CORRESPONDENCE

Comments on “The Regulation of Tornado Intensity by Updraft Width”

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1. Introduction

In a recent article, [Trapp et al. \(2017\)](#), hereinafter [T17](#) presented a theoretical case based on Kelvin’s circulation theorem to argue that wider updrafts are more likely to be associated with strong to violent tornadoes [enhanced Fujita (EF) ratings > 2] than narrower updrafts. They then presented idealized numerical simulations of supercell thunderstorms to support their contention. In their suite of simulated supercells, updraft area was highly correlated with midlevel mesocyclone area, downdraft area, and near-ground vertical vorticity magnitude. Larger midlevel mesocyclones were also strongly correlated with larger near-ground mesocyclones. The implications of their findings are potentially important, owing to the possibility of routinely measuring updraft widths in satellite imagery. Herein, we hope to shed additional light on the generality of their findings by presenting the relationships between updraft, downdraft, and mesocyclone area from a higher-resolution ensemble of nontornadic and tornadic supercells.

2. Methods

[Coffer et al. \(2017\)](#), hereinafter [C17b](#) produced an ensemble of 30 supercell simulations based on the nontornadic and tornadic environmental composite profiles sampled during the second Verification of the Origins of Rotation in Tornadoes Experiment [VORTEX2; [Wurman et al. \(2012\)](#); further details of the composite profiles are provided by [Parker \(2014\)](#) and [Coffer and Parker \(2017\)](#), hereinafter [C17a](#)]. The

ensemble was initialized by applying horizontal wind perturbations generated from a uniform distribution with a maximum magnitude of 2 m s^{-1} to the wind profile. The purpose of these small random perturbations was to produce a range of comparable, yet distinct storms in very similar environments.

The model configuration of [C17b](#) is summarized in [Table 1](#). Besides the differences in base-state thermodynamic and wind profiles (which will be discussed below), major variations between the model setup in [C17b](#) versus [T17](#) are as follows: finer horizontal grid spacing (125 vs 500 m), many more grid points in the lowest 1 km above ground level (AGL; 31 vs 2 grid points), different microphysical parameterization (NSSL rather than the Morrison scheme), and a different treatment of the bottom boundary condition (one that includes surface drag as opposed to a free-slip condition). Both sets of simulations use release 18 of the Cloud Model, version 1 [CM1; [Bryan et al. \(2003\)](#), also see the appendix of [Bryan and Morrison \(2012\)](#)].

In [section 3](#), relationships between updraft, downdraft, and near-ground and midlevel mesocyclone areas are compared using two different evaluation times. The first method uses the key time period of tornadogenesis or tornadogenesis failure as described in [C17b](#), while the second method uses the same definitions and approach as [T17](#). In either case, following [T17](#), we define core areas of updraft, downdraft, and mesocyclones by using the number of grid points within each storm that exceed a certain threshold. These thresholds are mostly as in [T17](#). Midlevel updraft and mesocyclonic vertical vorticity are defined by the thresholds of 20 m s^{-1} and 0.01 s^{-1} , respectively, at the closest model level to 6 km AGL. Also as in [T17](#), the vertical velocity threshold

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TABLE 1. Details of CM1 configuration from C17a and C17b.

Domain dimensions	200 km $\times$ 200 km $\times$ 18.16 km
Inner mesh	$\Delta x = \Delta y = 125$ m spanning 100 km $\times$ 100 km
Outer mesh	Stretching to $\Delta x = \Delta y = 4.875$ km (Wilhelmson and Chen 1982)
Vertical grid	115 levels starting at 10 m; $\Delta z = 20$ m below 300 m, stretching to $\Delta z = 280$ m at 12 km
Time step	Adaptive time stepping; initial large time step of 1 s
Microphysics parameterization	NSSL two moment (Ziegler 1985; Mansell 2010; Mansell et al. 2010)
Subgrid turbulence	1.5-order TKE closure (Deardorff 1980)
3D initialization	Updraft nudging (Naylor and Gilmore 2012)
Lateral boundary condition	Radiative upon outflow; specified upon inflow
Upper boundary condition	Impermeable and free slip, Rayleigh damping from a 14–18-km layer (Klemp and Durran 1983)
Bottom boundary condition	Semislip with $C_d = 0.0014$ (C17a)

