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EXAMINING THE DEVELOPMENT OF LAKE ERIE WATERSPOUTS USING THE NWSFO CLEVELAND WSR-88D

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1. INTRODUCTION

Previous studies regarding the formation of waterspouts over Lake Erie have found that waterspouts generally develop in two different types of synoptic weather patterns. The first pattern occurs when a cool air mass moves south across Lake Erie during the late summer and early fall months, when lake temperatures are still warm (greater than about 17°C; Kieltyka 1987). According to Eckert and Kapela (1993), weak vortices develop along a surface convergence boundary in this type of environment. Some of these vortices "spin-up" enough to form waterspouts when they interact with updrafts formed by the instability that is produced by the cool air situated over the relatively warm lake water. Quite often this kind of waterspout forms in the absence of precipitation. For the remainder of this study, this type of waterspout shall be referred to as a "cool type waterspout."

The second type of synoptic environment in which waterspouts commonly develop over Lake Erie, is similar to that in which tornadoes develop over land (i.e, an unstable air mass in which a strong veering wind profile exists with high helicity values; Davies-Jones et al. 1990). This type of synoptic environment can lead to the development of supercellular severe local storms, which can produce tornadoes on land and waterspouts over bodies of water. Waterspouts that develop in this kind of environment are usually much stronger than their cool type counterparts. For the remainder of this study, this type of waterspout will be referred to as a "warm type waterspout."

The Weather Surveillance Radar-1988 Doppler (WSR-88D) located at the NEXRAD Weather Service Forecast Office in Cleveland, OH, (NWSFO CLE) is positioned in an excellent location to gather extensive meteorological data on the formation of these waterspouts. Very sensitive WSR-88D base reflectivity, base velocity, and base spectrum width data, provide new opportunities to gain insight in the mechanics of waterspout formation over Lake Erie.

The purpose of this paper is to examine the NWSFO CLE WSR-88D data during two waterspout episodes during the summer of 1994. The utility of detecting waterspouts with various WSR-88D products will be discussed.

2. RADAR CONSIDERATIONS

The WSR-88D is a much more sensitive meteorological observing instrument than the conventional weather radars that have preceded it. However, as with any weather radar, the WSR-88D possesses limitations that may affect its ability to detect very small phenomena such as waterspouts. Because of the small spatial scale of the waterspout, detection by the radar can be very difficult. This is due to the radar beam broadening (aspect ratio problem) and increasing in altitude with range (radar horizon problem). This makes tight circulations located near the surface increasingly difficult to detect the further the beam gets from the Radar Data Acquisition (RDA) site (National Weather Service 1993; Fig. 1).

These limitations are important when observing the cool type waterspout. This type of waterspout tends to be narrow, usually less than one hundred yards at the base (Kessler 1986). Because these waterspouts spin up from the surface, there is no mid-level circulation that can be observed by the radar. Hence, any circulation that might be detected by the WSR-88D would be the narrow, intense low-level circulation directly associated with the waterspout, and would have to be observed relatively close to the RDA.

With the NWSFO CLE WSR-88D located approximately 9 km (5 n mi) from the south shore of Lake Erie, it is possible that a base velocity signature could be seen on some waterspouts over the southern part of the lake. However, Spratt and Choy (1994) noted that the WSR-88D rarely detects rotational signatures associated with waterspouts off of Florida. Since the cool type waterspouts on Lake Erie are similar to waterspouts off of Florida, it is reasonable to conclude that true rotational signatures will not be common for cool type Lake Erie waterspouts.

However, another WSR-88D base product that may be used to detect cool type waterspouts is the base spectrum width product. This is because a large dispersion in velocities would likely occur within a volume sample occupied by a waterspout, resulting in a high spectrum width value at the waterspout location (Spratt and Choy 1994). Thus, when synoptic conditions appeared favorable to the development of cool type waterspouts, a forecaster should examine base spectrum width data in areas where waterspout development was suspected (e.g., near convergence boundaries). Observing high base spectrum width values (12 kt or greater) would alert the forecaster to the possibility of a waterspout in that location.

Because cool type waterspouts tend to develop along low-level boundaries such as troughs and lake breeze fronts, another potential technique for identifying waterspout development would be through tracking such boundaries. Low-level boundaries may be identified by observing convective elements along boundaries through the use of base reflectivity data. Wind shifts noted in base velocity data may also identify the boundaries.

