Interpreting the Climatology of Derechos

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(Manuscript received 7 August 2003, in final form 15 December 2003)

ABSTRACT

Past studies have examined the climatology of derechos and suggest very different distributions of derechos within the United States. This uncertainty in the climatology of derechos is a concern for forecasters, since knowledge of the relevant climatological information is a key piece in the forecast process. A 16-yr dataset from 1986 to 2001 is used to examine the effects that changing the method of identifying derechos may have on the interpretation of the derecho climatology. In addition, an attempt is made to visualize the favored regions of particularly intense derecho events.

The results show aspects seen in earlier climatologies, including a southern axis in the southern plains that is favored in the mid-1980s and early 1990s and a northern axis centered from the upper Mississippi River valley into Ohio that is favored in more recent years. However, altering the criteria to not require three 33 m s^{-1} gust reports or F1-type damage (low-end events) significantly increases the number of events that are identified in the lower Appalachians, the Ohio valley, and in portions of the southern axis, particularly in the earlier period. To a lesser extent, the inclusion of low-end events also increases the frequency values in the northern axis in the later period. The overall effect of including the low-end events is to create a distribution that still suggests both a southern and northern axis, and a shift of the primary axis from the southern plains in the early period to the upper Mississippi valley in the later period. However, the frequency values of the maxima are noticeably reduced when the low-end events are excluded. Therefore, both the length of the dataset and the criteria used to define derechos can significantly influence the resulting climatology.

High-end derechos, which require three wind gust reports (or comparable damage) exceeding 38 m s^{-1}, appear to be favored in the northern corridor during the warm season, particularly in the later period, and are favored along the lower Mississippi River valley during the colder months in both periods.

1. Introduction

Long-lived convectively produced windstorms, known as derechos, continue to pose a significant hazard to life and property and remain a difficult forecasting and warning problem (Wakimoto 2001). One of the important early steps in the operational forecast process is the knowledge of relevant climatological information (Johns and Doswell 1992). However, as described below, criteria for identifying derechos and the geographical frequency distribution of derechos are still being debated in the literature. This study provides evidence that helps to improve the interpretation of the derecho geographical distribution.

Johns and Hirt (1987, hereafter JH87) were the first to develop specific criteria to define derechos and to estimate their preferred geographical regions. They define the term derecho to be associated with an extratropical mesoscale convective system (MCS; Zipser 1982) that produces, what Fujita and Wakimoto (1981) call, a ‘‘family of downburst clusters.’’ They identify derechos based on criteria (Table 1) that could be determined from the National Climatic Data Center (NCDC) publication *Storm Data* and logs of severe weather events from operations at the National Severe Storms Forecast Center (the predecessor to the Storm Prediction Center; SPC). The geographical distribution of the 70 warm season events identified by JH87 suggests that warm season derechos occur most frequently in a region from the upper Midwest to the Ohio valley and are relatively infrequent in other locations (Fig. 1a).

Bentley and Mote (1998, hereafter BM98) examined the SPC database of convective wind gust reports between the years of 1986 and 1995 and identified 113 events from all months of the year in an attempt to improve the visualization of the climatological distribution of derechos. However, their method for identi-

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TABLE 1. Criteria used to identify derecho events in JH87, BM98, and in our study.

No.	JH87 criteria	BM98 criteria	Our criteria
1	There must be a concentrated area of convectively induced wind gusts greater than 26 m s^{-1} that has a major axis length of 400 km or more	Same as in JH87	Same as in JH87
2	The wind reports must have chronological progression	Same as in JH87	Same as in JH87
3	No more than 3 h can elapse between successive wind reports	No more than 2 h can elapse between successive wind reports	No more than 2.5 h can elapse between succesive wind reports
4	There must be at least three reports of either F1 damage or wind gusts greater than 33 m s^{-1} separated by at least 64 km during the MCS stage of the event	Not used	Low end, not used; moderate, same as in JH87; high end, there must be at least three reports of either wind gusts greater than 38 m s^{-1} or comparable damage (see text), at least two of which must occur during the MCS stage of the event
5	The associated MCS must have spatial and temporal continuity	The associated MCS must have spatial and temporal continuity with no more than 2° of latitude and longitude separating successive wind reports	The associated MCS must have spatial and temporal continuity and each report must be within 200 km of the other reports within a wind gust swath
6	Multiple swaths of damage must be part of the same MCS as indicated by the available radar data	Multiple swaths of damage must be part of the same MCS as seen by temporally mapping the wind reports of each event	Same as in JH87

fying derechos differs somewhat from that used by JH87 (Table 1). BM98 remove the requirement that three wind gust reports of F1 damage (or wind gust estimates or measurements greater than 33 m s^{-1}) must be separated by at least 64 km. Additionally, they determined whether or not successive reports emanate from the same MCS by temporally mapping the reports instead of examining radar data. Reducing the maximum elapsed time between successive reports to 2 h and requiring that the maximum distance between successive wind reports is no more than 2° of latitude or longitude helps them make this judgment. In contrast to the results of JH87, BM98 suggested that warm season derechos are a much more common occurrence in the southern Great Plains than in the upper Midwest (Fig. 1b) and identified a smaller maximum (in spatial coverage) near the Ohio–Pennsylvania border.