of -8 m s^{-1} at approximately 3 km AGL is used to describe the downdraft area. One difference is that, for our simulations, we use “near ground” to refer to a height of 10 m AGL, compared to 250 m AGL in T17 (both are the lowest vertical model level in the respective CM1 configurations). Even so, the results presented below did not change appreciably if we instead evaluated near-ground statistics at 250 m AGL. Since vertical vorticity typically scales inversely with horizontal grid spacing, we also evaluated various thresholds of vertical vorticity. For example, we found that doubling the threshold to 0.02 s^{-1} roughly halved the computed mesocyclone area. Lower thresholds of vertical vorticity result in noisier far-field vorticity structures and higher total areas, but the “noise” is similar between each simulation and therefore the mesocyclone area is still the dominant signal. Therefore, for consistency, a threshold of 0.01 s^{-1} is employed as in T17.

3. Supercell thunderstorm characteristics from the VORTEX2 ensemble

a. Environmental differences between T17 and C17b

Common environmental forecasting parameters for the T17 and C17b simulations are shown in Table 2. The C17b simulations are characterized by larger convective available potential energy (CAPE) but similar lifting condensation levels (LCLs) as T17. Owing to the relatively minor wind perturbations used to initialize the ensemble, shear¹ parameters vary only by approximately 2 m s^{-1} in both the 0–2- and 0–6-km-AGL layer. The 0–2-km shear is considerably higher than the range tested in T17, while the 0–6-km shear values in the nontornadic (tornadic) ensemble approximately encompass the bottom (top) of the parameter space in T17. Notably, the values for both the nontornadic and tornadic

VORTEX2 ensembles (ntV2 and torV2, respectively) would be considered favorable for tornadogenesis relative to median values within the Great Plains region of the United States (e.g., Thompson et al. 2012; see further discussion in C17a). In short, these VORTEX2 environments seem like a worthwhile parameter space within which to investigate a possible updraft-tornado scaling relationship.

b. Relationships at time of tornadogenesis or tornadogenesis failure

First, storm characteristics are computed at the time of tornadogenesis or tornadogenesis failure as a test to see whether there is a clear discrimination between nontornadic and tornadic storms. In C17b, the key time period of tornadogenesis or tornadogenesis failure was subjectively determined in each ensemble member by looking at the vertical vorticity and pressure deficits throughout a 1-km-AGL column, as well as the near-ground wind speed. If the supercell failed to produce a tornado, then tornadogenesis failure was said to occur at the time of maximum surface vertical vorticity during the mature phase of the supercell. Figures 3 and 10 in C17b list the key time period for each simulation. The reader is referred to C17b for horizontal depictions of near-ground reflectivity, outflow temperature, and vertical vorticity, as well as low-level vertical velocity and lower-tropospheric dynamic lifting for each supercell.

TABLE 2. Environmental forecasting parameters from T17 and C17b. The surface-based parcel is used for CAPE (J kg^{-1}) and LCL (m). The 0–2- and 0–6-km shear values (m s^{-1}). Storm-relative helicity (SRH; $\text{m}^2 \text{ s}^{-2}$) was calculated using the Bunkers storm motion (Bunkers et al. 2000).

	CAPE	LCL	0–2-km shear	0–6-km shear	0–3-km SRH
T17	1500	1000	6–10	21–36	115–450
C17b-ntV2	2377	1129	13–15	24–26	353–388
C17b-torV2	2755	845	14–16	30–32	320–354

¹ The environmental vertical wind shear vector magnitude is referred to as simply “shear.”

