Modeling Icing in Exposed Mountain Terrain

Bjørn Egil K. Nygaard[1], Svein M. Fikke[2], Lennart Elvertrø[3], Knut Harstveit[1]
[1]The Norwegian Meteorological Institute, Box 43 Blindern, N-0313 Oslo, bjornen@met.no, k.harstveit@met.no
[2] Meteorological consultant, Lindeveien 1, NO-1470 Lørenskog, fikke@metconsult.no
[3] Statnett SF, NO-7493 Trondheim, lennart.elvertro@statnett.no

***Abstract*—One alternative for a new 420 kV line in Western Norway passes through a severe icing area at 1 100 m altitude. This paper describes the approach to quantify icing severities by using a local scale numerical weather prediction (NWP) model. A similar NWP model was also applied on a high altitude alpine site (Gütsch, Switzerland), a maritime site exposed to moist Atlantic winds (Deadwater Fell, UK) and a Norwegian ice measuring rack. The study shows coherent results for different cases, and good agreement is found compared to existing ice load measurements. Furthermore, the simulated ice loads are sensitive to the horizontal model resolution, indicating that a grid spacing less than 1 km is needed to produce realistic amounts of accumulated ice. Future improvements depend on available field data and more model verification studies.**

I. INTRODUCTION

Power production in Norway is practically 100 % from hydro. Norway is a coastal country that reaches from 58 °N to 71 °N, with the North Sea, Norwegian Sea and Atlantic Ocean to the west. The prevailing winds are from the sea (SW) and the average precipitation may reach up to 3 000 mm/year (with a high standard deviation) within the coastal side of the mountains. The electric power is transported through a complex grid of overhead transmission lines (mainly of 300 and 420 kV) to consumption areas elsewhere in the country.

Due to the industrial expansions in the middle part of Norway there is an increasing need to import electric power where local production is insufficient. Therefore the transport capacity has to be strengthened from the major hydro power production areas around the Sognefjord further south.

The western part of Norway is characterized by mountains, including glaciers up to more than 2 000 m asl, separated by fjords and deep valleys. Numerous towns, villages and recreation areas with cabins and cottages, skiing resorts, tourist hotels, pensions, popular tourist routes, etc. exist throughout this part of the country Due to the general beauty of these areas they are therefore also very important for the national and international tourist industry with numerous cruise ships, bus groups and individuals that come here both summer and winter for sightseeing, mountain hiking, skiing and recreation every year. For these reasons it is very difficult to find new routes for new overhead lines that can be accepted technically, economically as well as by the many public interests and legal restrictions connected to the area.

Most of the proposed alternatives therefore follow existing infrastructure and developed areas, although such solutions necessarily will deviate very much from straight lines and therefore result in both longer and more expensive lines.

One alternative route is to make a short-cut over an area in the county of “Sogn og Fjordane”. This alternative is the shortest and apparently less sensitive to the public. The differences in costs (according to general estimates) would be roughly 100 million Norwegian kroner (NOK), or more (15-20 million USD). This route passes however close by the glacier “Ålfotbreen” about 50 km inside of the coastline, where the annual snow deposit can be 10 m or more. And also this area is exposed to severe icing, from both in-cloud icing (rime icing) and wet snow. See picture and location in Fig. 1 and Fig. 2.

Statnett nevertheless decided in spring 2006 to study this alternative in more details to see whether it may be feasible to build and operate a 420 kV line in this environment. The study should involve both field measurements and model studies by advanced local scale meteorological models as outlined in [1]. However, the data acquisition campaign had to be cancelled since unusual persistent adverse weather made it impossible to install the instruments during autumn and early winter 2006/2007. As the final decision on the feasibility of this line route had to be taken by early autumn 2007 Statnett decided to continue with the modeling approach alone. The main purposes of this study were to get the best possible background for 1) assessing the construction feasibility, including estimates of adequate design loads of this line and 2) clarify the accessibility for line maintenance during winter seasons.

II. MODELING OF IN-CLOUD ICING

The use of numerical weather prediction models to estimate design loads for overhead transmission lines is not a widely used technique so far. On the other hand, the increase in available computing power have made it possible to apply much more sophisticated treatment of cloud physical processes, and simulations can be run with much higher resolution in time and space, which have generated a lot of new applications for such models.

In this study we have used the Weather Research and Forecasting (WRF) model [2] for simulations of in-cloud atmospheric icing. During the last two years, icing simulations with the WRF model has already been carried out and verified against icing measurements for several different sites in Europe.

In [3] simulated amount of supercooled cloud liquid water in stratiform continental air masses are compared to measured values, showing very good agreement in all the three cases considered. Also for a costal site in Norway, relatively good results are obtained when comparing modeled amounts of accreted ice to observations from a web camera. However, an underestimation was indicated in a situation with deep convection and intense snow showers.

