Method for valuation of the maximum wind speed using measurements of the meteorological observation times

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ABSTRACT

Long term wind measurements using Wild anemometer are available at the National Meteorological Services worldwide. By these measurements the average wind speed can be set only. However, in a number of meteorological assignments the maximum wind speed for a given or certain period of time is necessary to be known. Relations between the parameters of the Weibull distribution for the average and the maximum wind speed - on daily basis are obtained from a 10-year experimental data set from automatic anemometers. These relations are used to calculate the maximum wind speed for a day from the daily average wind speed. Examples for plain, mountain and sea-side stations are presented. The error of the method for valuation of the maximum wind speed is estimated for the 3 types of stations by using testing data. The applicability of the method is demonstrated.

INTRODUCTION

At the National Institute of Meteorology and Hydrology in Bulgaria (NIMH), as in most of the national meteorological services, for many years the wind speed and direction were measured by Wild anemometer. This measurement is averaging the wind speed and direction for 2 minutes period “by eye”. The maximum wind speed can be registered accidentally if it coincides with the time of observation. In a number of practical assignments, as valuation of the wind pressure for construction as an example, the maximum wind speed is necessary to be known. Based on these data the possible maximum wind speed once per definite period of time – for example once per 50 years – has to be calculated. Unfortunately, in many cases there is not enough data at a nearby meteorological station measured by modern automatic anemometer. That is why there comes the question: Is it possible to use the long data ranges, measured by Wild anemometer, for these types of tasks? The present paper is engaged in research on this question.

THEORY

The wind speed is mostly described by the Weibull probability distribution. The two-parameter Weibull probability density function is:

(1)
$$p(V) = \frac{\alpha}{\beta^{\alpha}} V^{(\alpha-1)} \exp\left(-\left(V / \beta \right)^{\alpha} \right)$$

where: α is the dimensionless shape parameter, β is the scale parameter in [m/s], V represents the wind speed observations in [m/s], and $p(V)$ is the probability density function.

Fig. 1 shows a typical Weibull probability density function of average and maximum wind speed of a meteorological station.

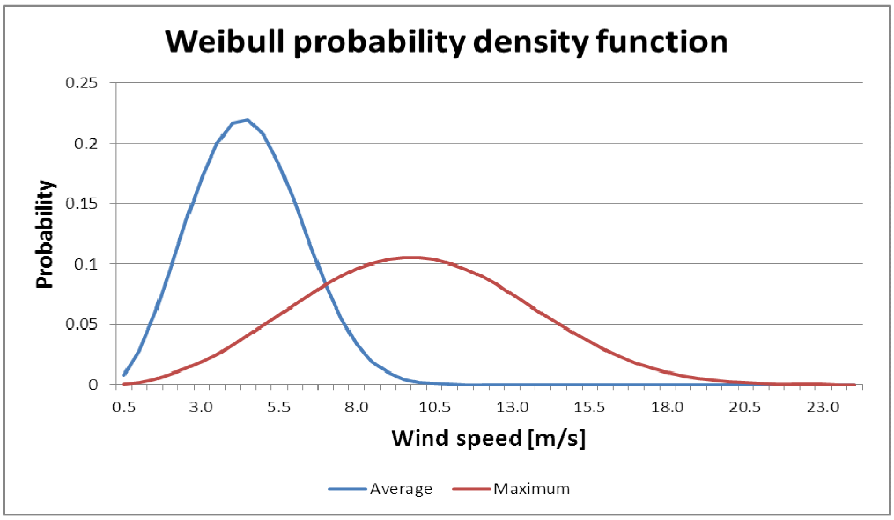

Fig.1. Typical Weibull probability density function of average and maximum wind speed of real data measurements at a meteorological station.

The cumulative distribution function *p(V)* is given by:

(2) $$p(V) = 1 - \exp\left(-\left(V/\beta\right)^{\alpha}\right)$$

Figure 2 shows the Weibull cumulative distribution function of the same data.

