Measured Severe Convective Wind Climatology and Associated Convective Modes of Thunderstorms in the Contiguous United States, 2003–09

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ABSTRACT

A severe thunderstorm wind gust climatology spanning 2003–09 for the contiguous United States is developed using measured Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS) wind gusts. Archived severe report information from the National Climatic Data Center publication *Storm Data* and single-site volumetric radar data are used to identify severe wind gust observations [≥50 kt (25.7 m s^{-1})] associated with thunderstorms and to classify the convective mode of the storms. The measured severe wind gust distribution, comprising only 2% of all severe gusts, is examined with respect to radar-based convective modes. The convective mode scheme presented herein focuses on three primary radar-based storm categories: supercell, quasi-linear convective systems (QLCSs), and disorganized. Measured severe gust frequency revealed distinct spatial patterns, where the high plains received the greatest number of gusts and occurred most often in the late spring and summer months. Severe wind gusts produced by supercells were most frequent over the plains, while those from QLCS gusts were most frequent in the plains and Midwest. Meanwhile, disorganized storms produced most of their severe gusts in the plains and Intermountain West. A reverse spatial distribution signal exists in the location between the maximum measured severe wind gust corridor located over the high plains and the maximum in all severe thunderstorm wind reports from *Storm Data*, located near and west of the southern Appalachians.

1. Introduction

Numerous studies have highlighted limitations and biases in severe thunderstorm wind reports in the National Climatic Data Center (NCDC) publication *Storm Data*. These reporting inconsistencies within the severe thunderstorm wind database (Schaefer and Edwards 1999; Brooks et al. 2003) have made climatological interpretation of these reports [defined as estimated or measured thunderstorm gusts ≥25.7 m s^{-1} (hereafter referred to as 50 kt), or thunderstorm-produced wind damage] problematic. Several nonmeteorological factors lead to variability and inconsistency within the severe wind report database (e.g., measured and estimated gusts versus damage) and some of these include overestimated wind speeds by human observers (Doswell et al. 2005), a nonmeteorological increase in the number of reports (Weiss et al. 2002), and the dependence of report frequencies on population density and time of day (Trapp et al. 2006). The inhomogeneous spatial distribution of population and wind damage tracers

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(e.g., trees, powerlines, etc.) and the variability in reporting standards (Weiss et al. 2002) undoubtedly influence *Storm Data* severe wind reports.

Many studies have examined the climatological frequency of severe wind reports and the synoptic and mesoscale environments associated with these events (e.g., Johns and Hirt 1987; Wakimoto 1985). While not focused solely on measured severe convective wind gusts, these studies provide important insight into the frequency and patterns of severe thunderstorms historically responsible for producing severe wind reports. Much of the subjectivity and inconsistency in a severe thunderstorm wind climatology can be alleviated—thereby lending credibility to the subsequent dataset (Weiss et al. 2002)—if such a climatology only includes data from a consistent source (e.g., calibrated instrumentation sited at similar locations), across a large area, and over a sufficiently long period. Hence, a severe thunderstorm wind gust dataset was developed using instrument-measured Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS) severe wind gusts observations ≥50 kt during 2003–09 for most of the contiguous United States.

Archived severe report information from the National Climatic Data Center's *Storm Data* and single-site volumetric Weather Surveillance Radar-1988 Doppler (WSR-88D) level-II radar data are used to identify measured severe wind gusts attributed to thunderstorms and to classify the convective modes associated with these measured gusts using the storm classification methodology of Smith et al. (2012, hereafter S12). The primary motivations for this study are to assess the spatiotemporal distribution of severe gusts with limited influence from nonmeteorological factors, and to document and analyze the spatial frequency of convective mode with respect to the severe gusts.

