P4.4 DERECHO FAMILIES

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1. INTRODUCTION

Early studies by Miller (1972) and Johns (1982) observed that severe weather outbreaks are likely to repeat on several successive days across the conterminous U.S. Johns (1982) found that 71% of all U.S. northwest flow (NWF) outbreaks during 1962-77 were associated with a series of severe weather events (defined by Johns as any combination of two or more outbreaks that occurs with no more than two calendar days between any outbreaks in the series). Most of the NWF outbreak series consisted of two or three severe weather outbreaks, but could contain as much as eight or more separate outbreaks within a series. Johns and Hirt (1987) suggested that warm-season derechos are often associated with meteorological parameters similar to those found in NWF outbreaks. In fact, Johns and Hirt (1987) discovered that derechos have the propensity to occur in succession; their analyses indicating that more than one-quarter of all 1980-1983 warm season derechos qualified as NWF outbreak series.

In a larger climatological study, Bentley and Sparks (2003) established the tendency for derechos to "train" or group over similar geographic regions. They found a tendency for summer, northern-tier U.S. derechos (a corridor reminiscent of Johns (1982) NWF scenario) and northeast moving, Great Plains derechos to occur in a series. Although, their criteria for derecho groupings was relatively liberal, with up to a 7-8 day period between events.

This study utilizes a more conservative approach to delineate derecho groupings and a much larger dataset to reveal the characteristics of these derecho groupings. This investigation reviews 10 yr of derecho data in order to detail the tendency for these convective events to replicate in coherent succession. Two or more derecho events occurring within several days are labeled a derecho "family" (from Bentley and Sparks 2003). Corridors that are most frequented by these derecho families are revealed as well as the overall temporal and spatial features of derecho families in the central and eastern U.S.

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2. METHODOLOGY

2.1 *Derecho Dataset*

The conterminous U.S. derecho dataset utilized in this study was compiled through several means, including: 1) two recently completed long-term climatologies by Bentley and Sparks (2003) and Coniglio and Stensrud (2004) [See 7A.2 (this volume) for further information on these datasets]; 2) an examination of all derecho literature to reveal any missing derecho events not documented by the aforementioned climatological studies; 3) the inclusion of several additional events that did not meet the Johns and Hirt (1987) length criteria due to land constraints, but were clearly derecho events (e.g., serial derecho crossing Florida peninsula); and 4) documenting derechos from 2002 and 2003 by examining the SPC's daily on-line severe storm reports, SPC's severe thunderstorm event database, *Storm Data*, *SeverePlot,* and available radar data.

All derechos that were identified or compiled for this study met a set of consistent criteria analogous to that proposed and utilized by Bentley and Mote (1998), Bentley and Sparks (2003), Evans and Doswell (2001), Coniglio and Stensrud (2004; their "low-end" criteria), and Coniglio et al. (2004). The unified derecho dataset, consisting of 377 events for the period 1986-2003, is used to improve the record of derechos by combining several sources of data into a single dataset.

Although the derecho dataset contains 18 yr of documented derecho events, only the 10 yr period from 1994-2003 is utilized for this study. The reason for this restriction is due to the large jump in the number of annual events evident after 1993 (Fig. 1). For example, the ten-year period between 1994 and 2003 consists of over 85% of the derechos associated with families in the dataset, while the nine-year period from 1985-1993 consists of *only* 15% of the events. This bias is likely a result of a number of human-related factors associated with an increase in the severe wind reports contained within the severe thunderstorm wind event database, including: 1) population growth and urban sprawl, 2) an increase in weather awareness by the general population, 3) improved communications (e.g., cell phones), 4) the development of spotter networks, 5) the deployment of WSR-88Ds, and 6) the implementation of the national warning verification program which has resulted in increased accountability of NWS warning products (Schaefer et al. 2003). Hence, for the years prior to the NWS modernization, many derecho events may be unidentified, resulting in an underestimate of the actual number of events during this early period of the dataset (Coniglio and Stensrud 2004). Therefore, this data restriction allows for an examination of the most *consistent* portion of the derecho database, which is a desirable condition when examining time-series data.

