Exploring the influence of outflow surges on developing and mature tornadoes using a toy model

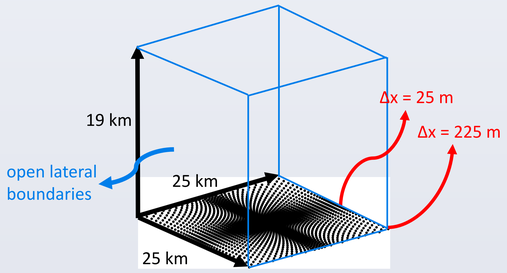
Valérian Jewtoukoff, Paul Markowski, and Yvette Richardson
The Pennsylvania State University, Pennsylvania, USA

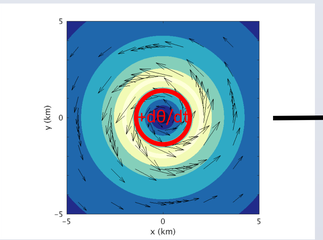
I. Motivation

- Downdrafts and negatively buoyant outflows important for development of near surface vorticity[2]
- Studies suggest an important role of outflow surges during tornadogenesis or on existing tornado vortices[5,7,6]
- ***Little is known about how they affect tornado-strength vortices***

II. Methodology

1. Highly idealized simulations of tornado vortex with CM1 version 18[1], modified to include TKE scheme by (3), with artificial heat source and sink added as in (4)

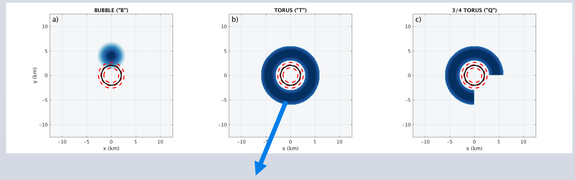




spinup a tornado through convergence and stretching

initial : Rankine vortex

2. In additional experiments, add heat sinks of various amplitude, timing, geometry ***to investigate influence on the tornado***



cool air to produce cold outflow or descending air to produce warm outflow

- **Possible effects:**

1. Convergence of high swirl air at lower radii
2. Baroclinic generation
3. Imbalance between inflow and outflow
4. Outflow totally undercuts the inflow

III. Control simulations (CTL)

- Structure qualitatively similar to (3): Early flow symmetry, and later development of asymmetry and presence of a central downdraft (Fig. 1)

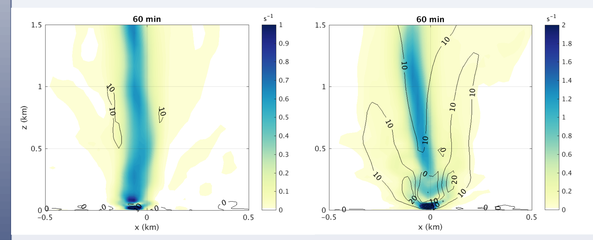


Figure 1: Vertical cross section along the x-direction. Vertical vorticity and velocity are represented using shading and contour. EF0 on the left, EF3 on the right.

- Intensification by convergence of high swirl air to lower radii (Fig. 2)

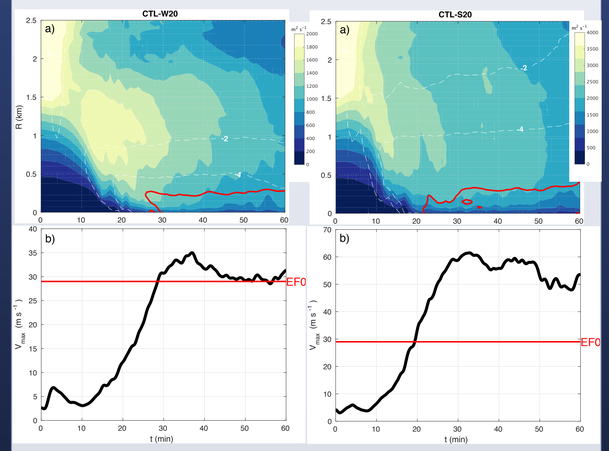
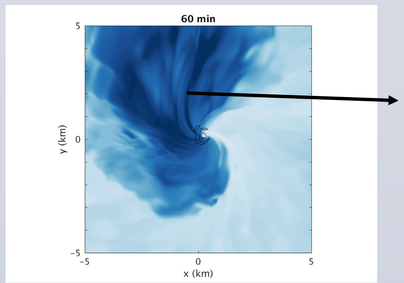


Figure 2: Time series of angular momentum (shaded) at 5 m versus range w = 4 m s^{-1} contour at 500 m AGL. EF0 on the left, EF3 on the right. Below are the maximum wind speeds at the surface.

