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Storm types influence on the extreme convective wind speeds: Iowa case study

D.T. Roegner [1], F.T. Lombardo [1], Z.B. Wienhoff [1]

[1]*University of Illinois at Urbana-Champaign, Urbana, United States, dtr2@illinois.edu*

SUMMARY:
The August 2020 Iowa Derecho caused a significant amount of damage to both structures and crops, and had estimated wind speeds that made it a design level event. The characteristics of wind produced by derechos are most likely different than that of the atmospheric boundary layer (ABL). In addition, the mechanisms in which derecho (i.e., multicellular) winds are produced may be different than other thunderstorm types (e.g., supercell) and between individual storms. This work seeks to determine the extreme wind climatology for the state of Iowa and the associated return periods by storm type. Using the ASOS network and NEXRAD radar data, all the non-synoptic events from 1996-2020 with wind speeds above 50 knots (25.7 m/s) were manually classified as single-cell, multicellular, or supercell storms. These classifications were then used to determine the associated return periods using a Gumbel Type I fit. A total of 169 independent events occurred in Iowa for the selected time period. Multicellular storms, specifically mesoscale convective systems, were found to dominate the extreme convective wind speeds for non-synoptic events in Iowa. This result is partially due to the spatial scale of these types of storms along with the frequency of these storms.

Keywords: Thunderstorm Hazards, Risk Analysis, Strom Classification

1. INTRODUCTION

Design wind load estimates are currently calculated using a mixed distribution of synoptic and non-synoptic winds (Lombardo et al., 2009; Solari, 2014; Vallis et al., 2019). In the United States, the ASOS network is used to classify the winds as synoptic or non-synoptic for wind design loading in ASCE 7-22 (2022). This approach assumes that all non-synoptic winds are the same where in reality they have been shown to have different properties (Lombardo et al., 2014). These characteristics most likely stem from the origin of these winds aloft which greatly depends on the storm mode of the non-synoptic system. In meteorology, storms are typically classified as single-cell storms, supercell storms, or multicellular storms, and are heavily influenced by the wind shear and buoyancy of the environment (Weisman and Klemp, 1982).

Single-cell storms are the smallest simplest storm type and have a short lifespan due to the low shear environment (Doswell, 1985). Evaporative cooling occurs in the storm which causes air to sink, where it eventually reaches the ground and spreads outward (Wakimoto, 2001). Supercell storms have a similar spatial scale but need more shear and buoyancy to persist. Surface winds can be produced by evaporative cooling in both the forward-flank and rear-flank of the storm. In the rear-flank, the rotating updraft causes a low pressure center which induces downward motion. This dry air then sinks in the moist environment of the supercell as seen in Fig. 1 (Klemp and Rotunno, 1983). This air eventually reaches the ground and spreads outward. Multicellular storms have a large spatial scale and include the sub-storm types of mesoscale convective system (MCS) and derecho. Like single-cell storms and supercell storms, evaporative cooling can cause the air to descend and spread out at the surface. However, the stronger winds are more typically associated with a feature known as the rear inflow jet as seen in Fig. 2 (Weisman, 1992). Another wind producing mechanism that is less understood is due to mesovortices near the surface (Trapp and Weisman, 2003). It is thought that the vortex near the surface creates an area of low pressure which draws air downward. Iowa is prone to all three storm types, but a derechos on 10 August 2020 caused a significant amount of structural and crop damage, and the event was likely a design level event.

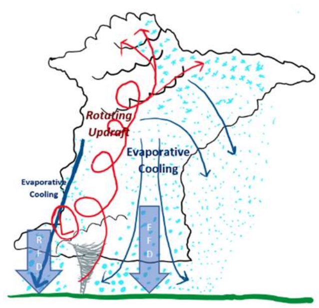

Figure 1. A schematic showing the features of an idealized supercell storm.

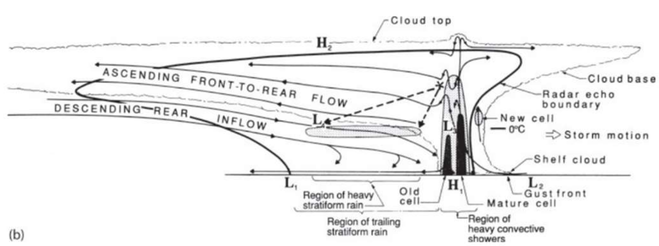

Figure 2. A plan view of a mesoscale convective system (Trapp 2013).