Johns and Evans (2000) proposed some explanations for these differences. They believe that the removal of the 33 m s^{-1} wind gust criterion and the tighter report density criterion allows for the deficiencies of the convective wind report database to have a larger effect on the results. They also suggested that clusters of individual thunderstorms or isolated supercells entered the

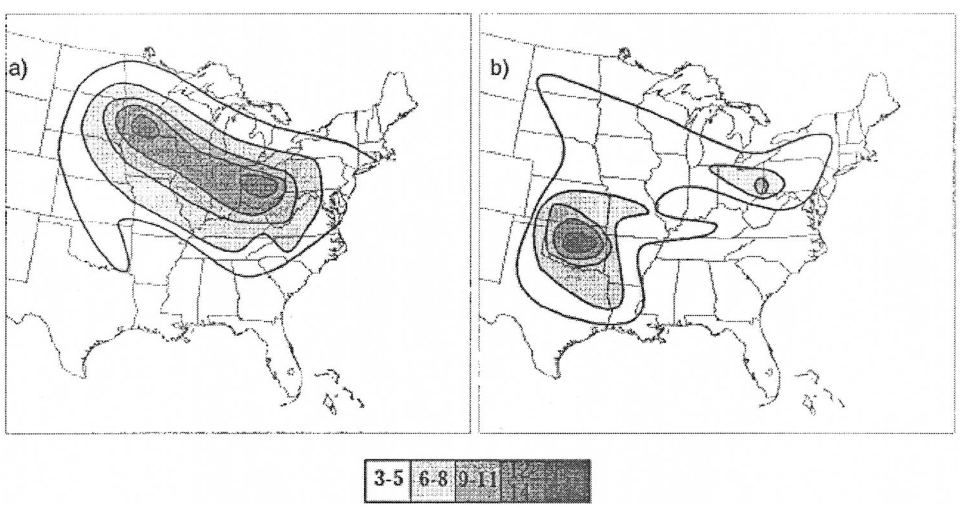

FIG. 1. (a) The total number of derechos identified during the warm season (May–Aug) 1980–83 by JH87. (b) The total number of derechos identified during the warm season 1986–95 by BM98 (from BM98).

dataset as a result of not examining the radar data and questioned the adequacy of a 10-yr period to depict the true climatology.

Bentley and Mote (2000b) argued that the 33 m s^{-1} wind criterion is unnecessary because Fujita and Wakimoto (1981) make no reference to wind gust magnitudes in the definition of downburst clusters, and is difficult to judge because of the uncertainties in the accuracy of wind gust/damage estimates in the SPC database. In addition, they suggested that an anomalously strong ridge in the central United States during 1980 provided a pattern that was unusually favorable for derechos in the upper Midwest (24% of the events in the JH87 database occurred during June–July 1980) and inflated the JH87 results toward that region. Finally, they believe that the parent convective structure should not restrict the definition of derechos.

Bentley and Sparks (2003) add an additional 118 derechos from the period 1996–2000 and show a reemergence of the primary frequency axis across the upper Midwest, which is similar to the results of JH87. They suggested that the shifts in synoptic patterns favorable to producing derechos, particularly during the warm season, help to explain this shift in derecho activity over multiyear time periods. Unlike JH87, Bentley and Sparks (2003) still show a significant secondary axis in the southern plains and do not suggest a maximum in southern Minnesota.

The above section highlights that several factors, relating to the definition of derechos and the time period of the investigation, could influence the different estimates of the derecho climatology. This study focuses on the effects of eliminating the higher wind gust criterion used in the definition of derechos by JH87. A 16-yr dataset is used to examine this effect. The development of the derecho dataset and the analysis method is described in section 2. As part of the design of this analysis, criteria are proposed that help to identify the preferred locations of particularly intense derecho events that have been identified in the past literature (see Miller and Johns 2000). Evidence of derecho multiyear variability is presented in section 3 that corroborates a recent estimate of the derecho climatology in the literature, but attention is focused on how this climatology is affected by eliminating the higher wind gust criterion. A summary and a final discussion are presented in section 4.

2. Derecho dataset

In this study, *Storm Data* and the SPC convective wind database are examined for the years of 1986–2001 to identify derechos. The first two gust criteria that are used in JH87 and BM98 (listed in Table 1) also are used in this study. For the criteria related to the density of reports, a compromise is proposed between JH87 and BM98 such that wind gust reports can be separated by no more than 2.5 h and 200 km. Note that *successive* wind reports (temporally) can be separated by more than 200 km, but each report must occur within 200 km of the other reports within a wind gust swath. This situation of successive wind reports that are separated several hundred kilometers frequently occurs with serial derechos (JH87).

Although there is substantial uncertainty in the accuracy and reliability of the wind gust estimates (Weiss et al. 2002), there appears to be enough fidelity to identify events that are noticeably more intense than those that only satisfy the 26 m s^{-1} criterion of BM98 and those that only marginally satisfy the 33 m s^{-1} criterion of JH87. In making this judgment, the use of *Storm Data* to supplement the SPC database is crucial because of the very detailed verbal descriptions of the damage that often accompanies the most severe events. Therefore, the effect of the higher wind gust criterion is examined by dividing the dataset into three groups that are separated by an estimate of the event's intensity (see criterion 4 in Table 1). The three categories are defined (''low end,'' ''moderate,'' and ''high end'' events) so that the low-end classification uses only the 26 m s^{-1} wind gust criterion, the moderate classification discriminates between low-end events and those events that satisfy the 33 m s^{-1} wind gust criterion, and the high-end classification emulates characteristics of particularly intense derecho events described in Miller and Johns (2000). Each event is categorized as low-end, moderate, or high-end and is not counted in more than one category. The high-end events require at least three reports of wind gusts greater than 38 m s^{-1} (75 kt or 85 mi h^{-1}) separated by at least 64 km, with at least two reports occurring during the MCS stage of the event. The MCS stage is reached when a group of convective echoes form a contiguous convective precipitation shield with a major axis greater than 100 km in horizontal extent and for longer than 3 h. This is based on the MCS definitions of Zipser (1982) and Parker and Johnson (2000).

If no wind gust measurement or estimate is given for the report, a high-end classification can also be met by examining the description of the damage associated with the report, as was similarly done by JH87. To determine the types of damage that should qualify for high-end classification, the damage descriptions in *Storm Data* that are associated with wind gusts of $>$ 75 kt for a wide variety of reports are examined. The complete destruction of mobile homes (usually tossed far from their blocks), significant damage to well-constructed homes and businesses (often including several roofs blown off), and large swaths of trees being flattened within forested areas are examples of this type of damage. Miller and Johns (2000) find this type of damage in several intense derecho events. The F1-type wind damage that helps to define the moderate derecho events also is examined in this manner.

