Icing measurements at Milešovka and their comparison with reanalysis and mesoscale model outputs

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***Abstract*—The measurements of the mass of ice accumulated on the sensor surface were carried out at the meteorological station situated on the top of Milešovka Mountain (837 m a.s.l.). The period of icing observation includes five winters 1999/00-2004/05 (the winter 01/02 is not covered). Two seasons – 2002/03 and 2003/04 – was simulated with data from mesoscale model. The necessary meteorological variables were taken from +7 to +12hrs forecasting horizon. At first, the performance of model concerning temperature and wind speed was tested. The values from the station altitude fitted to measurements best, even when they were very high above the model surface. The mesoscale model proved to be able to deliver reasonably inputs, when the microphysics was set to most advanced scheme. Some differences between simulation and measurements occurred, when the temperatures fluctuated around zero degrees Celsius.**

I. Introduction

THE icing belongs to the phenomena that can be dangerous for the structures like masts, power line towers or wind turbines. The wind energy in the Czech Republic started to develop quickly in about last three years and due to the climatic conditions of the country the turbines are built in exposed mountainous terrain. Consequently it means that they may experience significant ice loads during some synoptic situations. For example, the region most suitable for wind energy production in the Czech Republic – Krušné hory (Ore mountains) – is exposed to both northwestern and southeastern winds and so is often affected by severe icing during the winter. This area lies close to the measurement site and application of the measurements in the wind energy is straightforward. In the case of wind turbines, the icing causes two major problems: power production loss and falling ice. While the power loss affects only the energy production and the endurance of turbine, the falling ice may pose a thread to everything in the surroundings.

The aim of this work is to assess possibility of using limited area mesoscale forecasts with 9km horizontal resolution for icing estimation.

II. Site and Instrument Description

A. Test site

The meteorological station is situated at the top of Milešovka Mountain (837 m a.s.l.), which represents the highest peak of the tertiary volcanic range of České Středohoří. The station produces standard synoptic observations as well as a number of special measurements, including the icing intensity in last several years. The mountain has a shape of isolated forested cone, which exceeds the surrounding terrain by approximately 300 m. The steepness of slopes ranges from 20° to 30°.

Concerning temperature, the long time average reaches 5.1 °C, while absolute minimum fell as low as -28.3 °C and absolute maximum rose as high as 34.7 °C. The average of annual precipitation is 564 mm. The mean wind speed reaches 7.7 m/s with most frequent winds from northwest, west and southwest.

B. Icing sensor

The instrument (called icemeter) measures the mass of ice accumulated on the sensor surface. It was developed in the Institute of Atmospheric Physics, and its first prototype was described in [1], together with a short review of previous methods of ice measurements that were applied in the Czech Republic. Originally, it was considered for the investigation of the most favorable meteorological conditions for ice deposit growth. However, it can find its application also in the guarding system of power lines, wind turbine, and traffic roads.

The mass of accumulated ice is measured by means of tensometric bridge, the output of which is tied to the precise AD converter. The digital signal is preprocessed by a micro-controller, which assigns the time and stores the data into the device memory.

In order to prevent the freezing of the horizontal beam, which couples the sensor (cylinder) with the tensometer, to the housing of the tensometer and electronics, the passage in the housing may be heated. Whether it is heated or not, depends on the passage temperature. A testing electro-mechanical impulse can be provided to verify the free force transition to the tensometer. The cylinder is not rotating.

III. Icing Measurements

A. Configuration of measurements

The icing measurements at Milesovka were carried out from the winter 1999/00, however the data are not very complete in first few seasons (until 2001/02). The exact periods of measurements usually range from October to November and for some seasons are concluded in [2], together with maximum values of ice deposit for the given winter. Until the winter 2003/04 the measurements were performed at 10 m a.g.l. Afterwards one more sensor was installed at 5 m a.g.l. The sensors were attached to the fences on the terraces of the meteorological station at given heights above ground. The station anemometer is situated on the building tower at 20 m height. Temperature and humidity measurements are carried out under standard conditions at 2m above ground.