Warm type waterspouts should be easier to detect with the WSR-88D, since they are usually associated with mesocyclones. Hence, a forecaster could use similar type procedures for detecting a warm type waterspout as they could use for tornado development over land (i.e., observe the mid-level circulation of the mesocyclone using storm relative velocity data).

3. CASE 1: 26 JULY 1994

3.1 Synoptic Environment (Cool Type Waterspout)

On 26 July 1994, an unseasonably cool air mass was located over the Great Lakes and the Ohio Valley region. The 850 mb temperature at Flint, MI (FNT) at 1200 UTC was 9°C, while the Lake Erie water temperature off Cleveland was 24°C. This yielded an 850 mb-lake temperature differential of 15°C, which approached the 16°C differential noted by Kieltyka (1987) as an indication that cool type waterspout development was likely. Some secondary criteria for cool type waterspout development (Kieltyka 1987) were also met, including that the Lake Erie water temperature off Cleveland was greater than 19°C (24°C) and that the 850 mb wind at FNT was less than 25 kt. The synoptic situation appeared at least somewhat favorable for cool type waterspout development on this day.

3.2 WSR-88D Data

In the type of synoptic situation outlined above, a light offshore wind (or landbreeze) often develops along the shore of Lake Erie due to the direct thermal circulation formed by cool air sinking over land and the warmer air rising over the lake. Figure 2 shows a 0.5° elevation base reflectivity image from the NWSFO CLE WSR-88D valid at 1634 UTC 26 July 1994. Analysis of this image shows a narrow band of base reflectivity returns extending from near Mentor on the Lake, OH, to about 5 n mi north of Lorain, OH (LOR). These returns likely indicate the location of a band of cumulus clouds associated with the land breeze front. A few showers are embedded in the eastern end of the band where the highest reflectivity values were located. Base velocity data for the same time period (not shown) also depicted the boundary. However, it did not show its location as clearly as the base reflectivity data.

With this surface boundary in place and an atmosphere with synoptic conditions favorable for cool type waterspout development, a forecaster would expect cool type waterspouts to develop. This was the case, as three waterspouts were reported north of Cleveland in the vicinity of the boundary, near the time of the base reflectivity image shown in Figure 2. These waterspouts developed in an area in which the echo intensity was weak enough (less than 10 dBZ) to suggest that little or no precipitation was in the area.

As discussed earlier, with cool type waterspout development, there would likely be little indication of a circulation on the WSR-88D. However, a high spectrum width value might be found near the waterspouts. The 0.5° elevation base spectrum width product valid for 1634 UTC 26 July 1994 (Fig. 3), illustrates three small areas of high spectrum width values (16 kt or higher) embedded within the boundary. However, due to the inexact nature in which the location of the waterspouts were reported, it is impossible to say whether or not the three waterspouts reported correspond to these high areas of spectrum width. Also, the high spectrum width values could simply be indicative of turbulent flow associated with the boundary itself (other relatively high values of 8 kt or greater can be seen within the boundary).

4. CASE 2: 30 JULY 1994

4.1 Synoptic Environment (Cool/Warm Hybrid Type Waterspout)

The criteria outlined by Kieltyka (1987) for cool type waterspout development were not met on the morning of 30 July 1994. The 1200 UTC 850 mb temperature at FNT was 12°C. This yielded a 850 mb/lake differential temperature of 12°C, which did not meet the 16°C 850 mb-lake temperature differential that indicates that cool type waterspout development is likely. However, this lapse rate was close to being dry adiabatic (13°C between the surface and 850 mb), which indicated the atmosphere was unstable enough to support cumulus cloud development.

At 1200 UTC, a relatively cool air mass was over Lake Erie, with a 500 mb short wave trough and associated vorticity maximum moving across the lake. The short wave trough was producing mid-level cold air advection, which when combined with the low-level air that was modified by the relatively warmer waters of Lake Erie, produced a convectively unstable air mass.

In order to approximate the atmospheric thermal profile over the Lake Erie area at 1200 UTC 30 July, a sounding was created using the Skew-T Hodograph and Analysis Research Program (SHARP) workstation (Hart and Korotky 1991). The representative sounding used upper-air data temperature and wind data from the 1200 UTC 30 July sounding from NWSFO Pittsburgh, PA (PBZ). The Lake Erie water temperature was input as the surface temperature. Analysis of the sounding yielded a 500 mb based lifted index of -5, and a Total Totals Index of 44, indicating the potential for convection and possibly thunderstorms (Miller 1972).

