CWE-8
June 7-11, 2026
London, ON, Canada

Investigation of the Influence of Buildings on Tornado Characteristics Utilizing Large-Eddy Simulations and Post-Tornado Damage Surveys

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SUMMARY

Tornadoes pose significant risk to the built environment, yet near-surface tornado wind fields remain poorly understood due to limited in-situ measurements. Interactions with obstacles further complicate these flows, as indicated by post-event damage surveys and aerial imagery. This study employs high-resolution Large-Eddy Simulations (LES) based on the RIAM-COMPACT model to investigate tornado-building interactions. Multiple building configurations of varying size and height are included in the model, with a constant translation speed. The LES results resemble observed damage patterns and indicate enhancement of near-surface wind speeds in vicinity of large buildings. These findings demonstrate that large buildings can modify tornadic wind fields, highlighting the importance of accounting for building interactions in tornado design of structures.

Keywords: *Tornadoes, Near-Surface Wind Fields; Wind-Building Interactions*

1. INTRODUCTION

Tornadoes can cause significant damage to the built environment. However, due to limitations in in-situ measurements, the near-surface wind field of tornadoes remain poorly understood. Interactions between tornadoes and obstacles, such as buildings, further complicate characterization of these wind fields.

In real events, isolating the effects of large buildings on near-surface tornadic flow is particularly challenging due to the catastrophic nature of tornadoes. Nonetheless, post-event damage surveys and aerial imagery have revealed interesting patterns that suggest possible tornado-building interactions, especially in the proximity of large buildings (e.g., hospitals, schools). For example, after the damage assessment following the 2020 Nashville Tornado, a group of engineers reported that "The expected damage gradation towards a defined center was often not obvious", near downtown Nashville (Wood et al., 2024). Furthermore, these observations have motivated further investigation using high-resolution numerical simulations to better understand local flow modifications near large structures in tornado events.

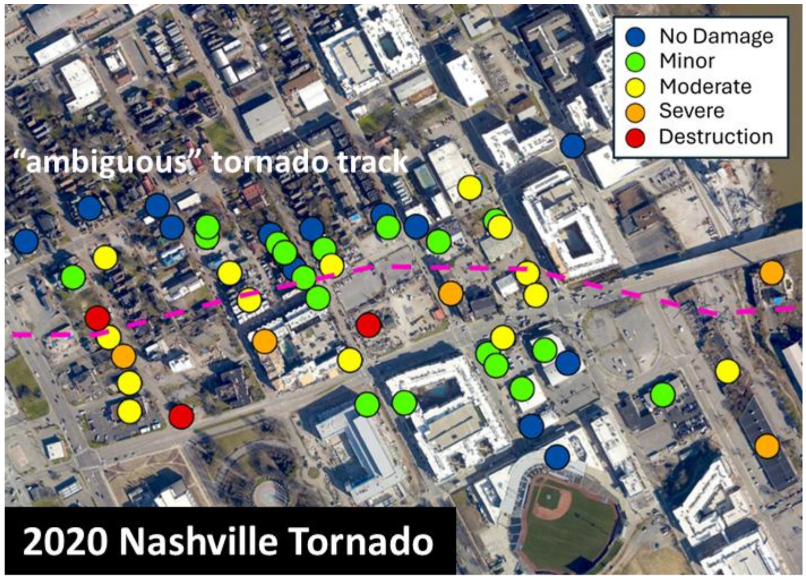

Figure 1. Aerial photo of downtown Nashville after the 2020 Nashville Tornado event

2. SIMULATION SETUP

High-resolution Large-Eddy simulations are conducted utilizing the Research Institute for Applied Mechanics Computational Prediction of Airflow over Complex Terrain (RIAM-COMPACT) model developed at Kyushu University (Uchida and Ohya, 2003). The LES model was subsequently adapted for tornado simulations by Maruyama (2011), Bodine et al. (2016), and Satrio et al. (2020). For additional details, please see the listed references.

The LES model is configured with 299 by 299 by 89 grid points and maximum domain dimensions of 1.2 by 1.2 by 1.5 km in the x, y, and z dimensions. At the center of the domain, the minimum horizontal and vertical grid spacing are approximately 1.7 m and 1.2 m, respectively, providing a high spatial resolution where the tornado-like vortex interacts with the structure. The domain is horizontally and vertically stretched to 7.3 m and 63 m, respectively. The horizontal boundary conditions supply air with angular momentum, and a central updraft is present at the top boundary. The swirl ratio is modified by varying the depth of the inflow layer.

Multiple building configurations with varying size and height were implemented into the LES model using an immersed boundary method (Saiki and Biringen, 1996) to represent solid obstacles within the domain. Furthermore, tornado translation was simulated by translating the bottom boundary at a constant speed of 10 $m\ s^{-1}$, allowing the relative motion between the tornado-like vortex and buildings to be examined.

