Using NWP models to simulate in-cloud atmospheric icing episodes

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Abstract— **We investigate the potential for predicting episodes of in-cloud icing, by using a state-of-the-art numerical weather prediction (NWP) model. For this purpose, we run the Weather Research and Forecasting model (WRF) with high spatial resolution, focusing on the amount of supercooled cloud water, as well as wind speed and temperature in the lowest levels of the atmosphere.**

In the first part of the study, simulated supercooled water content is compared to precise measurements on a hill in northern Finland. For the three cases considered, good agreement is found between the simulated and observed supercooled water content when a high spatial resolution and the most sophisticated condensation scheme are used. The results show a dramatic improvement compared to a similar study carried out 10 years ago.

In the second part of the study, the amount of accreted ice simulated by WRF at a coastal site in Norway is validated against observational estimates based on pictures from a web camera. Also for this site promising results are obtained, with relatively good agreement between simulated and observed ice loads. However, for convective weather situations (snow showers), the model tends to underestimate the icing amounts. For isolated hill tops and narrow ridges, the icing simulations are very sensitive to the horizontal resolution.

I. Introduction

THE parameterization of the sub-grid scale microphysical processes in NWP models has improved significantly over the last decades. The increase of computing power has made it possible to incorporate several microphysical processes in NWP models including explicit calculation of both mixing ratio, and for some moisture variables also number concentration, such that more accurate predictions of the development of precipitation and clouds can be made. One should expect that there is a potential to use NWP models with such detailed cloud microphysics to predict episodes with atmospheric icing.

This paper presents results from two different experiments where simulations are compared to measurements or observations of in-cloud icing.

II. Measurements and Data

A. Ylläs, Finland

Measurements have been carried out at the top of Mt. Ylläs (67.6°N, 24.3°E) in northern Finland, having an elevation of 706 m. It is a rounded peak, and is the highest mountain in a large region. At Mt. Ylläs, accurate in-situ measurements of in-cloud icing have been carried out for several years, using a rotating multicylinder instrument [1]. Three cases are selected for this experiment, characterized by stable stratification and advection of warm and moist air. Table 1 summarizes the observations.

TABLE 1
MEASURED VALUES AT MT. YLLÄS IN NORTHERN FINLAND FOR THE THREE CASES CONSIDERED.

Date	Time (UTC)	Wind direction	Wind speed ($m\ s^{-1}$)	T (ºC)	LWC ($g\ m^{-3}$)
14 Feb 1990	06	E	4	-5	0.27
09 Jan 1996	11	SSW	13	-5	0.30
10 Jan 1996	11	SW	20	-5	0.43

B. Gamlemsveten, Norway

The second experimental site is situated at Gamlemsveten (62.58°N, 6.32°E), 10 km north-east of Ålesund on the Atlantic coast of Norway. Mt. Gamlemsveten has an elevation of 790 m, and is exposed to moist air masses from the sea. The mountain top is relatively sharp and is typically well above cloud base when such air masses enter the area.

In this case direct validating measurements of cloud water, are not available, but instead measurements of accumulated ice on a steel wire, carried out by Kjeller Vindteknikk AS, were used. The measurements are retrieved from web camera pictures (Fig. 1) of an iced guy wire of a 10 m tall meteorological mast on the top of Gamlemsveten. Furthermore, ice loads (kg /m) are estimated by assuming an ice density equal to 500 kg /m³.

Fig. 2 shows the ice loads retrieved from the pictures. The discontinuity is due to black pictures during the night and foggy pictures in periods with heavy icing.

In addition, on site wind speed (heated anemometer) and temperature measurements are available for model verification.

Fig. 1. February 7 2004 10:00 UTC: Web camera picture in clear weather after an icing incident at Mt. Gamlemsveten. The ice load is estimated to 1.8 kg/m.