2. Data and methods

a. Data and event filtering

A surface observation database at the Storm Prediction Center (SPC) contains archived ASOS/AWOS data extending across much of the contiguous United States (excluding the West Coast and sites near the Canadian border) that can be used to extract wind gusts ≥50 kt from 2003 to 2009. To be included in this study, ASOS/AWOS stations must have archived data available for ≥95% of the days during the 7-yr period (686 sites). The method for measuring ASOS/AWOS wind gusts transitioned from an averaged maximum 5-s gust with an anemometer to an ultrasonic device and a 3-s gust for all sites. This occurred as early as 2003 for a few sites but little difference was found in comparing severe wind gusts frequency before and after sites transitioned to the new scheme (C. Turner 2012, personal communication). Coded observation data were manually examined, and maximum gusts in a 1-h period exceeding 50 kt were recorded with the first observed gust taking precedence if two or more qualifying gusts of equal magnitude occurred within a given hour. A multistep quality control (QC) approach was used to eliminate nonconvective high-wind events and erroneous recorded gusts from the dataset. To accomplish this, each candidate severe wind observation was placed on a Rapid Update Cycle (RUC) model (Benjamin et al. 2004) analysis grid with 40-km horizontal grid spacing in a 3×3 grid array centered on the closest grid to each ASOS/AWOS. The gusts were assigned to the closest prior analysis hour and were required to pass an initial environment check of most unstable convective available potential energy (MUCAPE) ≥1 J kg^{-1} from archived SPC mesoanalysis data (Bothwell et al. 2002; Schneider and Dean 2008) and the presence of a lightning strike as detected by the National Lightning Detection Network (NLDN). Next, observations were further scrutinized using archived single site WSR-88D level-II data and assigned a convective mode. Wind gust observations from landfalling tropical cyclones were omitted. This QC process retained 1911 wind gusts.[1]

b. Radar-based storm mode classification criteria

The Gibson Ridge radar-viewing software package (http://www.grlevelx.com/) was used to analyze archived WSR-88D level-II or level-III single site radar data from NCDC (http://www.ncdc.noaa.gov/nexradinv/). The closest radar-site data were used (for gusts within 230 km of radar) to classify the convective mode based on S12. Convective mode was determined using full volumetric radar data, especially when data through a deep layer were needed to perform a more thorough assessment of storm structure. Preference was given to the volume scan and lower-elevation tilts (e.g., 0.5°) of base reflectivity immediately prior to the time of the measured severe gust. If level-II data were unavailable, then level-III data were used. In situations when radar data were unavailable or incomplete, convective mode was not assigned (0.2% of total cases). Emphasis herein is placed on the three major convective mode classes: supercell, quasi-linear convective system (QLCS), and disorganized (i.e., cells and clusters clearly not meeting QLCS or supercell criteria).

[1] The 1911 wind gusts include 25 marginal supercell mode gusts and 3 gusts not assigned a mode; these are not included in Figs. 2–4.

