OPERATIONAL OBSERVATIONS OF EXTREME REFLECTIVITY VALUES IN CONVECTIVE CELLS

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Abstract

The observation of high reflectivity values aloft as an indicator of the potential for a convective storm to produce severe weather has been widely known for many years. The advent of the Weather Surveillance Radar-88 Doppler (WSR-88D) has given operational forecasters a new tool for looking at reflectivity data, and a greater spectrum of values at which to look. In the use of these new data, anecdotal evidence has suggested to some radar operators that extremely high reflectivity values (65 dBZ or greater) appear to have a correlation with the production of severe weather. Data from the Cleveland, Ohio and Jackson, Mississippi WSR-88D radars were examined to observe the formation of extremely high values of reflectivity in convective cells, and to determine any correlation with the production of severe weather. The data showed that a large majority of extreme reflectivity storms contained the extreme values above the freezing level, and that such storms had a high correlation with the production of severe weather. Conversely, the small percentage of storms which contained extreme reflectivity values only below the freezing level were infrequently associated with severe weather reports. Further analysis showed some relationship between the presence of extreme reflectivity and high Vertically Integrated Liquid (VIL) values with severe weather production, although this relationship appeared much less effective operationally than the association between severe weather and extreme reflectivity values above the freezing level.

1. Introduction

The use of radar reflectivity data in analyzing severe convective storms has been widely known for decades (e.g., Sadkowski and Hamilton 1959, Hamilton 1966, Staff of NSSL 1966). For many years prior to the advent of the Weather Surveillance Radar-88 Doppler (WSR-88D), the primary radar technique for detecting severe local convective storms using conventional radar (e.g., Weather Surveillance Radar-57 S-band) was the Weather Radar Identification of Severe Thunderstorms (WRIST) technique. The WRIST technique was taught by the NOAA/National Weather Service Training Center, after work done by Lemon (1980), as the most time efficient manner in which to examine the structure of a convective cell.

One of the critical components of a storm cell the WRIST technique was designed to find was the height of the Digital Video Integrated Processor (D/VIP) level 5. Lemon (1980) found that the presence of D/VIP level 5 or higher above 27 Kft had a strong correlation with a thunderstorm cell's capability to produce severe weather (winds of 50 kt or greater, hail 0.75 in. or larger in diameter, or tornadoes). This was because the presence of high D/VIP levels aloft was an indication of the presence of a strong updraft in the storm, and the strength of the updraft has a direct correlation to the ability of a thunderstorm to produce severe weather.

Although the WSR-88D allows for relatively easy examination of many meteorological parameters to determine a storm's severity, the height of high reflectivities in a particular storm cell continues to be an important factor in the warning decision, especially when warning for pulse-type convection. D/VIP level 5 on conventional radar is equivalent to reflectivity values of 51 to 57 dBZ (Burgess and Lemon 1990). The height of reflectivity in excess of 50 dBZ can be examined on the WSR-88D using several different products, including displays of base reflectivity at various elevation angles, reflectivity cross section (RCS) products, the Weak Echo Region (WER) product, and the layer composite reflectivity maximum (LRM) product. The Vertically Integrated Liquid (VIL; all references to VIL are grid-based VIL) product also gives the radar operator a rough analysis at which storms likely have high reflectivity values aloft.

In addition to the ability of the WSR-88D to show reflectivity data in many different formats, the WSR-88D also displays base reflectivity data on a much finer intensity scale, with 16 data levels versus the 6 D/VIP levels on the conventional radars. The advantage that the WSR-88D gives to the radar operator with respect to the better scale resolution is quite apparent at high reflectivity values. For example, the D/VIP level 6 only indicated to the operator of a conventional radar the presence of greater than 57 dBZ reflectivity (Burgess and Lemon 1990), while the WSR-88D currently displays data levels for 55 dBZ to 59 dBZ, 60 dBZ to 64 dBZ, 65 dBZ to 69 dBZ, 70 dBZ to 74 dBZ, and 75 dBZ or higher.

