The Origin, Organization, Maintenance & Decay of Near-Surface Vortex in Tornadoes

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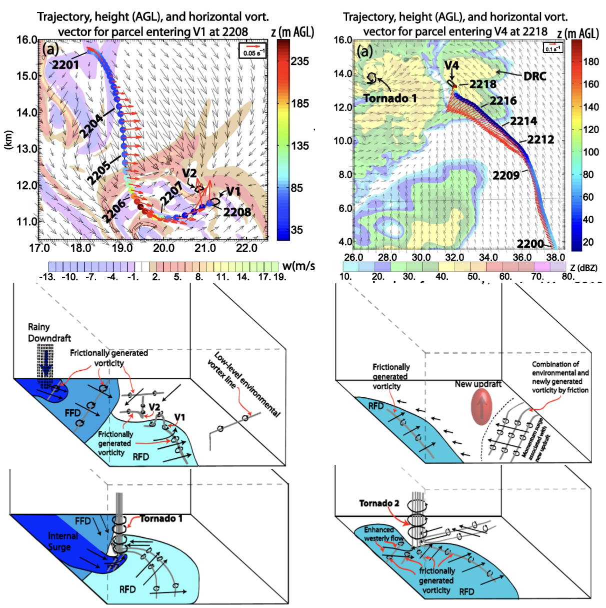
Introduction

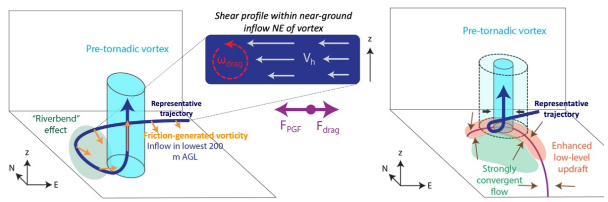
- The development of intense rotation near the ground is a fundamental aspect of tornadogenesis. The ***origin and organization of near-surface vertical vorticity*** leading to tornadogenesis have been topics of extensive research while ***the maintenance and dissipation of tornadoes*** have received less attention until recent years.
- As to the ***origin of vorticity,*** surface drag has been increasingly recognized to be able generate as much or even more near-surface horizontal vorticity as in-storm baroclinity. Such vorticity is then tilted into the vertical and amplified by intense vertical stretching to produce new tornadoes or maintain existing ones.
- For ***tornado maintenance or decay***, the ability for the parent storm to sustain sufficiently strong vertical stretching near surface is critical, while overcoming the tendency for strong downward motion within the tornado core is equally important. When and how intense near-surface vertical stretching can be created and maintained are topics of active research.
- In this poster, we highlight a number of our studies on these aspects of tornado dynamics.

Importance of Frictionally-Generated Vorticity

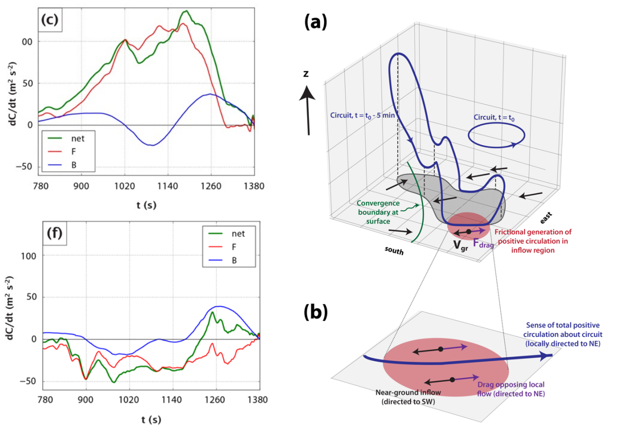
- Schenkman, Xue and Hu (2014 –SXH14) is the first study that elevated the community's interests on the role of surface-friction-generated vorticity. It is based on the analysis of a full-physics 50-m simulation of a supercell storm initialized via radar data assimilation.



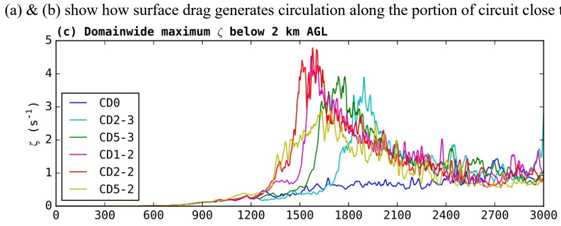
Detailed budget analyses along trajectories show that frictionally-generated horizontal vorticity within RFD internal surges and accelerated inflows from the east side contribute, much more than baroclinic generation, to horizontal vorticity that is tilted into developing tornadoes.



