Derechos: Widespread Convectively Induced Windstorms*

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ABSTRACT

The derecho, a widespread convectively induced windstorm, is identified and defined in terms of current nomenclature. A comprehensive dataset consisting of 70 derecho cases has been developed from the warm season months of May through August for the 4-year period 1980–1983. Analyses of this dataset reveal that the warm season derecho typically emanates from a mesoscale convective system (MCS) moving along a quasistationary, low-level thermal boundary in an environment characterized by high potential instability and relatively strong midtropospheric winds. In the continental United States these windstorms are most frequent in a zone extending from eastern South Dakota to the Upper Ohio Valley, and typically commence during the afternoon and evening hours. Particular radar and satellite imagery characteristics are associated with the derecho-spawning MCS. Based upon the meteorological parameters and synoptic patterns associated with derecho events, a decision tree has been developed to assist the operational meteorologist in anticipating derecho development.

1. Introduction

Over portions of the continental United States east of the Rocky Mountains, particularly in that region known as the Corn Belt, it is not uncommon during the late spring and summer for rapidly moving convective systems to produce widespread significant wind damage often resulting in multiple casualties (e.g., Hamilton, 1970; Ludlam, 1970; Fujita, 1978). Figure 1 illustrates the effects of one such system. This windstorm phenomenon was first recognized in the scientific literature in the latter part of the 19th century and was called a derecho (Hinrichs, 1888). Derecho (pronounced day-ray'-cho; for plural add "s") is a Spanish word which can be interpreted as "straight ahead" or "direct." Hinrichs chose to identify the convectively induced straight line windstorm in this way, since the term is analogous to "tornado," which also is of Spanish origin. From drawings produced by Hinrichs it appears that derechos are similar in scale to families of downburst clusters and to some of the larger downburst clusters (Fujita and Wakimoto, 1981).[1] To avoid ambiguity, we are specifically defining the term derecho to include any family of downburst clusters produced by an extratropical mesoscale convective weather system (MCS) (Maddox, 1980; Table 2, page 1376).

Operational forecasting experience suggests that there are at least two types of derechos. One type appears to emanate from rapidly propagating segments of an extensive squall line and is often associated with a strong, migratory low pressure system. Such events typically occur in the late winter and spring and correlate with the type I squall line as defined by Porter et al. (1955). (For an example of such a system, see the case of 19–20 June 1979 discussed by Forbes et al., 1980.) The second type of derecho, discussed by Hinrichs (1888), appears to be most common in the late spring and summer in areas where the midtropospheric flow is usually westerly to northwesterly. (See Johns and Hirt, 1985, for a detailed example.) These derecho events are frequently associated with relatively weak synoptic scale weather systems, and the associated convective systems may show characteristics of both squall lines (Newton, 1950; and others) and nonlinear types of mesoscale convective systems (Maddox, 1980). Consequently, during the warm season, the derecho phenomenon frequently presents a difficult forecast problem for the operational meteorologist.

The development of forecasting techniques for predicting convectively induced outflow winds has not advanced very far since the advent of severe local storms forecasting. Early studies by Fawbush and Miller (1954) and Foster (1958) presented methods for estimating the maximum convective gust potential at any point based on radiosonde data. However, Doswell et al. (1982) have shown that these forecast schemes demonstrate little operational skill. Recent studies have focused on the nature and causes of downbursts and

* A preliminary version of this paper (based on a small data sample) appeared in the Preprint volume of the 13th Conference on Severe Local Storms. Note that in the current version the definition of the term "derecho" has been altered for clarity and consistency.

[1] Fujita and Wakimoto have classified damaging wind patterns as follows: 1) burst swath (major axis 400 m or less); 2) microburst (major axis 400 m–4 km); 3) downburst (major axis 4 km–40 km); 4) downburst cluster (major axis 40 km–400 km); and 5) family of downburst clusters (major axis 400 km or more).

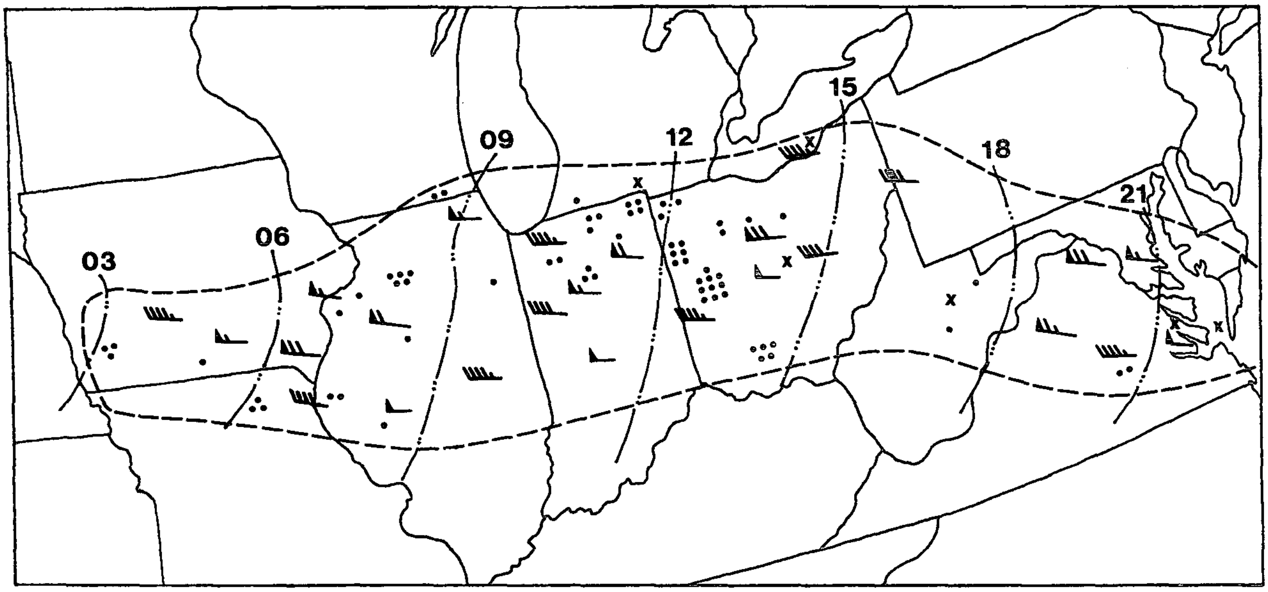

FIG. 1. Area affected by convective windstorm of 5 July 1980 (dashed line). Three-hourly squall line positions are indicated in UTC (from 0300 5 July to 2100 5 July). Officially measured convective gusts are indicated by wind barbs [full barb signifies 5 m s^{-1} (10 kt), flag signifies 25 m s^{-1} (50 kt)]. Personal injuries (67) are indicated by dots, and deaths (6) are shown by an "x". As is typical in such cases, a majority of the casualties involved persons engaged in outdoor activities, particularly of a recreational nature, and persons residing in mobile homes.

microbursts. Typical air mass profiles associated with High Plains region microbursts have been identified and some general forecast rules for "dry" microbursts have been developed (Caracena et al., 1983; Wakimoto, 1985). All of these forecast schemes are based on characteristics of the vertical profile of temperature and moisture. The vertical wind profile and synoptic patterns are generally not considered. Because of this, and because of the coarseness of the operational data network relative to the scale of the phenomena, these schemes have had limited operational success.

Derechos appear to account for many of the casualties and much of the damage owing to convectively induced nontornadic winds. However, other than a preliminary study by Forbes et al. (1980), little has been done to aid the operational meteorologist in forecasting these larger-scale damaging wind events. The purpose of this paper is to help remedy this situation by systematically examining the synoptic- and subsynoptic-scale conditions associated with a large number of derecho cases. The data network available to operational forecasters has been used to develop a comprehensive derecho dataset for the warm season months of May through August for the 4-year period 1980–1983. Analysis of this dataset reveals several characteristics which should help forecasters anticipate derecho development.

2. Identification of derecho cases

Based on operational forecasting experience and the definition of a derecho as previously stated, criteria have been developed to identity derecho events using STORM DATA (a publication of NOAA, NESDIS, National Climatic Data Center) and the National Severe Storms Forecast Center's operational log of severe weather events (Johns, 1982). The following four criteria are based on Fujita and Wakimoto's (1981) definition of a family of downburst clusters:

(a) There must be a concentrated area of reports consisting of convectively induced wind damage and/or convective gusts > 26 m s^{-1} (50 kt). This area must have a major axis length of at least 400 km (250 nm).

(b) The reports within this area must also exhibit a nonrandom pattern of occurrence. That is, the reports must show a pattern of chronological progression, either as a singular swath (progressive) or as a series of swaths (serial).

(c) Within the area there must be at least three reports, separated by 64 km (40 nm) or more, of either F1 damage (Fujita, 1971) and/or convective gusts of 33 m s^{-1} (65 kt) or greater.[2]

(d) No more than 3 h can elapse between successive wind damage (gust) events.

Cases which satisfy the preliminary screening criteria in (a) through (d) have been scrutinized further using both the National Weather Service radar summary charts and subjective surface mesoanalyses. For a case

[2] The Fujita scale for damaging winds is as follows: F0 (18–33 m s^{-1}); F1 (33–50 m s^{-1}); F2 (50–70 m s^{-1}); F3 (70–92 m s^{-1}); F4 (92–117 m s^{-1}); F5 (117–143 m s^{-1}).

TABLE 1. Monthly distribution of warm season derecho events for period 1980–1983.

Month	1980	1981	1982	1983	Monthly total
May	3	4	3	3	13
June	7	6	6	5	24
July	10	2	4	6	22
August	4	1	2	4	11
Seasonal total	24	13	15	18	70

to be accepted in the derecho database, it must also satisfy the following criteria:

(e) The associated convectively induced system, as indicated by surface pressure and wind fields, must have temporal and spatial continuity. However, movement of radar echoes associated with the system need not be continuous.