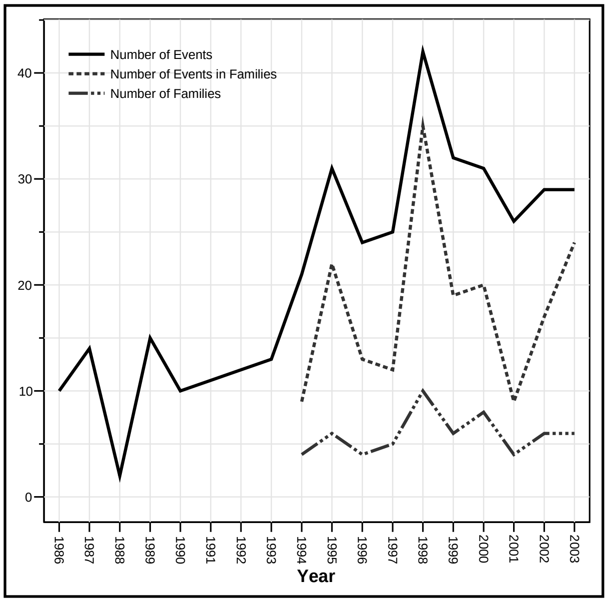

Figure 1. The number of derechos annually for the period 1986-2003 and the number of derecho families and derecho family members for the period 1994-2003.

2.2 *Derecho Family Identification*

Numerous mechanisms and environments can promote the formation of successive MCSs, including those producing derechos, such as: traveling baroclinic waves and their associated extratropical cyclones and fronts; a persistent low-level jet (LLJ) oriented perpendicular to zonal-oriented front promoting successive MCSs (Trier and Parsons 1993); a series of minor disturbances propagating through NWF aloft (Johns 1984); convectively generated propagation mechanisms such as residual outflow/cold pools (Tuttle and Carbone 2004), trapped gravity waves (Carbone et al. 2002), or mesoscale convective vortices (MCVs; Trier et al. 2000); a series of upper-level PV anomalies migrating atop a large-scale, stagnant ridge (Bosart et al. 1998). Moreover, Stensrud (1996) found that a persistent, mesoscale region of convection could have a significant impact on the large-scale environment that, in turn, can produce a positive feedback mechanism that promotes more convective systems. Although this study does not specifically classify the derecho families into their formative environments or mechanisms, we do use a temporal restriction and a subjective assessment of the large-scale environment and distance between systems to define the families.

Undoubtedly, the longer the interlude between two successive derechos, the greater the probability that the environment that generated the events has undergone change or the mechanism that produced the series of events has dissipated. Hence, the first requirement in developing a derecho family classification is to develop a temporal restriction that will limit the time interval between subsequent storms. Initially, in order to establish derecho families from the dataset, we determined the amount of time (in hr) that occurred between the *last* wind report from the previous derecho and the *first* wind report of the next derecho. Interestingly, the dataset reveals a strong clustering of derechos around the low-end of the reoccurrence interval distribution (Fig. 2). This supports the hypothesis that derechos have a tendency to form in coherent succession.

