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Thunderstorm characteristics from wind-field monitoring: analysis and prospects

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SUMMARY
This paper presents the analysis of a dataset comprising full-scale wind velocity records acquired by a wind and structural monitoring system located in Afumați, Ilfov County Romania. The monitoring system is installed on a 50 *m* tall telecommunication lattice tower and has been running continuously since its installation in 2023. The system was originally designed to include a single ultrasonic anemometer positioned at 50 *m* and it was later on completed with a meteorological station positioned at 30 *m*. This allows the characterization of thunderstorms in one or two points but is not sufficient to investigate the wind velocity profile development during such events. A new monitoring system is being developed within the PREPARE project which will be installed on a 200 *m* freestanding telecommunication lattice tower located in Bucharest. The new system will include 6 ultrasonic anemometers and 2 meteorological stations which will be positioned along the height of the tower with the aim of measuring thunderstorm winds and their vertical profiles.

Keywords: thunderstorms, monitoring system, lattice tower

1. INTRODUCTION

Thunderstorm winds have been responsible for significant structural damage worldwide (Loredo-Souza et al. 2019; Virman et al. 2025). Unlike boundary layer winds generated by large-scale atmospheric pressure systems, thunderstorm winds originate from convective processes and exhibit fundamentally different characteristics including rapid onset, non-stationarity, elevated gust factors, and distinct turbulence structure (Fujita 1990; Solari et al. 2015; Calotescu et al. 2025). These differences have critical implications for structural loading and dynamic response of slender structures.

Thunderstorms form when precipitation-cooled air descends rapidly from the cloud base, creating negative buoyancy that accelerates the downdraft. Upon impinging on the ground, the descending column spreads radially outward, generating intense horizontal winds that can exceed 50 *m/s* in extreme cases (Fujita 1985; Hjelmfelt 1988). This radial outflow structure results in velocity profiles, turbulence characteristics, and temporal evolution patterns which deviate significantly from the logarithmic profiles and stationary assumptions (Choi 2004; Holmes et al. 2008; Canepa et al. 2020; Solari 2020). Despite significant advances over the past two decades, substantial knowledge gaps remain in the understanding of thunderstorm wind characteristics, especially concerning vertical profiles of wind velocities produced by thunderstorms.

Recent field measurement campaigns have provided important but often conflicting evidence on the vertical structure of thunderstorm wind profiles, highlighting the need for further site-specific investigations. LiDAR measurements in the Northern Tyrrhenian Sea identified a nose-shaped profile with maxima between 50 and 120 *m* during the ramp-up and peak stages (Canepa et al. 2020), tall-tower measurements in Shenzhen confirmed the time-varying nature of the profile, transitioning from nose-shaped to log-like during dissipation (Liu et al. 2023), while multi-site measurements in the United States found that the mean normalised profile closely resembles standard ABL profiles up to 120 *m* (Lee and Lombardo 2026). These discrepancies across measurement sites and climatic regions underscore that the vertical wind profile developed within a given location is strongly conditioned by local atmospheric and topographic conditions

This paper presents thunderstorm characteristics determined based on measurements from an existing monitoring system and introduces a new monitoring system to be acquired and installed within the PREPARE project with the purpose of measuring thunderstorm profiles. The new system will be installed on the tallest freestanding telecommunication lattice tower in Romania.

2. THE MONITORING SYSTEMS

The existing monitoring system is installed on 50 *m* tall telecommunication lattice tower (Fig. 1a) located in Afumați, 20 *km* North-East of Bucharest, the capital city of Romania. The complete system comprises an ultrasonic anemometer (Thies Clima), a triaxial MEMS accelerometer, a data acquisition system (datalogger and modules) and a video monitoring system. This system was designed to acquire continuous wind and structural data at the top of the tower where both sensors were installed.

The new monitoring system will be installed on a 200 *m* tall telecommunication lattice tower located in Bucharest, one of the largest tower in Romania. The height of the tower allows for the installation of a multi-height system which will be able to acquire thunderstorm velocity profiles. The system will comprise 8 wind sensors (6 ultrasonic anemometers and 2 meteorological stations) and triaxial accelerometers. The wind sensors will be able to measure wind velocities and directions while the meteorological stations will additionally measure precipitation, atmospheric pressure and ambient illuminance (brightness).


(a)

(b)

Figure 1. (a) The Afumați tower and (b) the Bucharest tower

3. THUNDERSTORM CHARACTERISTICS

During its installation, the Afumați monitoring system has captured 23 thunderstorms records, mostly during the summer months of 2024 and 2025 (Fig. 2). Out of the 23 records, on July 17th, 2025, an extreme thunderstorm that produced peak velocities exceeding 40 *m/s* was recorded. The thunderstorm produced considerable damage in Bucharest and Ilfov County including roof damage to several buildings, tree and car damage and even loss of life.

