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Can idealised treefall patterns shed light on tornadoes?

Aleksander Pistol [1], Stefano Brusco [2], Daniel G. Butt [2], Mark Sterling [1,2], Fred L. Haan [3], Gregory A. Kopp [2]

[1]*Manchester Metropolitan University, Manchester, UK, a.pistol@mmu.ac.uk*
[2]*Western University, London, ON, Canada*
[3]*Calvin University, Grand Rapids, MI, USA*

SUMMARY
Treefall patterns are widely used as damage indicators for estimating tornado strength, particularly in sparsely populated boreal regions. Although this method benefits from the relatively uniform distribution of trees across large areas, it cannot be fully validated in the field as simultaneous wind velocity measurements are unavailable. This study presents the first attempt to address this limitation through wind tunnel model tests at WindEEE Research Institute. An idealised forest – constructed from uniformly spaced PVC tubes mounted on ball joints – was placed on a moving platform and translated through a spatially-stationary tornado-like vortex to simulate a tornado passing over a forested area. Wind velocities were recorded with four Cobra Probes, whilst two overhead cameras captured the resulting treefall patterns. This data allows direct comparison between measured wind fields and those estimated from analytical models based on the treefall patterns. The research is ongoing, and more results will be presented at the conference.

Keywords: forest damage, non-synoptic winds, experimental validation

1. INTRODUCTION

Damage surveys remain a key method for estimating near-surface tornado wind speeds, but their effectiveness depends strongly on landscape context. In urban areas, structural damage indicators provide relatively straightforward means of inferring lower-bound wind speeds, yet their sparse and uneven spatial distribution limits reconstruction of the full wind field (Rhee and Lombardo, 2018). These limitations, combined with the inherent variability of tornadoes, contribute to persistent gaps in observational data needed to support structural design.

In boreal regions, trees offer a more spatially continuous set of damage indicators. Although their mechanical variability introduces uncertainty in critical failure thresholds, treefall patterns allow tornadoes to be tracked across remote regions where conventional indicators are absent, such as in Canada, where ~25% of tornadoes occur in sparsely populated areas (Butt et al., 2025). Tree-based assessments have supported major advances in tornado documentation and climatology, including large-scale surveys undertaken through the Northern Tornadoes Project, hereinafter referred to as NTP (Sills and Elliott, 2024).

Recent developments have focused on extracting wind-field characteristics from treefall orientation patterns. Rhee and Lombardo (2018) introduced a framework which fits observed treefall directions to an analytical Rankine vortex model, enabling estimation of key wind field parameters and diagnostic metrics such as damage width and damage ratio. More recently, the NTP have advanced operational capabilities through high-resolution aerial surveys, automated treefall identification, and uncertainty analyses applied across multiple analytical tornado models (Butt et al., 2025). Their results suggest that tree-based methods could yield higher EF-scale ratings than those currently assigned under the Canadian system.

Despite these improvements, significant challenges remain, including limitations in analytical vortex models and uncertainties in tree strength and health. Furthermore, since tree failure only shows that winds exceeded a critical threshold, treefall-based estimates give only lower bounds on true tornado intensity, highlighting the need for further methodological refinement. This project aims at providing an initial verification of the reliability of using treefall patterns in estimations of tornado strength through wind tunnel model tests. The research is currently underway and in here, we present the experimental setup, methodology and initial results, with more detailed results expected to follow at the conference.

2. METHODOLOGY

The experiments were conducted at WindEEE Dome. In order to facilitate higher translation speeds of the tornado, the floor of the testing chamber has been modified to accommodate a track and a moving platform, shown in Fig. 1, which allows a translation of an instrumented plate along the length of ~11 m, with different speeds controlled through a servo-motor. Further details about this system have been described by Brusco et al. (2026).