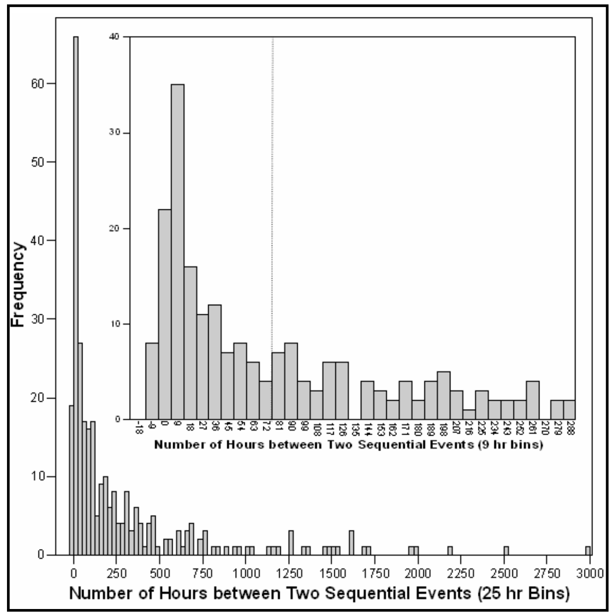

Figure 2. Two frequency histogram revealing the number of hours between two sequential derecho events. The outer histogram is restricted to 25 hr bins while the inner histogram is limited to 9 hr bins. A dashed line within the inner histogram reveals the maximum threshold for initial family criteria.

We subjectively determined that any events that were within three days of each other had the *possibility* of forming in similar troposphere environments or by the same mechanism. Thus, all events less than 72 hr apart were selected as initial derecho family members. This approach is much more restrictive than the 7-8 day temporal restriction put forth by Bentley and Sparks (2003) but consistent with the method that Johns (1982) utilized to identify NWF series – i.e., any combination of two or more NWF outbreaks that occur with no more than two calendar days between any of the outbreaks of the series. Of the 377 derechos occurring between 1986-2003, 225 (60%) derechos met the initial family criteria.

After these preliminary events were selected, 500 mb and surface analyses from the *Daily Weather Map Series* were examined for all days within each derecho family temporal window. All events that either were geographically (e.g., one event in North Dakota, another in Florida) or synoptically (e.g., associated with significantly differing mid-level tropospheric patterns or surface boundaries) disparate were discarded from the derecho family dataset. Groupings of derechos that met the initial temporal family criteria but also contained embedded derecho groupings associated with differing synoptic conditions were separated in order to create consistent families for each distinguishing environment.

3. RESULTS

3.1 *Temporal Frequency*

Of the 290 events in the derecho dataset from 1994-2003, 180 (62% of the dataset) met the family criteria discussed in the previous section. The 180 events consisted of 59 families with a mean of 3.05 derechos per family. On average, there were 5.9 families and 18 family members annually. Most families involved only two or three derecho events; however, 14 families contained four or more events. Two separate families – one in June 1998 and one in July 2003 – involved nine derecho events within a period of nine days.

Examining derecho family frequency by month (Fig. 3) indicates that derecho families occur predominantly during the warm-season months of May, June, and July. In fact, 75% of the families and 82% of derecho events in families occur during this three-month period. This is not surprising considering that 62% of derechos from 1994-2003 occurred during these months. Similar to the results of Coniglio et al. (2004), May is the leading month of derecho-producing convective systems in the U.S. The late-spring peak is likely due to a combination of both serial and progressive type events that tend to frequent the eastern two-thirds of the U.S. during this transition-season month. May is also the peak month for derecho families and the number of events constituting those families. The large occurrence of NWF outbreaks during July (Johns 1982) is the probable cause of the secondary maximum in derechos and derecho families experienced during this month. Interestingly, August has roughly one-third the derecho totals as the three preceding warm-season months. This diminishing frequency during late summer is likely caused by an increasingly capped environment in the region (i.e., northern-tier of the U.S.) favorable for derecho development (Farrel and Carlson 1989), a decrease in the thermodynamic instability of the atmosphere (Johns 1982), and a general weakening of the mid-troposhpheric westerlies leading to an overall decrease in the deep- layer shear needed to facilitate the growth of derecho-producing convective systems (Johns 1982, Coniglio and Stensrud 2001, Coniglio et al. 2004).

