What Controls Timing of Deep Convective Onset in the Tropics?
(Hint: Much more than only an environmental thermodynamic profile)

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Work presented in this talk has been supported by the U.S. Department of Energy Atmospheric System Research, an Office of Science Biological and Environmental Research program, under Interagency Agreement 89243021SSC000077. *Title slide photo: Shallow convection developing near Mount Whitney, California, 25 Aug 2022. Some of the clouds deepened and hailed on the author's tent, which was problematic since the author put the rain fly on upside down.*

How do we define buoyancy?

$$B \approx g\left(\frac{\theta^*}{\theta_0} + \left(\frac{R_v}{R_d} - 1\right) q_v^* - q_{lf}\right)$$

$$B \equiv g\left(\frac{T_v'}{\overline{T_V}}\right)$$

$$\frac{Dw}{Dt} \approx -\frac{1}{\rho}\frac{\partial p_D'}{\partial z} - \frac{1}{\rho}\frac{\partial p_B'}{\partial z} + B$$

"Effective buoyancy"
Davies-Jones (2003)
Doswell and Markowski (2004)

Vertical Pressure
Gradient
Accelerations

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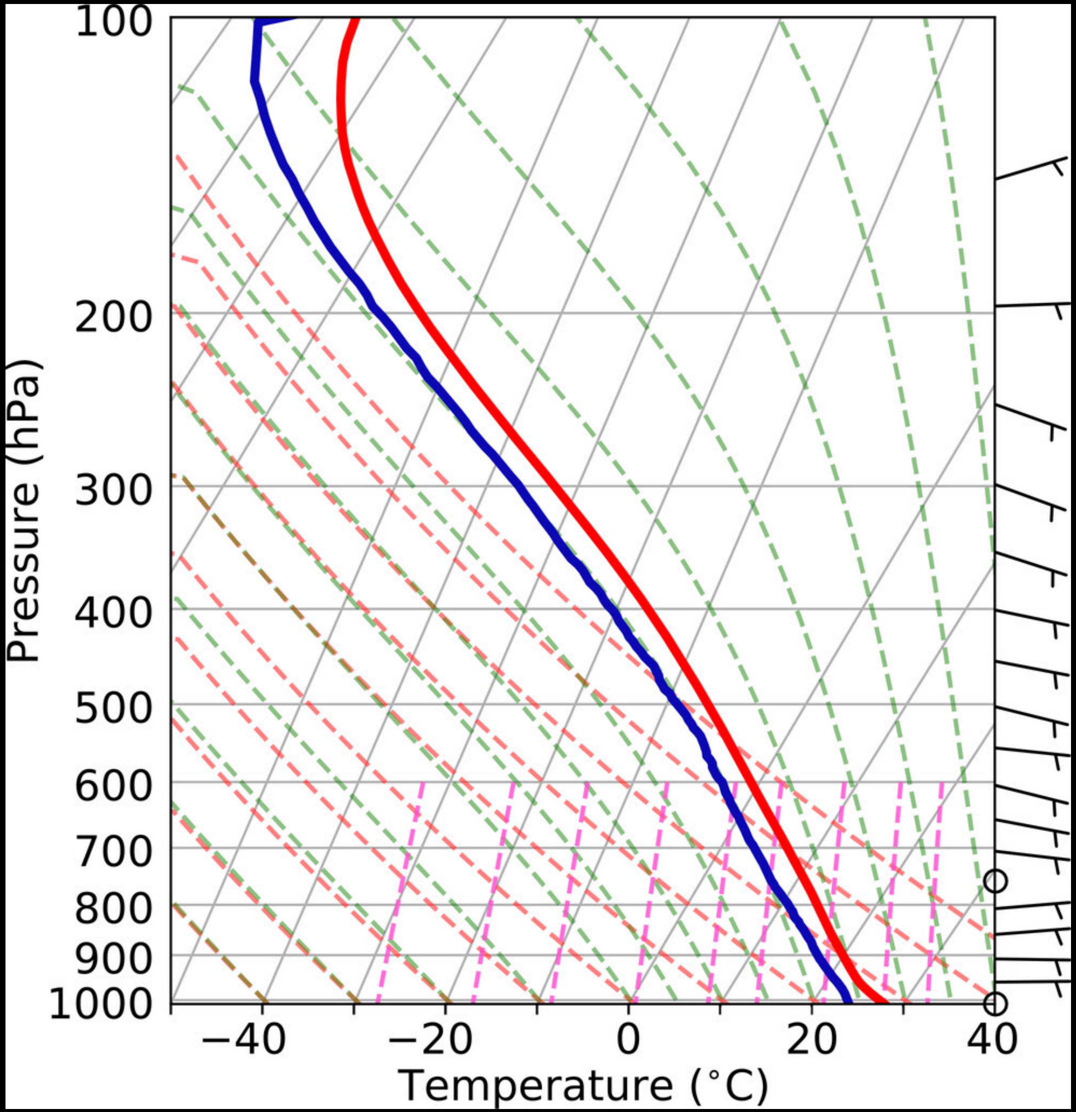
Vertical Pressure Gradient Accelerations



Bretherton et al. (2004)

