TROCHOIDAL PATHS TRACED OUT BY A SUBVORTEX REVOLVING AROUND A PARENT VORTEX: A SIMULATION STUDY

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OBJECTIVE OF THE STUDY
To develop novel parametric equations for simulating the transient behavior of a tornado track traced out by a hypothetical tornado rotating around a hypothetical parent mesocyclone (Fig. 1).

KINEMATICS OF A TROCHOIDAL MOTION
A trochoidal motion results from a rotating vortex that is itself revolving around another rotating vortex, as illustrated in Fig. 2.

EXPERIMENT A
Evolutionary characteristics of $C_{v}(t)$, $h_{v}(t)$, $h_{m}(t)$, $h_{p}(t)$, $C_{p}(t)$, and $C_{m}(t)$, as shown in Fig. 3. $C_{v}(t)$ denotes the cyclonic (positive) vorticity of the tornado vorticity field.

EXPERIMENT B
A cyclonic vortex (positive vertical circulation) is assumed to have a maximum vorticity of $C_{v}=10^{-2}$.

EXPERIMENT C
The tornado’s rotational speed $C_{v}$ linearly increases from 1 m/s to 40 m/s (Table 1 and Fig. 10).

ON-GOING AND FUTURE WORKS
Although trochoidal motions are the most interesting and useful of the many (semi-)analytic solutions that have been developed for open fields and town environments (Fig. 5), we believe that the model developed in this study highlights the gaps in our current understanding and interpretation of the relationship between the trochoidal motion simulations and the observed tornado damage.

To test our hypothesis, we will conduct laboratory experiments using a model tornado and a parent mesocyclone to simulate the interactions between the two.

FIG. 1: Idealized illustration of (a) basic trochoidal marks (black curves) on a surface of a hypothetical tornado’s center of rotation around a hypothetical mesocyclone (grey arrow) and the motion of the parent mesocyclone (white dot) for a given reference frame with origin $O$, $t_1$, given by the parent vortex position vectors $\vec{r}_{p}$ (green arrow), from point $O$ to point $P_{t_1}$ (heavy black dots). Subscript (s) stands for subvortex, and (m) is the position within which $P_{t_1}$ is centered represents a cyclonically rotating parent vortex. $\alpha$ is a small opening of the motion and is indicated by $\vec{e}_{\alpha}$. The parent vortex moving at its (red) vector velocity $\vec{v}_{p}$ around a curvilinear path (track) is defined by a blue dotted line.

FIG. 2: Damage map of the El Reno, OK tornado of 31 May 2011. Black, red, and green dots respectively denote the F0, F1, and F2 damage intensity footsteps. The tornado’s damage track, including loops and cusps, is indicated by a black, dotted curve. Black, thick circles denote the time (UTC) of the radar-detected location of the tornado. Red, dotted, dotted curves denote the location of an anticyclonic tornado and cyclonic circulation vortex. Magnetic arrows represent the approximate flow direction in the damage based on fallen trees, building debris, and streams in the examination based on a detailed survey find that the dots are deployment locations and times of the Radar mobile Doppler radar (shown by an arrow on the track). Photographic and high-definition videos of the tornado were taken at both sides. (Figure from Wackerman et al. 2015).

FIG. 3: Idealized trajectory of a vortex of a cyclonic vortex (positive vertical circulation) having $C_{v}$, Subscripts (s) and (p) respectively refer to subvortex and parent vortex. The model and essential components of the subvortex motion (speed and direction) are described on the circumferential plane of a circle (black) having its $(x, y, z)$ (blue thick line) respectively, indicated by the stochastic (or stochastic) position vector $\vec{v}_{s}(u, w, \theta)$ and the rotational velocity vector $\vec{u}_{s}(u, w, \theta)$ relative to the position of the parent vortex position $P_{t_1}$. A. Black, dotted lines represent the parent vortex’s track.

FIG. 4: Evolutionary characteristics of $C_{v}(t)$, $h_{v}(t)$, $h_{m}(t)$, $h_{p}(t)$, $C_{p}(t)$, and $C_{m}(t)$, as shown in Fig. 3. $C_{v}(t)$ denotes the cyclonic (positive) vorticity of the tornado vorticity field. A. Evolutionary characteristics of $C_{v}(t)$, $h_{v}(t)$, $h_{m}(t)$, $h_{p}(t)$, $C_{p}(t)$, and $C_{m}(t)$, as shown in Fig. 3. $C_{v}(t)$ denotes the cyclonic (positive) vorticity of the tornado vorticity field.