Analysis of the SHARP vertical wind profile indicated that the 0 to 3 km storm-relative helicity was only 22 m^2s^{-1}, which was well below the 150 m^2s^{-1} value given by Davies-Jones et al. (1990) as being indicative for supercellular tornadic development. This would seem to indicate that rotating supercellular thunderstorms were not likely this day, although the instability indices outlined above indicated that general convection was possible.

4.2 WSR-88D Data

The 0.5° elevation base reflectivity image from the NWSFO CLE WSR-88D valid at 1308 UTC 30 July 1994 (Fig. 4) indicated widely scattered showers over eastern Lake Erie and extreme northwestern Pennsylvania. The shower with the highest reflectivity return (40-44 dBZ) was located over Lake Erie about 10 n mi north of Ashtabula, OH (ASH). A waterspout was reported with this shower at approximately 1308 UTC.

The 1308 UTC 0.5° elevation storm relative velocity map product (SRM; Fig. 5) showed a very weak cyclonic circulation in the rain shower north of ASH. The circulation is indicated by the 5 to 10 kt outbound velocities and 1 to 5 kt inbound velocities, associated with the rain shower depicted in the middle of the figure. Hence, the gate-to-gate shear for this circulation could not have been more than 7.5 kt. The elevation of the circulation was located at approximately 8000 feet AGL. Hence, if the circulation was associated with the waterspout, it seems likely that the waterspout spun down from this circulation to the surface.

The base spectrum width product could also be useful to detect the waterspout's circulation, as mentioned in the discussion of the cool type case above. Figure 6 depicts a 0.5° elevation base spectrum width product for 1308 UTC. Note that a pixel of high base spectrum width (12 to 15 kt) can be seen in the shower that produced the waterspout. The high spectrum width pixel is surrounded by much lower values (less than 8 kt). Since a confirmed waterspout occurred with this particular shower, it is likely that the high base spectrum width represented the circulation associated with the waterspout.

The NWSFO CLE WSR-88D base reflectivity, base spectrum width, and SRM products indicate that the morphology of the development of the waterspout was more like that of a warm type waterspout. This is because the waterspout developed from an isolated rain shower rather than from non-precipitating cumulus clouds along a convergence boundary as one would expect in cool type waterspout synoptic environments. Additionally, the waterspout circulation appears to have spun down from a weak cyclonic circulation aloft (around 8,000 ft) rather than spun up from the surface as is common with cool air waterspouts. The circulation was much weaker than that which would normally be associated with a warm type waterspout.

5. CONCLUSION

In this study, the NWSFO CLE WSR-88D was used to examine waterspouts that developed on Lake Erie. With regard to the cool type waterspouts, this was the first real opportunity to examine their formation in detail with Doppler radar data. The results of this study indicate that when environmental conditions favor cool type waterspout development, the WSR-88D can be used to detect the convergence boundaries along which the waterspouts develop. Specifically, this can be done by observing the boundary in the WSR-88D base velocity and base reflectivity products. The possibility of seeing the actual location of the waterspout through observing high base spectrum width values is also intriguing. However, this study was not able to conclusively prove that such a technique is useful in cool type situations.

The best way of observing warm type waterspout development is to locate mid-level circulations with the storm relative velocity map product. The base spectrum width product also appears to be a useful tool in detecting the location of the warm type waterspout, especially when the circulation is more difficult to detect in base velocity data.

It should be noted that the results presented in this study are only a summary of one waterspout season. Additional research is needed to conclusively show the morphology of waterspout development, and how they can be detected by using the WSR-88D.

