Comparison of the Mean Wind Speed Fields Computed by Three Models over the Area of the Czech Republic

J. Hošek, J. Jež, J. Svoboda, J. Štekl
Institute of Atmospheric Physics, Czech Academy of Sciences, Prague

Abstract

Three different mathematical models were used to calculate the local average wind speed over the complex terrain of the Czech republic. The models are based on different methodology: a statistical model with 3D interpolation, a microscale model with interpolation, and a dynamical model. The models were supplied with meteorological, terrain and roughness digital data. The results were compared and obtained differences are displayed in the attached figures. Over most of the country the results were very close. Greater differences revealed areas not suitable for use of a particular model, which was, besides the assessment itself, also the main purpose of the project.

1. Introduction

Assessment of the wind resource and the following computation of the energy production of a wind turbine are affected by errors caused by various factors (Stack & Winkler, 2003). The treatment of meteorological data is of crucial importance. The distribution of meteorological stations should be as dense as possible, however, the measurements are useful only when situated at a representative site (e.g. at the top of a hill or in a flat terrain) without local orographical deformations, and when their time series are sufficiently long (reduction to a shorter period causes errors) and homogeneous (for instance, the observations could be influenced by a change of anemometer type, by technical equipment wear or by a growing of the forest in the vicinity of the station). For example, considering 210 meteorological stations operating in the area of the Czech republic during the period 1961-1990, only 20% of them were ranked as highly representative and 18% were classified as not representative at all (valley locations, etc.). The rest of the stations were marked as sufficiently representative (Sobíšek, 2000). Often there is a question whether one should use a less representative station not far away from the given site, or another one with higher representativeness but at a distant location. Applicability of data from a particular station depends on the surface roughness parameter in its surroundings, and worsens at measurement sites where there is great number of nearby obstacles. The determination of the roughness parameter is usually subjective, and so it leads to errors in the resulting vertical profiles of wind speed. In addition to that, the vertical profiles of wind speed that are calculated using simplified logarithmic or exponential relations are only approximate (Svoboda & Cermák, 2002), especially above the Prandtl layer (50-60 m a.g.l.). One of the main goals of mathematical modelling of wind field over the complex terrain is to express properly the influence of orography on the airflow deformation. In the conditions of Central Europe, the sources of deformations range from large orographic features to small hilly areas and even individual hills. From the meteorological point of view, that means a superposition of the whole range of mesoscale processes. For instance, in the case of southern wind, it is necessary to combine the influence of the mountain ranges - the Alps, Šumava mts. and Brdy mts. - with the influence of more or less isolated orographical obstacles.

Many authors have performed the mean wind field modelling. From them, the work of Sokol & Štekl (1995) could be mentioned, since it was aimed at the area of the Czech republic. Further modelling of the wind resource distribution can be found in Heinemann et al. (1999), Strack (2000), etc. In this study, we compared the annual mean wind speed fields obtained by three mathematical models based on different methods. While the first model (WAsP) represents the widespread tool for wind resource assessment of the site or the annual production estimation of a wind farm, the second one, (VAS2), referred to as statistical, uses 3D interpolation to solve the problem. The last one (PIAP) is dynamical non-hydrostatic and non-stationary. The comparison is intended to find the best method for wind resource assessment in the complex terrain of the Czech republic.

2. Methodology

2.1 Model WAsP

The model WAsP was developed in Risø, Denmark as a tool for evaluating the wind resource at a single site. The main objective of the model is to assess the wind climate at a locality, which is not very distant from a site of measurement or a meteorological station. The principle of the model is the exclusion of influence of the surface at the site of measurement, so that the measured characteristics could be modified to be close to conditions in which the terrain is flat, homogeneous, and without any obstacles. Furthermore, the modified characteristics are used to assess wind conditions in given locality by including the influence of the ambient surface. Model WAsP is designed to express the influence of terrain roughness, orography, and obstacles. The roughness parameter determines modelled vertical wind profile, which is, according to the classical expression for neutral stratification, considered to be logarithmic and is then modified by stability correction. Roughness changes produce the internal boundary layer above the surface, which is also taken into account. The influence of orography is computed by spectral model based on the potential function, that presumes the neutrally stratified atmosphere. The detailed description of all parts of the model WAsP including corresponding equations is given in Troen & Petersen (1989), and Hošek (2000). Advantage of the model is a grid with cylindrical coordinates, so the orography and the roughness have the best accuracy in the surroundings of the evaluated point. The other advantage is a high speed of the computation, although it is achieved by simplification of the basic equations. Conversely, presumption of the neutral stratification can be considered as a disadvantage. The greatest perturbations between the model and reality were found in mountainous areas (the authors mention the error being less than 10% for slopes under critical value of 0.29, so for steeper ones it may be much higher, due to flow separation; reasons are described in the work of Wood, 1995). Therefore, the model is suitable for flat or hilly landscape, especially non-homogeneous, where roughness changes may be expected.