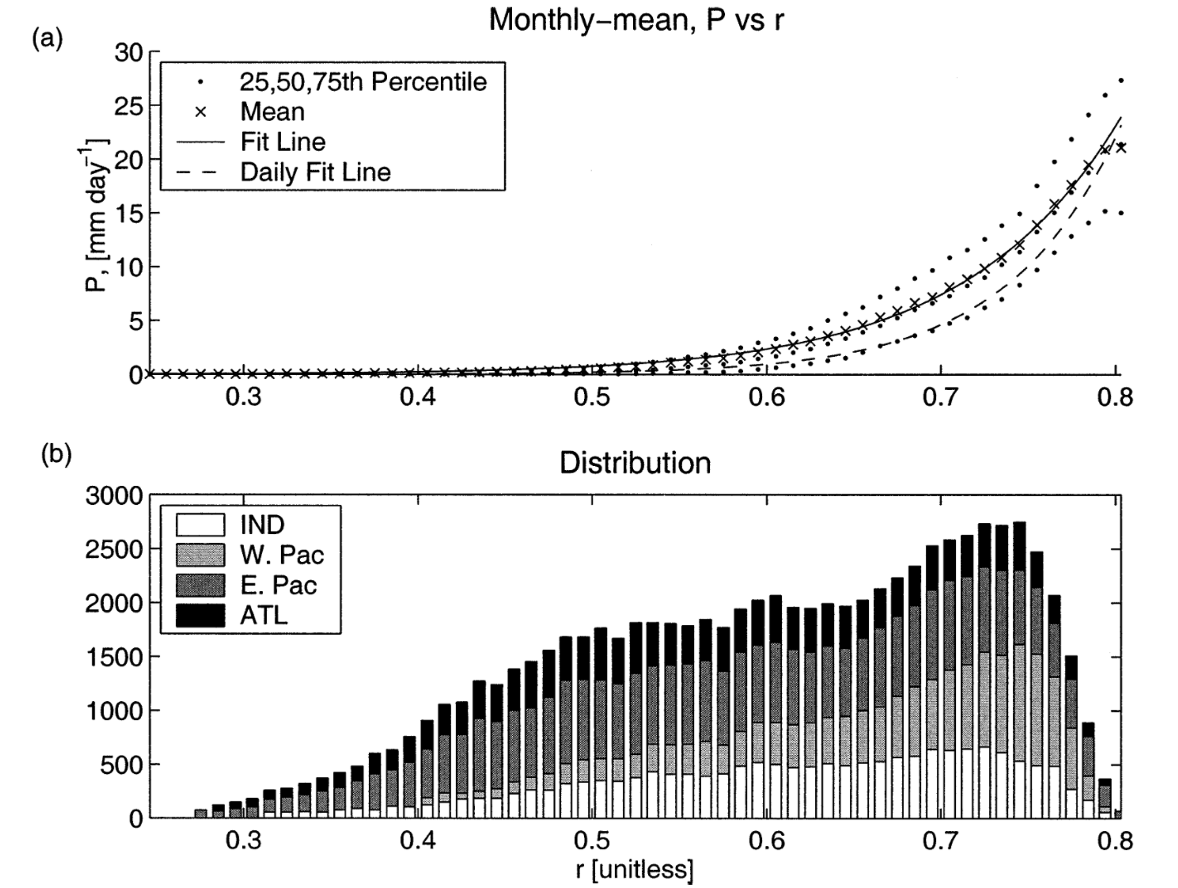
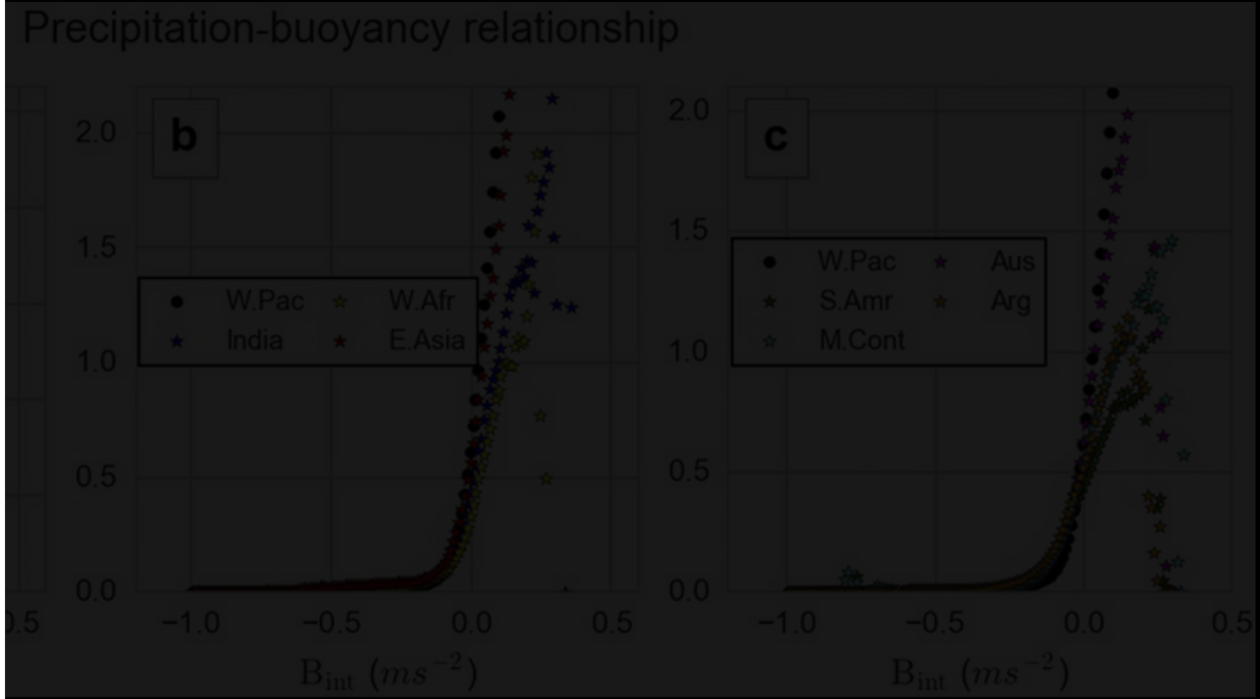


FIG. 6. (a) Distribution of monthly precipitation P in 1% bins of column-relative humidity r for all tropical ocean grid points in all months of 1998–2001. Dots show the 25th, 50th, and 75th percentiles of precipitation in each bin. The Xs show the bin-mean precipitation. The solid curve is the exponential fit (2) to the monthly data. For comparison, the dashed curve is the daily mean exponential fit (1). (b) Number of observations in each bin in the four regions.

Precipitation vs. tropospheric water vapor

Ahmed and Neelin (2018)



Precipitation vs. lower-tropospheric buoyancy

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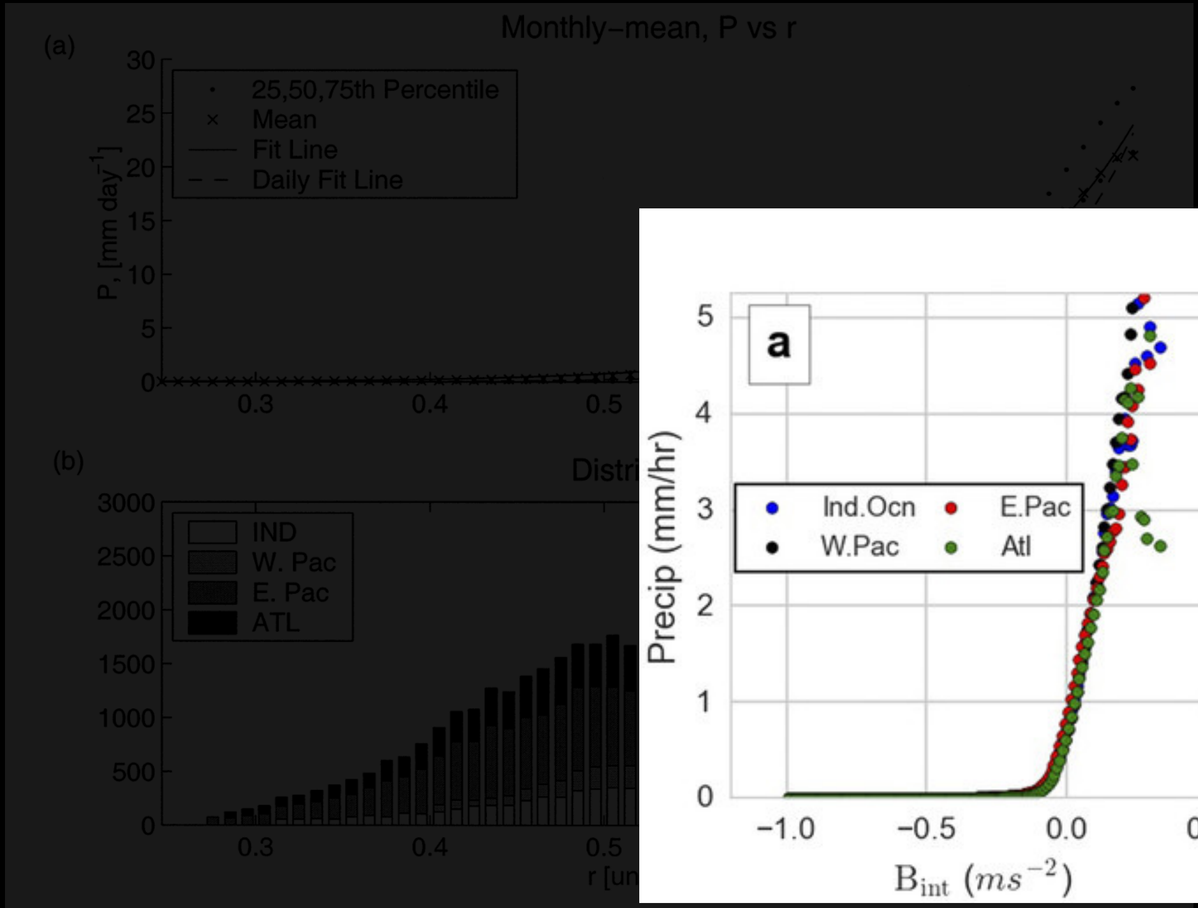

