P4.6 A REASSASSMENT OF THE PERCENTAGE OF TORNADIC MESOCYCLONES

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1. INTRODUCTION

An unresolved issue both in research and operational-forecasting endeavors concerns the percentage of mesocyclonic thunderstorms that spawn tornadoes. Underscoring the importance of the issue to forecasting is that: "Mesocyclone signatures are the most often used Doppler radar inputs to tornado warnings…" (Burgess et al. 1993). Often cited in the literature is the statistic that ~50% of all mesocyclones are tornadic (e.g., Burgess et al. 1979). This percentage is based on data collected using research Doppler radars, primarily on large, strong supercells in central Oklahoma during the 1970s; it is now generally believed to be lower, perhaps ~30% (e.g, Burgess and Lemon 1991; Burgess et al. 1993). Expressed in terms of height of mesocyclone base, the percentages of *mid-altitude* (nominally, 3–7 km AGL) and *low-altitude* (nominally, 500 m AGL) mesocyclones have yet to be formally estimated. The presumption that most low-altitude mesocyclones are tornadic has been called into question (Trapp 1999; see also Wakimoto and Cai 2000).

Herein, we exploit a large set of data, collected using the network of Weather Surveillance Radars-1988 Doppler (WSR-88Ds), to reassess the percentage of tornadic mesocyclones, especially those qualified as mid altitude and low altitude.

2. METHOD

Compiled from data during 1992–1999 and drawn from 54 different WSR-88Ds, our dataset is composed of 83 "events." Each event consists of data collected over a period of about 4-10 h (6.75 h on average), from a single WSR-88D, on at least one (tornadic or nontornadic) mesocyclonic thunderstorm. Of the 83 events, 10 are strictly nontornadic mesocyclonic thunderstorm events hereinafter referred to as "null" events. The remaining 73 contain a mixture of nontornadic and tornadic storms. Corresponding to the tornadic events is a total of 780 tornadoes with a range of damage-based intensities. The tornadoes originated from a variety of thunderstorm types (classic supercell, low-topped supercell, heavy-precipitation supercell, bow echo, cell embedded within a tropical cyclone, etc.).

Radar data in Archive Level II format (Crum et al. 1993) were post processed using the National Severe Storms Laboratory (NSSL) Mesocyclone Detection Algorithm (MDA; Stumpf et al. 1998). Cyclonic shear was detected automatically in the radar data by the MDA and then objectively classified as mesocyclones according to the diagnosed radial velocity difference (ΔV) across the perceived vortex, the vortex diameter, etc. (see Stumpf et al. 1998). We considered initially only those mesocyclones that satisfied the following "operational criteria" in the WSR-88D system:

Radial velocity shear $\geq$ 6 m s^{-1} km^{-1} and ΔV $\geq$ 30 m s^{-1}

- met over a depth $\geq$ 3 km,
- with a base (z_b) at altitudes $\geq$ 5 km above radar level (ARL), and
- persisting longer than 5 to 6 min (more than one radar volume scan);

these criteria were applicable within ranges $\leq$ 100 km, and thereafter reduced by some

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percentage (e.g., see Stumpf et al. 1998). We then considered as mid-altitude mesocyclones those operationally defined mesocyclones with 3 km $\leq z_b \leq$ 5 km, and as low-altitude mesocyclones, those with $z_b \leq$ 1000 m, $\leq$ 500 m, $\leq$ 250 m, or $\leq$ 125 m ARL.

For reference, an objectively defined mesocyclone during the Joint Doppler Operational Project (JDOP) was based first on the existence of azimuthal shear $\geq 5\times10^{-3}$ s^{-1} (at radar ranges less than 230 km), between closed contours of storm-relative radial velocity (isodops) (see Burgess et al. 1979). It was then necessary that this shear requirement be met: (i) throughout a vertical layer whose depth could be no less than 3 km or 50% of the nominal horizontal diameter of shear signature, and (ii) over a time interval defined by half the period of vortex revolution, deemed a "persistence scale:"

$$\frac{\pi R \Delta\beta}{V_2 - V_1},$$

where $\Delta\beta$ is the angular distance (radians) between the radial velocity maxima in the two closed isodops, R is radar range (m), and $V_2 - V_1$ is the difference (m s^{-1}) between the two radial velocity maxima.