2.2 Statistical Model VAS

Model VAS is based on the knowledge of statistical characteristics of the wind speed components in the assessed area with enough density of measuring stations. Following presumptions are made:

1. the measured values are representative in the surrounding region of the stations, thus the measured data include the influence of surface roughness and of orography in a wider neighbourhood,
2. roughness and the orographic influence are distributed continuously in both vertical and horizontal directions,
3. the density of measuring stations is sufficient, so that their representative areas cover the whole country (Czech rep.).

The field of the scalar variable - wind speed - is derived from discrete points of the measurements by a special method of interpolation (Štekl et al., 1994). The interpolation is based on description of the interpolated variable by its values and by values of its derivative along the height z in the reference level z_R (i.e. in the plane x, y, $z = z_R$). It is assumed that the interpolated variable is a linear function of z, i.e. the derivatives along z are constant. The interpolation gives the values of wind speed in the previously selected reference level $z=z_R$ and values of the vertical gradient of the interpolated variable in nodes of a horizontal net with a 4 km step, covering the whole Czech republic. The computed values and the values of vertical gradient are then interpolated by cubic splines into a net with 2 km step and transformed to values at 10 m above ground level. The selection of the suitable level z_R is based on the prevailing height of stations above sea level, therefore the level z_R=300 m was selected. Estimation of accuracy of the interpolation method was verified by excluding one station from the input data set, by performing the calculation, and by comparing resulting value with the measurement at the station. During 2001 and 2002 the model was extended to the period 1961 - 1990 and took on the name VAS2.

2.3 Model PIAP

The model was developed in the Institute of Atmospheric Physics as a 3-D non-stationary non-hydrostatic numerical model of the atmospheric boundary layer (Svoboda, 1990, Svoboda & Štekl, 1994). The model is based on the Reynolds equation for the mean flow. The Boussinesq approximation and terrain-following system are used in the model equations. The turbulent exchange coefficients are approximated by the turbulent kinetic energy and the characteristic length of the turbulent eddies (1.5 order of the turbulent closure). The surface layer is parameterised using an empirical law. A variable vertical grid step is permissible. The ambient flow is assumed to be sufficiently smoothed, thus it can be determined by the vertical gradients of the air temperature and geostrophic wind vector. The model can be used with horizontal steps 50 m - 5 km.

3. The Results

3.1 The Application of the Models

At first, the model WAsP was applied on data measured at individual stations, in order to obtain the regionally valid wind climatology. These "cleaned" characteristics were then interpolated by the kriging method, being one of the most used geostatistical tools. The detailed description of the method is given in Cressie (1991) and Journel & Huijbregts (1978). Finally, the model was applied inversely in all the grid points. This last step took most of the computation time, as over 8 million points were evaluated (the model ran in 100 x 100 meter grid). The input elevation model had the same resolution. Besides the orography, the model WAsP also required a digital map of distribution of the surface roughness parameter. The distribution of this variable was derived from the land-cover database CORINE with precision 1:100 000. The values of the parameter attached to land-cover classes were based on the article of Wieringa (1993). Whereas the model originally uses 5 standard classes of the roughness parameter, the land-cover categories were aggregated to 9 roughness classes used in the study, so that the range of the surface types was considerably wider. The number of measurements processed in the model WAsP reached 115 sites and there was absence of observation sites in the peripheral areas of the Czech republic.