(f) Multiple swaths of wind damage (including gusts) must be a part of the same mesoscale convective system as indicated by the National Weather Service radar summary charts.

3. Areal and temporal frequencies

A total of 70 derecho cases have been identified during the study period, or an average of 17 cases per warm season. The data in Table 1 suggest that there is a considerable variation in the total number of cases from year to year. The data also reveal that June and July are peak months for derecho occurrence; two-thirds (66%) of the cases in the dataset occurred during these two months.

To determine the geographical frequency distribution of the derecho cases, a grid was prepared dividing the continental United States into squares of 2° latitude by 2° longitude. The maximum areal difference in such squares from north to south is less than 10%. By consulting the plot of each case, a tally was kept of the number of derecho events that occurred within each grid square. The results are displayed in Fig. 2. Note the well-defined high frequency axis extending from the northern Great Plains east-southeastward to the mid-Atlantic states. The pattern closely resembles the axis of highest frequency associated with northwest flow severe weather outbreaks (Johns, 1982). This similarity will be discussed further in section 7.

Table 2 illustrates that the time of initiation of most derechos is closely associated with the diurnal heating cycle. Almost eight-tenths (79%) of all derecho cases begin during the 12 h period between 1600 and 0400 UTC. Durations of the derecho events range from 2.3 to 20.0 h with an average duration of 9.2 h. The four cases with durations of 4 h or less were associated with

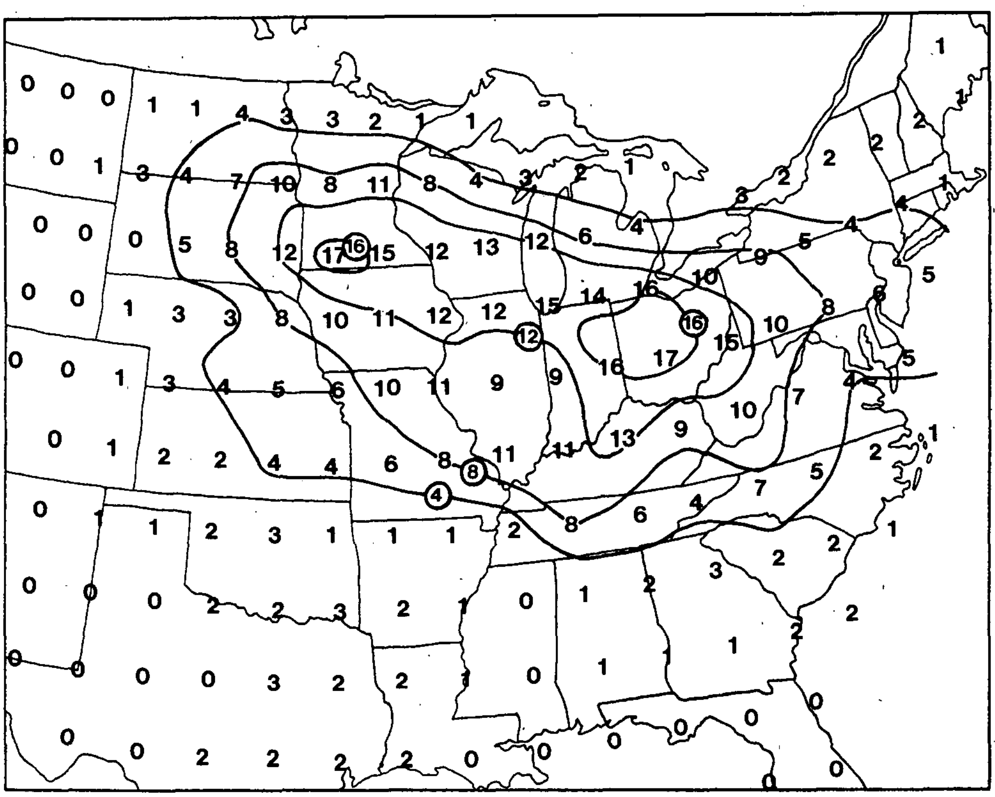

FIG. 2. Total number of derechos occurring in 2° lat by 2° long squares during the months of May through August for the period 1980–1983.

TABLE 2. Number of cases and percentage of total cases beginning during 6-h time periods.

Time period UTC	No. cases	Percentage of all cases
0400–1000	6	8%
1000–1600	9	13%
1600–2200	28	40%
2200–0400	27	39%

the multiple damage swaths of serial derechos (see section 2).

The lifetime of the convective system that spawns a derecho is usually considerably longer than the period of time when damaging winds are occurring. In most cases (88%), the associated convective complex develops at least 3 h before derecho initiation. In a majority of cases (57%), the thunderstorm complex develops more than 6 h before initiation.

4. Physical characteristics of the associated MCS

Examination of the radar summary charts associated with derecho occurrences reveals that the large-scale pattern of radar echoes takes a variety of forms. However, during the life cycle of most derechos, the radar configuration usually takes on one of two basic patterns. The *progressive* pattern is characterized by a short curved squall line oriented nearly perpendicular to the mean wind direction with a bulge in the general direction of the mean flow (Fig. 3).[3] It is along this bulging portion of the line where downburst activity occurs. With this pattern, it is not uncommon for a band of convective activity to extend downwind (eastward) from the north end of the bulging squall line. Figure 4 illustrates that on the scale of the radar summary chart, the bulging squall line often resembles a large bow echo (Fujita, 1978). When the eastward extension is present, the system resembles a LEWP (Line Echo Wave Pattern, Nolen, 1959), with the crest of the wave located at the north end of the bulging squall line. Case studies by Hamilton (1970), Prosser (1970) and Johns and Hirt (1985), however, have suggested that, on a smaller scale, the radar echo pattern associated with derechos is more complicated, often exhibiting a series of evolving LEWPs and bow echoes. Recent work by Przybylinski and DeCaire (1985) reveals that there are several types of radar signatures associated with derecho events. Figure 5 shows the surface pressure pattern (reduced to MSL) and the corresponding radar echo outlines associated with a progressive derecho near the midpoint of its lifetime.

[3] The mean wind vector is computed for the layer between approximately 1500 m (5000 ft) above ground level and the tropopause. If the tropopause level is not available, the 200 mb level is used as the upper limit of the troposphere.

The other convective form, the *serial* pattern, involves a squall line oriented such that a relatively small angle exists between the mean wind direction and the squall line axis (Fig. 6). Figure 7 illustrates that on the scale of the radar summary chart, the serial derecho convective system often consists of an extensive squall line. The downburst activity occurs with a series of LEWPs and bow echoes that move along the line (Figs. 8a and 8b). Generally, most of the downburst activity occurs toward the north end of the squall line. Figure 9 shows the surface pressure pattern (reduced to MSL) and the corresponding radar echo outlines associated with a serial derecho about 2 h after initiation.

Although several cases in the dataset show both progressive and serial characteristics, one pattern is usually dominant. Therefore, all 70 cases have been classified as either progressive or serial. More than three-quarters (76%) of the derechos in the dataset are progressive; the remainder are serial.

The serial derecho squall line usually moves at a speed of 15 m s^{-1} (30 kt) or less, in a direction nearly perpendicular to the mean flow vector (Newton, 1950), while the individual LEWPs move rapidly along the line in the direction of the mean flow. However, the progressive derecho convective system moves at an average speed of 23 m s^{-1} (45 kt) in a direction that is usually slightly to the right (averaging 15°) of the mean wind vector. Almost all progressive system cases (92%) move at a speed of 18 m s^{-1} (35 kt) or more (Fig. 10). In a majority of cases (56%), the progressive system moves more rapidly than the mean wind speed! Figure 11 illustrates that this characteristic is most common

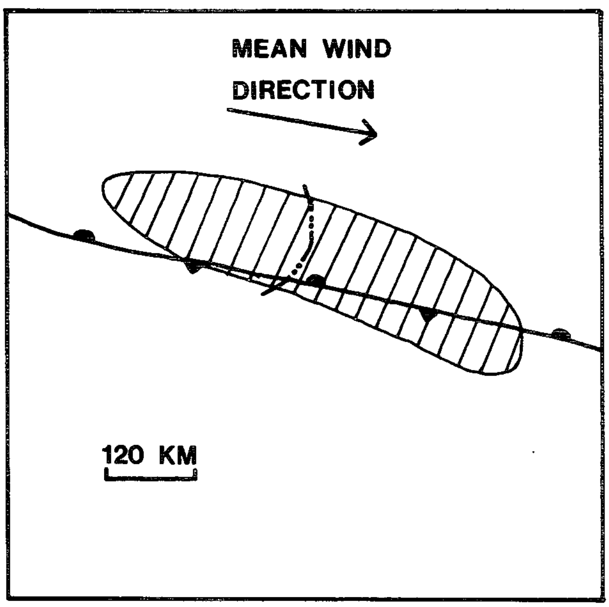

FIG. 3. Schematic representation of features associated with a progressive derecho near midpoint of lifetime. Total area affected by derecho during lifetime indicated by hatching. Frontal and squall line symbols are conventional.

