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Characteristics of a thunderstorm downburst measured in a suburban area

Characteristicile unei furtuni măsurate în zonă suburbană

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Abstract. *This paper analyses a thunderstorm downburst record measured by a monitoring system installed on a 50 m high telecommunication lattice tower. The structure is located in the suburbs of Afumați, Ilfov County, approximately 15 km from Bucharest, the capital city of Romania. The monitoring system was developed under the SEVAST research project which aims at identifying the full-scale behaviour of a telecommunication lattice tower subjected to synoptic and non-synoptic winds. Since its implementation, the system has captured more than 10 thunderstorms. In this paper, the statistical parameters of the wind velocity measured during a thunderstorm downburst measured on May 7th 2024 are evaluated.*

Key words: *thunderstorm downburst, full-scale monitoring, lattice tower, wind*

1. Introduction

Research on thunderstorms and their effect on structures has been developed for more than forty years around the world in an effort to identify their characteristics and establish guidelines for design practice [1]. However, current wind loading codes still make use of traditional techniques developed based on the synoptic extra-tropical cyclone model which assumes statistical stationarity and logarithmic wind velocity profiles [2]. This is partly due to the scarcity of quality full-scale data and partly to the lack of consensus regarding the characteristics of thunderstorms needed for engineering design. Thunderstorms show considerable differences from boundary layer winds, both in terms of meteorological phenomena producing each type of wind and in terms of wind flow characteristics relevant for structural response, such as velocity profiles, turbulence intensity gust factors. Field detection and instrumentation

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of real structures is of paramount importance in evaluating these differences and advancing the knowledge in thunderstorm research.

One of the first field programs to study thunderstorms, namely NIMROD (Northern Illinois Meteorological Research on Downbursts), was carried out by Fujita in 1978 [3] with the aim to depict the structure of downbursts by using Doppler radars and anemometers installed in the suburbs of Chicago, USA. Subsequently, a second monitoring network named JAWS (Joint Airport Weather Studies) was established in 1982, to understand the mechanism of microbursts which were the cause of a number of accidents involving aircrafts at the time [3]. More recent studies have focused on identifying thunderstorm characteristics based on downbursts measured by classical meteorological weather stations [4-6] or anemometric records [7-9] as well as differences between downburst and atmospheric boundary layer (ABL) induced loading on low-rise buildings [10] or slender steel structure [11,12].

This paper describes the characteristics of a thunderstorm downburst measured by a wind and structural monitoring system installed on a 50 m tall telecommunication lattice tower located in a suburban area approximately 20 km North-West of Bucharest, the capital city of Romania. Section 2 presents the site and tower characteristics. In Section 3, the monitoring system is described while Section 4 presents the characteristics of the thunderstorm record. Finally, Section 5 presents the main conclusions of the paper.

2. Site and tower characterization

The tower is located on the outskirts of Afumați (Fig. 1a), the site being characterized by different terrain categories according to the Romanian wind code CR1-1-4/2012 [13] i.e. terrain category II (roughness length z_0=0.05m) for North-East and South-West directions and terrain category III (roughness length z_0=0.3m) for South-East and North-West directions, the reference wind velocity being v_b=25.30 m/s. Assuming a logarithmic mean wind profile, the design wind parameters evaluated on a 10-min interval at heights of 10 m and 50 m are summarized in Table 1.

Table 1

Design wind parameters at the Afumați site evaluated based on CR 1-1-4/2012 [13]

Parameter	H=10 (m)		H=50 (m)	
	Category II	Category III	Category II	Category III
Mean wind velocity, v_{m10}^0 (m/s)	25.47	19.10	33.02	27.87
Peak wind velocity, v_p^0 (m/s)	43.12	37.05	50.82	45.82
Gust factor, G_{10}^0	1.70	1.93	1.54	1.64
Turbulence intensity, I_v	0.20	0.26	0.15	0.18

The monitored structure is a 50 m high telecommunication lattice tower having a triangular in-plane section (Fig. 1b). The tower is divided into 10 sections of approximately equal heights. The bottom 5 sections are made up of inverted V-bracing systems whereas the upper 5 sections are made up of N-bracing systems. All the structural elements of the tower are made of hollow circular cross-sections. Along the tower height there are two resting platforms at 15 m and 27.50 m as well as two working platforms at 40 m and 47.50 m. Various ancillary elements are supported by the tower amounting to approximately 4.5 tons. The total mass of the structure comprising structural and ancillary elements is 13.7 tons.

