Comparison of WRF simulations and icing measurements at Milešovka and Dlouhá Louka

Jiří Hošek[1] and Bjørn Egil K. Nygaard[2]

[1]Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic
Boční II / 1401, 141 31 Praha 4, *hosek@ufa.cas.cz*

[2]The Norwegian Meteorological Institute
Box 43 Blindern, N-0313 Oslo, *bjornen@met.no*

Abstract— **The aim of presented work is to assess possibility of using limited area mesoscale model for icing simulation at sites with very steep orography.**

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.) and at Dlouhá Louka (885 m a.s.l.). The installed instruments measure the mass of ice accumulated on the sensor surface - non-rotating cylinder with 3 cm diameter. The period of icing observation at Milešovka includes nine winters 1999/00-2008/09 (the winter 01/02 is not covered) and since 2005/06 the measurements are available for Dlouhá Louka as well.

Three icing events occurring in winters 2003/04 and 2007/08 were simulated with mesoscale model WRF. The horizontal grid step was defined to 800 m and the most advanced microphysical scheme was switched on. The resulting modeled ice amounts are significantly underestimated comparing to the real measurements in case of isolated Milešovka Mt., where the factor is two or more. The reason may be the fact, that height of the mountain in the model is reduced by 283 m compared to reality. A possible solution seems to be in simulating the flow induced by missing terrain feature. The easiest way represents adiabatic shift of the air between two levels. However, to produce more precise result some kind of numerical method would be needed. The results at the grid point of Dlouhá Louka give values a bit closer to the reality.

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 five 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. Due to recent significant improvement of description of microphysical processes in numerical weather prediction models, the results of liquid water simulation turn to be more promising.

The main goal of presented paper is to assess possibility of using limited area mesoscale model for icing simulation at exposed sites with complex orography.

II. Measurements

A. Milešovka

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°. The shape of mountain is shown in the Fig. 1.

The station anemometer is situated on the top of tower of the building at 23 m height. Temperature and humidity measurements are carried out under standard conditions at 2 m above ground. Icing is measured at 10 m above ground.

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.

Fig. 1. The view of Milešovka Mountain

Typical values of annual maximum of ice load ranged from 0.25 to 0.45 kg/m, while the maximum reached 1.3 kg/m in winter 2002/03. More detailed information on most of the measured data as well as the setup of measurement can be found in [1].

B. Dlouhá Louka

The site belongs to the range of Ore mountains (Erzgebirge) that extends from southwest to northeast and typical peak altitudes vary from 900 to 1200 m a.s.l. The mountains follow the borders between Czech republic and Germany, neighboring with windy north European lowlands. Consequently, the most frequent and the strongest winds appear from the west and northwest. The range has high wind energy potential comparing to the other parts of the country. Therefore in that area a lot of activities are carried out aimed at wind profile measurements and wind resource assessment. Icing measurements at Dlouhá Louka is installed on one such must at 50 m above ground.

The elevation of the site is 880 m a.l.s. and the terrain opens to the south with orientation to the azimuth approximately 190°. Its position is shown in Figure 1. The slope at the top of the site reach almost 4° and it is increasing to 32° down the hill.

C. Ice sensor

The installed instrument 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 [2], 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. The instrument measures the mass of ice accumulated on the standard cylindrical sensor that is not rotating.

III. Model

A. Setup of WRF model

The numerical simulations were carried out using widespread mesoscale non-hydrostatic model WRF model (Weather Research and Forecasting) version 2.2.1 (ARW). A detailed description of the model is found in [3]. The main argument for this model is that WRF includes more expensive, but also more sophisticated, scheme for parameterisation of cloud microphysics. This complex scheme is necessary for explicit calculation of the amount of supercooled water in the atmosphere.

