Daily wind gusts in relation to mean daily wind speed and atmospheric circulation

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Abstract

An important aspect in the design of wind farms and consequently in wind power production, is the sensitivity of wind turbines to wind gusts. This study aims at estimating the probability of occurrence of daily wind gusts for different atmospheric circulation regimes. The analysis is performed for a 31-year period (1979-2009) for the Hellinikon station in Athens, Greece. The proposed methodology estimates wind gust speed values from the mean daily wind speed observations for a given atmospheric circulation pattern. The large-scale atmospheric circulation classification is based on a two-stage clustering approach, using Self-Organizing Maps as a clustering methodology. The classification is based on the Sea Level Pressure, the geopotential at 500hPa, the zonal and meridional wind components at 10m and at 850hPa, the specific humidity at 700hPa and the air and dew-point temperature at 2m. Following the gust factor method, different statistical models are trained for each of the eight identified atmospheric modes. The results demonstrate the suitability of associating wind gusts and mean wind speeds. The adopted gust factor method provides accurate estimates of daily wind gust speeds and that the atmospheric circulation enhances the precision of the statistical models.

Keywords: wind gusts, wind speed, atmospheric circulation

1. Introduction

Extreme events are becoming increasingly important in climatological research. Wind gusts are related to turbulence in the atmospheric boundary layer and are a principal cause of damage to structures. Furthermore, wind gusts have a negative impact on wind turbines by mainly reducing their wind energy output amongst others. The scope of the study is to provide information concerning the interrelationship between maximum wind gust and mean wind speed in a daily scale and provide a transfer function through appropriate statistical analysis. Special focus is given to the effect of large-scale atmospheric circulation for more accurate approximation.

2. Methods, area of study and data

The applied methodology is based on the method developed by Weggel (1999) for estimating the maximum daily wind gusts from mean daily wind speed values. The analysis for increasing the estimation accuracy accounts for the effect of atmospheric circulation. The two-step approach consists of the atmospheric circulation classification and the estimation of local wind gust speeds.

A circulation type classification can be accomplished through a set of methodological approaches and consists of two stages. The first stage involves the atmospheric circulation regimes identification and the second the allocation of each case to these regimes. In this work the Self-Organizing Map (SOM) neural network is used as clustering tool for identifying non-linear relationships and patterns from complex spatio-temporal climatological fields. Following local pressure gradient and wind field criteria, the identified SOM regimes are further grouped into distinct atmospheric modes.

The wind gust estimation method (Weggel 1999) is applied for each atmospheric mode for the entire period and on a yearly basis. The gust factor *G* is calculated from:

$$G = \frac{U_g}{U} - 1 \qquad (1)$$

where U_g and U are the daily wind gust and mean wind speed respectively. The daily wind gust is obtained as the highest value of the daily wind recordings. From plotting $logG$ as a function of $logU$ a power function can be fitted according to:

$$G = AU^n \qquad (2)$$

and in a loglinear form:

$$logG = logA + nlogU \qquad (3)$$

where the intercept A and the slope n can be calculated. As shown by Weggel (1999) they have a linear relationship:

$$n = \varphi A - \psi \qquad (4)$$

where φ and ψ are the slope and intercept, which are site dependent. As one may expect, steeper negative slopes correspond to higher intercepts, so that φ and ψ are smaller than zero.

The area of study is the Hellinikon site in Athens, Greece at the Southeastern Mediterranean region. The study employs hourly wind data and a daily catalogue of atmospheric circulation patterns (Philippopoulos et al. 2014) from January 1979 to December 2009. The SOM classification method resulted into 32 distinct atmospheric circulation patterns, organized into an 8x4 map and a daily catalogue that associates each day with a single pattern.

3. Results

3.1. Atmospheric circulation classification

The 32 SOM atmospheric circulation patterns are further grouped into 8 Atmospheric Modes (AM), based on the pressure gradient over the study area and the corresponding wind field (Table 1).

3.2. Wind gust estimation

Following the Weggel (1999) methodology the power function is fitted to the wind data from the Hellinikon station for each year and for the entire period and for each atmospheric mode. In all cases a negative gust factor – mean wind relationship is found, which is dependent on atmospheric circulation conditions (Table 2). The analysis per year and AM shows that the A and n values are well-correlated with a significant variability between the slope and intercept values. Indicatively, the results of the analysis for the AM2, which is related to the higher mean wind speed values are presented in Figure 1. The resulting transfer functions are not universal and are related to the local circulation and topography of the area of study.

Table 1: Atmospheric modes (AM) description

Atmospheric Mode	Description
AM1	Weak pressure gradient: The high and low-pressure centers over Northwestern Europe and Middle East respectively do not affect the area of study.
AM2	Combination of the extension of Azores anticyclone in the Mediterranean region and the Middle East thermal low: Northerly flow with moderate to high wind speeds
AM3	Depression at the east of the study area
AM4	Low-pressure center at the east: Weak to moderate northerly flow
AM5	Depressions at the west (located mainly over Italy): Southerly flow
AM6	Depressions in Northern Europe (Great Britain, Baltic, Scandinavia): Westerly and Southwesterly flow
AM7	Anticyclonic circulation: Northerly flow
AM8	Weak pressure gradient: Pressure centers do not affect the area of study.

Table 2: φ and ψ parameters for each AM

AM	φ	ψ	AM	φ	ψ
AM1	-0.1733	-0.3305	AM5	-0.1372	-0.4552
AM2	-0.1292	-0.5507	AM6	-0.0597	-0.6145
AM3	-0.1284	-0.5244	AM7	-0.0121	-0.8208
AM4	-0.1432	-0.4586	AM8	-0.0316	-0.6853

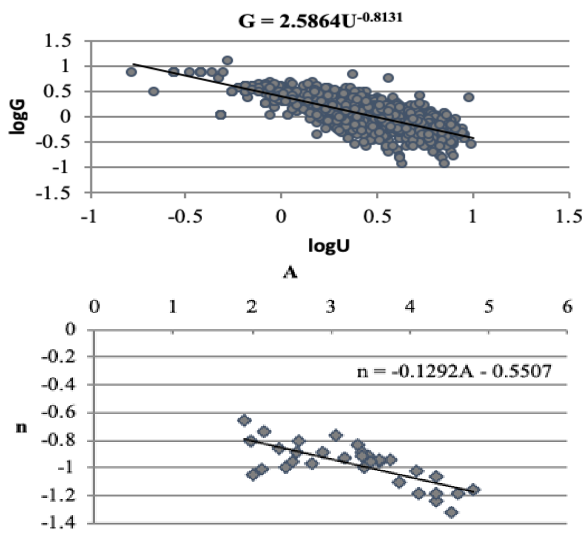

Figure 1. Gust factor as a function of mean wind speed (top) and n as a function of A (bottom) for AM2.

4. Conclusions

The results of the study enable the estimation of wind gusts probabilities of occurrence based on the mean wind speed per atmospheric circulation mode. The results exhibit that the gust factor and the mean wind daily wind speed are interrelated and the methodology provides a useful tool for estimating extreme wind values based on the mean daily wind speed.

References

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