Influence of Lifting Condensation Level on Low-Level Outflow and Rotation in Simulated Supercell Thunderstorms

Matthew Brown and Christopher Nowotarski

Department of Atmospheric Sciences, Texas A&M University

Introduction

- Tendency towards higher boundary layer relative humidity (and thus lower LCLs) in tornadic supercell environments (e.g. Thompson et al 2003; Craven and Brooks 2004)
- Ability of outflow parcels to be lifted depends on buoyancy of air near the updraft, and significantly tornadic storms often have less negatively buoyant outflow (e.g. Markowski et. al 2002; Grzych et al. 2007)
- Colder outflow inhibits the stretching of near–surface air and can potentially undercut low–level circulations, thus reducing the effectiveness of the vertical perturbation pressure gradient force (Gilmore and Wicker 1998; Markowski and Richardson 2014)
- Guarriello et al. (2018) found that low-level shear characteristics of simulated supercells affected the relative positioning of near-ground circulation embedded within storm outflow relative to the overlying updraft and mesocyclone, and subsequent production of near-surface vertical vorticity
- Given the relationship between LCL and outflow characteristics, it is plausible that LCL could influence mesocyclone positioning in a similar manner. We will assess this possibility by varying LCL in idealized simulations over a set of low–level wind profiles. The following research hypotheses will be addressed in doing so:

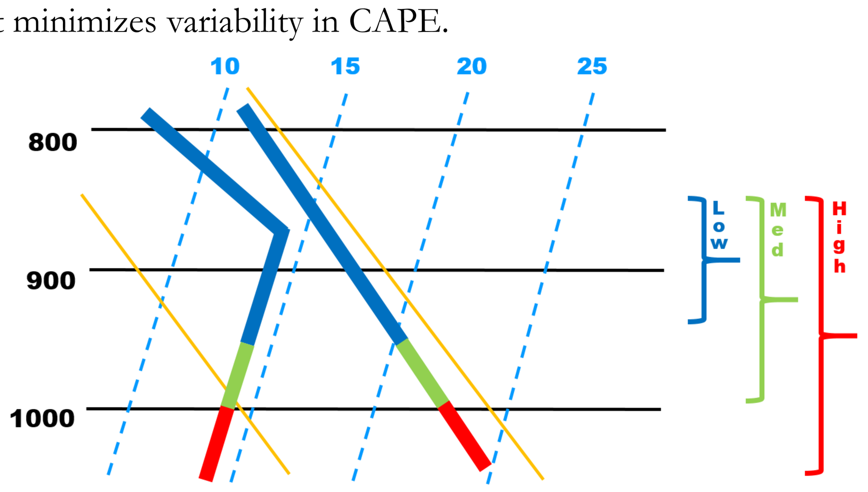
1) Changes in LCL will affect cold pool buoyancy in supercell thunderstorms, with higher LCLs leading to more negatively buoyant outflow.

2) A lower LCL will lead to less forward propagation of outflow and embedded near-surface circulation relative to the mesocyclone aloft in supercells.

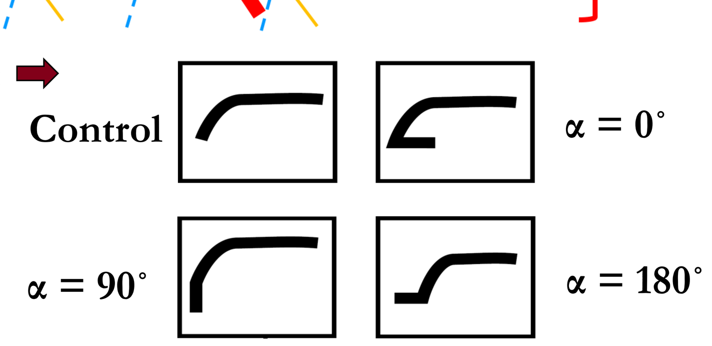
3) Near-surface vertical vorticity will be largest when the horizontal distance between the near-surface circulation and the mesocyclone aloft is minimized and the dynamic vertical perturbation pressure gradient force coincident with near-surface circulation is maximized.