ACKNOWLEDGMENTS

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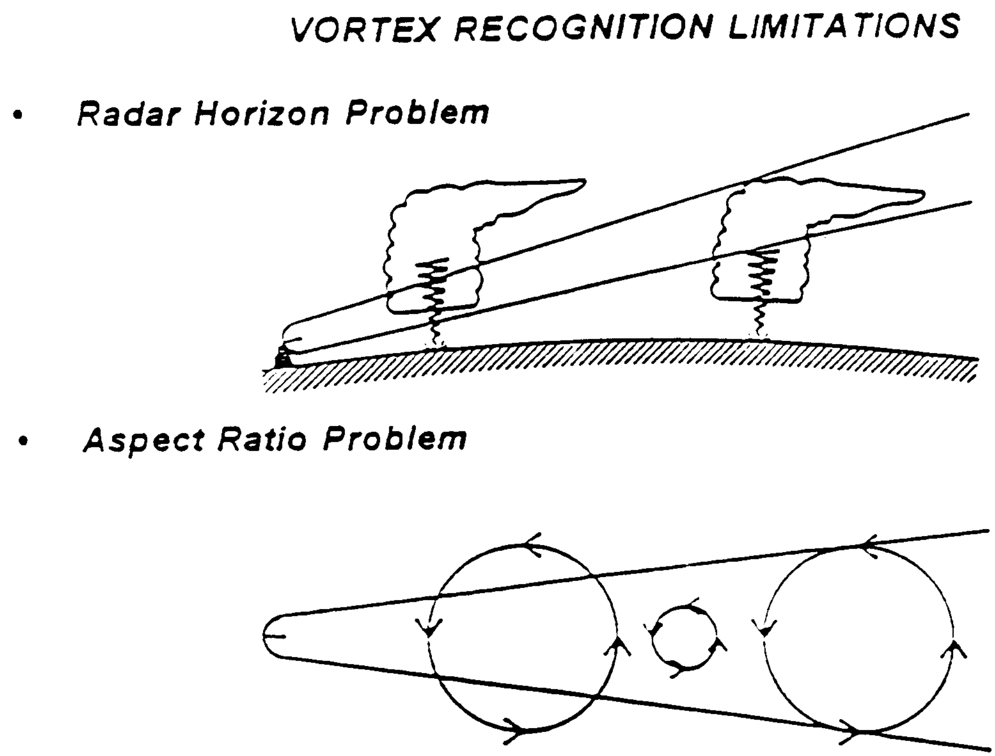

Figure 1. A diagram illustrating the radar horizon and aspect ratio problems of the WSR-88D radar beam. From the National Weather Service (1993).

