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A Mesonet–Based Climatology of Severe Convective Winds in West Texas

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ABSTRACT

Multiple studies have investigated the occurrence of severe convective winds and have increased our understanding of the forces driving severe winds and their spatial and temporal patterns. Some of the data used in studies have come from airport stations maintained by the National Weather Service. Their standardization across the United States makes them ideal for research, but they are limited in their distribution. This study aims to create a climatology of severe convective winds in West Texas using a mesoscale network ("mesonet"). Like their Automated Surface Observing System (ASOS) counterparts, these stations are standardized and well-maintained. This study provides a 15–y climatology (2005–2019) of severe convective gusts measured by the West Texas Mesonet (WTM). After extracting and manually verifying the measured gusts from over 30 WTM stations, both spatial and temporal distributions are presented. While temporal patterns in the gust distribution generally matched previous research, the high spatial resolution of the mesonet elucidated differences across a regional escarpment known as the Caprock. Comparison with regional AWOS and ASOS stations also revealed potential effects of a larger urban area. In addition to gust data, thermodynamic characteristics and rainfall accumulations associated with each gust were also investigated. In doing so, a substantial contribution from dry thunderstorm outflow winds and heatbursts to the production of regional severe wind was documented.

1. Introduction

Nontornadic severe convective winds (≥50 kt or 26 m s^{-1}) have been shown to contribute to fatalities as well as extensive property damage (Ashley and Mote 2005; Schoen and Ashley 2011). Unlike tornadoes or severe hail (>1 in or 2.5 cm in diameter) that also appear in Storm Prediction Center (SPC) storm reports database, severe winds require complex, well-sited, instrumentation to truly verify (Kelly et al. 1985; Edwards et al. 2018; Sherburn et al. 2021). If not verified by instrumentation (i.e., measured), then the severe wind reports will appear as estimated gusts or damage to trees or structures. Despite well-documented issues with estimated windspeeds associated with wind-damage reports these reports have been instrumental (Doswell et al. 2005; Trapp et al. 2006; Edwards et al. 2018), in broadening the understanding of severe thunderstorm winds on the national scale (e.g., Kelly et al. 1985; Doswell et al. 2005). The climatologies that were initially developed provided valuable insight into the spatial and temporal distribution of nontornadic severe convective winds. For example, peak occurrences of nontornadic severe winds were just before sunset on a normalized solar time scale, with a minimum at sunrise (Kelly et al. 1985), while significant-severe gusts, defined by the SPC as winds ≥33.4 m s^{-1} (Hales 1988), were found most often in the Great Plains during the warmer months of May–August (Kelly et al. 1985; Doswell et al. 2005).

Many of these results have been replicated in recent studies that focused solely on measured gusts. In an analysis between 2003 and 2009, Smith et al. (2013) also noted that May–August were the peak months for measured severe

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convective gusts. By assigning storm modes to each gust, this study also was able to identify disorganized thunderstorms as the primary producer of severe gusts, followed by quasi-linear convective systems (QLCS), and then supercells. However, there was significant regional and temporal variability in the dominant storm mode. Strikingly, Smith et al. (2012) found that most of the significant severe gusts were produced by linear and QLCS systems. Lombardo and Zickar (2019) also focused their analysis on significant severe gusts and found a maximum in the Great Plains, also demonstrated in Doswell et al. (2005).

Temporal patterns included maxima during June and July in the late afternoon to early evening timeframe. A pronounced northwesterly maximum in wind direction for significant severe gust was also analyzed in Lombardo and Zickar (2019), which is one of the few assessments of severe convective wind gust direction. Regardless, Automated Surface Observing System (ASOS) data have been critical in advancing severe-wind climatologies (e.g., Smith et al. 2013; Edwards et al. 2018; Gilliland et al. 2020), contributions to engineering design codes (Lombardo et al. 2014), and forecasting of severe convective winds (Sherburn et al. 2021).

Despite their high quality and standardization, the ability of these national networks (e.g., ASOS) to resolve small-scale convective phenomena is extremely limited. Regional or "meso" networks (i.e., mesonets) provide a greater station density in an area, while maintaining the standardization of large national networks. Multiple meteorological mesonets exist across the country, including portions of Texas and Alabama, as well as Oklahoma, Kentucky and New York, among others.

Data from these mesonets have been used to characterize convective phenomena further that are found more frequently in a given region. For example, the Oklahoma Mesonet has been used to explore the evolution of mesoscale convective systems (MCS; Engerer et al. 2008) as well as heatbursts (Johnson 1983; McPherson et al. 2011). These data showed, for example, that pressure rises and gusts were the greatest in the mature stage of a sample of MCSs (Engerer et al. 2008). McPherson et al. (2011) used Oklahoma Mesonet data to dispel the idea that heatbursts were rare, and noted that their perceived rarity was likely a result of the low spatial resolution of federal observation networks. Indeed, many meteorological phenomena that produce nontornadic severe winds are on the mesoscale or smaller (Fujita 1981; Trapp and Weisman 2003; Wakimoto et al. 2006).

Considering the importance of severe convective winds, as well as their regional diversity and small scale, the goal of this study is to examine the climatology and characteristics of severe convective gusts over a 15-y period from the spatial lens of the West Texas Mesonet (WTM). This goal can be distributed across several research objectives:

1. Describe the spatiotemporal patterns of severe convective gusts as measured by the WTM and compare those patterns to regional, federally supported surface instrumentation.
2. Evaluate the kinematic characteristics of the gusts and compare those results to other high-wind climatologies.
3. Examine thermodynamic perturbations and precipitation characteristics associated with each gust or sequence of gusts.

A description of the WTM data is presented first, followed by the analytic methodologies. The results are then separated into spatial and temporal components, as well as an analysis of gust thermodynamic perturbations. A summary of the results is then presented in the final section.

2. Study area and datasets

The WTM currently consists of >150 individual stations throughout West Texas and eastern New Mexico, and a single station in Colorado. This study only incorporates data from 33 stations that each collected continuous data over the same 15-y period (1 January 2005–31 December 2019). The selected stations were part of the initial deployment of the WTM as detailed in Schroeder et al. (2005), where the spacing between stations was described to be ≈35 km. These 33 stations fall within the county warning area (CWA) of the Lubbock National Weather Service Forecast Office (WFO) in West Texas (Fig. 1). The Lubbock CWA comprises 24 counties across 21 547 mi^2 (55 806 km^2; National Weather Service 2018). While this region was chosen primarily for data longevity and relevance to a specific WFO, limiting the spatial scope of the study has other benefits.

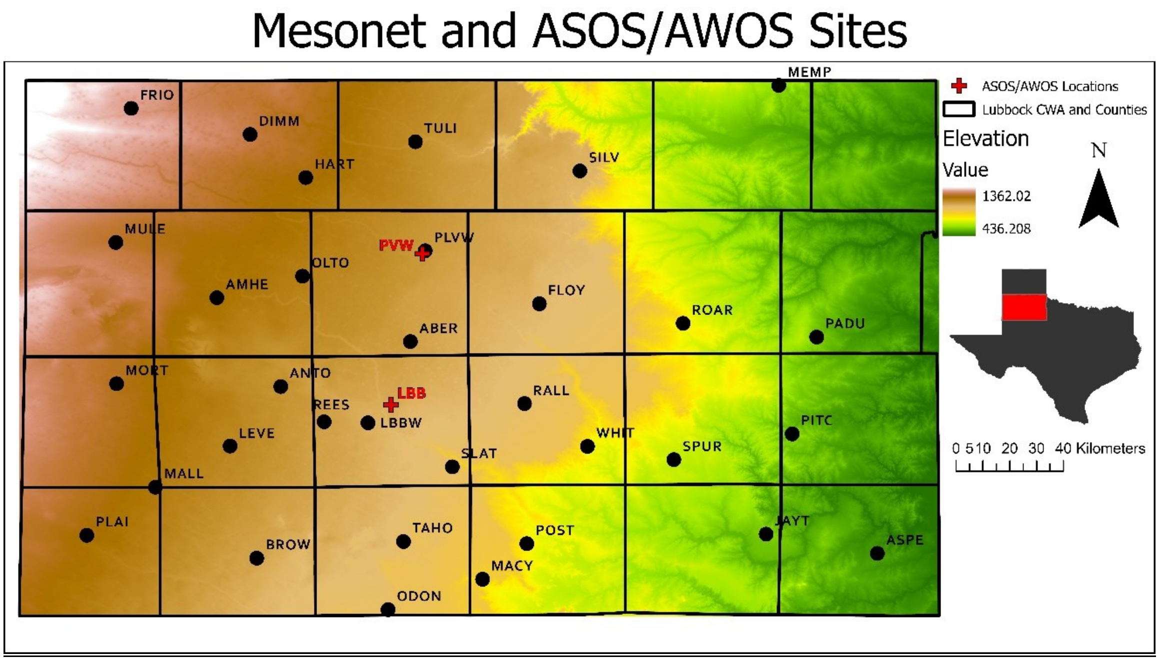


Figure 1: Lubbock County Warning Area with the location of WTM stations used in this study. The red rectangle on the right side of the inset map indicates the location of the Lubbock CWA within Texas. The underlying terrain map displays the elevation in m MSL. WTM station IDs are indicated at the top right of each WTM site. County names are included in the center of each county and appear in sentence case. The ASOS and AWOS sites are indicated the red crosses close to the LBBW and PLVW WTM site. See Table A1 in the Appendix for more information on each WTM station used in this study.

This part of West Texas is largely composed of uniform, flat terrain and minimal vegetation. The exception to this uniformity is a large escarpment (Caprock Escarpment; Schroeder et al. 2005) that runs approximately north–south through the center of the selected domain (Fig. 1). As seen in Fig. 1, just over two-thirds (23) of the WTM stations used in this study, and both ASOS and Automated Weather Observing System (AWOS) stations, were located on the higher terrain west of the escarpment (known locally as the “South Plains”) where elevations generally exceed 900 m MSL. The highest elevations are found in the western part of the domain, with the station near Friona, TX (FRIO), in the northwest corner, being the highest (1220 m MSL). The stations to the east of the escarpment (in the “Rolling Plains”) are lower in elevation with ASPE being the lowest at 530 m MSL. The WTM follows the siting protocols developed by the Oklahoma Mesonet (Brock et al. 1995), such that site slopes were limited to <5°, and the distance between the anemometer and an obstruction had to be at least 20 times the height of the obstruction (Brock et al. 1995; Schroeder et al. 2005). A study in 2008 also demonstrated that most WTM stations have an average aerodynamic roughness length (z_0) between 0.011–0.27 m (Vega-Avila 2008). These roughness values generally correspond to flat, open terrain, such as airport runways and farm fields (Stull 2017). Images of four WTM stations, each representing different areas of the domain, are in Fig. 2.

Each WTM station consists of a standardized array of sensors. The primary wind sensor collects windspeed and direction at a height of 10 m AGL. The 10-m anemometer is either the R. M. Young 05103-L Wind Monitor or the R. M. Young 05103-L Alpine Wind Monitor. Both are propeller-vane type. Schroeder et al. (2005) noted that the R. M. Young 05103-L measures winds from 1–60 m s^{-1}, has an accuracy of ±2%, and a resolution of 0.03 m s^{-1}. The wind-direction output from these anemometers ranges from 0–355° (with a 5° deadband) and maintains an accuracy of 3° and a resolution of 0.05°. Scalar average windspeed is also collected at 2 m and at 20 ft (6 m) AGL to support agricultural and fire-weather needs (Schroeder et al. 2005). Temperature and relative humidity are collected at 1.5 m with additional