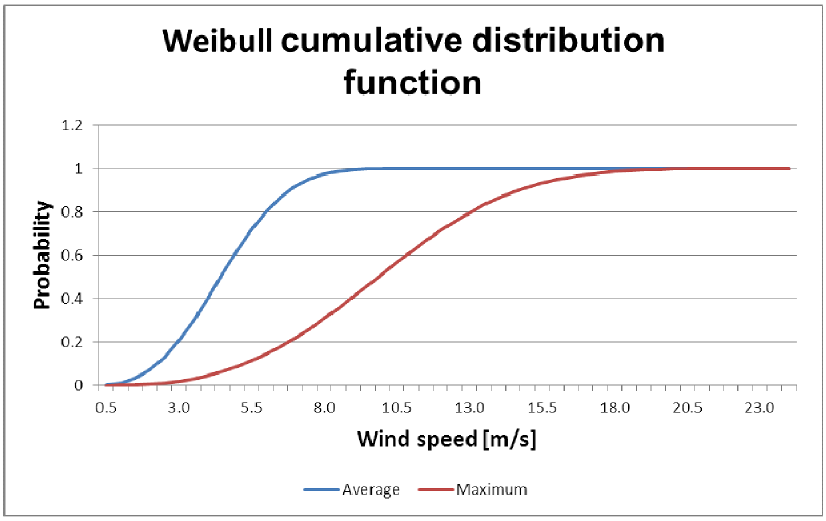

Fig.2. Typical Weibull cumulative distribution function of average and maximum wind speed of real data measurements at a meteorological station.

These distributions are valid if: V>0; α>0 and β>0.
For evaluating the relation between average and maximum wind speed the expression (2) is used, by the way described in (Branzov H., 2010).

EXPERIMENTAL DATA

Ten-year hourly data measured by automatic anemometer MS&E Wind-2 (MS&E) is used here. The data is stored as 10-minute average values and the frequency of the measurements inside the period is 10 seconds. The maximum wind speed is calculated by watching every cycle of measurement. The time, when the maximum wind speed is measured, is registered as well as the

wind speed and direction. Three meteorological stations are picked, situated at different geographical areas of the country. Station Shabla is at the Black sea coast, station Pleven is at the center of the Danube's Plain and station Rojen is at a 1500 m a.s.l. peak of Rhodope mountain. The data ranges are put under a quality assurance check and the incomplete sets of 24 hours, connected with break-downs and power offs are removed. Only data with a full 24 hours set are used for the analysis. The hourly wind speed data is arithmetically averaged for the day and the daily averaged wind speed is obtained. In this way for every day the pair of daily average wind speed and diurnal maximum wind speed is set.
Two groups of data are made: training one, including about 90% of the data and testing one – including about 10% of the data. The first one will be used for defining the demanded relation between maximum and average wind speed and the second one – for valuating the error of the method. Table 1 gives the count of the used data for every station. NV_{aver} stand for the count of average wind speed data and NV_{max} – the corresponding diurnal maximum wind speed.

Table 1. Used data

Station	Rojen		Pleven		Shabla	
group	training	testing	training	testing	training	testing
NV_{aver}	2440	259	2695	294	2635	292
NV_{max}	2440	259	2695	294	2635	292

RESULTS

Different statistical packages can be used for defining the Weibull distribution parameters. In this case Statgraphics is used. The estimated Weibull distribution parameters of the daily average V_{aver} and the diurnal maximum wind speed V_{max} for the training group data are given in table 2.

Table 2. Weibull distribution parameters' values

Station	Rojen		Pleven		Shabla	
group	α	β [m/s]	α	β [m/s]	α	β [m/s]
V_{aver}	3.102	3.1	1.921	2.0	2.818	5.1
V_{max}	3.200	9.9	2.588	8.5	3.008	11.2

Using (2) the demanded relation (3) between the diurnal maximum wind speed and the daily average wind speed for each of the three meteorological stations is obtained.

(3) $$V_{\max} = A.V_{aver}^{b}$$

where: $$A = \beta_{\max} / \beta_{aver}^{b} \qquad b = \alpha_{aver} / \alpha_{\max}$$

and c α_{aver} , α_{max} , β_{aver} и β_{max} are the parameters of the Weibull distributions of the average and maximum wind speed.
The following relations for the three types of meteorological stations are obtained:

Rojen (mountain): (4) $$V_{\max} = 3.4.V_{aver}^{0.97}$$

Pleven (plain): (5) $$V_{\max} = 5.1.V_{aver}^{0.74}$$

Shabla (seacoast): (6) $$V_{\max} = 2.4.V_{aver}^{0.94}$$

Fig.3. shows graphically these relations.

