Synoptic icing observations in central Europe and their applicability for icing mapping

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***Abstract*— The main goal of presented work is to compare automatic and synoptic icing measurements and to produce an icing map of the Czech republic based on the synoptic data. The icing phenomena are included in the regional section of Czech and Slovak synoptic code. The readings are in mm of accumulated ice observed on suitable object.**

The automatic icing measurements taken at Milešovka station were compared to corresponding values in routine synoptic measurements. Concerning the icing periods, the data agree very well, and with few exceptions the same is valid for amount of icing. The overall results showed that the synoptic measurements are applicable for the icing studies and mapping of icing.

In order to assess the icing climatology, a 15-year period of synoptic measurements was treated. The spatial distribution of mean number of icing hours was calculated using residual kriging, while the independent variables in the deterministic part of interpolation included elevation and wind speed. The resulting values ranged from 30 hours per year in lowlands to more than 2000 hours per year in the mountainous regions.

I. INTRODUCTION

THE atmospheric icing represents a serious hazard to the structures like telecommunication masts, high voltage power line towers or wind turbines. Concerning 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 wind energy in the Czech Republic started to develop quickly after introduction of feed-in tariff for renewable energy production in the year 2002. Due to the climatic conditions of the country the turbines are mostly built in exposed mountainous terrain. Consequently it means that they experience significant ice loads during certain synoptic situations.

The main goal of presented paper is to explore applicability of existing icing data extracted from the synoptic reports and to calculate icing climatology. The latter result is very needed at the moment, to provide the basic information on icing occurrence over the country to the wind energy developers. Taking into account the number of available meteorological stations and relatively good coverage in both horizontal and vertical dimension, purely geostatistical approach was chosen.

II. COMPARISON OF SYNOPTIC AND AUTOMATIC ICING DATA

The first part of this study is focused on comparison of manual synoptic data and automatic digital measurements at the same site. The main goal of the comparison is assess the reliability of manual observations and their applicability for icing mapping in the Czech Republic.

A. Icing in Czech synoptic code

In the Czech Republic and Slovakia the icing occurrence is coded in the regional section (section 3) of synoptic report. The observer reports the icing, if it is present, in mm based on the accumulation on reference object at the meteorological station. The codes 34 to 37 describe occurrence of rime ice, glaze, their combination and wet snow. Though, the frequency of phenomena other than rime ice is negligible and these types were not treated separately.

The total number of stations selected for analysis reached 32, while a few stations from the original set had to be removed due to not reliable data or because of expected strong influence of urban heat island. The spatial distribution of considered synoptic stations is shown in the Fig. 1.

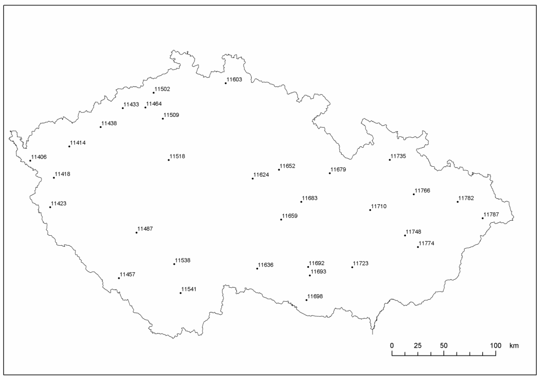

Fig. 1. The spatial distribution of synoptic stations with manual icing measurements over the Czech Republic

B. Automatic measurements at Milešovka

The meteorological station Milešovka is built at the top of the highest peak (837 m a.s.l.) of the mountain range of České Středohoří in the northeastern part of the country. The station produces standard synoptic observations as well as a number of special measurements, including the automatic icing measurements in last several years. The isolated mountain exceeds the surrounding terrain by approximately 300 m pushing the average wind speed up to 7.7 m/s, which is far more than typical values in the region.

The automatic icing measurements are carried out with the instrument Icemeter developed in the Institute of Atmospheric Physics. The specifications are given in [1]. The instrument measures the mass of ice accumulated on the standard cylindrical sensor that is not rotating. For the following comparison, all available data were chosen from the period 1999 – 2008.

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 [2].

C. *Data comparison*

In order to compare both above-mentioned icing data, original synoptic observations were converted from mm to kg/m considering the standard cylinder with 30 mm diameter and using typical average rime ice density 0.4 g/cm^3. As the sensor of the automatic instrument was not rotating, it was necessary to treat the shape of icing accumulation, when converting the synoptic data. The appropriate dimensions were taken from reference tables in the ISO standard [3].