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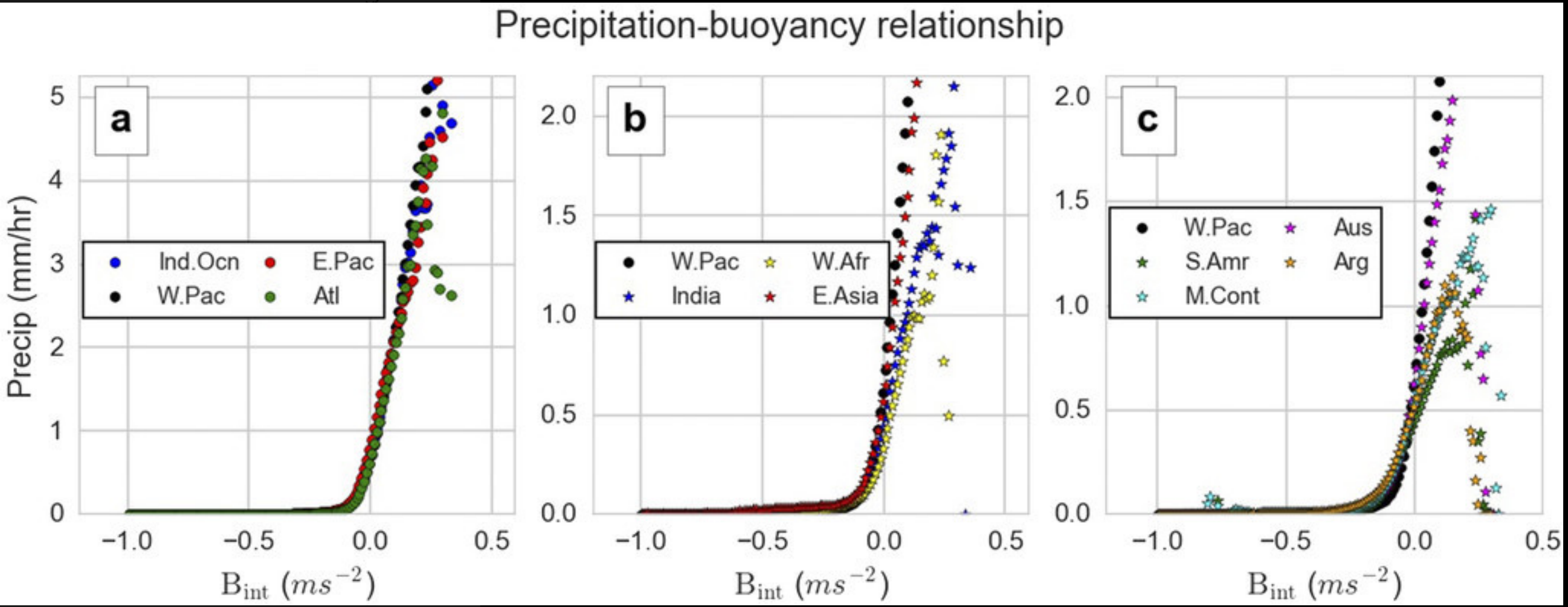

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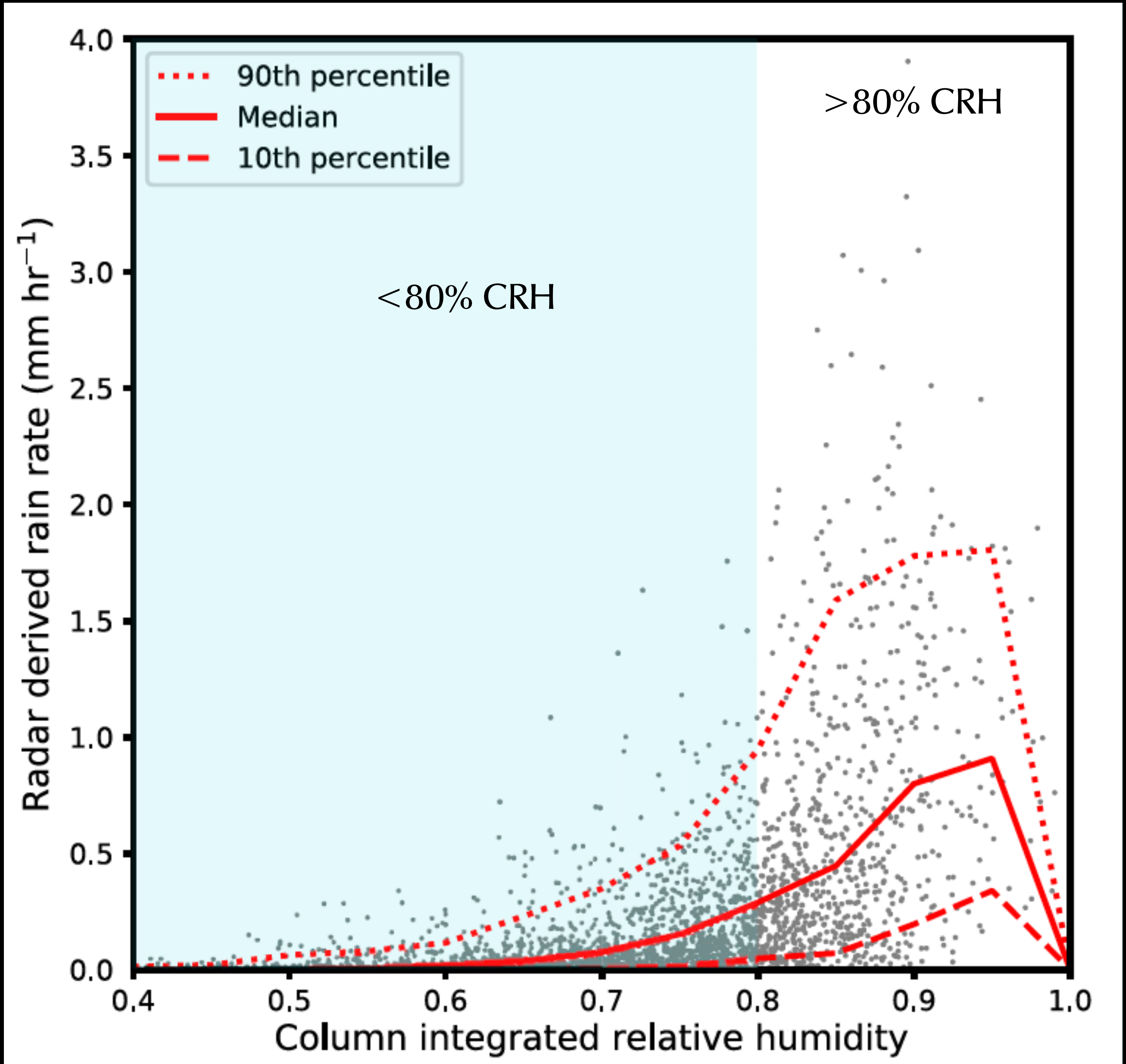
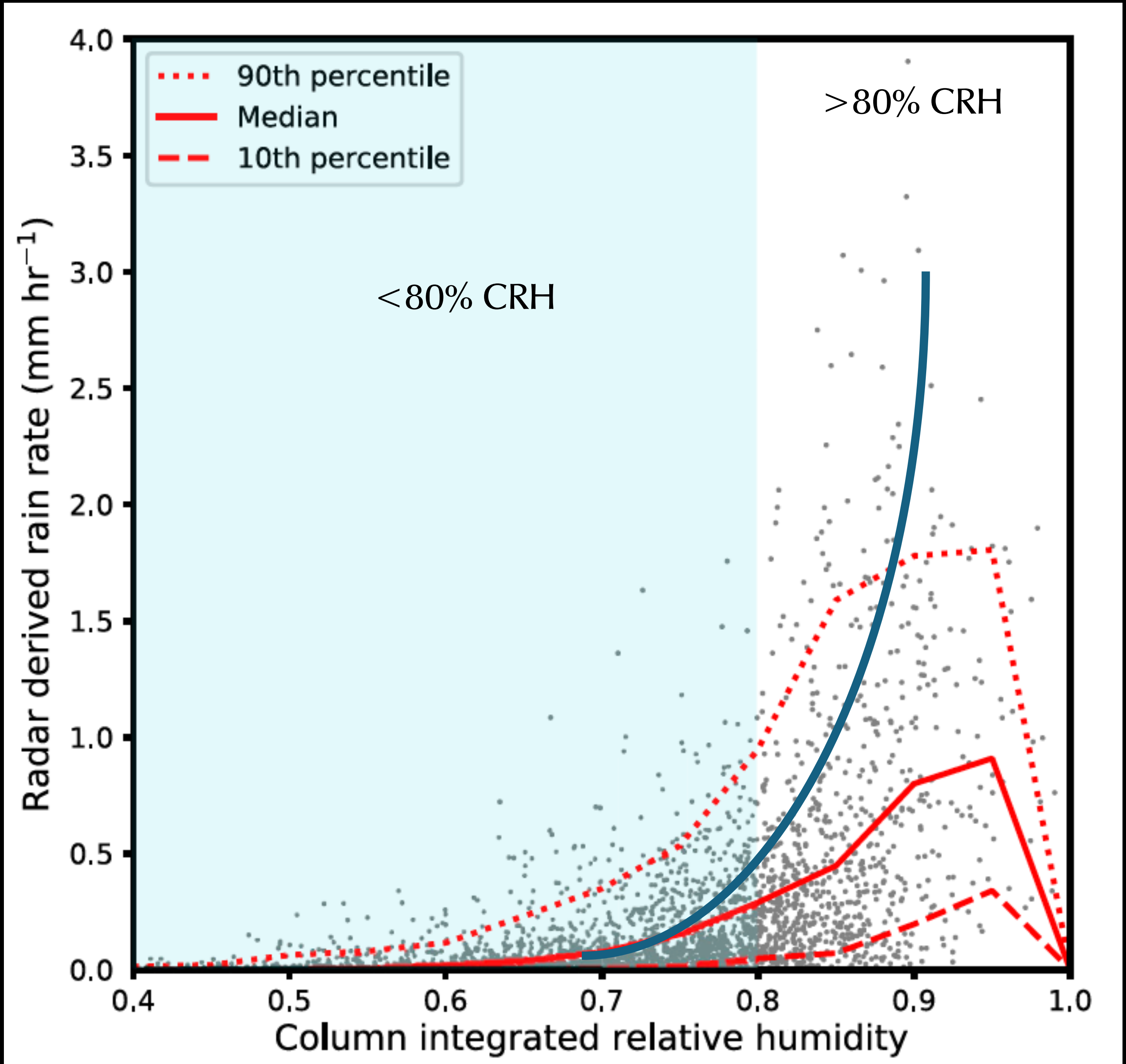