B. Icing events and corresponding synoptic situations

The most important icing events for both studied seasons are concluded in this section, while all of them are listed in Table I. All values are given in grams accumulated on the sensor cylinder with diameter 3 cm and length 0.5 m.

During the winter 2002/03, three major icing episodes were identified. The most important one occurred from 15.12. to 28.12., when the whole country experienced severe icing. The maximal value of ice mass measured at 10 m reached 2613 g. Simulations of this situation will be shown in the Section V. The event connected with the most severe icing in the studied period began with depression above western France and high pressure extending from Scandinavia to East Europe. The cyclone split and remained in Central Europe until 18.12., when a high pressure system developed above Great Britain. On 19.12. and 20.12. the anticyclone extended to Europe's mainland and on 21.12. it retraced to Balkan. Consequently, western winds established and the icing ceased. The situation with high pressure in the east and low pressure over West Europe developed again on 24.12. and lasted until the end of the icing period. Whole icing episode finished when frontal systems coming from the west passed Central Europe on 28.-29.12.

Another icing period in that season started on 18.1.2003 and lasted almost six days, with the maximal amount of ice at 10 m reaching 1110 g. The third significant occurrence of the phenomena began on 24.1. and lasted for only three days. The highest measured value was 511 g. The corresponding weather situation began with high pressure above East and Central Europe. The depressions above North Sea and Great Britain deepened to approximately 970 hPa on 20.1. and 21.1., and the anticyclone retraced to the east. During the next icing event starting on 24.1. a belt of high pressure extended throughout Europe.

In the winter 2003/04, we observed two icing events with similar maximal measured values. The first one started on 30.12. and lasted approximately six and half days. The highest observed ice mass reached 406 g at 5 m and 875 g at 10 m above ground. The second icing episode occurred between 8.1. and 11.1. and is connected with maximal values 595 g at 5 m and 904 g at 10 m above ground. The situation on 30.12.2003 can be characterized by high pressure system situated above East Europe and Great Britain. In the Mediterranean, a shallow cyclone developed. In the following period the cyclone deepened and the high pressure moved over Scandinavia. On 4.1. the high pressure returned to Central Europe. The second icing event of this season started on 8.1. with weather situation accompanied by vast system of low pressure above Northeast Atlantic and local depression above north cost of the Black Sea, which disappeared two days later. High pressure kept in the Balkan area.

TABLE I

ICING EVENTS OBSERVED AT STATION MILEŠOVKA, THEIR DURATION AND MAXIMAL HOURLY VALUE OF MEASURED ICE ACCRETION AT 5 AND 10 METERS ABOVE GROUND (IN GRAMS ON 0.5 M CYLINDER)

winter	start	end	days	max 5m	max 10m
99/00	12.1.00 15:27	17.1.00 8:18	4,70	---	369
00/01	20.1.01 3:00	25.1.01 4:00	5,04	---	564
02/03	10.12.02 3:52	11.12.02 16:52	1,54	---	386
02/03	15.12.02 7:00	28.12.02 20:00	13,54	---	2613
02/03	1.1.03 14:53	2.1.03 2:54	0,50	---	518
02/03	18.1.03 3:54	23.1.03 22:55	5,79	---	1110
02/03	24.1.03 7:55	27.1.03 10:56	3,13	---	511
03/04	30.12.03 13:00	5.1.04 18:00	6,21	406	875
03/04	8.1.04 18:00	11.1.04 19:00	3,04	595	904
04/05	16.12.04 12:00	18.12.04 12:00	2,00	390	497
04/05	16.2.05 6:00	18.2.05 11:00	2,21	203	509

IV. MODELING USING REANALYSIS

As the first approach to simulate the icing intensity at Milesovka, we chose reanalysis data of temperature, wind speed and liquid water content. The values of meteorological variables were taken from ERA40 reanalysis for given coordinates and pressure level. With very rough spatial (100km) and time resolution (6hrs), the reanalysis can't be a perfect tool for estimating icing occurrence in the complex terrain. However its advantage is the fact that the data are global and quite available for the long time period.