Methods and Sounding Design

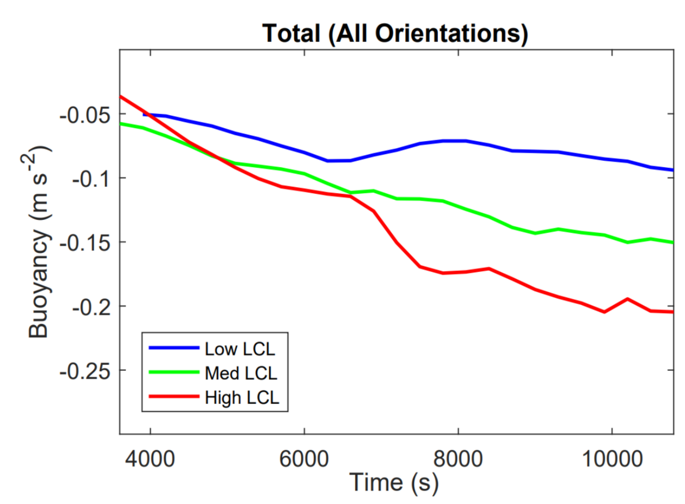
Three thermodynamic profiles were developed with different LCLs (~0.5, 1, 1.5 km) and combined with four low-level shear orientations, as illustrated below. Though previous studies, notably Lerach and Cotton (2012), have analytically altered LCL in model input soundings, this study changes LCL in a manner that minimizes variability in CAPE.



As per Guarriello et al. (2018), the angle (α) of the shear vector was altered over the lowest 500 m of hodograph.