FIG. 1. Supercell thunderstorm characteristics from the VORTEX2 ensembles: scatterplots showing relationships between (a) midlevel ($z \approx 6$ km) updraft area (km^2) and midlevel mesocyclone area (km^2), (b) midlevel mesocyclone area (km^2) and near-ground ($z = 10$ m) mesocyclone area (km^2), (c) midlevel updraft area (km^2) and

Adding only relatively minor variations to the environmental wind profile of the VORTEX2 composites produces a wide range of updraft, downdraft, and midlevel/near-ground mesocyclone widths (Fig. 1; Table 3) within the VORTEX2 ensemble despite similar 0–2- and 0–6-km shear. The full range of areal values from the VORTEX2 ensemble is comparable to the range produced by T17 via increasing the depth of the lower-tropospheric shear (and consequently increasing the deep-layer shear; Table 3). However, in our ensemble at the key time of tornadogenesis or tornadogenesis failure, there are only weak correlations between midlevel updraft core area and midlevel mesocyclone area (Fig. 1a; this lack of correlation will be briefly discussed below), between midlevel mesocyclone area and near-ground mesocyclone area (Fig. 1b), between midlevel updraft area and near-ground vertical vorticity (Fig. 1c), and between midlevel updraft area and 3-km AGL downdraft area (Fig. 1d). Similar results were found when looking 5 min earlier than the time of tornadogenesis or tornadogenesis failure. Notwithstanding T17's theoretical argument, the length scales of these features do not appear to be imparted on one another in this suite of 30 supercell simulations.

Only midlevel mesocyclone area and near-ground mesocyclone area show any appreciable correlation in our simulations ($R^2 \approx 0.21$), with larger midlevel mesocyclones being weakly associated with larger near-ground mesocyclones (Fig. 1b). In general, the more intensely tornadic supercells from the tornadic VORTEX2 ensemble have wider near-ground mesocyclones than the weakly tornadic and nontornadic supercells from the nontornadic VORTEX2 ensemble (Fig. 1b). Unfortunately, from an operational forecasting perspective, these larger near-ground mesocyclones are not appreciably correlated with the size of the midlevel updraft nor the midlevel mesocyclone.

We find an unexpected lack of correlation between the updraft and midlevel mesocyclone area within the VORTEX2 ensemble (Fig. 1a; this holds true for a variety of tested vertical vorticity thresholds). Of the theoretical relationships presented in T17, the correlation between updraft and midlevel mesocyclone size probably relies on the fewest assumptions. We speculate that the surprising lack of correlation in our output occurs because C17b used both real-world wind profiles and

near-ground vertical vorticity (s^{-1}), and (d) midlevel updraft area (km^2) and downdraft area (km^2) at $z \approx 3$ km. The values of updraft, downdraft, and midlevel mesocyclone areas represent the key time period of tornadogenesis or tornadogenesis failure for the respective ensemble members (as defined in C17b). Refer to Figs. 3 and 10 in C17b for the key time period for each simulation.

TABLE 3. Approximate ranges of storm areal characteristics (km^2) and near-ground vertical vorticity (s^{-1}) in T17 and C17b.

	Updraft	Downdraft	Midlevel mesocyclone	Near-ground mesocyclone	Near-ground vertical vorticity
T17	20–88	8–20	11–40	2–11	0.031–0.046
At tornadogenesis or tornadogenesis failure					
C17b-ntV2	37–65	2–15	48–72	16–31	0.08–0.46
C17b-torV2	42–60	4–13	61–83	25–36	0.3–0.68
At maximum extent as in T17					
C17b-ntV2	53–70	6–16	61–70	12–18	0.17–0.46
C17b-torV2	66–80	11–20	77–98	7–13	0.48–0.81

