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Thunderstorm outflow characteristics in the Beijing urban area

Shi Zhang [a,b,c], Qingshan Yang [d,c], Giovanni Solari [b]

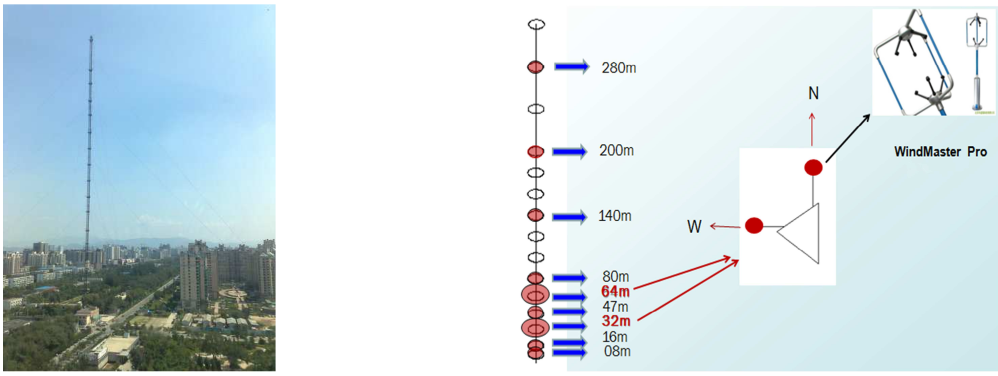
[a]*School of Civil Engineering, Beijing Jiaotong University, No.3 Shangyuancun, Haidian District, Beijing, China*
[b]*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Via Montallegro, 1, Genoa, Italy*
[c]*Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, No.3 Shangyuancun, Haidian District, Beijing, China*
[d]*School of Civil Engineering, Chongqing University, No.174 Shazhengjie, Shapingba, Chongqing, China*

ABSTRACT: The study of thunderstorm outflows and their effects on structures is a key topic in modern wind engineering. Based on the in-situ monitoring network in the northern Mediterranean carried out for the European "Wind and Ports" and "Wind, Ports and Sea" projects, the key characteristics of thunderstorm outflows in this area relevant to wind engineering with special concern for the wind loading of structures were analyzed in previous researches. Recently this work has been repeated and extended to the dataset detected by 9 anemometers installed at different levels on the Beijing 325 m high meteorological tower. This provides a unique opportunity to study the characteristics of thunderstorms in the Beijing urban area, to compare these with northern Mediterranean ones and to understand if thunderstorms in different areas have similar properties. Herein, the extraction and the cataloguing of thunderstorm outflows are illustrated firstly and then the directional signal decomposition strategy, in which their horizontal resultant velocity is decomposed along time-varying longitudinal and lateral directions, are presented. These analyses are preliminary for the further study and comparison of their characteristics.

KEYWORDS: Directional decomposition; Field measurement; Thunderstorm outflow; Wind characteristics; Wind dataset.

1 INTRODUCTION

Thunderstorms are transient phenomena at the mesoscale [1] that occur in convective conditions with "nose" velocity profiles different from those that are typical of the ABL [2,3]. Design wind velocities with mean return periods greater than 10-20 years are often associated with thunderstorm events [4]. They have been extensively studied in the northern Mediterranean ports in order to inspect to their parameters of major interest for evaluating the wind loading and response of structures to thunderstorm outflows. Analyses were carried based on the data provided by the in-situ monitoring network realized for the European "Wind and Ports" (WP) and "Wind, Ports and Sea" (WPS) projects [2,3,4]. Herein, these studies are replicated to the database created through with 9 ultrasonic anemometers with high resolution installed on the Beijing 325m high meteorological tower [5]. This provides a unique opportunity to detect thunderstorm records and to study their characteristics relevant to the wind loading of structures in Beijing urban area. In addition, these results may be compared with the previous ones in northern Mediterranean in order to understand their similarities and differences, to study this phenomenon systematically and to develop a unitary model.



(a) (b)

Figure 1. Picture of the Beijing 325m meteorological tower (a) and the arrangement of ultrasonic anemometers (b).

Herein, Section 2 illustrates the main properties of the measurement system in Beijing. Section 3 describes the criterion by which intense wind events are separated and thunderstorm outflows are catalogued. Section 4 depicts the directional signal decomposition strategy applied to decompose the thunderstorm outflow signals, which is preliminary to analyze their characteristics corresponding to Beijing and compare them with the northern Mediterranean ones. Accordingly, Section 5 summarizes the main conclusions and provides some prospects.

2 MEASUREMENT SITE AND OBSERVATIONS

The 325m high meteorological tower (39°58'N, 116°2'E), as shown in Figure 1a, is a guyed tower with regular triangle cross section and is situated in north central Beijing. The site around the tower can be regarded as terrain C according to the Chinese National Load Code [6]. As shown in Figure 1b (red ellipses), there are eleven three-channel ultrasonic anemometers mounted at nine different heights along the tower, which are 8 m, 16 m, 32 m, 47 m, 64 m, 80 m, 140 m, 200 m, and 280 m, with a sampling rate of 10 Hz. Especially at 32 m and 64 m there are two ultrasonic anemometers mounted at the same height with different directions (north and west) for validating the measured fluctuating speeds. The fidelity of instruments is well examined before further analysis by comparing firstly their average value with $T = 10$ min with the cup-type anemometers on this tower. To avoid the interference effects of the tower on wind, anemometers are fixed 1.5 m away from the tower in the north which is in the upwind direction of the tower during dominant synoptic wind in Beijing during winter and spring. Hence, the meteorological tower is the best observation station to study the urban intense storm of Beijing at present. The nine ultrasonic anemometers in the north at different levels along the tower from 8 to 280 m are applied for the following analyses.