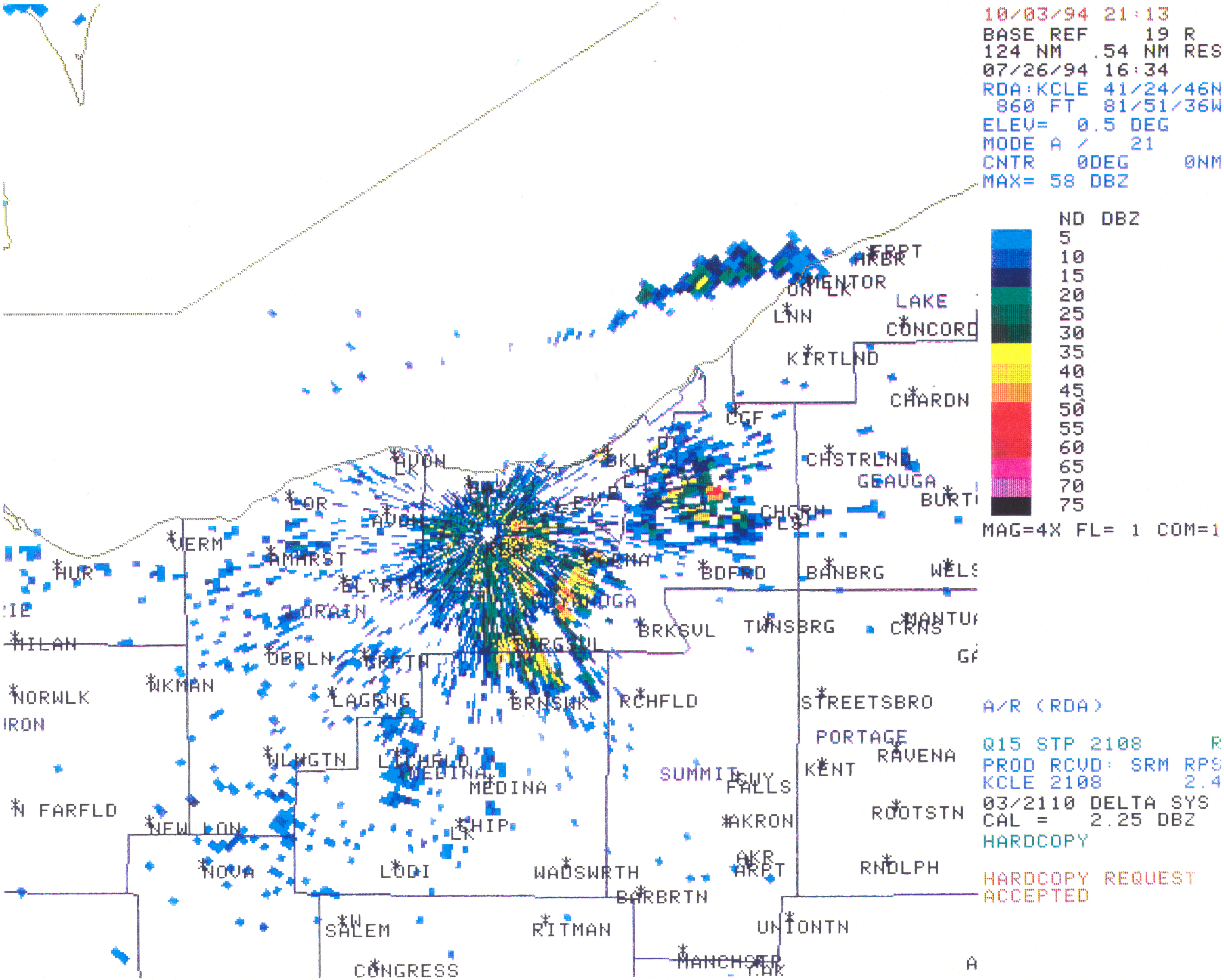

Figure 2. 1634 UTC, 26 July 1994 0.5° elevation base reflectivity product.