Since the implementation of the WSR-88D network and the associated availability of the finer scaled high reflectivity data, anecdotal evidence from radar operators at some NWS NEXRAD Weather Service Forecast Offices (NWSFO) and NEXRAD Weather Service Offices (NWSO) has suggested that severe weather seems to be quite common when extreme reflectivity values (defined here as 65 dBZ or greater) are detected in a convective cell by the WSR-88D. This study was undertaken to observe the formation of extreme reflectivity cores in convective cells, and to determine what correlation, if any, exists between the presence of extreme reflectivity and the production of severe weather.

2. Methodology

The data for this study were taken from two WSR-88D radars located in markedly different regions of the country, in an attempt to draw conclusions that might be valid over a large area of the country. The first data set used was all Archive Level IV data (products archived from the local Principal User Processor (PUP)) available from the Cleveland, Ohio, (KCLE) WSR-88D for convective events in 1994. This consisted of 20 convective events from 12 April to 1 November 1994. The second data set was from available Archive Level IV data from the Jackson, Mississippi, (KJAN) WSR-88D, for convective events during the 1996 season. This consisted of 19 convective events from 19 February to 16 September 1996.

For this study, any cell for which the WSR-88D detected at least 65 dBZ reflectivity was considered to have extreme reflectivity values and was examined. The cell was maintained as a single storm as long as it showed a discrete identity to the radar observer, and no more than 30 minutes passed between the volume scans during which it contained extreme reflectivity values (i.e., the storm would be considered a new storm if more than 30 minutes passed between occurrences of extreme reflectivity). For the KCLE WSR-88D, only storms detected within the range of the 0.54 nm resolution base reflectivity products (124 nm), and located within the state of Ohio, were used in the study. For the KJAN radar, storms located within the office's county warning area (CWA) were used (a range of approximately 90 nm from the KJAN radar). Of the 39 convective events in the KCLE and KJAN areas which were examined for this study, there were 19 events (12 from the KCLE radar and 7 from the KJAN radar) during which extreme reflectivity was observed (Table 1).

As has been discussed in previous research (e.g., Hales and Kelly 1985), one of the main problems in conducting a study with regard to production of severe weather is reliable verification reports. This is especially true with regard to a study, such as this, being conducted in an operational environment, as the source of verifying data is highly dependent upon population density and time of day (Wyatt and Witt 1997). Hence, this study will not focus on actual verification statistics or the determination of a criteria to distinguish between severe and non-severe convection. Rather, an attempt will be made to obtain criteria which would show enhanced potential for a storm to produce severe weather by looking at the likelihood of a storm to produce severe weather after the first observation of extreme reflectivity. For the purpose of this study, a storm without reports of severe weather was not considered in the comparison between severe and non-severe storms unless it moved over a significant population area (large town or city) during some part of the time it contained extreme reflectivity, and unless it occurred during normal waking hours. This prerequisite for a storm to be considered in the database as non-severe is similar to that used by Amburn and Wolf (1997). A storm was considered severe if it was clearly associated with a report of severe weather within one hour after containing extreme reflectivity for the first time.

Table 1. Days on which extreme reflectivity was observed, showing height of the freezing level in feet, type of severe weather reported, and predominant storm type based on subjective sounding analysis. Days from 1994 are for KCLE radar data and days from 1996 are for KJAN radar data.

Date	Freezing Level (FT)	Severe Weather	Storm Type
4/26/94	10600	HAIL	MULTICELL
6/14/94	14400	NONE	PULSE
6/15/94	13100	WIND	PULSE
6/16/94	12700	HAIL, WIND	PULSE
6/18/94	14500	HAIL, WIND	PULSE
6/19/94	14100	HAIL, WIND	PULSE
6/20/94	13700	WIND	PULSE
6/21/94	14100	WIND	MULTICELL
6/29/94	12900	HAIL, WIND, TORNADO	SUPERCELL
7/07/94	14200	WIND	PULSE
7/22/94	13150	WIND	MULTICELL
9/25/94	9200	HAIL, WIND	SUPERCELL
3/18/96	12150	HAIL, WIND, TORNADO	SUPERCELL
3/31/96	12000	HAIL, WIND, TORNADO	SUPERCELL
4/22/96	13400	HAIL	SUPERCELL
5/28/96	14200	HAIL, WIND	MULTICELL
6/12/96	13100	WIND	PULSE
6/20/96	14600	WIND	PULSE
7/08/96	14800	HAIL	PULSE

