Technical Attachment

NON-SUPERCELL TORNADOES: A REVIEW FOR FORECASTERS

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1. Introduction

Severe weather events often bring reports of funnel clouds and tornadoes. Some of these reports are from obviously questionable sources, while others come from reliable contacts, such as trained storm spotters or law enforcement agencies. The forecaster's challenge is to weigh all reports against confirming information such as radar data or environmental factors which are usually associated with tornadoes (high helicity, high CAPE, wind shear, and so on). Many times, however, valid reports may not appear to be supported by these other factors, and those instances are the most troublesome to forecasters. Such events are the subject of this review.

Tornadoes which are not associated with supercells seem to be common in the mid-South (east Arkansas, west Tennessee, southeast Missouri and north Mississippi), and likely in other parts of the country as well. On three consecutive days in July, 1995, trained spotters and law enforcement officials in west Tennessee and east Arkansas reported funnel clouds and strong winds associated with what the WSR-88D showed to be weak, low-reflectivity showers. These events appear to be most common during the late spring and early summer months.

With the advent of the WSR-88D and its enhanced capabilities, considerable attention has been focussed on mesocyclones and their association with severe weather. Forecasters and others involved in the warning process should keep in mind, however, that tornadoes are not confined to misocyclones; they can develop in a wide variety of situations and can take on many different forms. It is important to remember that many tornadoes, especially weak ones, are not easily detected by the WSR-88D, and a large number of tornadoes are not associated with a radar-detectable parent mesocyclone. The parent circulations of non-supercell tornadoes have been referred to as mesocyclones (Fujita 1981) due to their diameter (40 to 4000 m). Nevertheless, non-supercell tornadoes present a significant threat to the public, as well as a formidable task for those who must attempt to forecast conditions ripe for their occurrence, and detect their presence once they form.

Before reviewing non-supercell tornadoes, a brief examination of the classification of tornadoes is in order. A detailed discussion of tornado classification is beyond the scope of this paper, but interested readers should refer to Fujita (1979), Forbes and Wakimoto (1983), and Doswell and Burgess (1993) for more information on vortex classification. There has been some debate and much discussion concerning whether all ground-based vortices, including gustnadoes and landspouts, fit the definition of a tornado as put forth in the Glossary of Meteorology (Huschke 1959).

A tornado is defined in the Glossary as "a violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a 'funnel cloud' or tuba." Forbes and Wakimoto (1983) note this definition is somewhat vague and relies a great deal on someone seeing the tornado and the storm from which it is spawned. For simplicity, this review will use the definition of a tornado proposed by Forbes and Wakimoto:

*A vortex is classified as a tornado if **1)** it produces at least F0 damage or exhibits wind speeds capable of producing such damage, and if **2)** it forms in association with the wind field of a thunderstorm or its accompanying mesoscale features, such as the gust front or flanking line.*

In the following two sections we will briefly discuss two types of non-supercell tornadoes (following the Forbes and Wakimoto definition) which are particularly troublesome for forecasters in the mid-South, if not elsewhere.

2. Gustnadoes

One of the more common types of non-supercell tornadoes is the gustnado. The name, coined by storm interceptors, refers to the preferred location of development of these small-scale vortices—along the gust front of a thunderstorm. Gustnadoes have been noted in association with lines of thunderstorms, especially bow-echo structures, as well as with multicell thunderstorm clusters. Gustnadoes can also occur in conjunction with the forward-flank or rear-flank downdraft of a supercell thunderstorm.

Gustnadoes, like all tornadoes, are potentially dangerous to both life and property. While most are very weak, some gustnadoes may reach F1 intensity, with winds as high as 110 mi/hr. One such gustnado occurred on June 9, 1994, associated with bow echoes in a long line of thunderstorms which raced through southwest Tennessee. The gustnado was observed by an NWS meteorologist and storm spotters, and it passed within 100 yd of the Memphis NWS Forecast Office. The tornado caused F1 damage to apartments and homes northeast of the office, with one home suffering significant damage. Aerial and ground surveys confirmed the damage was the result of a tornado. Studies by Hunter and Klein (1993) and Stumpf and Burgess (1993) also document instances in which gustnadoes became rather intense.