Based on idealized simulations, Roberts et al. (2016) proposed the above conceptual model, where frictional force generates leftward-pointing crosswise vorticity as inflow accelerates into the developing vortex. Via "river-bend effect" the crosswise vorticity becomes streamwise (left panel), which is then turned upward by the intensifying updraft and the vertical vorticity is intensified via stretching leading to tornadogenesis (right panel).

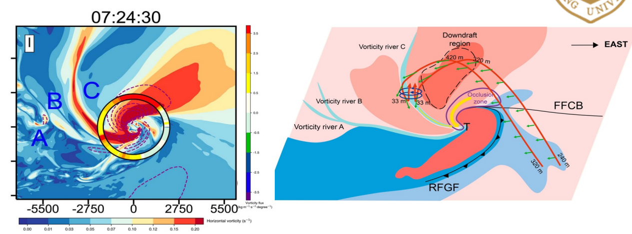


Roberts and Xue (2017) show how surface friction contributes significantly to the circulation of a material circuit ending around the 500 m AGL mesocyclone, which was critical for surface vortex intensification to reach tornado intensity (see panel c). Without the friction effect (f), the mesocyclone was much weaker and no tornadogenesis occurred until much later into simulation.
(a) & (b) show how surface drag generates circulation along the portion of circuit close to ground.



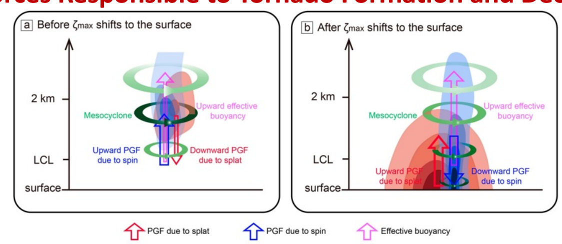
Roberts, Xue and Dawson (2020) show that tornado forms earlier as the surface drag coefficient Cd increases from low to moderately high values (from $2x10^{-3}$ though $2x10^{-2}$), but tornado forms later and is much weaker for high Cd value of $5x10^{-2}$. Tornado does not form with Cd=0.

The importance of fiction-generated vorticity is supported by recent studies from other researchers, including Markowski (2016, 2024); Yokota et al. (2018), Tao and Tamura (2020).

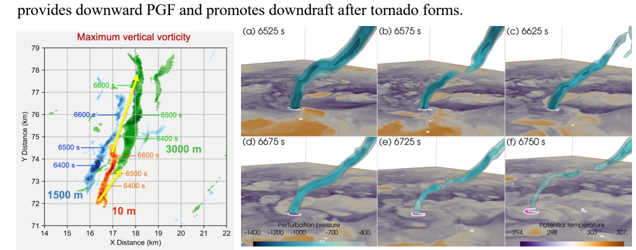


Huang and Xue (2025a) found that "rivers of vertical vorticity" in tornadic supercell simulations provide negligible vorticity contribution to the tornadic region, while influx of horizontal vorticity from the northeast side is much larger. The "rivers" form due to tilting of mostly friction-generated horizontal vorticity along narrow convergence bands in the left flank region.

Forces Responsible to Tornado Formation and Decay



Huang and Xue (2025b) show that while dynamic upward lifting by ~1 km low-level mesocyclone due to spin (rotation) term in dynamic perturbation pressure equation is critical for initial tornado vortex intensification, it is the spat term associated with near-surface convergence/deformation that provides continued dynamic upward PGF and stretching and keeps tornadoes going. The spin term provides downward PGF and promotes downdraft after tornado forms.



Our recent study (Huang and Xue 2026) reveals that the displacement of mid-level updraft/mesocyclone from ~1 km low-level mesocyclone (LLM) and tornado and the resulting weakening of LLM cause increase in downward dynamic PGF, decrease of near-surface upward acceleration/vertical stretching, and loss of large upward vertical vorticity advection critical for LLM maintenance. Occlusion downdraft also intensifies and connects up with central axis downdraft. Such sequences of events lead to tornado demise.

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