Two events were studied using temperature, wind and LWC from the 925hPa level of reanalysis fields. During the peak ice loads the reanalysis usually also gave significant amount of LWC. However, false icing events occurred too often in the periods without observed icing.

V. MODELING USING MESOSCALE FORECASTS

A. Model setup

The mesoscale model represents another possibility to simulate the fields of meteorological elements. It can be run in limited area domain with resolution better than global data and thus it can manage to express influence of orography better. For our purpose, we selected the widespread model MM5 version 3, which was developed in Pennsylvania State University and National Center for Atmospheric Research (PSU/NCAR), USA. In the area of the Czech Republic, the model runs operationally for a number of years in the Institute of Informatics of Czech Academy of Sciences. For the following task, archived data from winters 2002/03 and 2003/04 were treated. However, the microphysics scheme in the season 2002/03 was much simpler and didn't allow appropriate icing modeling.

Configuration of the model domains is composed from two nested areas, first one covers wider Central Europe and second one extends over the country. The horizontal resolution of the outer domain is set to 27 km, while grid points in the inner domain are spaced 9 km apart. The model runs with 30-second time step and 6-hour spin-up time. In the period 2002/03, the microphysics was set to simple ice (Dudhia) scheme, which was switched to more advanced Reisnel graupel scheme later in 2003. The less important settings (regarding the icing modeling) include Grell cumulus parameterization and MRF model of boundary layer. More details and actual forecasts of meteorological fields are available on-line (at http://www.medard-online.cz). The model starts every 6 hours, according to the time resolution of input global data. In the simulations we used hourly values from the forecasting horizon +7 to +12 hours.

B. *Icing model*

The icing rates were calculated according to the Makkonen icing model described in [3]. The ice mass accumulated in given time period *dm/dt* is calculated as follows:

$$\frac{dm}{dt} = \eta_1 \eta_2 \eta_3 \cdot w \cdot A \cdot v \tag{1}$$

where η_1 stands for collision efficiency, η_2 sticking efficiency and η_3 accretion efficiency, w is liquid water content, A cross-sectional area of the object and v wind speed. The liquid water content and wind speed is taken from the model. The efficiencies are computed using empirical equations based on temperature, pressure, wind speed and LWC. All cloud water is treated as liquid, so the sticking efficiency was set to one. In the case of rain droplets, the collision efficiency was set to one as well. The melting of ice is solved with heat balance of the iced surface.

C. Forecast of temperature and wind speed

The main inputs to the icing model chosen for estimating the intensity include temperature, wind speed and liquid water content. Values are taken from the mesoscale model, so their forecast may also be assessed individually. However only first two variables are measured directly at the site, the measurements of LWC are not performed during icing periods according to capabilities of the sensor.

Concerning the temperature, there were several possibilities which model variable to use. Besides near-surface temperature from sigma level 0.995, the model also calculates ground temperature and post-processed value in 2 meters above surface. Taking into account big difference between altitude of the site and that of 9 x 9 km grid point, we can also use data from appropriate model level (sigma level 0.945 in that case).

The simulated data were compared to the temperature measured at the station with original 15-minute sampling. The lowest rms difference between measured and simulated temperature (e.g. 2.88 °C in winter 2003/04) appears when using the value from sigma level 0.945. As an example, Fig. 1 presents measured and forecasted temperature during an icing period in December 2003 and January 2004.