In the model runs presented here, the sub grid processes are parameterised as follows:

- Thompson scheme for microphysics
- YSU for the planetary boundary layer
- Monin-Obukov scheme for the surface layer
- Noah scheme for the land surface processes
- RRTM longwave radiation scheme
- Dudhia shortwave radiation scheme
- no cumulus parameterisation scheme

Initial fields and the lateral boundaries are retrieved from the archived operational analyses of the ECMWF global model. The digital terrain model is based on the USGS 30 arc-second global data set GTOPO30.

The model domains are one-way nested at three levels as shown in the Fig. 2. The grid size in outer domain reached 12.8 km, while the inner domain was resolved with grid spacing 0.8 km. In the vertical direction the domain is divided into 51 levels with a model top at 100 hPa.

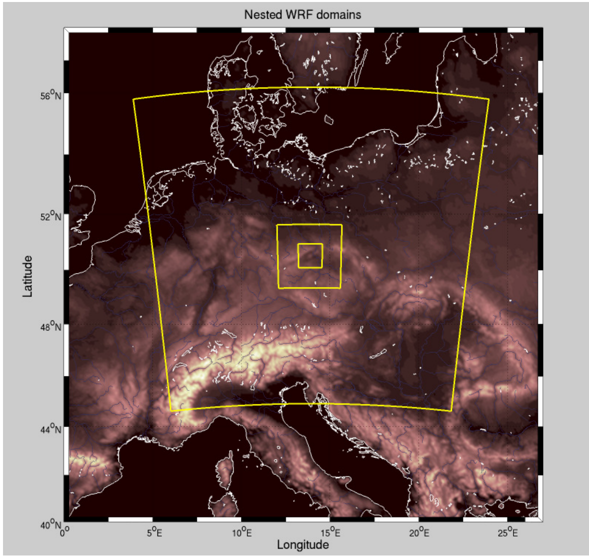

Fig. 2. Nested domains of WRF model

B. Ice accretion model

As the numerical model does not give icing rate as a parameter, we use a cylindrical rime ice accretion model to simulate ice loads. For this purpose a method was chosen based on the theory presented in [4]. The input data needed to run the accretion model include temperature, wind speed, liquid water content (LWC) in the atmosphere, and median volume droplet size (MVD). The collision and accretion efficiencies are computed using empirical equations based on temperature, pressure, wind speed, LWC and MVD. The melting of ice is solved with heat balance of the iced surface. The final result is a time series of accumulated ice load, which can be compared with the measurements. More information on usage of the ice accretion model can be found in [5].

IV. Results

Having the numeric model outputs and method for icing rate estimation, the corresponding model level must be chosen for the two sites. Since the model terrain is smoothed comparing to the reality, altitude of both exposed sites is reduced. While Dlouhá Louka lies “only” 80 m lower in the model, concerning Milešovka the difference reached enormous

270 m. Consequently we have two possibilities: to take the data from the lowest level or the level representing best the real altitude of the site. Following the results in [5], temperature and liquid water content is taken from the real height level, as it proved to estimate values closest to the measurements. At the end of this part, an alternative approach is presented based on adiabatic cooling of the lowest layer air. The wind speed is dealt in the following section.

A. *Simulated wind speed*

Wind speed is crucial parameter in the ice accretion model and should be regarded carefully. It influences the result twofold, as it directly affects the amount of incoming liquid water as well as the collision efficiency of the droplets. Although in most cases the real height model output correlates best with the measurements, the wind speed for simulation is taken from the lowest model layer, because the anemometer is installed at the top of tower (virtually in the free atmosphere), while the ice sensor is at 10 m above ground.

Comparison of the measured and simulated data revealed that the wind speed during the event of 2003/04 was heavily overestimated in the accretion part of the event (Fig. 3). Using this data leads to ice load that is double comparing to the reality. In order to avoid the impact of performance of wind speed modeling on the result, the measured wind speed was applied for this event and transformation to the height of ice sensor was done using the logarithmic wind profile. The wind speed of two other events is simulated reasonably well, having standard error of 2.94 m/s or 2.75 m/s respectively.

