Duration and Movement of Mesocyclones Associated with Southern Great Plains Thunderstorms

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ABSTRACT

Examination of 320 mesocyclones recorded by the National Severe Storms Laboratory's Doppler radars over Oklahoma and adjacent portions of Texas during 20 spring tornado seasons of 1971–90 shows that tornado-producing mesocyclones in this region typically travel farther and live longer than mesocyclones that do not produce tornadoes.

1. Introduction

Owing to a lack of systematically recorded data, very little information is available concerning general characteristics of thunderstorm mesocyclones. Burgess (1976) tabulated basic features of 37 Oklahoma mesocyclones that were recorded by the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory (NSSL) research Doppler radars during the 1971–75 annual spring data collection programs; 62% of these mesocyclones produced tornadoes. During 1977 and 1978, the operational experiment, Joint Doppler Operational Project (JDOP), was conducted using NSSL's Norman Doppler radar to determine whether use of Doppler radar would improve severe thunderstorm and tornado warnings (JDOP Staff 1979). This was a milestone toward development of the WSR-88D Doppler radars that are currently being installed around the country. During the first year of JDOP, 26 mesocyclones were detected, and one-half had tornadoes associated with them. Looking in more detail at the data collected in 41 Oklahoma mesocyclones from 1971 through 1977, Burgess et al. (1982) computed the temporal and vertical evolution of the mean rotational velocity and core diameter within a typical mesocyclone. One-quarter of the mesocyclones had multiple cores, and if a mesocyclone produced a family of tornadoes, each new tornado was associated with a new core region.

In this study, we provide mesocyclone duration and movement statistics based on the above-mentioned datasets collected from 1971 through 1978 as well as basic information from log sheets recorded in real time during NSSL spring data collection periods from 1979 through 1990. Approximately 330 mesocyclones over Oklahoma and adjacent portions of Texas were recorded using the NSSL's Doppler radars. Emphasis was placed on mesocyclone track information and not on characteristics of mesocyclone evolution, because representative values of the latter were not recorded on the log sheets.

2. Data sources

a. Mesocyclone data collection

The data collection record began in 1971 when the 10-cm-wavelength Doppler radar at NSSL in Norman, Oklahoma, became operational (Kessler 1990). In 1974, NSSL's second 10-cm-wavelength Doppler radar at Cimarron Field (now Clarence E. Page Airport) near Yukon, Oklahoma, (41 km northwest of Norman) became operational. Over the 20-yr period, at least one of the radars was operational on an average of 22 days in April, 29 days in May, and 18 days in June.

Donaldson's (1970) mesocyclone recognition criteria were applied to the Doppler velocity fields to determine mesocyclone existence. The criteria involved the detection of a significant magnitude of tangential shear (see Table 1) with sufficient steadiness during the time required for one-half of a revolution of the mesocyclone vortex and with a vertical extent greater than the horizontal diameter. In operational Doppler radar tests aimed at detecting mesocyclones in strong-shear environments,

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TABLE 1. Various mesocyclone recognition criteria during the spring tornado seasons of 1971–90.

Year	Thresholds for mesocyclone core region	Vertical depth (km)	Source
1971–76	Shear $\geq 5 \times 10^{-3}$ s^{-1}	3	Donaldson (1970) Burgess (1976)
1977–86	(a) Shear $\geq 5 \times 10^{-3}$ s^{-1} for range $\leq$230 km	3	
	(b) Shear $\geq 1 \times 10^{-3}$ s^{-1} for range $>$230 km	none	JDOP Staff (1979)
	Rotational velocity $\geq$15 m s^{-1}		
1987–90	Rotational velocity $\geq$15 m s^{-1} for range $\leq$150 km Rotational velocity $\geq$11 m s^{-1} for 150 km $<$ range $\leq$230 km Core diameter $\leq$10 km	3	AFOTEC (1989)