Each MDA detection was defined as either tornadic or nontornadic using damage survey information contained in *Storm Data* publications. Specifically, a tornadic mesocyclone must have satisfied the operational criteria at some time during the interval

$$(T_B - 20 \text{ min}) \leq T_B \leq T_E \leq (T_E + 6 \text{ min}),$$

where T_B is the reported tornado begin time and T_E, the reported tornado end time; a spatial association between tornado and mesocyclone was obviously also necessary. Additional information on the verification procedure can be found in Stumpf et al. (1998).

As might be noticed below, the mesocyclone sample produced using our methodology is exaggerated when compared to the mesocyclone sample due to Burgess et al. (1979) and others. This is an artifact of the MDA and associated verification procedure. Indeed, a new or different mesocyclone is defined for *each* radar volume scan within which the operational criteria are met. Hence, a single, manually identified mesocyclone that persists for one hour equates to 12 mesocyclones using our methodology, assuming 5-min volume scans (and of course a persistent operational mesocyclone). We are interested, however, only in percentages, rather than raw numbers of mesocyclones, and so comparison of our results with those of Burgess et al. should still be meaningful. Nevertheless, work is currently underway to piece together individual MDA detections to form single mesocyclones of appropriate duration. A proxy for this work is the time filtering procedure described in section 3.

3. RESULTS

A total of 5322 mesocyclones that satisfied the operational criteria were identified by the MDA. Of these, 25.5% were associated with a tornado (Fig. 1). As a function of base height (or *mesocyclone class*), 14.6% of the 1741 mid-altitude mesocyclones were tornadic, as were 40.0%, 39.3%, 46.4%, and 34.3% of the 1131, 438, 151, and 35 mesocyclones with $z_b \leq$ 1000, $\leq$ 500, $\leq$ 250, and $\leq$ 125 m ARL, respectively (Fig. 2). Hence, roughly 40% of the sampled low-altitude mesocyclones were tornadic, depending on how one defines "low altitude."

Following Wilks (1995, p. 119-121), error bars that represent a 95% confidence interval were calculated for each mesocyclone class (Fig. 1); result robustness is suggested for all mesocyclone classes except[1] $z_b \leq$ 125 m. Note that the calculations assumed that proportions or probabilities of tornadic (and nontornadic) mesocyclone occurrences in each class can be described by the binomial distribution, which is then approximated using a Gaussian distribution; the error bar lengths

[1]The unrealistic drop in tornadic mesocyclone occurrence from mesocyclone classes $z_b \leq$ 250 m to $z_b \leq$ 125 m owes to: the relatively small sample of mesocyclones with $z_b \leq$ 125 m, and also to the fact that automated mesocyclone detection at radar ranges $\leq$ 10–15 km can be unreliable in some instances, owing to radar-signal contamination by ground clutter, etc.

are inversely proportional to $\sqrt{N}$, where N is the number of observations.

A caveat to our error analysis is that the binomial distribution applies here only if the N mesocyclone observations are mutually independent[2] (Wilks 1995). This condition may be violated if a single (physical) mesocyclone is identified as more than one mesocyclone by the MDA, which, as mentioned above, may in some instances be the case.

To help filter out such dependant observations, we reprocessed the MDA data with the additional requirement that the time separation between any two mesocyclones in a given event be greater than 45 min. Based on results presented by Burgess et al. (1982), this rather stringent requirement implies that the equivalent of a mature mesocyclone stage (or of an entire "multiple mesocyclone core" life cycle) must lapse before another mesocyclone can be said to exist. As demonstrated in Fig. 2, our time filtering procedure markedly deflates the N for each mesocyclone class. However, the resultant proportions (with error bars) of all, mid-altitude, and low-altitude ($z_b \leq$ 1000 m and $z_b \leq$ 500 m only) tornadic mesocyclones —which are offered here as a high-end estimate of the effects of mesocyclone "duplication"—still do not differ significantly from those presented in Fig. 1.