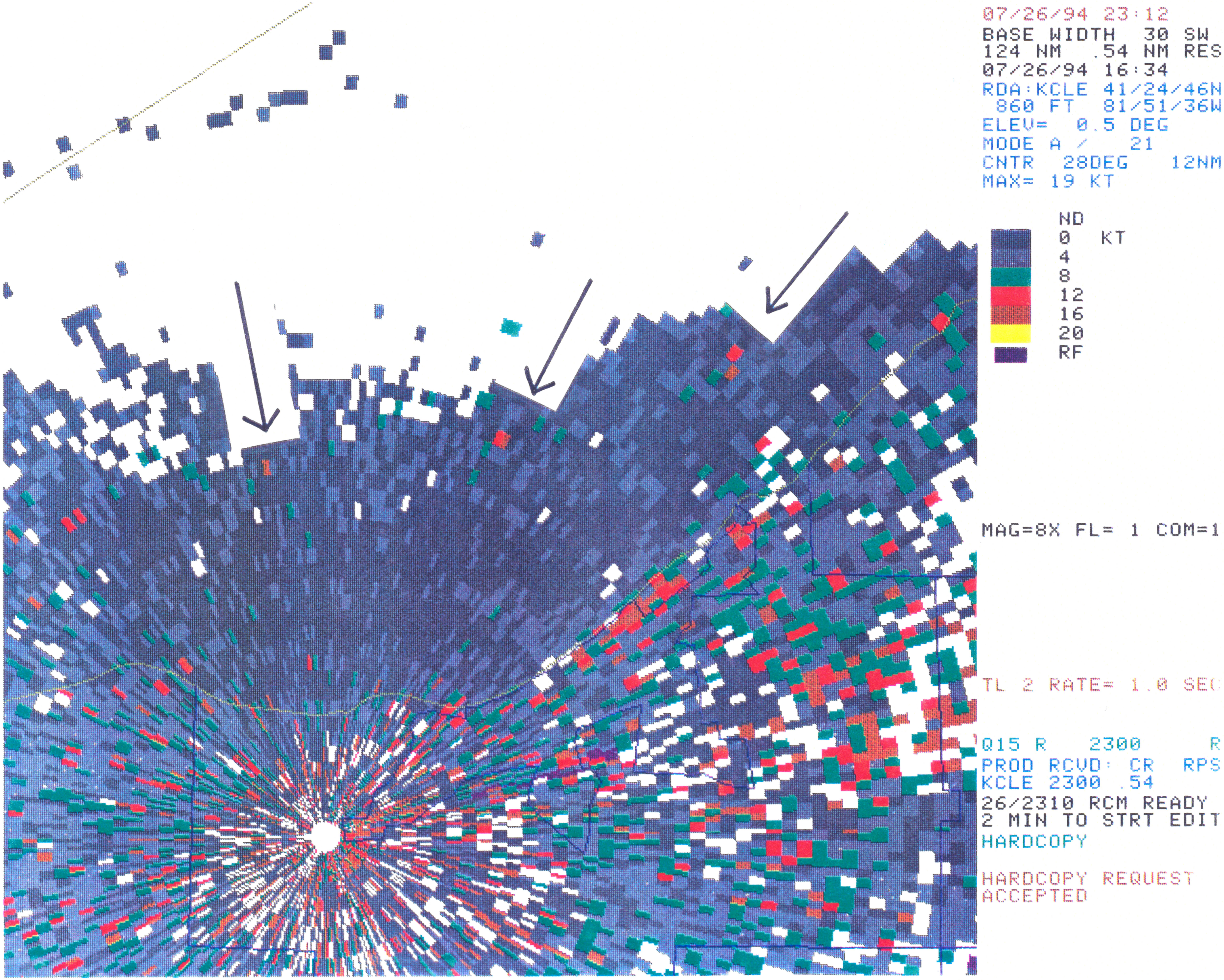

Figure 3. 1634 UTC, 26 July 1994 0.5° elevation base spectrum width product. Note the three small areas of high spectrum width values (16 kt and higher) marked by the arrows.

