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Vertical time-space evolution of wind field and temperature during the thunderstorm event on June 10, 2016 in Beijing

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SUMMARY:
The wind field of thunderstorm outflows is significantly different from that of synoptic winds. Most of the wind velocity measurements in the course of thunderstorm outflows available in the literature are provided by single instruments, whereas simultaneous measurements at the same location are needed to reconstruct the vertical wind profiles in terms of mean and turbulent components. The ultrasonic anemometers mounted at nine different heights, from 8 m to 280 m above ground level (AGL), along the 325 m high meteorological tower in Beijing provide the opportunity to inspect the vertical time-space structure and evolution of the wind fields of thunderstorm outflows that occur in this region. Herein, the horizontal and vertical fluctuating wind speed components of a typical thunderstorm outflow case is inspected using the analysis reported in Canepa et al. (2020). Also, the temperature change during the occurrence of the event further confirms the nature of the meteorological phenomenon and may give validation on the time and space stage recorded by the tower.

Keywords: thunderstorm outflow; vertical wind profile characteristics; Beijing urban area

1. INTRODUCTION

The understanding of the wind field characteristics during thunderstorms is key to the structural design for resistance to these events (Zhang et al., 2018a). Despite some previous analyses, the knowledge of the impact of thunderstorms on the built environment is quite fragmentary and a robust and shared framework is still lacking (Solari, 2014). Their short duration and small size make still a limited number of reliable data available overall. Besides, there is no systematic research conducted about the vertical time-space structure of thunderstorm outflows in Beijing. Thanks to the Beijing 325 m high meteorological tower, equipped with 9 ultrasonic anemometers, a catalogue of 70 thunderstorms was created in a previous research (Zhang et al., 2019), which provides a unique opportunity to shed new light on this crucial issue.

Section 2 illustrates the main properties of the field measurements and the catalogue of thunderstorm outflows mentioned above. Section 3 describes a specific thunderstorm event that occurred on June 10, 2016. Then, the vertical time-space structure of the slowly-varying mean wind speed, direction and temperature is analysed in Section 4. Finally, conclusions are reported in Section 5.

2. FIELD MEASUREMENTS AND THUNDERSTORM CATALOGUE

Fig. 1 shows a photo of the 325 m high meteorological tower in Beijing. The tower is a steel tube truss structure with equilateral triangular cross section located in the Northern 3rd Ring Road. According to the Chinese National Load Code (GB50009-2001), the site around the tower can be regarded as terrain C (an urban area). The records from 9 three-axial ultrasonic anemometers mounted at different heights along the tower, (8, 16, 32, 47, 64, 80, 140, 200, 280 m) are used for the analysis. This is the best observational station to study the urban boundary layer and intense storms in Beijing city. The anemometric data of the database is stored in terms of three instantaneous wind speed components (V_X, V_Y, V_Z), recorded with a sampling rate of 10 Hz.

Figure 1. Photo of the Beijing 325m high meteorological tower.

Zhang et al. (2019) extracted from the database 314 strongly non-stationary records that can be traced back to convective conditions and thunderstorm outflows which occurred from 2013 to 2017. Extraction was performed by a semi-automated procedure (De Gaetano et al., 2014; Zhang et al., 2018b) using a threshold on the horizontal 1-s peak wind speed $\hat{V}$ of 15 m/s. Totally, the number of events labelled as thunderstorms in the 5 years is 70, which is smaller than the number of thunderstorm outflow records because the same thunderstorm event is detected by all anemometers simultaneously.

3. THE THUNDERSTORM EVENT ON JUNE 10, 2016

Herein, the thunderstorm event that occurred on June 10, 2016 is analyzed. From the meteorological point of view, under the influence of the Northeast China cold vortex (i.e. a high-altitude vortex often active in the north-eastern region of China) and the low-level warm and humid airflow, a severe thunderstorm with 5 consecutive hailstorms broke out in the afternoon of June 10, 2016 in Beijing. In the mature stage of this process, three isolated cells were triggered in sequence and finally merged, resulting in waterlogging, collapse of some signboards on buildings and damage of vehicles in some areas of Beijing.

The vertical time-space structure of the wind field measured at the tower is shown in Fig. 2. Fig. 2 (a) presents the 1-h long time series of the wind speed (black) and wind direction (red) recorded at 32 m. A rapid and strong jump of the wind speed occurred at about 3 p.m. (15:00 BJT, Beijing time) when the thunderstorm outflow reached the tower. Simultaneously, the wind direction shifted about 180° from south-east to north-west. In addition, the temperature dropped by about 5 ℃, as shown in Fig. 2 (b).

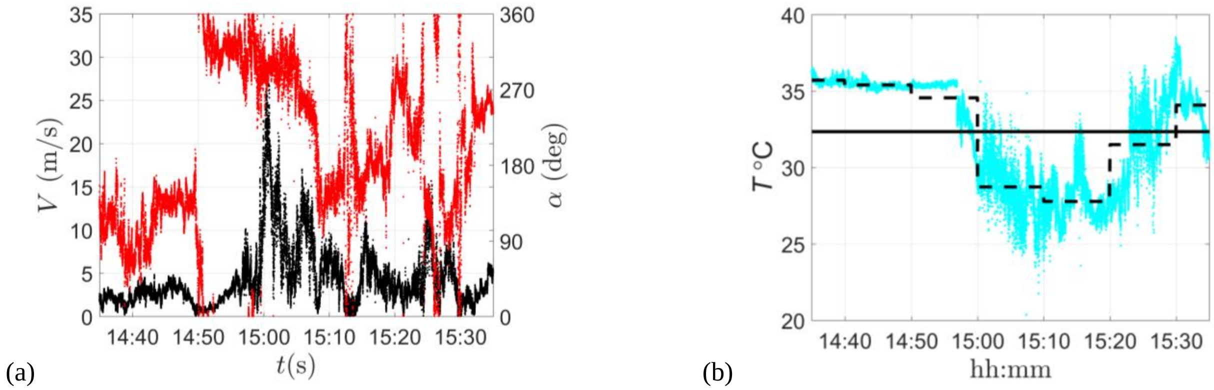

Figure 2. 1-h time history of wind speed (black) and direction (red) (a) and temperature (b) at 32 m AGL.