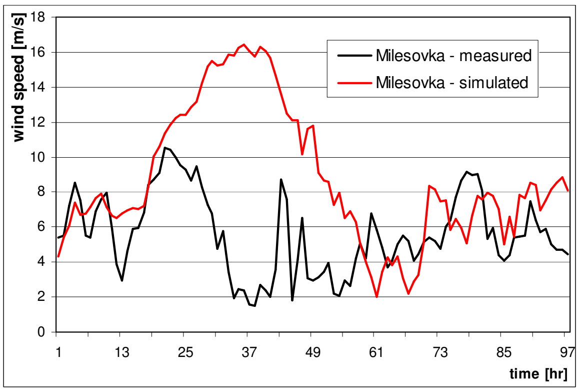

Fig. 3. Measured and simulated wind speed of icing event in 2003/04 at Milešovka Mt. The simulated wind corresponds to the lowest model layer

B. *Event Dec2003/Jan2004*

The first simulated event occurred from 30.12.2003 to 3.1.2004. The synoptic situation typical for icing phenomena was driven by a low pressure system extending over Italy producing southern wind at surface layer. A slight inversion layer appeared at about 850 hPa level.

In 2003 the measurements were carried out only at Milešovka Mt. Observed and simulated series are shown in the Fig. 4. The accumulated ice mass was increasing almost all the period reaching 1.52 kg/m at the end. The simulation follows the begging of event reasonably, but the icing stops in the second half of the period, leading to underestimation of final value with factor two approximately (0.76 kg/m). As the wind speed is based on measurements in that case and the temperature is modeled very well, the errors must have been produced by different liquid water content.

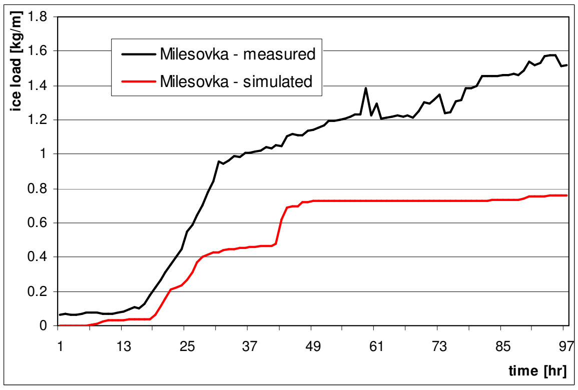

Fig. 4. Measured and simulated ice load of icing event in 2003/04 at Milešovka Mt.

C. *Event Dec2007*

The second considered event started on 27.12.2007 and continued next four days. The synoptic situation is not very typical for icing occurrence and it is defined by a strong pressure gradient between low-pressure system appearing over Great Britain (and over Scandinavia later on) and high-pressure belt over South Europe. The situation led to advection of moist air by northern and northwestern wind. A relatively thick inversion layer extended form 925 hPa level up to 850 hPa layer.

As can be seen in the Fig. 5, this event was the most difficult for the model to deal with. Measured ice load at both sites correlates quite well and at the end of chosen period reaches 2.0 kg/m at Milešovka and 4.0 kg/m at Dlouhá Louka respectively. In the model outputs, however, liquid water is almost missing at both sites producing only 0.2 kg/m at Dlouhá Louka and much less at Milešovka (not included in the Fig. 5). The reason for the bad results might be the complicated inversion layer, which was not advected from the south or southeast as is typical in the winter.

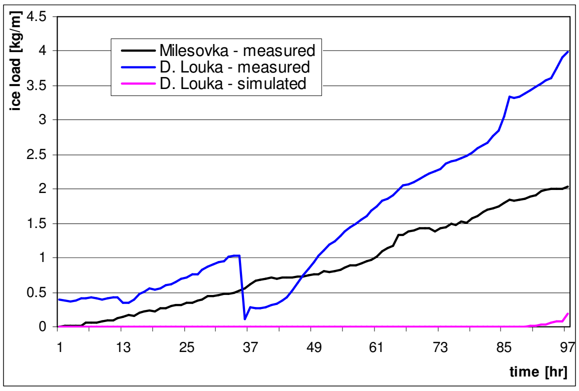

Fig. 5. Measured and simulated ice load of icing event in Dec2007 at Milešovka Mt. and Dlouhá Louka

D. Event Jan2008

The most recent simulated event occurred on 11.1.-16.1.2008. Same as the first studied case, the synoptic situation is typical for icing. Moderate pressure gradient between low pressure over Western Europe and high pressure over Turkey cause southern to southeastern wind, which brings strong inversion in whole air column up to 850 hPa layer.