Another major difference in the way that derechos have been identified in the literature involves the use of radar data. Unlike BM98, it was decided that radar data should be considered in the definition of derechos for two reasons: to ensure that the wind reports are associated with an extratropical MCS and to ensure that multiple swaths of damage emanate from the same MCS. Regarding the first reason, Bentley and Mote (2000b) argue that the parent MCS should not define a derecho, much like a tornado is not defined by its associated thunderstorm, and thus, isolated cells that produce sufficiently long swaths of severe wind gusts should be considered as derecho-producing MCSs. However, this study interprets the definitions of MCSs by Zipser (1982) and Parker and Johnson (2000) to be associated with groups of individual thunderstorms that merge to form a common precipitation shield and surface gust front on length scales of at least 100 km. Although we believe that the distinction between isolated cells and those that have their outflows merged is not always clear, this MCS definition clearly intends to exclude cells that remain isolated during the majority of their lifetime. Therefore, this study interprets the derecho definition of JH87 as one that intends to separate convective windstorms produced by supercells or groups of isolated cells from those produced by MCSs. Note that this definition allows MCSs that may contain embedded supercells and allows squall lines with limited cross-line extent, but extensive along-line extent. The available Weather Surveillance Radar-1988 Doppler (WSR-88D) level II reflectivity data obtained from NCDC, the WSR-88D mosaic reflectivity images at 2-km resolution produced by SPC (available online at http://www.spc.ncep.noaa.gov/exper/archive/events) or at 4-km resolution produced by NCDC (available online at http://www.ncdc.noaa.gov/oa/radar/radardata.html), or the archived hourly radar summary charts and the surface charts produced by the National Centers for Environmental Prediction (NCEP) (obtained from NCDC) are used to examine this criterion.

Although the effects of not including the radar data are not quantified in this study, it is worthwhile to briefly discuss these effects in a qualitative manner. BM98 and Bentley and Sparks (2003) attempt to determine whether or not multiple wind gust swaths emanate from the same convective system by mapping the wind gust reports alone. In terms of the method of identifying derechos in this study, it is found that the isolated, progressive MCSs that produce a compact and steady sequence of reports are often identified much the same, with and without the use of radar data. However, it is found that radar information (particularly WSR-88D data) substantially aids in the assessment that multiple swaths emanate from the same convective system. In many cases, it is essential in making this determination. This point is illustrated by plotting the wind reports from 2200 UTC 11 August 2000 to 0830 UTC 12 August 2000 in the northern high plains region (Fig. 2). Without the aid of radar data, it is very difficult to determine with certainty whether or not the reports emanate from the same convective phenomenon given the regular temporal progression of the reports from east-central Montana to northwestern Minnesota (Fig. 2). WSR-88D data reveal that the first portion of the swath occurring from 2201 to 0425 UTC emanates from an isolated, long-track supercell, whereas the swath from 0400 to 0830 UTC emanates from an MCS that develops along the intersection of a preexisting boundary and surging outflow ahead of the decaying supercell. Even if one permits a supercell to be considered a derecho-producing convective system, this cannot be considered a derecho since two separate convective systems are involved. Furthermore, the swath that emanates from the MCS does not satisfy the length criteria and, therefore, should not be considered a derecho.

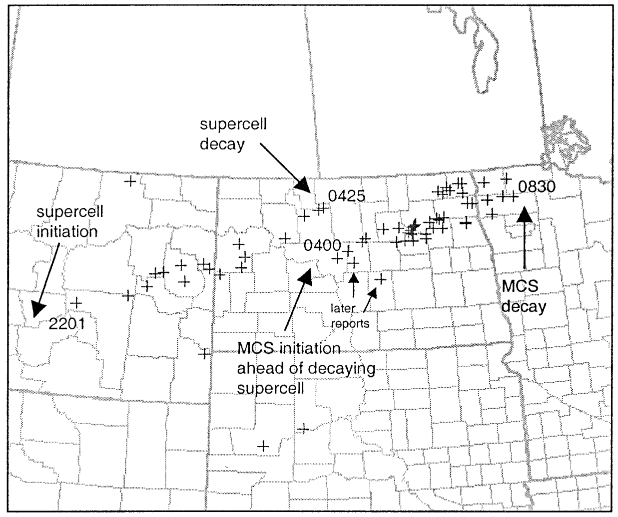

FIG. 2. A mapping of severe wind reports from 2200 UTC 11 Aug to 0830 UTC 12 Aug 2000 in the northern plains region. The location of each report is indicated by a plus sign (+). The times (UTC) of selected reports and descriptions of the associated convective structures are indicated in the figure.

Many other severe wind episodes are found that satisfy the wind criteria but never form an organized MCS structure. Additionally, the lack of quality radar information often hinders the ability to determine the reports that constitute the derecho, particularly with the serial events in which line segments or individual cells often flank the main squall line, but remain separated from its evolution. These points underscore the importance of examining quality radar data in order to produce the best possible record of derecho occurrences.

The time and location of the first wind report associated with the convection that becomes the parent MCS defines the origin of each event (i.e., wind reports from isolated cells are allowed, but only if those cells later become part of the MCS structure that produces the main swath of reports). Similarly, the time and location of the last wind report associated with the MCS defines the termination of the event. To examine the geographical distribution of the events, the wind reports from each event are mapped on to a Cartesian grid with 200 km by 200 km grid cells, which is not substantially different than the 1.83° × 1.83° resolution grid used by BM98 and the 2° × 2° resolution grid used by JH87. The distributions are determined by counting the cells that contain at least one wind report from each event and then contouring the sum of each cell over a given time period.

It should be noted that this study makes no explicit attempt to correct for many of the nonmeteorological factors, such as changes in population characteristics and especially reporting biases (Johns and Evans 2000; Weiss et al. 2002) that can complicate the interpretation of results. Therefore, biases in the wind report database should be considered as factors that influence the changes resulting from altering the wind criteria (shown in the next section). Likewise, given the fact that WSR-88D data are widely available for only the more recent years in the dataset, it is more difficult to identify events in the earlier years. Combined with the fact that the number of wind gust reports greatly increased in the early to late 1990s (Johns and Evans 2000), this skews the annual number of events toward the more recent years and likely results in an underestimate of the actual number of events prior to the WSR-88D era. Although these factors continue to limit the ability to depict the derecho climatology, the large number of events over a 16-yr time period can be used to examine the effect of the higher wind gust criterion on the estimated derecho climatology.