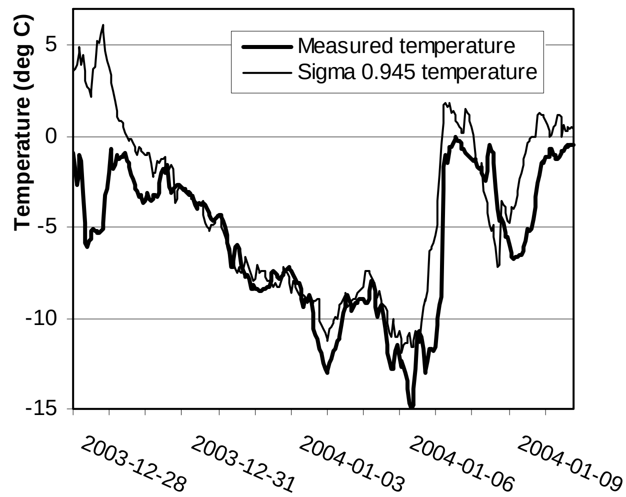

Fig. 1. Measured and forecasted (horizon +7 - +12hrs) temperature at meteorological station Milešovka.

Using the wind speed data represents the similar situation, since we have the variable from both above-mentioned sigma layers, as well as post-processed 10-meter wind speed. Again the lowest rms difference from measured values can be found when using data from sigma 0.945. As an illustration, Fig. 2 shows measured and forecasted wind speed for an icing period from winter 2003/04.

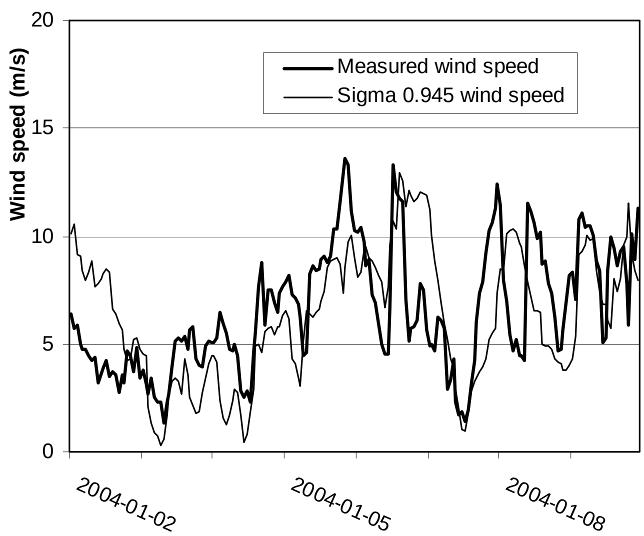

Fig. 2. Measured and forecasted (horizon +7 - +12hrs) wind speed at meteorological station Milešovka.

D. Results of icing estimation

As it was noted above, the model configuration for the winter 2002/03 incorporated a simple scheme for microphysics. This fact affected the results to certain extent. Combinations of negative temperature and large liquid water content occur only seldom, so the predicted values are very small. Moreover, there was heavy overestimation of temperature at the end of the most severe icing event in December 2002. In order to check the applicability of two other inputs – wind speed and LWC – we also simulated the event using the real temperature measured at the station, while other inputs remained forecasted. The results are shown in Fig. 3. While real amounts of ice mass accumulated on sensor reached over 2500 g, the amount according to model was underestimated by factor 10. If we use the real temperature instead, we can see that the maximal amount of ice is predicted well, but the increments concentrate at the end of icing event with simulated LWC around 0.4 g/kg for about 8 consequent hours and simulated wind speed around 7 m/s.

