Sensitivity of Idealized Updraft Accelerations to Relative Humidity, Vertical Wind Shear, & Radius Size

Daniel W. Bazemore and Scott W. Powell

Department of Meteorology, Naval Postgraduate School, Monterey, California

1. Motivation

Deep convection and its associated precipitation are a central component to Earth's hydrologic and energy cycles. Although the necessary key ingredients for deep convection initiation (DCI) are largely known (e.g., moisture, instability, lift), the timing of DCI and joint sensitivity of convection to non-thermodynamic factors such as vertical wind shear is not well understood. This includes inadequate understanding of internal cloud processes and interactions of clouds/updrafts with their environments (Feng et al 2021).

Climate models (and still most global-scale weather prediction systems) employ parametrization schemes for cumulus convection that fail to adequately represent both the dynamic and thermodynamic factors that affect a population of clouds. Even higher resolution models, which do not require cumulus parameterizations, are challenged at representing the near-cloud environmental characteristics (Feng et al 2021), sometimes leading to early DCI.

2. Background

Sufficient moisture and some degree of shear are intimately connected to the evolution of a convective updraft. These two factors directly impact the rate of entrainment (Morrison et al 2020; Morrison et al 2021b; Peters et al 2020a) and dilution of buoyancy within the updraft.

1. Convective growth is sensitive to environmental humidity, and particularly to lower-tropospheric humidity. <u>However, moisture is only a necessary but not itself sufficient condition for DCI</u>.
2. Shear has been demonstrated to hinder deep convection initiation both in dry and moist updrafts:
   a. Dry sheared updrafts experience larger entrainment-driven dilution of updraft buoyancy (Markowski and Richardson 2010).
   b. Moist sheared updrafts have lower maximum altitudes (Peters et al 2019a).
3. LES simulations of tropical convection suggest existence of a critical updraft acceleration below the 0°C level required for the transition of shallow convection into deep convection (Powell 2022). Total updraft acceleration ($\frac{Dw}{Dt}$) is influenced by vertical pressure gradients and Archimedean buoyancy relative to an arbitrary reference state.

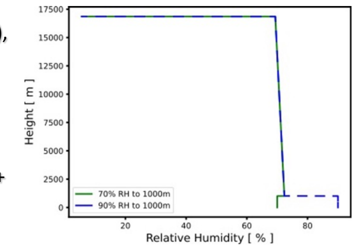
$$\frac{Dw}{Dt} = -\frac{1}{\rho_o}\frac{dp'}{dz} + B = -\frac{1}{\rho_o}\frac{dp_{D,NL}}{dz} - \frac{1}{\rho_o}\frac{dp_{D,L}}{dz} - \frac{1}{\rho_o}\frac{dp_B}{dz} + g\frac{\rho'}{\rho_o} \qquad B_{eff} = -\frac{1}{\rho_o}\frac{dp_B}{dz} + B$$

3. Objective

This work investigates how varying magnitudes of shear, low-tropospheric relative humidity, and updraft size jointly impact updraft accelerations in cumulus convection.