3. Results

The criteria outlined in section 2 are used to identify 244 derecho events that qualify for at least low-end classification. Among the 244 events from all times of the year, there are 73 low-end derechos (55 May–August events), 116 moderate derechos (82 May–August events), and 55 high-end derechos (31 May–August events). The derecho events occur year-round, but are primarily a warm season phenomenon (168, or 69%, of the cases occur in the months of May–August).

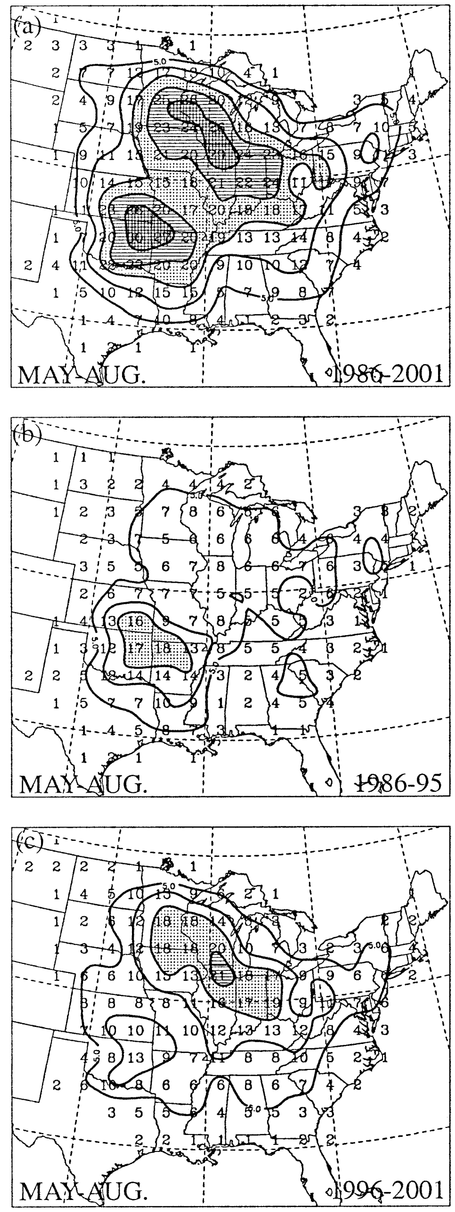

FIG. 3. The distribution of warm season (May–Aug) derechos for (a) all 168 events, (b) the 70 events from 1986 to 1995, and (c) the 98 events from 1996 to 2001. Contours are drawn every five events in all panels. In all panels (and subsequent figures), the sequence of shading from dots (·) to lines (−) to hatching (+) encloses the third, fourth, and fifth contour levels, respectively.

a. Geographical distribution with low-end events included

1) WARM SEASON EVENTS

The geographical distributions are first displayed for the 168 May–August (warm season) events from the years of 1986 to 2001. Results from all 16 yr show two main activity corridors that appear to combine the JH87 and BM98 results: one stretching from Minnesota to western Ohio and another that covers the southern and eastern portions of the plains through eastern Arkansas (Fig. 3a). The general locations of these corridors appear to be similar to the distribution of events defined and identified by Bentley and Sparks (2003) for events in the period 1986–2000 from all times of the year (see their Fig. 14), except that the distribution in this study identifies considerably more events farther north and west in the upper Mississippi River valley and the northern high plains. The two corridors identified in this study also resemble the favored regions of general northwest flow severe weather outbreaks identified by Johns (1982, 1984).

To facilitate comparisons to BM98 and Bentley and Sparks (2003), this distribution is divided into the 70 warm season events identified from 1986 to 1995 (the same time period examined in BM98[1]) and the 98 warm season events identified in the period of 1996–2001 [Bentley and Sparks (2003) examined 1996–2000 events]. In this study, the availability of WSR-88D data makes it easier to identify derechos in the latter period.

Despite the differences in the derecho definition between this study and BM98, warm season derechos (*with the low-end events included*) appear to be much more frequent in the southern plains than in the upper Midwest during the period of 1986–95 (Fig. 3b), as similarly suggested by BM98 (Fig. 1b). This conflicts with the distribution from 1980 to 1983 events presented in JH87. The distribution also suggests an extension of the southern plains maximum into the mid–Mississippi River valley as in BM98 (cf. Figs. 1b and 3b). However, one distinct difference between this study and BM98 in the period 1986–95 is the lack of a maximum in events near the Ohio–Pennsylvania border (cf. Figs. 1b and 3b). This difference is attributed to both the number of events that were discarded due to inconclusive radar data and the number of events that failed to satisfy the MCS criterion in this region.

In the 6-yr period of 1996–2001, warm season derechos (with low-end events included) appear to have been favored primarily in the upper Mississippi River valley through the western Ohio valley (Fig. 3c). This also appears to have been the case for events from 1980 to 1983 (JH87; Fig. 1a). However, Fig. 3c shows that events still occurred in the central and southern Great Plains, which is not evident in the JH87 distribution. A northward shift in the primary derecho regions also is suggested by Bentley and Sparks (2003), who argue that the pronounced southern plains maximum in the late 1980s–early 1990s, combined with the lack of events in the upper Midwest, may have been the result of a shift in favorable synoptic conditions on multiyear time scales. However, it is stressed that the magnitude of this northward shift in events is noticeably dependent on the way derechos are identified, as shown in section 3b.