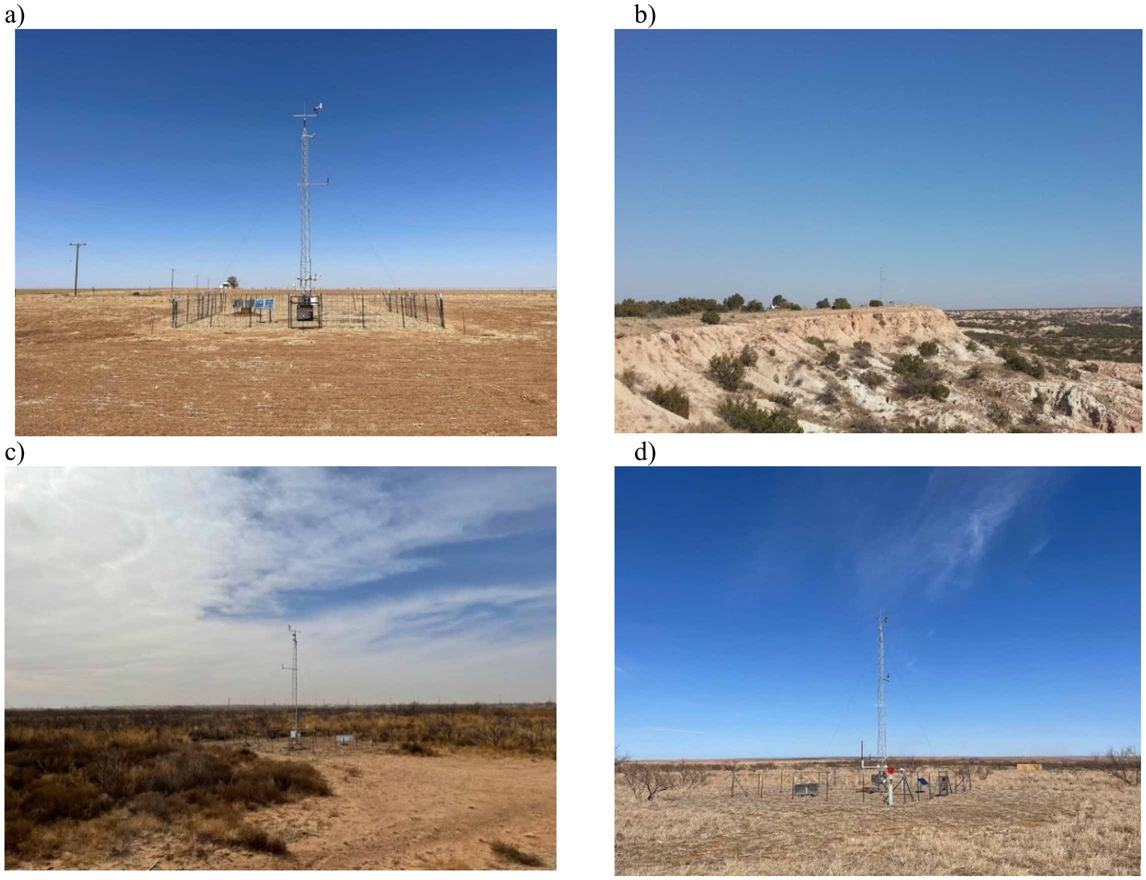


Figure 2: Examples of WTM stations in the a) higher elevations in the western part of the domain (DIMM), b) along the Caprock Escarpment (MACY), c) near the city of Lubbock (LBBW), and d) in the Rolling Plains (PADU). These and images for all the WTM stations can be found on the WTM website. Used with permission.

temperature sensors at 9 m and 2 m. Each station also measures pressure using a digital barometer, and precipitation with a tipping-bucket rain gauge and wind screen. More detailed information regarding the WTM sensors can be found in Schroeder et al. (2005). Summary data can be accessed through the WTM website (mesonet.ttu.edu), while detailed data are available through Synoptic Data (synopticdata.com).

WTM wind data are recorded in 5-min intervals. Each interval includes the average windspeed of 3-s samples, the vector average wind direction, and the peak windspeed (maximum of the 3-s samples). Each interval is independent of the previous interval, and a peak 3-s gust can occur at any time within a 5-min interval. The direction associated with the peak 3-s gust is not recorded. Averages of temperature and relative humidity are also included as the mean of 3-s samples, while the average station barometric pressure is included as the average of 12-s samples within the 5-min period. Each 5-min interval recording is based on the following 5 min. For example, the values with a time stamp of 1055 Central Standard Time (CST) (1655 UTC) were generated from data collected between 1055:00–1059:59 CST (1655:00–1659:59 UTC).

Data are distributed in monthly station files that contain the atmospheric measurements as well as soil and ground measurements. The file differentiates between atmospheric and soil data lines by giving each an “Array ID” of 1, 2 or 3. This research only focused on the data with an “Array ID” of 1. An “Array ID” of 2 is the set of instruments monitoring soil conditions and only reports every 15 min. An “Array ID” of 3 is only present on three specific stations which gather more in-depth wind measurements used in fire-weather forecasting. These wind measurements lack gust values, and were not used in this study.

Other data used in this study include federally supported surface measurements (ASOS and AWOS) and data from the WSR-88D radar network. The ASOS and AWOS severe gusts were compared with the WTM data, while radar data were used to verify that a measured gust was convective in origin. Only two federally supported surface stations reported data within the domain and over the same 15-y period: the ASOS station located at the Lubbock International Airport (KLBB) and the AWOS-3 station located in Plainview (KPVW). Both stations are located west of the Caprock Escarpment and relatively close to WTM stations. KPVW is just over 2 km southwest of the PLVW WTM station, while KLBB is ≈9 km northeast of the LBBW WTM station. As noted in many of the previous studies that incorporated ASOS and AWOS data (e.g., Smith et al. 2013; Letson et al. 2018; Lombardo and Zickar 2019), gusts are measured as a 3-s maximum at 10 m AGL.

The WSR-88D network includes several radars in or near the Lubbock CWA, including Lubbock (KLBB), Amarillo (KAMA) and Cannon Air Force Base (KFDX), NM. Other regional radars were also used in rare instances. The archived data produced by these radars is available in Level-II or Level-III format and readily accessible from a variety of sources, including the NCEI and Amazon Web Services (AWS).

3. Data processing and methodology

WTM data are subject to numerous quality-control and quality-assurance (QC and QA) algorithms prior to being stored in the monthly station files and available for distribution. These QC and QA processes include five different tests that compare data from a given station against itself, as well as nearby stations. For example, the range test employed by the WTM verifies that output from a given sensor falls within the expected range of the sensor (Schroeder et al. 2005). Minimal additional QC beyond that described in Schroeder et al. (2005) was performed on the raw data. Missing values (designated by -99.99, –88.88, or NaN) were filtered out, and data availability was examined.

In terms of data availability, most stations achieved nearly continuous sampling over the 15-y period. On average, the monthly availability was 99.9% across studied stations. Since no station achieved 100%, a severe convective gust could have happened during station downtime. However, the months with the worst availability tended to be in the late fall and winter, when severe convective winds were less likely based on previous climatologies (e.g., Smith et al. 2012).

In terms of uniformity, stations across the WTM consistently sampled using the previously described 5-min intervals. The exception to this was the WTM station located in Tahoka, TX (TAHO). In September 2014, the station was upgraded to 1-min sampling from the standard 5-min sampling. To ensure no bias from the increased sampling rate, the 1-min data were resampled to 5-min intervals by averaging the 1-min windspeed and direction (vector average) and recording the maximum 3-s gust that occurred over 5 min in the 1-min data. ASOS and AWOS data for both KLBB and KPVW were acquired through the Iowa Environmental Mesonet (IEM) archive of local storm reports, as in Sherburn et al. (2021). Other studies have noted the need to perform low-level QA and QC on ASOS and AWOS data (e.g., Letson et al. 2018). Once duplicate values and seemingly erroneously high values were removed, the ASOS and AWOS data were processed the same way as the WTM data.

The primary task of data processing was to isolate the gusts that met the National Weather Service severe criterion of ≥ 25.7 m s^{-1}. These gusts then would be extracted from the monthly station files or the ASOS record. As demonstrated in previous climatologies (e.g., Gilliland et al. 2020), this region of Texas frequently experiences non-thunderstorm-related gusts that exceed severe criteria, due to the development of large extratropical cyclones in the region, as well as downslope winds from the higher terrain to the west.

As a result, radar data associated with each identified severe gust were inspected to ensure that the gust originated from a convective complex or the resulting outflow. This verification was performed in the NOAA Weather and Climate ToolKit (Ansari et al. 2018) by analyzing the radar data closest to a measured gust in space and time. The WTM timestamps were converted from CST to UTC. The UTC times then were used to download radar data via AWS in the Toolkit. In addition to quick downloads, the Toolkit also allowed for the placement of a shapefile of the WTM stations, which then could be compared with radar imagery. Animations of the associated radar images, coupled with the addition of the WTM station locations within the viewer, allowed for the quick identification of the stations within the study that may have experienced severe convective wind. Once a convective gust was identified, the gust speed, 5-min average windspeed and direction, 5-min accumulated rainfall, station identification, and temporal information were recorded in a spreadsheet for analysis.

Considering the availability of WTM thermodynamic data, perturbations in temperature, dewpoint, relative humidity and station pressure associated with each severe gust were also of interest. Calculating the perturbation values for stations experiencing a single severe convective gust was relatively simple: the value of a thermodynamic parameter 15 min before the gust was subtracted from the value of the thermodynamic parameter 15 min after the gust. The amount of precipitation during the 5-min period containing the severe gust was also logged.

This methodology had to be modified slightly when multiple severe convective gusts were experienced in sequential 5-min segments. These serial severe gusts were treated as "events", such that only the first gust in the series triggered the calculation of perturbation values. The event continued as long as subsequent severe gusts were not separated by >30 min (Cook 2023). Accumulated rainfall during the event was also recorded. This methodology not only allowed for back-to-back events from training cells to be reflected, but it also permitted several long events to be separated according to seemingly different forcing mechanisms. While this methodology differs from previous studies that examined gust events or perturbation values (e.g., Engerer et al. 2008; McPherson et al. 2011; Cook 2023), there has been no established methodology for such a technique. The goal of examining the thermodynamic perturbation values was simply to provide insight into meteorological phenomena driving the event and associated gusts.

Several statistical analysis techniques were used to establish the significance of both spatial relationships and differences between distributions. Spatial correlations and patterns were assessed through the Local Indicators of Spatial Association (LISA; Anselin 1995). Specifically, the Anselin Local Moran's I (Anselin 1995) was used to identify statistically significant clusters and outliers of the number of gusts across the domain. This particular LISA, unlike the Getis-Ord G* statistic, which only identifies statistically significant clusters (Getis and Ord 1992; Anselin 1995), can determine both statistically significant hot and cold spots, as well as spatial outliers (ESRI 2023a). Gilliland et al. (2020) demonstrated the utility of the Local Moran's I in exploring spatial patterns of high-wind measurements across the Eastern U.S. The results, as seen in Gilliland et al. (2020), are easily interpreted as either clusters, outliers, or nonsignificant patterns. A high value among other high values (High-High) or a low value among other low values (Low-Low) represents statistically significant high and low clusters. A high value among low values (High-Low) represents a statistically significant positive outlier, while a low value among high values (Low-High) represents a statistically significant negative outlier. The implementation of the Local Moran's I in ArcGIS Pro (ESRI 2023b) produces statistically significant results with a 95% confidence interval.

In addition to spatial associations, various subsets of the entire severe convective wind gust distribution developed for this study were compared using a nonparametric rank-sum test (or the Wilcoxon-Mann-Whitney rank sum test; Wilks 2019). The implementation of the rank-sum test in Matlab yields results that are significant at the 5% significance level by default (Mathworks 2022).

4. Results

a. Spatial distribution

Over the 15-y study period, 1042 measured severe gusts were identified as generated by or associated with convection across the Lubbock CWA. Their distribution by station is provided in Fig. 3. In general, stations on the west side of the domain experienced a greater number of severe convective gusts. For example, four stations to the West of the Caprock Escarpment experienced over 50 severe convective gusts during the 15-y period, while no Rolling Plains stations did. The FRIO station experienced the largest number of severe convective gusts (63) over the 15-y period, while the station near the center of the city of Lubbock (LBBW) experienced the fewest (9). Some influence of the terrain was apparent, with two stations near the escarpment reporting elevated gust totals (MACY and WHIT). A similar analysis was performed for significant severe gusts (Fig 4).

In their analysis of ASOS and AWOS severe convective gusts over the contiguous United States, Smith et al. (2013) documented 1911 between 2003 and 2009. Lombardo and Zickar (2019) identified ≈1500 significant severe convective gusts. While the present results are similar in magnitude to the result of national studies, differences in methodology, spatial extent, and dataset duration prohibit direct comparisons. However, the Lubbock ASOS station does stand out in the Smith et al. (2013) analysis as having 16–18 severe convective gusts over their 6-y analysis period.

To identify any spatial correlations or local patterns in gust frequency, as well as the significance of the severe gust distribution, ArcGIS Pro was used to perform an Anselin Local Moran's I analysis on both the entire severe convective gust measurements and those exceeding the significant criteria, defined by the SPC as winds ≥ 33.4 m s^{-1} (Hales 1988). The Local Moran's I was performed using the Zone of Indifference function and 75-km radius to determine which neighbors to include in the analysis (ESRI 2023c).

When considering all convective gusts, no station or group of stations was considered a statistically significant high gust cluster (High-High Cluster; Fig. 5). However, stations on the western side of the domain generally experienced more severe gusts than those on the eastern side (Fig. 3). The primary exception to this trend was the station located near Muleshoe, TX (MULE) that was analyzed as a statistically significant low outlier (Low-High). Four stations were analyzed as statistically significant "hot spots": two in the Rolling Plains (PADU and ASPE) and two along the escarpment (MACY and WHIT). The latter two quite possibly reflect terrain-induced accelerations, such that gusts with a southerly or easterly component will accelerate due to the Bernoulli effect (e.g., Jensen and Peterson 1978; Barthelmie et al. 2016).