Gustnadoes typically appear as a swirl of dust or debris along the leading edge of the thunderstorm outflow. There is usually no condensation funnel or other visible connection to the cloud base above. Since they develop along the leading edge of a storm, gustnadoes are not usually associated with a wall cloud or rain-free cloud base, therefore, these tornadoes are typically extremely difficult to identify visually. Some ground-based circulations associated with thunderstorm outflow can become more intense and more closely resemble a "traditional" tornado (that is, they fit the Glossary definition).

The gustnado is typically associated with bow echoes or squall lines, and should not be confused with tornadoes that may develop in the rotating portion of the bow echo which Fujita refers to as the comma head (Fig. 1). The latter tornadoes, as noted by Pryzbylinski (1995) and others, are often associated with a mesocyclone circulation that develops as the bow echo evolves into a comma echo.

3. Landspouts

Bluestein (1985) first used the term "landspout" to identify another type of non-supercell tornado which has similarities to waterspouts. These tornadoes are most common in the Plains states, but the mechanisms responsible for their formation are found in other areas of the country as well.

Landspouts form when pre-existing horizontal circulations are stretched and tilted upward by a developing thunderstorm updraft (Figs. 2 and 3). As with gustnadoes, landspouts do not usually form from mesocyclones or supercells. In fact, a large number of landspouts are observed in association with lines of cumulus congestus or towering cumulus clouds, often before precipitation is visible on radar. However, storm interceptors have noted the presence of landspouts in conjunction with supercell thunderstorms, sometimes at the same time as, but in a different part of the storm than a supercell tornado.

Landspouts are usually visible, unlike gustnadoes, and most have a narrow, rope-like condensation funnel extending from cloud base to the ground. Wall clouds are not usually observed with landspouts, and these tornadoes are typically short-lived and weak. Damage associated with landspouts can be significant, however, with damage in the F1 category not uncommon. Vasiloff (1993) noted a landspout which reached F2 intensity.

Although typically thought of as a High Plains phenomena, landspouts occur in other regions, including the Southern Plains and the Mississippi Valley. Rogash (1990) detailed the occurrence of a tornado in northeast Arkansas that, judging by its appearance and development, was most likely a landspout. The synoptic and mesoscale environments that favor the development of landspouts in the High Plains also exist in other regions; the higher number of landspouts in the Plains may be attributable to the fact that they occur in drier environments and therefore are easier to see.

The Table below provides an overview of both types of non-supercell tornadoes described above.

TORNADO TYPE	VISUAL APPEARANCE	F-SCALE RATING	LOCATION IN STORM	CIRCULATION DEPTH	RANGE OF RADAR DETECTION	THREAT TO LIFE AND PROPERTY?
Gustnado	Whirl of dust or debris at or near ground; no condensation funnel	F0 - F1 (possibly higher)	along gust front or outflow; often with squall line or bow echo	generally less than 1-2 km	generally less than 25 nm	YES
Landspout	Narrow, rope-like condensation funnel, often resembling a tube	F0 - F2	form with rapidly developing updrafts near convergence boundaries	generally from 1 to 4 km; may grow upward with time	generally less than 25 nm	YES

Table 1. Summary of Non-Supercell Tornadoes

4. Forecasting Non-Supercell Tornadoes

While much is known about environmental conditions that favor the development of supercell thunderstorms, atmospheric parameters and forecasting techniques are not as well researched for non-supercell tornadoes. This makes forecasting their occurrence extremely difficult. Providing warnings for these short-lived, transient vortices is also very difficult. There are some clues, however, which may help forecasters recognize environments suitable for the development of non-supercell tornadoes.

Gustnadoes pose the most significant challenge to forecasters, since they can form with several different types of storms and in many different environments. Most significant gustnadoes (those that are capable of producing damage, deaths and injuries) occur in conjunction with squall lines,

and especially bow echo storms. When bow echoes are expected, gustnadoes might also be anticipated. Johns (1993) provides a detailed examination of the meteorological conditions associated with bow echo development. A careful review of that work is a good start toward understanding conditions in which gustnadoes may occur.