In all studied winter periods, the ice mass calculated from synoptic data fitted reasonably well the automatic measurements, as can be seen, for example, on the Fig. 2. The differences appeared mainly in December 2004, when the readings were shifted by approximately 300 g due to the late installation of the instrument (Fig. 3). Further difference occurred during the strongest event in winter 2007/08, when the peak ice mass obtained from the instrument exceeded the synoptic estimates with factor two (Fig. 4). Using constant ice accumulation density, while it may vary in specific real situations, might cause the error. Concerning the icing frequency, no big differences were present in the data.

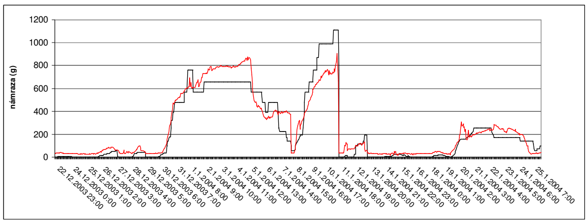

Fig. 2. Comparison of automatic (red) and manual synoptic (black) icing measurements at Milešovka in winter 2003/04

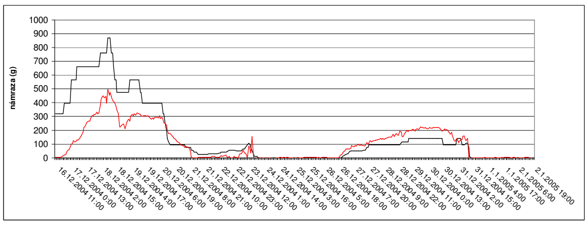

Fig. 3. Comparison of automatic (red) and manual synoptic (black) icing measurements at Milešovka in winter 2004/05

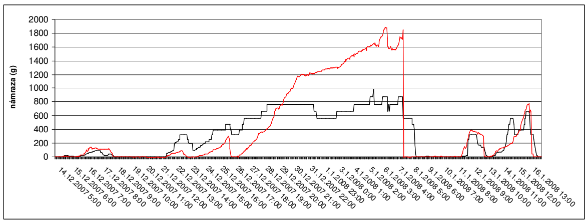

Fig. 4. Comparison of automatic (red) and manual synoptic (black) icing measurements at Milešovka in winter 2007/08

III. Map of Icing Frequency

The icing climatology is usually described by maps of icing frequency or ice load of certain return period, as can be found for example in [4]. Concerning the above-mentioned facts, however, calculation of an ice load map would require further processing and verification of synoptic data. Therefore, the following analysis is focused on spatial structure of icing frequency in the Czech Republic.

A. *Method of spatial interpolation*

A wide set of interpolation methods exist that are used in geosciences. A good survey is made for instance in [5]. Here the method of residual kriging is applied, which can be found frequently in climatological applications [6].

The basic idea of kriging (and stochastic methods in general) is that the variability of values at points close together is smaller comparing to the variability of values at those separated by larger distances. This fact is expressed by semivariogram - the function that describes relationship between variability and distance. The function, together with set of linear equations, could then be applied in arbitrary point to calculate weights of every location with known value. More details on kriging can be found in [7].

The method of residual kriging consists of two individual steps. The deterministic part of the interpolation usually involves some kind of regression analysis. In the second (stochastic) part of the process, one of the kriging types is applied to the remaining residuals.

Therefore, in the first step it was necessary to find suitable and available predictors of icing occurrence for the regression analysis. The set of such variables was chosen, including altitude, wind speed and several parameters of site exposition based on digital model of terrain. The altitude proved to be the best explaining variable for the icing occurrence frequency. The best-fitted relationship was approximately quadratic. Since it was assumed that local effects also influence icing frequency, a measure of site exposition had to be chosen as a second predictor. The mean wind speed fitted this purpose better than various terrain based parameters like convexity or relative height, probably because the wind speed is not only affected by terrain but also includes the effects of surrounding obstacles.

B. Regression on altitude

As already mentioned, altitude was considered the most important predictor of icing frequency. The spatial source of the terrain data represented the digital elevation model DMR with horizontal grid step of 100 meters, which is displayed in the Fig. 5.