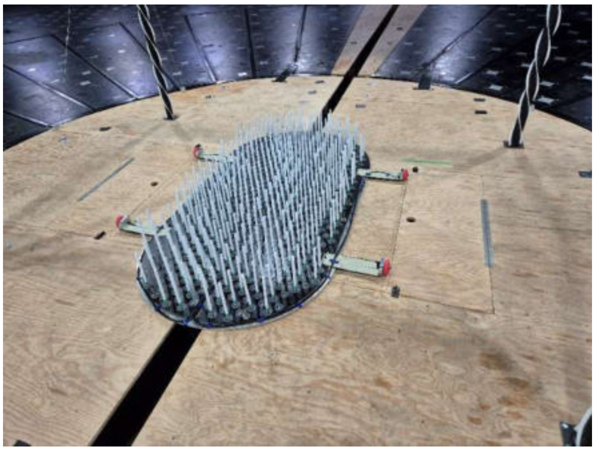


Figure 1. Track with a moving platform mounted in WindEEE testing chamber and model trees

The idealised forest (Fig. 1) consisted of 280 PVC model trees, each 220 mm long and 12 mm in diameter, spaced 80 mm apart on a baseplate. Trees were mounted using steel ball joints attached to paired circular magnets, allowing 90° rotation in any vertical plane whilst providing a consistent resisting moment. The critical wind speed for failure of a single model tree was ~6.5 m/s.

Wind velocity measurements above the canopy were recorded simultaneously with overhead plan-view video of treefall. Four Cobra Probes were positioned 330 mm above the moving platform to minimise canopy interference. Two straight (probes 2, 3) and two J-type (probes 1, 4) probes were mounted on either side of the platform, oriented to capture the horizontal tornado velocity components (Fig. 2). Two cameras were mounted on overhead beams ~2 m above the floor, supported by poles spaced ~2.8 m apart. The platform position and translational speed were obtained from a laser sensor referenced to a fixed vertical plate beneath the floor. Cobra Probes and the laser sensor were sampled at 625 Hz, whilst cameras recorded at 50 fps.

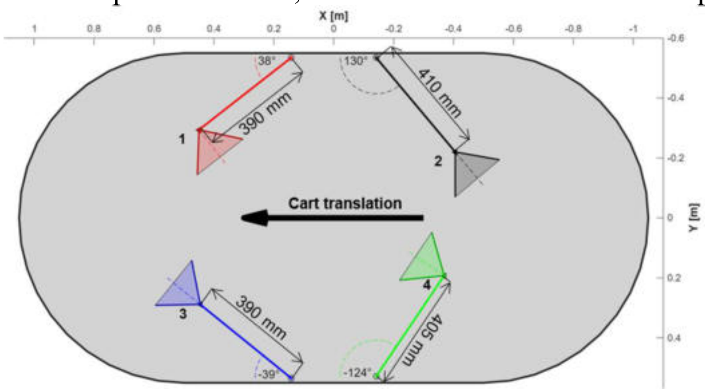


Figure 2. Dimensions of the moving platform and arrangement of the Cobra Probes.

A total of ten different test scenarios were investigated, each over ten subsequent runs to ensure the repeatability of the experiment, varying three different translation speeds, two different density configurations of the trees and two different tornado-like vortex setups: TLV1 (radius of maximum wind velocity R≅0.6 m, swirl ratio S≅0.76) and TLV2 (R≅0.25 m, S≅0.47).

3. INITIAL RESULTS

After the initial review of the collected data, we have decided to focus on two representative cases for backward (opposite to the tornado translation direction) and forward (in the tornado translation direction) convergence, which are typically observed in tornado damage field surveys. These cases are Case III (TLV1, 200 RPM, 280 trees) and Case VII (TLV2, 400 RPM, 280 trees).

