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Evaluating WRF-Simulated Winds Against Full-Scale Measurements in the August 2020 Derecho

Wesam Mohamed [a], David T. Roegner [b], Franklin T. Lombardo [c], Kyle Jarrard Killion [d], Robert J. Trapp [e]

[a]*University of Illinois Urbana-Champaign, Urbana, Illinois, USA, wesammm2@illinois.edu*
[b]*University of Illinois Urbana-Champaign, Urbana, Illinois, USA, dtr2@illinois.edu*
[c]*University of Illinois Urbana-Champaign, Urbana, Illinois, USA, lombaf@illinois.edu*
[d]*University of Illinois Urbana-Champaign, Urbana, Illinois, USA, killion3@illinois.edu*
[e]*University of Illinois Urbana-Champaign, Urbana, Illinois, USA, jtrapp@illinois.edu*

SUMMARY

The 10 August 2020 Iowa derecho is the costliest thunderstorm disaster in U.S. history, with insured losses near $11 B and widespread crop and infrastructure damage (NOAA National Centers for Environmental Information (NCEI), 2025). Roegner et al., (2024) shows that multicellular systems dominate Iowa's non-synoptic extreme wind climatology and also that the 10 August 2020 likely produced 10 m, 3-s gusts near 120 mph (54 m/s) in Cedar Rapids—on the order of a 700-year event. Building on existing WRF (Weather Research and Forecasting) simulations (Killion, 2024), this study compares WRF output for the August 2020 derecho event against high-resolution wind and pressure records from an instrumented tower in central Iowa and against independent damage-based wind estimates.

Keywords: *derecho, Weather Research and Forecasting (WRF) model, thunderstorms, full-scale measurements, wind engineering*

1. INTRODUCTION

Thunderstorm-generated winds dominate the extreme wind climate across much of the Central United States and have caused some of the most damaging events in recent decades. The 10 August 2020 Iowa derecho, produced by a long-lived mesoscale convective system (MCS), generated extreme, long-duration straight-line winds across Iowa and neighboring states and is now recognized as the costliest thunderstorm disaster in U.S. history, with estimated insured losses of $11 B, much of it associated with crop damage (Roegner et al., 2024).

For the August 2020 derecho, the Wind Engineering Research Lab (WERL) at the University of Illinois Urbana-Champaign conducted detailed damage surveys near Cedar Rapids, IA. Roegner et al., (2024) analyzed the failed and unfailed traffic signs, and nearby non-ASOS anemometers, and estimated a 10 m, 3-s gust near 120 mph (54 m/s) in open terrain.

From an engineering perspective, models such as the Weather Research and Forecasting (WRF) model can provide three-dimensional wind fields that evolve continuously in time, information that cannot be obtained from surface measurements and post-event damage surveys alone. If the errors in these models are quantified for extreme events like the August 2020 derecho, WRF simulations may be used to derive representative wind fields for derechos, realistic boundary conditions for computational wind engineering models and wind loading for structural analysis models, and ultimately support hazard and risk assessments for distributed infrastructure such as transmission lines. The focus of this study is a detailed intercomparison between (i) simulated WRF winds, (ii) full-scale near-surface measurements, and (iii) independent damage-based wind estimates for the same event. By comparing the WRF model output with tower data and damage-based wind estimates, this work aims to quantify the strengths and limitations of WRF simulations for representing derecho wind fields and to provide a step towards developing a physics-informed derecho wind field model suitable for wind engineering applications.

2. DATA

2.1. WRF Simulation

The WRF model is a state-of-the-art mesoscale numerical weather prediction system developed by a broad partnership between NCAR, NOAA, U.S. Air Force, NRL, and the FAA. WRF is widely used by national weather centers and the research community for simulating phenomena from tens of meters to thousands of kilometers. This makes it well-suited for resolving the structure and evolution of a derecho. The August 10, 2020, derecho WRF simulation conducted by (Killion, 2024) is adopted in this study.