However, two stations farther removed from the influence of the escarpment (RALL and FLOY) were analyzed as a significant Low-Low cluster. While proximity to the High outliers on escarpment may be driving the significance of the Low-Low cluster, further inspection reveals that many stations on the eastern side of the escarpment had lower gust counts compared to those on the western side. What may drive these lower counts is unclear. Similarly, no station reported a statistically higher number of significant-severe gusts (Fig. 6). Rather, the stations on the eastern edge of the Escarpment once again were identified as a statistically significant "low" cluster.

The station near Plains, TX (PLAI) also was identified as a "cold spot" in terms of significant severe gusts. While the Anselin Local Moran's I analysis confirmed many of the trends noted in the raw gust counts, this analysis did not identify the "extreme" stations (e.g., FRIO and LBBW) as significant, nor did it highlight stations without significant severe wind observations (discussed in section 4c). Increasing the radius of indifference of the analysis rendered even more stations being identified as insignificant. As such, the results could be biased by the presence of too few WTM stations.

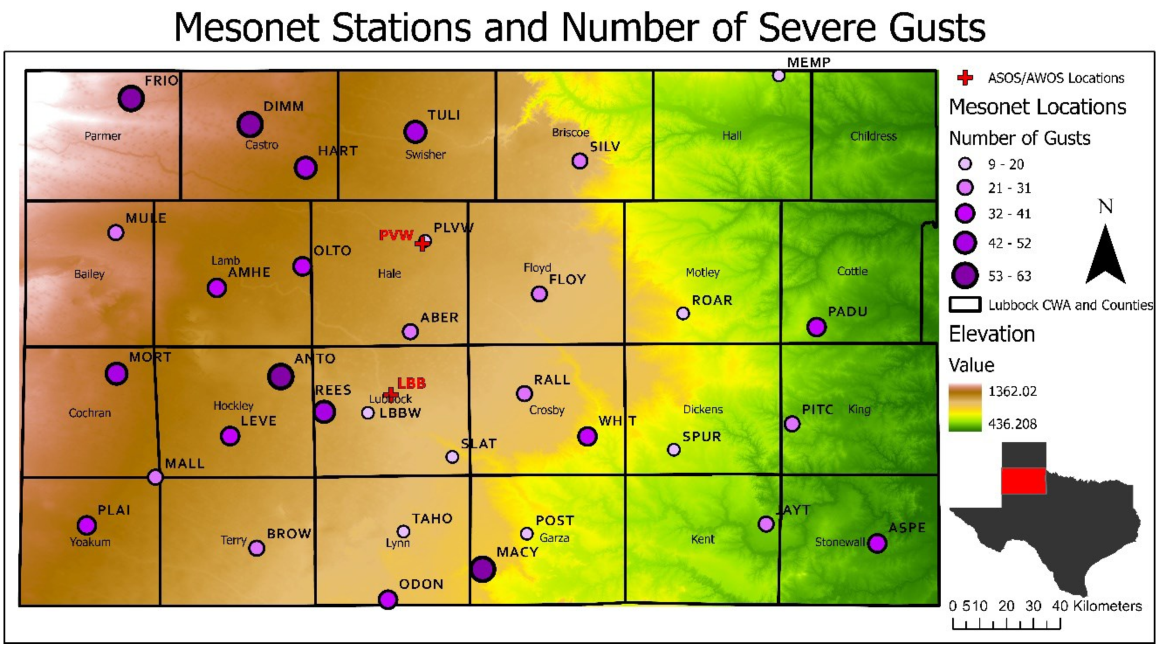


Figure 3: WTM sites within the Lubbock CWA displaying the number of total severe gusts experienced at that site. The red square on the right side of the figure indicates the location of the Lubbock CWA within the state of Texas. The size of the circles indicates the number of measured gusts at a given WTM site. Site IDs are also included to top right of each station. As in Fig. 1, the underlying terrain map displays elevation in m MSL.

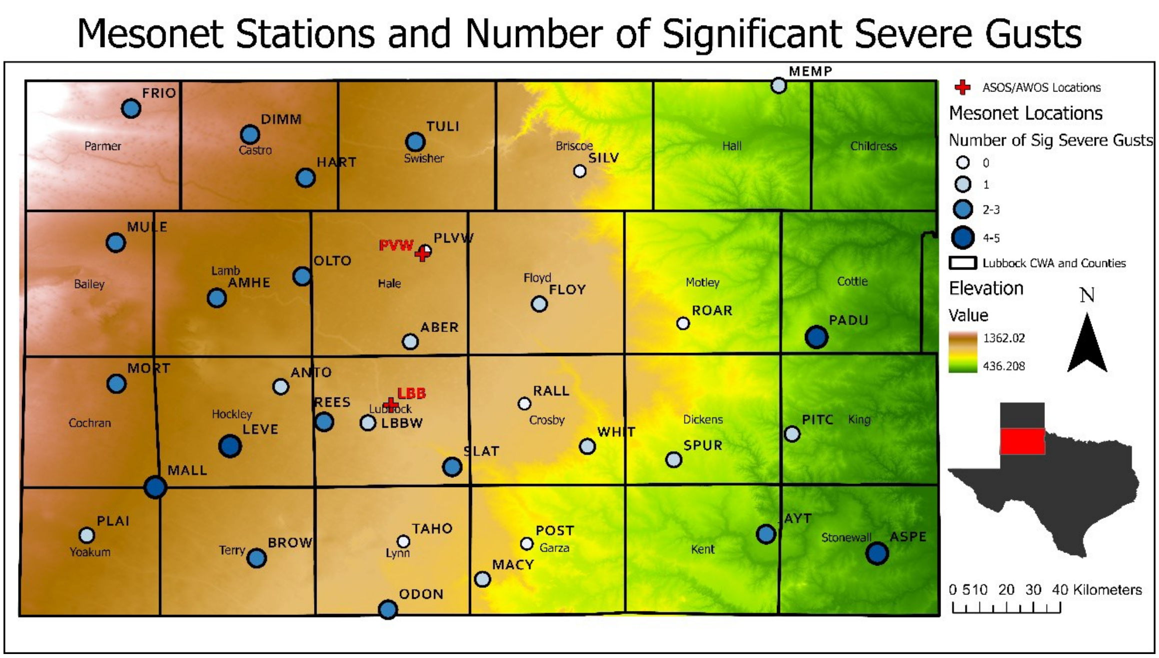
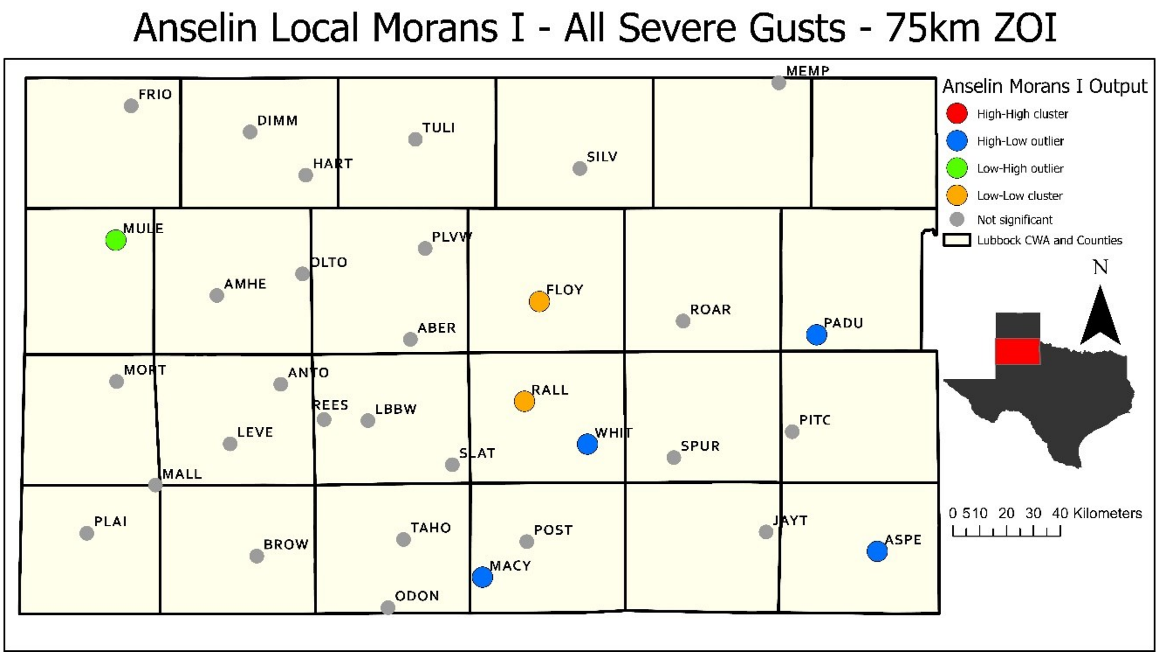
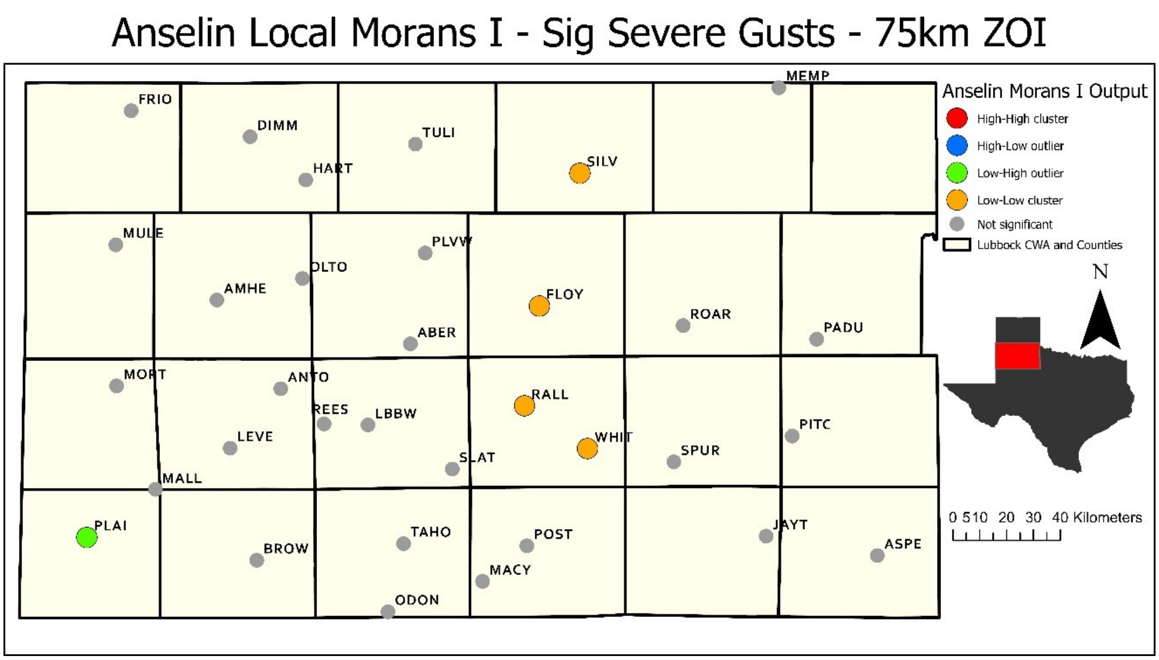


Figure 4: As in Fig. 3, but for significant severe (≥33.4 m s^{-1}) gusts.



<u>Figure 5</u>: Statistical spatial analysis of all severe gusts measured by the included stations. ZOI indicates the tapered Zone of Indifference around each station. Shaded stations (outliers or clusters) indicate a statistically significant result at the 0.05 level. Gray stations indicate no statistically significant trend.



<u>Figure 6</u>: As in Fig. 5, but for significant severe ($\geq$33.4 m s^{-1}) gusts.

Despite the fact the WTM station in Lubbock (LBBW) is well-sited within an open field comprising approximately a quarter of a city block, this station reported the fewest number of severe gusts. Additionally, the magnitude of the difference in the severe convective gust counts between the LBBW WTM station and nearby stations was surprising. For example, the REES station, <15 km to the west, reported 46 individual severe convective gusts. Urbanization and more varied vegetation, in the blocks surrounding the LBBW site, may be driving some of these differences. The average aerodynamic roughness length (z_0) computed in Vega-Avila (2008), based on 2 y of data, supports this hypothesis, with z_0 values of 0.033 m for the LBBW station and 0.009 m for the REES station.

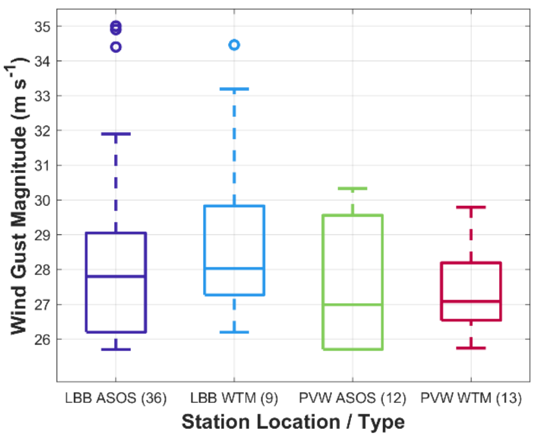


Figure 7: Box-and-whisker plot of severe convective wind gust distribution for two pairs of ASOS/AWOS and WTM stations. The box encloses the interquartile range (IQR; central 50% of the data) of each distribution with the horizontal line representing the median. The whiskers represent the extent of non-outlier extremes in the data, with a maximum of 1.5 times the IQR. The closest non-outlier to the maximum represents the extent of the whisker. The open circles represent outliers of the distributions.