3. Maximum Height of the Extreme Reflectivity

Starting with data from the KCLE radar, 45 storms were found which contained extreme reflectivity during the convective events shown in Table 1. Based on the criteria outlined above, 41 of these storms were able to be classified as severe or non-severe. Of these storms, 34 (82.9%) were severe. From the KJAN radar, 25 storms were found that contained extreme reflectivity, 23 of which were able to be classified as severe or non-severe. Twenty-one of these 23 storms (91.3%) were severe based on the criteria above. This yields a total of 64 extreme reflectivity storms from the two data sets for which a determination of severity could be made, and 55 (85.9%) of these storms were severe.

Figures 1 and 2 show the maximum height of the extreme reflectivity for each storm which was examined from the KCLE and KJAN radars, respectively. It must be noted that these measurements contain an inherent uncertainty due to characteristics associated with the WSR-88D radar (Howard, et al. 1997). These are mainly associated

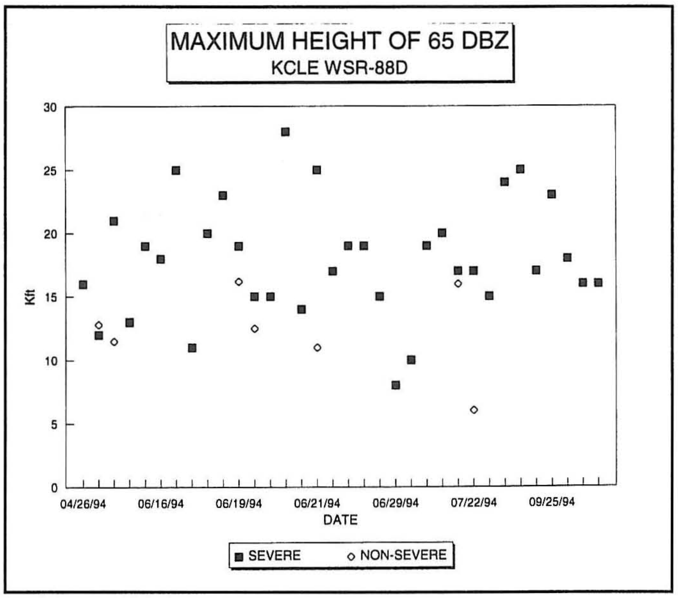

Fig. 1. Plot of the maximum height (Kft) of 65 dBZ reflectivity for severe and non-severe thunderstorms from the KCLE WSR-88D.

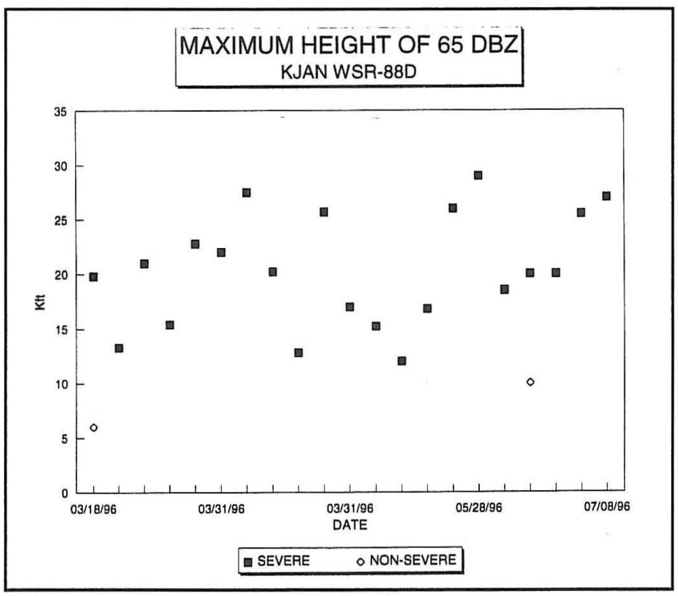

Fig. 2. Same as Fig. 1, except from the KJAN WSR-88D.