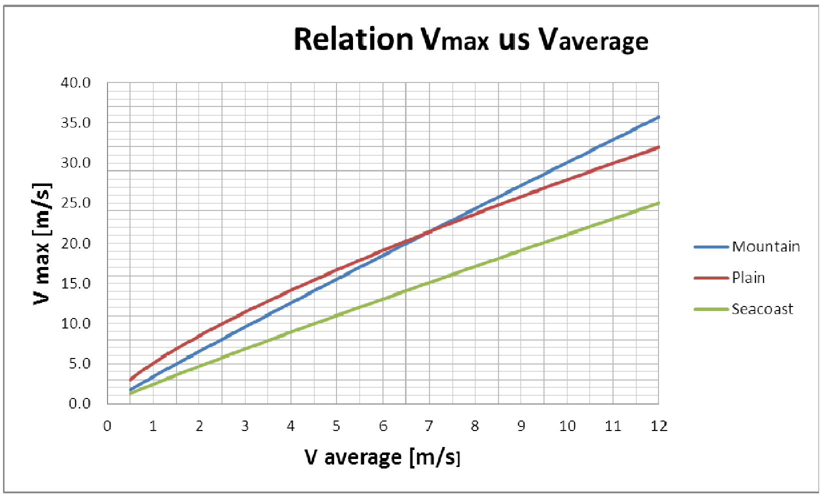

Fig.3. Relation between the diurnal maximum and the daily average wind speed for the three types of meteorological stations.

The different slopes of the curved lines are probably connected with the different roughness of the area around the stations.

EVALUATING THE ERROR OF THE METHOD

The testing data is used to evaluate the error of the method. A classical method for evaluating a reliability of a meteorological prognosis is used (Panofsky and Brier, 1958). The diurnal maximum wind speed is calculated using the daily averaged wind speed as defined by the relations (4), (5) and (6). The calculated by the method $\mathbf{V_{cal}}$ is compared with the real measured $\mathbf{V_{meas}}$ diurnal maximum wind speed and the error of the method is defined.
The absolute uncertainty of the method is defined as:

(7) $$\Delta V_{\max} = \frac{1}{n}\sum_{1}^{n}\left|V_{cal} - V_{meas}\right|$$

In this case better picture gives the maximum relative error

(8) $$RV_{\max} = \frac{1}{n}\sum_{1}^{n}\left(1 - \frac{V_{cal}}{V_{meas}}\right).100[\%]$$

and the root-mean-square error:

(9) $$RSEV_{\max} = \sqrt{\frac{1}{n}\sum_{1}^{n}\left(1 - \frac{V_{cal}}{V_{meas}}\right)^2}.100[\%]$$

The results are given in table 3.

Table 3. Evaluated errors of the method

Station	Rojen (mountain)	Pleven (plain)	Shabla (seacoast)
ΔV_{max}	1.7 [m/s]	1.8 [m/s]	1.5 [m/s]
RV_{max}	3.3 [%]	-2.6 [%]	-2.7 [%]
$RSEV_{max}$	20.4 [%]	29.0 [%]	18.7 [%]

The results show that the errors of the proposed method for evaluation of the maximum wind speed by using the daily average speed are in range, which allows the method to be used in

practice. At the plain and seacoast areas there is slight underestimation of the calculated values, while at the mountain area – slight overestimation.
Figures 4-6 show graphically the Weibull distributions of the testing data diurnal maximum wind speed – measured and calculated by the proposed method values.

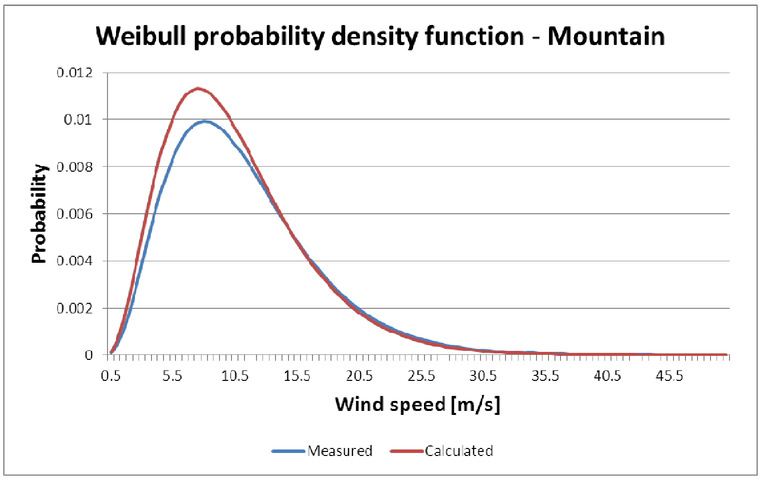

Fig.4. Weibull distribution of the measured and the calculated diurnal maximum wind speed at mountain area.