2. METHODS

Using the Iowa ASOS network, which consists of 15 stations, events with a wind speed above 25 knots (12.9 m/s) between the years of 1996 and 2020 were selected using the method from Lombardo et al., 2009. For this analysis, the data was further filtered to include only non-synoptic events above 50 knots (25.7 m/s). Using the new dataset, GIFs were created with NEXRAD radar data from the nearest 88D radar as seen in Fig. 3. These GIFs were then used to classify each event as a single-cell storm, multicellular storm, or supercell storm. After the initial classification of these events, the classifications were checked by using a 500 km by 500 km radar mosaic.

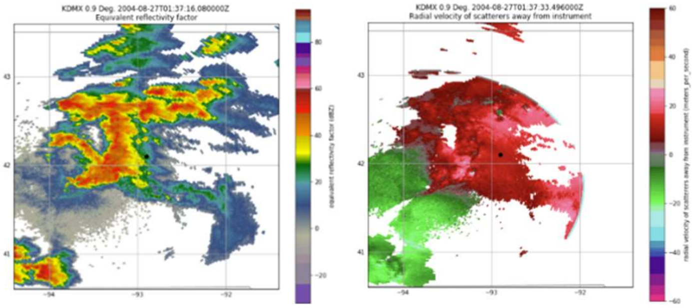

Figure 3. A still image of a GIF used in the analysis. The left plot is reflectivity, and the right plot is radial velocity.

The classified data was used to create the extreme wind climatology for the whole state of Iowa. A superstation approach was used to combine all the Iowa data. Due to multiple events per year being used for the extreme-value analysis, the data was standardized for each individual storm type by taking the Gumbel Type I CDF to the power of the number of events divided by the number of years, and the associated return periods were calculated.

3. RESULTS

In total, there were 169 independent non-synoptic events captured by the ASOS stations between 1996 and 2020 in Iowa. A total of 6 events had a low classification confidence, so they were omitted from the results. The majority of the events occurred in the month of June. It is also important to note that around 2008, there was an increase in the number of events captured per year due to sonic anemometers being implemented. Multicellular storms accounted for 83% of the extreme non-synoptic wind events in Iowa between 1996 and 2020 with most of the multicellular storms being MCSs based on the notes recorded for each event during the classification process. Overall, MCS-type storms averaged 5-6 events per year with a wind speed above 50 knots (25.7 m/s) in the state of Iowa. Fig. 4 shows the wind speeds and the associated return period based on storm type. Single-cell storms and supercell storms have the lowest wind speeds while multicellular storms, specifically MCSs have the highest wind speeds. Since the multicellular wind speeds and non-synoptic wind speeds (all types together) were identical, multicellular storms, specifically MCSs, dominate the extreme wind climatology in Iowa.

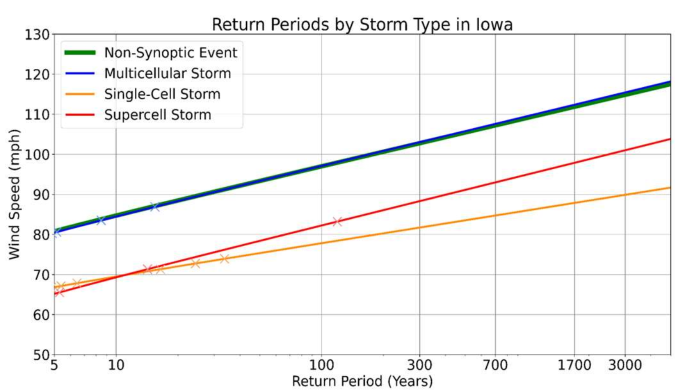

Figure 4. The return periods for each storm type and event.

4. CONCLUSION

ASOS stations and radar data were used to classify non-synoptic events by storm type. The analysis showed that multicellular storms, specifically MCSs dominate the extreme convective winds in Iowa. However, the spatial scale of multicellular storms is an important consideration as this allows these storms to have a higher likelihood of being captured by the network (Lombardo and Zickar, 2021). Single-cell storms and supercell storms have a smaller spatial resolution that makes them less likely to produce extreme winds that can then be captured by the ASOS network. More work comparing different station networks and the ability to capture storm-types needs to be done to determine if the ASOS network accurately captures the convective climatology of Iowa and the rest of the United States.

Each storm type will likely have different characteristics at the surface as the mechanisms producing these winds aloft are different. These mechanisms are different across storm types, so a non-binary method of classifying the wind events is needed. The single-cell, supercell, and multicellular classification is commonly used in meteorology and would allow for more collaboration across fields. To deal with the large number of events that would need to be classified, a machine learning method is currently being developed. This will be implemented for the United States to determine the convective climatology of different regions for extreme winds. By doing this, it will be more manageable to research the small-scale characteristics of surface-based winds for non-synoptic storms and understand their importance for wind loading.

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