Of the 290 events documented during this 10 yr period, 110 were “loner” derecho events and 180 events were associated with one of the 59 families. These numbers indicate that once a derecho event occurs, there is a 35% chance that this event is the first of a series of two or more, and a 20% chance that this is the first of a derecho family consisting of three or more events. Upon examining the months with the highest frequencies of derecho events for this same period,

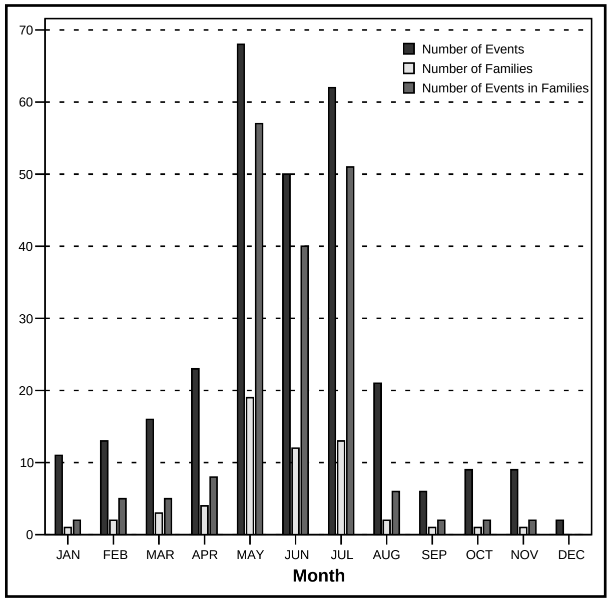

Figure 3. The number of derechos, derecho families, and events in families by month for the period 1994-2003.

considerably higher percentages are obtained. For example, during May, June, and July for the 1994-2003 period, there were 32 “loner” events and 148 events associated with one of 44 families. These data suggest that *once a derecho occurs during the warm-season months, there is a 58% chance that this event is the first of a series of two or more, and about a 46% chance that this is the first of a derecho family consisting of three or more events!*

When examining the percentages on an annual basis, the chance that an event is the initial member of a family is highly variable (not shown). This variance is likely caused by a shift in annual, and even monthly, synoptic patterns favorable to producing derechos, particularly during the warm-season (Bentley and Sparks 2003, Coniglio and Stensrud 2004). For example, during the warm-season of 1998, the coexistence of a large region of weak static stability and abnormally strong polar and subtropical jet streams across the U.S. provided a synoptic situation that was particularly favorable for the formation of a large number of derechos. In terms of 1998 derecho families, there was a 59% chance that an initial event was the first of two or more and a 46% chance that it was the first of a family with three or more events. These statistics are larger when the analysis is restricted to the warm-season months of May, June, and July during this year (80% chance that an initial event was the first of two or more and a 75% that it was the first of a family with three or more events). Conversely, during two years, 1994 and 2001, the chance that an event was the first of two or more remained at or below 25%, suggesting that the pattern was not as favorable for derecho family formation during these years as other, more active, years.

3.2 *Spatial Frequency*

In order to reveal spatial distributions of derechos and derecho families in the U.S., wind damage and gust reports from derechos for the period 1994-2003 were mapped onto 1º latitude by 1º longitude grid. Not unlike past studies (e.g., Bentley and Mote 1998, Coniglio and Stensrud 2004), the distributions were determined by counting the cells that contain at least one wind report from each event or family of events and then contouring the sum of each cell over a given temporal period utilizing an inverse-distance interpolation technique and a 3 by 3 moving window smoothing method. The smoothing technique was employed to smooth any excessive variability in the initial contour analysis to leave only the moderate to strong signals. This smoothing leads to a underestimate of the original gridded values. For this reason, the locations of maximum grid cells prior to the smoothing, and their values, are indicated on the maps in order to reveal the magnitudes of the stronger signals.