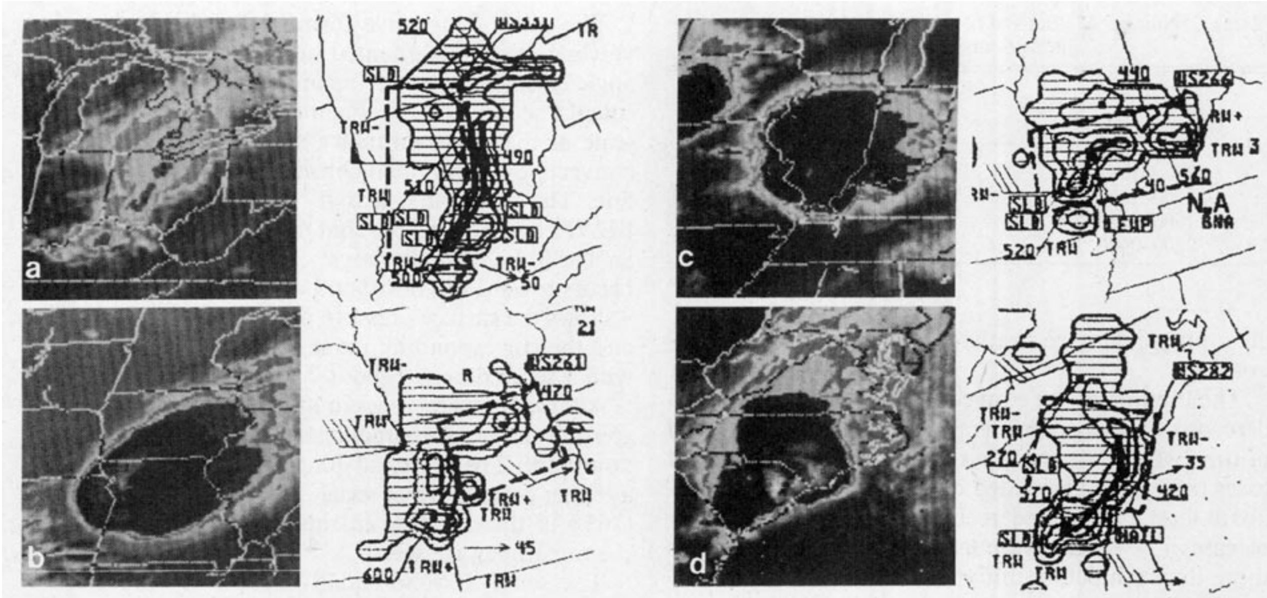

FIG. 4. Examples of radar echo patterns and cloud features associated with progressive derechos as depicted by Radar Summary Charts and corresponding 3.2 km (2-mile) equivalent resolution infrared (mb curve) satellite images: a) 1335 UTC 5 July 1980; b) 1135 UTC 7 June 1982; c) 1535 UTC 8 June 1982; and d) 2235 UTC 10 June 1982.

when the mean wind speed is relatively low. Furthermore, the wide scattering of points on Fig. 11 suggests that the progressive system's movement is strongly influenced by factors other than the mean wind. The movement of progressive derecho convective systems will be discussed further in section 7.

By definition, derechos consist of the widespread damaging outflow winds resulting from multiple

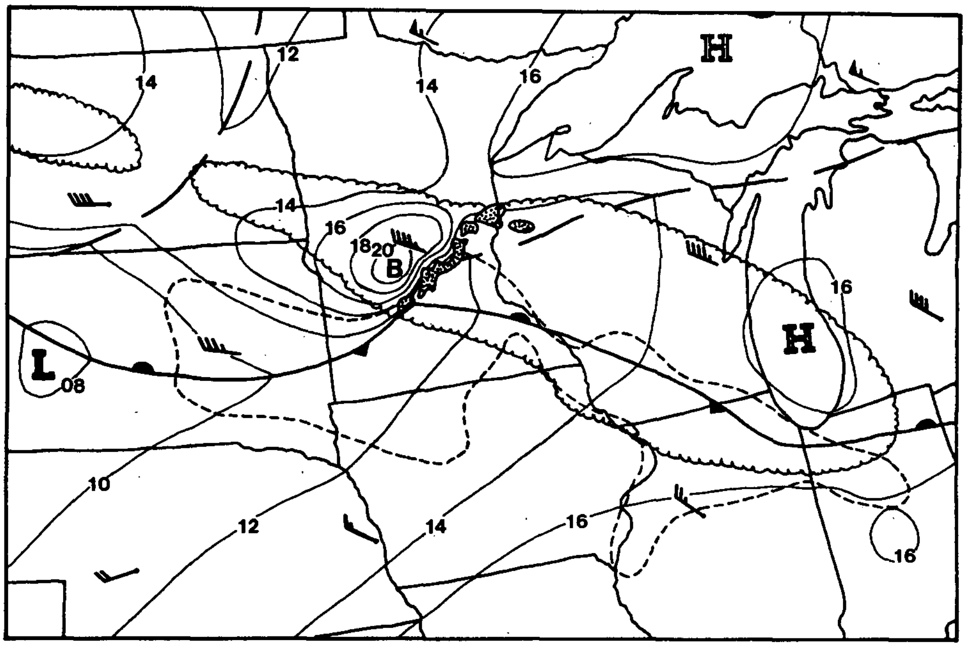

FIG. 5. Features associated with progressive derecho of 19–20 July 1983 near midpoint of its lifetime. Surface MSL pressure pattern (light solid lines), interpolated mean winds (barbs and flags as in Fig. 1), and corresponding radar echo outlines (stippled) for 2100 UTC 19 July. Mesohigh center indicated by "B". Area of surface dewpoints 24°C (76°F) or greater enclosed by dashed line. Area affected by widespread damaging winds during derecho lifetime (1100 UTC 19 July to 0500 UTC 20 July) enclosed by scalloped line. (Radar echo outline data courtesy of Ron Przybylinski, WSFO Indianapolis.)

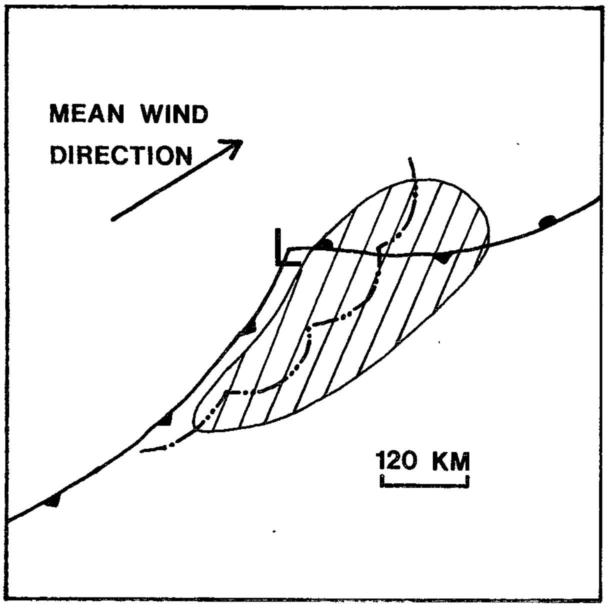

FIG. 6. As in Fig. 3, except schematic representation of features associated with a serial derecho.

downbursts. It is well documented that downbursts are sometimes accompanied by tornadoes (Forbes and Wakimoto, 1983). Examination of the derecho dataset reveals that tornadoes are associated with most cases (81%); however, less than half (47%) of the cases produce more than two tornadoes per event. The frequency of tornado occurrence with derechos is highest in June, averaging almost five tornadoes per event. About one-quarter (26%) of all cases produce six or more tornadoes per event; however, such episodes do not occur after mid-July. The frequency of occurrence decreases to 1.5 tornadoes per event during August. These data correlate well with the frequency distribution of tornadoes in general (Kelly et al., 1978). The distribution of tornado intensities associated with derechos is similar to that found for tornadoes in general (Schaefer et al., 1980). Over two-thirds of all derecho-associated tornadoes are weak (F0 or F1 intensity; see footnote 2). Only 8% of derecho tornadoes are of F3 intensity or stronger, and all of these occur before August. No F5 intensity tornadoes were reported. The three F4 intensity tornadoes occurred in June and early July, and were associated with strong 500 mb short-wave troughs (see section 5).

Satellite imagery for the eighteen derecho events occurring during 1983 has been examined to identify the types of satellite signatures. The signatures displayed are equally distributed among mesoscale convective complexes (MCC), convective clusters, and squall lines (Maddox, 1980). All of the squall line signatures are associated with strong 500 mb short-wave troughs (see section 5). In the MCC signature cases, a line of very cold cloud tops is usually seen near the leading edge of the system (see Fig. 4c, d). This line of colder tops is related to the line of intense convection near the bulging squall front (Gurka, 1976) and appears to be a reliable indicator of the occurrence of strong, often damaging straight-line winds at the surface (McCarthy, 1985).

5. Synoptic patterns

Examination of the 500 mb charts associated with the 70 cases reveals that a large majority of derecho events occur beneath westerly or northwesterly flow

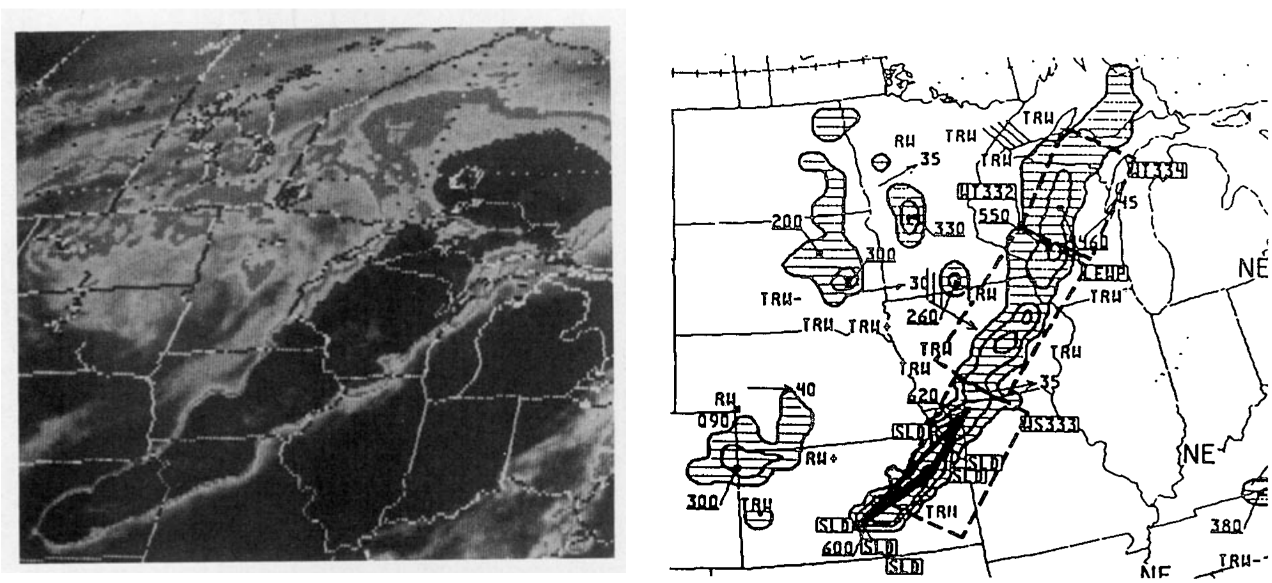

FIG. 7. An example of the radar echo pattern and cloud features associated with a serial derecho as depicted by the Radar Summary Chart for 0035 UTC 4 July 1983 and the corresponding 3.2 km (2-mile) equivalent resolution infrared (mb curve) satellite image.

