The impact of variations of low-level structure associated with surface drag on intensification of simulated tornadoes

QIN JIANG, DANIEL T. DAWSON II Department of Earth, Atmospheric and Planetary Sciences, Purdue University
Email: jiang703@purdue.edu Twitter: @Qinjiang46

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

Introduction

Surface boundaries in supercells have long been suspected of being important in the arrangement and concentration of vorticity for the development and intensification of tornadoes. It is known that surface drag can enhance radial inflow in tornadoes (Fig. 1), but additional research is required to clarify the role of surface drag in preconditioning the near-surface environment of tornadoes. We focus on the following two questions in this study:

1. How are the formation and evolution of surface convergence boundaries affected by the presence or absence of surface drag?
2. How do these variations of low-level structure affect the development of simulated tornadoes?

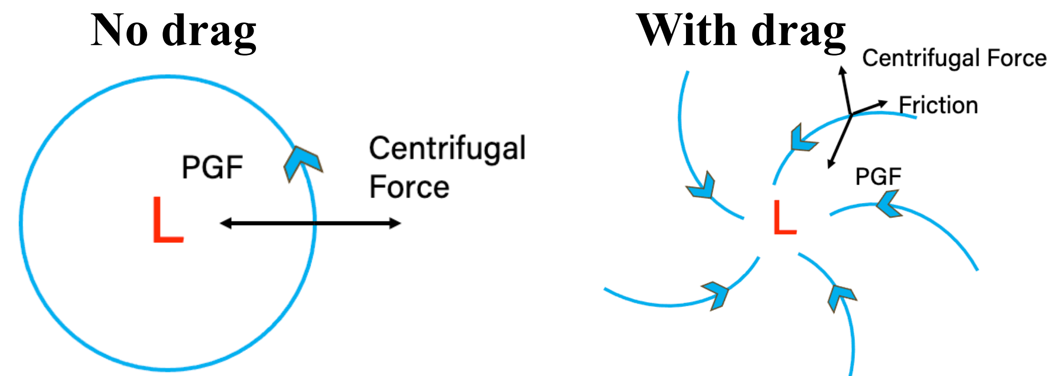

Fig.1. Surface drag disrupts cyclostrophic balance and enhances radial inflow near the surface (e.g. Howells et al. 1988)

Methodology

We use the CM1 model (Bryan and Fritsch 2002) to perform two idealized simulations at 100-m horizontal grid spacing of a tornadic supercell using an observed sounding from 31 March 2016 in northern Alabama: one without surface drag (FreeSlip) and one introducing drag (Free2Drag) 600 s prior to tornadogenesis. The goal is to focus on the impact of surface drag on the low-level structure on short time scales.