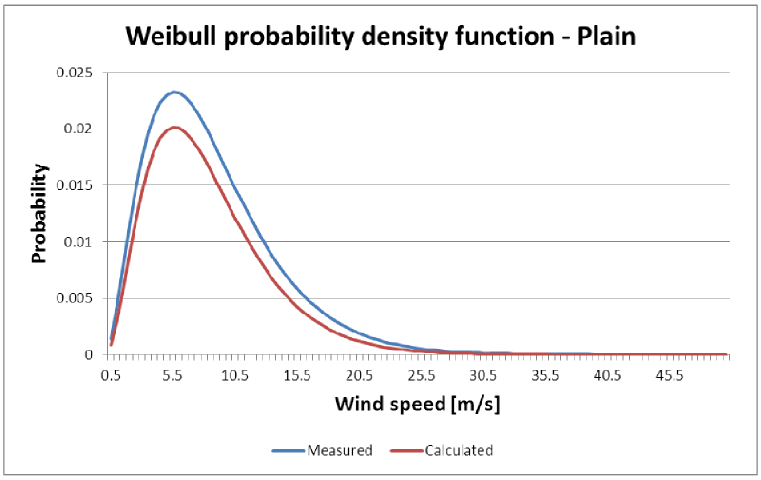

Fig.5. Weibull distribution of the measured and the calculated diurnal maximum wind speed at plain area.

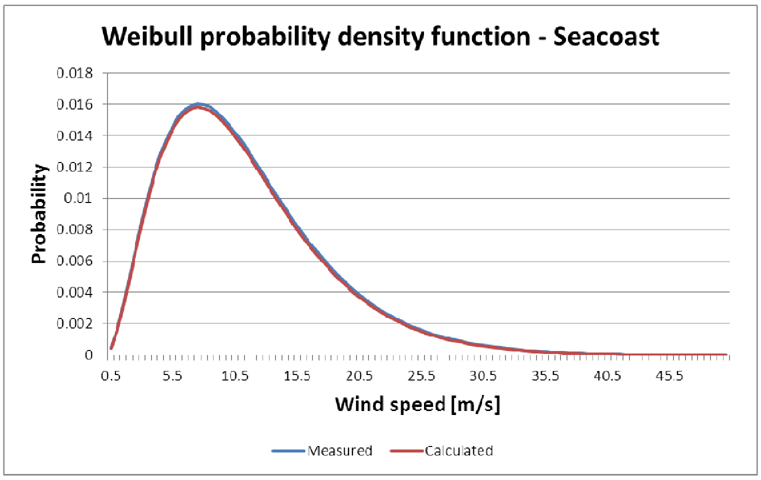

Fig.6. Weibull distribution of the measured and the calculated diurnal maximum wind speed at seacoast area.

APPLYING THE METHOD

The developed method is applied to the data of two other meteorological stations – at the coast of Black sea in Burgas (seacoast) and in the Thracian Plain in Elhovo (plain). The data ranges are for the period 1961-1990.

The Weibull distribution parameters of the daily averaged wind speed are α=1.515 and β=4.7.

Using the obtained relation between daily averaged and the diurnal maximum wind speed for the seacoast area (6) the diurnal maximum wind speed for every day of the period is calculated. In this way the Weibull distribution parameters of the diurnal maximum wind speed are estimated. The values are α=1.785 and β=9.8. Using (1) the two-parameter Weibull probability density function is:

$$p(V) = \frac{1.785}{9.8^{1.785}} V^{(1.785-1)} \exp\left(-\left(V/9.8\right)^{1.785}\right) \qquad (10)$$

It is shown graphically in Fig. 7.

