Vertical Acceleration of Near-Surface Downdrafts in a Simulated Supercell Thunderstorm

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Introduction/Methods

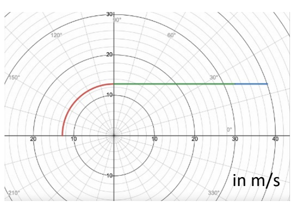
Research Goals

- Determine the vertical velocity (w) budget of supercell downdrafts
- Identify the term responsible for downward acceleration
- Connect that term to a physical process that occurs in supercells

Relevant CM1 Simulation Info

- 50-meter grid spacing below 6 km to better resolve vertical accelerations
- Boundary conditions: open radiative lateral, semi-slip lower
- Morrison 2-moment microphysics
- Warm bubble initiation at center of domain
- Grid translated at the Bunkers right mover velocity of the initial base state hodograph

Input sounding for the simulation is from Weisman & Klemp 1982 with a custom vertical wind profile (right)



0-1 km, 1-6 km, 6-10 km

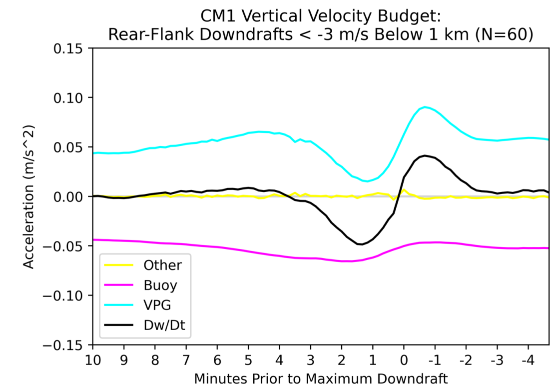
CM1 can solve for Lagrangian trajectories, along which the w-budget of downdrafts was analyzed.

- 108,000 trajectories initialized in a 3D box upstream of the simulated supercell
- Outputted w-budget data every 10 seconds

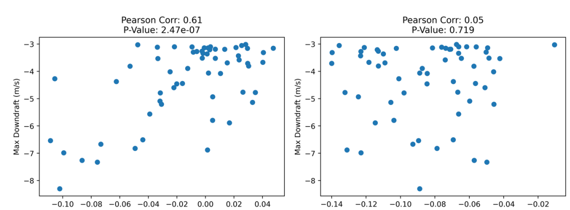
Results Part I

w-Budget: Vertical Momentum Equation

$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial p'}{\partial z} - \frac{\rho_{eff}'}{\bar{\rho}}g + Other$$



A drastic reduction in the vertical pressure gradient (VPG) combined with negative buoyancy results in downdraft acceleration.

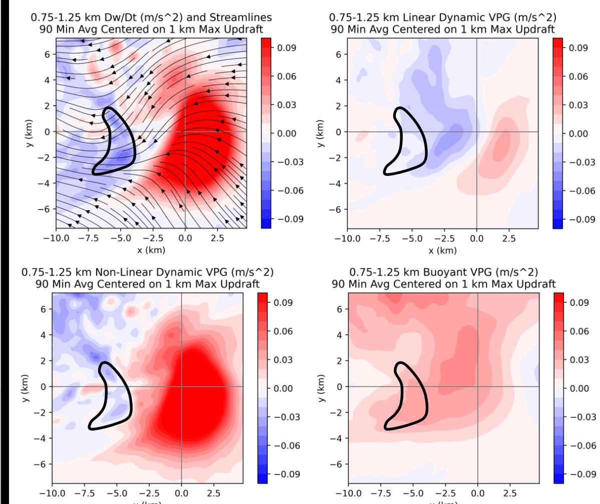


While the VPG was strongly correlated with resultant downdraft strength, buoyancy surprisingly showed no such relationship, indicating that reductions in the VPG are the driving force behind supercell downdrafts.

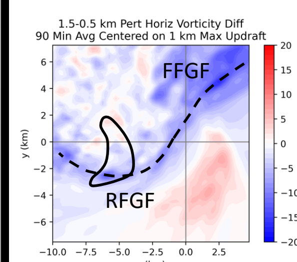
Results Part II

VPG Decomposition

$$-\frac{1}{\rho}\frac{\partial p'}{\partial z} \propto \underbrace{-\frac{\partial (e'_{ij})^2}{\partial z} + \frac{1}{2}\frac{\partial |\vec{\omega}'|^2}{\partial z}}_{\text{Dynamic Non-Linear}} \underbrace{- 2\frac{\partial(\vec{S}\cdot\nabla_h w')}{\partial z}}_{\text{Dynamic Linear}} + \underbrace{\frac{\partial^2 B}{\partial z^2}}_{\text{Buoyant}}$$



The primary contributor to the reduced VPG term is the dynamic non-linear term. Further analysis shows that horizontal perturbation vorticity associated with the supercell's rear flank gust front decreasing with height at cloud base level is the physical culprit.



Future Work

Only one simulation was used for the analysis. Future work will involve testing for this gust front downdraft mechanism across a wider range of supercell environments.