Since landspout tornadoes can form from even non-descript developing thunderstorms, and sometimes before precipitation is detected on radar, they are next to impossible to forecast. Landspouts can form in rather benign synoptic environments (Brady and Szoke 1988) and in a variety of other synoptic settings. Typically, since landspouts develop as the result of strong updrafts interacting with surface boundaries, high values of instability are present. Large values of convective available potential energy (CAPE) are usually necessary for the explosive thunderstorm development that often occurs with landspout tornadoes.

5. Radar Detection Problems and Strategies

Radar detection of non-supercell tornadoes is severely limited due to a variety of factors as discussed above. In fact, many of these weak tornadoes are undetectable using radar. Algorithms designed to detect incipient tornadoes are of little use with these small, short-lived vortices, therefore forecasters must use other methods when dealing with non-supercell tornadoes.

Problems inherent in all radar systems make the detection of tornadoes difficult. Some tornadic circulations will likely be too small to resolve, unless they are very close to the radar. Misocyclones/tornadoes at greater distances from the radar may occur below the beam, due to the increasing height of the radar beam with increasing distance from the antenna. In addition, the WSR-88D scan strategy may limit the detection of short-lived gustnadoes and landspouts, since they may occur between radar volume scans. Burgess, et al. (1993) describe some of the problems inherent in the radar detection of tornadoes.

Studies have revealed that while most gustnadoes are undetectable, in a few cases they have been identified using radar. Such occurrences are limited to gustnadoes within about 25 nm of the radar, and the majority of radar-detectable gustnado circulations have been confined to the lowest 1 to 2 km above the ground (Brandes 1993, Vasiloff 1993, and Stumpf and Burgess 1993).

Przybylinski (1995) noted areas of enhanced shear along the leading edge of an outflow boundary associated with a bow echo. These zones of enhanced shear were associated with tornadoes along the gust front (gustnadoes). It is possible that in some situations enhanced shear zones detected by the WSR-88D could provide clues to the possibility of gustnado occurrence, especially at close ranges and in conjunction with spotter reports.

Difficult as they may be to anticipate, studies have noted slightly more promising results in the radar detection of landspouts, although most are still unlikely to be seen on radar. Studies that identify radar-detectable circulations associated with landspouts note little, if any, mid-level storm rotation, as well as rotational signatures that often developed first in the lower levels and built upward with time (Wakimoto and Wilson 1989).

Brady and Szoke (1988) recommend closely monitoring the position and movement of low-level convergence boundaries. They suggest forecasters look for small, low-level circulations along such boundaries which (1) display time continuity, (2) strengthen and develop vertically, and (3)

are located near a rapidly developing storm. The WSR-88D is often capable of detecting such boundaries, especially using reflectivity products.

Choy and Spratt (1994) outlined strategies for using the WSR-88D to detect waterspouts. Since the mechanisms associated with the formation of landspouts appear to be similar to those associated with waterspouts, their techniques may prove useful in watching for landspout development. Choy and Spratt's approach involves using reflectivity products to locate and monitor convergence boundaries, paying special attention to movement and intersections. Rapid cell development adjacent to these boundaries may then be detected using the Echo Tops (ET), Vertically Integrated Liquid (VIL) and Composite Reflectivity (CR) products of the WSR-88D.

This method might help identify the most likely areas for landspout formation, but as Choy and Spratt note, this technique offers little help in the detection of the circulation itself, since the rotational signatures associated with landspouts are usually unresolvable by the WSR-88D. Nevertheless, knowledge of conditions that favor the development of landspouts will lead to increased **awareness** on the part of forecasters, who will then be able to act quickly if tornado reports are received from the area.

6. Discussion and Recommendations

While the WSR-88D is a valuable tool in the early detection and analysis of severe weather, it is only one weapon in the forecaster's arsenal. The most effective warnings come as the result of the integration of all available data, including mesoanalyses and ground-truth spotter reports. Of utmost importance is the forecaster's knowledge of storm structure and the integration of that knowledge into a conceptual model of "today's storms." This knowledge arms the forecaster to recognize the **potential** for severe developments, and enables him or her to act quickly and with more confidence when presented with confirming radar signatures and spotter reports.