90th percentile
Median
10th percentile
<80% CRH
>80% CRH
Radar derived rain rate (mm hr^{-1})
Column integrated relative humidity
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Powell (2019)



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>80% CRH
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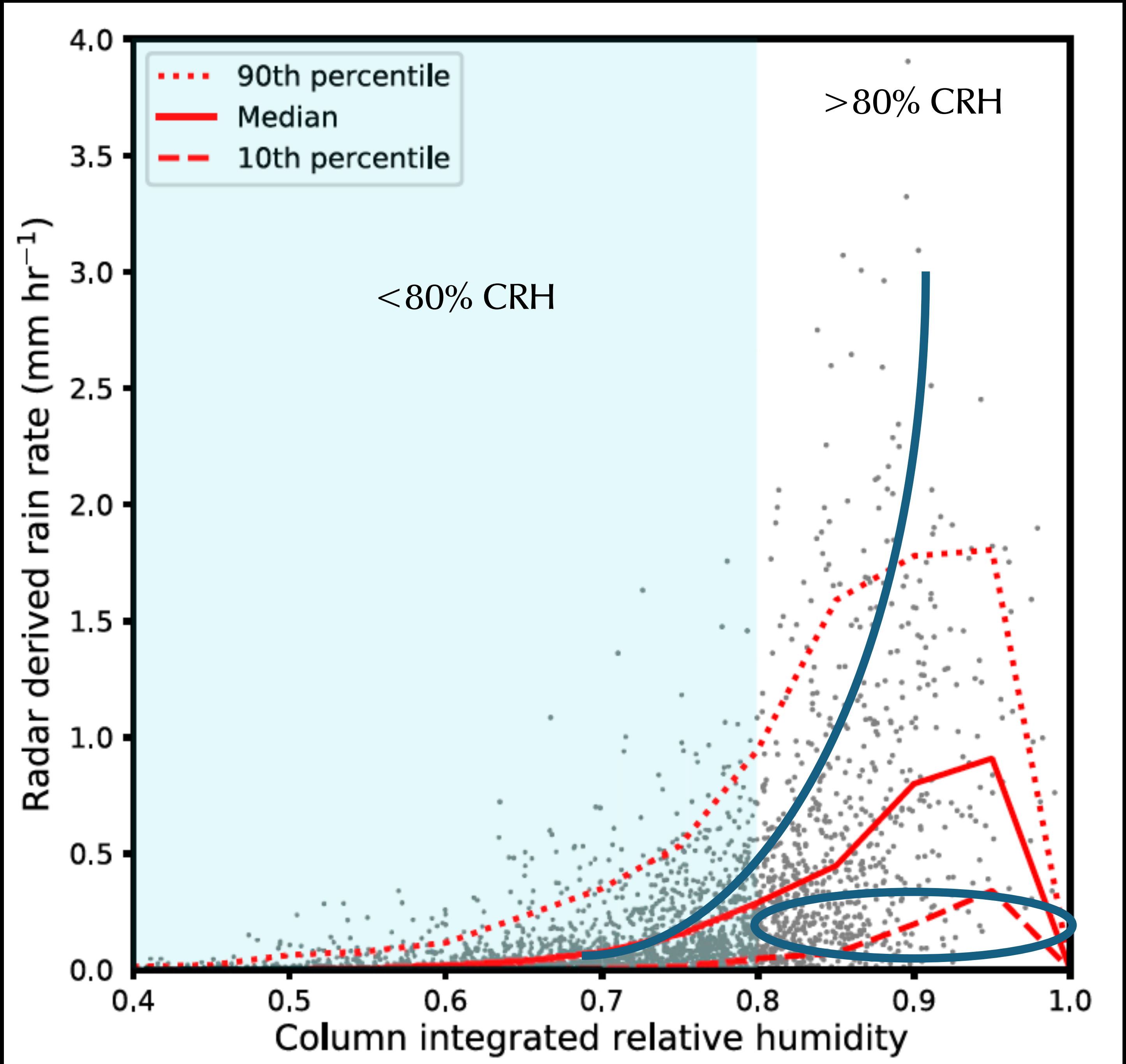

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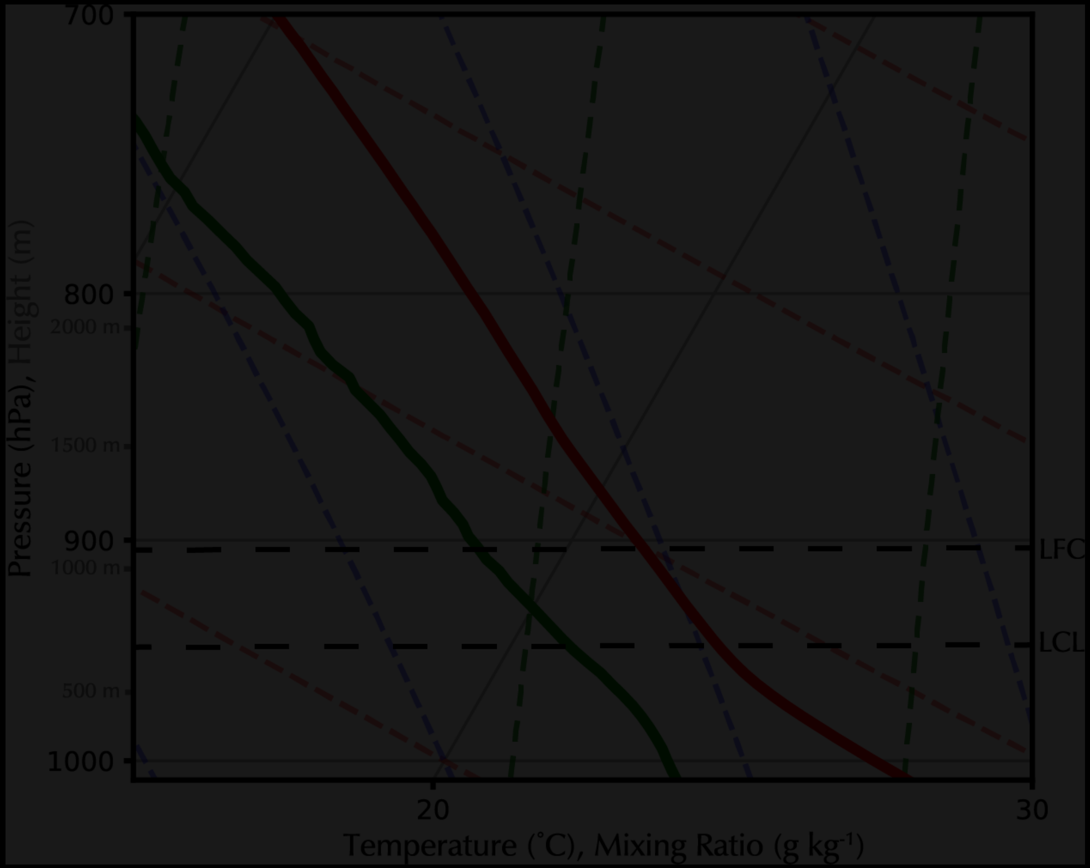
Powell (2024)