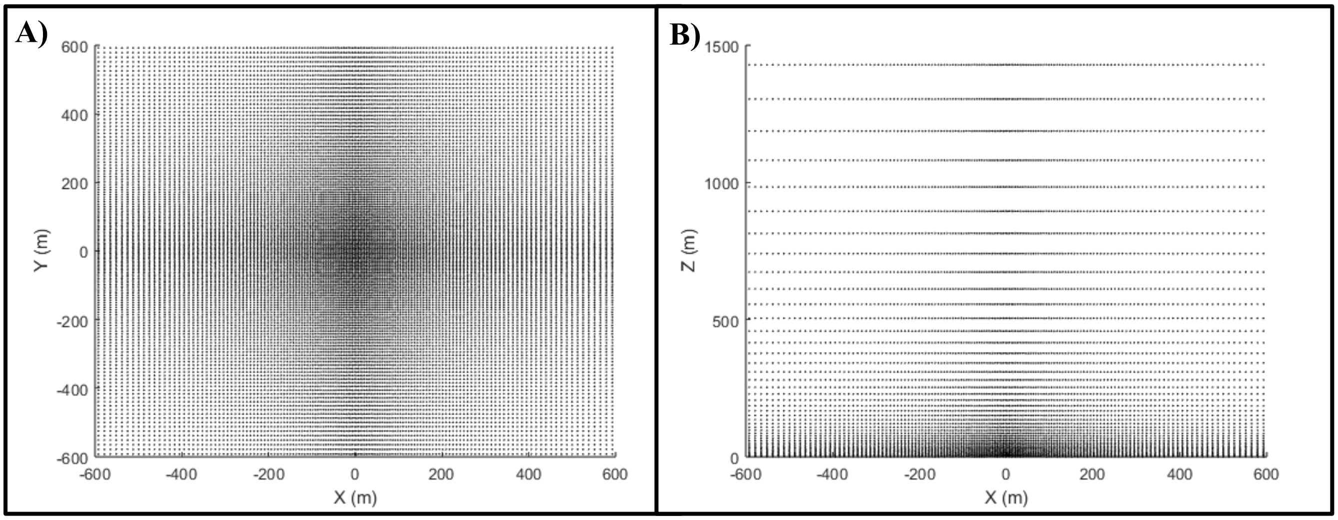

Figure 2. Computational grid utilized in the simulations: A) in the X-Y plane; B) in the X-Z plane

3. PRELIMINARY RESULTS

Damage characteristics, such as debris streaks and damage gradients, suggesting possible enhancement of near-surface wind speeds were identified in real tornado cases through analysis of aerial imagery and damage assessments. Theses characteristics suggest the presence of tornado-building interactions near large buildings. An example of such interaction between large building and tornado is shown in Fig. 3. Fig. 3 A) illustrates debris streaks and a possible wind enhancement zone observed near Highland East Junior High School during 20 May 2013 Moore, OK tornado. Fig. 3 B) shows the instantaneous wind speed at 10 m above ground level (AGL) obtained from the LES results. As shown in Fig. 3 B), the simulated near-surface wind field resembles the observed debris streak patterns, with a region of increased wind speed downstream of the building. These results suggest that large buildings can modify near-surface tornadic wind fields, consistent with post-event observations.

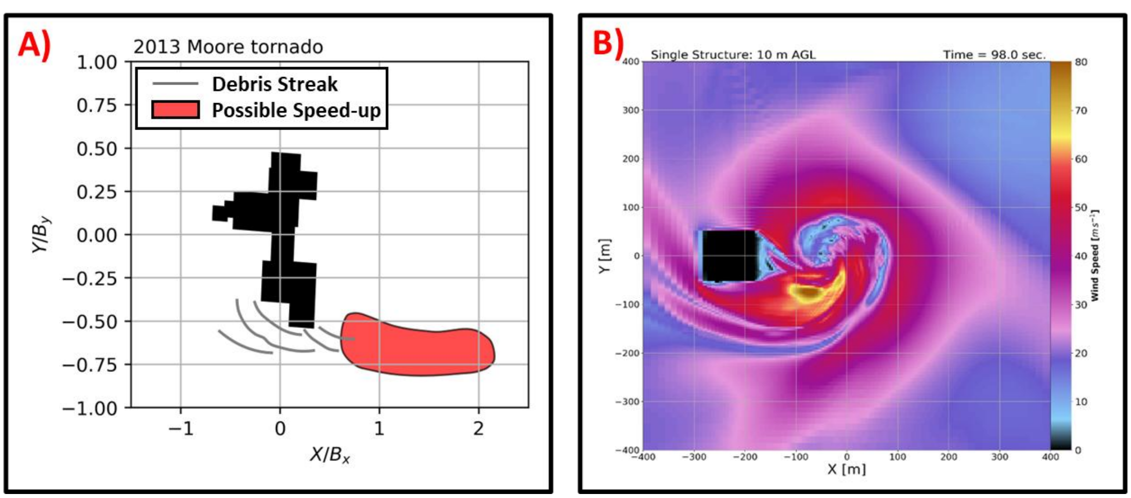

Figure 3. Comparison of LES results to observed indications of possible speed-up from the 2013 Moore, OK tornado near Highland East Jr. High School: (A) Observed possible speed-up; (B) Color plot of the wind speed from the simulation at t = 98.0 s at 10 m AGL

4. CONCLUSIONS AND FUTURE WORK

This study developed and implemented a novel simulation framework which could reinforce our understanding of building influences on near-surface tornadic wind fields. The findings demonstrate that large buildings can modify near-surface wind characteristics of tornadoes, enhancing wind speed in certain regions. High-resolution LES model successfully captured these tornado-building interactions, reproducing features such as wind speeds intensification downstream of structures. Future work will extend these simulations to more precisely quantify the impacts of large buildings on the tornado wind fields across a broader range of conditions.

ACKNOWLEDGEMENTS

Authors would like to gratefully acknowledge the support from the NOAA VORTEX-SE (NA17OAR4590202), VORTEX-USA (NA19OAR4590217) and BAA(NA23OAR4590646) programs.

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