This is especially true when it comes to non-supercell tornadoes, which are usually difficult to detect using radar alone. Landspouts, gustnadoes and other non-supercell tornadoes present numerous problems for forecasters because of their small size, short duration and sometimes non-existent radar signatures. The following recommendations are intended to enhance forecaster awareness and knowledge regarding non-supercell tornadoes:

- Tornado and funnel cloud reports should not be discounted simply because of a lack of confirming radar data. Of course, there will be many more reports than actual events, and every effort should be made to avoid over-warning. Every reliable report should be investigated using all available radar and surface data. When possible, careful questioning of the person reporting the tornado/funnel cloud is extremely valuable in determining the validity of the report. This practice will not only increase the chances of obtaining reliable ground-truth reports of tornadoes and funnel clouds, but it will also help enhance the credibility and utility of spotters whose reports may otherwise be discounted.

- Information regarding the existence, appearance and formation of non-supercell tornadoes should be incorporated into spotter training materials, beginning at the basic level. Many spotters may think that only supercells produce tornadoes, and that all tornadoes occur in conjunction with mesocyclones, wall clouds and large hail. Education regarding non-

supercell tornadoes will likely lead to more accurate reporting of these potentially dangerous events.

- When a non-supercell tornado occurs, or damage associated with a possible tornado is reported, every effort should be made to investigate the event as completely as possible. This includes both a timely, detailed storm survey and intensive post-analysis of mesoscale and radar data to try to determine whether 1) a tornado actually occurred, and 2) what signatures were present that alerted (or might have alerted) forecasters to the development or existence of a tornado. Documentation of such events will assist others in learning to forecast and warn for non-supercell tornadoes. Forbes and Wakimoto (1983) and Bunting and Smith (1993) offer valuable information concerning damage surveys and the classification of storm damage.

There is much to be learned about non-supercell tornadoes, and researchers are just beginning to explore these potentially dangerous storms. VORTEX (Verification of the Origins of Rotation in Tornadoes Experiment) gathered data on non-supercell tornadoes, and findings from that field project (Rasmussen, et al. 1994) will undoubtedly be of great use to operational forecasters in the years to come. Until then, we must use what information we have concerning non-supercell tornadoes to increase awareness and to enhance our detection capabilities.

7. Acknowledgements

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8. References

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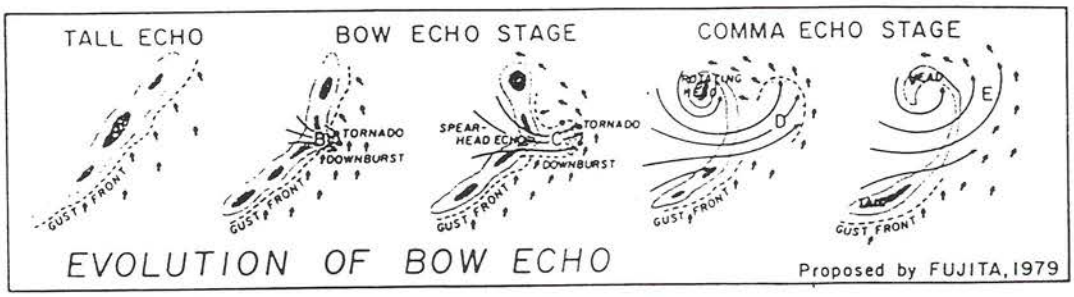

Figure 1. Evolution of a bow echo and favored tornadogenetic regions (from Fujita, 1979).

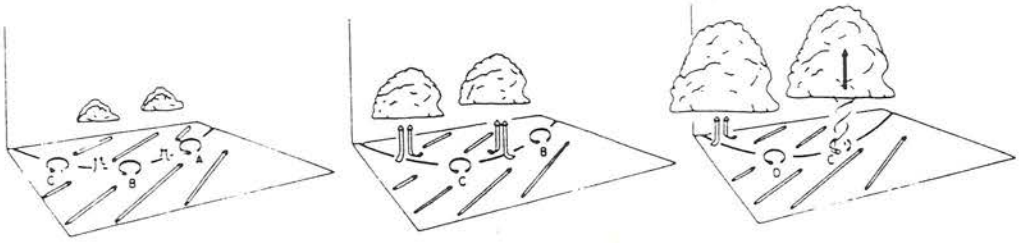

Figure 2 Life cycle of a non-supercell tornado (from Wakimoto and Wilson, 1989)