(a)

(b)

Fig. 1. (a) Location of monitoring system (North aligned vertically) and (b) the monitored tower

3. The monitoring system

The monitoring system (Fig. 2) is made up of (*i*) meteorological sensors, comprising an ultrasonic anemometer and a four-camera video system, (*ii*) structural monitoring sensors, including three strain gauges and one triaxial accelerometer, (*iii*) data acquisition system, comprised of a datalogger and modules located in the shelter at the base of the structure. The ultrasonic anemometer has a sampling frequency of 10 Hz and is able to measure wind speed, wind direction and ambient temperature. It is installed on a leg member at the top of the tower. A four-camera video system was installed on the tower to complement the meteorological sensors. Three cameras were installed at 12 m and are pointing to the horizon to capture cloud formations and evolution whereas one camera was installed at 15 m and is pointing towards the shelter for surveillance aim. Each video camera has a 120^{o} angle range approximately centered on the North-East, South-West and North-West directions. The triaxial accelerometer is installed at 50 m on a tower leg and has a sampling rate of 125 Hz. Finally, the strain gauges are installed at the tower base on the three leg members and have a sampling frequency of 100 Hz. The datalogger is installed in the shelter located at the base of the tower. It stores the data corresponding to all sensors on a continuous basis and transmits it to the server located at the Technical University of Civil Engineering Bucharest (UTCB).

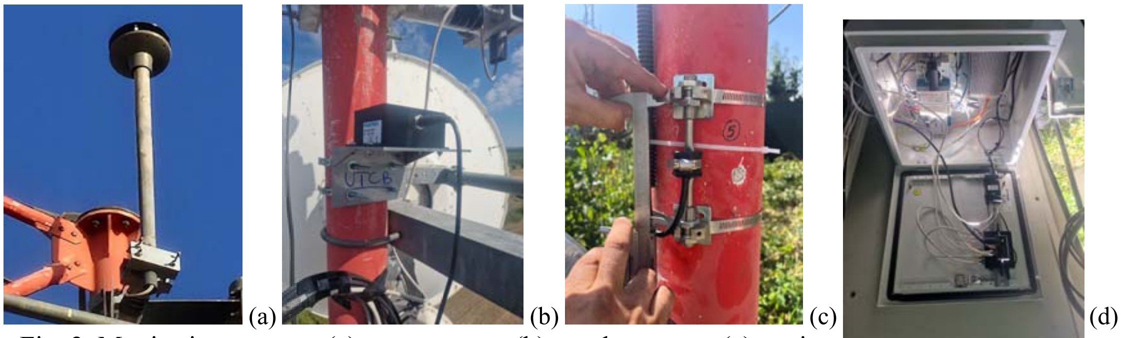


Fig. 2. Monitoring sensors: (a) anemometer, (b) accelerometer, (c) strain gauge and (d) datalogger

4. Thunderstorm characteristics

Thunderstorm records are generally characterized by a sudden increase (ramp-up) and decrease (ramp-down) in wind velocity observed in a short interval of time; sometimes it is coupled with a sudden drop in temperature and a change in wind direction. A thunderstorm record may also be characterized by large peak velocities and gust factors defined as the ratios between the peak and the mean wind speed on the specified averaging time interval.

Classification and separation of records from anemometric data [14] may be done by means of quantitative controls mainly based on expert judgement of the wind velocity time history patterns and qualitative controls expressed in terms of gust factor ratios defined as G_1/G_{10}, G_{10}/G_{10}^0 and G_{60}/G_{60}^0 where 10 and 60 represent the wind speed averaging time interval expressed in minutes and 0 indicates the reference values (Tab. 1). Three categories of records are considered: depressions (D), gust fronts (F) and thunderstorms (T) determined by considering a threshold of 15 m/s of the peak wind velocity averaged on 1-s.

In this paper, a thunderstorm record measured on May 7th 2024 extracted based on the above-mentioned procedure [14] is analysed and its main statistical parameters are evaluated. Figure 2 shows the cloud formation during the event as recorded by the video cameras. The downdraft is mostly visible in the NW direction which is in agreement with the direction measurements acquired by the anemometer. The radar images captured at the time of the event and published on the website of the Romanian National Meteorological Administration confirm the occurrence of the thunderstorm.