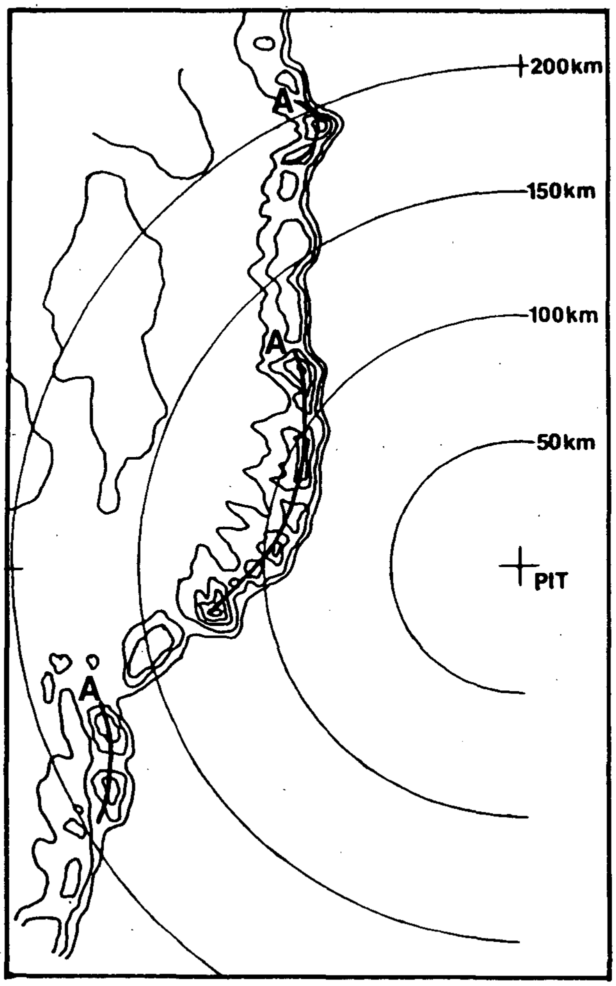

FIG. 8a. Detailed analysis of radar imagery from the NWS radar at Pittsburgh, PA, for 2210 UTC 4 July 1983. A serial derecho is in progress. The contours represent video integrator and processor intensity (VIP) levels with the outside contour indicating VIP level 1, and interior contours generally representing successively higher VIP levels. The dark solid lines marked with an "A" connect the higher VIP levels and represent bow echoes. A well-defined crest of a LEWP is evident at the north end of the southern bow (near the lowest A). (This detailed analysis and the one for Fig. 8b were prepared by Ron Przybylinski of WSFO Indianapolis.)

aloft. Almost nine-tenths (86%) of the cases occur with the 500 mb flow from a direction of 240° or greater. Furthermore, over one-quarter (27%) of the cases occur with a 500 mb flow direction of 280° or greater, thus satisfying the 500 mb flow criterion for northwest flow severe weather outbreaks (Johns, 1982).

The surface charts associated with the dataset reveal that a quasi-stationary east–west-oriented thermal boundary plays a key role in most cases. Nearly nine-tenths (86%) of all derecho events begin along or to the north of such a boundary. It is more common for initiation to occur to the north of the boundary (37 cases) rather than in the boundary zone itself (23 cases). The boundary is usually frontal in nature (48 cases), but it is sometimes generated by prior convective activity (12 cases). Although the initiation of derechos typically occurs either in the cooler air mass to the north of the boundary or in the boundary zone itself, slightly over one-half (36) of all cases terminate in the warm sector. Generally, the progressive derecho convective system moves in a direction nearly parallel to the boundary but with a slight angle toward the warm sector. In the case of the serial derecho, both a quasi-stationary front and a cold front are often involved (see Fig. 6). The convection usually initially develops along or north of the quasi-stationary boundary. With time, a squall line develops southward into the warm sector along or just ahead of the cold front.

The close association between derecho development and quasi-stationary frontal zones (or convective outflow boundaries) suggests that low-level warm advec-

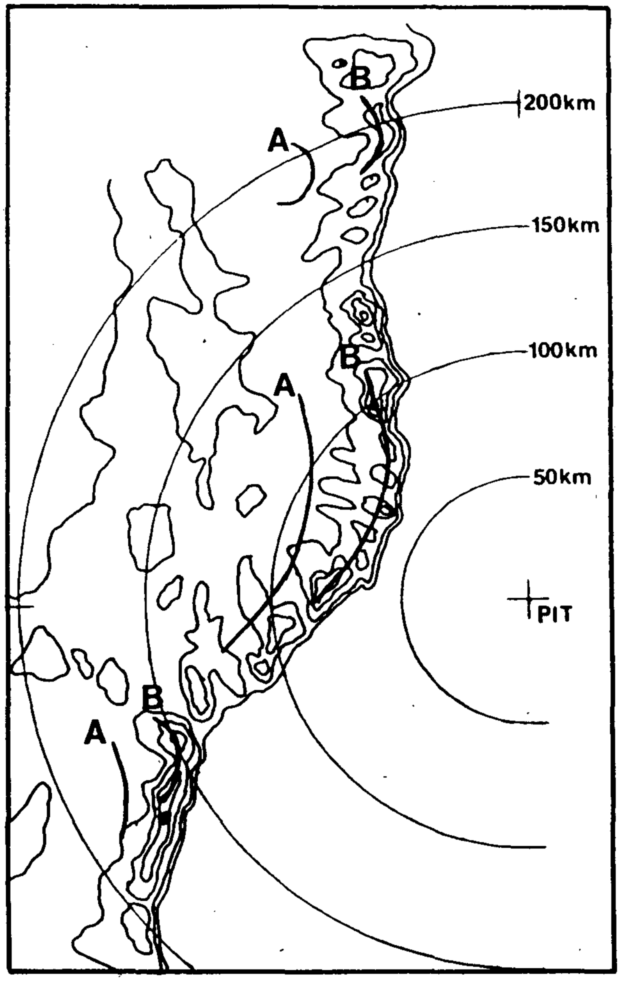

FIG. 8b. As in Fig. 8a, except for 2230 UTC with the bow echoes indicated by lines labeled "B". Location of bow echoes at 2210 UTC (labeled "A") are superimposed. Note how the bow echoes have moved east-northeastward to northeastward along the line while the line has moved east-southeastward. Wind damage occurred with all three bow echoes during the time interval between Figs. 8a and 8b.

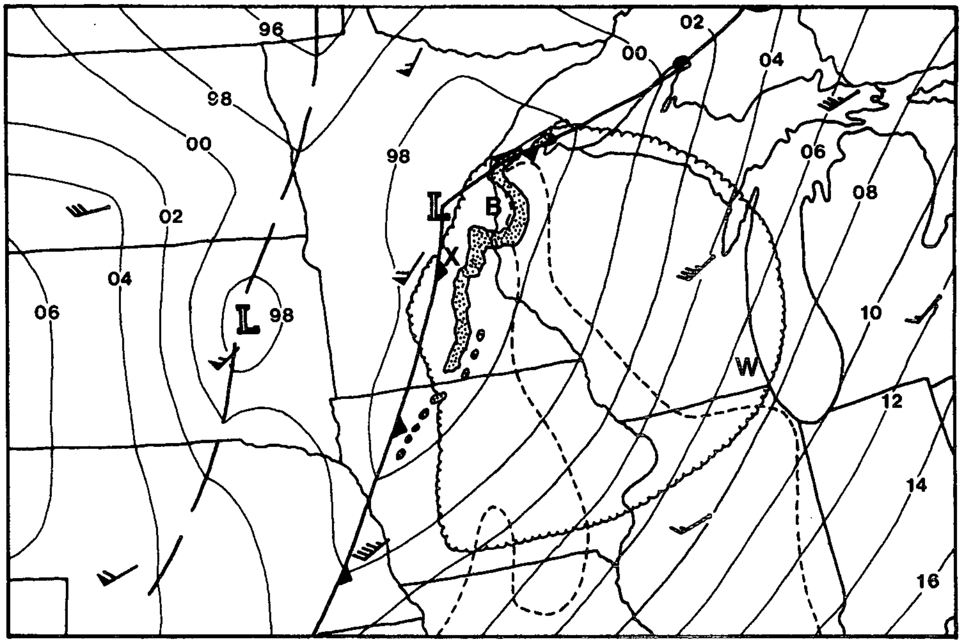

FIG. 9. As in Fig. 5, except for serial derecho of 3–4 July 1983 at 1900 UTC 3 July, a little over 2 h after derecho initiation. In this case isodrosotherm encloses area where surface dewpoints are 23°C (74°F) or greater. An "X" indicates point of derecho initiation at 1645 UTC July 3; "W" denotes point of derecho termination at 0500 UTC July 4. Note that the derecho-inducing squall line eventually developed southward as far as Kansas (see Fig. 7). (Radar echo outline data courtesy of Brian Smith, Univ. of Chicago.)