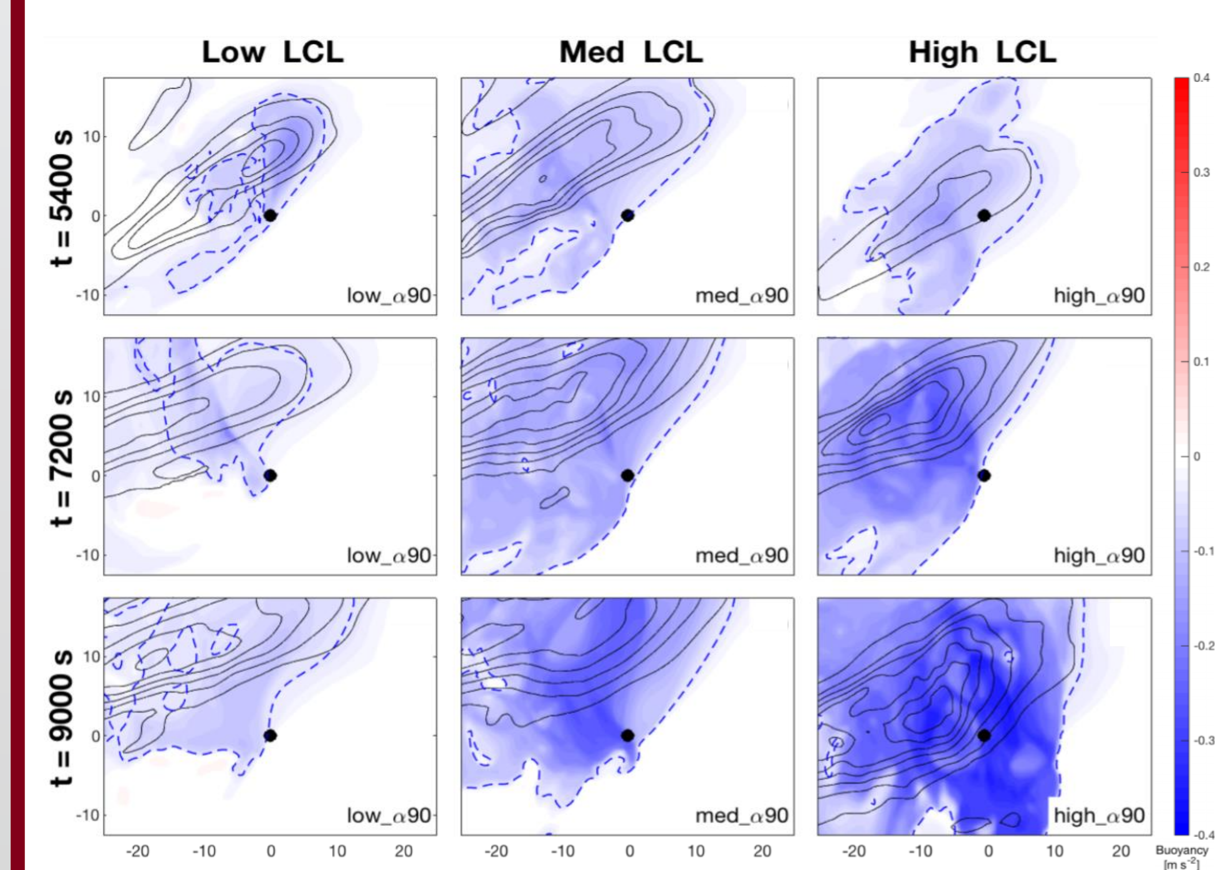


LCL and Outflow Buoyancy



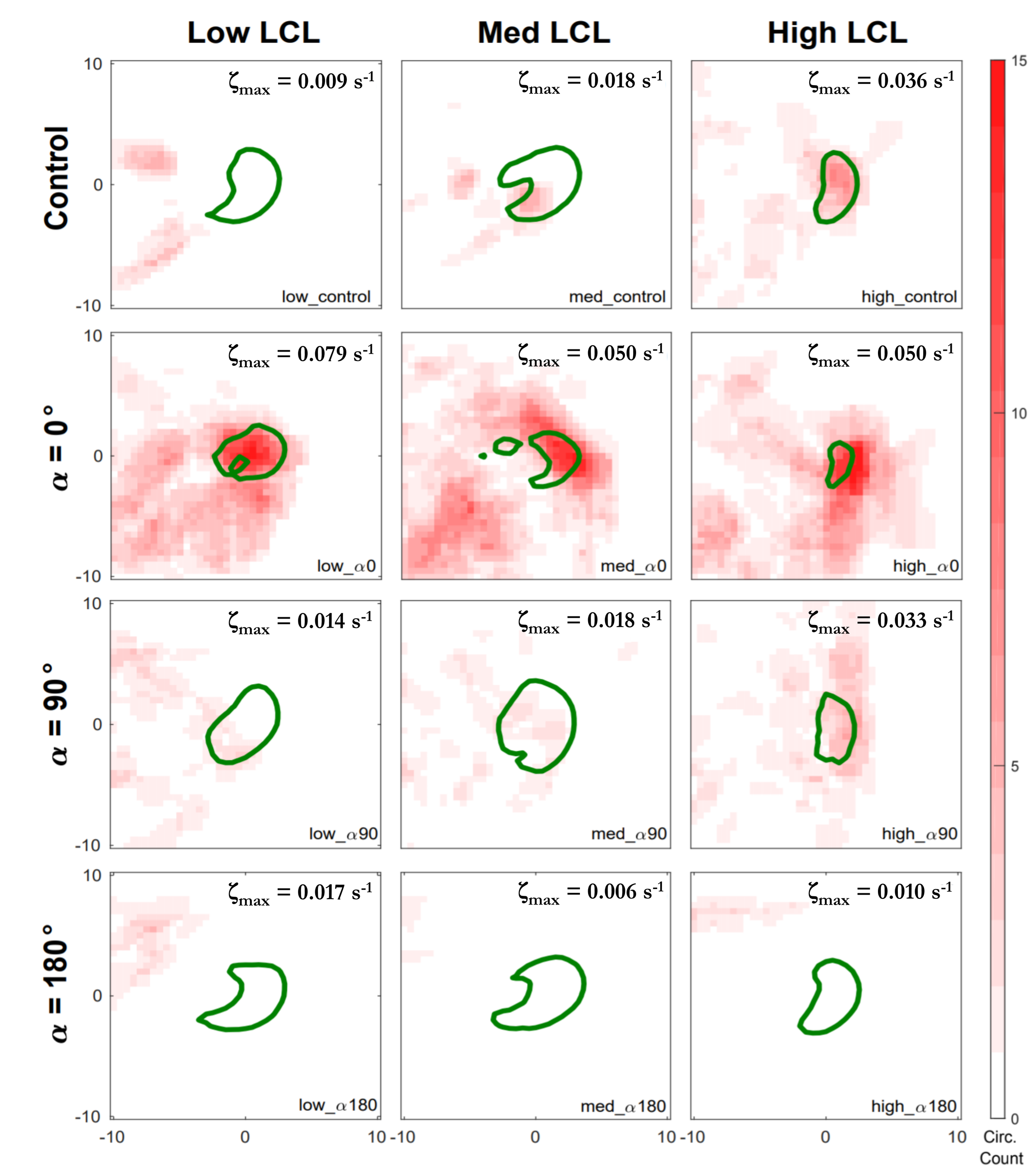
Cold pool buoyancy profiles diverge within the last 1.5 hours of model integration. This same divergence appears when the buoyancy profiles are separated by low-level shear orientation.

For a given shear angle (α = 90°, shown below for example), the cold pool becomes broader and more negatively buoyant as LCL is increased, supporting our first research hypothesis.