2) COLDER SEASON EVENTS

There is less evidence of a regional shift in the distribution of the September–April events within the two time periods examined above. The results from the entire 16-yr period show a primary region in the lower Mississippi River valley and the Gulf coast states and a secondary axis from the lower Ohio valley into Pennsylvania (Fig. 4a). A similar distribution is suggested for cold season events as estimated from the tracks of events shown in Bentley and Mote (2000a). Most of these events are produced by elongated squall lines, which often show characteristics of both progressive and serial derechos (JH87) in association with a mobile up-

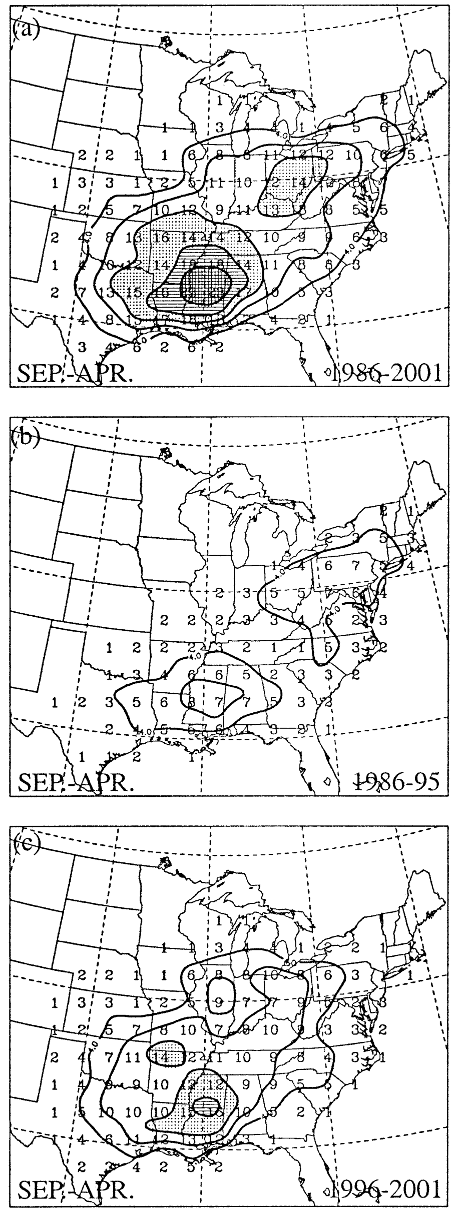

FIG. 4. The distribution of derechos for the months of Sep–Apr for (a) all 76 events from 1986 to 2001, (b) the 26 events from 1986 to 1995, and (c) the 50 events from 1996 to 2001. Contours are drawn every four events in all panels.

stream trough and a deepening or mature low-level cyclone.

Unlike the maximum frequency axis for the warm season events, the maximum in colder season events remains in approximately the same location for both the 1986–95 and 1996–2001 time periods (in Mississippi; shown in Figs. 4b and 4c). However, there are some differences among these time periods including the northward extension of events into the mid–Mississippi River valley and southeastern plains region, as well as the appearance of a significant number of events in Ten-

[1] BM98 identified 98 events in this same time period. The MCS criteria and the relaxed requirement of temporal and spatial continuity in this study both influence the change in the number of events.

nessee and Kentucky in the later period, as shown by Bentley and Sparks (2003). As with the distribution of the warm season events, this suggests the more frequent occurrence of synoptically favorable regimes in this region in later years, but the extent to which the nonmeteorological factors discussed in Weiss et al. (2002) affect this change in the distribution is not clear. The next section examines the effects of one such factor, namely the effects of excluding low-end events from the dataset, on both the warm and colder season derecho distributions.

b. Effects of excluding the low-end events

1) WARM SEASON EVENTS

As was done previously, the distribution among the low-end, moderate, and high-end derecho events is first presented in terms of the warm season events to facilitate comparisons to JH87 and BM98. Note that the maximum frequency axis for the low-end events stretches across the southern plains (Fig. 5a). The distribution for the moderate events contains maxima in the southern plains, the upper Mississippi valley, and in Indiana (Fig. 5b). For the high end events, the maximum frequency axis is found in the upper Mississippi River valley (Fig. 5c), particularly for the later period (1996–2001) (not shown). Most of the high-end events show primarily progressive MCS characteristics and contain long-lived and well-defined bow echoes (Fujita 1978) during maturity, some of which may contain embedded supercells or may begin as groups of isolated supercells (Klimowski et al. 2000; Miller and Johns 2000).

The effects of including the low-end events during the warm season are emphasized in Fig. 6. The low-end events appear to account for the largest percentage of the total number of events in the lower Appalachians, particularly in eastern Tennessee and the western Carolinas, where the low-end events account for greater than 50% of the total number of events (note that the percentages are calculated only if the location contains 10 or more total events over the 16-yr period). Additionally, locations in the lower Ohio valley also show areas in which the low-end events account for greater than 40% of the total number of events. As stated before, the Ohio valley region contained many severe wind episodes that were not included as derechos because of both inconclusive radar data and a number of events that failed to satisfy the MCS criterion. Figure 6 shows that the exclusion of low-end events further contributes to lowering the frequency values in this region, as compared to BM98 (Fig. 1b).

In terms of the preferred southern and northern frequency axes found in the overall warm season distribution (Fig. 3a), there are locations within the southern axis in which the low-end events account for greater than 40% of the total number of events, specifically in eastern Oklahoma and southern Arkansas (Fig. 6). In

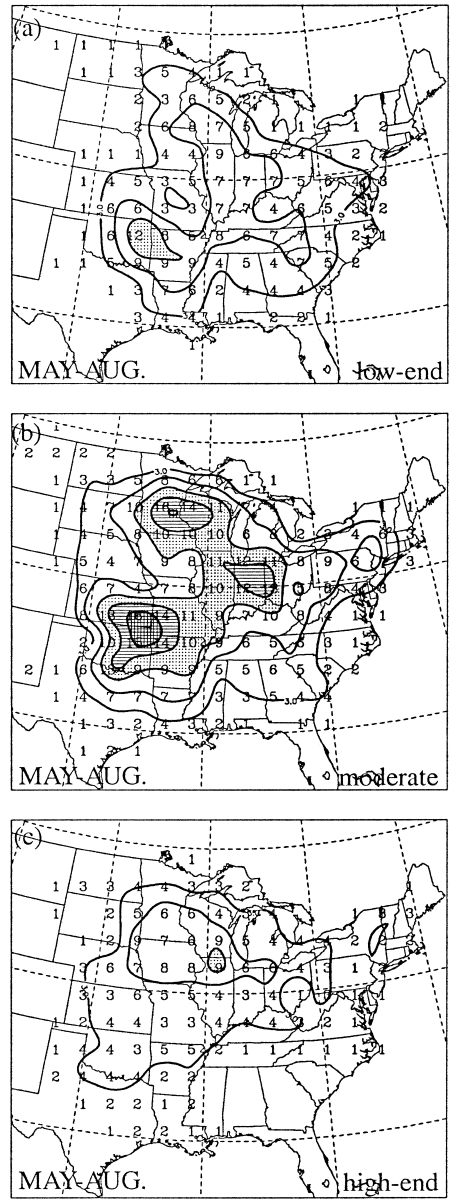

FIG. 5. The distribution of warm season derechos from 1986 to 2001 for (a) the 55 low-end events, (b) the 82 moderate events, and (c) the 31 high-end events.