The temporal resolution of the simulation varies within the subdomains of the model between 1 minute and 15 minutes. Spatially, the domain extends over the Central US with a grid resolution of 3 km x 3 km for the domain and 1 km x 1 km resolution for the subdomains. Vertically, the domain is divided into 45 levels. The simulated fields are then interpolated in space and time to the measurements highlighted in section 2.2 to enable a comparison of wind speeds and vertical profiles.

2.2. Field Measurements

Different data sources are used in the comparison between the wind field produced in WRF simulations and field measurements. These sources include:

2.2.1. Data from the Iowa Atmospheric Observatory

Data from the Iowa Atmospheric Observatory, operated by Iowa State University (ISU), are analyzed and compared to the WRF results. The site includes a 120 m instrumented tower that measures a time series of wind speed, wind direction, and pressure at multiple levels in the lower atmosphere. These measurements are then analyzed to obtain 1-minute mean and gust statistics, which are then compared with the nearest WRF grid point and vertical levels. This allows an evaluation of how well the simulated derecho reproduces the timing, intensity, and vertical profile of the observed wind field at a fixed location within the derecho swath.

2.2.2. Wind Speed Measurements and Damage-Based Estimation

Wind speeds are estimated at various points throughout the wind field using the damage assessment conducted by the Wind Engineering Research Laboratory at the University of Illinois Urbana-Champaign for the Cedar Rapids area after the August 10, 2020, derecho. These estimates are based on the approach described in (Roegner et al., 2024) for the analysis of failed and unfailed traffic signs, damage to structures, and trees. In addition to the damage-based estimates, measurements from a private anemometer, Automated Surface Observing System (ASOS) wind speed measurements, and nearby surface-based stations are compiled to provide independent point measurements of peak wind speeds. These observed and estimated wind speeds are used to evaluate the spatial pattern and magnitude of the WRF-simulated wind field.

2.2.3. Radar Reflectivity Comparisons

Moreover, archived reflectivity from nearby weather radar sites is analyzed to characterize the convective structure of the derecho as it passes through Iowa. Plan-view and vertical cross-sections from the radar data are compared qualitatively to the reflectivity from the WRF simulations. This comparison helps ensure that the simulated storm organization and rear-inflow jet structure are consistent with observations.

2.3. Comparison Methods

To evaluate the accuracy of the WRF model, wind speeds and pressure are interpolated to the latitude–longitude of the Iowa Atmospheric Observatory tower and vertically interpolated to the tower measurement heights. For each height, we compare time series of wind speed, wind direction, and pressure, and construct vertical profiles at key stages of the event (pre-storm, derecho passage, and decay). Error metrics are then computed, along with differences in peak wind speed and duration above selected thresholds. For Cedar Rapids and the surrounding region, WRF-simulated winds at 80 m elevation are sampled at the locations of damage-based wind speed estimates and nearby surface stations, then interpolated vertically to the ground surface. The spatial pattern and magnitude of the simulated wind speeds are then compared to the damage–based estimates and measured wind speeds, with emphasis on whether the model reproduces both the broad high-wind swath and the localized extreme winds.

3. RESULTS

3.1.1. WRF Simulations

Figure 1 shows a sample of the results from the WRF simulation for the East Iowa subdomain used in the comparison with wind speed measurements. Figure 1a presents the maximum column reflectivity over the East Iowa subdomain for the analysis period, highlighting the bow-echo structure as the convective line crosses the state. Figure 1b shows a time history of the 80-m wind field at a sample point from the same subdomain during the derecho passage. For the same point, Figure 1c shows the wind speed profile at the time of maximum wind speed. Figure 1d shows a snapshot of the wind field over the same subdomain during the derecho passage.

3.1.2. Iowa Atmospheric Observatory

A sample of the wind speed and wind direction profiles, along with the barometric pressure time histories at 10 m and 80 m, recorded by the Iowa Atmospheric Observatory at ISU during the derecho event, is shown in Figure 2. The tower data capture the approach and passage of the convective line, where winds initially associated with the pre-storm environment strengthen rapidly as the leading edge of the bow echo arrives.