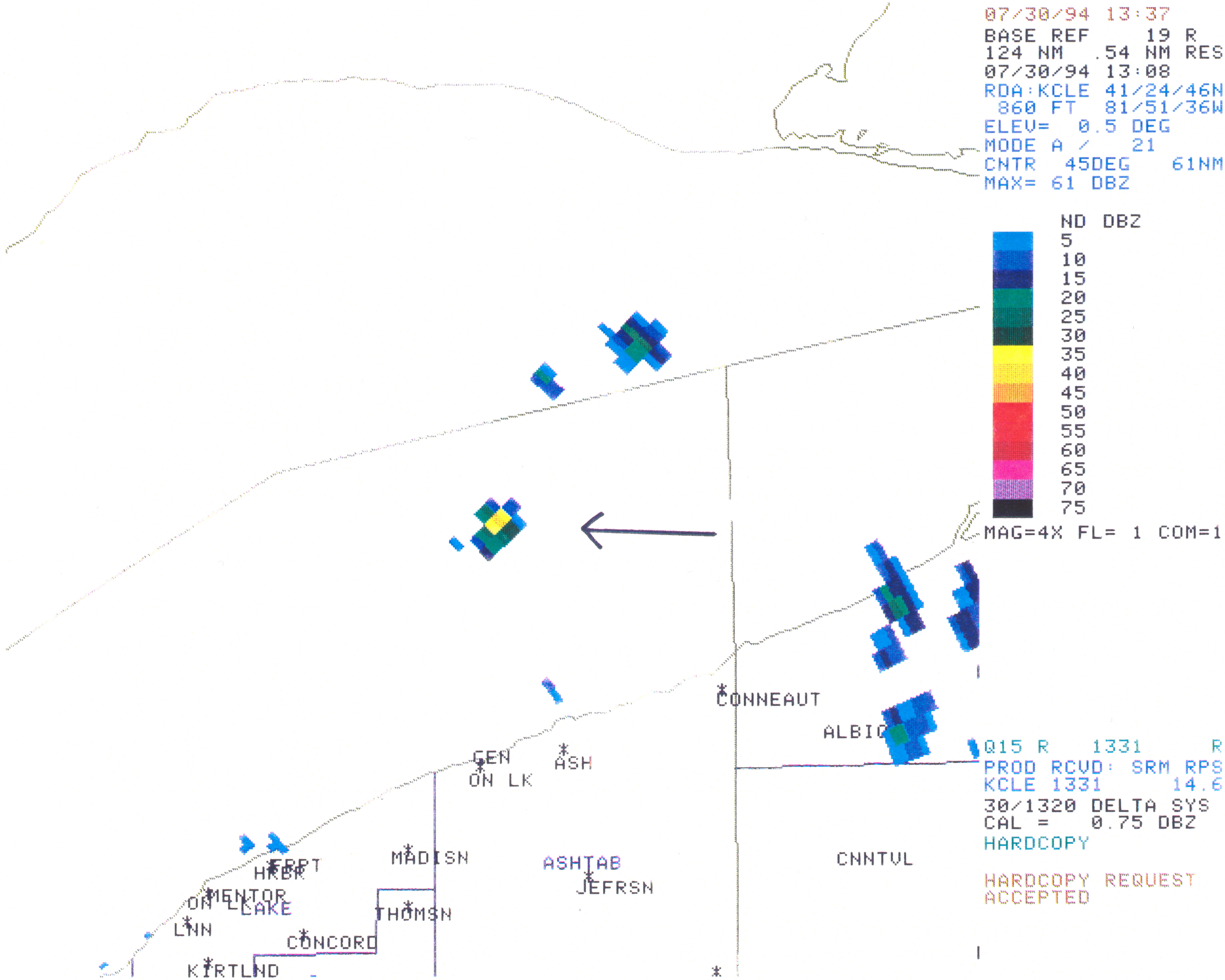

Figure 4. 1308 UTC, 30 July 1994 0.5° elevation base reflectivity product. Note the rain shower with the highest reflectivity return marked by the arrow.

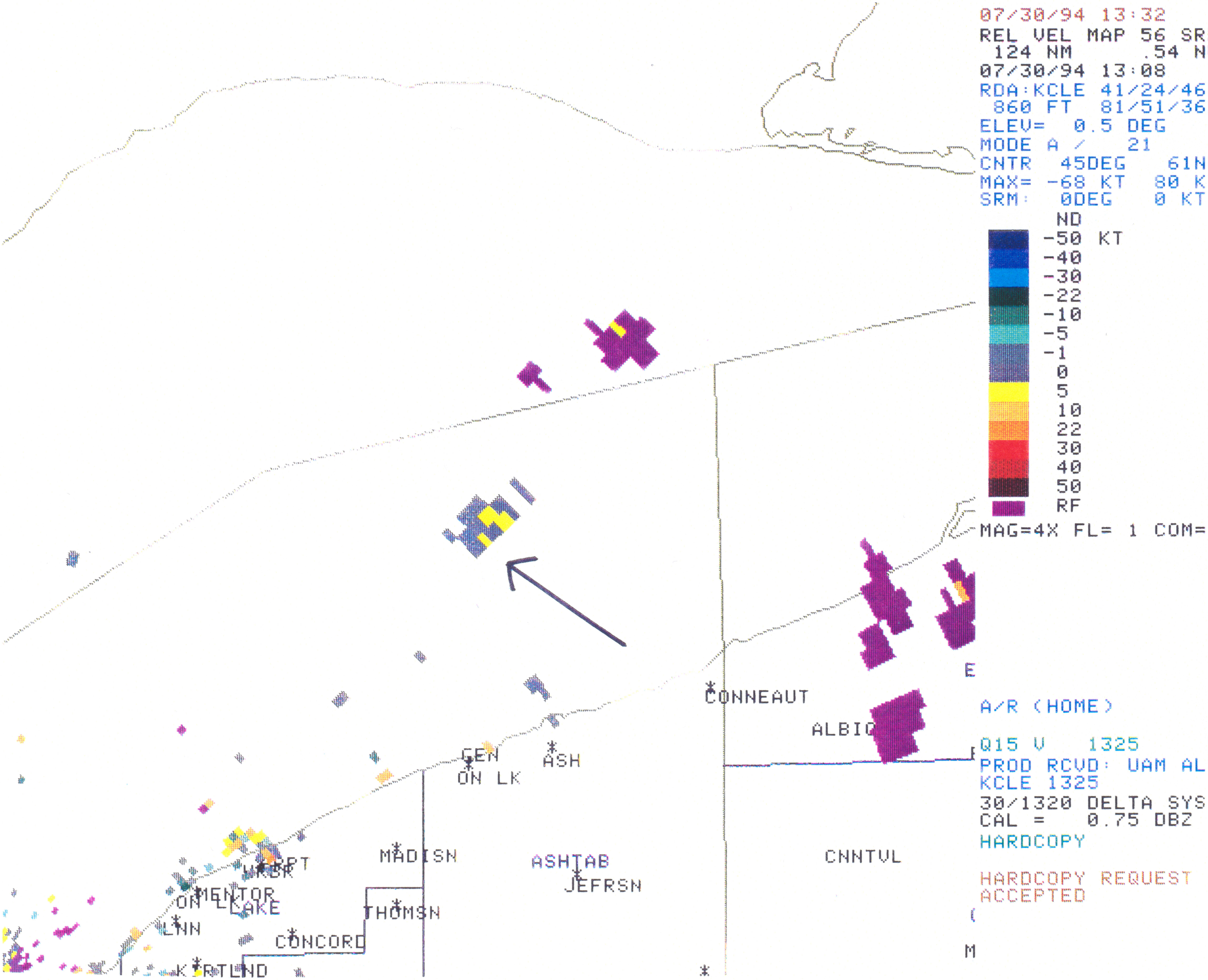

Figure 5. 1308 UTC, 30 July 1994 0.5° elevation storm relative velocity map product. Note the very weak cyclonic circulation in the rain shower marked by the arrow