comparison, the low-end events generally account for only 20%–30% of the total number of events in the upper Mississippi River valley through the western Ohio valley (Fig. 6). The low-end events in the southern axis largely occur in the period 1986–95 (Fig. 7a), whereas the low-end events in the upper Mississippi River valley and Ohio valley occur almost exclusively in the period 1996–2001 (Fig. 7b). Low-end events from both time periods contribute to the inflation of events in the lower Appalachians (Figs. 7a and 7b), but the relatively low number of total events in this region (Fig. 3a) lessens the significance of this result.

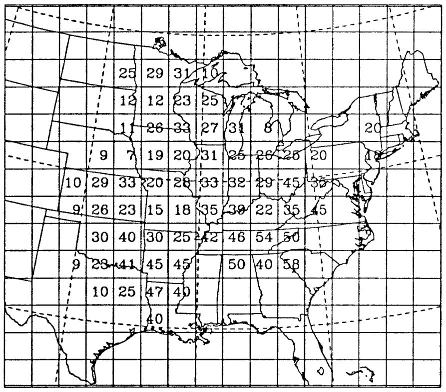

FIG. 6. The percentage (%) of the total number of warm season events accounted for by the low-end events within each grid box. Only the percentages for those locations with at least 10 total events are shown. Note that the number of low-end events can be found from Fig. 5a and the number of total events (low end, moderate, and high end combined) can be found from Fig. 3a.

Figures 6 and 7 show that the removal of the higher wind gust criterion (33 m s^{-1} in Table 1) inflates the numbers in all locations, but appears to have the greatest impact on the distribution of warm season events in the southern United States in the earlier years. To reinforce this point, the moderate and high-end warm season

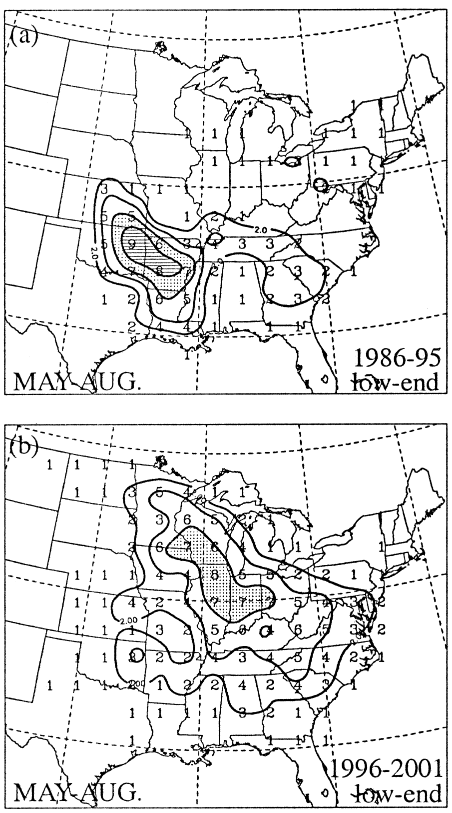

FIG. 7. The distribution of warm season, low-end derechos from (a) 1986 to 1995 (21 events) and (b) 1996 to 2001 (34 events). Contours are drawn every two events in both panels.

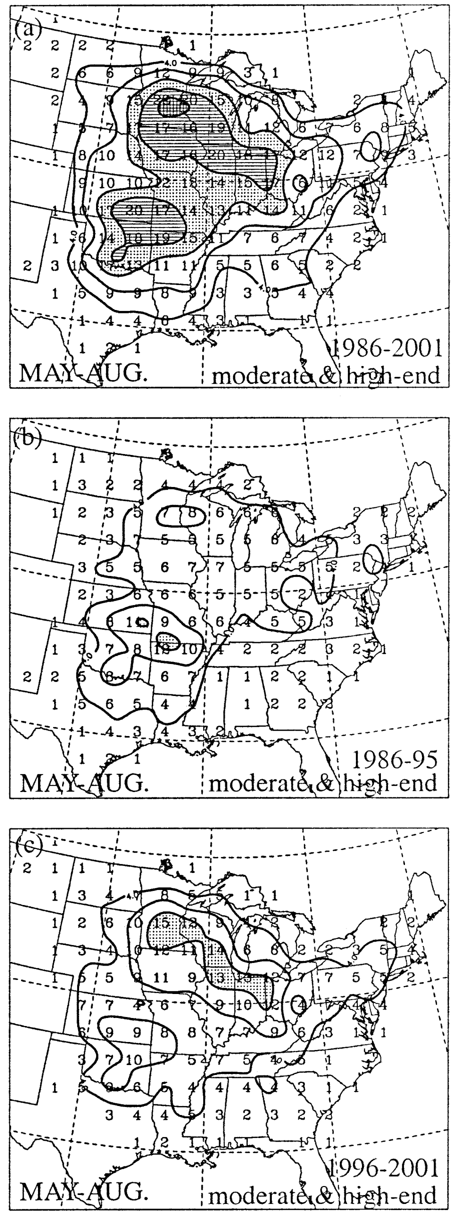

FIG. 8. The distribution of warm season, moderate, and high-end derechos from (a) 1986 to 2001 (113 events), (b) 1986 to 1995 (49 events), and (c) 1996 to 2001 (64 events). Contours are drawn every four events in all panels.

events are combined into one distribution (Fig. 8). The most apparent effect is the shrinking of the distribution in the lower Appalachians (cf. Figs. 3a and 8a). The effect on the primary frequency axes is subtler when viewing the entire 16-yr distribution. The southern axis is similar in frequency to the northern axis when low-end events are included (Fig. 3a). With the low-end events excluded, the frequency values for the northern axis become slightly larger and cover a larger geographical area than those for the southern axis (cf. Figs. 3a and 8a).