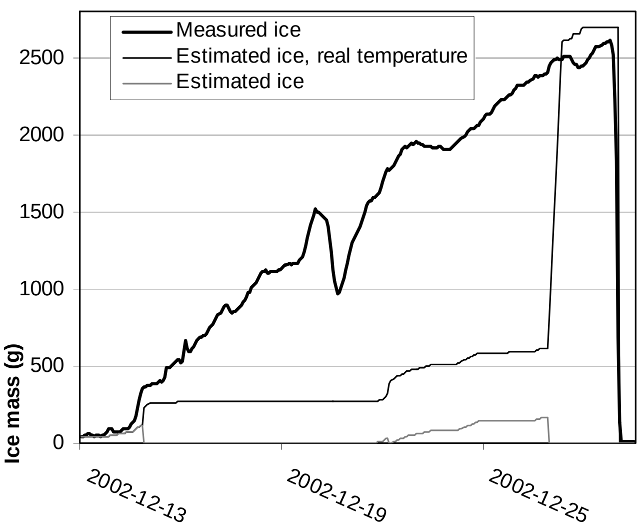

Fig. 3. Ice loads measured at Milešovka during an event in the winter 2002/03 and simulations based on data from mesoscale forecasts, first series is based on measured temperature and predicted wind and LWC, second one is based fully on forecast.

During the year 2003 the microphysics was switched to more advanced scheme. The measurements and simulated ice loads are shown in Fig. 4. At the beginning of the icing event (approximately from 30.12. to 6.1.) the both temperatures – measured and forecasted – were almost all the time below zero. Consequently the event is quite well represented in the model, although the maximal value is underestimated. On 5.1. a sudden decrease of accumulated ice happened, while the temperatures dropped down under –10°C. The ice might have fallen down due to the strong winds having reached 8 m/s and more. The modeled ice remains on the same level, because this effect was not considered. Later on, the model predicted positive temperatures around 1°C and melting. In fact, the real temperatures were negative and only slightly lower, between –1.5°C and –0.5°C. Naturally, the model is sensitive on the temperature, if it is around zero, so the modeled icing develops differently from the measured values from that moment. The real melting occurred one day later, even when the real temperatures kept just below zero. As it happened at noon, it might have been caused by radiation. The model gives, however, very different behavior – large LWC and negative temperatures, which means strong icing. The next icing event really occurred about half a day later.

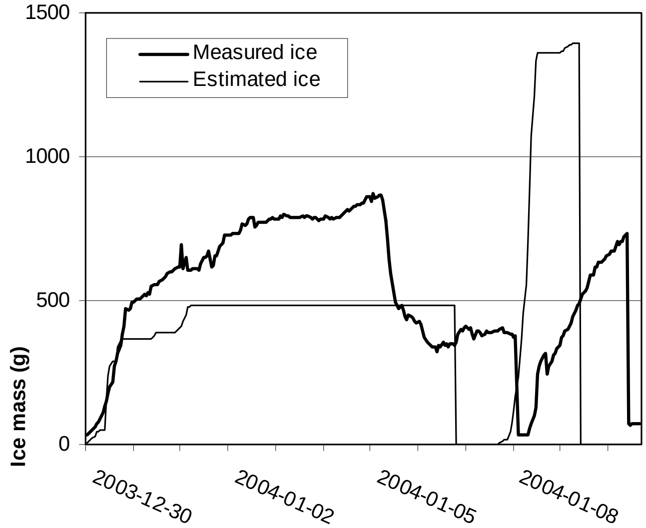

Fig. 4. Ice loads measured at Milešovka during an event in the winter 2003/04 and simulation based on data from mesoscale forecasts.

VI. CONCLUSIONS

The icing measurements from two winters 2002/03 and 2003/04 were compared to the simulations based on reanalysis and MM5 forecasts. The global data not seem to be detailed enough for icing estimation in mountainous terrain due to the rough spatial and time resolution. The mesoscale forecasts depended much on the microphysics settings. With full microphysics scheme, the model is able to predict the icing event to certain extent. The most differences in predicted ice mass are obviously caused by errors in temperature prediction during periods with temperatures around zero. The other effect that causes the model to behave differently to reality is the decrease of ice mass when the temperatures are negative.

Since the mesoscale simulations were performed in a domain with horizontal resolution of 9 km, the station altitude was several hundred meters above the grid surface and the inputs were taken from that model layer. No doubt the model temperature would be influenced by radiation much less than it should be, so there is a possible future improvement for the icing forecast. The other way is to increase horizontal resolution and to have more detailed terrain inputs.

VII. ACKNOWLEDGMENT

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