much finer grid spacing than T17. First, it is only in Beltrami flows (i.e., purely streamwise initial horizontal vorticity) that vertical velocity and vertical vorticity within the mesocyclone are perfectly correlated (e.g., Davies-Jones 1984, 2002; Lilly 1986). In contrast, both the nontornadic and tornadic VORTEX2 lower-tropospheric wind profiles contain crosswise horizontal vorticity components, especially in the lowest 500 m of the nontornadic wind profile. Crosswise horizontal vorticity leads to more unsteady updrafts and midlevel mesocyclones because of the lack of correlation between the updraft and the mesocyclonic vertical vorticity (C17a; C17b), as predicted by Davies-Jones (1984). Second, the midlevel mesocyclonic area will scale most directly with the area of tilting (i.e., $\nabla_h w$), rather than the area of the updraft (i.e., w) itself (Markowski and Richardson 2010). Pairing realistic hodographs (which are not smooth) with fine model grid spacing, these areas of tilting turn out to be rather compact.

These properties of unsteadiness and compactness should be more fully realized in simulations using a grid length closer to that of large-eddy simulation scales (i.e., ~ 100 m; Bryan et al. 2003). Indeed, we find that in simulations using coarser horizontal and/or vertical grid spacing, storm-scale features are steadier, broader, and smoother than in the present simulations (Figs. 2, 3). These overly smooth fields might give the mistaken impression that tornadogenesis occurs via “contraction of deep mesocyclonic-scale vertical vorticity” (as posited in T17, p. 4205). However, this differs from the process that appears to occur both in high-resolution simulations (e.g., Dahl et al. 2014; Markowski and Richardson 2014; Markowski 2016; Schenkman et al. 2014; Coffey and Parker 2017; Orf et al. 2017; Rotunno et al. 2017) and in high-resolution radar observations (e.g., Alexander 2010; Markowski et al. 2012a,b; French et al. 2013) of supercell thunderstorms. In these more detailed representations of tornadogenesis, finescale surface vertical vorticity maxima emerge from adjacent downdrafts and ultimately become superposed beneath the preexisting low- and midlevel mesocyclones in the parent supercell.

In this regard, the locations and scales of downdrafts are quite pertinent, and the hierarchical assumption of T17 is that the horizontal length scale of the primary downdraft relates to the horizontal length scale of the primary updraft. We find that in addition to their less-steady updrafts, the C17a and C17b simulations also do not exhibit a single persistent downdraft area. At 125-m grid spacing, downdraft areas are numerous, small in scale, and highly transient in the low levels (Fig. 2a), which makes it difficult even to define a “downdraft area” at times. This highly resolved depiction stands in contrast to the relatively steady forward-flank downdraft and rear-flank downdraft of the classical Lemon and Doswell (1979) supercell conceptual model. There are many mechanisms for downdraft formation, including latent cooling, hydrometeor loading, and dynamic pressure perturbations (i.e., the “spin-splat” forcing; Markowski and Richardson 2010). It stands to reason that these mechanisms can become much more volatile and short-lived in more turbulent flows, particularly those related to dynamic forcing. Presumably for these reasons, our simulated downdraft areas are not meaningfully related to updraft area (and, in fact, have a negative correlation).

c. Relationships using the T17 criteria for maximum extent

Storm characteristics were also computed as in T17. In this case, the values of updraft, downdraft, and midlevel mesocyclone areas represent their individual peak extents over an evaluation period between the time of storm split and the time of maximum near-ground vertical vorticity. The value of near-ground mesocyclone area is evaluated at the time of peak mesocyclone area at cloud base ($z \approx 1$ km AGL) rather than the actual maximum extent in near-ground mesocyclone area (i.e., the maximum at 10 m AGL). Based on the authors’ experience with simulations initialized with the VORTEX2 composite environments, storm splitting was defined at $t = 40$ min across each simulation (see Figs. 2 and 3 from C17a for examples of the evolution of reflectivity in the VORTEX2 environments).