In a second study, measurements of conductor tension from a test span on the hill Deadwater Fell (UK) [4] were used to verify the icing model. Deadwater Fell is exposed to maritime air both from the western direction (Atlantic Sea) and from the east (Northern Sea), causing both in-cloud and wet snow icing in winter time. One case with a well defined in-cloud icing episode was selected, and the results from the study showed a surprisingly good coherence between the time series of modeled accreted ice load and the measured conductor tension.

The model has also been tested for a high altitude Alpine site (Gütsch, Switzerland, [5]). The test site is characterized by extremely steep terrain, typical continental air masses and much lighter icing episodes than the sites in the northern Europe (maritime Atlantic air). Two cases were studied, where in-cloud icing was detected by a web camera. Also in this study the results were promising. The model was able to detect the icing episodes (starting time and duration), but the ice loads seemed to be underestimated compared to what the pictures indicated. However, in this study the simulations were carried out with a lower horizontal resolution, compared to the other studies mentioned, in order to keep the model stable in this extremely complex terrain. In future studies, the model will be initiated by the Swiss local scale weather prediction model, in order to be able to run icing simulations with a higher horizontal resolution.

III. SITE DESCRIPTION

A. Local terrain

The terrain around this line route is very rough and steep and therefore exposed for falling rocks, deep snow, avalanches snow drift and snow creep. Hence the line route has to be selected very carefully to avoid devastating damage already the first winter season.

Fig. 1. View towards SW-W from the proposed right-of-way of the new 420 kV line. The Norwegian Sea can be seen towards WSW.

The picture in Figure 1 shows the view towards southwest – west from the only possible route to minimize those effects. It can easily be seen that here, at the elevation of 1 100 m asl, the line will be heavily exposed to rime icing as well as wet snow accretions on the conductors.

B. Climate

The Ålfoten glacier belongs to the coastal mountains in western Norway. Due to the prevailing westerly winds the precipitation rate is high, a nearby observation station has an annual rainfall of 3 520 mm and the average snow depth on the top of the glacier is about 8 – 10 m, measured in the spring. Due to drifting snow the snow depth near the line can therefore easily become 20 m or more.

The Norwegian coast is also frequently exposed to strong winds and wind gusts in the range of 60 – 70 m/s may well occur here.

C. Model setup

The studies mentioned above showed that high horizontal resolution is important when icing simulations are carried out in a complex terrain. In order to obtain such high resolution, the nesting (telescoping) technique is used, by stepwise increasing the grid spacing (resolution) from the outermost to the innermost domain. In this study we decided to run simulations with three different domain configurations:

- A double nested domain with 10 and 2 km grid spacing respectively. The 2 km domain covers most of the western part of Norway.
- A triple nested domain with 12.8, 3.2 and 0.8 km grid spacing respectively, where the 0.8 km grid is limited to an 80.8 km by 96.8 km area around the Ålfoten glacier.
- A triple nested domain similar to the previous one, but the 0.8 km grid is covering an area around an ice-measuring rack "Bjølsegrøv" north of the Hardanger fjord.

The 2 km domain is intended to give a larger overview over the severity of the in-cloud icing, and ice loads along the planned route can be compared to other exposed areas where experiences with in-cloud icing already exist from measurements or existing electrical overhead lines.

In the 0.8 km grid, the topography is much better represented in the numerical model, so small scale variations of the icing intensity will be apparent, and the magnitude of the ice loads is expected to be more realistic than in the 2 km grid.

All simulations are carried out using the Thompson scheme for parameterization of micro physics [6], and the model is configured with 35 vertical levels below 100 hPa. Time series of wind speed, temperature and supercooled cloud liquid water content (SLW) from each grid point produced by the WRF model are used as input to an ice accretion model described in [7], [8] producing estimates of accumulated ice loads (kg/m).

D. Cases

Three different time periods have been selected for the icing evaluation. All three cases are dominated by advection of air from the Atlantic Sea, with a low cloud base, and typical conditions for in-cloud icing in the western part of the Norwegian mountains. The two first time periods considered are selected based on the highest icing intensity ever recorded on the ice rack "Bjølsegrøv" since it was installed in 1995. They are both characterized by strong, relatively mild winds from S and SW.

The third case is dominated by much colder winds from N and NW, and icing is expected to occur in the area around the Ålfoten glacier, however the ice rack is not exposed to this wind direction and maintained ice free in this case.

E. Ice load estimates from cloud observations

In addition to the mentioned model studies, a parallel study is performed based on hourly cloud, wind and temperature observations from the airport Førde, about 40 km to the south. This model is described in [9].