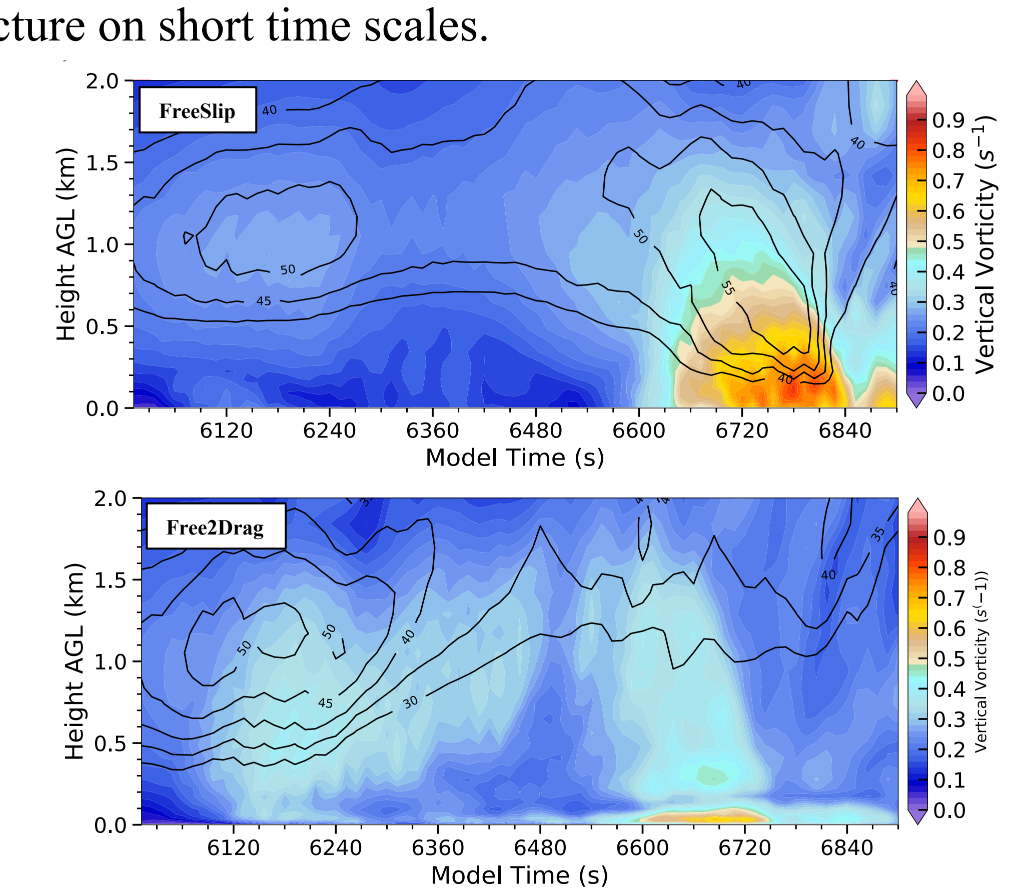

Fig. 2. Time-height plots of maximum vertical wind speed and vorticity for experiment FreeSlip and Free2Drag leading up to and during the period of tornadogenesis.

Evolution of convergence boundaries

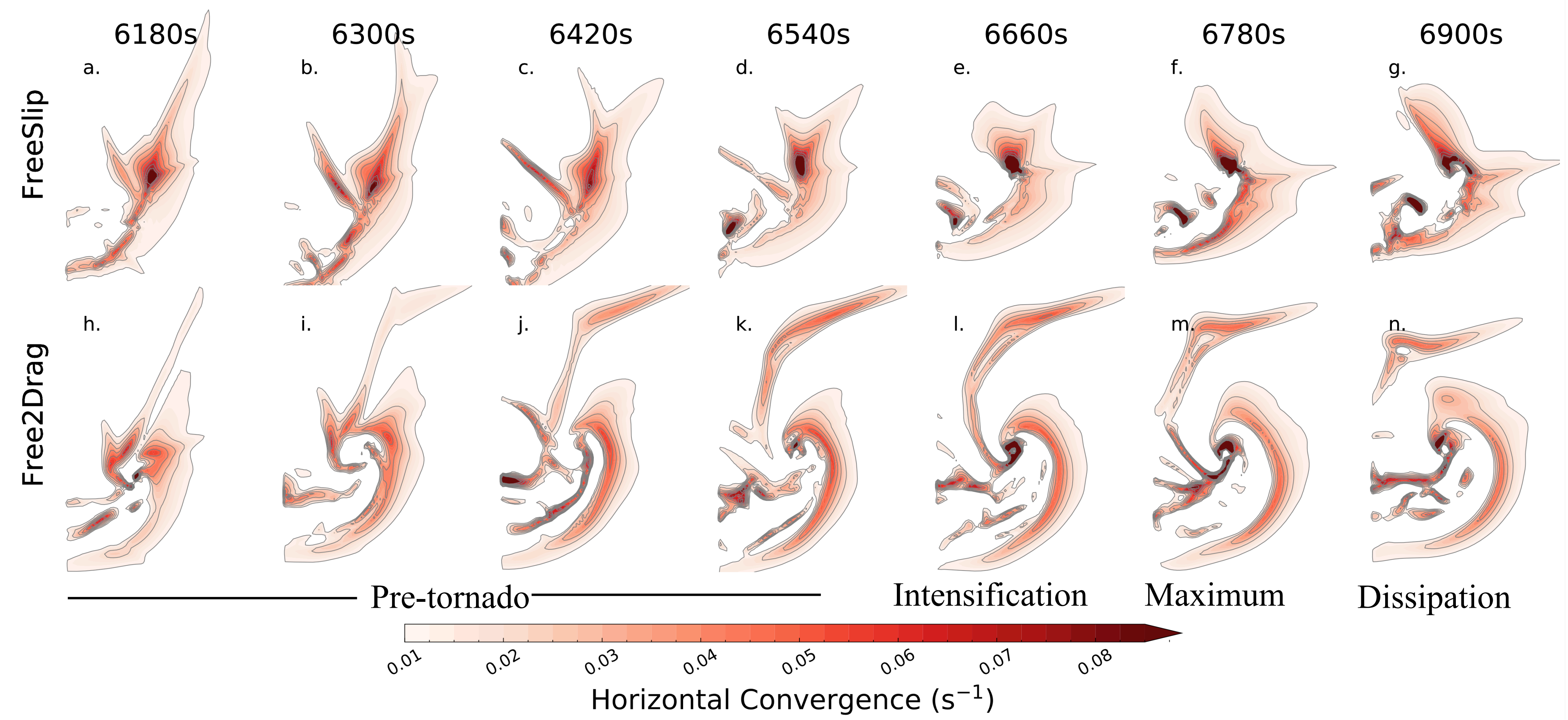

Fig. 3. Evolution of convergence boundaries at 30m AGL. Inclusion of surface drag substantially alters the low-level structure within minutes, resulting in greater curvature of the convergence boundaries, a stronger and more stable left-flank convergence boundary (LFCB; Beck and Weiss 2013), and additional transient secondary-rear flank convergence boundaries (SRFCBs).