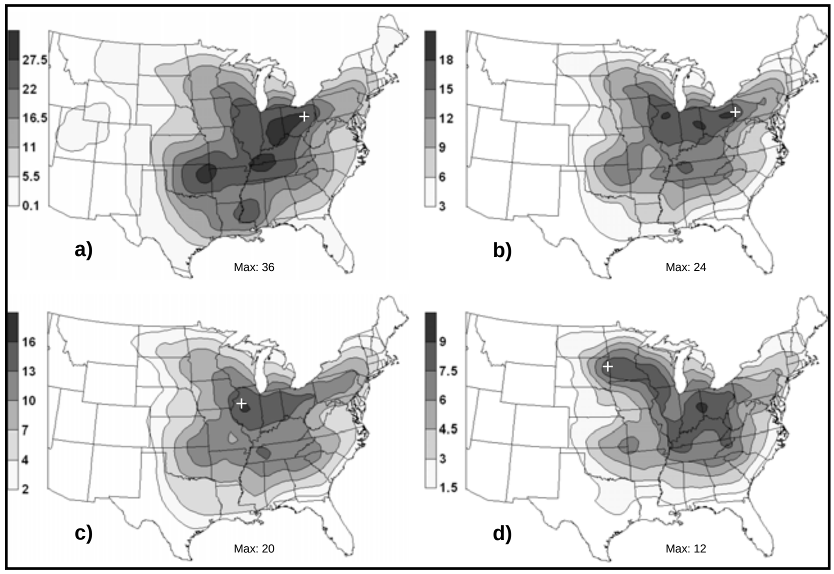

Figure 4. Total number of a) derechos, b) derechos associated with families (i.e., derecho members), c) derecho families, d) derecho families with three or more members for the duration of the 10 year period 1994-2003.

Examining the derecho frequency for the 10 yr period utilized in this study reveals that derechos predominately occur throughout the eastern two-thirds of the U.S. (Fig. 4.a). In general, the distribution is similar to the results of Bentley and Sparks (2003) and Coniglio et al. (2004); however, there are some minor differences in the strength and placement of the maximum frequency corridors as suggested by the previous research. Similar to Bentley and Sparks (2003) and Coniglio et al. (2004), two maximum frequency axes exist within the analysis – one in the south-central Plains; the other, larger corridor, in the Ohio Valley. However, in comparison to these previous studies (cf. Bentley and Sparks' (2003) Fig. 14 and Coniglio et al.'s (2004) Fig. 3.a), the southern Plains corridor is more subdued and the region including western Kentucky and northwestern Tennessee is more substantial. Our analyses, which contain only the latter, more consistent 10 yr of the available 18 yr dataset, indicate that the Ohio Valley region has the highest derecho frequency, with one grid cell in this region affected by 36 events during the 10 year period (i.e., roughly 3.6 events per year).

The comparatively smaller frequency maximum in the southern Plains could be due to the exclusion of late 1980s-early 1990s data, which is argued to have been a period of favorable synoptic conditions for southern Plains events (Bentley and Sparks 2003, Coniglio and Stensrud 2004). Derechos for the period 1986-1993 occurred primarily within a distinct, high-frequency southern Plains maximum (not shown), with two grid cells in Oklahoma affected by more than 15 events and an area stretching from north-central Oklahoma through northern Louisiana affected by more than nine events. This supports the hypothesis presented by Bentley and Sparks (2003) that the southern Plains region was the primary derecho corridor during the late 1980s-early 1990s. Thus, there do appear to be important, long-term climatological shifts in the primary derecho corridors; however, further analysis of these trends is limited by the number of years of consistent derecho data available for analysis. As suggested by Bentley and Sparks (2003), the examination of many more years of derecho activity will be needed to accurately capture the genuine character and long-term variation of derechos in the U.S.

Restricting the analysis to only those events that were members of derecho families (Fig. 4.b) illustrates that derechos associated with families are more likely to occur in a region from the Upper Midwest through the Ohio Valley. This primary high-frequency axis indicates that northern-tier events have a larger derecho family association than their southern-tier counterparts. Nevertheless, there remains a high occurrence of derecho events associated with families in the northeast Oklahoma – southwest Missouri region. This region is frequented by both springtime northeastward and summertime southeastward moving (i.e., "southward-burst" type) derechos (Bentley and Mote 1998). The central Mississippi and lower Ohio Valleys may experience derecho families during any season due to their proximity to a number of seasonal derecho corridors.