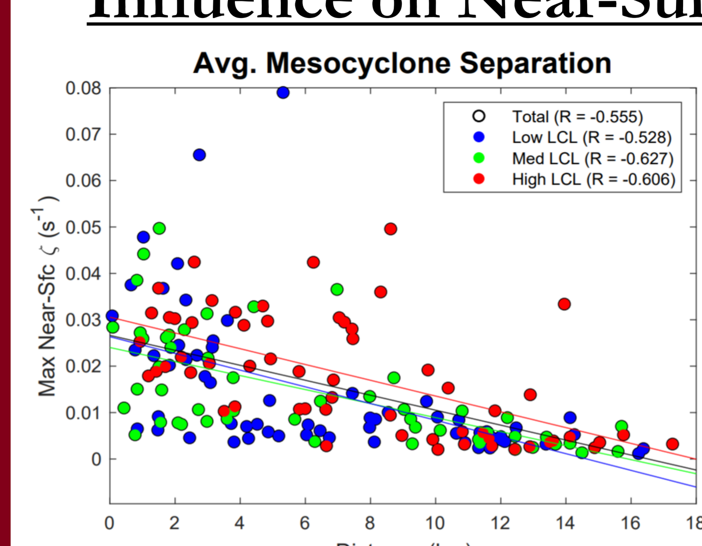


Circulation/Mesocyclone Alignment

In order to assess the influence of LCL on circulation positioning, we can create heat maps of appreciable (>5000 m^2 s^{-1}) near-surface circulation relative to the mid-level mesocyclone (500 m^2 s^{-2} 2-5 km integrated UH contour). These heat maps reveal a more forward positioning of near-surface circulation with higher LCLs. The influence of low-level shear orientation can also be distinctly seen.