IV. Cold surges

- Example for bubble shows cold air wrapping around the vortex (Fig. 3)



~ -1 K

Figure 3: Perturbation potential temperature (shaded) at 5 m AGL and w = 4 m s^{-1} contour for a weakly cold outflow.

- EF0: ***rapid*** intensification by 20-35% for strong outflows then death, no significant impact when intermediate outflow (Fig. 4 left)
- EF3: ***late*** intensification by 10-25% for weak outflows, death for stronger outflows (Fig. 4 right)

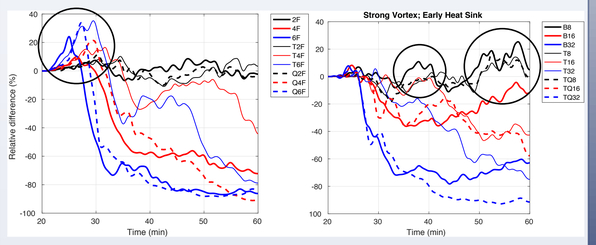


Figure 4: Relative difference for maximum wind speeds at 5 m AGL. EF0 on the left, EF3 on the right. Black: weak outflow (~ -1 K), red: intermediate outflow (~ -2 K), blue: strong outflow (~ -4 K).

a. Intensification

- Intensification coincides with correlation between updraft velocity and local convergence of high swirl air at lower radius (Fig. 5)

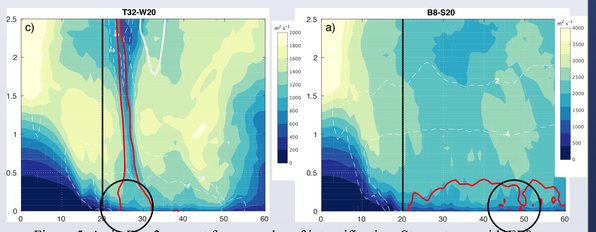


Figure 5: As in Fig. 2, except for examples of intensification. Strong torus with EF0 on the left, weak bubble with EF3 on the right.

b. Low impact or weakening

- Intrusion of high swirl air at lower radii but does not correlate with strong updraft velocity (Fig. 6)
- Momentum surge associated with cold air pushes vortex away from updraft (Fig. 7), in extreme scenario the outflow undercuts the updraft

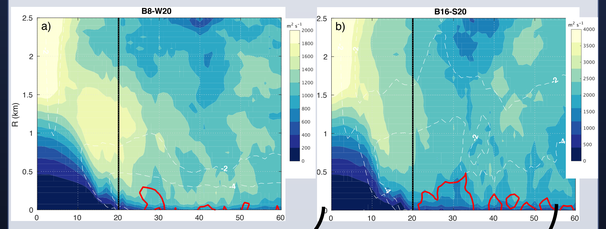


Figure 6: As in Fig. 2, except for examples with no impact or even weakening. Weak bubble torus with EF0 on the left, intermediate bubble on EF3 on the right.

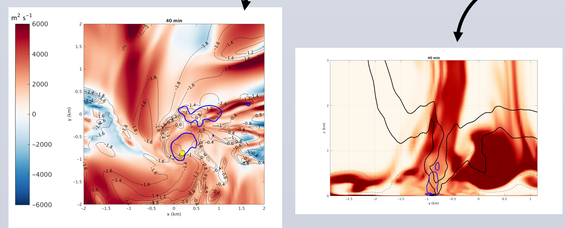
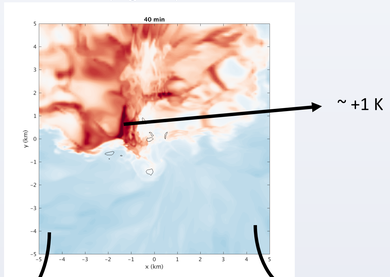


Figure 7: Left: Horizontal map of angular momentum (shaded) and perturbation potential temperature (black) at 5 m AGL, w = 4 m s^{-1} contour (blue) at 500 m AGL. Yellow dot denotes the vortex. Right: Tracer (shaded), w (black), vorticity (blue).