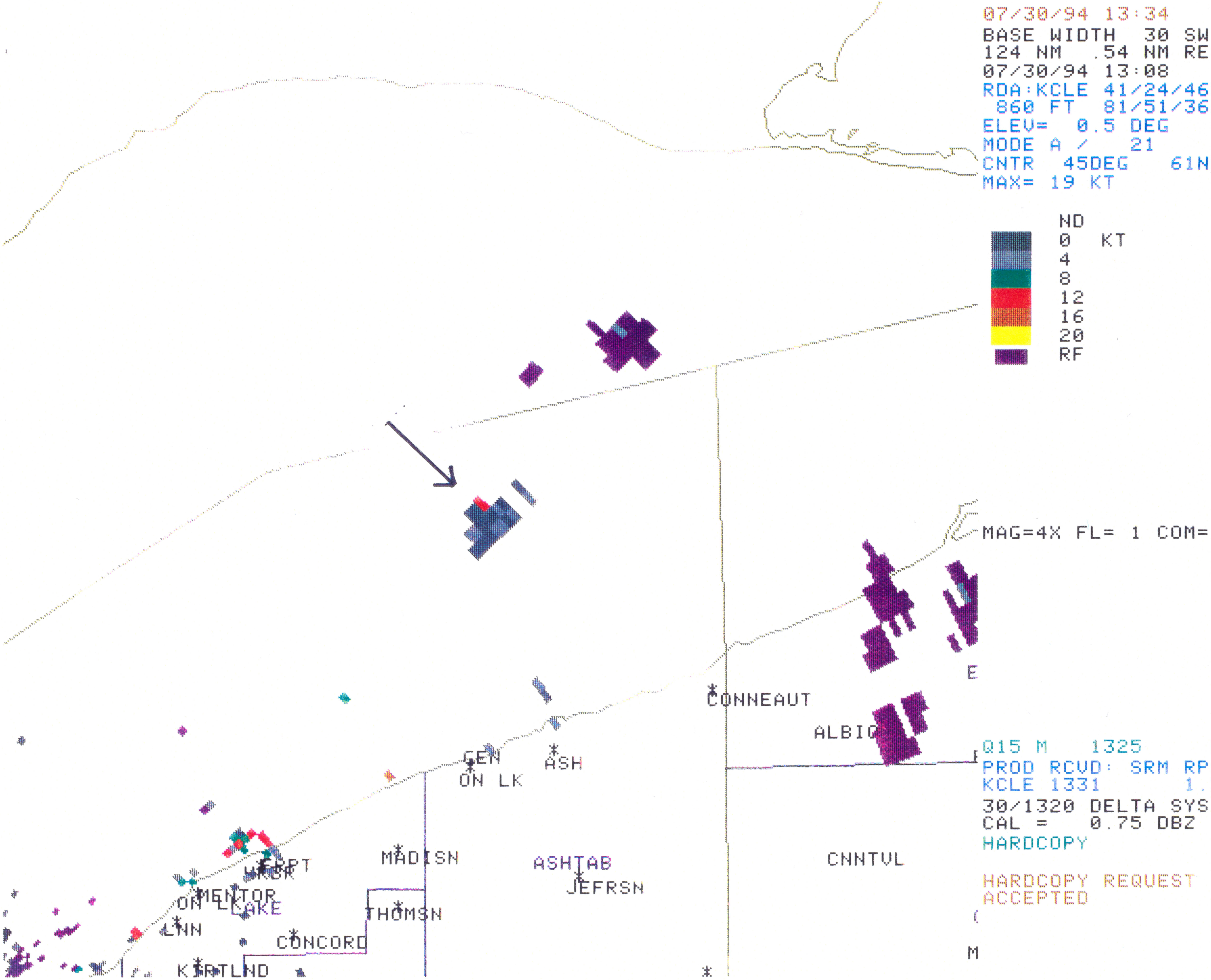

Figure 6. 1308 UTC, 30 July 1994 0.5° elevation base spectrum width product. Note the high spectrum width value (12-15 kt) in the rain shower marked by the arrow.