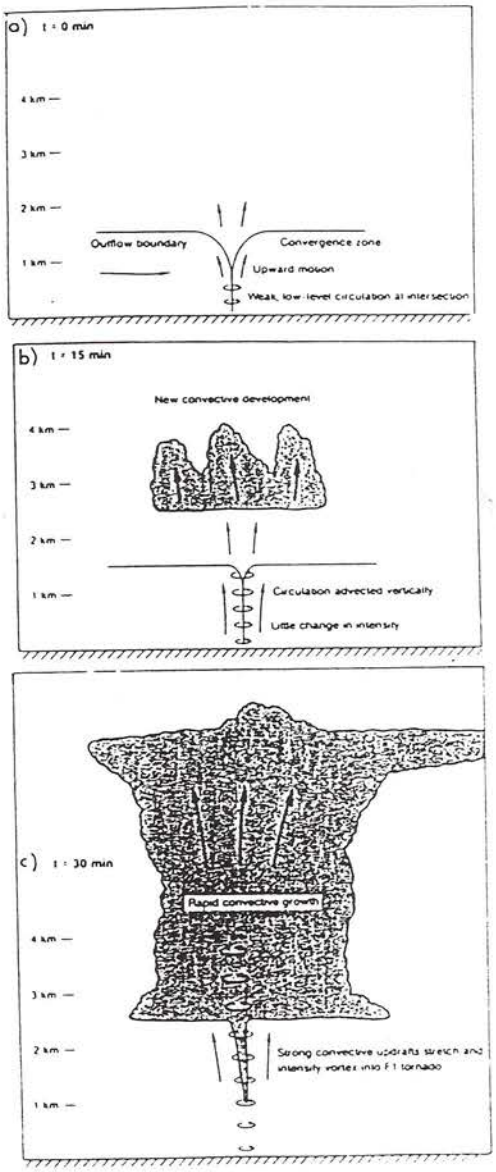

Figure 3 Development of a landspout at the intersection of colliding boundaries (from Brady and Szoke, 1988)