tion plays a significant role in the derecho phenomenon (Maddox and Doswell, 1982; Johns, 1984). Examination of the dataset reveals that at the radiosonde observation time immediately preceding derecho development, 850 mb warm advection is present at the initiation point in 86% of the cases. In *every* case, 850 mb warm advection is occurring within 320 km (200 nm) of the initiation point. At 700 mb, the association of warm advection with derecho initiation is not quite as close, but still very high. The predevelopment 700

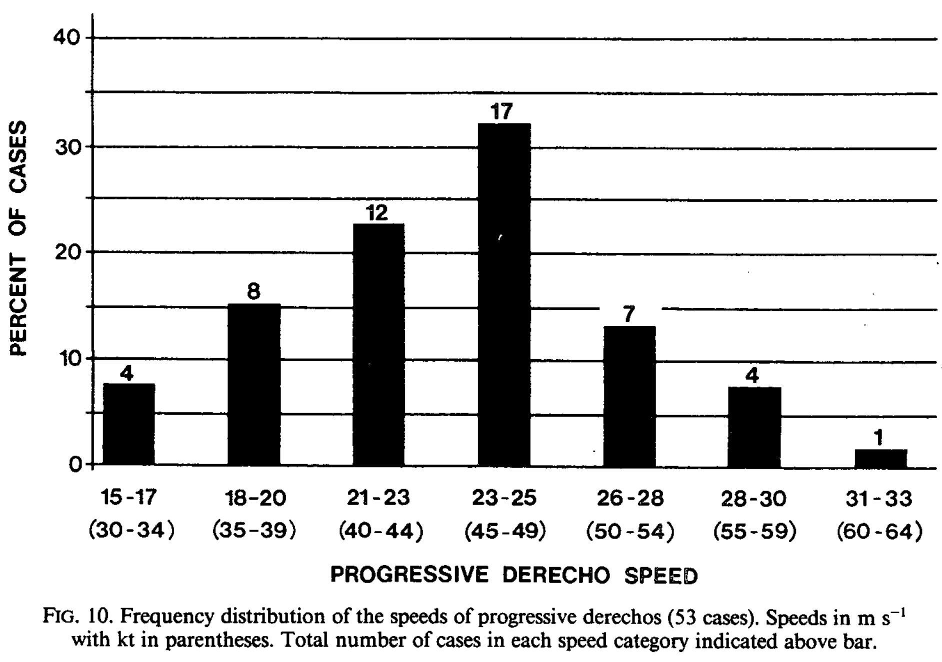

FIG. 10. Frequency distribution of the speeds of progressive derechos (53 cases). Speeds in m s^{-1} with kt in parentheses. Total number of cases in each speed category indicated above bar.

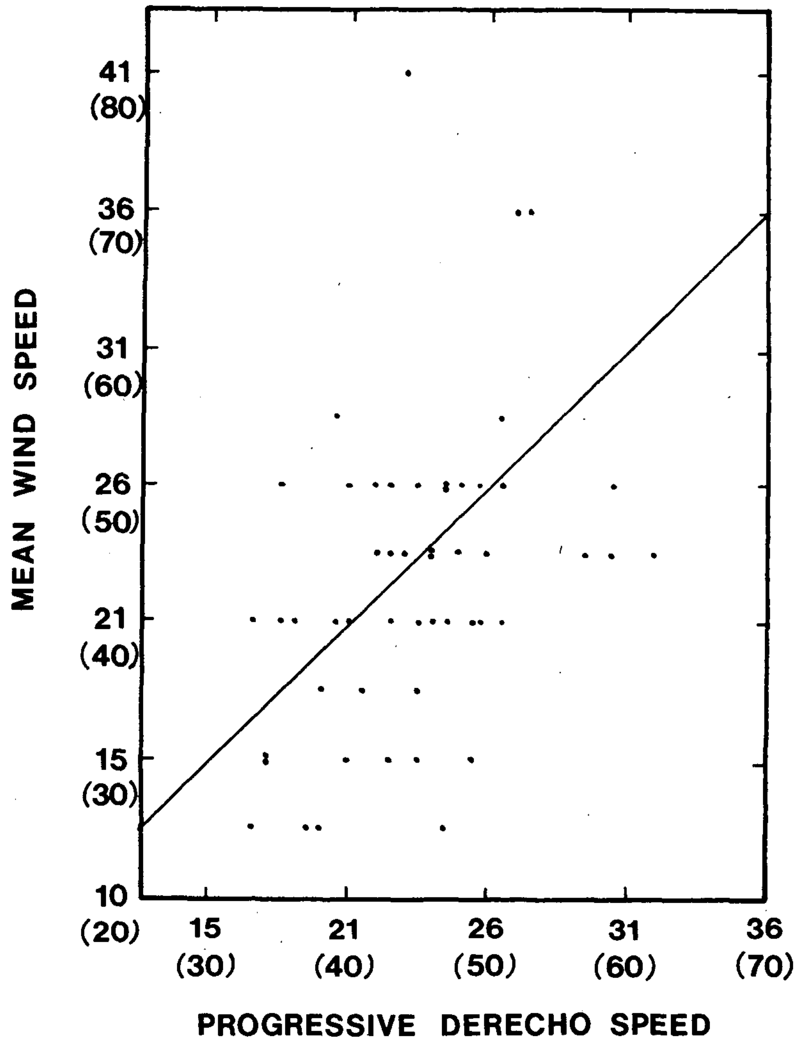

FIG. 11. Scatter diagram showing the relationship between progressive derecho speed and the mean wind speed (51 cases). Speeds in m s^{-1} with kt in parentheses. Diagonal line represents 1:1 correlation. Streaked appearance of the data points along horizontal plane is due to the fact that the mean wind speed values were estimated to the nearest 2.6 m s^{-1} (5 kt) increment. Note that mean wind data were available for only 51 of the 53 progressive derecho cases.

mb chart shows warm advection at the initiation point 74% of the time, and within 320 km of the point in almost every case (96% of the time).

As mentioned in the Introduction, operational meteorologists face a difficult forecast problem when derecho development occurs with weak synoptic scale features. To examine this problem directly, the dataset has been classified according to the relative strengths and motions of the associated upper systems. Any 500 mb short-wave trough associated with a derecho event is defined as *weak* if 1) the radiosonde data taken at the observation time occurring at or immediately before the beginning of the derecho indicates a maximum 12-h 500 mb height fall of less than 60 m if the data are from the 1200 UTC observation time or less than 50 m if the data are from the 0000 UTC observation time,[4] and 2) data taken at the following radiosonde observation time meets the same height fall criteria.[5]

[4] The 10 m difference in height fall criteria is used as an attempt to eliminate most of the diurnal change. This diurnal change value is based on operational forecasting experience and is thus only an estimate.

[5] Although this method of classifying 500 mb trough strength may be considered somewhat simplistic, it is easily applied in the operational setting, and most importantly, provides useful information to the forecaster regarding derecho characteristics. Note that in a few cases there was no identifiable 500 mb short-wave trough associated with the derecho event. These events were classified as weak trough cases.

TABLE 3. Monthly averages for meteorological parameters associated with derechos at their temporal midpoint. Temperatures and dewpoints in degrees Celcius (degrees Fahrenheit in parentheses). The 500 mb wind speeds in meters per second (knots in parentheses).

	850 mb temp	850 mb dewpoint	700 mb temp	500 mb temp	500 mb wind speed	Surface temp	Surface dewpoint
May	15.2	12.0	5.8	−12.7	23.6 (46)	27.9 (82)	21.3 (70)
Jun	19.0	15.4	9.3	−10.0	22.6 (44)	32.5 (91)	23.9 (75)
Jul	20.2	15.6	10.3	−8.4	20.1 (39)	34.9 (95)	25.5 (78)
Aug	19.7	14.5	9.6	−9.5	19.0 (37)	33.3 (92)	23.4 (74)
Warm season	18.8	14.7	9.0	−10.1	21.1 (41)	32.6 (91)	23.8 (75)

Using these criteria, 40% (28) of the cases in the dataset are associated with weak 500 mb short-wave troughs.

The synoptic patterns associated with weak 500 mb short-wave trough cases show even less variation than those of the general dataset. *All* weak trough events have their initiation point along or to the north of a surface quasi-stationary thermal boundary. All but one of these cases occurs with a 500 mb wind direction of 240° or greater and almost forty percent (39%) meet the northwest flow 500 mb criteria (Johns, 1982). Almost all weak trough cases (89%) are progressive in nature.

6. Meteorological parameters[6]

In addition to low-level warm advection (section 5), Johns and Hirt (1985) have postulated that convective instability, as well as the relative humidity and the wind speeds in the lower midtroposphere [LMT: the layer from approximately 2.5 to 5.5 km (8000 to 18 000 ft) above MSL], are important parameters in the development and maintenance of derecho-producing convective systems. Examination of the 70 cases reveals *extreme convective instability* of the air mass along the derecho tracks. The average Showalter index (Showalter, 1953) is −5.9. This compares with an average Showalter index of −4.8 for northwest flow outbreaks (Johns, 1984). The average SELS lifted index (Galway, 1956) for derechos is −9.0. The range of instability varies from −2 to −13; however, most cases (84%) are associated with a SELS lifted index of −6 or less. Those cases associated with a SELS lifted index more stable than −6 are restricted to strong 500 mb short-wave trough events and occur only in May and August. Weak 500 mb short-wave trough events are almost always (93% of the time) associated with a SELS lifted index of −8 or less.