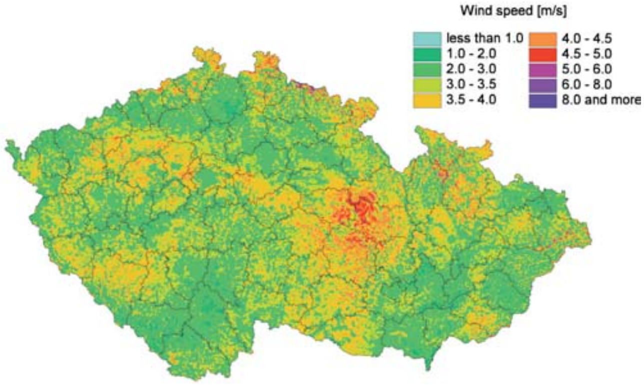

Fig. 1: The results of the model WAsP. Mean wind speed at 10 metres above ground.

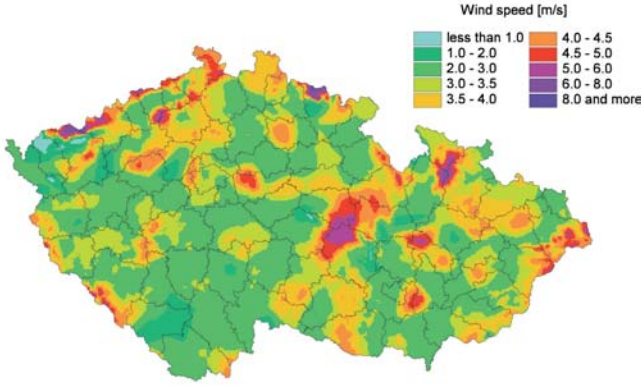

Fig. 2: The results of the model VAS2. Mean wind speed at 10 metres above ground.

Original resolution of the results of VAS2 was 2 x 2 km. The grid of input orographic data had the finer resolution of 1 x 1 km. The basic set of wind speed and direction observations entering the model VAS2 consisted of 210 stations in the area of the Czech republic, 30 stations in the neighbouring areas, and 15 special measurements in the mountains. The data was taken from the normal period 1961-1990. Shorter measurements were statistically transformed to the given period.

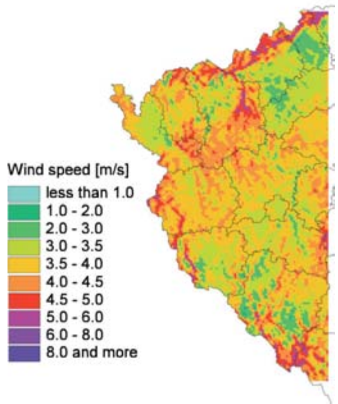

Fig. 3: The results of the model PIAP. Mean wind speed at 10 metres above ground.

The model PIAPBLM was only used for calculation of wind scenarios. These scenarios were statistically processed with respect to the wind measurements at the reference station. Only a simulated difference of wind velocity between the reference station and the site has been used as an input to the statistical calculation. By applying the scenario with a similar wind at the reference station as the one measured, virtual wind data at the site can be generated. Standard methods can then be used for statistical processing of these virtual wind data. The ratio of the wind velocity at these two points of the model domain (reference station and site) has been used rather than the absolute difference of the wind speed, in order to restrict the influence of the wind speed of the ambient flow. Thus we can minimise the number of the flow scenarios calculated if the wind speed of the ambient flow is selected in such a way that the more significant cases for wind turbines are described. The results presented here were calculated using only one wind speed of the ambient flow and one temperature stratification (10 m/s and dT/dz= 0.6 grad/100m). On the other hand, we have