with the volume coverage pattern used by the WSR-88D which leaves "gaps" in the data between the elevation angles at which it scans (Fig. 3). Hence, the values given for the maximum height of the reflectivity are based on the height of the highest elevation angle at which extreme reflectivity was observed. It is possible that this reflectivity core could extend up to just below the next highest elevation angle, and this fact would not be detected by the radar. As has been observed with echo heights and tops, this problem would likely also lead to a "stair-step" appearance to any plot of maximum height of the extreme reflectivity for a given storm, possibly leading to an incorrect interpretation of the trend of the maximum height (Howard, et al. 1997). Also, the values given for the height of the extreme reflectivity assume normal propagation of the radar beam (i.e., in a standard atmosphere), and subrefraction or superrefraction of the beam would give erroneous height mea-

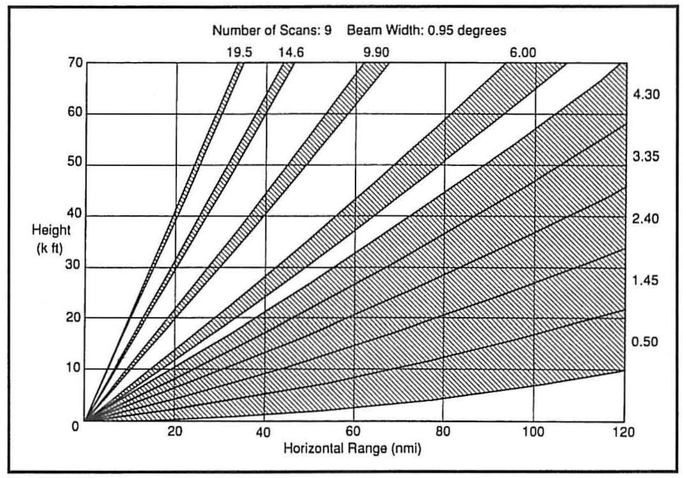

Fig. 3. Graphic showing the elevation angles for Volume Coverage Pattern 21 of the WSR-88D radar. Note the gaps between elevation angles, especially at higher elevations. From NOAA 1991.

surements. Thus, it must be kept in mind that the maximum height data was derived in an operational environment, and could be subject to error as outlined above.

The mean maximum height of the extreme reflectivity for the combined KCLE and KJAN data set was 17.5 Kft, with a standard deviation of 4.5 Kft. Looking at Figs. 1 and 2, one can see that a large majority of the storms which had extreme reflectivity contained it above 13 Kft, a value approximately one standard deviation below the mean maximum height of extreme reflectivity. Fifty-two of the 64 storms (78.5%) contained 65 dBZ above 13 Kft; of these 52 storms, 49 (94.2%) were severe, while 6 of the 12 storms (50.0%) which had extreme reflectivity below 13 Kft were severe.

This 13 Kft value may be a good first guess as a likely threshold for enhanced severe weather potential with a storm containing extreme reflectivity. However, as has been discussed by Wagenmaker (1992), such firm criteria for reflectivity height often fail as they do not account for differing convective environments. Hence, more useful criteria may be derived by performing sounding analyses for each case, and examining several different temperature, stability, and shear parameters. Such sounding analyses were performed for each day of the study, using soundings closest to the time in which the extreme reflectivity occurred, with Dayton, Ohio (DAY) sounding data used for the KCLE data set, and Jackson, Mississippi (JAN) sounding data used for the KJAN data set. The most useful discriminator by far appeared to be the height of the freezing level. Using the sounding data for each day on which extreme reflectivity occurred, an average freezing level height of 13.2 Kft was obtained. Obviously, this average freezing level is very close to the critical value suggested by the simple statistical analysis as discussed above. In fact, if one compares the maximum height of the extreme reflectivity to the observed freezing level for each individual case, one finds that 54 storms (83.8%) had extreme reflectivity above the freezing level. Of these storms, 52 (96.3%) were associated with reports of severe weather. Of the 10 storms which contained extreme reflectivity only below the freezing level, just three (30.0%) were severe.