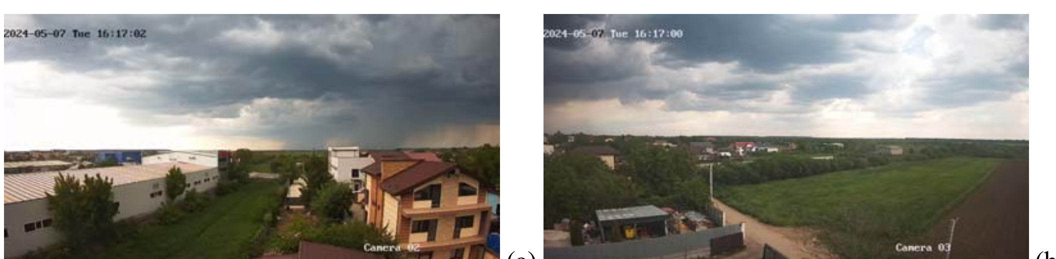


Fig. 3. Snapshots taken during the May 7th 2024 event at 16:17 EEST (a) NW and (b) NE directions

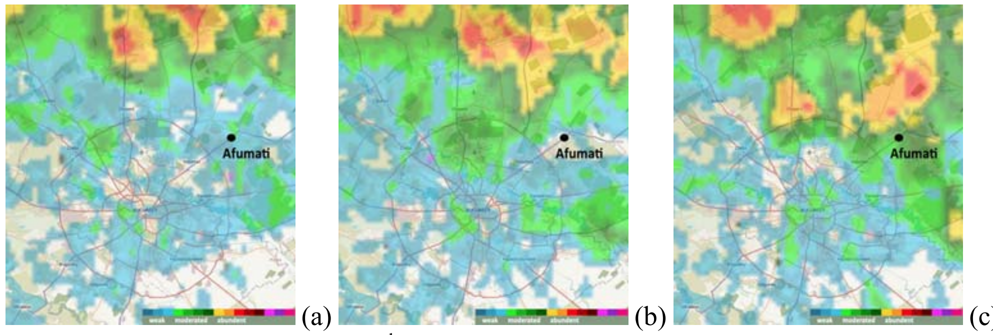


Fig. 4. Radar images on May 7th 2024 at: (a) 16:21, (b) 16:31 and (c) 16:41 EET (https://www.meteoromania.ro/)

Figure 5 shows the variation of the wind speed and wind direction together with their respective Probability Density Functions (PDF) within a 10-min interval centered around the peak velocity. The ramp-up and ramp-down of this thunderstorm are clearly visible in the 10-min interval. The total duration of the event was approximately 5 minutes. The temperature dropped by approximately 5 ºC and the wind direction changed gradually from 180 to 270 degrees. The registered instantaneous peak wind speed was v_{max} = 20.3 m/s whereas the 10-min mean wind speed was $\overline{v}_{\mathrm{m}10}$= 9. 82 m/s. The skewness and kurtosis resulted s=0.83 and k=3.28 respectively which deviate considerably from the normal distribution. Finally, the 10-min gust factor defined as $G_{10} = v_{\max} / \overline{v}_{10}$ resulted G_{10}=2.07 which much larger that the code-recommended one (Tab. 1).