The effect of eliminating the low-end events is more clearly seen when comparing the distribution for the moderate and high-end warm season events for the time period of 1986–95 (Fig. 8b) to the distribution over the same time period with low-end events included (Fig. 3b). From 1986 to 1995, the southern plains still contain the primary warm season axis, but the frequency values and their geographical coverage are significantly reduced as compared to those found in this study with the low-end events included (cf. Figs. 3b and 8b) and also in BM98 (Fig. 1b). Concurrently, the frequency values in the northern axis are essentially unchanged (cf. Figs. 3b and 8b). As discussed by Johns and Evans (2000), the distribution presented by BM98 suggests that derechos were several times more likely in the southern plains than the northern Mississippi River valley in this time period. However, with the low-end events excluded, Fig. 8b shows frequency values in the southern axis that are much more comparable to those in the northern axis. Therefore, *the removal of the 33 m s^{-1} wind criterion, which allows the identification of low-end events in this study, appears to play a significant part in the distinct southern plains maximum in derechos shown in BM98.*

The removal of low-end events also reduces the frequency values in the northern axis for the time period of 1996–2001 (cf. Figs. 8c and 3c). However, this reduction is not as apparent as when compared to the reduction in frequency values and geographical coverage of the southern axis in the earlier period, which is to be expected from Fig. 6. The overall effect is to create a distribution that still suggests a shift of the primary axis from the southern plains in the late 1980s to early 1990s to the upper Mississippi River valley from the late 1990s to the early 2000s, but with frequency values in the maximum that are considerably lower than what is suggested by BM98 and Bentley and Sparks (2003; see their Figs. 5 and 6).

Although we have shown that the exclusion of low-end events mutes the amplitude of the frequency values, derechos still appear to be more frequent in the southern plains in both time periods than what is inferred from the results of J87. Since JH87 use the 33 m s^{-1} criterion, this is likely related to other factors and perhaps gives credence to the anomalous-ridging argument given by BM98 and Bentley and Mote (2000b) stated earlier.

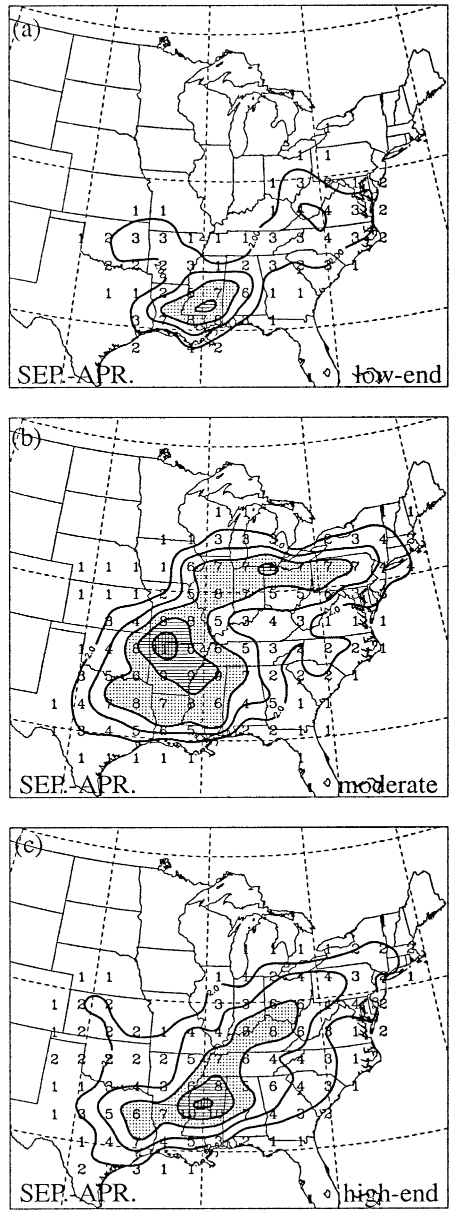

FIG. 9. The distribution of derechos for the months of Sep–Apr from 1986 to 2001 for (a) the 18 low-end events, (b) the 34 moderate events, and (c) the 24 high-end events. Contours are drawn every two events in all panels.

2) COLDER SEASON EVENTS

For completeness, the regional distributions for the 18 low-end derechos, the 34 moderate derechos, and the 24 high-end derechos for the remaining months (September–April) are shown in Fig. 9. This reveals that the largest concentration of low-end events is found in a relatively confined area from southern Louisiana through central Alabama (Fig. 9a), where 30%–50% of the total number of events are low-end derechos (not shown). This decreases the large frequency values shown in this region (Fig. 4a), but does not significantly change the location of this maximum frequency axis along the Gulf coast states. Also notice that most of the colder season derechos that constitute the majority of the events from the southern plains through the Ohio valley are either moderate or high-end events (Fig. 9b) and are found in the later period (Fig. 4c). The high-end events alone are favored along the western Gulf coast states, but also show an extension into the Ohio valley, similar to the overall distribution. The overall distribution with low-end events excluded (not shown) still shows a maximum in the number of events in the lower Mississippi River valley, but with frequency values that are more comparable to those in the Ohio valley (as compared to Fig. 4a).

4. Summary and conclusions

A dataset of 244 derecho events over a 16-yr period is used to examine the effects of changing the criteria for identifying derechos, which helps to gain further insight into the interpretation of the underlying geographical distribution of derechos. This study focuses on the choice of BM98 to remove the requirement preferred by JH87 of three 33 m s^{-1} wind gust reports. In this study, events that do not meet this criterion are termed low-end events. This study also proposes new criteria to help identify particularly intense derecho events (high-end events) and identifies their preferred geographical regions.