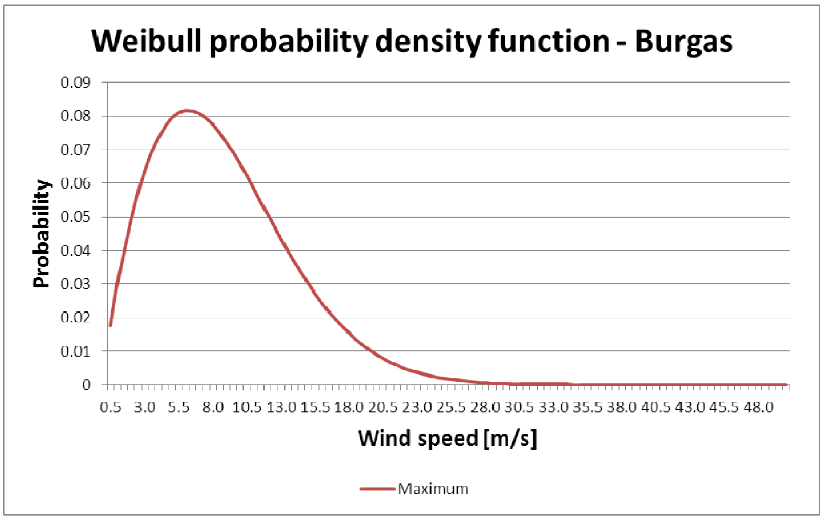

Fig.7. Weibull distribution of the maximum wind speed at the meteorological station in Burgas, defined by the suggested method.

The maximum possible once per 50 years wind speed can be estimated by using the quantiles of the obtained distribution. This value is demanded when designing industrial and other complicated buildings. For the area of Burgas it is 38.7 $\pm$ 1.1 [m/s], including the error of the method.

The Weibull distribution parameters of the daily averaged wind speed for the station in Elhovo are α=1.469 and β=2.9. The estimated Weibull distribution parameters of the diurnal maximum wind speed are α=1.986 and β=11.3. The two-parameter Weibull probability density function for the area of Elhovo is:

$$p(V) = \frac{1.986}{11.3^{1.986}} V^{(1.986-1)} \exp\left(-\left(V/11.3\right)^{1.986}\right) \qquad (11)$$

The distribution is graphically shown at Fig. 8. The maximum possible wind speed once per 50 years in the area of Elhovo is calculated to be 34.2 $\pm$ 0.9 [m/s].

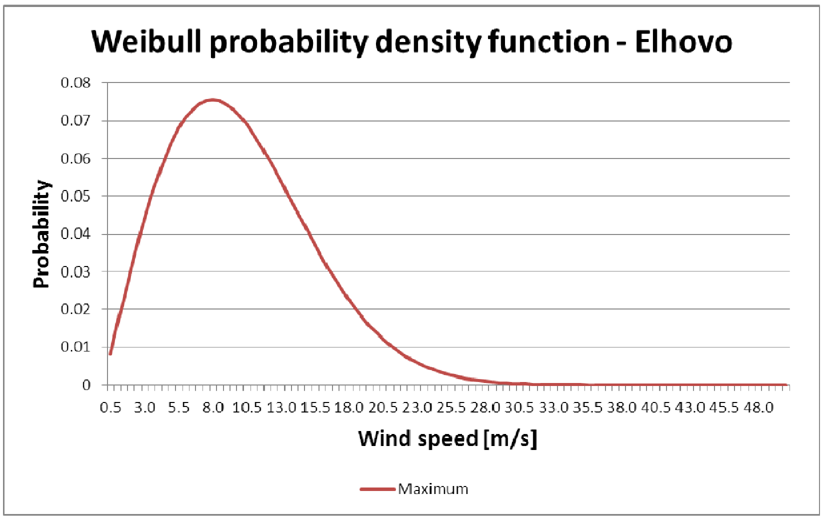

Fig.8. Weibull distribution of the maximum wind speed at meteorological station Elhovo, defined by the suggested method.

CONCLUSIONS

A method for using the long data series of wind speed, measured by Wild anemometer in the meteorological stations of the national meteorological services, is proposed. It allows the long data series to be used widely in different applicable assignments, connected with the meteorological service. The method consists of:

1. Relations between daily averaged and diurnal maximum wind speed are determined on the base of contemporary experimental data and statistical distributions;
2. The error of the maximum wind speed, determined with the suggested method, is evaluated by the method of comparison with a testing data;
3. The method is applied to data from meteorological stations, situated in three geographical areas: plain, seacoast and mountain;
4. The work of the method is demonstrated with calculation of the maximum possible once per 50 years wind speed using data, measured by Wild anemometer at two meteorological stations – plain and seacoast;

FINAL REMARKS

If using these results one must have in mind that they are calculated for concrete areas. It hasn't been examined if they are applicable for other areas, even ones with analogical geographical conditions.

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Panofsky and Brier „Some Applications of Statistics to Meteorology“,1958 г.
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