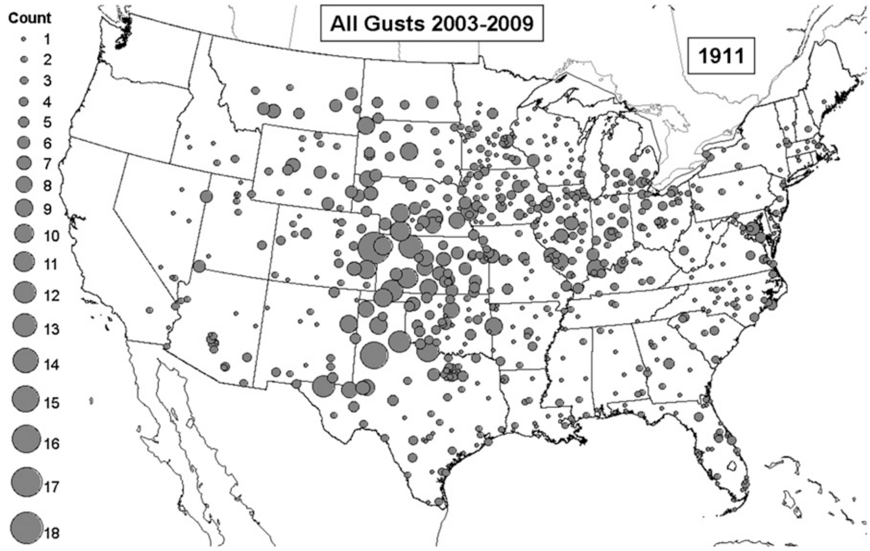

FIG. 1. Proportional symbol (gray circles) plot of measured severe thunderstorm wind gusts [$\geq$25.7 m s^{-1} (50 kt)] per ASOS/AWOS site during 2003–09. The total gust count (1911, labeled top right) was corroborated with *Storm Data* reports. The maximum measured gust count was 18 at Burlington, CO (near the eastern CO and northwest KS border).

Discrete or embedded cells with focused areas of cyclonic (or anticyclonic) azimuthal shear were further scrutinized as potential supercells, following the mesocyclone nomograms developed by the Warning Decision Training Branch of the National Weather Service (Andra 1997; Stumpf et al. 1998). Supercells required a peak rotational velocity $\geq$10 m s^{-1} (i.e., a peak-to-peak azimuthal velocity difference of roughly 20 m s^{-1} over a distance of less than 10 km). Range dependence was included in the mesocyclone designation, per the 1-, 2-, and 3.5-n mi [where 1 nautical mile (n mi) = 1.852 km] mesocyclone nomograms (Andra 1997).

A QLCS is defined as consisting of contiguous reflectivity at or above the threshold of 35 d*BZ* for a horizontal distance of at least 100 km and a length-to-width aspect ratio of at least 3 to 1 at the time of the event, similar to Trapp et al. (2005). Disorganized storms were cellular modes that did not include supercell structures, and consisted mainly of conglomerates of storms meeting the reflectivity threshold but not satisfying either supercell or QLCS criteria. The most challenging storm mode assignments involved cases of line segments or loose bands of storms near the QLCS threshold (i.e., 35 d*BZ* extending $\geq$100 km, 3:1 aspect ratio), as well as those that exhibited arcing gust fronts $\gg$100-km length, but possessed discontinuous higher reflectivity. For a more thorough discussion pertaining to the complexity and challenges of categorizing convective mode, please refer to S12.

3. Results

The ASOS/AWOS sites recording the highest counts of severe gusts were primarily confined to the high plains (Fig. 1). Station sites such as Burlington, Colorado (located along the Colorado–Kansas border), tallied the highest count (i.e., 18 measured severe thunderstorm wind gusts) and other locations in the high plains recorded comparable severe gust counts [e.g., Lubbock, Texas (15), and Hill City, Kansas (13)]. A secondary corridor of higher counts extends eastward from the central plains into the Midwest and Ohio Valley regions. Reduced counts prevail across the lower Mississippi Valley northeastward into the upper Tennessee Valley region.

Several spatial patterns became evident when the gusts were categorized by convective mode. Supercell gusts most commonly occurred east of the Rockies and primarily favored the plains and central Mississippi Valley (Fig. 2). Supercell gusts were infrequent across much of the South and along the Atlantic coast, while supercell gusts were nearly nonexistent from the Rockies westward. Sites located over the plains and Midwest displayed nearly equal QLCS gust counts (Fig. 3). QLCS gust counts were lower across the Southeast and rarely measured across the Rockies, Intermountain West, and Sonoran Desert. Disorganized storm mode gusts were most frequent across the high plains, with other higher counts observed over the Midwest, Intermountain West, Sonoran Desert, and portions of Florida and Carolinas