Lagrangian analysis of “parcel” trajectories emerging from the boundary layer in CM1 LES

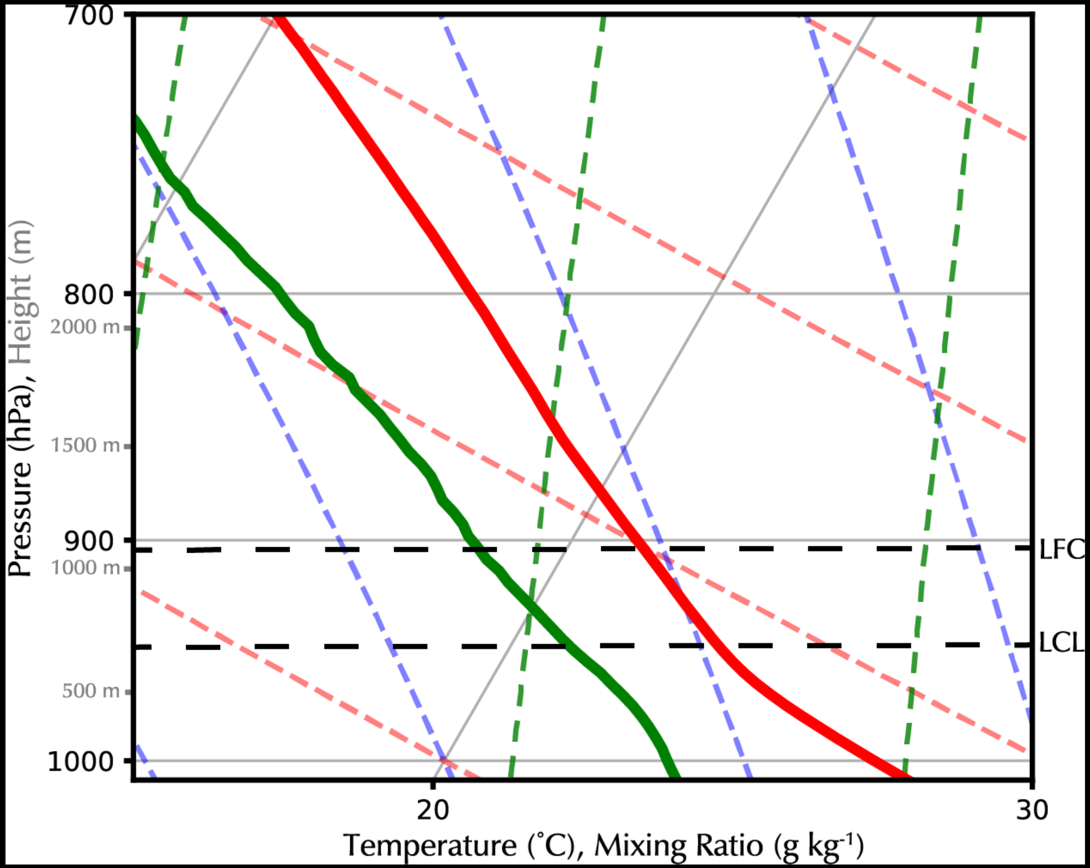
- 10,240,000 parcel trajectories analyzed
- Over 5 Tb of output for just one simulation

- Trajectories were split into two categories based on whether they entered convection that grew deep or did not:
    - Growers: Trajectories reach at least 6000 m.
    - Non-growers: Stopped between 1500 m and 3000 m.

<u>Cloud Model 1 (CM1) configuration:</u>
Domain size: 64 km x 64 km x 20 km
Horizontal grid spacing: 100 m
Vertical grid spacing: 50 m in boundary layer, stretched to 250 m above 3500 m.
Time step: 1 s
Output written: every minute

Boundary conditions: Periodic
Surface: Fixed SST; Monin-Obukhov
Microphysics: Morrison
Radiation: RRTM-G (shortwave turned off)
No cumulus or boundary layer parameterization
Turbulence promoted by random temperature perturbations up to 0.25 K.

Powell (2024)



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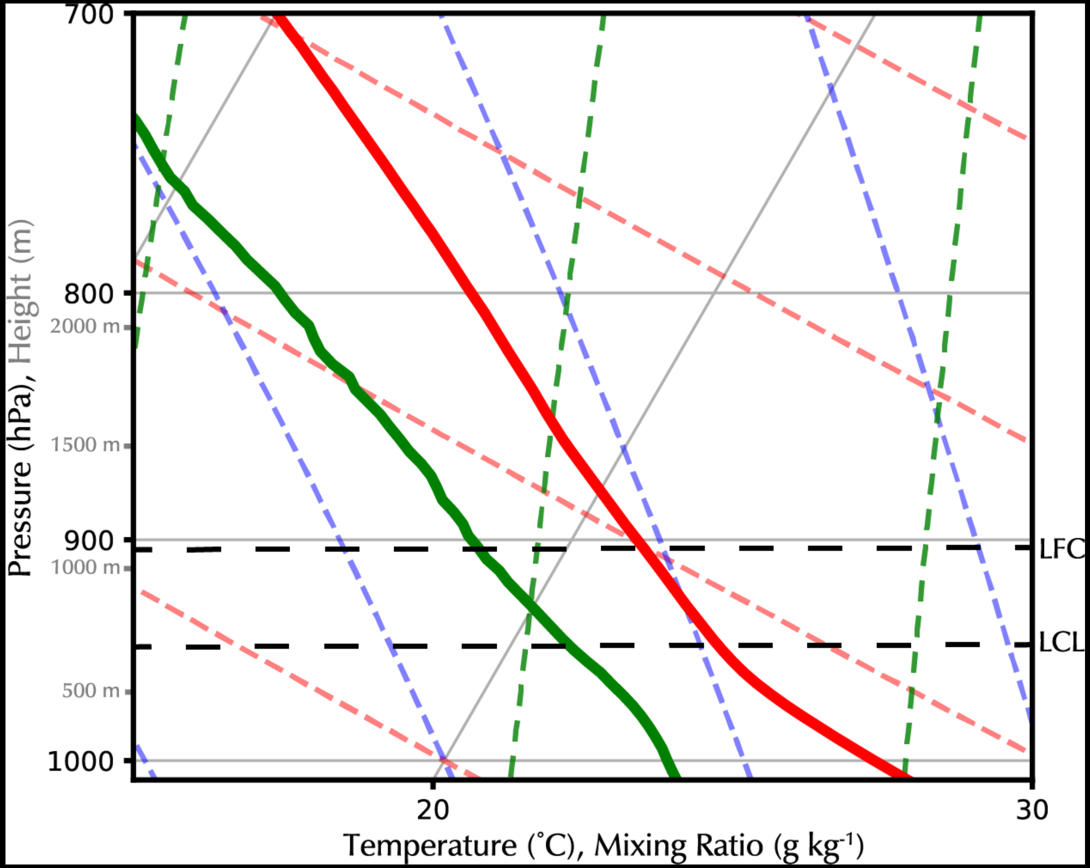