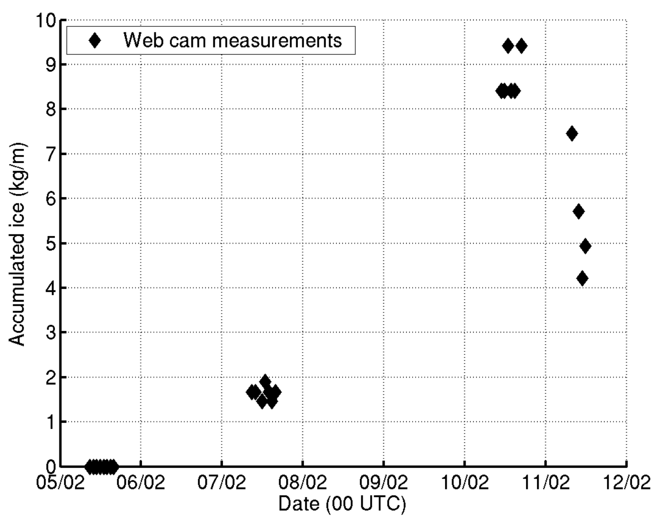

Fig. 2. Measured ice loads from web camera at Mt. Gamlemsveten, February 2004.

III. MODEL SETUP

The WRF model has been used for our simulations of in-cloud icing. It is a non-hydrostatic mesoscale NWP model, developed jointly by several institutions in the United States [2]. WRF is a flexible modeling system, used both for operational weather forecasting and for research applications.

For both of the experiments, the simulations have been carried out using a two-way nested grid. In order to resolve the small scale topography, with steep hills and narrow ridges, a triple nested domain is used, with a horizontal grid spacing of ~800 m in the innermost domain. The model is configured with 35 vertical levels below 100 hPa.

For the cases at Ylläs, two simulations have been carried out for each time period; a Control run using the Thompson scheme for cloud microphysics [3], including a prognostic calculation of ice cloud number concentrations (2-moment scheme), and a run with a more economical 6-class 1-moment cloud microphysics scheme termed “WSM6” ([1] chap. 8). The three nested domains have horizontal grid spacings of 13.2 km, 3.3 km and 0.825 km, respectively. In order to spin up the cloud physics, the model is started 12 hours ahead of the time of measurement.

The second experiment, at Gamlemsveten, covers a time period from Feb 5th 2004 to Feb 13th 2004. To be able to compare simulations to measured ice loads, an ice accretion model ([4], [5]) is applied. Time series of temperature, wind speed and supercooled liquid water content modeled by WRF are used as input to the ice accretion model, and the resulting accumulated ice is compared to measurements.

IV. RESULTS FROM NUMERICAL SIMULATIONS

A. *Ylläs, Finland*

For all three cases considered, with temperatures below 0ºC and a presence of supercooled cloud liquid water (SLW) at ground level, the model successfully simulates icing conditions on the top of the hill. Fig. 3 shows a typical situation with a low cloud base and a local maximum in SLW just above the hill top.