The strong instability associated with both northwest flow outbreaks and derechos is at least partly due to the combined contributions of strong diurnal heating and the high values of low-level moisture typically found east of the High Plains during the warm season. Note that the derecho dataset indicates the convective instability associated with derecho events is even stronger than is the case with general northwest flow outbreaks. The 500 mb temperatures in the derecho dataset (Table 3) are typical of those associated with tornadoes during the summer season (David, 1976) and compare closely with those Johns (1984) found with northwest flow severe weather outbreaks. Therefore, it appears that the additional instability associated with derecho events may result from warmer and/or wetter conditions in the lower layers of the atmosphere. Table 3 supports this premise. In comparison with northwest flow outbreaks, derecho 850 mb temperatures are about the same; however, derecho 850 mb dewpoints average about 1.5°C higher.

Examination of the surface and 850 mb charts associated with derecho cases reveals that in most episodes (74%) "pooling" of low-level moisture takes place along or near a quasi-stationary boundary.[7] It is not uncommon for surface dewpoints in the convergence zone to reach or exceed 27.4°C (80°F) in July. Generally, 850 mb moisture pools along and north of the surface boundary position. Surface dewpoints, on the other hand, tend to pool in or south of the convergence zone (see Fig. 5). Progressive derecho convective systems often propagate on the north side of the quasi-stationary boundary in an area where surface dewpoints are lower than in the pooling zone itself. Table 3 shows averages of the highest surface temperatures and dewpoints associated with derechos during their life cycle. For cases where the derecho-producing convective system is north of the surface boundary, temperature and dewpoint values have been taken from that portion of the pooling zone closest to the system, since it is likely that this air mass is being ingested into the convective updrafts.

The dewpoint values at 850 mb associated with weak trough cases average 1°C higher than in those cases involving strong troughs. Low-level moisture values are uniformly high throughout the warm season for weak trough cases. However, derecho occurrences with strong troughs are occasionally accompanied by more

[6] Unless stated otherwise, parameter values have been subjectively interpolated for the temporal midpoints of derecho events.

[7] The term "pooling" refers to the development of an area where dewpoint values become higher than those found generally in the warm sector. This area or zone is usually associated with a convergence boundary (Galway, 1957).

moderate 850 mb dewpoints near the beginning and end of the warm season. Pooling of surface dewpoints takes place with almost all (89%) of the derecho cases associated with weak troughs; in 75% of these cases, the pooling occurs either along the boundary or within 290 km (180 nm) to the south of the boundary.

The average 500 mb wind speed occurring with derecho events is 21 m s^{-1} (41 kt). This value is relatively constant regardless of 500 mb short-wave trough intensity (Table 3), and is greater than both the 12 to 17 m s^{-1} (24 to 34 kt) average associated with general northwest flow outbreaks (Johns, 1984), and the 13 m s^{-1} (25 kt) average associated with May through August tornadoes (David, 1976). Furthermore, the average 700 mb wind speed occurring with derecho events is 17 m s^{-1} (34 kt), with almost all cases (88%) associated with 700 mb winds of 13 m s^{-1} (25 kt) or greater. These values are considerably stronger than the 9 m s^{-1} (17 kt) average 700 mb wind speed that David found to be associated with May through August tornadoes. These data suggest that the strength of the winds in the LMT during derecho events is often greater than the case with either nonderecho northwest flow outbreaks or warm season tornado occurrences. The mean wind speed in the LMT can be estimated by averaging the 700 and 500 mb wind speeds. Using this technique, the estimated LMT wind speed (ELWS) associated with derechos averages 20 m s^{-1} (38 kt). Almost all cases (93%) are associated with an ELWS of 13 m s^{-1} (25 kt) or greater. Those few cases associated with an ELWS of less than 13 m s^{-1} appear to be associated with lower relative humidities in the LMT layer and greater atmospheric instability than is the case with the general dataset.

The mean relative humidity for the LMT layer (ELRH) can also be estimated by averaging the 700 and 500 mb data. The average ELRH associated with derechos is 58%. The ELRH tends to be lower at the beginning of a derecho event, averaging 51%. Note that of the five derecho events in which the beginning ELRH was 80% or greater, four cases had an ELWS of 21 m s^{-1} (40 kt) or more. Only two (7%) of the weak trough cases were associated with an ELRH of 70% or greater at the beginning point.

7. Discussion

The data suggest that warm season derechos are often associated with meteorological parameters and synoptic patterns similar to those found with northwest flow (NWF) severe weather outbreaks (Johns, 1984). This is not surprising, since warm season derechos occur during the NWF outbreak season and typically occur beneath westerly to northwesterly flow at 500 mb. Recall that the warm season derecho frequency distribution (Fig. 2) resembles the NWF A1 axis (Johns, 1982). Johns noted that the A1 axis represents a favored position of the polar front during the times when NWF outbreaks are taking place. Since warm season derechos usually occur beneath westerly to northwesterly flow at 500 mb and are closely associated with low-level warm advection along a quasi-stationary east–west oriented thermal boundary (i.e., the polar front), it follows that the derecho frequency distribution should show a similarity to the NWF A1 high frequency axis.

However, the warm season derecho frequency distribution pattern has no feature similar to the NWF A2 high frequency axis. The primary reason for this difference probably concerns low-level moisture distribution. Johns (1984) found that NWF outbreaks occurring along the A2 axis are usually associated with a relatively narrow north–south tongue of low-level moisture. Thus, the enhanced instability along any quasi-stationary boundary through the region is usually not extensive enough for a convective system to produce widespread wind damage along a major axis of at least 400 km (a derecho criterion). Also, a majority of NWF outbreaks in the southern Plains region are not associated with a quasi-stationary boundary (NWF Q-type surface pattern). Thus, there is often no extensive east–west convergence boundary along which low-level moisture can pool.

Since more than one-quarter of all warm season derechos qualify as NWF outbreaks, the question arises as to how derecho events differ from nonderecho NWF outbreaks. A review of the NWF dataset reveals that wind damage associated with nonderecho NWF outbreaks often emanates from several small-scale convective systems concentrated in the same geographical area. In the nonderecho NWF cases where the wind damage emanates from a single convective system, the wind damage reports are too isolated to qualify as a widespread convective windstorm. In these cases, reports of large hail and/or tornadoes help to satisfy the "number of severe reports" requirement for a NWF outbreak. Therefore, the wind damage patterns associated with nonderecho NWF outbreaks tend to be more random and/or not as widespread as with derechos.

On the synoptic scale, the meteorological conditions associated with derecho events show some differences from those conditions occurring with nonderecho NWF outbreaks. Generally, derecho situations involve greater convective instability and stronger LMT wind speeds than is the case with nonderecho NWF outbreaks. Also, derecho development is essentially dependent on the presence of a quasi-stationary east–west thermal boundary. Nonderecho NWF outbreaks frequently occur ahead of a southeastward-moving cold front or trough line without the presence of a quasi-stationary east–west boundary.

If a convective complex is to develop a derecho, the downdrafts associated with the system must become exceptionally strong. Two primary contributors to outflow intensity are 1) negative buoyancy created by evaporation of precipitation (or cloud particles), and 2) transfer of higher momentum air aloft to the boundary layer (Newton, 1950; Fujita, 1959). Properties of the downdraft air reaching the surface suggest that most of the significant entrainment of environmental flow into the downdraft occurs in the midtroposphere (approximately 3 to 7 km above ground level) (Newton, 1966; Zipser, 1969). Therefore, it appears that derecho development would be aided by relatively strong winds and low humidities in the LMT. The dataset used for this study indicates that relatively strong LMT winds are associated with derecho events. The LMT relative humidities from the derecho dataset are not particularly low; however, they also are rarely near saturation.

The degree of convective instability appears to play at least an indirect role in derecho development. Recall that very strong instability is typically present in the prederecho environment. This strong instability is partly a result of extremely high values of low-level moisture pooled along a quasi-stationary boundary. Numerical models suggest that the speed of convective downdrafts becomes greater as the low-level moisture is increased (Droegemeier and Wilhelmson, 1985). The reason for this is not clear. However, recent numerical simulations by Srivastava (1985) suggest that the lower densities associated with high relative humidities in the subcloud layer may enhance the negative buoyancy of the downdraft.

The low-level synoptic pattern appears to play a critical role in the initiation and maintenance of derecho-producing convective systems. Recall that derechos are almost always associated with a quasi-stationary surface thermal boundary oriented parallel to the mean flow. The boundary provides a thermal gradient across which low-level warm advection develops. This advection is a source of upward vertical motion and appears to be an important contributor to the development of strong convective activity along and/or to the north of the boundary (Maddox and Doswell, 1982; Johns, 1984). Once the convective system has formed, a mesohigh usually develops with a gust front moving out in all directions from the mesohigh (Fujita, 1955, 1959). Since the LMT wind direction is similar to the direction of the mean flow (Newton and Katz, 1958; Newton and Fankhauser, 1964), transfer of momentum from the LMT to the gust front is maximized and convergence is enhanced on the downwind side (with respect to the mean wind direction) of the mesohigh. This is a primary reason that the gust front moves most rapidly in the general direction of the mean flow (Byers and Braham, 1949; Fujita and Brown, 1958). The convergence against the downwind portion of the gust front is enhanced further by the easterly component of the low-level winds on the north side of the quasi-stationary boundary.

Other factors also play a role in maintaining deep convection along that portion of the gust front moving downwind along the boundary zone. Examination of several cases in the dataset suggests that the warm advection field usually shifts eastward with the convective system along the thermal gradient. Furthermore, the quasi-stationary boundary is a focus for extremely strong convective instability resulting from the pooling of moisture in the convergence zone along the boundary. The downwind portion of the gust front is near this boundary and encounters air that is more moist and unstable than air farther into the cool air mass on the north side of the boundary or farther south into the warm sector. Besides contributing to greater positive buoyancy for a lifted parcel and possibly enhancing convective downdrafts, the increased values of low-level moisture have an additional effect on convective development. The higher moisture values effectively lower the level of free convection in the boundary zone, thus decreasing the amount of lift necessary for deep convection to continue.