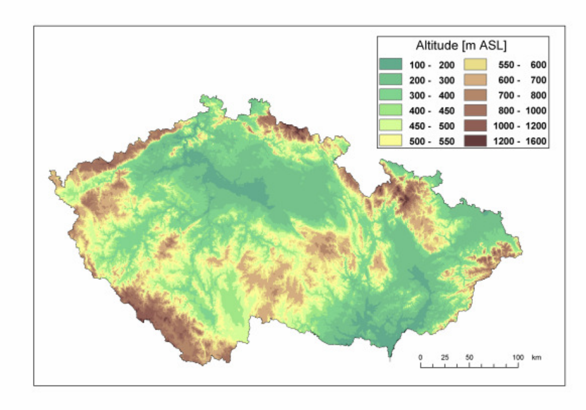

Fig. 5. Digital elevation model DMR

In our case both variables - icing frequency and altitude - had strongly asymmetrical distribution and a transformation should have been applied. Following the common practice, a power-law model was applied for the relationship, similarly to the regression model in [8]. This leads to logarithmic transformation of variables and decrease the weight of outliers in the dataset. Also, due to the original roughly quadratic relationship, the linear regression fits much better after transformation than before that. The result can be found in the Fig. 6. Further analysis revealed that good exposition of a station is often responsible for significant positive residuals, while stations in valleys or surrounded by trees or buildings have negative residuals. This fact justifies the next step – regression on mean wind speed that proved to be good measure of site exposition.

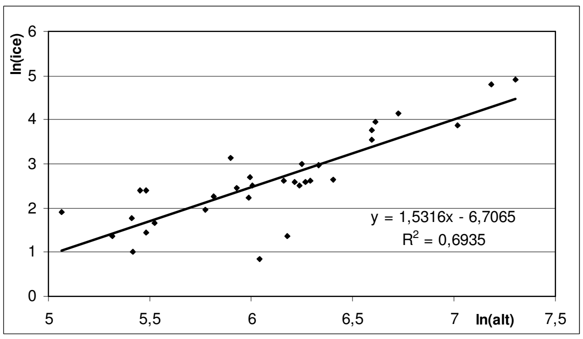

Fig. 6. Linear regression of icing frequency [days] on altitude [m] after logarithmic transformation

After the regression on altitude the semivariogram shows that variability of residuals does not change much with the distance (Fig. 7) and taking into account the above-mentioned facts further step of regression should be tested.

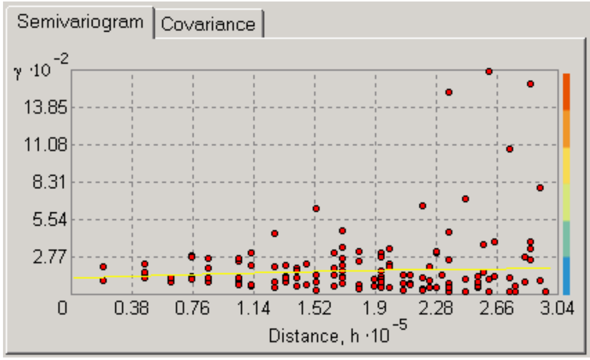

Fig. 7. Semivariogram of icing frequency residuals after regression on altitude

C. Regression on mean wind speed

The second independent variable chosen for the regression analysis was mean wind speed at 10 m a.g.l. Therefore it was necessary to find suitable detailed mean wind speed map. Most recent version of such calculation was applied. In the corresponding project, the model WAsP and special interpolation VAS were combined into a hybrid model [9] to produce the result. Here, WAsP was used for calculation of the "regional wind climates" from the wind measurements and for final detailed calculation of wind parameters, whereas the interpolation of "regional wind climates" was based on the method VAS. The map is shown in the Fig. 8.

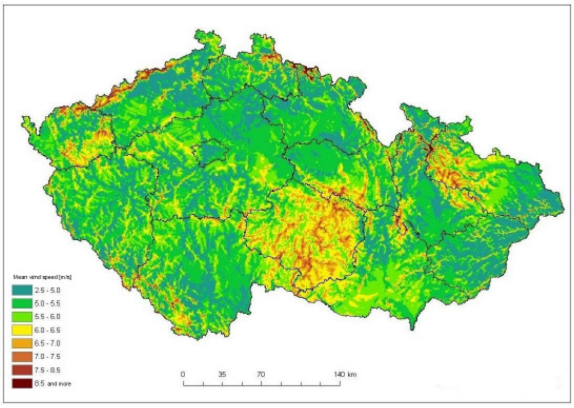

Fig. 8. Mean wind speed at 10 m a.g.l. based on WAsP and VAS methods

The residuals after the first step of regression were distributed almost normally and so in that case the logarithmic transformation was applied only to the mean wind speed. After the second regression, the residuals yield much more suitable semivariogram with increasing variability at smallest distances (Fig. 9).