The Fig. 6 shows the measured and simulated ice loads at both sites. The measured series have two separated icing periods with maximal ice load at the end of chosen interval that reaches 0.91 kg/m at Milešovka and 1.35 kg/m at Dlouhá Louka. The simulations produced the ice accretions only in the second part of the event and the modeled icing also occurred too early. Ignoring the time shift, the ice load at Dlouhá Louka was overestimated by 30% comparing both maxima, while in case of Milešovka it was underestimated with factor two approximately (0.59 kg/m). The differences were probably caused by difficulties in temperature simulation, as it was fluctuating around zero in most of the time.

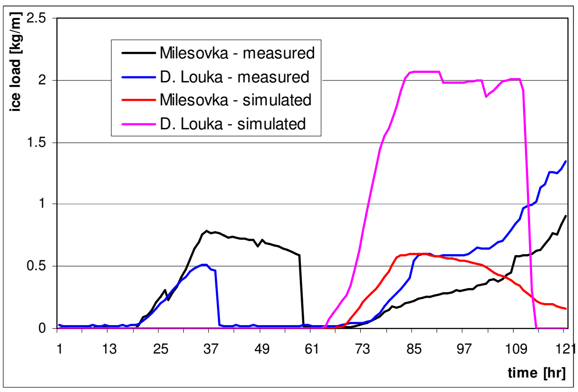

Fig. 6. Measured and simulated ice load of icing event in Jan2008 at Milešovka Mt. and Dlouhá Louka

E. Adiabatic correction

In order to improve the results at Milešovka, a method to lift the air from the lowest model layer to the real height was tested. Under suitable conditions (with enough wind speed) the air was lifted as terrain induced flow. Assuming this process as adiabatic, the air parcel was moved to real height with dry adiabatic lapse rate until saturated and moist adiabatic lapse rate further on. The threshold for this effect was set to 5 m/s and was based on surface wind speed. For lower wind speed the final temperature was scaled linearly, so at 0 m/s it will be equal to the value at real height layer.

The differences between the temperature of lifted air parcel and the temperature of the target layer appear mainly in cases with inversion, i.e. last two events. The improvement is well documented by comparison to the temperature measured at station. It is displayed in the Fig. 7 for the event Dec2007.

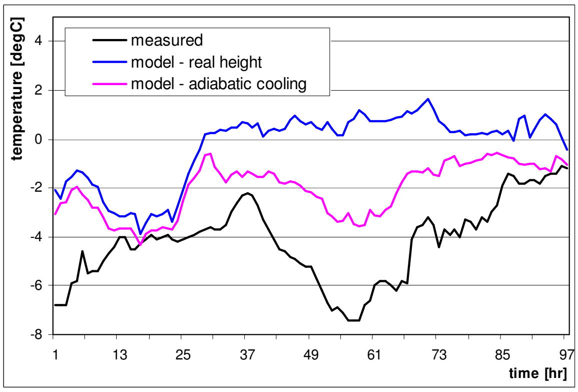

Fig. 7. Measured temperature Tm, output from the model level Tlev and temperature of lifted air T during icing event in Dec2007 at Milešovka Mt.

During the adiabatic cooling certain amount of vapor may convert to liquid water. To estimate this amount, Magnus formula is applied to new temperature to calculate maximal allowed vapor content. All excess water is added to initial liquid water in the lowest model layer. A cap of 0.5 g/kg is then applied to the resulting value according to the typical values of stratiform clouds, as based on observation [6]. All cloud water above this threshold is considered to be converted to rain and removed. The ice accretion model was then run alternatively with new temperature and liquid water content series.

