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Insights into Tornadogenesis from integrals of the vorticity equation and from angular-momentum advection

Robert Davies-Jones
Emeritus, National Severe Storms Laboratory

The first part of the paper reviews recent insights into tornadogenesis obtained through integrals of the vorticity equation for inviscid, dry, supercell-like flows. The flow is assumed to be steady so that the streamlines and trajectories coincide, and to be isentropic so that the potential vorticity is zero and the streamlines and vortex lines lie in the stationary isentropic surfaces. A parcel's vorticity consists of three partial vorticities: Beltrami-flow (barotropic) vorticity, non-Beltrami barotropic vorticity, and baroclinic vorticity. Beltrami vorticity is purely streamwise storm-relative vorticity that is imported from the environment. It explains why abundant environmental storm-relative streamwise vorticity close to the ground favours tornadic supercells. This vorticity flows directly into the base of storm updraft unmodified apart from streamwise stretching, thus establishing mesocyclonic rotation and low pressure in the updraft at low altitudes. The associated vortex suction can lift quite negatively buoyant air that may be underneath the updraft. The transverse component (positive leftward of the streamlines) of imported barotropic vorticity arises from environmental crosswise vorticity. Baroclinic streamwise (positive transverse) vorticity is generated in positive transverse (streamwise) temperature gradients. In the cyclonically curved flow outside the mesocyclone core, a 'river-bend process' turns positive transverse (imported or baroclinic vorticity) into the streamwise direction. Thus, increase (decrease) in storm-relative wind with height near the ground aids (hinders) tornadogenesis because the imported positive (negative) transverse vorticity is turned into streamwise (antistreamwise vorticity) within the mesocyclonic left-turning flow. The river-bend effect is particularly significant in air subsiding in the rear-flank downdraft. As this air approaches the ground, its streamwise vorticity is amplified due to packing of isentropic surfaces and streamline confluence. Subsequent upward tilting and convergence of this air causes a tornado.
The second part discusses circulation around fixed circles centered on vortices as a tool for tornado warning and tornadogenesis diagnosis. Computations of the Doppler circulation around and areal contraction rates of circles surrounding the Union City TVS indicate that aloft the initial mesocyclone had totally contracted into the mature tornado within a broad region of constant convergence, and that circulation is a useful warning parameter. Regarding tornadogenesis, the circulation around a fixed circle (in axisymmetric and asymmetric flow) increases via the line integrals of positive angular-momentum (AM) advection and decreases via the line integral of negative AM diffusion. An animation of an axisymmetric simulation (Davies-Jones 2008) illustrates tornado formation from inward and downward (positive) AM advection initiated by precipitation within the mesocyclone.