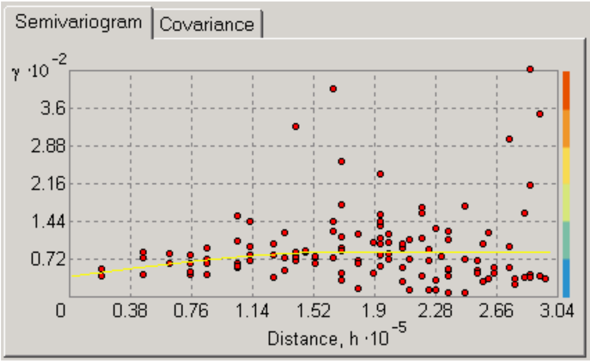

Fig. 9. Semivariogram of icing frequency residuals after regression on altitude and mean wind speed

D. Kriging

In the stochastic part of interpolation, the ordinary kriging was used to interpolate the regression residuals. The empirical semivariogram cloud was fitted with spherical model, as it is marked in yellow in the Fig. 9. All calculations were performed in ArcGIS environment using Geostatistical Analyst extension. In most of the country, the residuals keep between ±6 °C. Their largest absolute values can be found in the SW, with less than -9 °C and in the NE with more than +9 °C. The interpolated residuals are shown in the Fig. 10.

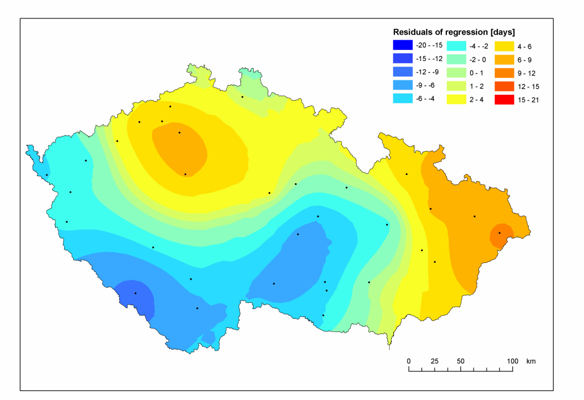

Fig. 10. Ordinary kriging of icing frequency residuals after regression on altitude and mean wind speed

E. Results

The final map of icing frequency expressed in number of icing days per year is shown in Fig. 11. As expected, the map follows the orography very well. The regression on altitude removed 69.4% of variability from the data (Fig. 6) and the map must reflect that. Naturally, the differences from the overall trend can be found mainly in SW and in NE, where the residuals reached highest (or lowest) values. Finally, the wind speed is responsible for detailed fine mapping of the icing frequency, as it was intended.

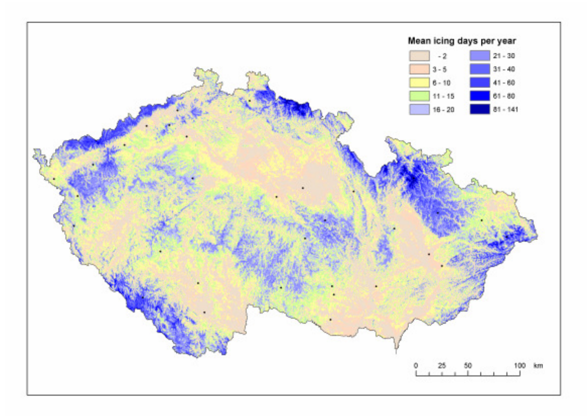

Fig. 11. Resulting map of icing frequency in days per year

IV. Conclusions

In the first part of the paper, the automatic icing measurements taken at Milešovka station were compared to icing observation from routine synoptic measurements. The time periods with icing occurrence agreed well, while certain differences were found comparing icing intensity from both sources. The overall results showed that the synoptic measurements are applicable for mapping of icing, at least concerning the icing frequency.

The next step started with processing of a 15-year period of synoptic measurements. Based on these data spatial distribution of mean number of icing hours was calculated using residual kriging. Before the interpolation the data were detrended removing influence of elevation and wind speed. The values in the resulting map range from 30 to more than 2000 hours per year.

The icing map was calculated using only geostatistics, so it lacks any physical processes, however, developers in wind energy sector demand an estimate of icing and such result could be obtained relatively quickly as a first step. In the near future, further improvement of icing climatology can be expected through the numerical modeling.

V. Acknowledgment

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VI. References

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