As similarly suggested by Bentley and Sparks (2003), the overall distribution over the entire 16-yr period (with low-end events included) suggests two primary axes of warm season events: one from the southern plains–Arkansas region and one stretching from the upper Mississippi River valley through the Ohio valley. Similar to what was found by Bentley and Sparks (2003), the southern axis is preferred in the earlier years (1986–95), while the northern axis becomes prominent in later years (1996–2001). Collectively, the estimation of the derecho climatology presented in JH87, BM98, Bentley and Sparks (2003) and in this study suggests that warm season derechos can occur almost anywhere east of the Rocky Mountains, but seem to favor both the upper Midwest–upper Mississippi River valley and the central and southern Great Plains, depending upon the nature of the mean flow regime. However, it is stressed that these results are noticeably altered with the choice of including the 33 m s^{-1} wind criterion, which can substantially influence the interpretations of the derecho climatology. In particular, we estimate that low-end events (mostly from the period 1986–95) account for greater than 40% of the total number of events in portions of the southern plains–Arkansas region. Low-end events also are estimated to increase the frequency values in the upper Mississippi River valley region through the western Ohio valley in the time period from 1996 to 2001, but generally account for only 20%–30% of the total number of events. Therefore, the removal of the 33 m s^{-1} criterion appears to have contributed to the relatively large frequency values and the pronounced maximum found in the southern plains by BM98.

Future studies will be able to improve the assessment of statistical significance with more data, but we have shown that the estimates of the derecho distribution that we can garner from the present database are sensitive to the choice of including or excluding the 33 m s^{-1} criterion. Although this study shows no quantitative results on the total effects of including radar data in the analysis, we have also shown that radar data greatly assist, and can be essential, in removing non-MCS events and can greatly assist in determining the wind reports that constitute the derecho. The overriding theme of these results is that nonmeteorological factors (Johns and Evans 2000; Weiss et al. 2002), including seemingly minor changes in the derecho definition, need to be thoughtfully considered in interpreting any derecho climatology that has appeared to date.

Regarding our estimation of the high-end derecho distribution, we believe it is useful to display this result since this has not been attempted in the past literature (the warm season events are found mostly in the northern axis, particularly in the later years). With the knowledge of the potential biases and complications noted herein, our estimation of the high-end derecho distribution can therefore provide a baseline for future studies to refine with additional years of improved data. However, it is stressed that a substantial increase in confidence in the derecho climatology, no matter how it is defined, will likely have to wait for many more years of quality WSR-88D data and improvements in the treatment of the convective wind database.

Acknowledgments. We greatly appreciate the constructive comments and suggestions provided by the four reviewers, Robert Johns, and Dr. Harold Brooks. Motivation and ideas for this work came from discussions with Steven Weiss and several of the forecasters from the NOAA/Storm Prediction Center. It would not have been possible to complete this work in any reasonable amount of time without the software to view the SPC convective wind database (svrplot 2.0) developed by John Hart and Paul Janish of the Storm Prediction Center. This research was supported by NSF Grant ATM-0138559 and was made possible under the NOAA–OU Cooperative Agreement NA17RJ1227 for the establishment of CIMMS.

REFERENCES

Bentley, M. L., and T. L. Mote, 1998: A climatology of derecho-producing mesoscale convective systems in the central and eastern United States, 1986–95. Part I: Temporal and spatial distribution. *Bull. Amer. Meteor. Soc.,* **79,** 2527–2540.

——, and ——, 2000a: A synoptic climatology of cool-season derecho events. *Phys. Geogr.,* **21,** 21–37.

——, and ——, 2000b: Reply. *Bull. Amer. Meteor. Soc.,* **81,** 1054–1057.

——, and J. M. Sparks, 2003: A 15 yr climatology of derecho-producing mesoscale convective systems over the central and eastern United States. *Climate Res.,* **24,** 129–139.

Fujita, T. T., 1978: Manual of downburst identification for Project NIMROD. SMRP Research Paper 156, University of Chicago, 104 pp.

——, and R. M. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts on 16 July 1980. *Mon. Wea. Rev.,* **109,** 1438–1456.

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

——, 1984: A synoptic climatology of northwest flow severe weather outbreaks. Part II: Meteorological parameters and synoptic patterns. *Mon. Wea. Rev.,* **112,** 449–464.

——, and W. D. Hirt, 1987: Derechos: Widespread convectively induced windstorms. *Wea. Forecasting,* **2,** 32–49.

——, and C. A. Doswell III, 1992: Severe local storms forecasting. *Wea. Forecasting,* **7,** 588–612.

——, and J. S. Evans, 2000: Comments on ''A climatology of derecho-producing mesoscale convective systems in the central and eastern United States, 1986–95. Part I: Temporal and spatial distribution.'' *Bull. Amer. Meteor. Soc.,* **81,** 1049–1054.

Klimowski, B. A., R. Przybylinski, G. Schmocker, and M. R. Hjelmfelt, 2000: Observations of the formation and early evolution of bow echoes. Preprints, *20th Conf. on Severe Local Storms,* Orlando, FL, Amer. Meteor. Soc., 44–47.

Miller, D. J., and R. H. Johns, 2000: A detailed look at extreme wind damage in derecho events. Preprints, *20th Conf. on Severe Local Storms,* Orlando, FL, Amer. Meteor. Soc., 52–55.

Parker, M. D., and R. H. Johnson, 2000: Organizational modes of midlatitude mesoscale convective systems. *Mon. Wea. Rev.,* **128,** 3413–3436.

Wakimoto, R. M., 2001: Convectively driven high wind events. *Severe Convective Storms, Meteor. Monogr.,* No. 50, Amer. Meteor. Soc., 255–298.

Weiss, S. J., J. A. Hart, and P. R. Janish, 2002: An examination of severe thunderstorm wind report climatology: 1970–1999. Preprints, *21st Conf. on Severe Local Storms,* San Antonio, TX, Amer. Meteor. Soc., 446–449.

Zipser, K. A., 1982: Use of a conceptual model of the life cycle of mesoscale convective systems to improve very-short-range forecasts. *Nowcasting,* K. Browning, Ed., Academic Press, 191–204.