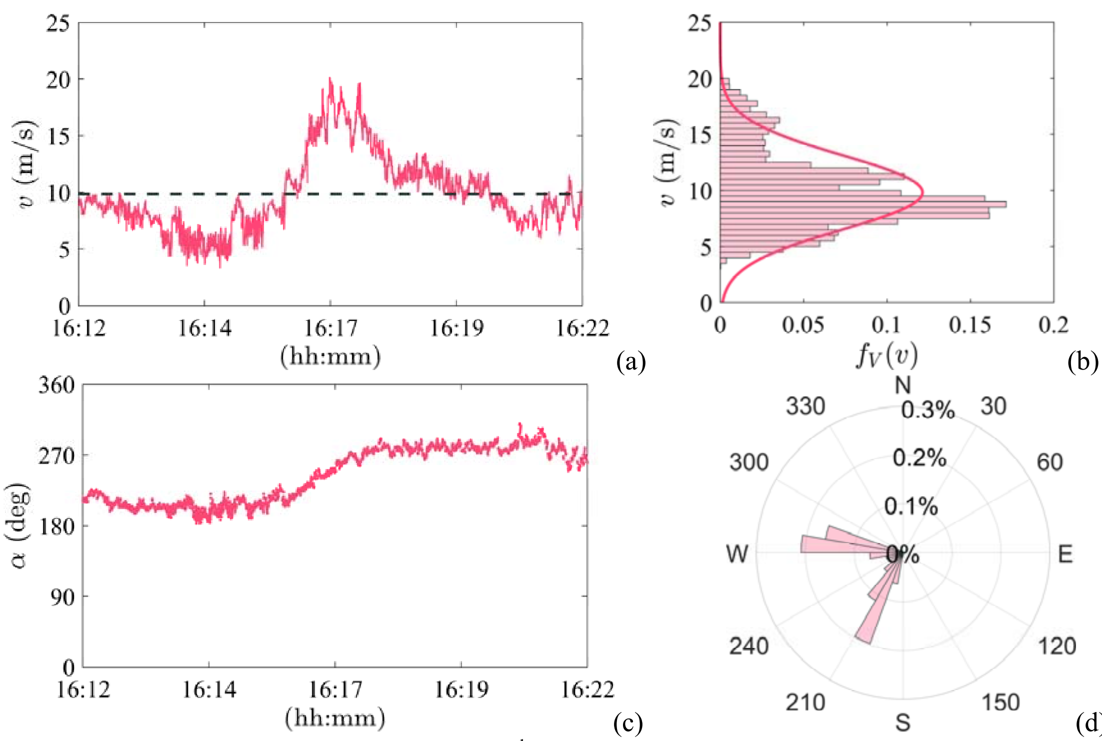


Fig. 5. Thunderstorm event recorded on May 7th 2024: (a) wind speed, (b) wind direction, (c) PDF of wind speed and (c) PDF of wind direction in 10-min

The decomposition of the velocity records associated with thunderstorms is expressed as [15]:

$$v(t)=\bar{v}(t)+v'(t)=\bar{v}(t)+\sigma_v(t)\tilde{v}'(t)=\bar{v}_{\max}\gamma(t)\left[1+\bar{I}_v\mu(t)\tilde{v}'(t)\right] \quad (1)$$

where t is the time, $\bar{v}$ is the slowly varying mean wind velocity and v' is the residual fluctuation extracted by making use of the moving average filter considering a moving average period T = 30 s [15], σ_v is the slowly varying standard deviation of v', $\tilde{v}'$ is the reduced turbulent fluctuation, I_v represents the slowly varying turbulence intensity and γ and μ represent two non-dimensional ratios defined as:

$$\gamma(t)=\bar{v}(t)/\bar{v}_{\max} \quad (2)$$

$$\mu(t)=I_v(t)/\bar{I}_v \quad (3)$$

where $\bar{v}_{\max}$ is the maximum value of the slowly-varying mean wind velocity of $\bar{v}$ and $\bar{I}_v$ is the value of I_v averaged on a 10-min interval. Some noteworthy wind velocity ratios of thunderstorm records are given by [15]:

$$R=v_{\max}/\hat{v} \quad (4)$$

$$G_{\max}=v_{\max}/\bar{v}_{\max} \quad (5)$$

$$\hat{G}=\hat{v}/\bar{v}_{\max} \quad (6)$$

where $\hat{v}$ is the 1-s peak wind velocity. The wind velocity decomposition of the selected thunderstorm record is shown in Figure 6.

The turbulence characteristics of thunderstorm wind record were evaluated based on the residual fluctuation component, v' (Eq. 1) obtained from the wind velocity decomposition in 10-min (Fig. 6). The mean value of the slowly varying turbulence intensity resulted $\bar{I}_v$ = 0.08. The integral length scale of turbulence, L_u, was determined by fitting the experimental PSD to the model proposed by Solari and Piccardo [16] resulting L_u = 19.25 m. Figure 7 shows the Power Spectral Density Functions (PSD) of the residual fluctuation component, v' (Eq. 1) and the normalized PSD corresponding to the May 7th 2024 thunderstorm record. A good fit is obtained in the inertial sub-range as emphasized by the slope of the curve n-5/3 shown with black continuous line on Figure 7a. Moreover, a good fit match me be observed between the normalized PSD obtained from measurements and the theoretical PSD [16].