Given the proximity of two ASOS and AWOS stations to WTM stations, data were compared to provide further insight into local trends. Over the same 15-y period, the KLBB ASOS station measured 36 convective gusts. Of these, three were significant-severe, while the LBBW WTM measured only one significant gust. The KLBB ASOS gust data also demonstrated a greater spread and slightly lower median (Fig. 7). Some of these differences seen in Fig. 7, particularly the wider spread and lower median, could be a result of different instrumentation, with the LBB ASOS station being upgraded to a sonic anemometer in 2007 (Lombardo and Zickar 2019). Also of interest was the intersection of gust days for the two stations. Considering the number of unique severe gust days for the ASOS station (29) and the WTM station (6), both stations experienced a severe gust on three days.

The other pair of stations close to each other was in Plainview, TX, where the AWOS-3 station is only separated from the PLVW WTM station by ≈2 km. Both stations are located south of the main development region of Plainview, with the AWOS-3 station sited in a more open, flat area near the regional airport runway. These stations recorded a similar number of gusts, and the data were characterized by similar median values (Fig. 7). Neither of the Plainview stations recorded a significant-severe gust over the 15-y period.

Both stations experienced severe gusts on 10 unique days. As with the LBBW station, the z_0 value computed by Vega-Avila (2008) was also larger for the PLVW station at 0.0413 m. Despite the similarities between the stations, only 4 of the 10 unique gust days were the same for both stations. In other words, there were 6 days over the 15-y period where the PVW AWOS station measured a severe gust, but the WTM station did not. These differences reflect the highly localized nature of severe convective winds.

b. Temporal distribution

The entire dataset was analyzed on the yearly, monthly, and hourly time scales to identify temporal patterns, such as annual trends or common times of the year and day for severe convective gusts. Considering the raw number of severe gusts over the 15-y period, the number of severe gusts per year has varied substantially, with the most gusts being measured in 2013 (Fig. 8a). This aspect of the data is largely driven by specific convective events. Most of the 2013 events occurred on the same day with a damaging bow echo and subsequent wake low on 5 June (Gunter et al. 2017). The fewest severe convective gusts were in 2011, during an intense drought that occurred across much of the Great Plains (Fernando et al. 2016). Regardless, no statistically significant trend was noted in the yearly frequency, which suggests seasonal to sub-seasonal drivers.

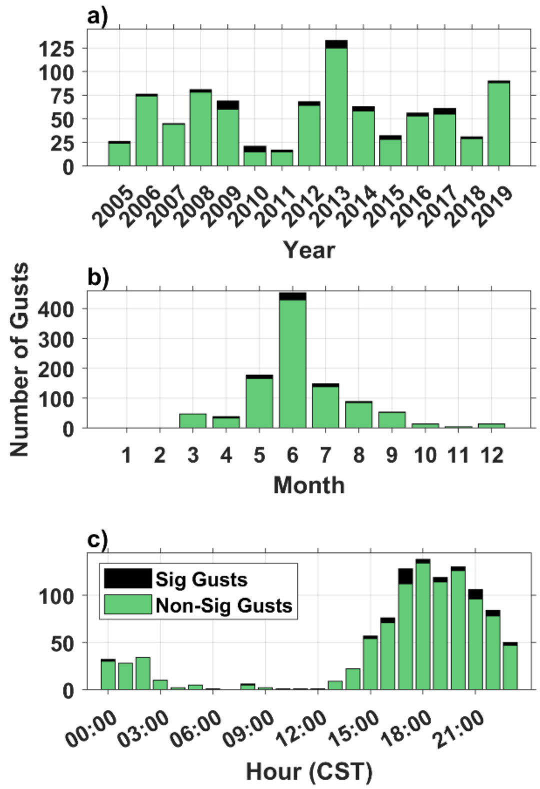


Figure 8: Temporal frequency of the raw gust counts for each a) year, b) month, and c) hour.

There was also no trend in the yearly distribution of significant severe gusts (Fig. 8a). The median yearly values for non-significant and significant severe convective gusts were 55 and 3, respectively. Monthly patterns of severe convective gusts across the WTM (Fig. 8b) were consistent with larger-scale climatologies, as just over 70% of severe convective gusts occurred in the May–July time frame. Over the 15-y period, January, February and November experienced the fewest severe convective gusts with 0, 1, and 4 reported gusts respectively. Significant severe gusts did not occur at all during these three months, in addition to March. The greatest number of significant severe gusts was in June, with 24.

Diurnal patterns exhibited an expected peak in the early evening (Fig. 8c). Kelly et al. (1985) noted a minimum in the diurnal frequency of severe convective gusts near sunrise in their nationwide study. A similar diurnal minimum was observed in the WTM gust data at 0700 CST (1100 UTC), with no severe gusts reported during this hour. Severe gusts were also infrequent between 1000–1200 CST (1600–1800 UTC), with each hour only reporting one gust. While the 1800 CST (0000 UTC) hour contained the greatest number of measured severe convective gusts, the greatest number of significant severe gusts occurred an hour earlier.

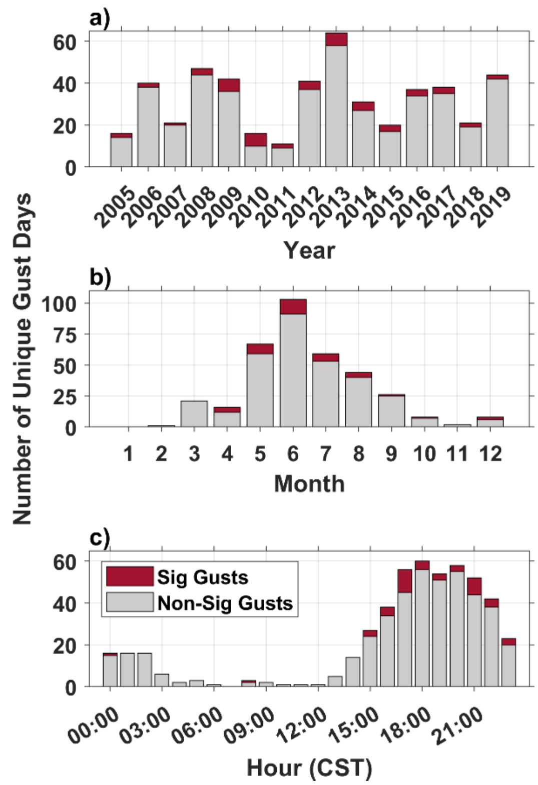


Figure 9: Temporal frequency of unique gust days for each a) year, b) month, and c) hour.

Given the ability of a single event to skew the temporal distribution, the same analysis was performed by counting the number of days in a given year (Fig. 9a), month (Fig. 9b), and hour (Fig. 9c) with at least one severe convective gust. While the overall patterns of each distribution are similar, the magnitude of the extrema are much less. For example, 2013 had only 14 more unique gust days than the next most active year (2008). Considering individual severe gusts per year, 2019 was the second most active year. However, it lagged 2013 by 37 gusts. March also overtook April in terms of total unique gust days compared to the total amount of gusts. Using this same definition of unique gust days, there were on average 1.3 severe convective gust days per year across the 33 stations. Separating the stations into the aforementioned regions, the South Plains stations averaged slightly more severe convective gust days per year (1.4) than the Rolling Plains stations (1.1). The most common day to experience a severe convective gust was 5 June. Twenty-four WTM stations measured a severe convective gust on this day across three different years. However, the widespread event on 5 June 2013 contributes disproportionately to this observation with 92 of the 106 occurrences.

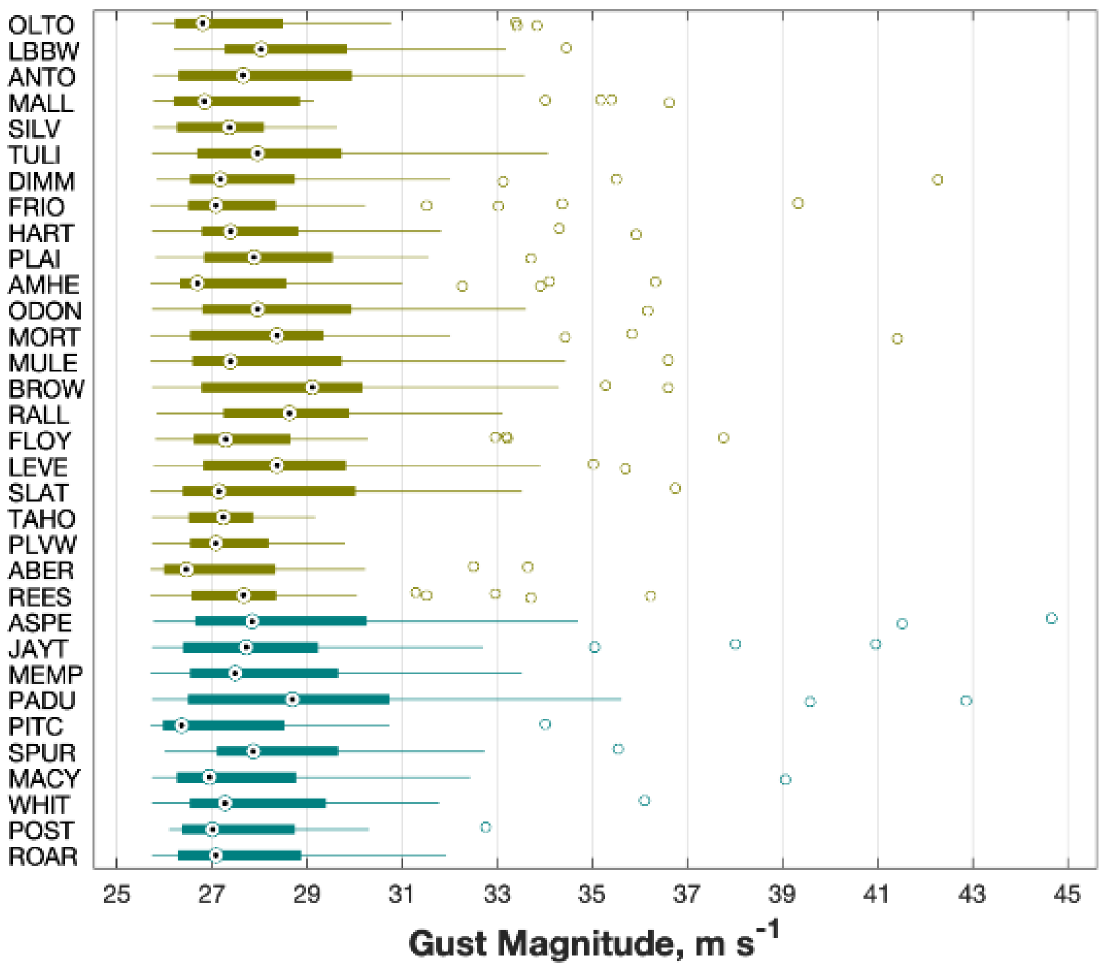


Figure 10: Condensed box–and-whisker plot of the severe gusts for each station. Plotting conventions as in Fig. 7, except for horizontal orientation, and circled dot representing median. South Plains stations are displayed in tan, while Rolling Plains stations are in teal. Four-letter station identifiers are included on the left. See Table A1 in the Appendix for more information on each WTM station used in this study.

c. Gust characteristics

Considering all 1042 severe convective gusts measured across the selected WTM stations over 15 y, the median gust magnitude was ≈27.5 m s^{-1} (Fig. 10). The station near Brownfield, TX, yielded the only median >29 m s^{-1}, while there were several stations with median values <27 m s^{-1}. There was virtually no difference between the median gust magnitudes of the Rolling Plains and South Plains stations, with values of 27.38 m s^{-1} and 27.39 m s^{-1} respectively. This result was confirmed with the Wilcoxon-Mann-Whitney ranked sum test (Wilks 2019), where the null hypothesis that median values were the same could not be rejected at 95% confidence. The highest 3-s gust recorded during this period was 44.7 m s^{-1}. This gust was associated with the rear flank downdraft (RFD) of a tornadic that closely approached the Aspermont WTM station on 13 June 2009.