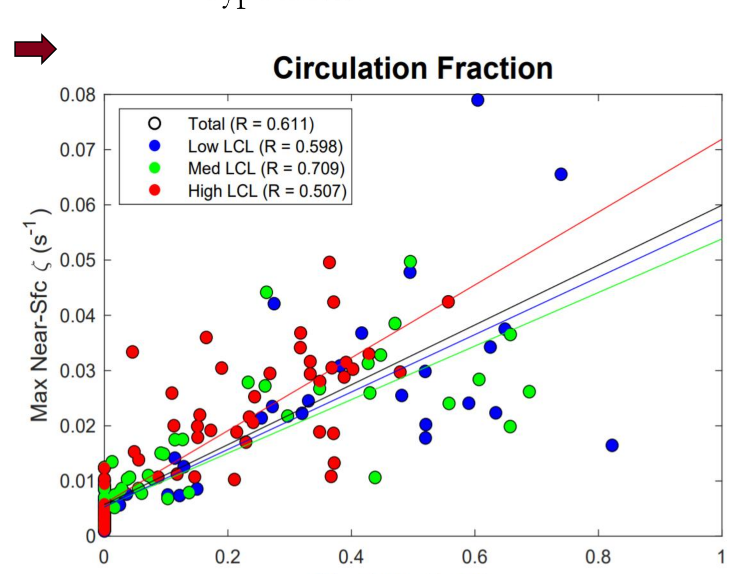


Influence on Near-Surface Vertical Vorticity

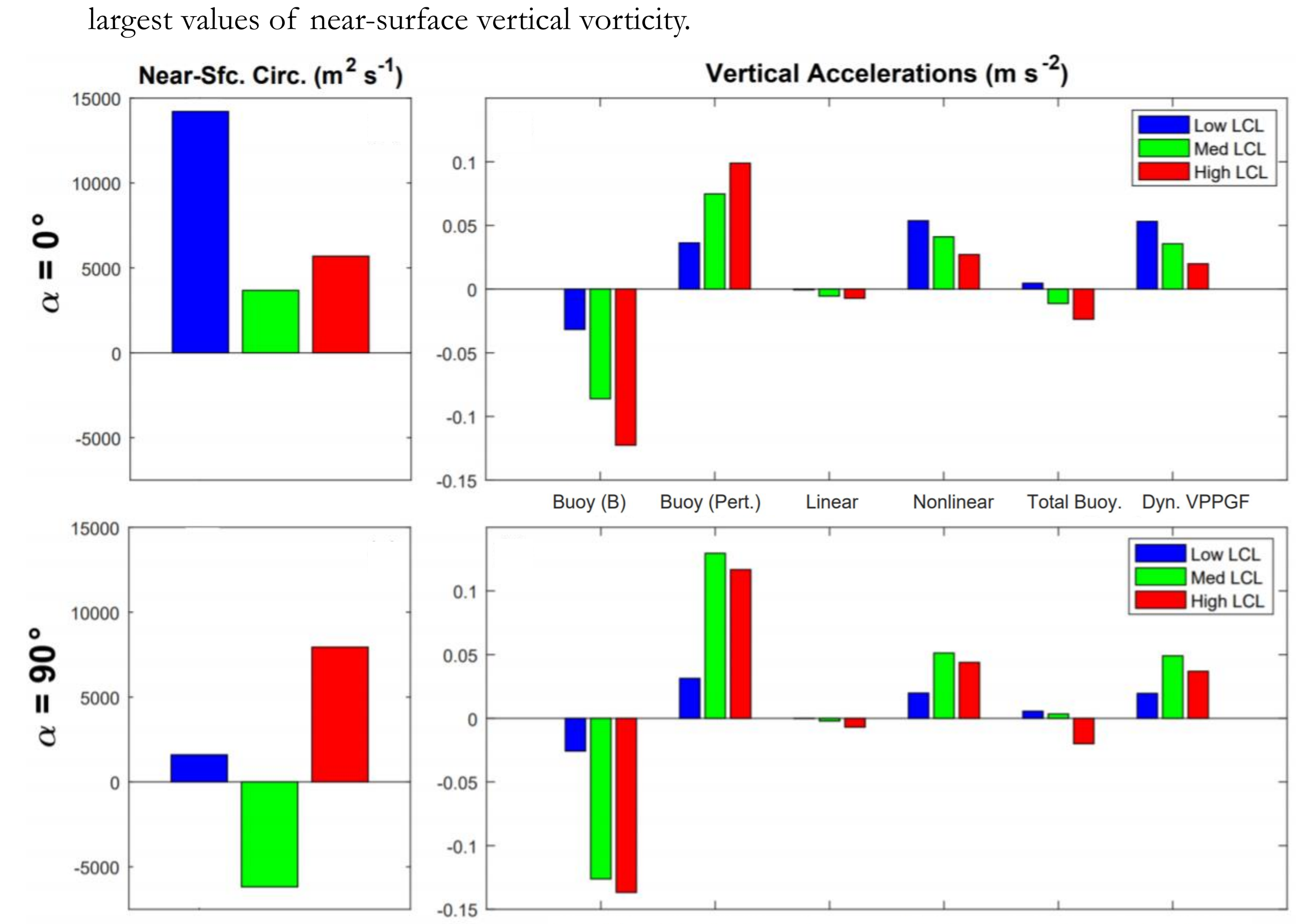


We can quantify mesocyclone separation by looking at the average displacement of appreciable near-surface circulation and the mid-level mesocyclone. A 5-minute lag correlation between this quantity and the maximum near-surface vertical velocity in our domain yields a general inverse correlation, which is consistent with our third hypothesis.

The position of the low-level mesocyclone is equally important for dynamic uplift and stretching of near–surface rotation. We quantify this using circulation fraction, defined as the fraction of grid points beneath the low–level mesocyclone (area at z = 1 km with w > 1 m s^{-1} and circulation > 10^4 m^2 s^{-1}) containing appreciable near–surface circulation. This quantity is positively correlated with near-surface vertical vorticity.



Following Hastings and Richardson (2016), we can decompose our pressure field one time step prior to the maximization of near-surface vertical vorticity. Integrating the 0-500 m vertical forcing beneath the mid-level mesocyclone, we see that positive dynamic VPPGF is collocated with appreciable near-surface circulation for the simulations which realize the largest values of near-surface vertical vorticity.



Conclusions

1. As LCL increases, storm outflow becomes more forward propagating and negatively buoyant.
2. Appreciable near-surface circulation tends to propagate faster, and is more likely to advect beneath and subsequently ahead of the mesocyclone aloft as LCL is increased.
3. When appreciable, positive near-surface circulation is collocated with the mesocyclone aloft and positive dynamic perturbation forcing at low levels, intense vertical vorticity can develop at the surface.
4. The interaction between low-level shear and LCL plays a distinct role in regulating the magnitude of rotation realized at the surface.

→The combination of LCL and shear effects influence the ability of surface circulation to propagate beneath the mesocyclone.

→Depending on low-level shear orientation, the LCL most favorable for the development of intense near-surface rotation may not be the lowest one.

Future Work

- Compare results with the near-storm environments of observed tornadic supercell cases, particularly those with higher LCLs and/or an ambient wind profile similar to our α = 0° simulations
- Rerun simulations with different model parameters, including:
  - →Grid spacing – *how does the positioning of circulation change when smaller scale vortices are resolved?*
  - →Microphysics – *how does the model's handling of hydrometeors change precipitation fields, and thus the spatial patterns of buoyancy?*
  - →Friction – *to what extent does frictionally-generated vorticity contribute to observed trends in near-surface rotation, especially as they relate to low-level shear alterations?*

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