Derecho families (Fig. 4.c) occur throughout the eastern two-thirds of the U.S., but are confined generally to the southern Plains, the southern Great Lakes, and the Mississippi, Ohio, and Tennessee River Valleys. Families with three or more members (Fig. 4.d) are more likely to occur in a region from southern

Minnesota to the Ohio Valley, with one grid cell along the Minnesota-South Dakota border affected by 12 and another grid cell in western Ohio impacted by 11 of these larger families. Derecho families with four or more members (not shown) generally occur in either southern Minnesota or in the region near southwest OH/northern KY, while families with five or more members (not shown) are restricted to the Ohio River valley. These analyses illustrate that the area from the Upper Midwest through the Ohio Valley is the area most likely to be impacted by derecho families. As illustrated by Johns (1982), this region is also the primary high-frequency axis of NWF outbreak series.

Examining the months with the highest derechos and derecho families – May, June, and July – illustrates that warm-season family events occur primarily in the northern-tier in an axis from the northern Plains, through the Midwest, eastward to the lower Great Lakes region (Fig. 5). During May, derechos associated with families occur largely in the central Mississippi and lower Ohio Valleys, with a secondary frequency maximum occurring in the Northeast. Derechos associated with June families take place across primarily the Midwest, Ohio Valley, and lower Great Lakes region, but the Southeast is also impacted by several events. July family derechos transpire in a well-defined primary high-frequency axis from the northern Plains through the lower Great Lakes region that is reminiscent of Johns' (1982) primary NWF high-frequency axis. A secondary high-frequency axis exists in Kansas and Oklahoma and is an artifact of two separate derecho families that were made up of sequentially occurring, "southward-burst" type derecho events embedded within northwest flow aloft.

4. CONCLUSION

This study has outlined the tendency for derecho-producing MCSs to group together – forming families. The derecho family was recognized as any succession of derechos that occur within a similar synoptic environment or develop by way of the same convective mechanism with no more than 72 hr separating the individual events constituting the family. Analyses revealed that derecho families frequent regions of the Midwest, Ohio Valley, and south-central Great Plains during May, June, and July. Utilizing the most consistent portion of the dataset, the analysis revealed that once a derecho occurs during the warm-season months, there is a 58% chance that the event is the first of a family of two or more derechos. Thus, forecasters within these high-frequency regions need to remain alert following a derecho event for the likely reoccurrence of derecho events thereafter. A future study considers several unique derecho family events and examines how the large-scale environment induces groupings of these severe convective windstorms.

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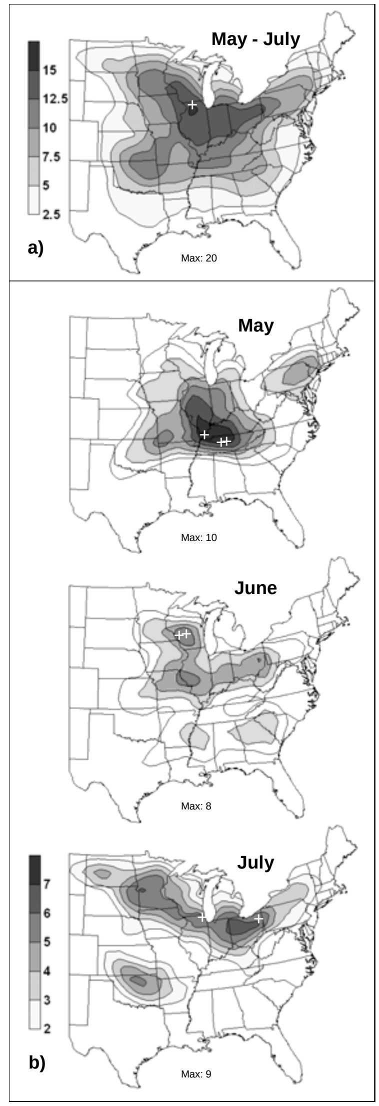

Figure 5. Number of derechos associated with families for a) May-July and b) for the individual months of May, June, and July.

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