Structure of simulated tornadoes

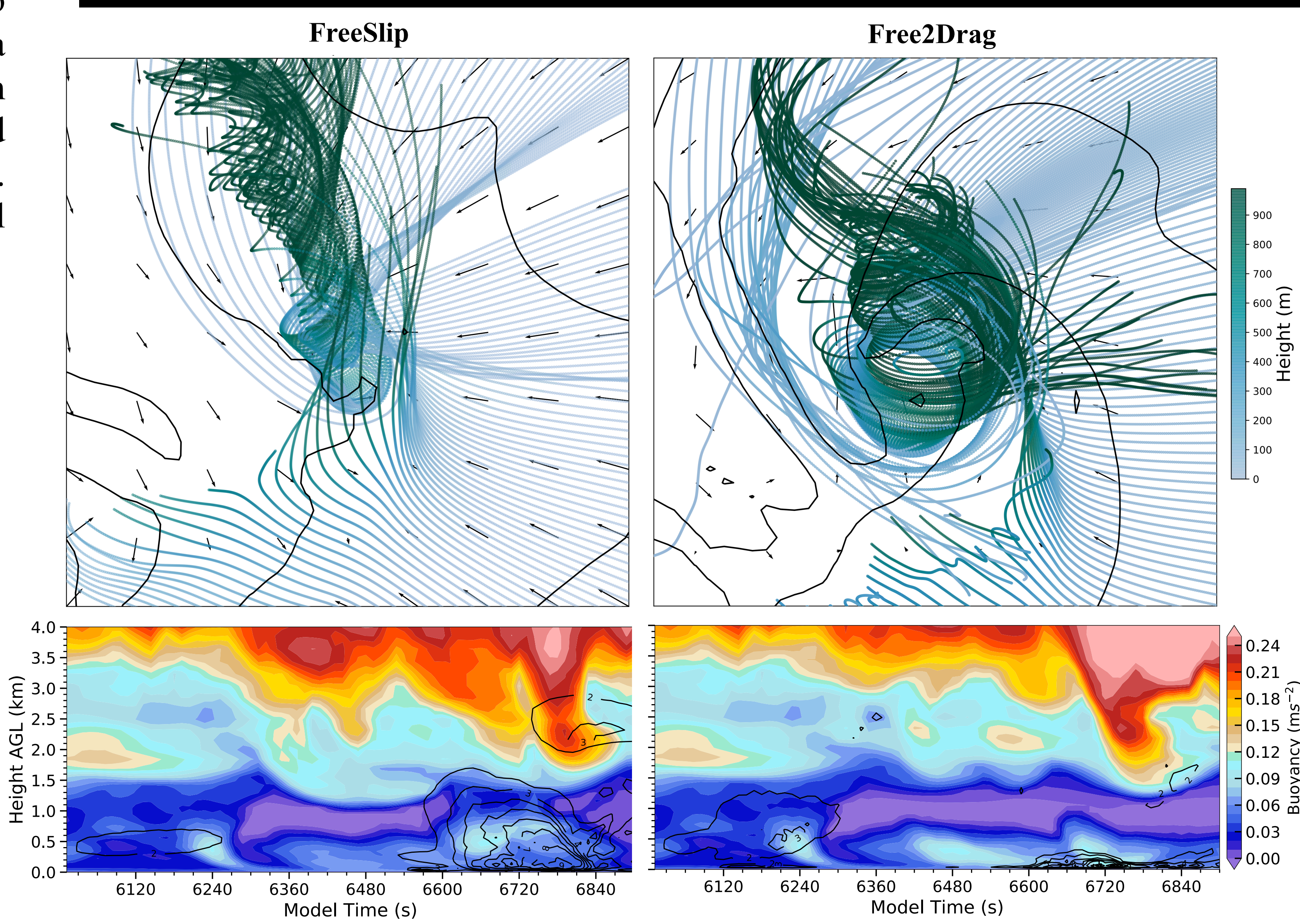

Fig. 4. (Top row) Collection of tornado source parcel trajectories; (Bottom row) time-height plot of buoyancy (shaded) and vertical perturbation pressure gradient force (VPPGF; black contour).