4. MAIN CHARACTERISTICS OF THE VERTICAL WIND PROFILES

The analysis already performed by Canepa et al. (2020) to LiDAR vertical profiles is applied to the thunderstorm outflow measurements described in Section 3. Fig. 3 depicts the 30-min diagrams of the horizontal and vertical 30-s slowly-varying mean wind speed, direction, and temperature ($\bar{V}(t)$, $\bar{w}(t)$, $\bar{\alpha}(t)$, T(t), respectively) centred on the occurrence of the maximum horizontal mean wind speed at 32 m, i.e., height of maximum gust factor in a 10-min interval, $G_{10} = \hat{V}/\bar{V} =$ 3.67 ($\bar{V}$ is the mean wind speed in the same 10-min interval of detection of $\hat{V}$).

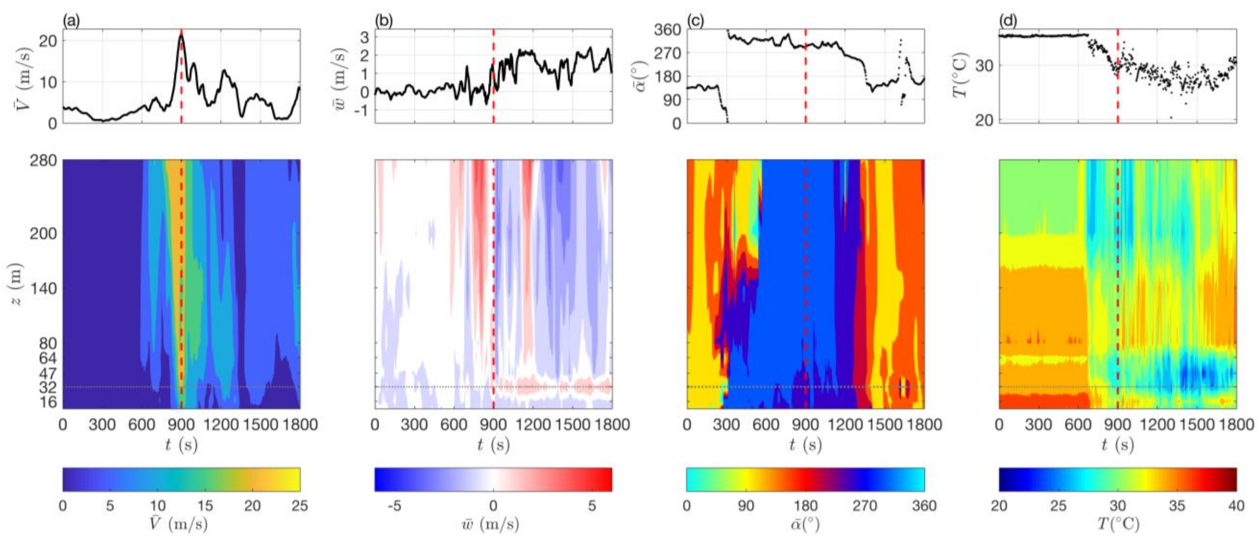

Figure 3. 30-min horizontal (a) and vertical (b) slowly-varying mean wind speed; 30-min slowly-varying mean wind direction (c) and temperature (d). Time histories at 32 m AGL (upper pictures); interpolated magnitude-maps as function of time and height (bottom pictures).

At about 900 s, when the spike of the horizontal wind speed occurs, Fig. 3 (a) points out a rapid increase of the mean wind speed that occurs up to the top measurement height, which means that the primary vortex (PV) of the thunderstorm is higher than the meteorological tower. It is also worth noting that the duration of the spike increases on increasing the height. Fig. 3 (b) shows the vertical component of the wind velocity, which is positive upwards. Slightly before the peak of $\bar{V}(t)$, the maximum positive values observed at the higher elevations could be due to the frontal part of the PV. Then, after the peak of $\bar{V}(t)$, the negative sign of $\bar{w}$ at higher elevations suggests that the PV has passed over the instrument. The positive and negative values of $\bar{w}$ after about 1200 s might be related to a trailing vortex after the PV, which is confirmed by a secondary peak of $\bar{V}(t)$. Finally, slightly before 1500 s, the negative $\bar{w}$ of the impinging-jet like flow suggests that the downdraft is passing over the tower. Fig. 3 (c) depicts the two changes of the wind direction that occur at about 300 s and 1300 s; the duration of this directional shift is a measure of the duration of the whole thunderstorm as recorded by the instruments. Fig. 3 (d) illustrates the sudden decrease of temperature near the ground, which is related to the cold pool carried by the outflow after the downdraft impinged on the ground.

5. CONCLUSIONS

The catalogue of thunderstorm outflows created from the data recorded by the Beijing 325 m meteorological tower provides an opportunity to study their key parameters in the Beijing urban area. Based on the measured data, the vertical evolution of the wind field and temperature with time in a typical thunderstorm event in Beijing is investigated. This also makes it possible to compare their characteristics with those measured in other areas, e.g., in the Mediterranean area (Canepa et al., 2023), which is crucial to learn whether thunderstorm outflows are all similar in different places around the world to eventually describe them through a unique model.

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