The above findings suggest that a critical aspect to the production of extreme reflectivity and the related severe weather potential in a convective cell is the height of the freezing level. It is clear that the large majority of storms which contain extreme reflectivity do so above the freezing level, and that when such extreme reflectivity values are observed above the freezing level, there is a high threat for the storm to produce severe weather.

The exact physical reasons for this relationship are unclear. However, a possible explanation is suggested by the fact that such extreme values of reflectivity are unlikely to occur without water coated hail (Doviak and Zrnic 1984). Based on this fact and the results outlined above, it would seem logical to assume that extreme values of reflectivity may most often be observed when an intense updraft is present to maintain a core of wet, large hail at some height above the freezing level. Similar to the D/VIP level 5 above 27 Kft criteria of the WRIST technique (Lemon 1980), the presence of this intense updraft could then be correlated to the large percentage of storms with extreme reflectivity values above the freezing level producing severe weather (large hail, damaging wind, or both). Conversely, the physical process by which storms contain extreme reflectivity only below the freezing level may simply be due to hail melting below the freezing level, with the hail often not maintaining enough size to be severe when it reaches the surface. In these situations, when extreme reflectivity is observed only below the freezing level, other radar products would have to be examined in order to accurately determine the potential for large hail or damaging winds with the convective cell. It should be stressed that further research would be needed to determine clearly if these hypotheses are correct, or if other mechanisms are responsible for the production of extreme reflectivity in a convective cell and the corresponding relationship to the production of severe weather.

4. Grid-based VIL

Another possible tool to use in conjunction with the height of the extreme reflectivity in determining the potential for an enhanced severe weather threat would be the VIL. The VIL would provide a measure of the overall depth of high reflectivity values in the convective cell, thereby yielding another means for anticipating the possibility of severe weather with a storm containing extreme reflectivity.

For this study, grid-based VIL was used, as it was the only VIL product available. However, later software builds of the WSR-88D Radar Product Generation (RPG) software, as well as the NOAA/National Severe Storms Laboratory software package WATADS (National Severe Storms Laboratory 1997), have made available cell-based VIL values. Cell-based VIL values are calculated for each convective cell identified by the Storm Centroid Identification and Tracking Algorithm (National Severe Storms Laboratory 1997), while grid-based VIL values are calculated by using gridded reflectivity data and computing VIL values at each grid point (National Weather Service 1993). Although not discussed here, future research on this topic would likely need to include cell-based VIL, and any use of the data described below in an operational setting must be done with the clear knowledge that the VIL used in this study was grid-based, not cell-based.