Figure 10 also demonstrates that most gusts were clustered near the low end of the distribution. The overall interquartile range was 2.64 m s^{-1}, with values of 2.72 m s^{-1} and

2.56 m s^{-1} for the Rolling and South Plains respectively. While many of the measured severe gusts were closer to the lower threshold, there were 59 significant-severe gusts. Considering the distinction between the Rolling Plains and Caprock stations, the WTM stations in the Rolling Plains exhibited 18 significant gusts, while the South Plains stations measured 41 significant gusts. These values represent 5.3% of all South Plains severe convective gusts and 6.7% of all Rolling Plains severe convective gusts in this dataset. Six stations overall did not measure any significant severe gusts. Four of these stations were in the South Plains (PLVW, TAHO, RALL, and SILV), while two were in the Rolling Plains (ROAR and POST).

The maximum 3-s gust can be divided by the 5-min average windspeed to produce a gust factor for each observation, to indicate how much larger a given gust was than the 5-min average. Gust factors are an important consideration in designing wind-resistant structures (Lombardo et al. 2014), and have been explored for both extreme thunderstorm and non-thunderstorm winds (e.g., Orwig and Schroeder 2007; Lombardo et al. 2014; Letson et al. 2018). In an analysis of gust factors from a larger set of WTM stations, Lombardo et al. (2014) noted that thunderstorm gust factors associated with a peak speed >31 m s^{-1} ranged from ≈1.5–2.

For the 15-y period analyzed, WTM gust factors ranged from 1.16–4.85. The mean gust factor was 1.59. While these values likely are impacted by nonstationary means (i.e., the 5-min mean varies with time; Holmes et al. 2008; Lombardo et al. 2014) and include low mean windspeeds as well as a close pass of a tornado, they do illustrate the range of gust factors that can be computed from standard 5-min WTM data in generally open terrain. The gust-factor values are demonstrated further in Fig. 11, where the 3-s gusts are plotted against the 5-min average windspeeds. In general, severe gusts of greater magnitude were associated with larger 5-min mean windspeeds. More “gusty” or “abrupt” conditions are represented on the left side of the scatter plot. For example, a severe gust of over 26 m s^{-1} occurred in a 5-min window with an average windspeed of just over 5 m s^{-1}. The gust histogram on the left side of Fig. 11 also shows that the majority of severe gusts were within 5 m s^{-1} of the severe wind threshold of 26 m s^{-1}.

The 3-s gust speeds were also plotted with respect to the 5-min vector-averaged wind direction that was included in each station’s data file (WD; Fig. 12). While severe gusts occurred with 5-min average wind directions from virtually all compass points, there was a distinct preference for a northwesterly average during the same 5-min window as the severe gusts. Relatively few severe gusts occurred with easterly 5-min mean wind directions. To quantify this difference, wind direction bins 30° in width were created, and the gusts were distributed into their respective 5-min average WD bin. Table 1 presents the actual count of WD sectors that were associated with the severe gusts. Most of the severe gusts occurred when the average wind direction was from the north-northwest, with 17% of all severe gusts in this study associated with this sector.

The second highest value was from the northwest, with 166 recorded gusts, or 15.9%. The fewest severe gusts were associated with 5-min mean wind directions in east-northeast sector, with 22 gusts, or 2.1% of the total. While these results only reflect the average wind direction over the 5-min period in which the severe convective gust was measured, these values demonstrate some of the common synoptic drivers of convection in the area. For example, Johns (1982) noted that West Texas region, in addition to the Texas Panhandle, experienced multiple severe-weather outbreaks associated with northwest-flow events and demonstrated the general northwest–southeast track of thunderstorms in such environments. Other suspected drivers of the high frequency of northwesterly wind directions include the initiation of convection off the higher terrain in New Mexico and subsequent eastward propagation, as well as the passage of convection produced by cold fronts.

The occurrence of precipitation within each 5-min period that recorded a severe convective gust was also analyzed to contribute to an understanding of the driving meteorology as well as explore the frequency of “dry” microbursts and outflows in this region of the country.

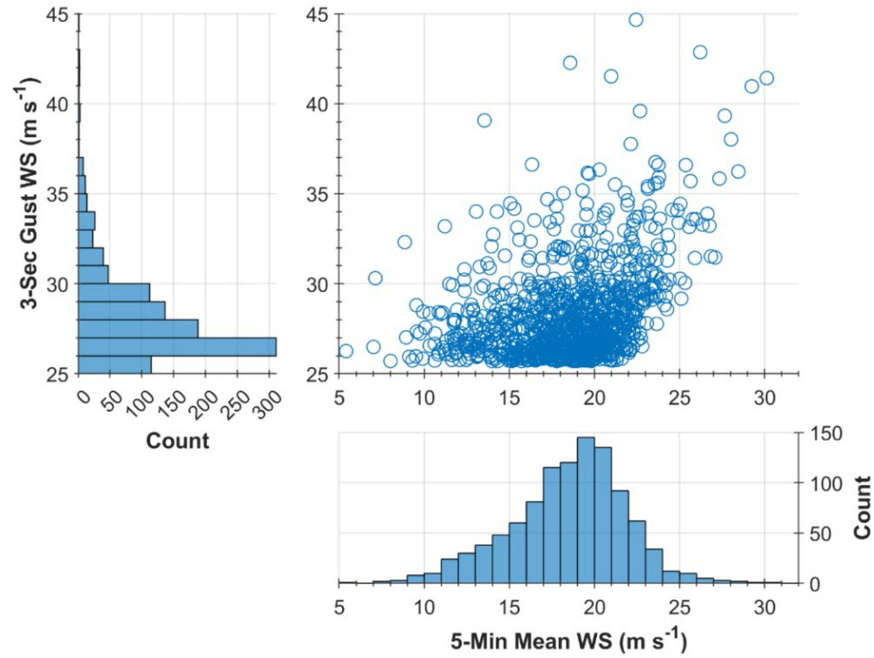


Figure 11: Scatterplot and histogram combination for all data points. The x-axis and lower histogram correspond to the 5-min mean windspeed, while the y-axis and left histogram correspond to the 3-s gust speed. Windspeed values are 1 m s^{-1} bins.

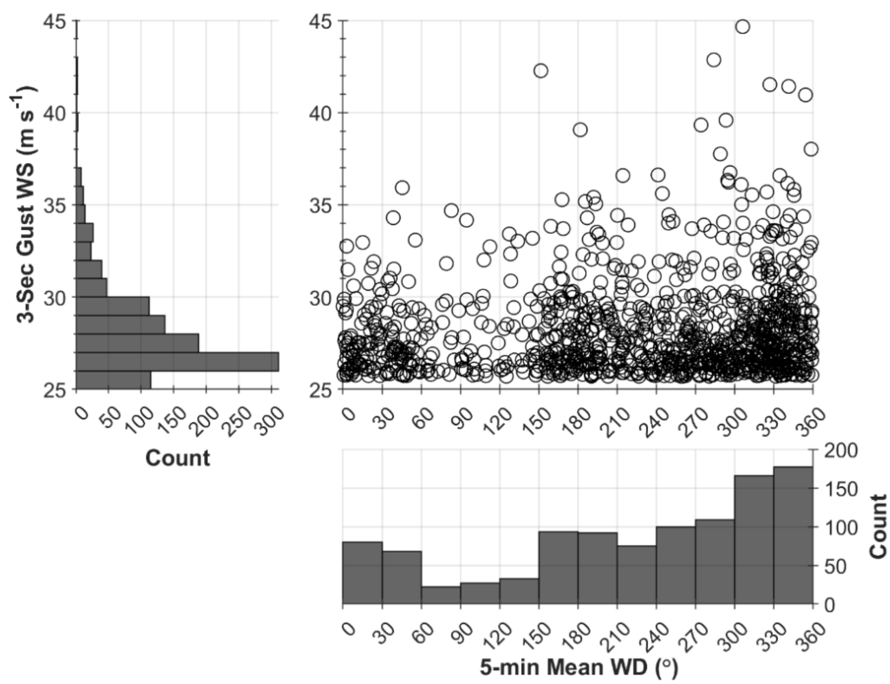


Figure 12: Scatterplot and histogram combination for all data points. The x-axis and lower histogram correspond to the 5-min mean wind direction, while the y-axis and left histogram correspond to the 3-s gust speed. 5-min mean wind direction values are in 30˚ bins.

Precipitation data were divided into two categories: dry (no precipitation recorded in the 5-min interval) and wet (>0 in of precipitation reported in the 5-min interval). Dry gusts were more frequent and comprised 55.9% of the total gusts. These two subsets were also compared to their associated gust magnitudes to produce the box plot in Fig. 13. Comparing the medians of each distribution, the wet category had a median almost 1 m s^{-1} higher than the dry category with values of 27.1 m s^{-1} and 28.0 m s^{-1} respectively. The Wilcoxon-Mann-Whitney rank sum test confirmed that the medians of the distribution were statistically different to a 95% confidence. There was also a larger interquartile range with the wet category, while the dry category was more closely clustered around the median. The greater median gust speed associated with the wet gusts likely reflects a greater contribution to downward vertical momentum through precipitation loading (Wakimoto 2001), but increased evaporation from excess water vapor also could play a role.

Table 1: Distribution of severe gusts by wind direction sector. Each sector is 30° wide.

Wind Direction Sector	Count
0°–29.9°	80
30°–59.9°	68
60°–89.9°	22
90°–119.9°	27
120°–149.9°	33
150°–179.9°	93
180°–209.9°	92
210°–239.9°	75
240°–269.9°	100
270°–299.9°	109
300°–329.9°	166
330°–359.9°	177

d. Event analysis

The individual severe-gust occurrences were combined into station-specific events, in order to reveal the meteorological drivers of each gust or sequence of gusts, through the exploration of thermodynamic perturbations. The events were segregated through the methodology described in section 3. While this process yielded 651 events across all stations, the fact that the same convective event was likely sampled by multiple stations was not accounted for. Most events were composed of a single severe gust (Fig. 14). However, 12% of events experienced 3 or more consecutive severe gusts. These long-lasting severe events were likely associated with wake lows in the trailing precipitation region of convective complexes. For example, the intense bow echo that occurred on 5 June 2013 produced almost 2 h of consecutive 5-min periods in which a gust meeting the severe criteria was measured. Other stations impacted by this complex (e.g., REES, LBBW, SLAT) also experienced long periods of severe gusts after the passage of the leading edge of the convection. However, these extended periods of severe gusts were rare in the dataset with over 95% of events occurring over a span of ≤30 min. This observation lends credence to other severe–wind-event methodologies that use a period of ≤30 min to define an "event" (e.g., Cook 2023).

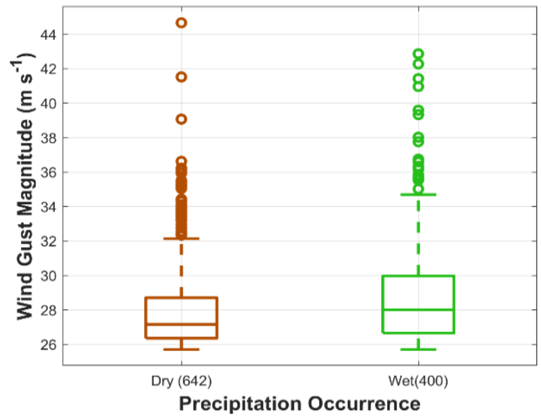


Figure 13: Box-and-whisker plot of the wet and dry gusts as defined in the text. Plotting conventions as in Fig. 7.

The occurrence of precipitation was also analyzed from the event perspective, such that precipitation that fell during the event time was summed and compared to the maximum gust experienced. For example, the maximum gust in the entire dataset appears in the dry category of Fig. 13, since no precipitation was recorded in the 5 -min period containing the gust. This same gust fell in the "wet" category of the event analysis, since precipitation occurred with other gusts in that event. Similarly, the "dry" category had no precipitation measured during that or subsequent gust that was part of that event.

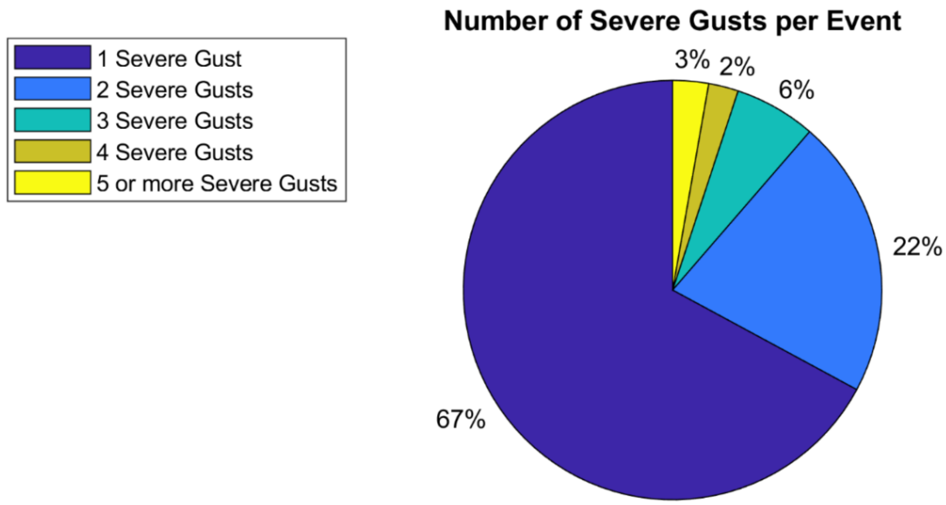


Figure 14: Pie chart depicting the distribution of severe gusts among events.

