Persistent low-level mesocyclones in simulated supercell thunderstorms

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Motivation:

- Recent studies (e.g., Thompson et al. 2003; Markowski et al. 2003; Doswell and Evans 2003; Esterheld and Giuliano 2008) have found that tornado occurrence is more likely with strong low-level wind shear (from the surface to ~1 km layer) (see references for details).
- We are evaluating whether this relationship is reproducible in idealized numerical model simulations. As a first step, here we use mesocyclone-resolving grid-spacing to evaluate the intensity and longevity of low-level mesocyclones.

Methodology:

Using a 3D cloud model, we conduct a series of idealized numerical simulations varying the 0-1 km shear only.

- Model: Bryan Cloud Model (CM1) (http://www.mmm.ucar.edu/people/bryan/cm1/)
- Domain: 120×120×20 km
- Grid spacing: 250m horizontal grid spacing, vertical stretch from 50 to 450m.
- Microphysics: Thompson et al. (2008), a hybrid scheme (having some characteristics of a single-moment scheme, and some characteristics of a double-moment scheme). Large-ice category is graupel in some conditions, and is hail in some conditions.
- Free-slip surface boundary condition.

Initial conditions:

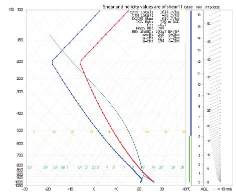

Fig. 1: Initial sounding [an idealized representation of the "significant tornado" composite from Doswell and Evans (2003)].

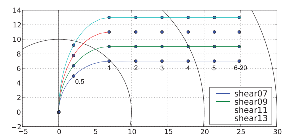

Fig. 2: Initial hodographs (axes in m s^{-1}) [idealized representations of composite hodographs from Markowski et al. (2003)].

Results: overview of all simulations

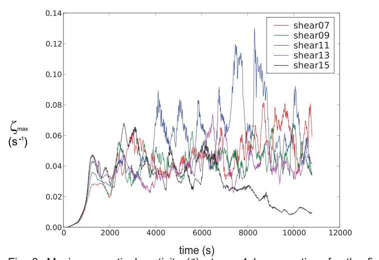

Fig. 3: Maximum vertical vorticity (ζ) at z = 1 km over time for the five simulations.

- Sustained supercells do not occur in these simulations if low-level shear is too strong (see "shear15" case).
- Low-level vertical vorticity (ζ) is largest for intermediate low-level shear for these simulations (see "shear11").

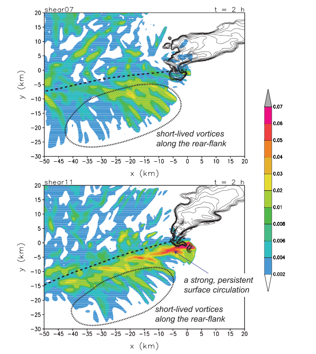

Fig. 4: Color shading shows the maximum value of ζ at the lowest model level from any time in the simulation (0-2 h). Thick, dashed, black line shows the approximate track of the mid-level updraft (0-2 h). Thin black contours show reflectivity at z = 1 km and t = 2 h (contour interval is 5 dBZ). Top panel is shear07, bottom panel is shear11.

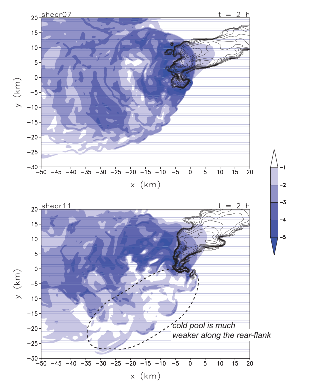

Fig. 5: Color shading shows potential temperature perturbation (K) at the lowest model level at t = 2 h. Black contours show reflectivity at z = 1 km and t = 2 h (contour interval is 5 dBZ). Top panel is shear07, bottom panel is shear11.

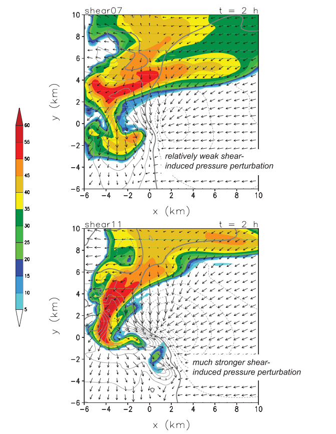

Fig. 6: Output at t = 2 h and z = 25 m. Color shading is reflectivity (dBZ). Vectors illustrate storm-relative flow at this level. Contours (negative values are dashed) show the linear component of perturbation pressure, defined by $\nabla^2\pi_l' = -2\, d\mathbf{V}_h/dz \cdot \nabla w$. Top panel is shear07, bottom panel is shear11.

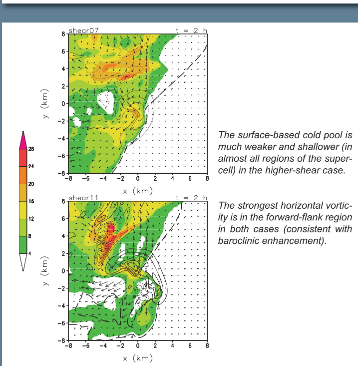

Fig. 7: Output at t = 2 h. Color shading is cold pool intensity (i.e., vertically integrated buoyancy in cold pool, m s^{-1}). Vectors illustrate horizontal vorticity at z = 25 m. Contours show vertical velocity at z = 1 km (negative values are dashed, contour interval is 3 m s^{-1}). Top panel is shear07, bottom panel is shear11.

Conclusions (preliminary, pending further analysis)

- Consistent with previous observational studies (e.g., Doswell and Evans 2003, Thompson et al. 2003, Markowski et al. 2003) and idealized numerical simulations (e.g., Wicker 1996) we find that strong, persistent low-level mesocyclones are more favorable as low-level (0-1 km) wind shear increases.
- The intensity of cold pools around the low-level updraft are notably weaker with strong low-level shear. [This result holds over different soundings, hodograph structures, model resolution, and model physics (not shown).] We surmise that the interaction between cold pools and low-level flow is playing an important role in these simulations.
- There may also be a role from shear-induced pressure perturbations in low-levels. Perturbation pressure is much lower on the downshear side of the low-level updraft, and this seems to be affecting flow and baroclinity in the forward flank region. Further analysis is necessary to understand these effects.
- Finally, the *direct* effect of low-level shear (via tilting and stretching of the low-level environmental vorticity) appears to be of small importance; further quantitative analysis is needed.

Acknowledgments:

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