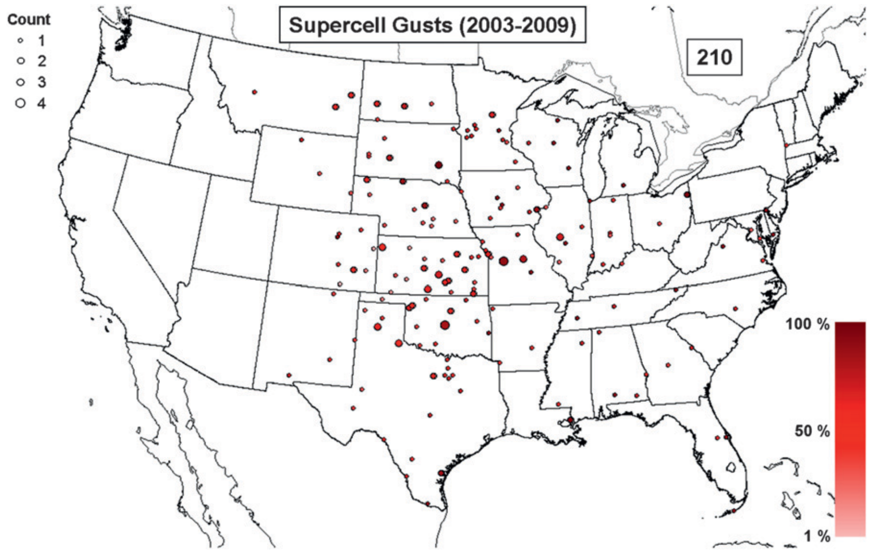

FIG. 2. As in Fig. 1, but for supercell gusts. Shading denotes relative frequency of supercell gusts to total measured gusts at each site. Supercell gusts compose 11% of the total measured severe gusts.

(Fig. 4). An areal minimum was found over the lower Mississippi Valley northeastward into the central Appalachians.

Supercell wind gusts were most frequent *relative* to all mode gusts during March–June and in November, with an absolute peak in June (Fig. 5). Supercell wind gusts contributed to a greater fraction of wind gusts at higher thresholds [e.g., $\geq$33.4 m s^{-1} (65 kt)] than QLCS and disorganized modes, similar to S12. QLCS wind gusts were more frequent *than* those for the other modes from November through April, but with an absolute peak in June. Disorganized storm wind gusts were uncommon during the winter (i.e., December–February) but rapidly increase in number during the spring (i.e., March–May). By May, disorganized storm gusts contribute to the greatest number of gusts by mode, reach a maximum in July, and rapidly decrease in number by September. The majority of measured gusts (63%) occurred during the summer (i.e., June–August), most of which were produced by disorganized

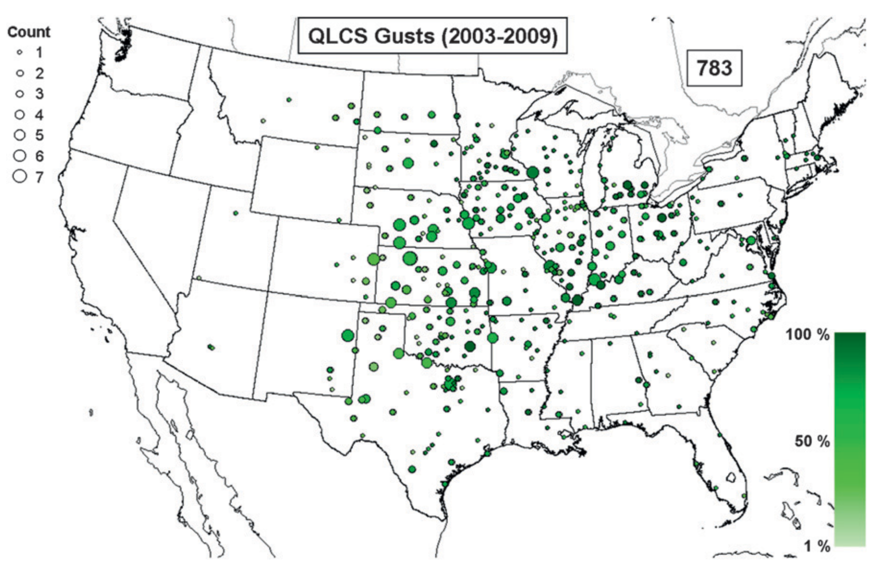

FIG. 3. As in Fig. 2, but for QLCS gusts. QLCS gusts compose 42% of the total measured severe gusts.