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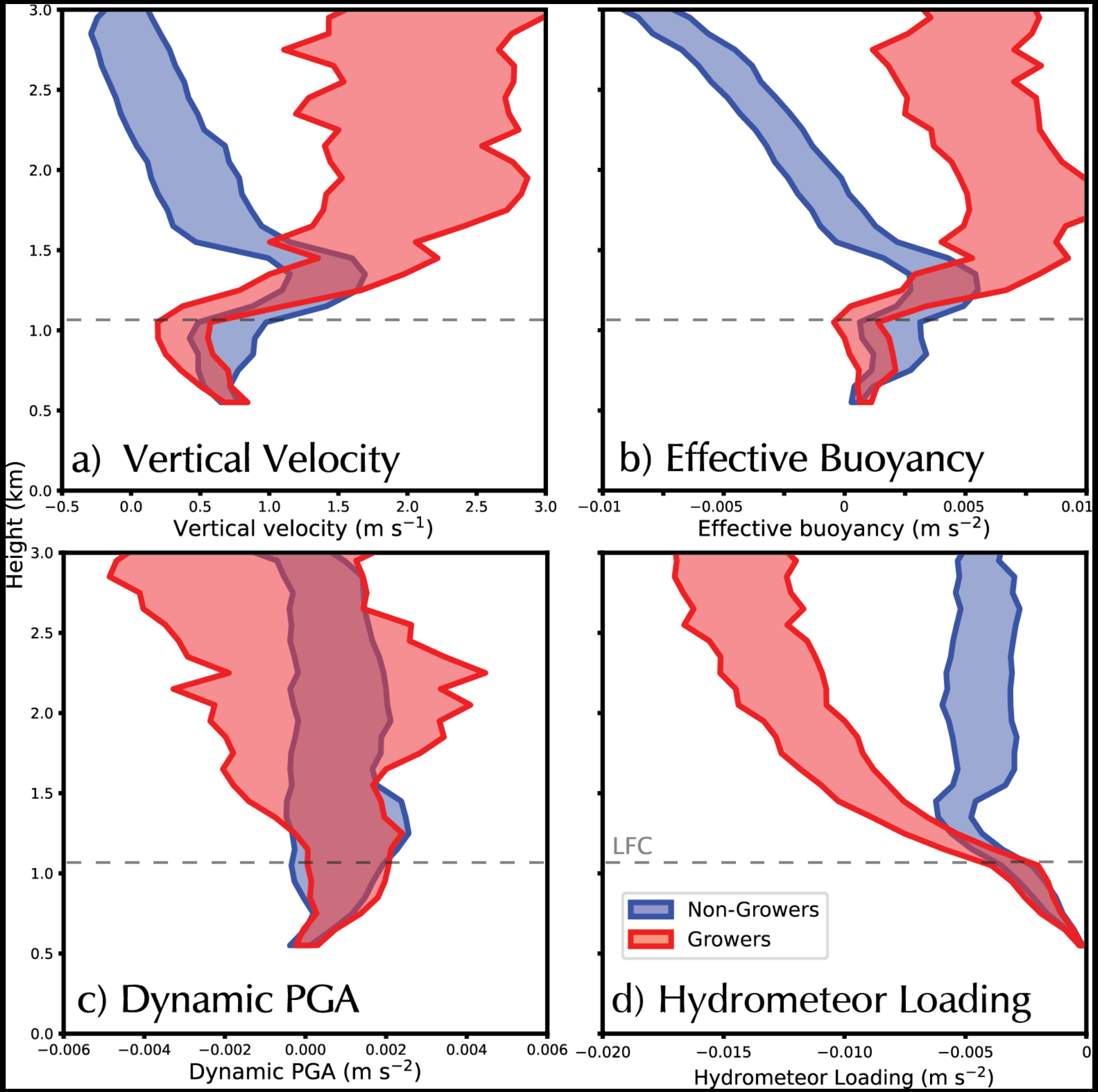
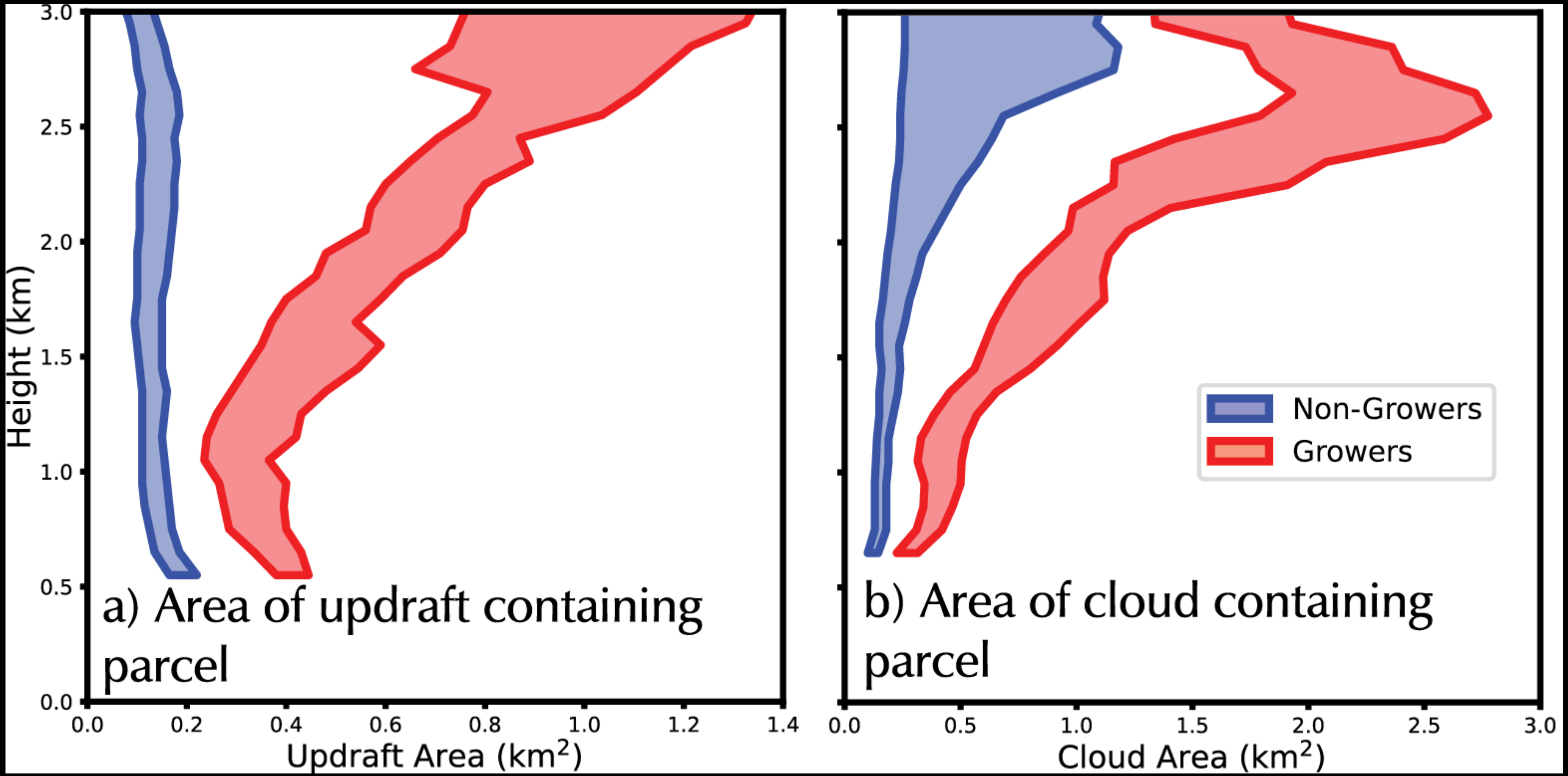
$$-\frac{1}{\rho}\frac{\partial p'_B}{\partial z} + B$$