As expected, in all three cases the new ice loads exceed the original values. Despite significant improvement in temperature simulation, the new results for the event Dec2007 is still underestimated with factor four (0.53 kg/m). However, there is at least any icing comparing to the original negligible values. The other two events are both overestimated with factor two approximately. Since they were originally underestimated at the same rate, there is not much improvement in maximal amount. The series, however, follow the measured ice loads much better, as it is demonstrated in the Fig. 8. This also results in improvement of total icing time.

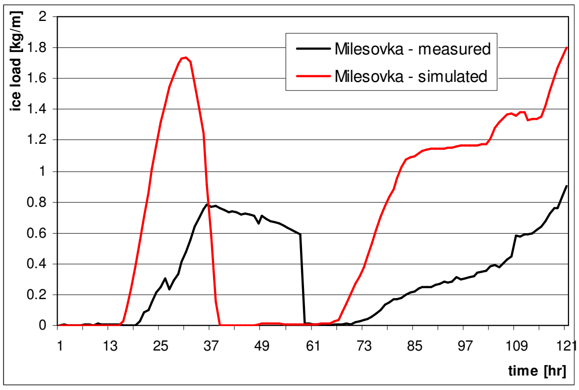

Fig. 8. Measured and simulated ice load of icing event in Jan2008 at Milešovka Mt. after adiabatic correction

V. Conclusions

The mass of ice accumulated on the sensor surface was measured at the meteorological station situated on the top of Milešovka Mountain and at Dlouhá Louka. The installed instruments were equipped with non-rotating cylinder with diameter of 3 cm.

Three icing events occurring in winters 2003/04 and 2007/08 were simulated with mesoscale model WRF. The horizontal grid step was set as low as 800 m and the most advanced microphysical scheme was switched on.

At Milešovka, the resulting modeled ice loads are underestimated with factor two or more. During event at the end of year 2007, the simulated ice load was even negligible. The errors are probably caused by reduction of height of the mountain in the model by 283 m compared to reality. The other drawback in post-processing of model outputs is use of non-rotating sensor and ice accretion scheme assuming rotating cylinder.

An alternative solution offers simulation of the terrain-induced flow from the lowest model layer to the real height. Under conditions with enough wind speed the air between two levels was shifted using dry or saturated adiabatic lapse rate. The amount of liquid water produced by adiabatic cooling was capped by threshold typical for stratiform clouds. This should reflect, although in very simple way, the conversion of cloud water to rain and its removal from the air parcel. To produce more precise results of liquid water content a special 1-d numerical model would be needed.

VI. Acknowledgment

This work is done in the framework of the EU project COST727 “Measuring and forecasting atmospheric icing on structures” and the national project 1P05OC034 supported by Ministry of Education, Youth and Sports of the Czech Republic.

VII. References

[1] J. Hošek, J. Chum, J. Vojta, "Icing measurements in northwestern part of the Czech Republic," in *Proc. Boreas VII,* Saariselkä, 2005.

[2] J. Fišák, J. Chum, J. Vojta, M. Tesař, "Instrument for measurement of the amount of the solid precipitation deposit - ice meter," *J. Hydrol. Hydrolmech,* vol. 49, 3-4, ISSN 0042-790X, Praha, pp. 187-199, 2001

[3] W. C. Skamarock, 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.

[4] L. Makkonen, "Models for the growth of rime, glaze icicles and wet snow on structures", Phil. Trans. R. Soc. Lond. A (2000) 358, 2913–2939.

[5] B. E. K Nygaard, "Evaluation of icing simulations for the “COST727 icing test sites” in Europe," in *Proc. of 13th Int. Workshop on Atmospheric Icing on Structures (IWAIS)*, Andermatt, 2009.

[6] D. P. Rogers, J. W. Telford, "Metastable stratus tops," *Quart. J. R. Met. Soc.*, vol. 112, pp. 481-500, 1986.