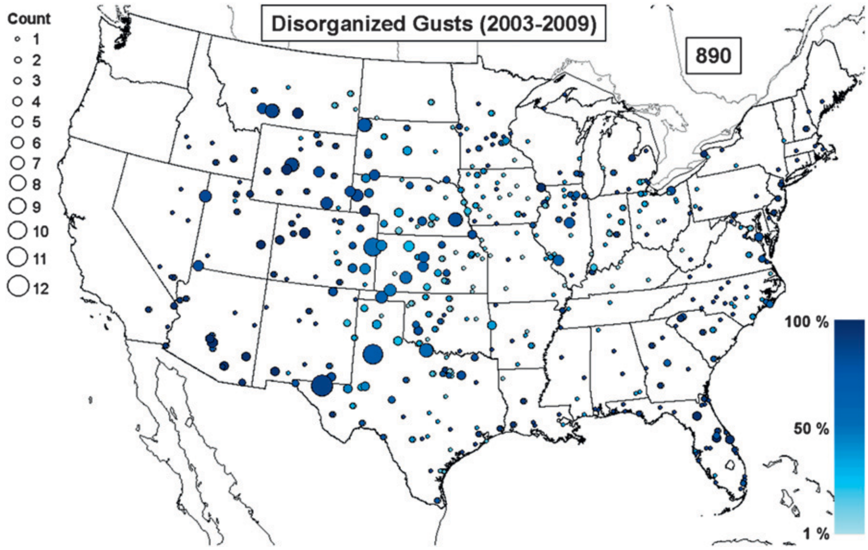

FIG. 4. As in Fig. 2, but for disorganized gusts. Disorganized gusts compose 47% of the total measured severe gusts.

storm (53%) and QLCS (35%) modes (Schoen and Ashley 2011).

Spatially, QLCS gusts in the summer (not shown) were not recorded over the Intermountain West and were rare from the northern Gulf Coast and Florida northeastward through the Carolinas. The greatest proportions of gusts for the Midwest and southern Great Lakes were attributed to QLCS (Fig. 3) (Johns and Hirt 1987). Although QLCS summer gust frequency was maximized in the Midwest and southern Great Lakes, where northwest flow events (Johns 1982) are common, much of the central plains southward into the southern high plains exhibited a nearly equal rate of summer QLCS occurrence (Coniglio and Stensrud 2004).

Kernel density estimation was performed on a 40-km analysis grid to depict the spatial density of all *Storm Data* severe wind reports in the publication during 2003–09. A striking difference is evident in the distribution of severe wind reports from *Storm Data* and the spatial distribution of measured ASOS/AWOS severe wind gusts (Figs. 6a,b). The maximum in all severe thunderstorm wind reports from *Storm Data*, in which