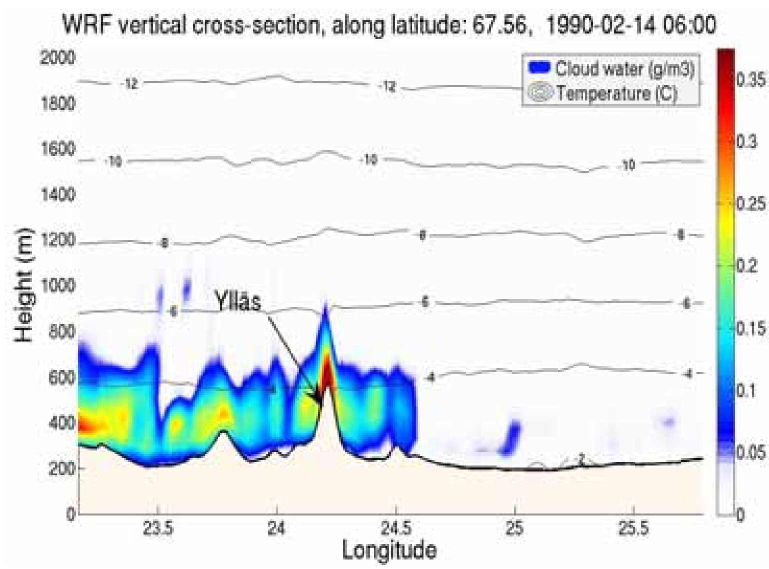

Fig. 3. Simulated SLW (color shading) and temperature (isolines, ºC) in a longitude-height cross section at a latitude of 67.56°N from Control run at 06 UTC on 14 February 1990. The observed supercooled cloud water content at Mt. Ylläs was 0.27 g m^{-3} (see Table 2)..

A summary of the results from the simulations is shown in Table 2. In the same table we have included the results from the same icing events obtained in 1998 using the HIRLAM model with a horizontal grid spacing of 5.0 km in the finest grid [6].

We note that the simulated cloud water contents are greatly underestimated by the coarsest grid, while good agreement is found for the finest grid, but with some overestimation. When the 1-moment WSM6 cloud microphysics scheme is used, a large portion of the condensate is in the form of ice (not shown), and the supercooled liquid water is partly removed by precipitation, resulting in an underestimation of the liquid water content.

TABLE 2
THE RATIO OF SIMULATED VS. OBSERVED SUPERCOOLED LIQUID WATER CONTENT

Case	Ctrl, 0.825 km	WSM6, 0.825 Km	Ctrl, 3.3 km	Ctrl, 13.2 km	[6] 5.0 km
14 Feb 1990	1.37	0.80	0.80	0.13	0.00 (0.44)
09 Jan 1996	1.30	0.57	0.83	0.08	0.00 (0.33)
10 Jan 1996	1.19	0.67	0.76	0.08	0.00 (0.23)

The ratio of simulated vs. observed supercooled liquid water content (g m^{-3}) for the three grids and the two model simulations described in the text. For [6] the values in parentheses are for the next-to-lowest model level.

B. Gamlemsveten, Norway

An eight days long simulation is carried out with a horizontal grid spacing of 800 meters in the area around Gamlemsveten. Even in an 800 meter grid, the topography is smoothed out so that the simulated height is 580 meters, whilst the real height of Gamlemsveten is 790 meters. A temperature adjustment is performed to compensate for this height difference.

The time series in Fig. 4 show in general a good agreement between the simulated and the measured parameters. The difference in wind speed on the 8th of February 2004 is probably caused by heavy ice accretions which have affected the anemometer by slowing it down.

Based on the time series of LWC, wind speed and temperature shown in Fig. 4, accumulated ice on a vertical freely rotating cylinder is calculated by using the method described in [4] and [5]. The resulting time series of accumulated ice is drawn in Fig 5. For the results on the top of Gamlemsveten (blue curve) we find very good correspondence between modeled and measured ice loads after the first icing period on the 7th of February. The next few days, the model seems to underestimate the ice growth, reaching 4.7 kg/m on the 10th of February, while the observations show a growth from 2 kg/m to ca. 9 kg/m during the same period. From Fig. 4 we see that this time period is dominated by winds from the north or northwest and low temperatures, compared to the first icing event, for which the model performed very well.