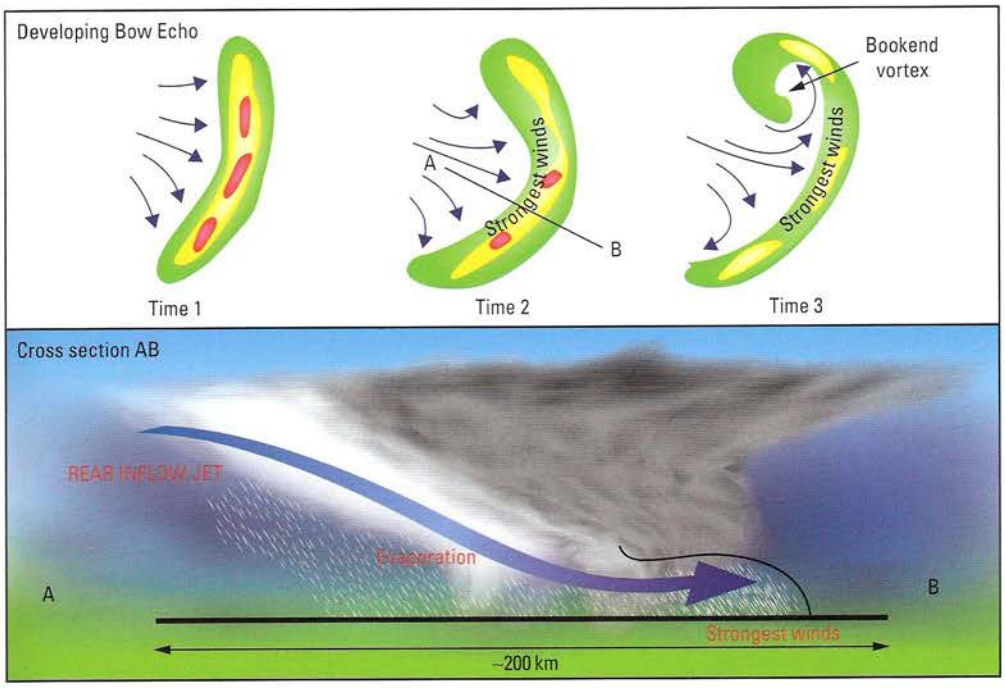

FIGURE 18.8 (Top) Schematic showing plan view of the typical evolution of the radar reflectivity field during the evolution of a bow echo. (Bottom) A schematic vertical cross section through a bow echo showing the clouds, rain, and the rear inflow jet descending to the surface from aloft.

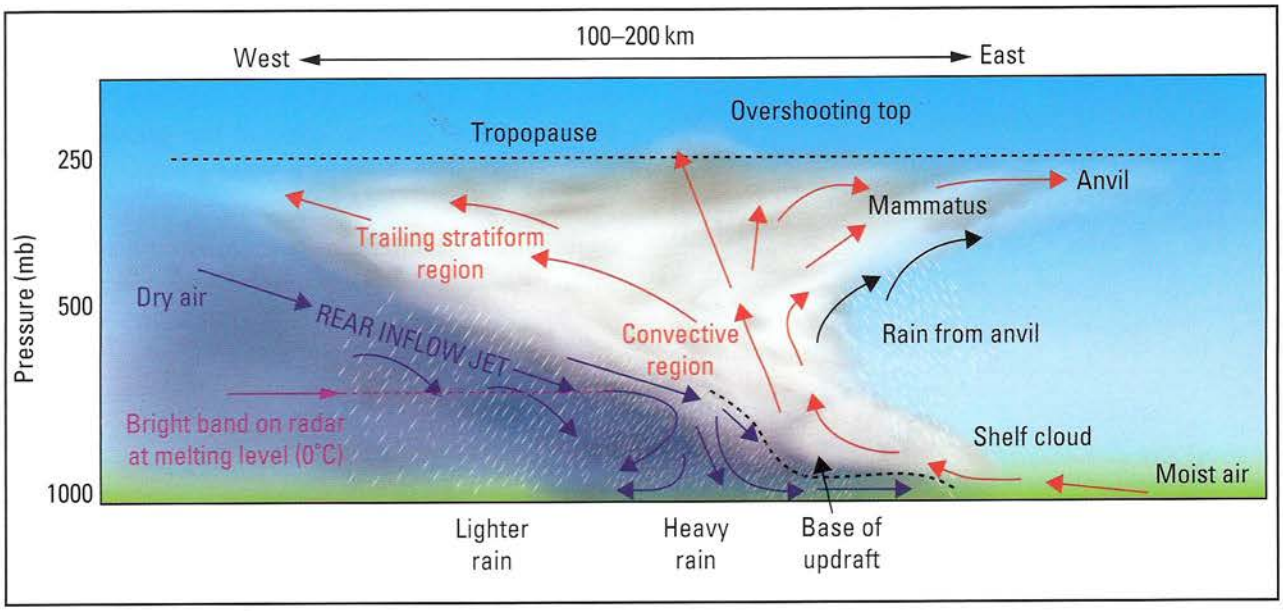

FIGURE 18.9 Schematic cross section through an MCS squall line showing key structural features. The bright band and rear inflow jet can also be seen on Figure 18.10.

these boundaries (for example, note the storms developing rearward and to the north of the MCS in Figures 18.5D–H).

Figure 18.9 summarizes the key structural features of a thunderstorm in a mature MCS. The heavy rain, the location where the rain falls out from the **convective region** of the storm, is located just to the rear (west) of the updraft region. Lighter rain falls farther to the west from the stratiform region of the squall line where air aloft is rising slowly and to the east of the convection from the anvil. A radar cross section illustrating the convective and stratiform regions of an MCS appears in Figure 18.10A. On radar cross sections, the stratiform region is characterized by a **bright band** of radar reflectivity (BB in Figure 18.10A) at the level where snowflakes falling from aloft melt into raindrops. (Note that the bright band is responsible for the higher reflectivity