A gust front in this environment often features nearly continuous new convective development along its leading edge (e.g., Weaver and Nelson, 1982). The numerical simulations of Wilhelmson and Chen (1982) suggest that this discrete development of new cells along the gust front results in a propagation rate of the entire convective system that is faster than individual cell movement. Furthermore, the simulations of Droegemeier and Wilhelmson (1985) suggest that the rate of development of new downdrafts increases with higher values of low-level moisture. Thus, discrete propagation of cells along the gust front and the presence of very large quantities of low-level moisture appear to play key roles in the unusually rapid movement of progressive derecho convective systems—systems that often move faster than the mean wind.

Progressive derecho convective systems move in a direction averaging 15° to the right of the mean wind, often moving into the warm sector before ending (sections 4 and 5). This characteristic appears to be partly related to the capping pattern in the region of occurrence.[8] Johns and Hirt (1985) found that the progressive derecho of 19–20 July 1983 developed quite far north of a quasi-stationary boundary, well into the cooler air mass. Soundings in the development region indicated that convectively unstable air was being lifted, primarily through the process of low-level warm advection, to around 700 mb in order to break the cap (reach the level of free convection). As the associated convective system moved eastward from the northern Great Plains, the cap became weaker. Consequently, the system appeared to build southward toward the quasi-stationary boundary as progressively less lifting was required to eliminate the cap. The system even-

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[8] The term "cap" refers to a relatively warm stable layer of the atmosphere that often overlies a convectively unstable moist layer near the surface.

tually entered the warm sector. Examination of several other progressive derecho cases in the dataset suggests that the capping pattern present on 19–20 July 1983 is a common one associated with derechos occurring along the high frequency axis (see Fig. 2).

Most of the prior research concerning meteorological conditions associated with downbursts and microbursts has involved cases occurring in the High Plains region. These studies have identified two types of vertical profiles of temperature and moisture (VPTM) associated with microbursts: "dry" and "wet" (Caracena et al., 1983). The derecho dataset suggests that the multiple downbursts and microbursts comprising a derecho often occur in areas where the VPTM is different from either of the two High Plains types. The lower layers of the derecho VPTM are moist and resemble the wet VPTM. However, the actual moisture values are apparently much higher with the derecho VPTM. These extremely high values of low-level moisture appear to be a major contributor to the high degree of positive buoyancy associated with derecho events. By contrast, the High Plains wet microburst VPTM typically exhibits weak positive buoyancy.

In summary, it has been shown that the widespread convective windstorms of the warm season are associated with particular synoptic patterns and a restricted range of parameter values. Although these data cannot define exactly when and where a derecho will develop, they do help determine the relative risk of development. To aid the forecaster in assessing this risk, a decision tree has been prepared for operational use (see Appendix). Future studies employing more detailed observations of individual derecho situations may lead to a better understanding of the physical processes associated with the phenomenon. This, in turn, could lead to improved forecast techniques.

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APPENDIX

Forecasting Derecho Development

1. Derecho checklist

The derecho dataset reveals several characteristics that can help an operational meteorologist determine the potential for derecho development. The following decision tree is designed to address the problem of forecasting derechos during the warm season. Since it is particularly difficult to determine exactly when and where warm season convection will develop, it is expected that the decision tree will be most useful for short-term forecasting once convection has developed. Recall that development of the derecho-producing convective system usually precedes derecho development by at least 3 h. The forecaster should proceed through the checklist and also consult the list of additional considerations when determining the potential for derecho development in his/her area of interest.

(A) If *all* of the following five conditions are present in the area of interest, proceed to part B. Otherwise, derecho development is not likely.

	YES	NO
1) 500 mb flow direction 240° or greater?	____	____
2) Quasi-stationary boundary nearly parallel to 500 mb flow?	____	____
3) 850 mb warm advection within 200 nm?	____	____
4) 700 mb warm advection within 200 nm?	____	____
5) ELWS 25 kt or greater?	____	____

(B) If *all* of the following three conditions are present in the area of interest, proceed to part D. Otherwise, proceed to part C.

	YES	NO
1) Maximum 500 mb, 12 h height falls 60 m or greater? (50 m or greater at 0000 UTC?)	____	____
2) SELS lifted index −6 or lower?	____	____
3) ERLH < 80%?	____	____

(C) If both of the following conditions are present in the area of interest, proceed to part D. Otherwise, derecho development not likely.

	YES	NO
1) SELS lifted index −8 or lower?	____	____
2) ERLH < 70% in initiation area (<80% downstream?)	____	____

(D) Do the parameter values satisfying the criteria for the SELS lifted index and the ELWS extend downwind along the quasi-stationary boundary for a distance

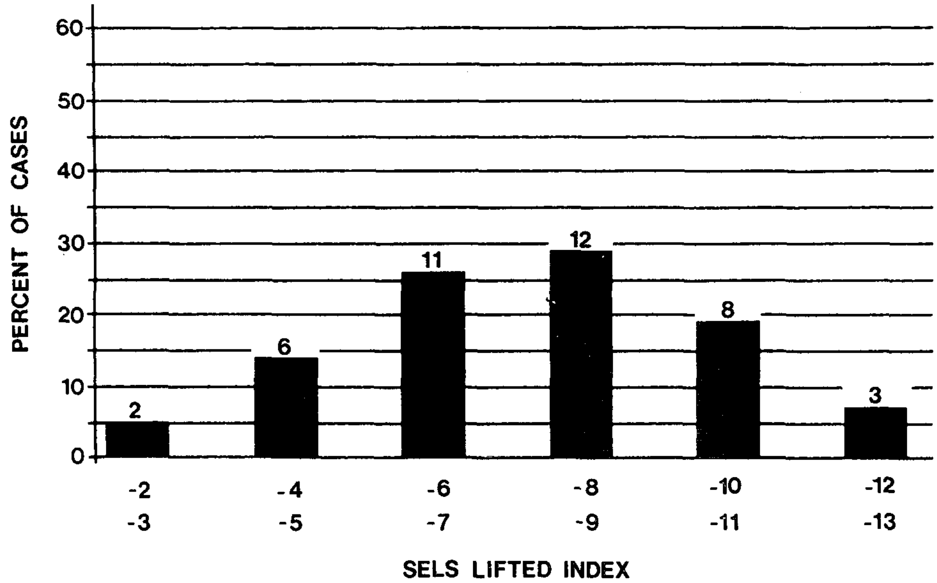

FIG. A1. Frequency distribution of SELS lifted index values associated with those derecho cases occurring with strong upper short-wave troughs (42 cases). Total number of cases in each lifted index category indicated above bar.

of at least 250 nm from the convective system (or where the system is expected to develop)? If yes, go to E. If no, note that the potential for wind damage will probably be too localized to meet the areal criterion for a derecho. Nevertheless, forecasters in the affected area should be alert for the severe weather indicators listed in E.

(E) *Be alert for derecho development.* If a convective system does develop, be particularly suspicious of any short squall line or squall line segment that moves at

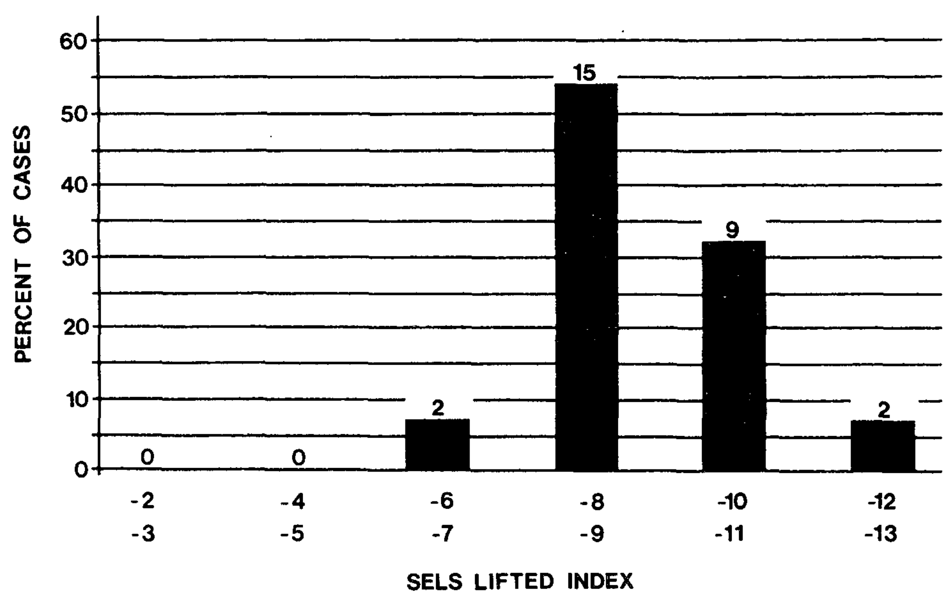

FIG. A2. As in Fig. A1, except for those derecho cases associated with weak upper short-wave troughs (28 cases).

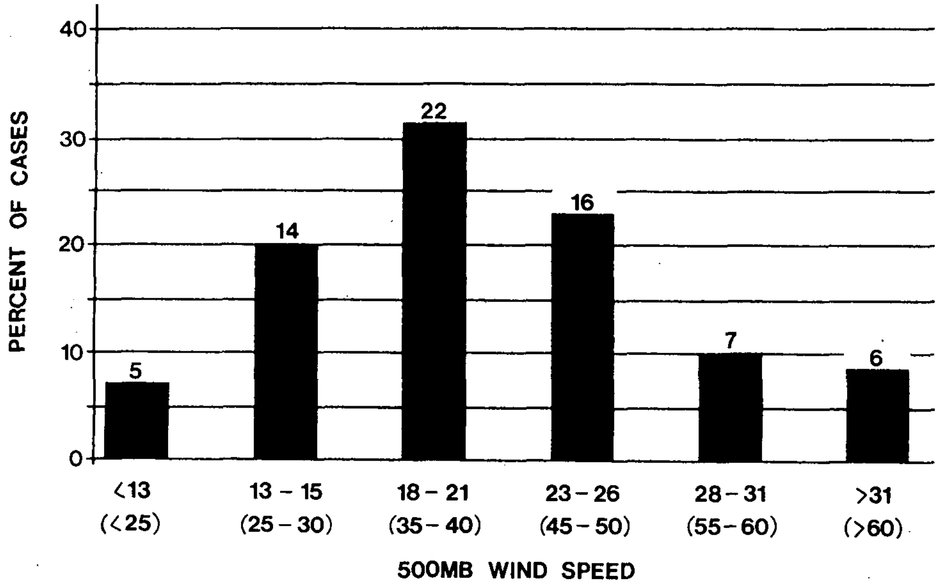

FIG. A3. Frequency distribution of 500 mb wind speeds associated with derechos (70 cases). Speeds in m s^{-1} with kt in parentheses. Total number of cases in each speed category indicated above bar.

a speed of 35 kt or greater in the direction of the mean flow. Watch for satellite indications of damaging winds (McCarthy, 1985) and monitor radar closely for those signatures suggesting damaging winds or tornadoes (Lemon, 1980; Przybylinski and De Caire, 1985).