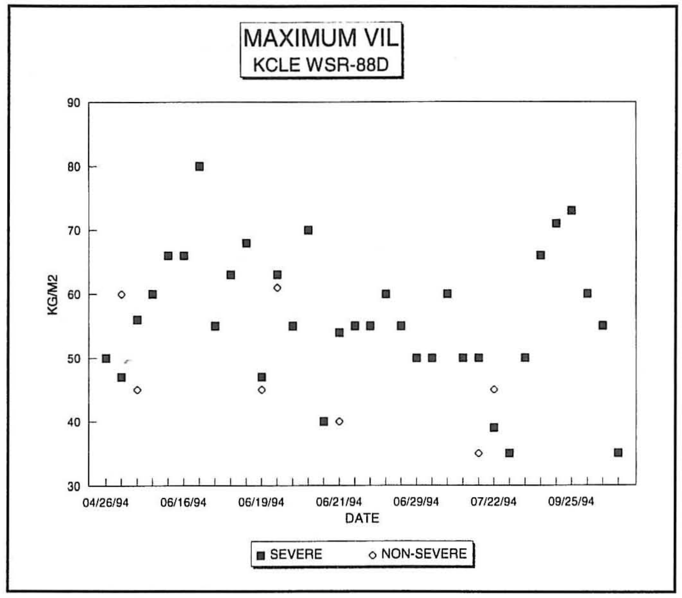

Fig. 4. Plot of maximum Vertically Integrated Liquid (VIL) observed when 65 dBZ or higher reflectivity was being detected for severe and non-severe thunderstorms from the KCLE WSR-88D.

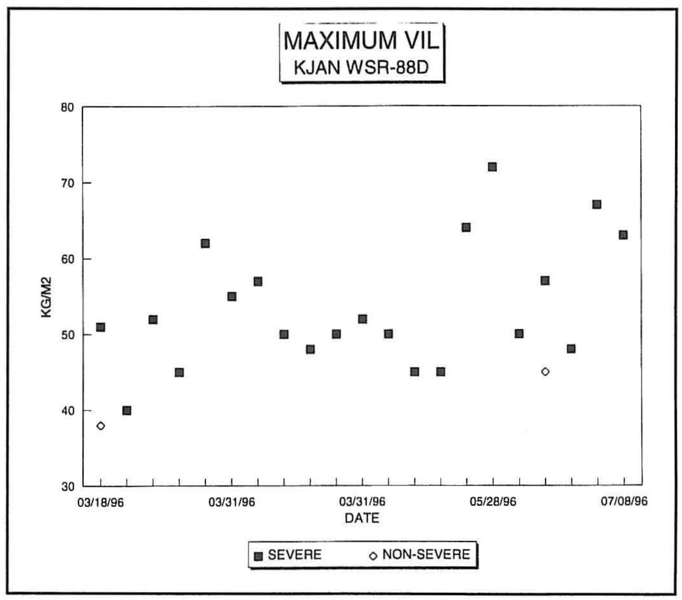

Fig. 5. Same as Fig. 4, except from the KJAN WSR-88D.

Figures 4 and 5 show the distribution of the maximum VIL values while extreme reflectivity was observed for the KCLE and KJAN radars. The mean VIL for all the storms was 53.9 kg m^{-2}, with a standard deviation of 10.0 kg m^{-2}. Using a simple statistical analysis similar to that used for maximum height of extreme reflectivity discussed above, one obtains a potential threshold dividing severe storms and those not associated with severe weather of 45 kg m^{-2}, a value approximately one standard deviation below the mean. As can be seen in Figs. 4 and 5, a large majority of those storms with extreme reflectivity and a VIL at or above 45 kg m^{-2} were severe. For the combined KCLE and KJAN data set, 50 out of 56 storms (89.3%) which had a

VIL of 45 kg m^{-2} or above were severe, while 5 out of 8 storms (62.5%) with a VIL less than 45 kg m^{-2} were severe. No consistent discriminator could be determined through sounding analysis which might yield a criteria for the VIL that would be more reflective of different convective environments. Hence, the lower percentage of severe storms with higher VIL's and the high percentage of severe storms with lower VIL's implies that the presence of extreme reflectivity above the freezing level is likely a much better discriminator than the VIL for determining enhanced severe weather potential when extreme reflectivity is observed in a convective cell.

5. Results, Discussion and Cautions

Reflectivity values of 65 dBZ or higher are not observed with every severe thunderstorm. However, when such values of reflectivity are present, it can often be a sign of increasing severe weather potential with the storm.

