Insights into directional effects in assessing extreme wind speeds

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SUMMARY
The assessment of extreme wind speeds is in most cases performed using omnidirectional approaches, disregarding wind direction and the relative orientation of structures. However, the estimation of extreme values can follow different strategies, which may lead to different use of available data. This study compares two approaches for estimating the extreme omnidirectional wind speed within a given return period: direct estimation based on omnidirectional maxima and an alternative approach based on sectorial maxima. The latter accounts for the directional variability of wind events, which may affect multiple sectors during a single storm and provide additional relevant information. The analysis is based on a 34-year dataset from the Rome Ciampino Airport, including both annual maxima and independent storm events.

Keywords: extreme wind speed, directional effects, independent storms

1. INTRODUCTION

The evaluation of wind actions on structures, particularly for the assessment of extreme values used in wind risk analyses, is often carried out regardless of the direction from which the wind blows and of the relative orientation of the structure with respect to it (Holmes, 1990; Miller et al., 2001). For global actions on ordinary structures, this approach is mainly driven by current code provisions, which are generally formulated within an omnidirectional framework, and provide neither the directional aerodynamic coefficients nor directional wind speed factors required for a fully directional assessment of wind loading. Consequently, design is typically based on a conservative assumption in which the maximum omnidirectional wind speed is combined with the most unfavourable aerodynamic coefficients, effectively representing the worst-case scenario. A similar approach is adopted for local effects on secondary elements, such as cladding and components, where design is similarly based on the maximum wind-induced loads, regardless of wind direction.

Even for both global and local actions on ordinary buildings, the omnidirectional extreme wind speed – defined as the maximum wind speed expected within a given return period regardless of the wind direction – can be estimated through different approaches. On the one hand, the most common approach estimates extreme wind speeds at a given site using the maximum values observed over a sufficiently long observation period, such as annual maxima, or the peak values associated with independent storm events, without accounting for direction. On the other hand, the probability of exceeding a given wind speed threshold within a specific return period depends on the probability of exceedance in the different angular sectors into which wind directions can be binned. Accordingly, this probability can be estimated by analysing the maximum wind speeds observed in each sector over time (Miller et al., 2001).

Synoptic wind events are often characterized by a change in wind direction, potentially affecting multiple directional sectors during the same event. As a result, sector-based analysis allows retaining significant wind speed values that would otherwise be disregarded when only omnidirectional maxima are considered. These values, although not governing at the omnidirectional level, provide additional information on the wind climate and can be incorporated into the estimation of extreme wind speeds (Holmes, 1990; Kasperski, 2007).

Based on 34-year dataset recorded at a meteorological station in Italy, this study compares two alternative approaches for estimating the extreme omnidirectional wind speed expected within a given return period, namely direct estimation from omnidirectional maxima and estimation based on sectorial maxima. This preliminary study estimates the omnidirectional maximum from real wind data. The aim of the study is evaluating whether the use of directional data affect significantly the estimates. A future work will extend the study by performing a Montecarlo investigation, aimed to evaluate if and how the use directional data affects the performances of the estimation procedure.

2. EXPERIMENTAL CAMPAIGN

Analyses are based on a 34-year dataset (1990-2023) recorded at the meteorological station of Ciampino, Italy (WMO Code:16239). The available data consist of 10-minute mean wind speeds and corresponding mean wind directions, sampled at regular time intervals (hourly in the earlier years and half-hourly in the most recent period). The records come from METAR bulletins, with wind speeds given at a resolution of 1 knot. Wind direction is discretized into 16 sectors of 22.5°. From this dataset, two samples are extracted, corresponding to different types of wind speed maxima. The first sample consists of the annual maximum wind speeds, defined as the largest recorded value within each year regardless of wind direction (omnidirectional yearly maxima). The second sample is obtained by identifying independent storm events, defined as periods starting with the up-crossing of the threshold speed $v_{low} = 6\ \mathrm{m/s}$, and ending with its down-crossing. Events with a duration shorter than 3 hours or not reaching a peak value of at least $v_{up} = 10\ \mathrm{m/s}$ are discarded.