2. Additional considerations

1) The data set suggests that instability, the lower midtropospheric mean wind speed and the lower midtropospheric mean relative humidity interact to compensate for each other in regard to derecho potential. If one of these parameters rates marginal on the checklist, very strong ratings in one or both of the other two could still indicate significant derecho potential. Figures A1–A7 show the frequency distribution of these parameters, and should aid the forecaster in determining the relative strength of each one.

2) Note that the ELWS and the ELRH are estimated values. The forecaster should closely examine individ-

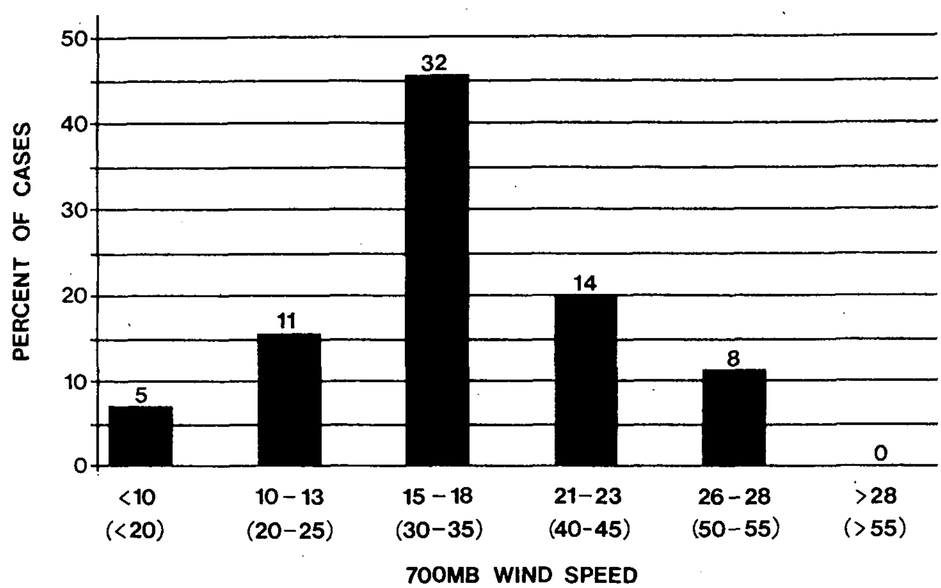

FIG. A4. As in Fig. A3, except for 700 mb wind speeds (70 cases).

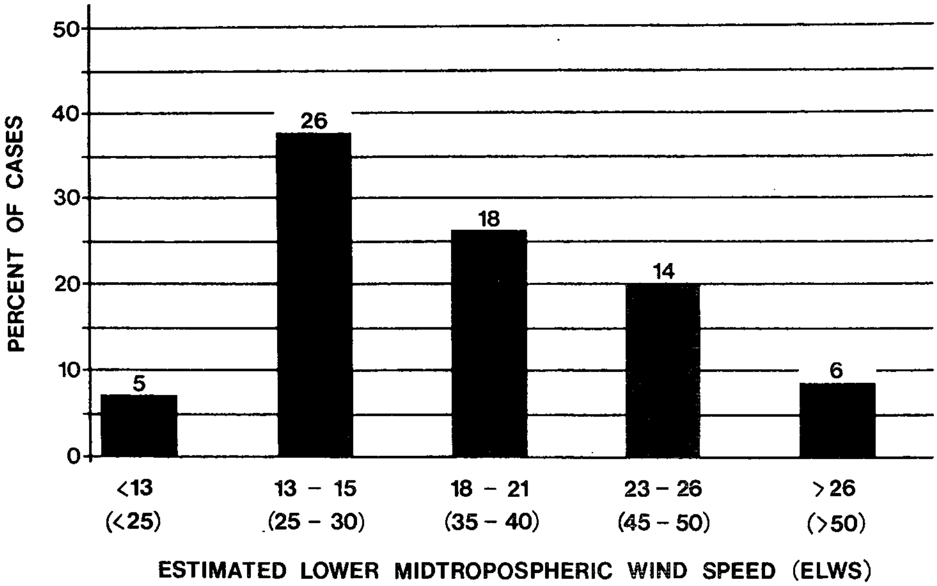

FIG. A5. As in Fig. A3, except for estimated lower midtropospheric wind speeds (ELWS) (69 cases). One case was not used due to interpolation problems.

ual soundings to determine if the estimated values are representative.

3) Operational experience suggests that at surface elevations below 1067 m (3500 ft) MSL, severe thunderstorm activity is usually restricted to areas where the 1000–500 mb thickness values are 5790 m or less. Thickness values greater than 5790 m appear to be associated with a capped environment. Therefore, the forecaster can use the 1000–500 mb thickness field prognoses from the National Meteorological Center to aid in the determination of derecho development and evolution.

4) If the severe weather parameters associated with derecho development appear marginal, or if the strength of one or more of the parameters is in doubt, climatology (diurnal, seasonal, and geographical) should become a primary consideration in the decision-making process.

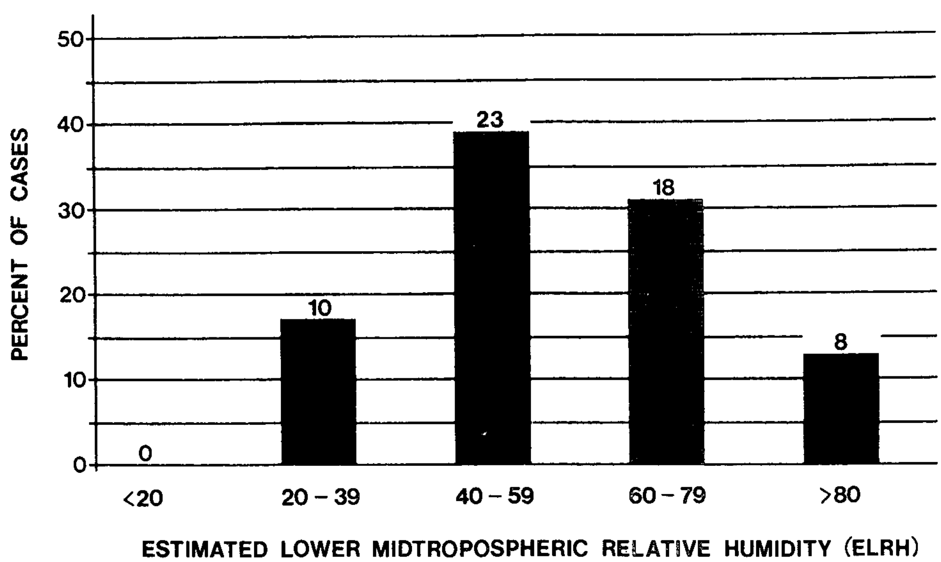

FIG. A6. Frequency distribution of estimated lower midtropospheric relative humidities (ELRH) associated with derechos (59 cases). Total number of cases in each humidity category indicated above bar. Several cases were not used due to interpolation problems.

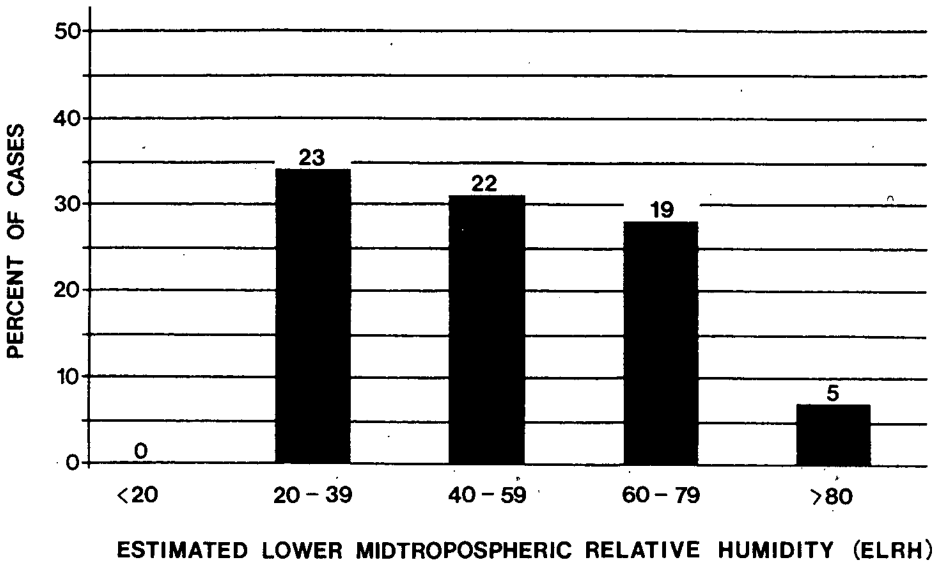

FIG. A7. As in Fig. A6, except at the beginning of derecho events (69 cases). One case not used due to interpolation problems.

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