specific recognition criteria were proposed that were expansions and modifications of the Donaldson guidelines (Burgess 1976). Recognition rules used during the JDOP featured single-Doppler azimuthal shear thresholds calculated from mesocyclone core diameter and maxima in outbound–inbound radial velocities (assumed to be tangential velocities). Because shear was not displayed directly but had to be computed, the recognition rules were further modified for the DOPLIGHT (Doppler/Lightning) '87 exercise (Forsyth et al. 1989) to replace shear with tangential (rotational) velocity. Rotational velocity is defined as the mean of the absolute values of maximum inbound and outbound radial velocities in a mesocyclone core signature. The rotational velocity represents an operationally expedient substitute for mesocyclonic shear. Table 1 lists the various mesocyclone recognition criteria used during the spring tornado seasons of 1971–90.

b. Limitations and problems with Doppler radar measurements

Doppler radar measurements were not collected continuously (i.e., 24 hours a day). Some mesocyclones were missed because of radar malfunctions and other hardware problems, and others were missed because the radars were not operated throughout all storm outbreaks. Sector scans rather than complete 360° scans were routine during portions of the storms' life cycles, except for certain projects: JDOP in 1978, DOPLIGHT '87 (Forsyth et al. 1988, 1989), and WSR-88D Initial Operational Test and Evaluation, Phase II in 1989 (AFOTEC 1989; Burgess and Lemon 1991). The interval of observation did not always include the entire lifetime of the mesocyclone. This resulted from frequent changes in the sector of Doppler sampling and movement of mesocyclones both into and out of the range limit associated with useful Doppler velocity data. Some mesocyclones were well formed before data collection commenced, and some still existed when data collection ended. Changes of pulse repetition frequency sometimes did not eliminate range-folding echoes, and mesocyclone signatures thus were obscured. Many mesocyclones were recorded beyond 230-km range by using finer azimuthal and vertical sampling (Burgess 1976). At far range, the width of the radar beam degraded measurement of peak velocities and mesocyclone recognition problems arose when the radar beamwidth approached the core diameter (e.g., Donaldson 1970; Brown et al. 1978). Owing to the earth's curvature, only the upper portions of mesocyclones were detectable at far ranges.

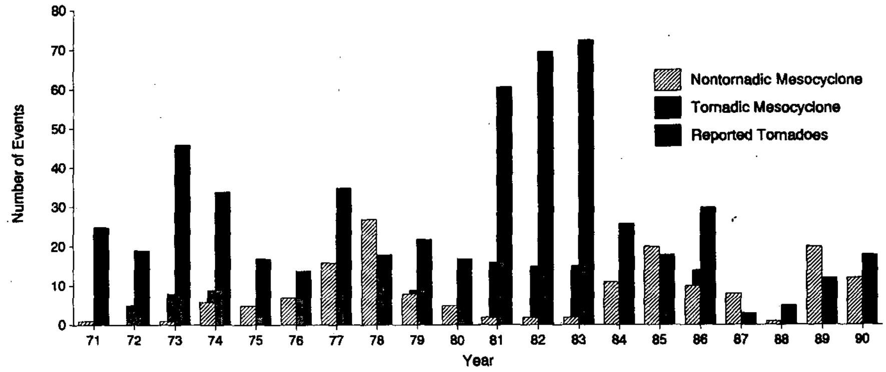

FIG. 1. Annual frequency distribution of nontornadic and tornadic mesocyclones sampled by NSSL Doppler radars from noon to midnight and the total number of tornadoes reported in Oklahoma for the spring tornado seasons (April–June) of 1971–90.

c. *Tornado report source*

The most reliable tornado reports used to assess and distinguish a tornadic mesocyclone from a nontornadic mesocyclone were from storm intercept teams (NSSL and others). The teams provided visual observations of thunderstorms that were measured simultaneously by Doppler radar and documented and photographed severe storm phenomena and related damages (Bluestein 1980; Lee et al. 1981; Davies-Jones 1988). Aerial and ground damage surveys were used to reveal relationships between damage and tornadoes associated with Doppler-observed mesocyclones. When a mesocyclone was recorded by Doppler radar and neither a tornado path nor debris was observed, the mesocyclone was considered nontornadic.

