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A new method for estimating maximum wind gust speed with a given return period and a high areal resolution

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ABSTRACT

We propose a new method for estimating maps of extreme wind gust speed. This method uses observed wind data and maps of general wind climate (GWC). The GWC consists of parameter values for the Weibull distribution of the observed wind speeds in 8 wind sectors and the wind frequencies of these sectors. The proposed method assumes that the maximum annual wind gust speeds have a Gumbel distribution. It consists of two steps. In the first step, the parameters of the Gumbel distribution are estimated using observations at single stations. In the second step, a relationship between the Gumbel parameters and the GWC is derived and applied to maps of the GWC. The GWC permits areal estimates of extreme wind speeds with high horizontal resolution. The resolution is dependent on the resolution of the GWC. A map of the maximum wind gust speeds, for a return period of 50 years, was calculated for the Czech Republic with a horizontal resolution of 100 m using the proposed method and its error was estimated. The results showed that only mean wind speeds and sector frequencies from the GWC are the important parameters for the target area.

1. Introduction

Extreme wind speeds and wind gusts cause significant economic damage and casualties. An understanding of the space and time distribution of damaging wind speeds can be used to reduce the negative effect of these winds. For example, by the use of an appropriate construction technology or the selection of a suitable location. Wind gust information, with a return period of 50 years, is required for the construction approval of large buildings.

Determining wind gust values with given return periods is not straightforward. Wind speed is variable with time and space and depends on local conditions. Continuous long-term wind measurements are rare and limited to a small number of stations. To estimate basic statistical characteristics of wind gusts, it is necessary to solve two problems: (1) describe the statistical distribution of extreme wind speed based on time series of measurements (applying a known distribution model) and (2) interpolate/extrapolate this statistical distribution for a given location. Both steps are complicated, and inaccuracies can lead to significant errors.

The study of extreme wind speeds can be divided into three fields. The first field encompasses the analyses of extreme wind speed measurements and events with extreme wind speeds (e.g., Kašpar et al., 2009). The second field contains studies that address possible changes in wind speed statistics related to climate changes (e.g., Brooks, 2013). The third group, including the present report, processes observed data and estimates the statistics of extreme wind speeds in a given location or area.

The majority of methods that determine extreme wind speeds and their probability are based on a theoretical distribution (e.g., Gumbel distribution, Generalized Extreme Value (GEV) distribution or Generalized Pareto Distribution). These distributions are applied to measured extreme wind speeds which are usually selected by one of the following methods: Method of Block Maxima, Peak-over-Threshold and Cook's method of Independent Storms. Palutikof et al. (1999) has published an overview of these techniques. These methods are applicable to sites where long term wind speed measurements are available. The minimal measurement length sufficient for the estimation of parameters of the distribution of maximal annual wind speed was extensively discussed by Hong et al. (2013). Statistical methods that construct artificial series of data have been developed to avoid the requirement of long term data. For example, Dukes and Palutikof (1995) applied a one-step Markov chain to simulate a long series of wind speed data. For the lower return periods, they found that the results were similar to the results obtained by conventional techniques. However, for longer return periods (above 1000 years) the proposed approach yielded lower values than conventional techniques. Dukes and Palutikof suggested that their technique yielded more reliable results and argued that there should be a limit to theoretical wind

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speed at given location imposed by atmospheric circulation characteristics that the Gumbel distribution does not fulfil. A similar method was proposed by Sanabria and Cechet (2010) using Monte Carlo simulation for data from Australia. They demonstrated that their algorithm is robust and can produce long records equivalent to thousands of years of data.

The calculation of areal estimates of extreme wind speed is more difficult than in sites with wind speed measurements. Kasperski (2002) created a map of extreme wind speed for Germany by grouping station measurements with similar statistical characteristics. The resulting map consisted of several areas/zones with identical values of extreme wind. The disadvantage to this approach is that this method is unable to reveal local effects on extreme wind speeds (Fig. 10 in Kasperski, 2002). An interesting approach was suggested by Gatey (2011), who assimilated wind speeds with 50-year return period, which were calculated from surface observations, and the background wind field derived from pressure fields using the Bratseth scheme for statistical interpolation.

An alternative method employing reanalysis data was suggested by Miller (2003), which used a relationship between the maximum geostrophic wind speed with the return period of 50 years and a maximum 10 min. wind speed with an identical return period observed at a height of 10 m above the surface with a roughness of z_O = 0.05 m. The resulting spatial resolution was lower than those reported in Kasperski's map (Fig. 5 in Miller, 2003). This approach is problematic for the case of extreme wind speed resulting from severe convective events (e.g., thunderstorms). In this case, the actual wind speed is not related to the geostrophic wind speed. An advantage of this method is absence of discrepancies at the borders of different countries resulting from different wind speed measuring methodologies (Miller, 2003). A similar method was employed by Larsén et Mann (2009). They proposed that local effects could be modeled using a microscale model WAsP Engineering (Jørgensen et al., 2005). This approach may result in inaccuracies for regions with strong mesoscale effects on wind flow, namely in Gulf of Suez and the Caribbean Sea. Possible limitations of reanalysis data were published by Mo et al. (2015) who showed that the use of reanalysis for extreme wind speed estimations may lead to unsatisfactory results in regions with steep terrain gradients and coastal regions.