The application of the procedure to the entire dataset results in approximately 800 independent events, corresponding to an average of about 24 events per year. An overview of the dataset and the extraction procedures is provided in Figure 1, which shows the time history of wind speed for a representative year and the identification of independent storm events.

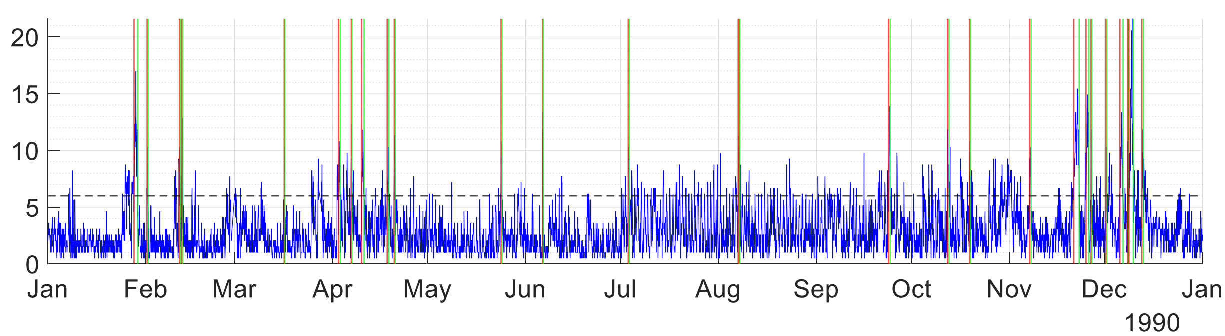
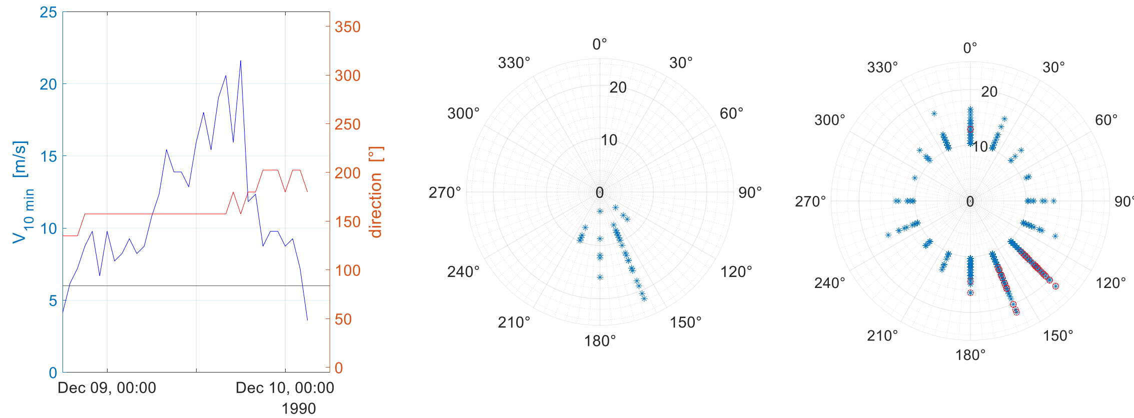


Figure 1. Time history of wind speed at Ciampino for a representative year. Independent storm events are bounded by red (on the left) and green (on the right) vertical lines. Dashed line indicates the threshold v_{low} = 6 m/s.



(a) (b) (c)

Figure 2. A selected storm at Ciampino: (a) temporal evolution of the wind speed and direction; (b) polar plot of the wind velocity; (c) omnidirectional maxima from the selected storms (blue circles) and annual maxima (red circles) collected within the observation period (1990-2023).

Figure 2a reports the time evolution of the 10-minute averaged wind speed and direction for one of the 800 storms selected with the described approach. The values are also reported in Figure 2b, highlighting the variation of wind angle during the storm and showing that its dominant wind direction is SSE. Figure 2c reports the wind speed and direction of all 800 omnidirectional storm maxima observed between 1990 and 2023 (blue circles). In addition, the 34 annual omnidirectional maxima are highlighted in the figure (red circles). Each of the latter values clearly corresponds to the maximum value among the storm maxima within each corresponding year.