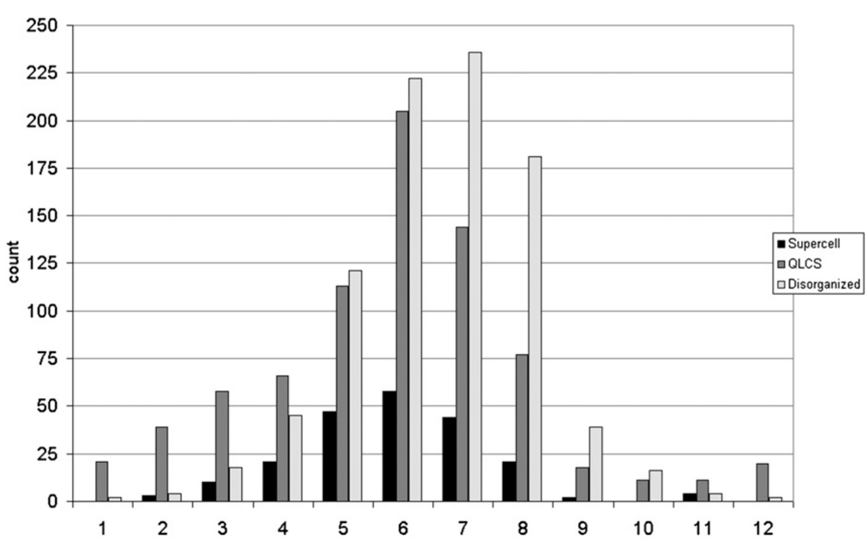

FIG. 5. Convective mode count distribution by month (supercell, black; QLCS, medium gray; disorganized, light gray).