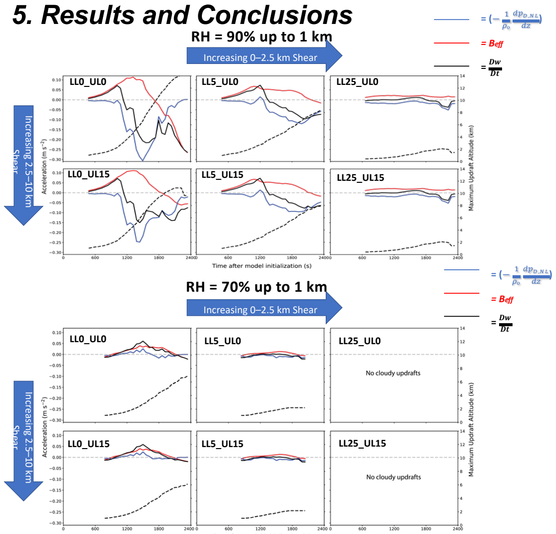
4. Methodology

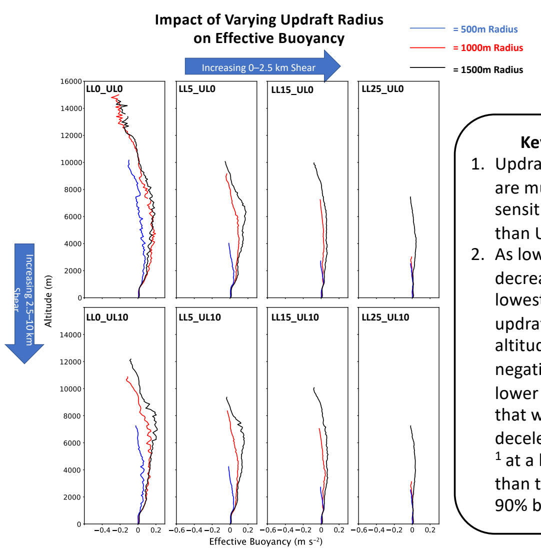
1. Updrafts were generated in Cloud Model 1 (CM1), V21.0 1K warm bubble with varying radius (250m, 500m, 750m, 1000m, 1250m, 1500m deep) in the center of a 10km x 10km doubly periodic domain at central altitude of 250 m.
2. Initial temperature profile had 7.5K km^{-1} lapse rate throughout the column
3. Initial relative humidity (RH) profiles are shown in the below figure. Here, two different values of RH were used in lowest 1000m: 70% and 90%.
4. Surface pressure was set to that at AMF site during CACTI, about 882 hPa.
5. The wind fields were adjusted to test the sensitivity to wind shear below and above 2.5 km altitude following Mulholland et al. (2021).
6. The magnitude/impact of effective buoyancy (B_{eff}), non-linear dynamic perturbation pressure gradient and buoyancy perturbation pressure gradient within the uppermost 1000 m of the cloudy updraft produced by each simulation was recorded.
7. Updrafts were classified as cloudy regions (cloud + mixing water ratios > 1e-6 kg kg^{-1} and vertical velocity exceeding 2 m s^{-1}).



UL (2.5km - 10km AGL) Shear	LL (0km - 2.5km AGL) Shear			
	<u>10 m s^{-1} km^{-1}</u>	<u>6 m s^{-1} km^{-1}</u>	<u>2 m s^{-1} km^{-1}</u>	<u>0 m s^{-1} km^{-1}</u>
2 m s^{-1} km^{-1}	LL25_UL15	LL15_UL15	LL5_UL15	LL0_UL15
1.33 m s^{-1} km^{-1}	LL25_UL10	LL15_UL10	LL5_UL10	LL0_UL10
0.67 m s^{-1} km^{-1}	LL25_UL5	LL15_UL5	LL5_UL5	LL0_UL5
0 m s^{-1} km^{-1}	LL25_UL0	LL15_UL0	LL5_UL0	LL0_UL0

5. Results and Conclusions





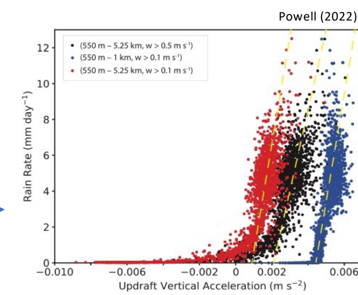
**While various simulations were executed, results from just a few are illustrated here to capture the salient conclusions.

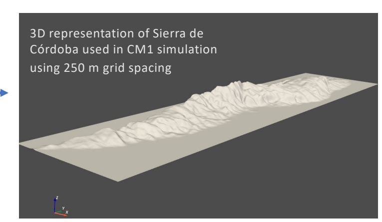
Key Takeaway

1. Updraft accelerations are much more sensitive to LL shear than UL shear.
2. As low-level RH decreased to 70% in lowest 1 km, updraft B_{eff} at low altitudes was slightly negative, leading to a lower updraft velocity that was ultimately decelerated to 0 m s^{-1} at a lower altitude than those with RH = 90% below 1 km.

6. Future Work

1. Test sensitivity of thermodynamic and kinematic factors impact on in-cloud condensation and/or rain rate and determine if critical updraft accelerations are necessary for continental convection like that observed during CACTI to undergo DCI.
2. What controls which cumulus clouds in a population grow and those that do not? Use CM1 with Sierra de Córdoba to assess updraft accelerations in growing and non-growing clouds along terrain.
3. Assess fidelity of CM1 representations of convection to radar-derived statistics of convection.





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Author Contact: daniel.bazemore@nps.edu