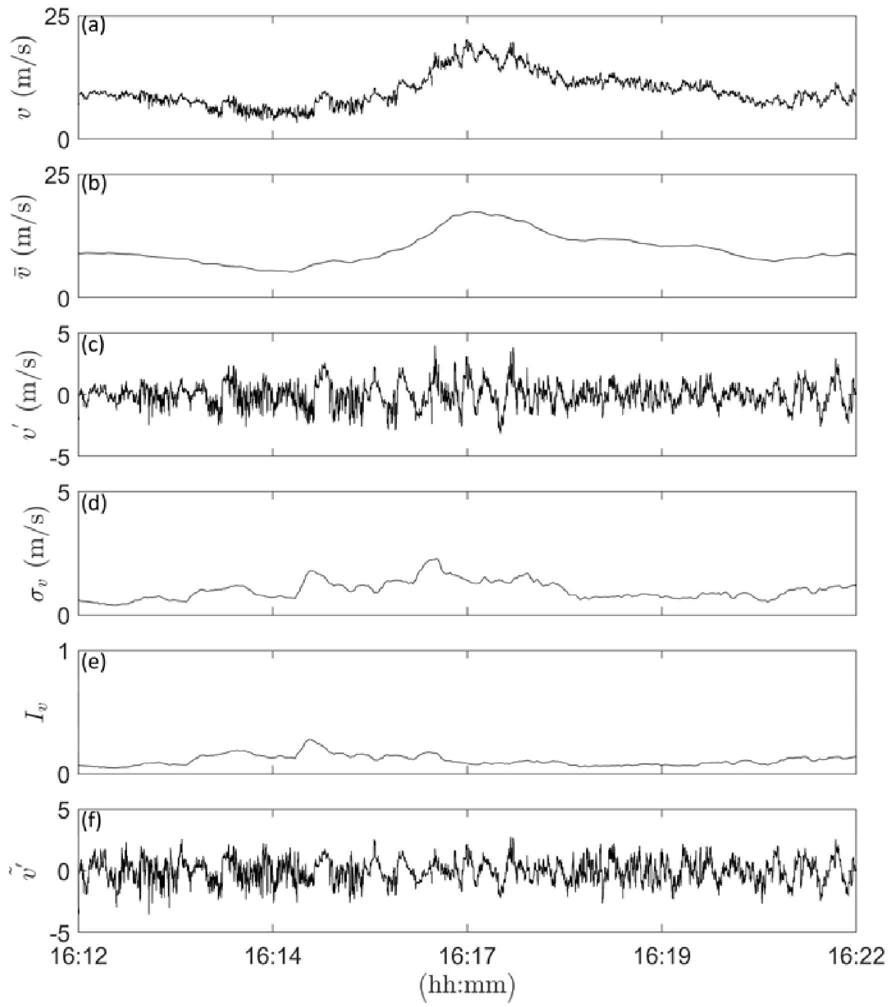
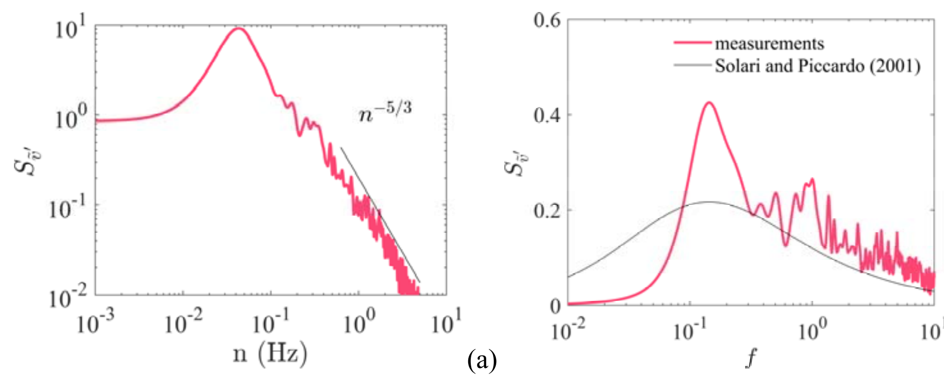


Fig. 6. Wind velocity decomposition in 10-min: (a) v, (b) $\overline{v}$, (c) v', (d) σ_v, (e) I_v and (f) $\tilde{v}'$



(a) (b)

Fig. 7. (a) PSD and (b) matching between the measured and the theoretical normalized PSD

The time period during which thunderstorms develop their maximum intensity may be defined in terms of the non-dimensional γ function (Eq. 2) shown in Figure 8a.