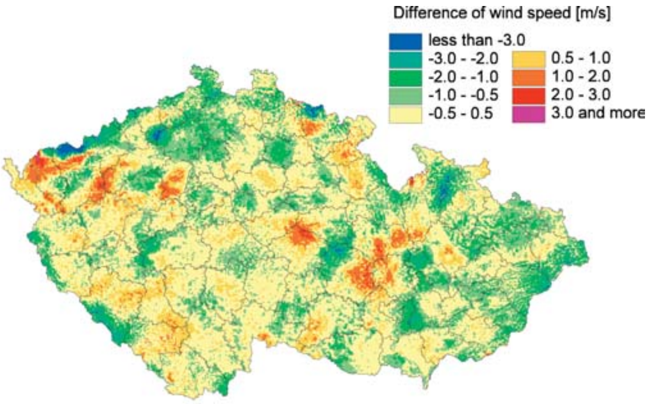

Fig. 4: The differences of mean wind speed WAsP - VAS2.

used a 16-direction rose of the ambient wind. Comparing the calculated time averages of the wind speed and the measured ones (usually time period of 30 years was used), we have found that growth of the geostrophic wind speed with height should be included in our calculation of the wind scenarios. Of course, this rule need not be satisfied, if the reference station and the site have approximately the same terrain height. The growth of the geostrophic wind speed in the ambient flow should be theoretically and experimentally studied in detail in the future, but it seems that this time gradG = 0.2 - 0.3 (m/s)/(100m) is a convenient value to get an acceptable difference between modelled and measured values. The results presented in this paper were calculated with the grad G=0.25. The wind fields obtained by WAsP and VAS2 were resampled to grids with one-kilometer step, in order to be able to compare them. The results from the model PIAP were already in the required resolution, however, the computation was performed only in a limited area, since running of a dynamic model is very time consuming and the time spent on computation rapidly increases with the domain dimensions. So while the outputs from models WAsP and VAS2 cover the whole country, the domain of the model PIAP was limited to the westernmost part of the Czech republic. The outputs of the three models can be seen in the Fig. 1 to 3.

3.2 Comparison of the Results

Due to the limited domain of PIAP only one comparison between models WAsP and VAS2 could be made for the whole area. The spatial distribution of the differences is displayed in Fig. 4. The greatest negative values can be found in the peripheral regions, as the WAsP is not able to treat the larger orographic features properly without sufficient amount of observations. In the interior of the country, the majority of area fell into the class of differences ±0.5m/s, and there are several regions with positive values. The resulting differences were also aggregated to wind speed classes and the resulting histogram is displayed in Fig. 7. Provided that the limit of ±0.5m/s is considered as a good accord, than this was fulfilled in 59% of grid points. The occurrence of absolute differences greater than 1 m/s reached 18.8 % and the corresponding values for limits 2 m/s, resp. 3 m/s, was 2.38 % and 0.34%, resp. With the highest frequency of differences at -0.1 m/s, the graph shows that in general there is virtually no systematic shift of the results. However, when comparing the results of the models in different altitude ranges, we can see the mean difference significantly increasing from almost zero at heights of 200-600 m a.s.l. to more than 2 m/s at heights over 1000 m a.s.l. (see Fig. 8). In general, the altitude corresponds to terrain ruggedness, so the differences can be expressed as a function of terrain type (rough or flat) as well. The ranges of VAS2-WAsP differences in various terrain types are listed in Table 1. Comparisons between the model PIAP and the other two models were performed on the PIAP grid. The results are shown in Figures 5 and 6. In both cases the mean wind speed obtained by PIAP is slightly higher, especially in the west of the domain. It is caused by the ability of a dynamical model to perform well without a sufficient number of measurement sites, and by the fact that observations nearest to this area are weak and non-representative, so an interpolation underestimates the wind speed.

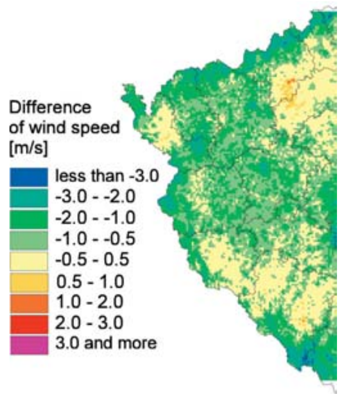

Fig. 5: The differences of mean wind speed WAsP - PIAP.