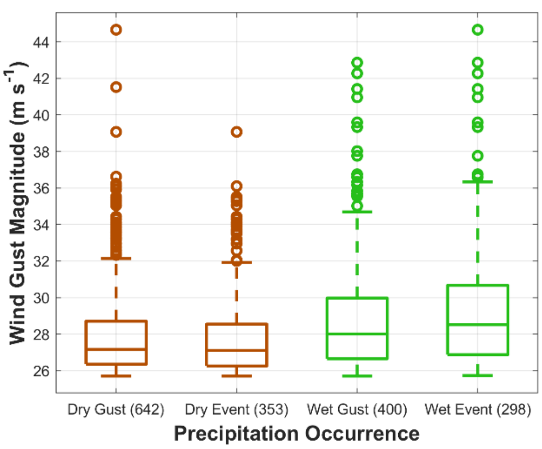


Figure 15: Box-and-whisker plot of the gusts associated with both wet and dry gusts and events. Plotting conventions as in Fig. 6.

The maximum amount of precipitation produced in any one severe convective gust event was 1.02 in (2.59 cm) on 7 June 2014, which fell over a period of only 15 min.

The result of this analysis yielded a greater percentage of events with precipitation (45%) than individual gusts with precipitation (38%). The increase in percentage of wet events likely reflects scenarios where a "dry" gust was just well ahead of the parent thunderstorm. Compared to the analysis of the individual gusts, the medians of the wet and dry events differed by a greater amount (Fig. 15). As such, the rank sum test yielded more statistically significant results. The gust medians for the dry events and the wet events were 27.1 m s^{-1} and 28.5 m s^{-1} respectively. This difference in magnitude could be related to the proximity of the precipitation core to the WTM station, such that the occurrence of precipitation meant the station was closer to the downdraft core. As such, the outflow would have less time to weaken. Similarly, "dry" gusts may either be associated with dry microbursts, or have occurred from outflow that have traveled a significant distance from the parent thunderstorm and precipitation core. A more thorough radar analysis would be needed to test these hypotheses.

The thermodynamic perturbations associated with each event were calculated by subtracting the value of temperature, barometric pressure, relative humidity, and dewpoint 15 min after the severe gust from the values 15 min prior to the 5-min segment containing the first severe gust of an event. As expected, the majority of temperature perturbations were negative, indicating cooler outflow air as compared to the pre-outflow environment (Fig. 16a). The median temperature perturbation was –6.2°C, but the values ranged from a maximum of 4.9°C (indicating a warmer "outflow") to a minimum perturbation of –19.4°C (Table 2). There was no relationship between the magnitude or sign of the temperature perturbation and the gust magnitude.

The histogram of Fig. 16a shows multiple instances of positive temperature perturbations. While many of these events are suspected to be heatbursts (Johnson 1983; McPherson et al. 2011), any outflow producing a rapid return to pre-outflow conditions (e.g., spatially small or fast moving) would also contribute to more positive temperature perturbations. Further, McPherson et al. (2011) used an upper threshold of 2.7°C increase in temperature over 10 min (in conjunction with a decrease in dewpoint and wind gust) to detect a heatburst. Based solely on this temperature threshold, there 11 events would qualify as heatbursts. However, 76 events had a positive temperature perturbation.

A similar analysis was conducted with event dewpoint (Fig. 16b), relative humidity (Fig. 16c), and station pressure perturbations (Fig. 16d). The latter two parameters generally reflected the trends seen in the temperature values (Table 2). Namely, most gusts were also associated with higher values of relative humidity and station pressure as would be expected of typical outflows (Goff 1976; Wakimoto 1982; Engerer et al. 2008).

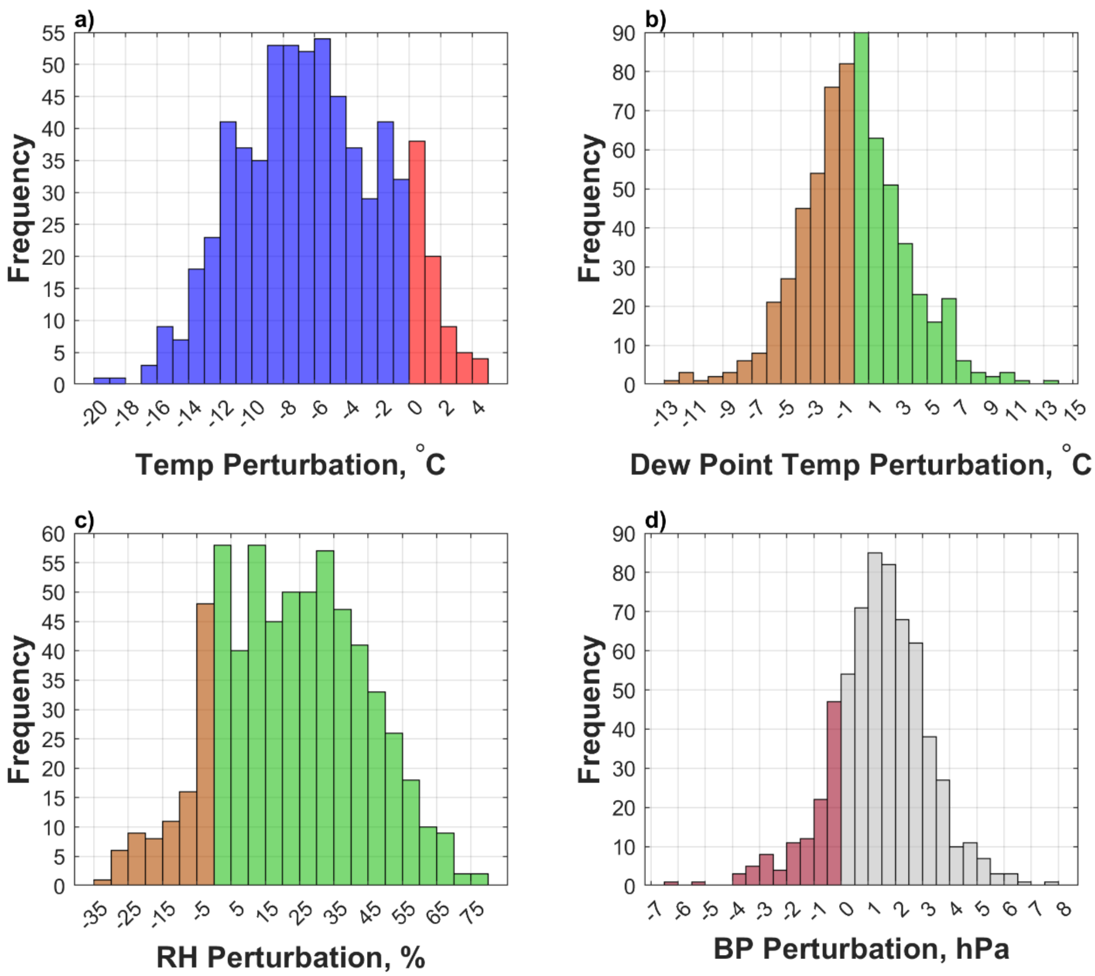


Figure 16: Histogram of a) temperature, b) dewpoint, c) relative humidity, and d) station pressure perturbations associated with each severe convective gust event. Negative values represent colder post-gust temperatures and are shaded in blue, while positive values represent warmer post-gust temperatures and are shaded in red. For (b) and (c), brown shading indicates negative perturbations, while green shading indicates positive perturbations. For (d), maroon shading indicates negative perturbations, while gray shading indicates positive perturbations.

The distribution of dewpoint perturbations, however, exhibited very little skew, as compared to the other variables. A slight majority of events (50.85%) exhibited a decrease in the dewpoint within 15 min of the first severe gust of an event. While there was no discernable trend in terms of gust magnitude and event dewpoint perturbation values, combining these values with the event temperature perturbations can provide insight into the driving mechanism of the gust. For example, of the 76 events that demonstrated a positive temperature perturbation, 57 also involved a decrease in dewpoint. This combination of variables increases the likelihood that the 57 events were heatbursts. Of the 11 events exceeding the temperature threshold of McPherson et al. (2011), 9 were characterized by a decrease in dewpoint. Several other factors could explain these complex observations, including a rapid return to pre-outflow conditions (e.g., spatially small or fast moving) or the proximity to large, cultivated fields. Analysis of the corresponding radar data would also help to clarify the perturbation values seen in the event analysis.

Table 2: Perturbation values of thermodynamic variables.

Parameter	Median	Max	Min
Temperature (°C)	–6.2	4.9	–19.4
Dewpoint (°C)	–0.06	13.8	–12.8
Rel. Hum. (%)	22.2	76.6	–31.6
Station Pressure (hPa)	1.4	7.9	–6.1

5. Summary and discussion

a. Summary

Using a rich, 15-y dataset from 33 stations across West Texas, the primary objective of this study was to generate an initial climatology of severe convective gusts across the region. This dataset also allowed for the computation of other meteorological parameters associated with each severe convective gust. Based on the data and analyses presented:

- Spatial statistical analysis revealed several positive and negative outliers in terms of severe-gust frequency. Two of the positive outliers were on or close to the Caprock Escarpment.
- Stations located west of the Caprock Escarpment experienced more frequent severe convective gusts than their Rolling Plains counterparts.
- While the Plainview AWOS compared well with the PLVW WTM station, a likely influence of urbanization was found with the LBBW WTM station, which had fewer gusts than the LBB ASOS or the REES WTM, both located just outside of the urban area.
- No significant trend was present in the annual variation of severe convective gusts. Rather, the distribution was driven by regional severe-weather episodes.
- Monthly and diurnal patterns in the severe convective gust distribution reflected expectations consistent with the regional climatology of convective activity, with the number of severe gusts peaking in June and the early evening.
- Most of the measured severe gusts within this dataset were within the first 4.5 m s^{-1} of the severe-wind threshold. These account for about 80% of the severe gusts observed.
- Significant gusts (classified as ≥33.4 m s^{-1}) occur very rarely and account for about 5.5% of all gusts.
- Most severe gusts occur when the 5-min average winds have a westerly component to them, primarily from the west or northwest (270–359.9). This 90° sector accounted for over 43% of observed 5-min mean wind directions.
- Fewer events were recorded than individual gusts, indicating that almost one-third of convective events involved more than one severe gust.
- Most severe gusts were associated with a decrease in temperature, increase in relative humidity, and increase in station pressure. Suspected heatbursts and wake lows were also identified.

Many of these results reflect the outcomes of similar climatologies developed using the national network of ASOS stations (e.g., Lombardo and Zickar 2019, Smith et al. 2013, and Kelly et al. 1985). However, this study also shows that detailed regional climatologies may be derived from dense mesoscale networks. These regional climatologies could be used to improve forecasts in CWAs that are fortunate enough to contain a mesonet.

b. Limitations and future work

While the climatology based solely on WTM data is useful in highlighting mesoscale aspects of severe convective winds, the results could be greatly improved by including a detailed radar classification, such as done in Smith et al. (2013), for each individual gust or each event. In addition to documenting the frequency of different convective modes associated with severe gusts in the region, such an analysis could help in formally identifying heatburst events and differentiating them from rapid boundary-layer recovery.

Exploring the radar data could also help explain the trends seen in the wet vs. dry gusts. For example, were “wet” gusts stronger because they were more directly impacted by a precipitation core? Similarly, is there a relationship between the distance from the parent thunderstorm and the number and intensity of gusts? Finally, an analysis of the corresponding radar data would also more thoroughly describe the trends seen in the average 5-min wind direction of the severe gusts. Was the fact that the majority of gusts were associated with a northwesterly wind direction related to storm motion or the location of the parent storm with respect to the station? What type of convective modes or phenomena were associated with the “rarer” 5-min wind average wind directions? Higher-resolution wind direction, such as that associated with the maximum 3-s gust, also would be helpful in further describing the directional distribution of severe convective gusts.

Considering these research questions, future work with this dataset will include a radar classification of the convection related to the severe gusts, as well as an analysis of damage reported in close proximity to the measured severe gusts. Additionally, WTM sensors are in the process of being upgraded to 1-min sampling. As the WTM continues to collect data and more stations are upgraded, similar studies should be done utilizing its entire dataset to see how these meteorological variables may change in a changing climate.

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APPENDIX

Table A1: Summary table of WTM stations used in this study. This information, as well as that of other mesonet stations is also available on the West Texas Mesonet website: www.mesonet.ttu.edu/site-info.