V. Warm surges

- Example of warm bubble (Fig. 8, 9)



~ +1 K

Figure 8: As in Fig. 3, except for a intermediately warm outflow.

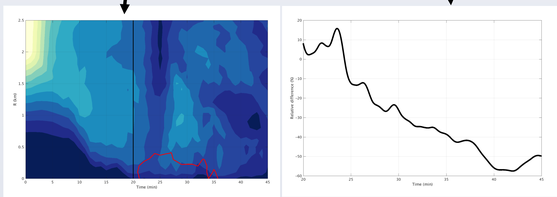


Figure 9: As in Fig. 2, except for a intermediately warm outflow.

- In this case, the updraft is not disturbed, but the inflow is significantly altered at 25 min

VI. Summary and conclusions

- Simulation of tornadoes with larger domain, and more realistic forcing and boundary conditions than (3)
- Circulation analyses (not shown) reveal that the surges are not significant *generators* of circulation (via baroclinic horizontal vorticity generation and subsequent tilting into the vertical)
- Intensification is ideal when a balance is achieved between convergence of high swirl air and updraft intensification
- Strong cold outflow (-4 K) has the potential to increase ***rapidly*** an EF0 vortex to EF1 for 10 min before killing it, but weaker outflows (-2 K, -1 K) do not significantly alter the vortex
- Weak cold outflow produce ***slow*** convergence of high swirl air that can potentially increase an EF3 vortex to EF4, but stronger outflows are detrimental
- In our simulations: -4 K always eventually kills the vortex

Acknowledgments

The authors would like to thank Dr. Dave Lewellen for clarifications about his parameterization, Dr. George Bryan for support with CM1, and Dr. Lou Wicker for discussions related to this study.

References

(1) Bryan, G. H., and J. M. Fritsch, 2002: A benchmark simulation for moist nonhydrostatic numerical models. *Mon. Wea. Rev.*, **130**, 2917-2928.

(2) Davies-Jones, R. P., R. J. Trapp, and H. B. Bluestein, 2001: Tornadoes and Tornadic Storms. Meteorological Monographs, 50, 167–222, doi: 10.1175/0065-9401-28.50.167.

(3) Lewellen, D. C., W. S. Lewellen, and J. Xia, 2000: The Influence of a Local Swirl Ratio on Tornado Intensification near the Surface. *J. Atmos. Sci.*, 57, 527–544.

(4) Markowski, P. M., and Y. P. Richardson, 2014: The Influence of Environmental Low-Level Shear and Cold Pools on Tornadogenesis: Insights from Idealized Simulations. J. Atmos. Sci., 71, 243–275.

(5) Marquis, J., Y. P. Richardson, P. M. Markowski, D. Dowell, and J. Wurman, 2012: Tornado Maintenance Investigated with High-Resolution Dual-Doppler and EnKF Analysis. *Mon. Wea. Rev.*, 140, 3–27.

(6) Schenkman, A. D., M. Xue, and D. T. Dawson II, 2016: The Cause of Internal Outflow Surges in a High-Resolution Simulation of the 8 May 2003 Oklahoma City Tornadic Supercell. *J. Atmos. Sci.*, 73, 353–370.

(7) Skinner, P. S., C. C. Weiss, M. M. French, H. B. Bluestein, P. M. Markowski, and Y. P. Richardson, 2014: VORTEX2 Observations of a Low-Level Mesocyclone with Multiple Internal Rear-Flank Downdraft Momentum Surges in the 18 May 2010 Dumas, Texas, Supercell. *Mon. Wea. Rev.*, 142, 2935–2960.

RESEARCH POSTER PRESENTATION DESIGN © 2015
www.PosterPresentations.com