3 SEPERATION AND CATALOGUING OF THUNDERSTORM

The separation of intense wind phenomena into homogeneous families is a fundamental step to interpret the events of engineering interest and to deal with them by models coherent with their physical reality. To achieve the separation and classification of different intense wind events as easily and efficiently as possible, a semi-automated procedure was proposed in [7] and improved in [8] selecting those records with the horizontal 1-s peak wind velocity greater than 15 m/s. Based on it, the analysis of the data recorded by 14 ultrasonic anemometers of the WP and WPS network in the period 2010-2016 led to the extraction of 141 strongly non-stationary thunderstorm outflows related to the 10-min family (the presence of an evident peak is clear over 10-min periods) [8].

The examination of the data detected by the Beijing meteorological tower shows that the semi-automatic procedure implemented for the northern Mediterranean area is also applicable to its measurements. According to this approach and to the data recorded by 9 ultra-sonic anemometers during the period 2013-2017, 339 strongly non-stationary records are extracted that can be traced back to convective conditions and thunderstorm outflows. Transient records are separated into five groups as a function of the peak wind speed as shown in Table 1. This classification is aimed at recognizing the existence of any correlation between the height and its wind speed; of course, intense events with high wind speed are the most relevant hazard from a structural viewpoint. The results also point out that around 37 % of the thunderstorm outflow records whose peak wind speed exceeds 20 m/s can be found for all the anemometers from 8 m to 280, similar to the results in the northern Mediterranean. Only the anemometers higher than 64 m detected the thunderstorm outflow records whose peak wind speed exceeds 30 m/s, which surely should be considered for the design of structures. It is worth mentioning that the same thunderstorm event may be detected by several anemometers simultaneously. In this regard, the total number of events labelled as thunderstorms in the considered period is 77.

Table 1. Classes of membership of the peak wind velocity of thunderstorm outflows.

Anem.(m) / V (m/s)	8	16	32	47	64	80	140	200	280	ALL
15-20	7	14	19	25	32	26	29	28	34	214
20-25	3	3	7	8	7	13	15	14	14	84
25-30	0	1	2	2	3	2	7	7	6	30
30-35	0	0	0	0	1	1	2	2	2	8
35-40	0	0	0	0	0	0	1	1	1	3
ALL	10	18	28	35	43	42	54	52	57	339

4 DIRECTIONAL SIGNAL DECOMPOSITION

Based upon the new directional decomposition strategy introduced in [9], each horizontal velocity component (V_X,V_Y) is decomposed into a slowly-varying mean speed $\left(\bar{V}_X,\bar{V}_Y\right)$ evaluated by a moving average filter with period T = 30 s, and a residual fluctuation $\left(V'_X,V'_Y\right)$. The slowly-varying horizontal mean wind velocity vector is defined in terms of wind speed and direction as:

$$\bar{u}(t)=\sqrt{\bar{V}_X^2(t)+\bar{V}_Y^2(t)},\bar{\alpha}(t)=270-a\tan 2\left(\frac{\bar{V}_Y(t)}{\bar{V}_X(t)}\right) \tag{1}$$

where $\bar{\alpha}\in[0:360]$ according to the geographical notation.

The residual fluctuations are then projected onto a new Cartesian reference system (x,y), where the x-axis coincides with $\bar{u}(t)$. Thus:

$$u'(t)=-V'_X(t)\sin\bar{\alpha}(t)-V'_Y(t)\cos\bar{\alpha}(t),v'(t)=V'_X(t)\cos\bar{\alpha}(t)-V'_Y(t)\sin\bar{\alpha}(t) \tag{2}$$

where u' and v' are referred to as the longitudinal and lateral turbulent fluctuations. They are rewritten as the product of their slowly-varying standard deviations ($\sigma_{u'}$,$\sigma_{v'}$) by a couple of reduced longitudinal and lateral turbulent fluctuations $\left(\tilde{u}',\tilde{v}'\right)$. Accordingly, the longitudinal and lateral components of the wind velocity may be expressed as:

$$\begin{aligned} u(t) &= \bar{u}(t)+u'(t)=\bar{u}(t)+\sigma_u(t)\tilde{u}'(t)=\bar{u}(t)\left[1+I_u(t)\tilde{u}'(t)\right] \\ v(t) &= v'(t)=\sigma_v(t)\tilde{v}'(t)=\bar{u}(t)I_v(t)\tilde{v}'(t) \end{aligned} \tag{3}$$

where $I_u(t)=\sigma_u(t)/\bar{u}(t)$ and $I_v(t)=\sigma_v(t)/\bar{u}(t)$ are the longitudinal and lateral slowly-varying turbulence intensities, respectively.

5 CONCLUSION AND PROSPECT

The characteristics relevant to the wind loading of structures of thunderstorm outflows in northern Mediterranean were presented in previous research by a novel directional decomposition approach. Recently, a dataset detected in Beijing urban area provides an opportunity to create a new catalogue of thunderstorm outflows and study herein their key parameters. This makes it possible to compare the statistical characteristics of thunderstorm outflows with regard to these two catalogues, which is crucial to learn if thunderstorm outflows are similar in different areas and to develop a unitary model. Further studies are still in progress and will be reported in the full paper.

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