IV. RESULTS AND DISCUSSION

Fig. 2 and Fig. 3. show the estimated ice load after a six day long simulation in the 2 km and the 0.8 km grids respectively. Note that local amplifications and maxima are much better described in the 0.8 km grid, showing that the planned line is very exposed to in-cloud icing in this case. The outcome of the first simulation (Fig. 2) shows that the Ålfoten glacier in fact is the most exposed area in the whole western part of Norway in this situation. Increasing the resolution from a 2 km grid to a 0.8 km grid, results in almost a doubling of the ice loads for some of the most exposed areas in this case. This can be explained by the fact that orographic production of cloud water is stronger and more realistically simulated in the 0.8 km terrain.

A summary of the results from the simulations is displayed in table 1. Compared to the ice rack measurements at Bjølsegrøv, we find a very good agreement when the highest resolution is applied, while loads are slightly underestimated in the 2 km grid. The ice rack Bjølsegrøv is of the same type as previously used by Statnett SF [10].

Compared with the simpler model using only hourly meteorological observations from Førde airport, it can be seen that the results are in good agreement for southwesterly winds (January 1999) considering that there may be further orographic lifting of the air mass towards the Ålfoten area. In the case with westerly winds (February 2000) the Ålfoten site is somewhat sheltered by the glacier. In the last case with northwesterly wind (February 2004) both Ålfoten and Bjølsegrøv are sheltered behind higher mountains than what is the case for Førde.

Statnett is currently discussing to install available sets of instruments both at Ålfoten and Bjølsegrøv in order to validate the model results during the next winter.

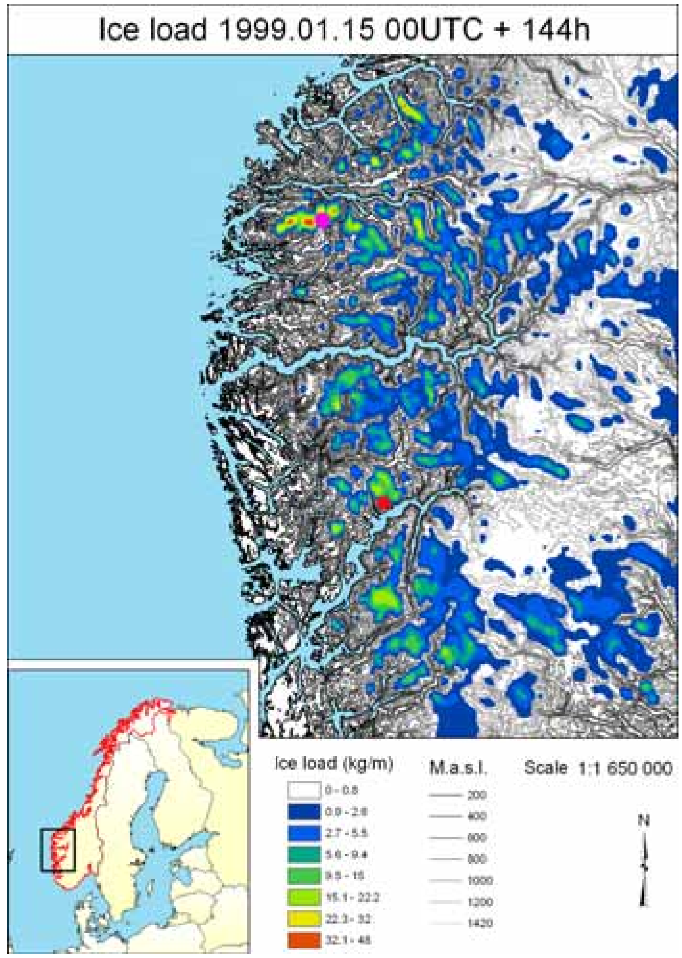

Fig. 2. Accumulated ice (color shadings). The red circle indicates the location of the ice rack, while the pink circle indicates the exposed part of the planned line.

	Ice rack	Simulation Bjølsegrøv		Simulation Ålfoten		Modeled from Førde airport
Grid spacing		2 km	800m	2 km	800m	
15. – 21. January 1999	9 kg/m	7 (5) kg/m	14 (11.5) kg/m	25 kg/m	50 kg/m	30 kg/m
10. – 13. February 2000	8 kg/m	5.5 (4) kg/m	8,5 (7) kg/m	7 kg/m	11 kg/m	32 kg/m
8. – 10. February 2004	0 kg/m	0 (0) kg/m	0 (0) kg/m	0,5 kg/m	1 kg/m	5.4 kg/m

TABLE 1
MEASURED AND SIMULATED VALUES FOR THE THREE CASES CONSIDERED.

Measured and simulated ice loads. Values in parentheses are simulated ice loads based on the wind component normal to the ice rack.