Analysis of maximum height of the extreme reflectivity (65 dBZ or higher) has shown that a large majority of those storms which have extreme reflectivity contain it above the freezing level, and most of these storms are severe. Over 95% of the storms examined in this study which were observed to have extreme reflectivity above the freezing level were severe. Hence, it seems clear that a warning forecaster should be greatly concerned when extreme reflectivity values are observed above the freezing level, and a severe thunderstorm warning should likely be issued if one is not already in effect (i.e., already issued based on spotter reports or other radar signatures). This criteria is similar to that which has been derived for the presence of mesocyclones in a convective storm; in other words, not every severe storm contains a mesocyclone, but when one is observed it indicates a greatly enhanced potential for the storm to produce severe weather (Keighton, et. al. 1994). Similarly, not every severe storm will contain extreme reflectivity above the freezing level, but when it is observed, the potential for severe weather is greatly enhanced.

About 30% of the severe storms in this case produced severe weather at some point prior to the first observation of extreme reflectivity in the storm, although all of them did also produce severe weather after the first observation of extreme reflectivity. For those storms which did not have reported severe weather prior to the first observation of extreme reflectivity, the time between the extreme reflectivity exceeding the freezing level and the first report of severe weather was 22.5 min. However, it is important to note that this is the time difference between the criteria being met and the first observation of severe weather, not necessarily the first occurrence of severe weather. Also, a large variability in lead times was observed, ranging from as little as one minute to as much as one hour. These points, combined with the fact that some storms were already producing severe weather prior to the development of extreme reflectivity, means that ***a warning forecaster cannot necessarily expect a significant lead time, and should promptly take the necessary action when extreme reflectivity is first observed above the freezing level.***

Although the percentage of severe storms with extreme reflectivity only below the freezing level is much less than those with extreme reflectivity above it, it is not negligible. Hence, a warning forecaster must take an intensive look at **any** storm containing extreme reflectivity, no matter where the extreme reflectivity appears in the storm. A variety of available radar products and data sources must be examined when making warning decisions. An additional tool related to extreme reflectivity which was examined in this study was the VIL, but data showed that for storms with extreme reflectivity, VIL did not make as useful a tool as the height of the extreme reflectivity did.

As can be seen in Table 1, the majority of storm days used in this study were favorable for the development of pulse thunderstorms. However, some organized multicell and supercell cases were included in the data set. Although previous research has shown that reflectivity-based criteria do not work as well for organized convection such as supercells and derechos (e.g., Johns 1993), this is probably due to the fact that severe weather can occur with lower reflectivity values than those typically observed with other severe convective storms. As discussed by Burgess and Lemon (1990), the WRIST D/VIP level 5 height criteria was proposed for use with pulse storms, but was also a good discriminator of severe weather for other storm types. Similarly, the criteria for enhanced severe weather potential given here based on the height of extreme reflectivity values should be applicable to all storms. Hence, the observation of extreme reflectivity values above the freezing level should be an immediate concern for enhanced severe weather potential in any thunderstorm. However, as mentioned above, a radar meteorologist must actively interrogate many available radar products during potentially severe weather, and must have a complete knowledge of the storm environment.

Again, it cannot be stressed too often that the thresholds discussed above indicating enhanced severe potential when extreme reflectivity is observed are not meant to distinguish between severe and non-severe convection, but rather to show when a warning may be needed if one is not already in effect. Although further research would be needed to determine the exact percentage of severe storms that contain extreme reflectivity values, from operational experience it seems clear that many (possibly a large majority of) severe thunderstorms never contain extreme reflectivity values, and the lack thereof does not in any way indicate that a storm is non-severe. Research to identify criteria for severe weather relationships in storms with lower reflectivity values (e.g., 55 dBZ or 60 dBZ) might also prove useful to the warning meteorologist.

One final caution must be given with regard to the selection of 65 dBZ as the threshold of extreme reflectivity. Clearly, this is an arbitrary value, selected because it is a value displayed by the WSR-88D, it is significantly higher than the highest dBZ value that could be distinguished by pre-WSR-88D radars, and anecdotal evidence suggested some correlation between this dBZ value and the occurrence of severe weather. Obviously, warning forecasters who observe reflectivity values near this threshold in a convective cell, especially above the freezing level, must use other radar products and meteorological data sources, knowledge of storm structure and morphology, and good judgement when making their severe weather warning decisions.

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