When both storm intercepts and damage surveys were not available, Grazulis's (1993) tornado documentation was used to determine tornadic or nontornadic mesocyclone events. The F0 and F1 (weak) tornadoes were excluded from Grazulis's (1993) chronology of tornado events, except when a confirmed F0 or F1 tornado killed a person. Where an F0–F1 rating was not available in the Grazulis book, tornado reports obtained from *Storm Data* (NOAA 1971–90) were used. When the approximate time and location of a reported tornado closely corresponded with the time and location of a mesocyclone as measured by Doppler radar, the mesocyclone was considered tornadic. Otherwise, the mesocyclone was labeled nontornadic. A funnel-producing mesocyclone was counted as nontornadic.

3. Mesocyclones sampled during the spring tornado seasons of 1971–90

Figure 1 shows the number of mesocyclones sampled between noon and midnight and the total number of tornadoes reported throughout the state during the spring tornado seasons of 1971–90. Several mesocyclones that were sampled during the 12-h period between midnight and noon were filtered out. The yearly totals indicate that nearly an equal number of tornadic and nontornadic mesocyclones were sampled over the 20-yr period. See section 2b for some reasons for the low number of sampled mesocyclones in comparison with the number of reported tornadoes in the figure. Some sampled mesocyclones produced multiple tornadoes.

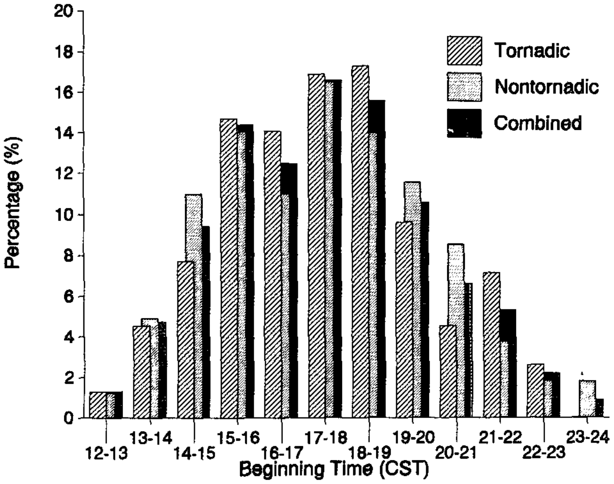

FIG. 2. Hourly distribution (%) of initial mesocyclone detection for tornadic, nontornadic, and combined mesocyclones sampled by NSSL Doppler radars from noon to midnight during the spring tornado seasons of 1971–90.

The distribution of initiation times for the sampled mesocyclones (Fig. 2) indicates a peak during late afternoon and early evening. Most mesocyclones began between 1500 and 1900 CST, with no significant differences between tornadic and nontornadic mesocyclones. The diurnal variation of tornado occurrence nationwide (Kelly et al. 1978; Grazulis 1993) is very similar to that of tornadic mesocyclones in Fig. 2.

The mean characteristics of nontornadic and tornadic mesocyclones are summarized in Table 2. The two characteristics that are different for the two mesocyclone categories are the distance traveled by the mesocyclone and mesocyclone duration. The data suggest that a tornado-producing mesocyclone typically travels about 30 km (63%) farther and therefore lasts about 40 min (62%) longer than a mesocyclone that does not produce a tornado. Other characteristics are quantitatively similar for both tornadic and nontornadic mesocyclones.

Most of the tornadic (nontornadic) mesocyclones traveled from directions between southwest and west

TABLE 2. Mean characteristics of nontornadic and tornadic mesocyclones sampled by NSSL Doppler radars between noon and midnight during the spring tornado seasons of 1971–90.

Characteristic	Nontornadic mesocyclone	Tornadic mesocyclone
Total number	164	156
Time of initial occurrence (CST)	1725	1728
Distance traveled (km)	43	70
Duration (min)	60	97
Speed (m s^{-1})	10	11
Direction moved from	263°	254°

TABLE 3. Monthly number and total number and percentage of weak (F0–F1), strong (F2–F3), and violent (F4–F5) tornadoes associated with tornadic mesocyclones between noon and midnight during the spring tornado seasons of 1971–90.