$$-\frac{1}{\rho}\frac{\partial p'_D}{\partial z}$$

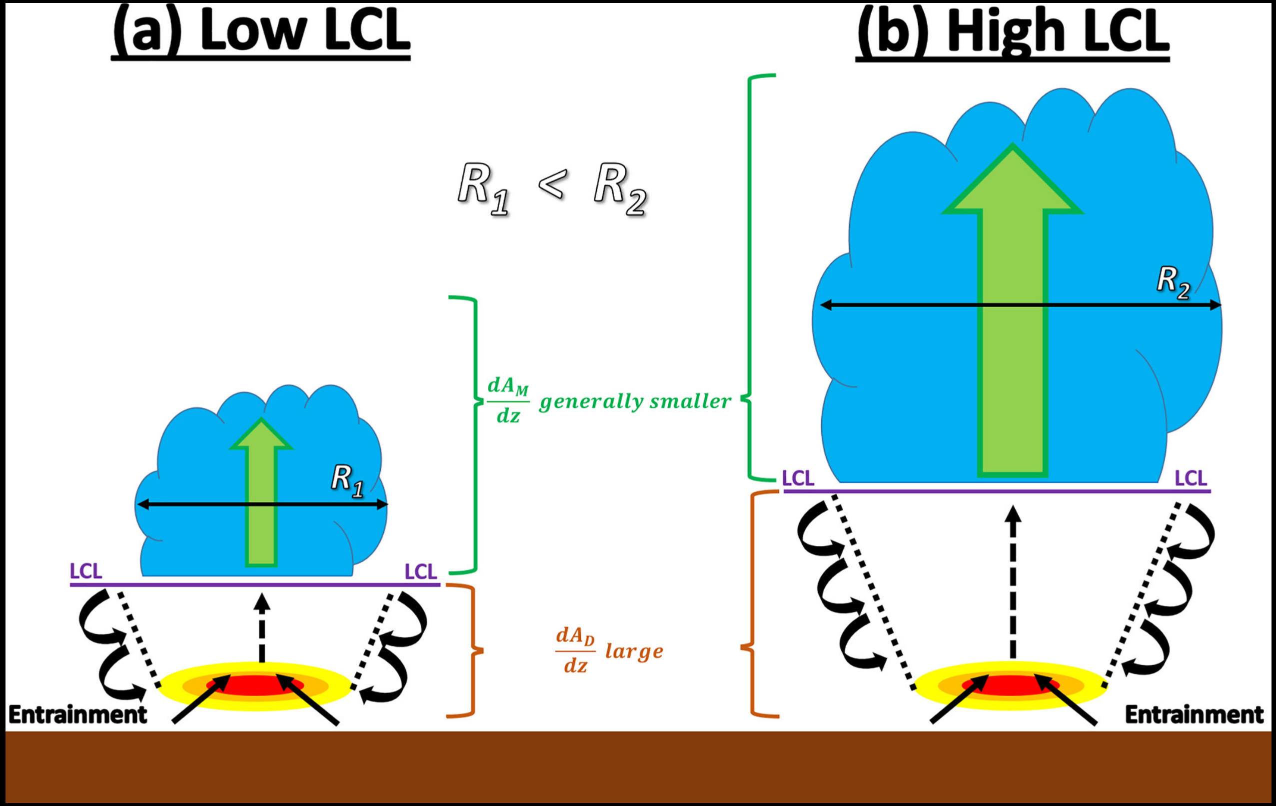




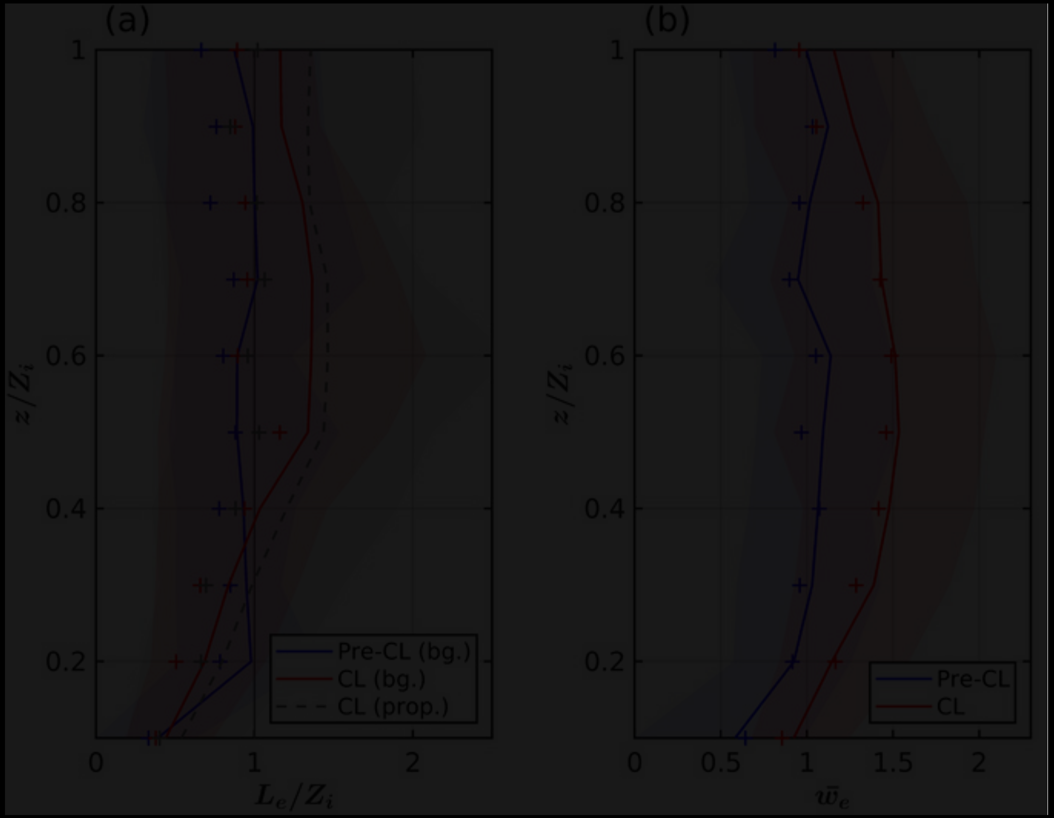
Shaded regions indicated 95% confidence interval of median.

Why are some updrafts wider than others?