Mesonet ID	Station Name	Commission Date	Texas County	Latitude	Longitude	Elevation (m)
ABER	Abernathy	7/1/2000	Hale	33.87538	−101.75718	1015
AMHE	Amherst	7/1/2001	Lamb	34.02178	−102.40453	1111
ANTO	Anton	3/1/2002	Hockley	33.72525	−102.19082	1037
ASPE	Aspermont	6/1/2004	Stonewall	33.16789	−100.19602	530
BROW	Brownfield	3/1/2001	Terry	33.15188	−102.27102	1009
DIMM	Dimmitt	10/1/2001	Castro	34.56751	−102.29317	1181
FLOY	Floydada	3/1/2001	Floyd	34.00158	−101.32588	970
FRIO	Friona	9/1/2001	Parmer	34.6545	−102.69097	1220
HART	Hart	9/1/2001	Castro	34.42319	−102.10735	1125
JAYT	Jayton	8/1/2003	Kent	33.23241	−100.56778	614
LBBW2	Lubbock TTU	10/1/2002	Lubbock	33.60408	−101.89919	984
LEVE	Levelland	2/1/2001	Hockley	33.5265	−102.36	1064
MACY	Graham	1/1/2002	Garza	33.08152	−101.51615	874
MALL	Sundown	2/1/2002	Cochran	33.38912	−102.60994	1104
MEMP	Memphis	7/1/2003	Hall	34.73136	−100.52543	626
MORT	Morton	4/1/2001	Cochran	33.73476	−102.73978	1143
MULE	Muleshoe	3/1/2001	Bailey	34.20635	−102.7424	1159
ODON	O'Donnell	6/1/2001	Lynn	32.97988	−101.8322	930
OLTO	Olton	4/1/2001	Lamb	34.09378	−102.11808	1085
PADU	Paducah	3/1/2003	Cottle	33.89053	−100.39886	615
PITC	Guthrie	12/1/2002	King	33.56703	−100.48061	609
PLAI	Plains	9/1/2001	Yoakum	33.22814	−102.83936	1130
PLVW	Plainview	2/1/2001	Hale	34.17872	−101.70788	1022
POST	Post	11/1/2001	Garza	33.20033	−101.36804	792
RALL	Ralls	3/1/2001	Crosby	33.6684	−101.37576	943
REES	Reese Center	6/1/2000	Lubbock	33.60759	−102.04597	1019
ROAR	Roaring Springs	2/1/2001	Motley	33.93635	−100.8454	796
SILV	Silverton	11/1/2001	Briscoe	34.4454	−101.1905	980
SLAT	Slaton	2/1/2001	Lubbock	33.4569	−101.61723	933
SPUR	Spur	8/1/2002	Dickens	33.48085	−100.87636	696
TAHO	Tahoka	2/1/2001	Lynn	33.20747	−101.78025	945
TULI	Tulia	10/1/2001	Swisher	34.54294	−101.7405	1059
WHIT	White River Lake	12/1/2001	Crosby	33.52533	−101.16506	824

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REVIEWER COMMENTS

[Authors' responses in *blue italics.*]

REVIEWER A (Philip N. Schumacher):

Initial Review:

Recommendation: Accept with major revisions.

Summary: The authors perform a 15-y climatology of severe convective wind events using data from the West Texas Mesonet in the WFO Lubbock CWA. The authors examine the frequency of events as a function of time of day and time of year. They also examine how the number of events vary by location in the LBB forecast area. They note that the number of severe gusts is generally more common in the west of Lubbock and becoming less common moving east of Lubbock. Despite fewer gusts, significant severe gusts (>65 kt) were more common east of the Lubbock area. The authors also find that dry severe convective winds and heat burst are somewhat common.

Substantive Issues: The authors [in the Introduction] cite two papers, Brotzge et al. (2011) and Sherburn and Parker (2014), in the discussion observations of severe wind events. Brotzge et al. (2011) includes a tornado climatology in their analysis. This climatology is not relevant to the paper as they are examining how tornado frequency evolves through the day while this paper examines how wind events evolve through the day. Sherburn and Parker (2014) are looking at a subset of wind events that occur in a high shear-low CAPE (HSLC) environment and how severe events within this environment vary through the year. In their case, the HSLC environment does shift north and west from the cold season to warm season. However, convective environments still exist in the southeastern United States during the summer and severe wind events can still occur – usually as wet microbursts (see Atkins and Wakimoto 1991). They just occur in environments that are likely dominated by High CAPE and low shear and were not included in the Sherburn and Parker paper. I believe Sherburn and Parker (2014) paper's results are misstated in the introduction.

There are many other papers that do a climatology of severe weather. One example is Doswell et al. (2005) which developed a way to look at the probability of severe weather events near any location at any time of the year. There are other papers in the literature as well and I recommend that the authors do a literature search for these types of papers in their review of past work on severe weather frequency across the country.

Section 1 underwent a drastic overhaul to not only better represent the vast amount of research already done on this topic, but to also outline the research objectives of our submission. Additionally, the specific references that were mentioned (Brotzge et al. 2011 and Sherburn and Parker 2014) were removed. Generally, we now discuss severe storm reports, their issues, and the climatologies developed using them. We then discuss the severe wind climatologies generated from measured (ASOS/AWOS) data. This topic now leads to an overview of mesonets and some of the work done there before we outline the purpose of our research. We are grateful to the reviewer for comments on this and hope the new Introduction and Background is more fitting of the work. We also added other relevant, but infrequently cited, works such as Gilliland et al. 2020 and Letson et al. 2018.

The spatial analysis using Figure 3 needs to be redone. The figure shows a maximum at each station with minima between stations. These minima are not supported by the data. The radius of influence appears too small, which makes analysis of the results difficult at best and misleading at worst. I am not familiar with the specific algorithm used in ArcGIS and its strengths and weaknesses, but the authors need to redo this analysis by increasing the radius of influence, such that most minima are removed from the analysis, leaving what is the actual spatial distribution of wind reports across the analysis area. In addition, there are likely boundary issues at the edge of the domain. The authors could consider adding stations outside to the domain for the paper so that there does not appear to be a decrease in reports at the edges of the domain.

Once the data is re-analyzed, the statistical analysis used to identify statically significant maxima and minima should then be redone using the new analysis. In addition, if the authors believe that the station LBBW is not representative of frequency of wind events in the area due to its location within the city, I would recommend removing the station when computing the heatmap using the reasoning in the text on the first paragraph of page 5 to justify its removal, since it may have a negative impact on both the statistics and the heatmap.

We are grateful to the reviewer for picking out some of these issues and encouraging us to pursue a new, better spatial analysis. After an exhaustive literature search, we decided to use a similar spatial analysis as Gilliland et al. (2020). This analysis (the Anselin Local Moran's I) is well supported in the literature and has been used for severe wind gust analyses in Gilliland et al. 2020. While the Zone of Indifference (akin to a radius of influence) was selected without any guidance as to the best value, we believe the results at least reflect what is suggested by the raw gust distributions. We also eliminated the heat map as we believe it didn't offer any relevant information—the heatmap patterns (akin to kernel density) are largely driven by the station/station placement themselves (not the gust frequency). The results of the new statistical analysis are provided in the revised Fig. 4 (for all gusts) and Fig. 5 (for significant gusts).

Comparison to ASOS/AWOS stations: In the manuscript, you mentioned that there were 3 AWOS/ASOS stations in the domain. Assuming there are not issues with obstructions, are the number [of] events at these stations similar to nearby WTM stations over the same time period? I would recommend doing a brief comparison of the WTM gusts climatology to the AWOS/ASOS stations to see if ASOS/AWOS have a lower or higher number gusts relative to gusts of neighboring WTM stations. While the small number of ASOS/AWOS stations will not allow one to make generalizations about any biases in either set of instruments, it would begin to answer the question as to whether the WTM wind sensors may reach severe criteria more or less frequently than nearby AWOS/ASOS stations.

This comparison was provided in section 4a at the request of multiple reviewers. While there are several ASOS/AWOS stations in the LUB WFO, only 2 had data for the entire 15-year period: KLBB and KPVW. These stations are located at the Lubbock International Airport and the Plainview Regional Airport respectively. The proximity of these stations to WTM stations proved to be an excellent comparison. The WTM station within the city of Lubbock now really does seem to be an outlier, despite not being indicated as such in the spatial analysis. Conversely, the two Plainview stations yielded relatively similar outcomes. We are grateful for the encouragement to pursue this comparison.

Does the average number of gusts on the Caprock include LBBW? Also, is this difference statistically significant? You could do a non-parametric test such as a Mann-Whitney-Wilcoxon rank sum test.

This paragraph was removed in favor of the ASOS/AWOS discussion. However, we do compare the gust magnitudes across the escarpment at the beginning of section 4c. We employed the rank sum test here, which showed the gust magnitudes of the two subsets were not statistically different.

For your seasonal analysis and hourly analysis, it appears that one or two events may be skewing the analysis based on the statement in the next paragraph. If you plotted the number of days each month (or hour) that had severe gusts instead of the raw number of severe gusts, would the results be the same–[or], would June more than twice the number of days with severe winds compared to May and July?

Thank you for this comment! We did just that—for the yearly, monthly and hourly histograms and included those in revised Figs. 7 and 8. June still represents a maximum, but it is not nearly as prominent as when individual gust occurrences are considered.

You discuss the relatively low frequency of gusts with an easterly component and also that low frequency of events with gusts that persist for 10s of minutes. By using the pressure data with the wind data, are you able to ascertain if any of the severe wind gusts were associated with wake lows?

Excellent question. We included an outflow pressure perturbation (as well as dewpoint and RH) in the event analysis of the last section. There do seem to be multiple events that were associated with a wake *low. In particular, the extreme event on 5–6 June 2013 consisted of significantly severe bow echo followed by over an hour of borderline severe winds likely driven by a wake low.*

You hypothesize that many of these [positive temperature perturbations] are heatbursts. Heatbursts are also accompanied by reductions in dew point. Did you check how many of these events have both an increase in temperature and decrease in dew point to ascertain what percent of these events could be heatbursts?

In our update of the event analysis, we also included a histogram of dewpoint. Interestingly, the perturbation appeared normally distributed about zero. We explored this further by comparing the dewpoint data with temperature perturbations and wind gusts. While nothing statistically significant jumped out, most (75%) of the positive temperature perturbations were associated with a decrease in dewpoint.

Figure 12: Are the differences between "dry" and "wet" gusts statistically significant?

Based on the reviews for a previous section, we thought a Wilcoxon ranked-sum test would be appropriate here as well. Upon testing, the results were significant to a 95% confidence for both individual gusts as well as "dry vs. "wet" events.

[Minor comments omitted…]

Second Review:

Recommendation: Accept with minor revisions.

Summary: This paper reviews severe convective within the West Texas Mesonet (WTM) from 2005–2019. The authors find that areas on the Caprock have more wind reports than those east of the Caprock. The authors also compare the frequency of events at two nearby ASOSs to two nearby WTM sensors. They also found that there is a relative minimum in reports just west of the Caprock Escarpment. Finally the authors find that most severe gusts occur with northwesterly winds, falling temperatures, increasing humidity, and rising pressure.

I appreciate all of the work the authors went through to address my concerns with the manuscript. Overall, the manuscript is greatly improved—the objectives of the analysis are better described, the statistical analysis is appropriate for the data set, and the figures are easier to read and interpret.

Substantive Comments: [Y]ou show that LBBW likely has fewer gusts because it is in an urban area. Did Vega-Avila (2008) calculate the roughness length in the vicinity of LBBW and was it larger than the other WTM sites in the study? If so you could mention that either here or when you discuss the anomalously low number of severe gusts at LBBW in section 4?

This is an excellent question/point. Vega-Avila (2008) did compute the roughness length for WTM stations that reported data from 2004–2006. In this analysis, The LBBW station roughness length is one of the largest at 0.033 m. PLVW, MEMP, and ASPE show up as even rougher at 0.0413, 0.047, and 0.0718 m respectively. The REES station, however, has an average roughness length of 0.009. So, while these findings corroborate the low gust numbers for these stations, they do not fully explain them (in the sense that the roughest location did not experience the least number of severe gusts). One major issue with this result is that there is only 1 year of overlapping data. Anecdotally, Lubbock has experienced a lot of growth since 2006. Another issue is that several stations are not represented in the Vega-Avila (2008) analysis. Specifically, the MACY station on the edge of the escarpment did not have the requisite two years of data and wasn't included. Regardless, we have included a brief statement about the roughness lengths for these stations was included in Section 4 prior to and within the ASOS discussion.

I believe it would be possible to provide a more definitive answer on the number of heat bursts. Since heat bursts are defined by both an increase in temperature and decrease in dew point, I recommend counting how many events had both. While that does not guarantee the gust was associated with a heat burst, it makes it more likely.

The comparison was indeed interesting, but it wasn't as definitive as we hoped. Of the 76 events that had a greater than zero temperature perturbation, 57 had a decrease in dewpoint. Constraining the temperature perturbations to match McPherson et al. (2011) yielded 11 warm gusts. Nine of these 11 also had a decrease in dewpoint and would therefore be classified as heat bursts by an approximation of the methodology of other researchers. We included this information in the last paragraph of section 4c as suggested by the reviewer.