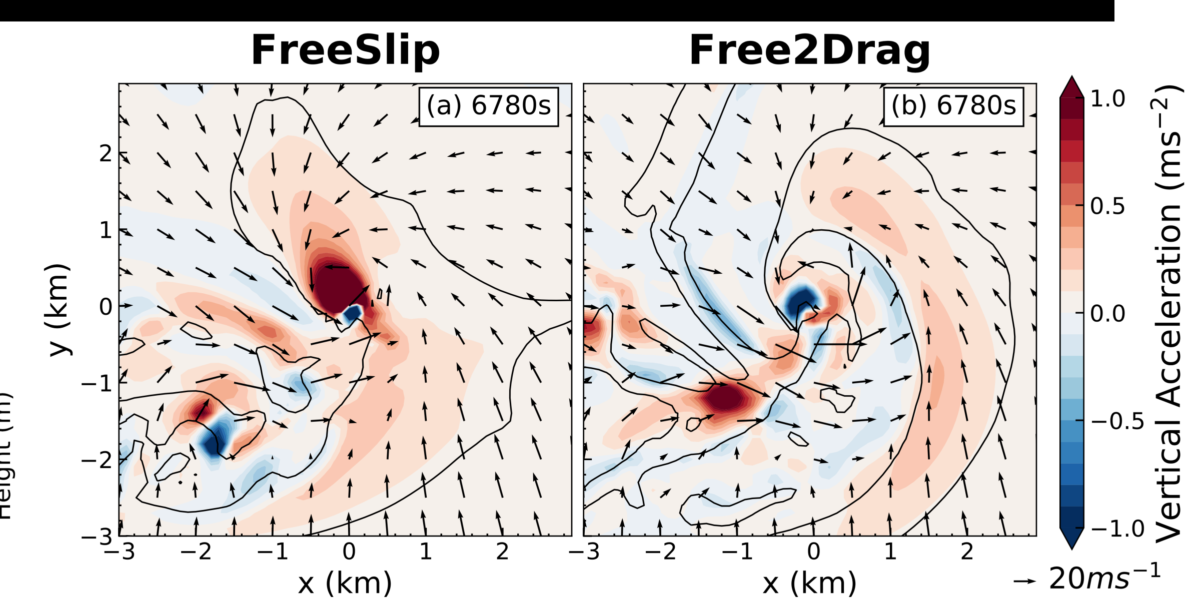

Fig. 5. vertical acceleration at 200 m AGL (shaded).

- In Free2Drag, the center of the simulated tornado near the surface develops detached from the rear flank gust front, whereas in FreeSlip, it remains embedded within the region of convergence associated with the gust front.
- The downward VPPGF associated with the stronger near-surface pressure deficit in Free2Drag suppresses vorticity stretching near the center, resulting in a weaker tornado (Fig.2 and 4).
- The tornado in Free2Drag also develops a larger horizontal circulation, suggestive of a two-cell vortex structure.