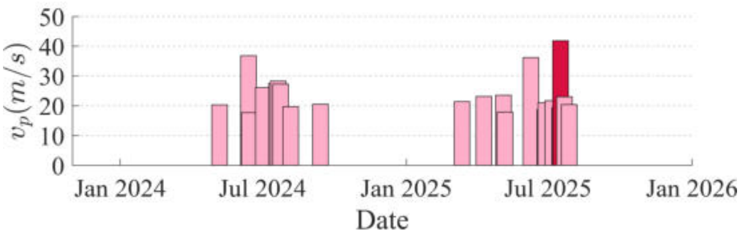

Figure 2. Timeline variation of the thunderstorm records; July 17, 2025 record is shown with red colour

Figure 3 shows the wind velocity, direction and temperature corresponding to the July 17th, 2025, thunderstorm within a 10 minutes interval centred on the peak. The ramp-up and ramp-down are clearly visible within a 10-min interval. The wind speed increased from 6 *m/s* to 41.8 *m/s* over a 5-minute period (rate of 0.12 *m/s²*). Within a 1-second time interval centred around the peak wind speed, a final surge from 16.4 *m/s* to 41.8 *m/s* (rate exceeding 25 *m/s²*) is observed immediately before the peak, followed by an equally sudden decrease from 41.8 *m/s* to 24.3 *m/s* (rate exceeding 17.5 *m/s²*). After the peak value is reached, a plateau of large peaks is observed for the next 2 minutes. The most intense part of the event has a duration of approximately 3 minutes. Over the 10-minute interval, wind direction shifted between 247° and 332°, indicating that the storm track did not pass directly over the measurement location. The event was also accompanied by a notable temperature drop of 13.6 °C across the full interval, with 9.1 °C of that decrease occurring during the ramp-up phase alone. Table 1 shows the characteristics of determined for this event such as the peak wind speed, the mean wind speed, the skewness and kurtosis as well as the gust factor within the 10 minutes interval showing a strong deviation from the Gaussian stationary records.

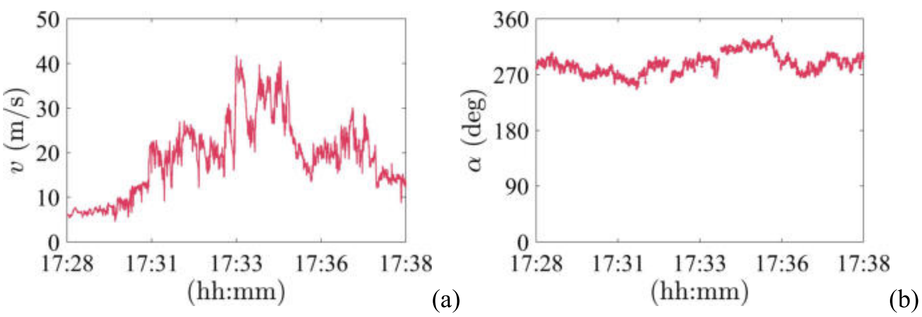

Figure 3. Thunderstorm event recorded on July 17, 2025: (a) wind speed (b) wind direction

Table 1. Characteristics of the July 17th 2025 thunderstorm record

Date	v_p (m/s)	v_{m10} (m/s)	s_{10}	k_{10}	G_{10}
July 17, 2025	41.8	18.91	0.34	2.65	2.20

4. CONCLUSIONS

This paper evaluated full-scale wind velocity data from the 50 *m* tall monitoring tower in Afumați, Romania, to analyse localized convective thunderstorm events. The extreme event recorded on July 17th, 2025, demonstrated highly non-stationary wind behaviour, with speeds exceeding 40 *m*/*s*, and temperature drops 13.6 °C and an elevated gust factor of 2.20, confirming a significant deviation from traditional Gaussian stationary boundary layer assumptions. While the current single-anemometer configuration in Afumați effectively tracks peak intensities at a single point, it remains insufficient for capturing complex spatial wind structures or tracking vertical profile transformations during convective outflows. To address these limitations, the upcoming PREPARE project monitoring system on the 200 *m* freestanding lattice tower in Bucharest will deploy a multi-sensor vertical array consisting of 6 ultrasonic anemometers and 2 meteorological stations. This expanded multi-height framework will provide the critical empirical data required to model full vertical thunderstorm wind profiles.

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