Month	Weak	Strong	Violent
April	14	16	5
May	53	35	6
June	18	7	2
Total	85 (55%)	58 (37%)	13 (8%)

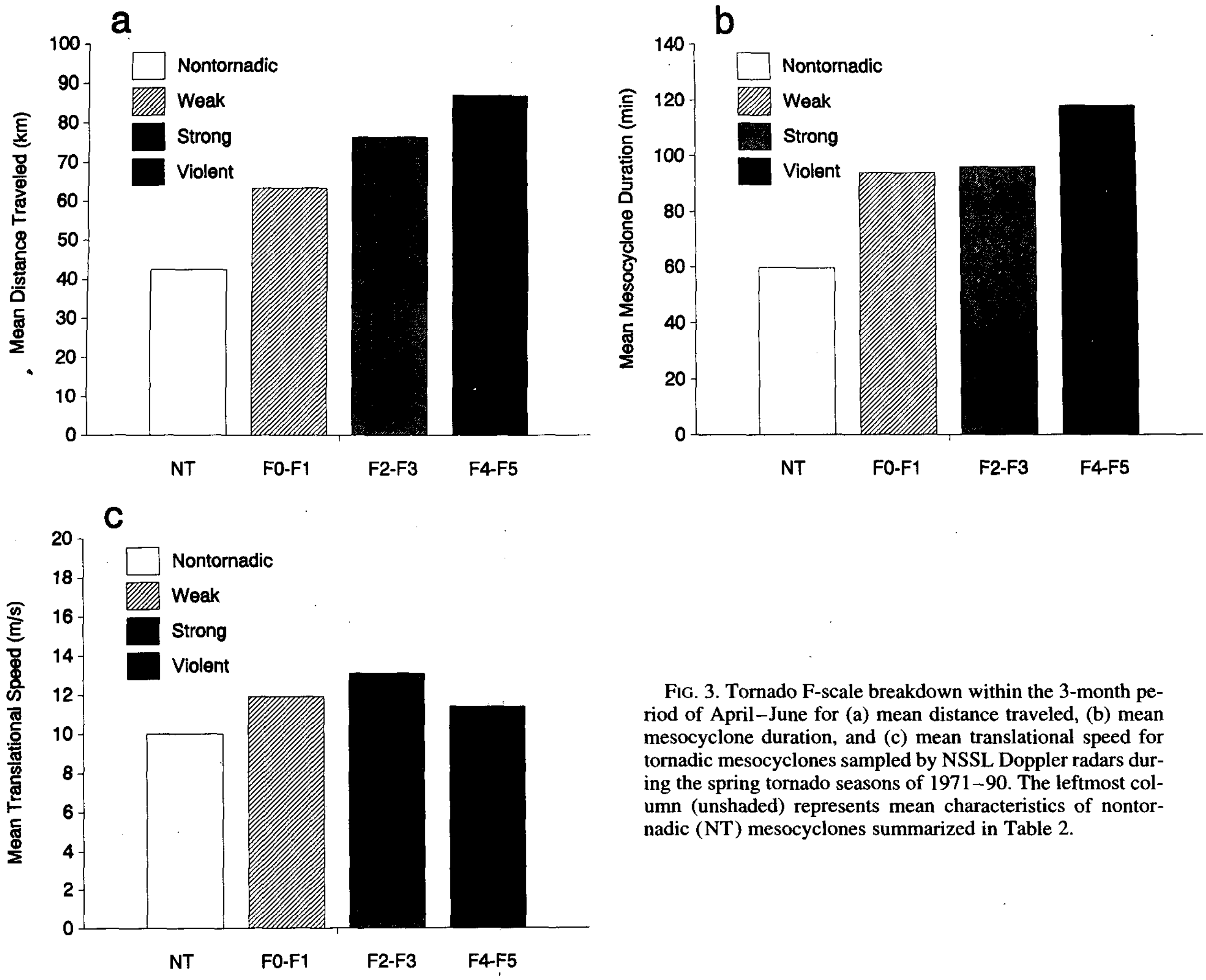

FIG. 3. Tornado F-scale breakdown within the 3-month period of April–June for (a) mean distance traveled, (b) mean mesocyclone duration, and (c) mean translational speed for tornadic mesocyclones sampled by NSSL Doppler radars during the spring tornado seasons of 1971–90. The leftmost column (unshaded) represents mean characteristics of nontornadic (NT) mesocyclones summarized in Table 2.