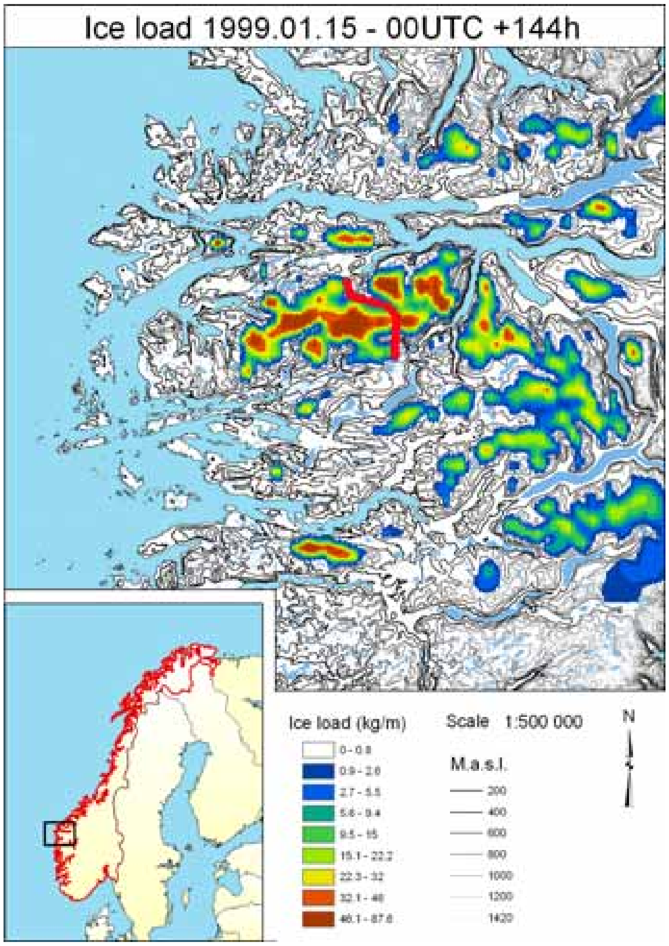

Fig. 3. Accumulated ice (color shadings). The red line indicates the location of the most exposed part of the planned line.

V. CONCLUSION

This study demonstrates that numerical weather prediction models are useful tools for assessing ice loads on structures. Simulations of three cases with the WRF model show very good consistence when comparing to measured ice loads as long as the highest horizontal resolution (grid spacing of 0.8 km) is applied.

There are reasons to believe that the ISO defined ice collector is an adequate instrument for collecting ice loads to be compared with this model.

This model tool will be further validated and developed along with the access to measured icing data from the field.

So far the model is not applied to wet snow or freezing rain. It will be of great interest to apply the same type of numerical weather prediction model also on such events.

VI. ACKNOWLEDGEMENT

The authors are indebted to Bergenhalvøens Kommunale Kraftselskap (BKK) for the establishment and operation of the ice measuring rack Bjølsegrøv through many years.

VII. REFERENCES

[1] S. M. Fikke, “Modern meteorology and atmospheric icing”, In Proc. IWAIS 2005, Montreal Canada, 2005.
[2] Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Power, 2005, “A description of the Advanced Research WRF Version 2,” NCAR Technical Note, NCAR/TN-468+STR.
[3] B. E. Nygaard, J. E. Kristjánsson, E. Berge and L. Makkonen, “Using NWP models to simulate in-cloud atmospheric icing episodes,” In: Proc. IWAIS 2007, Tokyo, Japan, 2007.
[4] A. Veal. A. Skea and B. Wareing, “Validation of ice loads predicted from meteorological models”, In: Proc. IWAIS 2005, Montreal Canada, 2005.
[5] R. Cattin, A. Heimo, S. Kunz, G. Russi, M. Russi, M. Tiefgraber, S. Schaffner, B. E. Nygaard, “Alpine Test Site Guetsch, Meteorological measurements and wind turbine performance analysis,” In: Proc. IWAIS 2007, Tokyo, Japan, 2007.
[6] Thompson, G., R. M. Rasmussen, and K. Manning, “Explicit forecasting of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis.” Mon. Wea. Rev., 132, 519-542, 2004
[7] L. Makkonen, "Models for the growth of rime, glaze icicles and wet snow on structures", Phil. Trans. R. Soc. Lond. A 358, 2913–2939, 2000
[8] International Standardization Organization, 2000: Atmospheric icing of structures. ISO 12494, 2000.
[9] K. Harstveit, L. Tallhaug, A. Fidje, “Ice accumulation observed by use of web camera and modeled from meteorological parameters.” In: Proc. Boreas VII, Wind energy production in cold climates, Saariselkä, Finland, 2005.
[10] K. Savadjiev, M. Farzaneh, S. M. Fikke, “Extreme value analysis of ice accretion data from Norwegian measurement rack network”, In: Proc. 11th Int. Offshore and Polar Engineering Conference, Stavanger Norway, 2001.