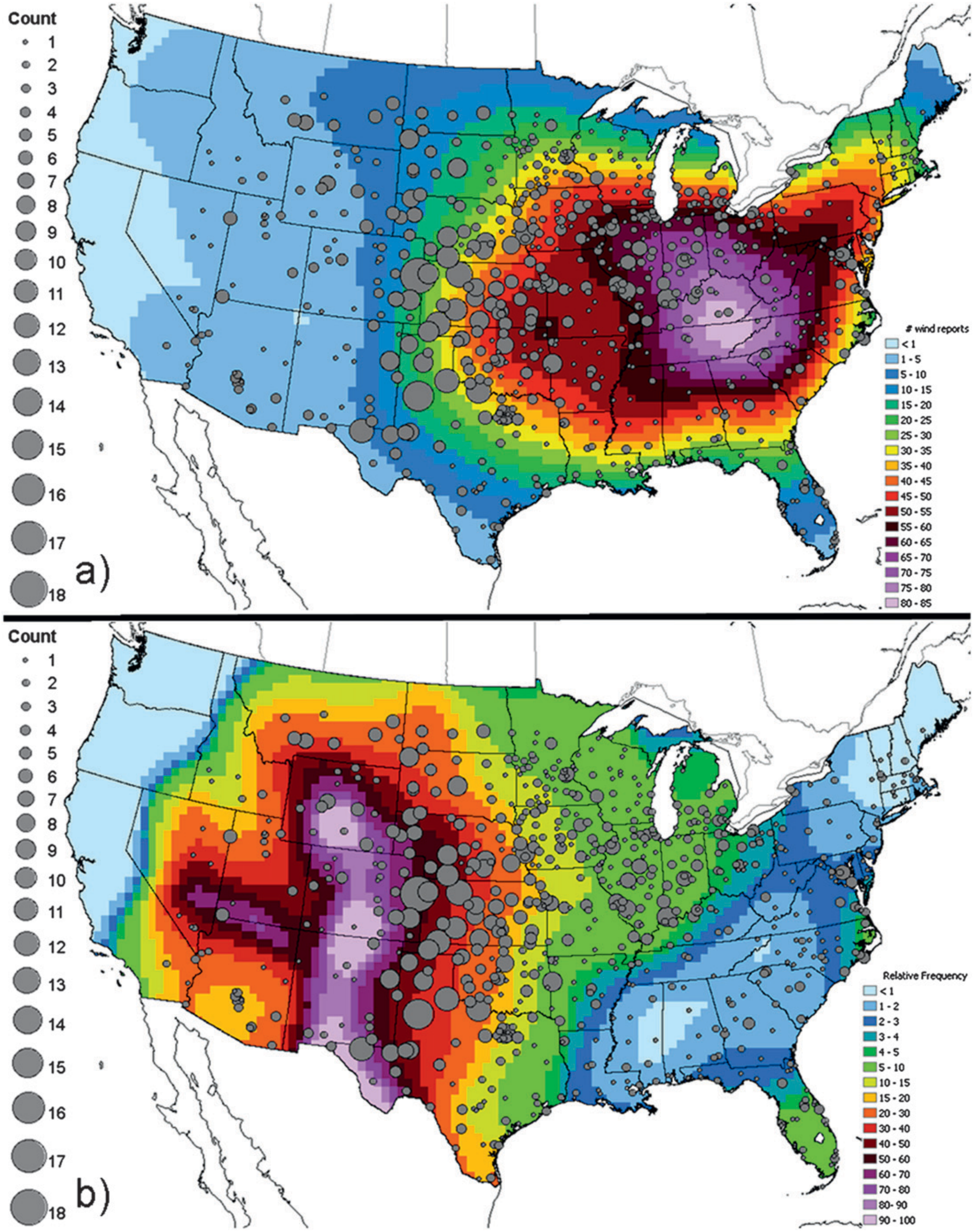

FIG. 6. (a) As in Fig. 1, but the kernel density estimation (40-km grid) of all severe wind reports in the *Storm Data* severe wind database during 2003–09 is shaded. Wind report count normalized to 10 yr. (b) As in (a), but the kernel density estimation of ASOS/AWOS measured $\geq$25.7 m s^{-1} (50 kt) wind gusts relative to all severe wind reports (92 652) in the *Storm Data* severe thunderstorm wind database during 2003–09 is shaded. The low kernel density estimate values over much of CA, OR, and WA are due to insufficient ASOS/AWOS kernel density data being calculated over those states.

gust magnitudes were mostly estimated, is located near and west of the southern Appalachians (Fig. 6a), where measured severe gusts were relatively infrequent. A much higher percentage (~30%–60%) of severe thunderstorm wind reports were associated with measured ASOS/AWOS gusts in the high plains, whereas $\leq$2% of reported severe thunderstorm gusts were sampled by ASOS/AWOS from parts of the Deep South and Appalachians northward into New England (Fig. 6b). These differences are likely related to factors such as vegetation and population densities, both of which contribute to the potential for wind damage thresholds below 50 kt. Cintineo et al. (2012) identified a similar dichotomy between radar-derived maximum expected size of hail (MESH) and large-hail report frequency near the southern Appalachians.

4. Summary

The measured severe wind observations originating from ASOS/AWOS data were subjected to multiple QC procedures that filtered candidate severe wind observations using lightning data, radar reflectivity, and manual examination of coded observation data. Identified gusts were compared to *Storm Data* to assess the confidence in the validity of the gust. This QC approach yielded over 1900 measured severe wind gusts ≥50 kt across a large portion of the contiguous United States from 2003 to 2009. Most gusts occurred in the May–August period, though our sample of measured gusts represents only 2% of the severe wind reports in *Storm Data*. Analysis of measured severe thunderstorm gust frequency shows a primary corridor over the southern and central plains states with a secondary axis extending eastward from the central plains into the southern Great Lakes states. A much lower observed frequency is evident from the lower Mississippi Valley northeastward along the spine of the Appalachians.

Using a methodology outlined in S12, convective mode was assigned to storms based on radar reflectivity and velocity thresholds with three primary categories of mode classification (i.e., supercell, QLCS, and disorganized). Supercells accounted for only 11% of gusts and were mainly distributed across the central United States. Supercell severe gusts were most frequent during March–August. QLCS gusts were most frequent east of the Rockies from the plains into the Midwest and Ohio Valley regions—composing 42% of gusts—and were the most common mode for severe gusts from November to April. Disorganized thunderstorm gusts—accounting for 47% of the dataset—were most frequent during the summer. An overwhelming majority of wind gusts from the immediate lee of the Rockies into the Intermountain West and Sonoran Desert were attributed to disorganized thunderstorm modes. A reverse spatial distribution signal exists in the location between the maximum measured severe wind gust corridor located over the high plains and the maximum in all severe thunderstorm wind reports from *Storm Data*, located near and west of the southern Appalachians. The *stark contrast in the measured versus estimated* spatial distribution of severe wind gust observations calls for further development of an explicitly measured severe wind gust dataset.

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