4. CONCLUSIONS

A large set of data collected by numerous WSR-88Ds was analyzed using the NSSL Mesocyclone Detection Algorithm to estimate the percentage of tornadic mesocyclones, both at mid and at low altitude. A total of 5322 mesocyclones satisfied the objective criteria used in the WSR-88D system: (i) a height-unqualified 25.5% of these mesocyclones were tornadic; (ii) 1741 were considered mid-altitude mesocyclones, and only 14.6% of these were tornadic; and (iii) 1131, 438, and 151 mesocyclones, whose bases were at altitudes $\leq$ 1000, $\leq$ 500, and $\leq$ 250 m ARL, respectively, were considered low-altitude mesocyclones, and 40.0%, 39.3%, and 46.4% of these mesocyclones were tornadic.

Our study confirms that the percentage of all tornadic mesocyclones is indeed much lower than initially reported, and now provides estimates of the percentages of tornadic mesocyclones, qualified by base height, as mid and low altitude. Additionally, it quantifies Trapp's (1999) conclusion that existence of a low-altitude mesocyclone is an insufficient condition for tornadogenesis, and thereby aids those researchers forming tornadogenesis theories. Lastly, it provides guidance and confidence bounds to those forecasters responsible for issuing radar-based tornado warnings. Such forecasters likely have already reached conclusions similar to ours through their personal observations and, hence, are fully aware of other mesocyclone attributes as well as of the storm-spotter reports, radar and satellite data, and other information about the near-storm environment that must be considered during the warning decision process.

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[2] Another condition is that the probability of a tornadic mesocyclone must not change from observation to observation (Wilks 1995). We assume that this condition is met at least approximately.

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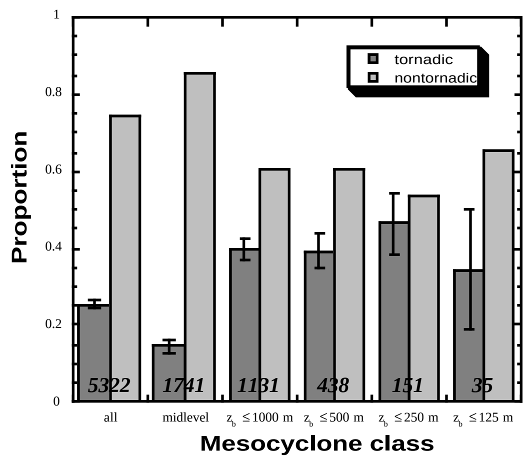

FIG. 1. Proportion of tornadic versus nontornadic mesocyclones, as a function of mesocyclone class. Here, “all” is all operationally defined mesocyclones, “midaltitude” denotes those mesocyclones with bases at altitudes $3000 \le z_b \le 7000$ m ARL, and $z_b \le 1000$ m, ≤ 500 m, ≤ 250 m, and ≤ 125 m refer to those mesocyclones with bases at or below 1000 m, 500 m, 250 m, and 125 m ARL, respectively. Bold numbers at bottom of columns are the number of mesocyclones in each class. Error bars represent a 95% confidence interval and assume that probabilities of tornadic (and nontornadic) mesocyclone occurrences in each class are binomially distributed (see text).

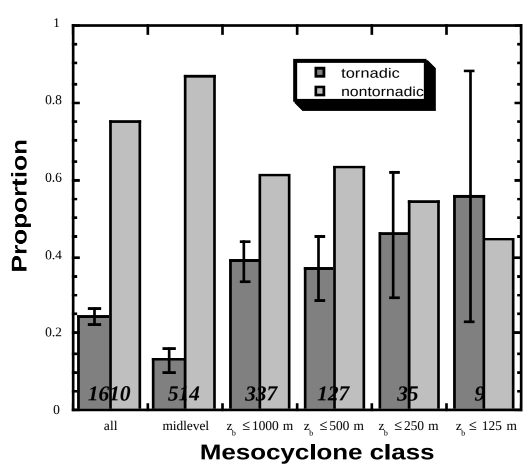

FIG. 2. As in Fig. 2, except for a subset of the dataset, in which consecutive mesocyclones within the same event are separated temporally by 45 min or more.