Distribution of near-surface vorticity

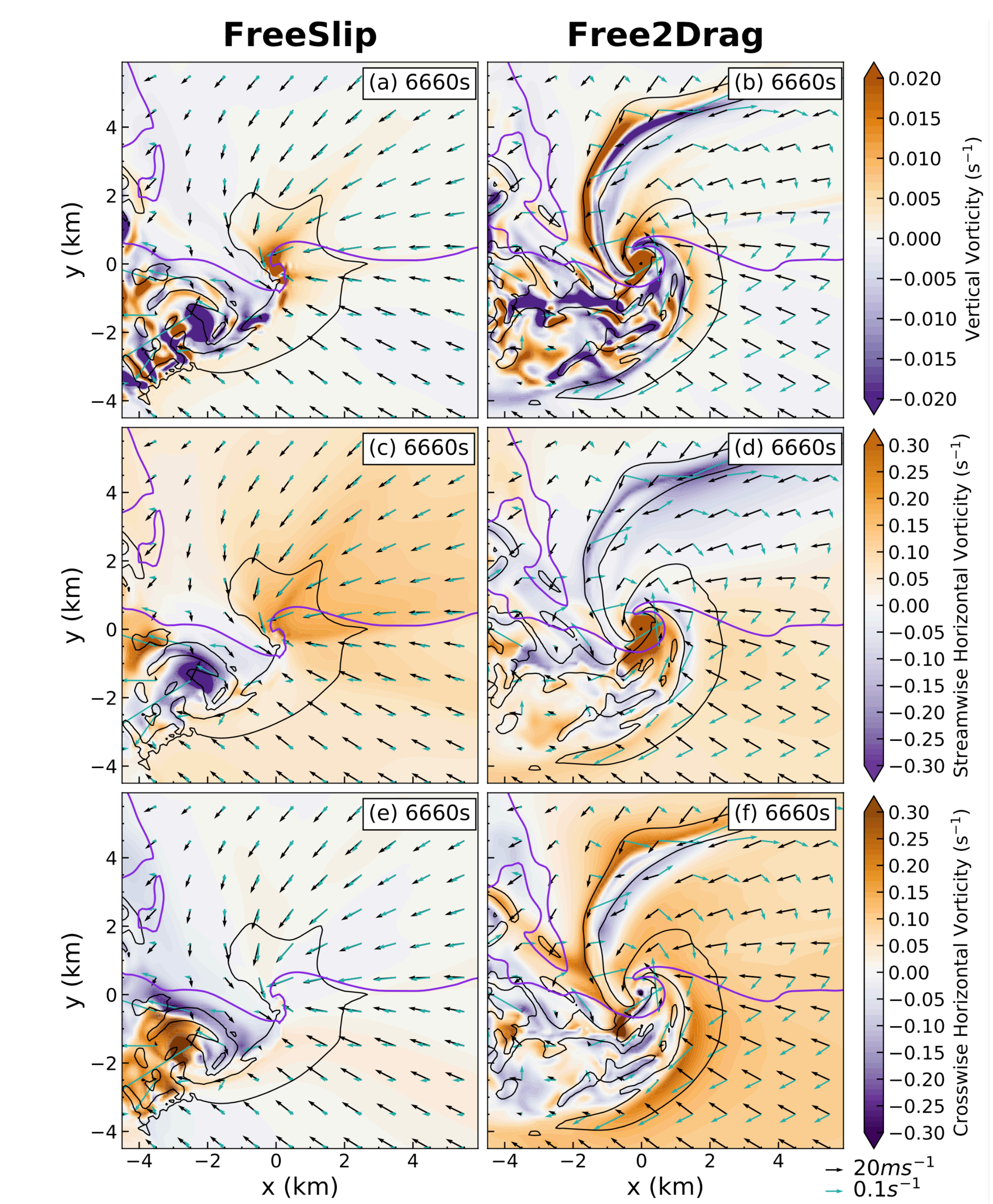

Fig. 6. Distribution (shaded) at 30 m AGL of vertical (top row), horizontal streamwise (middle row), and horizontal crosswise (bottom row) vorticity (shaded). Radar reflectivity (purple contour), storm-relative horizontal wind (black arrows) and horizontal vorticity vector (Green arrows) are also shown.

- The horizontal vorticity in FreeSlip is streamwise primarily in the forward flank region, which contributes to tornadogenesis through tilting and stretching.
- Friction-driven crosswise horizontal vorticity dominates near the surface in Free2Drag until the river-bend effect (Davies-Jones et al. 2001; Roberts et al. 2016) exchanges it into streamwise, resulting in the majority of positive streamwise vorticity located in the rear-flank region.
- The enhanced updraft associated with drag-induced convergence boundaries facilitates generation of vertical vorticity by tilting.
- Work continues to quantify the tornado vorticity sources and the role of the surface boundary evolution

Acknowledgments

This study is supported by a NASA FINESST Fellowship (Grant #12000402). We thank Mike Baldwin for providing the observed sounding used in the simulations and Ted Mansell for the use of the NSSL-3M microphysics scheme.

Reference

Beck, J., and C. Weiss, 2013: An Assessment of Low-Level Baroclinity and Vorticity within a Simulated Supercell. *Monthly Weather Review*, **141**, 649–669.
Bryan, G. H., & Fritsch, J. M. (2002). A Benchmark Simulation for Moist Nonhydrostatic Numerical Models, *Monthly Weather Review*, *130*(12), 2917-2928.
Davies-Jones, R., R. J. Trapp, and H. B. Bluestein, 2001: Tornadoes and tornadic storms. Severe Convective Storms, Meteor. Monogr., No. 50, Amer. Meteor. Soc., 167–221.
Howells, P.A.C., Rotunno, R. and Smith, R.K. (1988), A comparative study of atmospheric and laboratory-analogue numerical tornado-vortex models. Q.J.R. Meteorol. Soc., 114: 801-822.
Roberts, B., M. Xue, A. D. Schenkman, and D. T. Dawson, 2016: The Role of Surface Drag in Tornadogenesis within an Idealized Supercell Simulation. *Journal of the Atmospheric Sciences*, **73**, 3371–3395.