4. CONCLUSIONS

By combining WRF simulation, full-scale tower data, and independent damage-based wind estimates for the 10 August 2020 Iowa derecho, this study provides a detailed comparison for assessing the suitability of using WRF models in wind-engineering applications. The full study will expand on the analysis of the tower data and damage datasets and compare them to the results from the WRF model.

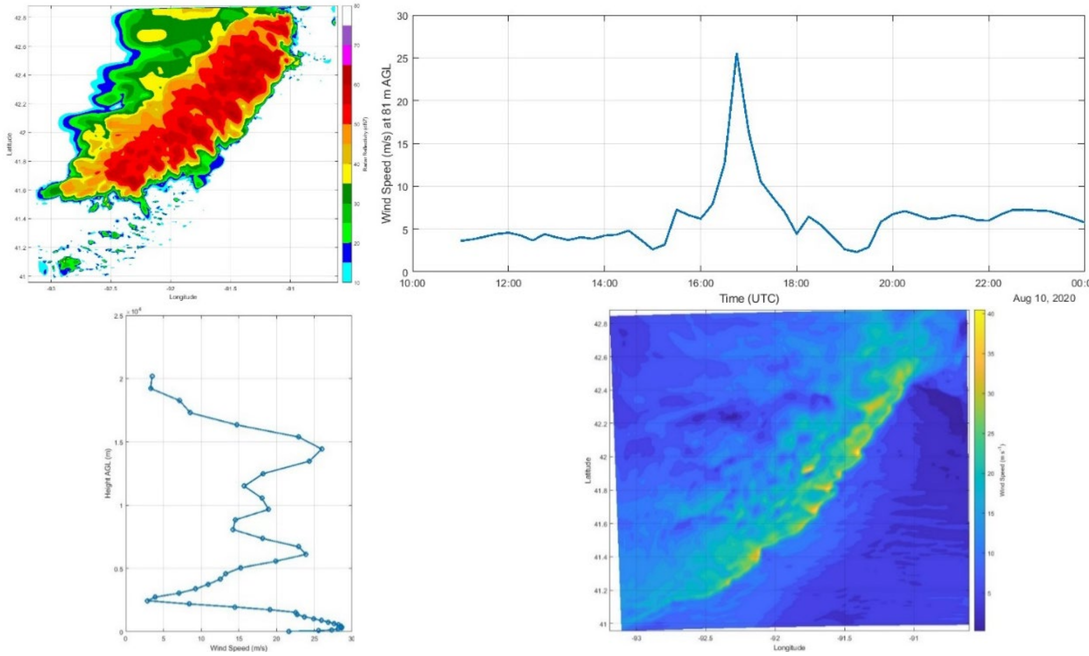

Figure 1: (a) Maximum reflectivity in the East Iowa subdomain. (b) Wind speed time history at a sample point. (c) Wind speed profile at a sample point. (d) Sample snapshot of the wind field in the East Iowa subdomain.

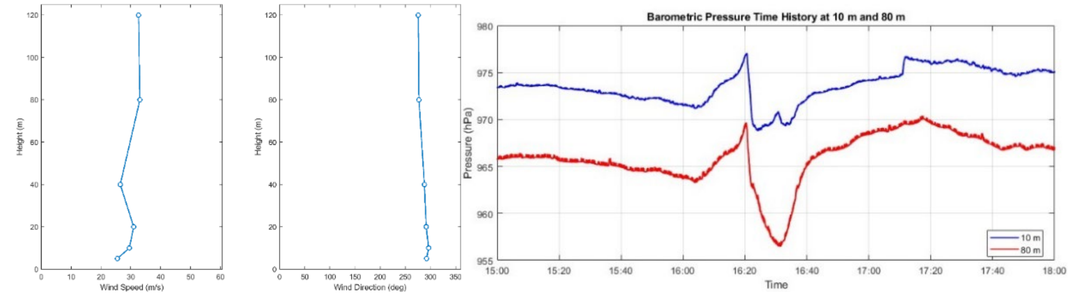

Figure 2: (a) Wind speed profile. (b) Wind direction profile. (c) Barometric pressure time history

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