It is observed that the maximum annual values are clustered between approximately 120° and 190° with respect to the North, with an absolute maximum wind speed of 22 m/s. Using storm maxima, large values of wind speed populate also other directions, which would otherwise be discarded in an approach using only annual maxima.

3. APPROACHES FOR ESTIMATION OF CDF OF OMNIDIRECTIONAL MAXIMA

This section briefly describes the two alternative approaches that can be used to obtain the omnidirectional maximum wind speed. Due to space constraints, numerical results obtained by these approaches are not reported in this abstract and will be presented at the conference.

3.1. Estimate from omnidirectional maximum wind speeds

The first approach uses omnidirectional maxima only. Within it, the estimate of the distribution of the omnidirectional maximum wind speed in one year $F_{V_{M,y}}(v)$ can be obtained from data consisting in omnidirectional maxima collected in the considered observation period. As an alternative, the distribution $F_{V_{M,s}}(v)$ of the storm maxima can be estimated from the maximum wind speed observed within each selected independent storm. Hence, the omnidirectional maximum wind speed in one year $F_{V_{M,y}}(v)$ can be obtained as:

$$F_{V_{M,y}}(v) = \left(F_{V_{M,s}}(v)\right)^{r} \tag{1}$$

where r is the average number of storms in one year. More rigorously, r in Eq. (1) can also be treated as a random variable.

3.2. Estimate from directional maximum wind speeds

Within the second approach, the estimation of the distribution $F_{V_{M,y}}(v)$ of the omnidirectional yearly maxima is obtained starting from directional data. To the aim, it is necessary to replicate the analysis described in Section 3.1 for each sector of interest, identified through its nominal direction. As an example, let's consider the case where the analysis focuses on only two complementary sectors, identified by directions θ_1 and θ_2. As a first step, directional data should be used to estimate the annual joint distribution $F_{V_{M,\theta_1,y},V_{M,\theta_2,y}}(v_1, v_2)$ of the maximum wind speed in the directions θ_1 and θ_2. This CDF can be estimated either directly from the yearly directional maxima (corresponding to the yearly maxima observed in the given direction) or from directional storm maxima (corresponding to the maximum values of independent storms observed in the given direction). In the latter case the distribution $F_{V_{M,\theta_1,y},V_{M,\theta_2,y}}(v_1, v_2)$ can be retrieved from the joint distribution of directional maxima in one storm by means of the following equation:

$$F_{V_{M,\theta_1,y},V_{M,\theta_2,y}}(v_1, v_2) = \left(F_{V_{M,\theta_1,s},V_{M,\theta_2,s}}(v_1, v_2)\right)^r \qquad (2)$$

where r assumes the same meaning as in Eq. (1).
Starting from the annual joint distribution of Eq. (2), the CDF of the omnidirectional maxima can be hence defined as:

$$F_{V_{M,y}}(v) = F_{V_{M,\theta_1,y},V_{M,\theta_2,y}}(v, v) \qquad (3)$$

In the formulation of the joint CDF of the directional maxima, particular care should be devoted to the stochastic dependence between maxima, which should be accounted for by using suitable modeling solution, if available data give evidence of its existence.

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REFERENCES

Kasperski, M. (2007), Design wind loads for a low-rise building taking into account directional effects. Journal of Wind Engineering and Industrial Aerodynamics, Volume 95, Issues 9–11, Pages 1125-1144, https://doi.org/10.1016/j.jweia.2007.01.019.

Miller, C.A., Cook, N.J., Barnard, R.H. (2001), Towards a revised base wind speed map for the United Kingdom, Wind and Structures, An International Journal, Techno Press, https://doi.org/10.12989/was.2001.4.3.197

Holmes, J.D. (1990), Directional effects on extreme wind loads, Civil Engineering Transactions, Institution of Engineers, Australia, Vol. 32, pp45-50