[Minor comments omitted…]

REVIEWER B (Mark Conder):

Initial Review:

Recommendation: Accept with minor revisions.

General Comment: Overall, I think this paper reflects some excellent data analysis of West Texas Mesonet data and contributes to the understanding of severe convective wind climatology in West Texas, and will be a useful resource for operational meteorologists to understand the regional climatologies, and what may be some geographic distinctions to be aware of. Of course there's a lot more that can be done with this data. The authors only touched on methods to distinguish some type of events (e.g., wake lows and heatbursts), but I think what has been done in this paper is certainly sufficient. My comments in the attached MS Word doc are mostly grammar and typo-type things that likely have already been fixed. There is one potential sticking point that I found, and that was the disagreement between the Caprock and Rolling Plains gust characteristics in section 4c and those in the conclusion. Once that is resolved (unless I just misunderstood it) I've recommended the paper for acceptance. Thanks for the opportunity to review, and I'll be glad to give it another look if requested.

Substantive Comments: Not disagreeing with the definition, but I suppose in a few cases this (4-h separation) could lump multiple gusts generated by different storms together into one event.

We invested a significant amount of effort in our methodology for defining an event. The new methodology is provided in section 2, paragraph 3. Further, a recent paper published in the Journal of Wind Engineering and Industrial Aerodynamics *(Cook 2023) provides a really good overview on all the different methodologies used to define wind "events".*

Just eyeballing Fig. 7, to me it looks almost certain that the Caprock stations would have had a greater number of significant-severe gusts. And it seems to contradict your conclusion about the geographic distribution of gusts.

While this is incredibly embarrassing for the authors, you are correct. The total number of sig severe gusts for the Caprock stations was 41, while that of the Rolling Plains station was 18. I have no idea where we got that idea—unless it was on a "per station" basis or something. Regardless, our apologies for the incorrect statement are very grateful for the reviewer's keen eye in pointing this out.

[Minor comments omitted…]

Second Review:

Recommendation: Accept with minor revision.

[Minor comments omitted…]

REVIEWER C (Megan Schargorodski):

Initial Review:

Recommendation: Accept with major revisions.

General Comment: This paper provides a background of severe gust climatologies and presents new findings regarding the construction of a severe convective gust climatology for the National Weather Service Lubbock's County Warning Area, based on West Texas Mesonet data. Demonstrating the high value of a high quality, high density mesoscale network is crucial to the continuance of their existence. Your work is greatly appreciated by the community. Overall, the manuscript was enjoyable to review and a good fit for this journal but could be greatly enhanced as a standalone paper in a few ways, including improvement of figures/tables and review terminology/methodology of desired climatologies.

Substantive Comments: Is there any background climatology of mean wind speeds for the area outside of the severe gusts? Such information may provide a good baseline for the significance of the gusts compared to the climatological mean.

This is an excellent point. This information is surprisingly hard to find for this region. The lack of general mean-wind climatology specifically for this region may justify more work in the future. However, we did include other references that have included the region in general climatologies. For example, Gilliland et al. (2020) looked at both non-convective and convective high-wind events. We pulled some information from convective climatologies (Smith et al. 2013; Lombardo and Zickar 2019) for comparison with our data as well. Similarly, there was a study performed looking at convection generated by northwest flow events (Johns 1982). We have included references to these studies as well as some others throughout the document.

Did you investigate data from the other two levels of winds? ASOS data? While perhaps not standard, this could provide another means of finding events.

Excellent question. We initially had an interest in looking at the other levels of wind on the WTM stations. However, they only report the 5-min average and did not include any peak gust information. There may be some value in comparing the 5-min averages, but we elected to not go down that road and instead focus on the 10-m gusts from the WTM stations. Additionally, the other two levels don't have any wind direction information (scalar averages only). Only cup anemometers are used at this time.

Between the reviewer's comments about the ASOS data and similar comments from other reviewers, we included a brief analysis of ASOS data in section 4a. This analysis was very informative and highlights the extreme local nature of severe convective winds.

Comparing the WTM climatology to one previously analyzed for ASOS data could provide additional value to the WTM network and further justify your analysis.

We agree with the reviewer's comments and are grateful for the encouragement to pursue the ASOS comparison!

Do you have an explanation for why the Caprock may influence severe wind gusts?

The most likely explanation is the difference in land cover east and west of the Caprock Escarpment. Eastward, there is less land developed for agriculture, more low brush, and a greater variability in terrain. West of the escarpment, it is extremely flat, and much of the land is agricultural fields. This idea has been clarified some with added information from Schroeder et al. (2005). Other hypotheses include more disorganized convection that develops on the higher terrain in the west (Raton Mesa) and makes it to the western side of the WTM domain as well as the general higher elevation to the west. However, there were *several western stations with strikingly lower gust values as well (e.g., MULE). We have updated Section 4a to include some of these details.*

[Minor comments omitted…]

Second Review:

Recommendation: Accept with minor revisions.

General Comment: The only feedback I have is superficial and could likely be smoothed out during the final typesetting.

[Minor comments omitted…]

REVIEWER D (Brian J. Squitieri):

Initial Review:

Recommendation: Accept with major revisions.

Major Comments: The submitted manuscript provides a statistical overview on the distribution of severe convective gusts across portions of the TX Panhandle over a 15-y period, with the goal to derive a regional severe-gust climatology. Spatial and temporal distributions of the severe gusts were shown, as well as diurnal trends in the occurrence of severe gusts. While these tasks were carried out robustly, there are several questions that seem to be unanswered that are core to typical severe weather climatologies. Toward the end of the conclusions section, it was mentioned that work was underway to associate the distribution of severe gusts with respect to storm mode (using radar as observations). For this regional climatology, I think this task is a must for the manuscript. In short, I think merging the storm mode results and the most pertinent information in this current manuscript would make for a very interesting and informative contribution to the literature.

We are very grateful to the reviewer for their time in assessing our work and their relevant comments. It was obvious that the reviewer put in significant effort to not only understand the paper but also in conceptualizing ways to make it better.

I recommend major revisions for this manuscript based on the need for the association of gusts with storm mode so a more accurate picture for the causes of the severe gusts may be made. For example, it was shown that some severe gusts were associated with a positive temperature perturbation. However, as mentioned by the authors, this warming could be generated by either a heatburst or a rapid return to pre-outflow conditions (when evaluating gusts on an event-basis). Evaluation of radar data would be needed to confirm for sure how many severe gusts actually originate from heatbursts.

While we absolutely agree with the reviewer regarding the need for a radar-based storm classification of the identified gusts, we did not include it in this revision of the manuscript. It was beyond our capabilities in terms of time and marginally beyond the scope of what we intended for this manuscript. We were originally given a deadline of two months and have already exceeded that beyond what may be considered reasonable. We want to avoid rushing through the process and producing a sub-par classification. Instead, we hope to produce a robust classification combined with more stations and a more intentional event methodology based perhaps on the gust front instead of the severe gust measurement. Perhaps this could be included in a "Part II" of the work that would be submitted within a certain time frame? We are open to suggestions that would expedite the publication of this manuscript while still doing the necessary work to classify the gusts. We had hoped to collaborate with another group doing similar work through the comparison of a national dataset and mesoscale dataset classified the same way, ideally through machine learning / artificial intelligence.

Meanwhile, there are several other questions I have that I feel need to be addressed in the manuscript. First, what was the intent in grouping gusts into "events"? Was this to ultimately associate severe gusts with mesoscale meteorological setups or storm modes?

The primary purpose of grouping gusts into events was to explore the impact of long-lived convective systems on the kinematic characteristics of the distribution. An added benefit was the ability to identify the thermodynamic characteristics of the gusts and perhaps provide some guidance for comparisons with numerical modeling as well as identifying the meteorological drivers of the gusts. We have updated the text describing our methodology and have added some justification in the events section.

Also, why did the Rolling Plains have more significant severe gusts (especially above 37 m s^{-1}), when only a fraction of the total number of severe gusts occurred in this region? Could it be that Caprock gusts are more associated with pulse severe during the summer, and Rolling Plains spring gusts are associated with more dryline supercells? Or maybe the most intense gusts (which seemed to have also occurred across the Rolling Plains) were associated with organized MCSs, which was also why the strongest gusts were associated with overall stronger 5-min periods of sustained surface winds? Again, pairing severe gusts with storm mode would be needed to answer these questions. Finally, why were most severe gusts from the Northwest?

This characteristic of the gust data is likely driven by the tendency for convective initiation on the higher terrain out west (Raton Mesa, etc.). Additionally, northwest flow events are common in the region, as documented in Johns (1982), where a local axis of increased northwest flow events was noted in the Texas Panhandle and the Southern Plains, especially in June. This information has been added to the manuscript (along with the reference below) in the section that describes the wind directions associated with the severe gusts.

Johns, R. H., 1982: A synoptic climatology of northwest flow severe weather outbreaks. Part 1: Nature and Significance. *Mon. Wea. Rev*., **110**, 1653−1663.

Another major issue associated with this manuscript was the vagueness in the writing. In multiple paragraphs, you were relatively close to making your points, but you would not offer explanations for your results. A classic example would be paragraph four in your Results—Spatial Distribution section. You mention that the Caprock escarpment may play a role in the distribution of severe wind reports with the WTM across the Lubbock CWA. However, you never state that the higher terrain may be contributing to the higher report densities, whereas the slightly more sheltered, lower terrain of the Rolling Plains may potentially be reducing the number of observed gusts. I think many readers would pick up on the points you are trying to make. Nonetheless, they should be clearly conveyed in your writing. In a separate review of manuscript grammar, structure, and technical issues, I pointed out several examples of vagueness and made suggestions.

We appreciate the reviewer for pointing out these issues. We tried to be more direct in relating our findings to an explanation, including the example provided by the reviewer. While it wasn't our specific intention to be vague, we still wanted to be careful about what we could confidently say was supported by the data. We are happy to continue to improve our writing if the reviewer notes other instances of vagueness.

Since relative humidity and pressure had both positive and negative perturbations, I think showing this information in the form of plots (as in temperatures) and making a panel would be helpful for readers to better understand the distribution of severe gusts with surface thermodynamic parameters.

Based on this excellent suggestion, we included histograms of these thermodynamic parameters, as well as dewpoint, as a 4-paneled figure. The distributions were very informative. The histogram of dewpoint was particularly surprising. We expected a more skewed distribution toward lower dewpoints.

In all, I think pairing severe gusts with storm mode while answering some of the above questions would result in a rich manuscript that would prove how dense mesonet networks can be valuable in establishing regional climatologies of severe gusts (and in a broader sense, any recurring mesoscale phenomena). I think these results would be quite interesting and I look forward to revised submissions in the future.

[Minor comments omitted…]

Second Review:

Recommendation: Accept with minor revisions.

General Comment: The authors have submitted a revised manuscript, which has provided more details on the climatology of severe wind gusts across portions of western Texas. The writing of the paper flows nicely, with some of the findings more clearly explained relative to the previous manuscript. As such, I think this manuscript is quite close to being ready for publication. I have a few comments below that I would like the authors to consider.

[Substantive] Comments on Content: The proposed scenarios for the predominant northwesterly gusts are certainly plausible. However, it would be beneficial if we could see some form of supporting evidence for the cause of dominant northwest-oriented severe gusts. An elaborate undertaking such as a radar-based climatology or storm-mode climatology may not be necessary to accomplish this task. However, at least some supplemental evidence would help in providing a more substantial explanation for why northwest-gusts dominate. Perhaps something as simple as compositing upper-flow fields in something like mesoanalysis fields by month of occurrence, or some other measure of gust frequencies? I leave it to the authors to decide what is most appropriate. If this request is not feasible, then I strongly recommend further discussing the limits of the current work and the importance of continuing this work with a radar climatology at the end of the manuscript (please see the next comment below for more details and a potentially more feasible solution).

In lieu of adding more methodology and analysis to an already dense work, we opted for the reviewer's more feasible solution below. We included separate a "Limitations" subsection near the end of section 5. This section is discussed more below. We are grateful to the reviewer for pushing us on this idea!

When mentioning the radar classification as part of future work, it may be beneficial to mention that this radar-based climatology will help confirm or refute theories about the origin of severe gusts made in this manuscript. For example, a radar-based climatology may shed more light on why there is a prevalence of northwesterly severe gusts, or why the Rolling Plains had less severe gusts then the Caprock Escarpment. Finally, the radar climatology could potentially help in differentiating between heat bursts and rapid-recovery events. Overall, I think this manuscript would benefit from a separate but brief "Discussion" or "Critical Reflections" section after the Summary and Conclusions section where the importance of a radar-based climatology are elaborated on in a little more detail.

We added Section 6b: Limitations. This new section describes the limitations of the study without a formal radar classification. These limitations lead nicely into the description of future work. See the revised manuscript for the full text of the Limitations section.

[Minor comments omitted…]