The maximum value of the slowly-varying mean wind velocity, $\overline{v}_{\max}$ occurs at t=0 while t_i and t_d indicate the conventional limiting values of t for which the most intense part of the thunderstorm occurs [15]; these values correspond to γ = 0.6 which represents a wind velocity pressure equal to 36% of its maximum value. The total duration of the most intense part of the May 7th 2024 thunderstorm resulted 200 s which is in agreement with literature results [15]. Finally, Figure 8b shows the μ function of the selected thunderstorm record which is a measure of turbulence intensity.

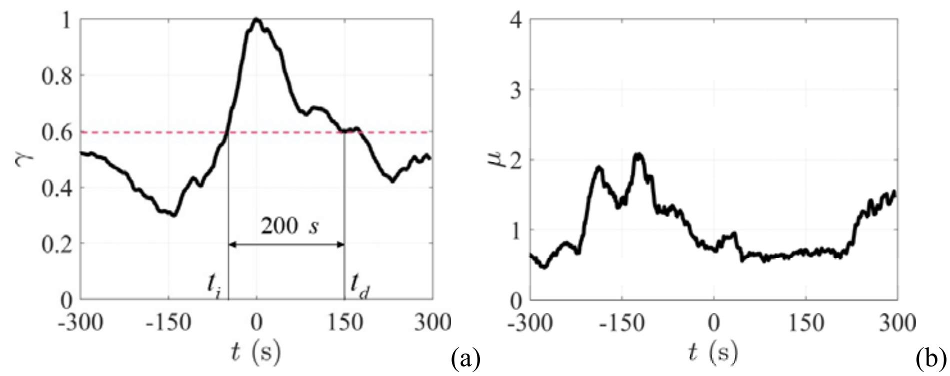


Fig. 8. (a) γ function and (b) μ function for the May 7th 2024 thunderstorm record

Finally, Table 2 shows the values of the noteworthy parameters of the wind velocity record measured on May 7th 2024 compared to similar results provided in literature. As it may be seen, very similar results are obtained between the May 7th 2024 record and thunderstorms measured in Romania [12] while a slight difference may be noticed when results are compared to thunderstorms measured in Italy [15]. This might be caused by the different climate and location of the anemometric stations. The monitoring system described in [12] is located in a flat, open field while the monitoring systems described in [15] are located near costal regions.

Table 2

Comparison between noteworthy parameters of the wind velocity record measured on May 7th 2024 and literature results

Parameter	$v_{\max}$ (m/s)	$\hat{v}$ (m/s)	$\overline{v}_{\max}$ (m/s)	$\overline{v}_{m10}$ (m/s)	$\overline{I}_v$	L_u (m)	R	$G_{\max}$	$\hat{G}$
Value	20.3	20.15	17.83	9.82	0.08	19.3	1.00	1.14	1.13
Solari et. al, 2015 [15]					0.12	34.6	1.06	1.27	1.20
Calotescu et. al, 2025 [12]					0.08	54.5	1.03	1.15	1.12

5. Conclusions and prospects

This paper presents the statistical characteristics of a thunderstorm record measured near Bucharest, Romania in a suburban terrain category. The record was captured by a wind and structural monitoring system installed on a 50 m telecommunication lattice tower which has been continuously running since September 2023.

The thunderstorm record was measured on May 7th 2024 and was extracted based on a separation and classification methodology which makes use of gust factor ratios and expert judgement in order separate synoptic from non-synoptic wind records. In this paper, video camera images of the cloud formation during the event together with radar data was used in order to validate the identified thunderstorm record. The resulted thunderstorm characteristics such as gust factor ratios, turbulence intensity, integral length scale of turbulence and thunderstorm duration show good agreement with similar results available in literature, especially for monitoring systems located in similar climatic conditions and terrain category.

The monitoring system presented in this paper is the second developed by the authors in Romania in an effort to collect long term continuous and synchronous wind and structural thunderstorm data. The first system was installed in Sânnicolau Mare, Romania [12] on a 50 m lattice tower identical to the one presented in this paper with the only difference being the number and position of ancillary elements. Prospects of this study include identifying similarities and differences between the two monitoring systems both in terms of thunderstorm wind velocities as well as the thunderstorm-induced response of the two towers.

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