This article presents a method for estimating the maximum wind gust speed with a given return period. The method is suitable for areal estimates with a high resolution. It was applied to an area of the Czech Republic with a resolution of 100 m. The approach estimates the distribution of extreme wind gust at stations, derives a relationship between the distribution parameters and general wind climate (GWC) in corresponding places and applies this relationship to the existing areal map of wind climate. By the GWC we mean that the wind speed is described by the Weibull distribution with known parameter values for various wind sectors and sector frequencies. The parameter values for eight wind direction sectors (Hanslian et Hošek, 2015) were available for this study. It will be shown that for our area of interest only knowledge of the mean wind speed of the wind sectors and the sector frequencies are sufficient information to estimate the maximum wind gust speed with a given return period.

The applied approach is similar to the technique described in the report of the International Electrotechnical Commission (IEC, 2005). This report applies a direct proportion between the mean wind speed and the assumed wind gust speed at each site. Our method employs a more sophisticated relationship between extreme wind gust speed and the GWC, which results in more accurate estimates. The application of the GWC is an advantage because of the experience with the calculation of wind maps and the variety of available maps (Landberg et al., 2003). In case of site measurements, the GWC may be calculated with acceptable accuracy using a shorter time series of data than is required for calculating wind gust speeds with a given return period (Rogers et al., 2005).

The paper consists of 5 Sections. After the introduction, the 2nd Section describes the data and data homogenization. Section 3 presents the proposed model and describes the estimation of maximum wind gust speed with a given return period and high areal resolution. The results and a discussion are presented in Section 4. The 5th Section presents the conclusions.

2. Data

2.1. Data types

Three data types were used to calculate the areal estimation of the maximum wind gust speed with a given return period. The first type of data was the daily maximum wind gust speeds and their directions. This information was measured at Czech meteorological stations operated by the Czech Hydrometeorological Institute (CHMI). We excluded the stations with less than 20 years of data over the period 1961–2009. In total, 28 stations remained in the dataset. 8 stations had time series of less than 30 years, another 8 had time series between 30 and 39 years long and 12 stations had time series with length at least 40 years. 8 stations observed in the whole period 1961–2009. The positions of 28 selected stations and the orography of the Czech Republic are depicted in Fig. 1.

The second type of data consisted of 15 min. mean wind speeds and directions measured at the identical stations in years 2005 to 2009.

The third type of data were derived from GWC maps for the Czech Republic with a horizontal resolution of 100 m calculated by Hanslian and Hošek (2015). The GWC contains maps with parameters of Weibull distribution and frequency of wind from each of the 8 direction sectors at 10 m above the surface. The method used to calculate GWC maps combines an interpolation method (VAS; Sokol and Štekl, 1994) with the Wind Atlas methodology applied by using the microscale model WAsP (Mortensen et al., 2005). The VAS was originally developed to estimate the mean annual wind speed over the Czech Republic (Sokol and Štekl, 1994); however, the technique can perform a 3D interpolation/extrapolation of any variable. The method estimates vertical gradients using observations at various elevation and transforms data to a selected reference level where standard 2D interpolation of both values and vertical gradients is performed. Resulting fields of values and vertical gradients are used to calculate values in 3D space. The WAsP is standard tool for the wind resource estimation. It considers wind conditions at a specific site as a combination of a generalized wind above a flat homogeneous terrain (GW) and site-specific effects like roughness and orography, which modify the GW in microscale.

The method calculating GWC worked in three steps. Initially, the original measured data at meteorological stations were separately processed by the model WAsP. In the second step, the GWs for station locations were interpolated into the entire domain using the VAS. The interpolated quantities included wind frequency, mean wind speed and Weibull shape parameters for each direction, roughness and height-above-ground category of the GW. In the third step, the model WAsP was applied to the interpolated GWs using detailed maps of orography and roughness. As a result the wind map with the same resolution as the input fields was obtained. Fig. 2 depicts the derived map of mean wind speed and the estimated root mean square error of this map is 0.30 m/s (Hanslian and Hošek, 2015). It should be noticed that the resulting map does not consider local obstacles.

2.2. Homogenization of station maximum annual wind gust speed

The World Meteorological Organization (WMO) publishes recommendations for methods of wind gusts measurements (e.g., WMO, 2010) and requirements on station locations. The CHMI follows these instructions, but measurements are influenced by changing ambient conditions and replacing old measuring devices by new ones. These