(southwest and west-northwest) with mean direction of 254° (263°). Fujita's (1987) findings on tornado movement nationwide are similar.

Mean translational speeds and directions are vector averages that were used to determine monthly variation of mesocyclone track characteristics during April–June 1971–90. Between April and June, mean mesocyclone (especially tornadic) distance decreased, mean duration and translational speed decreased slightly, and mean direction from which mesocyclones moved changed slightly from west-southwest to west. These changes were associated with the upper-level jet stream weakening and moving north with time and with more storms being in northwest flow in June.

4. Tornado F-scale ratings in relation to tornadic mesocyclone tracks

Essentially one-half of all thunderstorm mesocyclones sampled by NSSL Doppler radars during the spring tornado seasons of 1971–90 produced tornadoes, as shown in Table 2. The numbers of weak (F0–F1), strong (F2–F3), and violent (F4–F5) tornadoes associated with tornadic mesocyclones are presented in Table 3; the F scale is defined by Fujita (1981). Generally, 55% of all tornadic mesocyclones produced weak tornadoes, 37% produced strong tornadoes, and 8% produced violent tornadoes. This distribution is similar to that for tornadoes nationwide (63%, 35%, and 2%, respectively) according to Fujita (1987).

The relationship between tornadic mesocyclone duration and movement and associated tornado F-scale ratings is determined by averaging mesocyclone distance traveled, duration, and translational speed in the weak, strong, and violent categories of F-scale ratings (Fig. 3). Figure 3a indicates that mean distance traveled by mesocyclones increases with increase in F scale. This is in general agreement with Fujita's (1987) findings for tornadoes nationwide. Since the mean translational speed was essentially the same in all four mesocyclone categories, mean distance traveled and mean duration have similar characteristics.

5. Concluding discussion

A study of 320 tornadic and nontornadic mesocyclones recorded by NSSL's Doppler radars over Oklahoma and adjacent portions of Texas during the 20 spring tornado seasons (April–June) of 1971–90 reveals that (a) essentially one-half the mesocyclones were tornadic; (b) tornadic mesocyclones typically traveled 30 km (63%) farther and lived 40 min (62%) longer than nontornadic mesocyclones; (c) the mean translational speed was 10–11 m s^{-1} for both tornadic and nontornadic mesocyclones; (d) the movement of tornadic mesocyclones was predominantly from the southwest through west, with mean direction of 254°: for nontornadic mesocyclones, the movement was from the southwest through west-northwest, with mean direction of 263°; (e) most mesocyclones formed between 1500 and 1900 CST, with a mean formation time of 1727 CST; (f) early-season (April) tornadic mesocyclones traveled farther and faster and lived longer than late-season (June) tornadic mesocyclones; (g) more than one-half of all tornadic mesocyclones spawned weak (F0–F1) tornadoes, more than one-third produced strong (F2–F3) tornadoes, and a very small fraction produced violent (F4–F5) tornadoes; (h) mean distance traveled and mean duration of mesocyclones increased slightly with F-scale ratings. Despite limitations in data collection, we believe that the characteristics of the 320 mesocyclones used in this study are representative of southern Great Plains mesocyclones.

The data needed for comprehensive study of mesocyclones will become available as the network of WSR-88D radars is fully deployed. In the future, extensive digital data (Crum et al. 1993) will be available to derive automatically statistical relationships between Doppler velocity mesocyclone signatures and tornadoes. These relationships can be tailored to regional and even local differences in tornado climatologies.

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