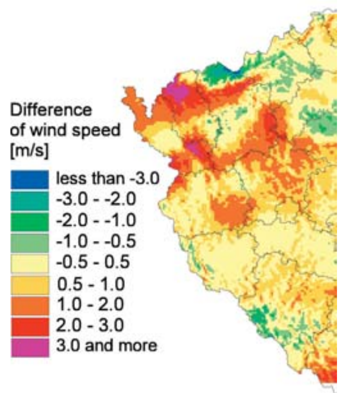

Fig. 6: The differences of mean wind speed PIAP - VAS2.

Terrain type class	Altitude [m]	Vertical ruggedness [m]	VAS 2-WAsP [m/s]
1) plains, lowlands far from the mountains	less than 400		± 0.2
2) flat hilly landscape	450-600	75-150	± 0.2
3) hilly landscape	600-750	150-200	≤ 0.5
4) rough hilly landscape	750-900	200-300	≤ 0.9
5) flat mountainous terrain	900-1200	300-350	≤ 2.0
6) mountainous terrain	1200-1600	450-600	≤ 2.3

Tab. 1: Differences of the outputs from models VAS 2 - WAsP in various terrain types

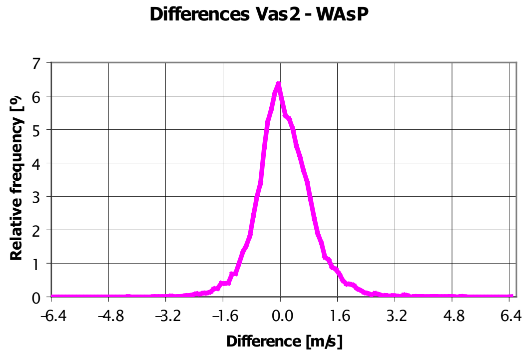

Fig. 7: The distribution of differences of the outputs from models VAS 2 - WAsP.

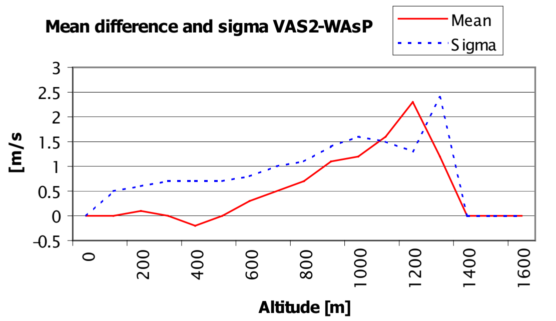

Fig. 8: Differences of the outputs from models VAS 2 - WAsP as a function of altitude.

4. Conclusion

The comparison of the models WAsP and VAS2 showed that they give similar results up to approximately 800 metres of altitude. Although the two-dimensional interpolation method, which we applied on the WAsP results, is one of the best currently available, it cannot take into account large orographic features if there is not a sufficient number of measurements. In our case many peripheral regions of the country, especially at its northwestern borders, lack observation sites in the WAsP input data set. Consequently, the interpolation takes values of the variables from nearest lowland meteorological stations and the wind speed is underestimated. For example, one of the windiest regions in the Czech republic - Krušné hory (Ore Mountains) in the northwest of the country - fell predominantly to the wind speed class of around 3 m/s, as can be seen in Fig. 1. Because the statistical model VAS2 assessed the area more realistically (4 - 6m/s) due to the 3D interpolation and the special mountain measurements, the most important differences between the models appeared in that region (see Figure 4). However, there are some areas, where even the VAS2 lacks any representative observation. In that case, there is no doubt that the dynamical model PIAP performed best. One such area lies in the westernmost part of the country. Despite these differences, the models performed well over most of the country. For the wind resource assessment it is essential to know where the models perform best and, conversely, where their critical areas lie. To sum up, the model WAsP should be used for detailed modeling in non-homogeneous areas with not very rugged terrain, while in the mountainous areas the use of statistical model VAS2 would be more appropriate. Finally, in the regions without sufficiently dense station network or with non-representative observations, a dynamical model (e.g. PIAP) should be used. From another point of view, it does not seem necessary to use the models separately, especially when they effectively involve the orographic features of different scale. Therefore, in the future we intend to combine the models, as it was already done in the KAMM/WAsP methodology, where the microscale WAsP was combined with the mesoscale dynamical model KAMM (Frank et al., 2001).

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