Tornadic grid spacing experiments: 1 km vertical velocity

FIG. 2. Horizontal cross sections of 1-km-AGL vertical velocity (m s^{-1} ; shaded) at the key time period of tornadogenesis for various horizontal grid spacings. The 10-dBZ reflectivity contour (black) at 10 m AGL for the respective simulations is shown for reference.

When defining the analysis time as in T17, the correlations increase but are still rather marginal (Fig. 4). Each panel in Fig. 4 has an R^2 value that is consistently lower than the corresponding panel in Fig. 5 of T17. What correlations do exist seem largely to hinge on the bulk differences between the two VORTEX2 ensembles; the trends within each ensemble are just as weak as when looking at the specific time of tornadogenesis or tornadogenesis failure in section 2b (evident by the dashed individual trend lines in Fig. 4).

Using T17's definitions, the more intensely tornadic supercells from the tornadic VORTEX2 ensemble have wider updrafts, downdrafts, and midlevel mesocyclones, in addition to stronger vertical vorticity values (Fig. 4) than the nontornadic and weakly tornadic from the nontornadic VORTEX2 ensemble. However, the

near-ground mesocyclone area is actually larger for the nontornadic and weakly tornadic supercells from the nontornadic VORTEX2 ensemble than the intensely tornadic supercells from the tornadic VORTEX2 ensemble. The strongest correlation at the time of tornadogenesis or tornadogenesis failure in Fig. 1 is between the near-ground mesocyclone area and the midlevel mesocyclone area. However, this trend is reversed using T17's definitions in Fig. 4, with larger midlevel mesocyclones being associated with smaller near-ground mesocyclones.

Because T17 extracted peak values for each storm characteristic, irrespective of timing, each point in the scatterplot of Fig. 2 may represent a pair of values at different times. Although not directly reported in T17, in the VORTEX2 ensemble of C17b, these differences

FIG. 3. As in Fig. 2, but for the 500-m tornadic VORTEX2 supercell with (a) 115 and (b) 56 vertical levels.

in timing can be quite large. The maxima plotted on the abscissa in Figs. 4a–d can precede or lag the maxima plotted on the ordinate by as much as 25 min. Thus, while we find weak evidence for some of the relationships reported by T17, we question whether they are truly meaningful when these features' occurrence is often separated by over 20 min.

4. Summary

We wondered whether the linkages suggested by T17 would be evident in the large ensemble of high-resolution supercell simulations of C17b. Our findings are as follows:

- 1) In the C17b ensemble of nontornadic and tornadic supercells, midlevel updraft core area, midlevel mesocyclone area, near-ground mesocyclone area, near-ground vertical vorticity, and downdraft core area display minimal to no correlation ($R^2 \approx 0.04$ – 0.21 ; Fig. 1) at the time of tornadogenesis or tornadogenesis failure.

FIG. 4. As in Fig. 1, but for supercell thunderstorm characteristics from the VORTEX2 ensemble over an evaluation period between the time of storm split and the time of maximum near-ground vertical vorticity, similar to Fig. 5 in T17. Trend lines for the respective nontornadic and tornadic ensembles are shown as dotted lines.

- 2) When using values from the peak time for each variable (as in T17), correlations between the variables increase but are still rather marginal ($R^2 \approx 0.29$ – 0.54 ; Fig. 4) and much weaker than those reported in T17. The purported relationship between midlevel and near-ground mesocyclone areas is actually reversed in our ensemble.
- 3) Using T17's method for computing storm characteristics in our ensemble, the variables are often defined at different times, sometimes as much as 25 min apart.

With the near-LES resolution of the C17b ensemble, the characteristics of simulated supercells' drafts and mesocyclones are much more unsteady than in coarser simulations, which may explain a sizable portion of the differences between the T17 and C17b suite of simulations. Although we cannot conclusively state that our set of simulations is "correct" or even "more correct," we argue that the purported relationships between updraft width and tornadoes seem tenuous and require more stringent testing.

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