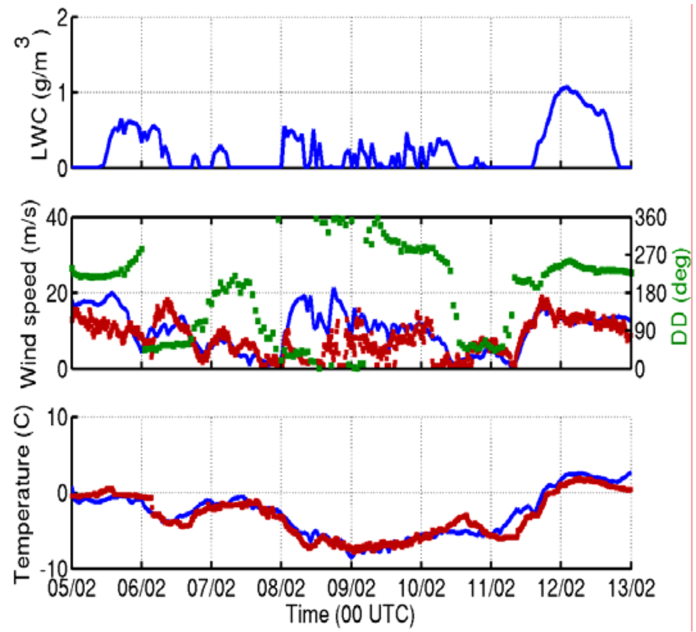

Fig. 4. Time series from numerical model (blue and green curves) and on site measurements (red curves) at Gamlemsveten, Norway.

The green curve in Fig. 5 shows an equivalent result from a hill called Storfjellet, situated 15 km east of Gamlemsveten. In the model terrain, Storfjellet has an elevation of 788 meters, which is comparable with the real height of Gamlemsveten. The modeled ice load is now much closer to the maximum value on the 10th, but the first icing event is slightly overestimated, while the ice growth observed between the 7th and the 10th is still underestimated.

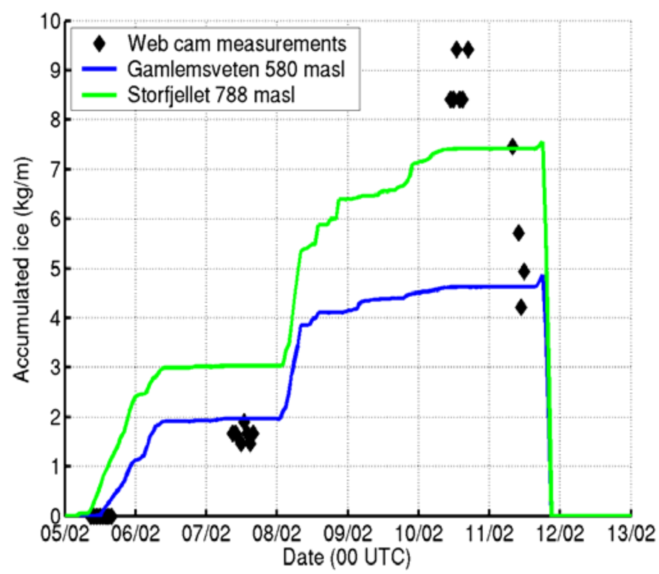

Fig. 5. Accumulated ice, simulated and measured loads for the Norwegian coastal site Gamlemsveten.

V. CONCLUSIONS

The above results suggest that there is a large potential for quantitative forecasts of episodes of in-cloud icing, using current NWP models at high spatial resolution and with sophisticated cloud microphysics parameterizations. The case studies for Ylläs demonstrate that high horizontal resolution is crucial when simulating a realistic production and loss of SLW by lifting of air over an isolated hill like Ylläs.

The results also indicate that icing in stratified air like the cases at Ylläs, and icing in connection to warm fronts (first event at Gamlemsveten) are very well handled by the model. On the other hand, the model seems to underestimate the amount of SLW in cold and deep mixed phase convective clouds. This may be related to the parameterization of mixed-phase processes such as e.g., accretion, which is typically much more important in convective than in stratiform clouds. This needs to be investigated further. Also, for convective situations, simulations with an increased number of vertical layers should be attempted, in order to resolve the convective clouds better. Finally, to more realistically simulate maritime air, the prescribed number concentration of cloud condensation nuclei of 100 cm^{-3} in WRF should probably be replaced by a lower value.

VI. References

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