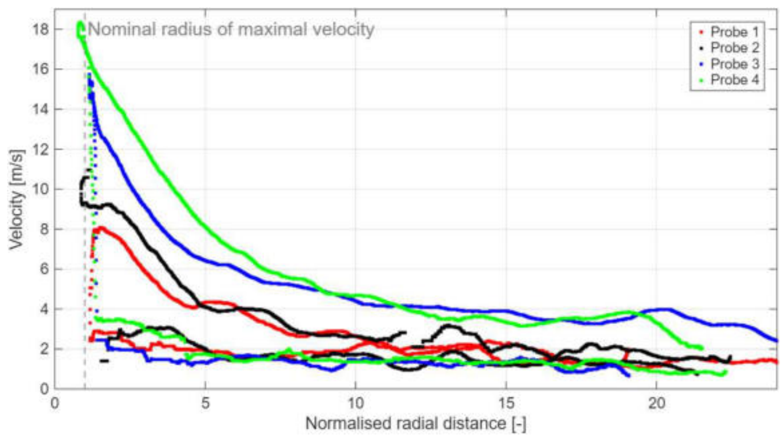
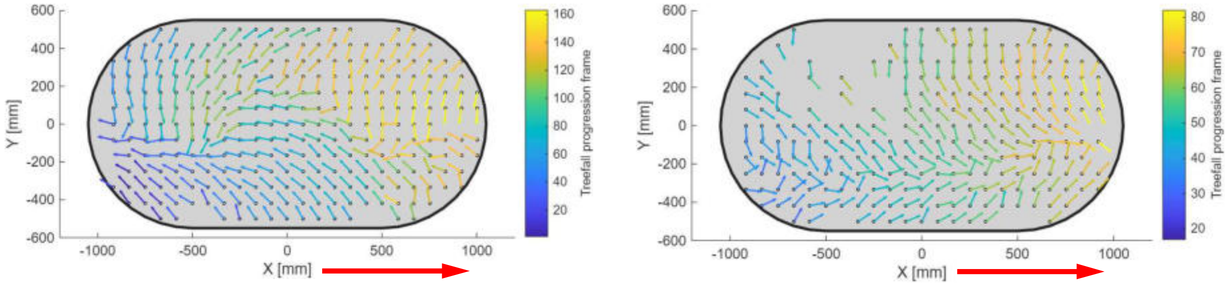


Figure 3. Horizontal velocity magnitude related to normalised radial distance from the vortex centre.

As only Cobra Probes were used to measure the tornadic wind field, locating the vortex centre, essential for velocity decomposition, was challenging. Using the nominal vortex radius and estimating the centre from Cobra Probe static pressure readings, the measured velocities were plotted against radial distance (Fig. 3). The close match between the location of velocity magnitudes and the expected radius indicates the sufficient accuracy of the adopted methodology.

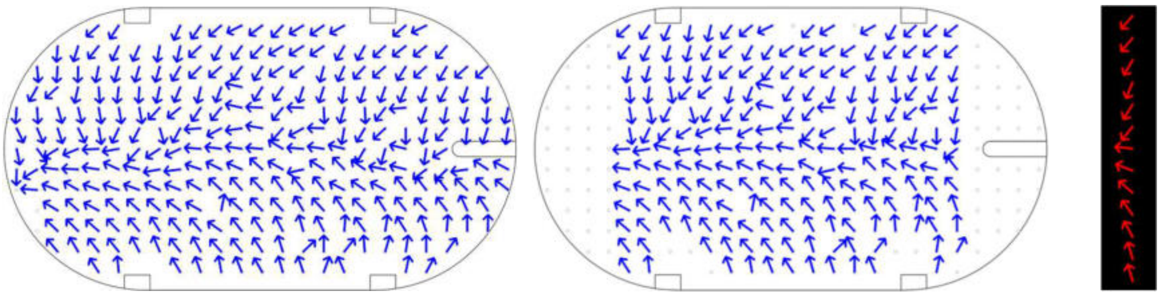
With the vortex centre, core radius, and associated velocity data established, the flow can be decomposed into radial and tangential components to reconstruct the idealised wind-field model. This can be then compared with the wind field inferred from treefall directions. Example treefall patterns for both analysed cases are shown in Fig. 4.



(a) (b)

Figure 4. Vectors obtained from the analysis of treefall recordings: backward convergence – Case III, repeat 5 (a) and forward convergence – Case VII, repeat 9 (b). The red arrow denotes tornado translation direction.

The extracted treefall patterns were then processed following the standard NTP procedure (Butt et al., 2025), shown in Fig. 5. The front and rear four rows were removed due to differing boundary conditions compared to the rest of the trees. A re-centring step shifted selected rows in the Y-direction to align the convergence line and make post processing easier. Finally, for each repeat, remaining direction vectors were spatially averaged along the platform's X-direction.



(a) (b) (c)

Figure 5. Steps of the initial processing of the extracted treefall patterns: original extracted pattern (a), exclusion of front and rear rows and re-centering the convergence line (b), averaged directional vectors across all rows (c).

Data analysis is on-going, and more detailed analysis will be presented at the conference, including the comparison between the wind fields inferred from velocity measurements and treefall patterns.

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