the northern parts of Norway, Sweden and Finland in the future.

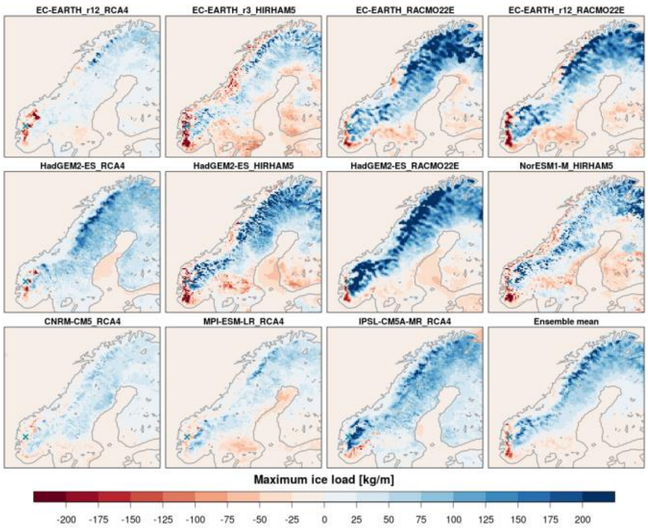

Fig. 3 Difference between future (2071-2100) and past (1971-2000) absolute maximum ice load in kg/m. All values below -200 kg/m and above 200 kg/m are shown with the same colour. The location of the grid point from Fig. 1 is marked with a blue cross.

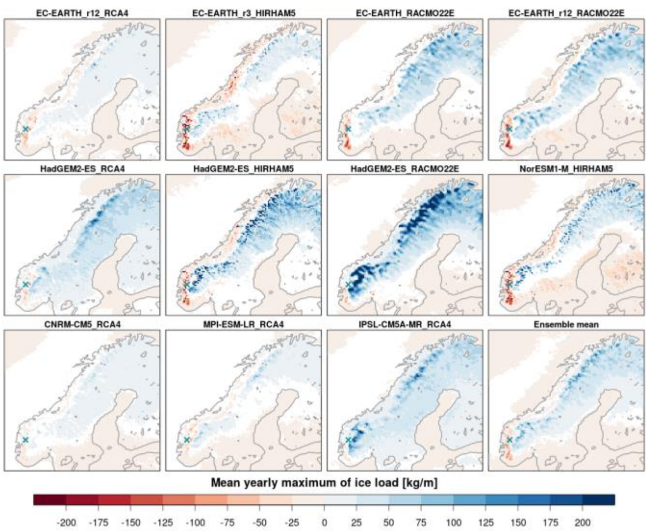

Fig. 4 As Fig. 3 but for the mean annual maximum ice load. White coloured areas indicate areas with a non-significant difference (α=0.05).

Interestingly, the decrease of icing is located in the area where the icing is strongest for the years 1971-2000 (see Fig. 2). A possible reason are less favourable conditions for icing due to a warmer climate in this area. Whereas, areas in the north that are now often too cold for significant icing are getting warmer and will favour icing conditions in the future with a general increase in specific humidity in winter time.

IV. Summary and Conclusions

In this work we have used an icing model to simulate the ice loads over Norway and large parts of the Scandinavian Peninsula. The ice loads were computed for the past (1971-2000) and the future (2071-2100) using data from 11 EURO-CORDEX model runs. Since the EURO-CORDEX simulations do not provide cloud liquid water content necessary to model icing, we have estimated cloud liquid water based on relative and specific humidity and temperature.

The final results show that the ice amounts depend on the chosen regional model, rather than on the driving general circulation model, highlighting the importance of the microphysics scheme in the regional model. We found that icing is mostly influenced by the estimated cloud liquid water contents due to the fraction of days with relative humidity above 90 %.

Further, the results indicate a significant increase of maximum ice loads on power lines in the northern parts of Norway. Southwestern parts of Norway, that are nowadays prone to atmospheric icing, seem to undergo a significant decrease in ice loads in the future. We suppose this is due to the fact that there will be fewer winter seasons with prolonged icing events at temperatures remaining below freezing in a warmer climate. On the other hand, areas that are now mainly too cold for icing during the winter months will favour icing conditions in the future climate, due to increased temperature, and consequently increased specific humidity.

Daily ice load data calculated from the EURO-CORDEX simulations has been converted to NetCDF files and is freely available at

http://thredds.met.no/thredds/catalog/metusers/andreasd/WISLINE-Collection/CORDEX-EUR11_Icing_NORWAY-12km/catalog.html.

Acknowledgments

This work has been carried out within the WISLINE project funded by the Research Council of Norway. We acknowledge the World Climate Research Programme's Working Group on Regional Climate, and the Working Group on Coupled Modelling, former coordinating body of CORDEX and responsible panel for CMIP5. We also want to thank the climate modelling groups (listed in Table 1) for producing and making available their model output and the Earth System Grid Federation infrastructure – an international effort led by the US Department of Energy's Program for Climate Model Diagnosis and Inter comparison, the European Network for Earth System Modelling, and other partners in the Global Organization for Earth System Science Portals (GO-ESSP).

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