Mulholland et al. (2021): LCL height



Liu et al. (2023): Convergence lines



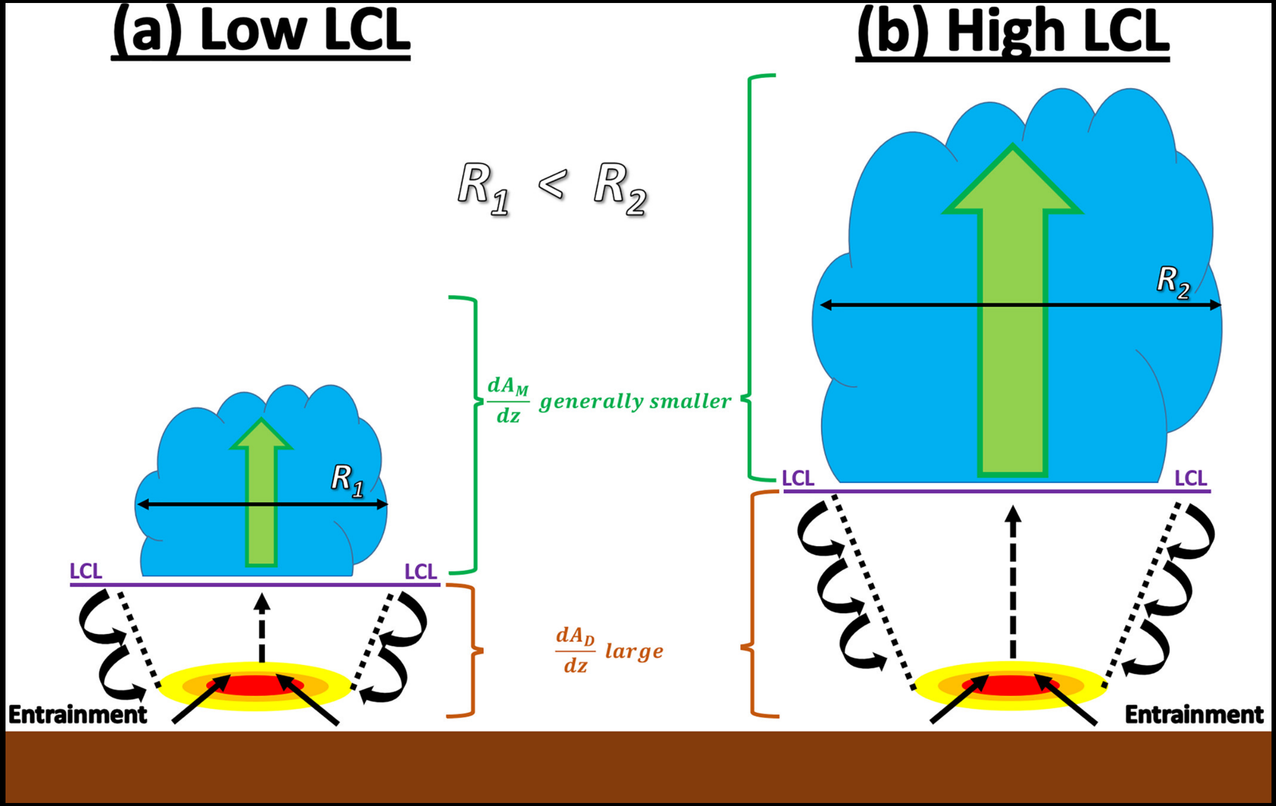
Size

Strength

Red = In convergence line

Blue = Not in convergence line

Mulholland et al. (2021): LCL height



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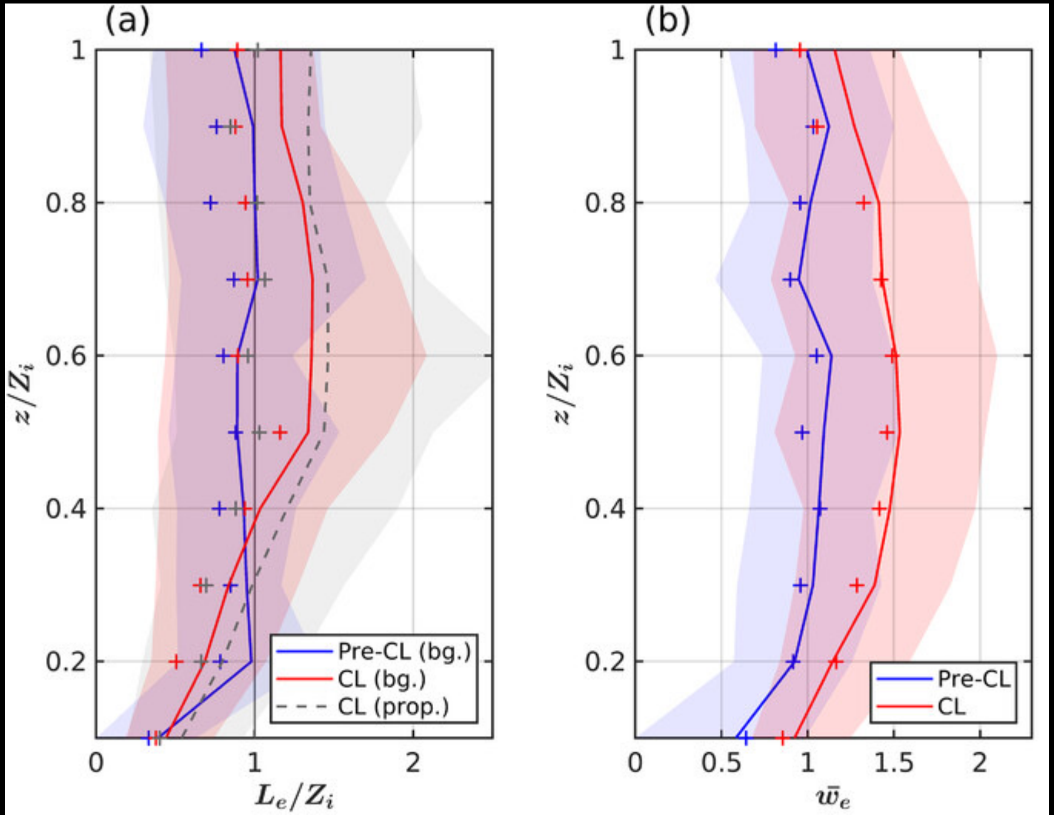

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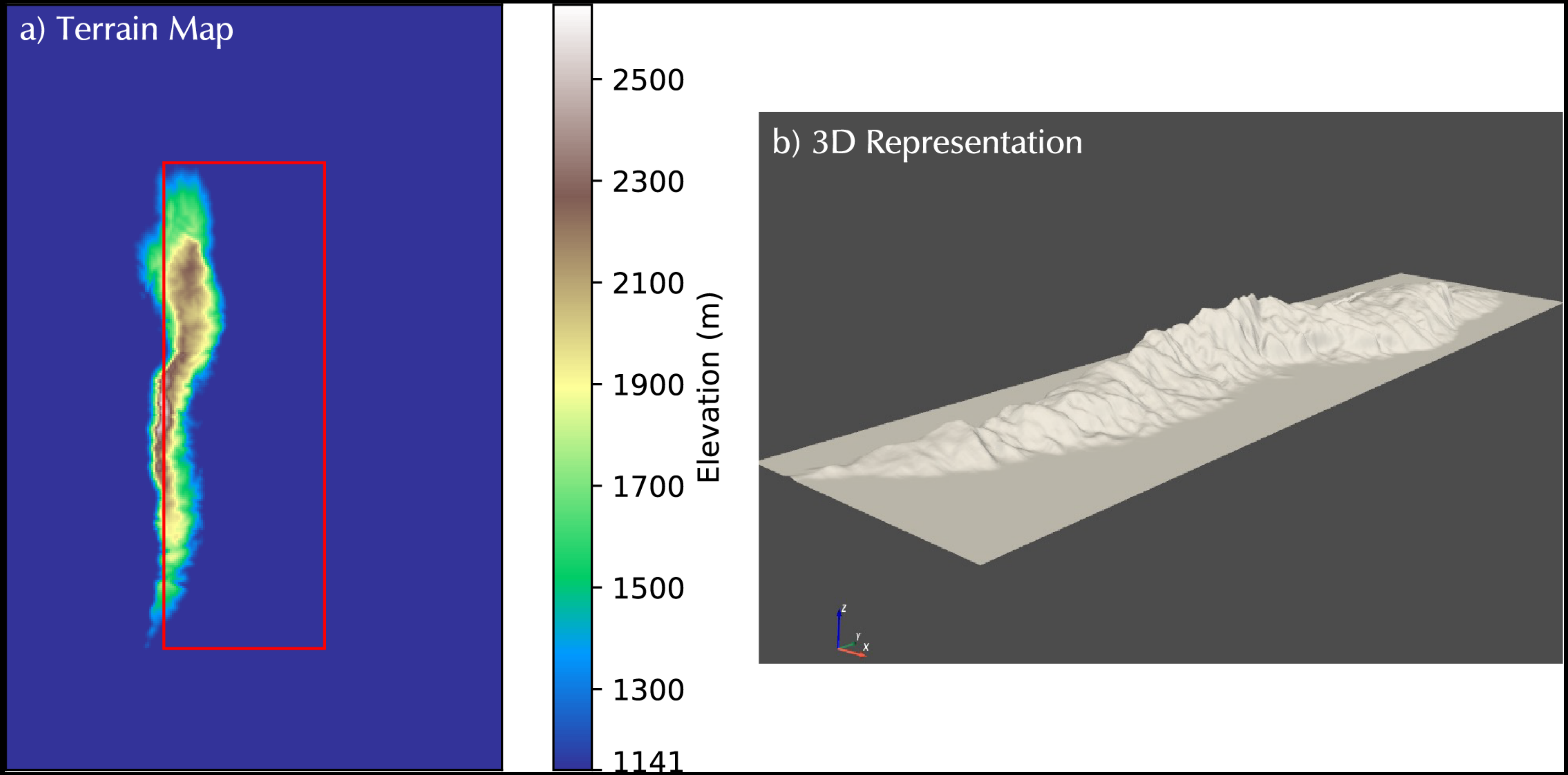

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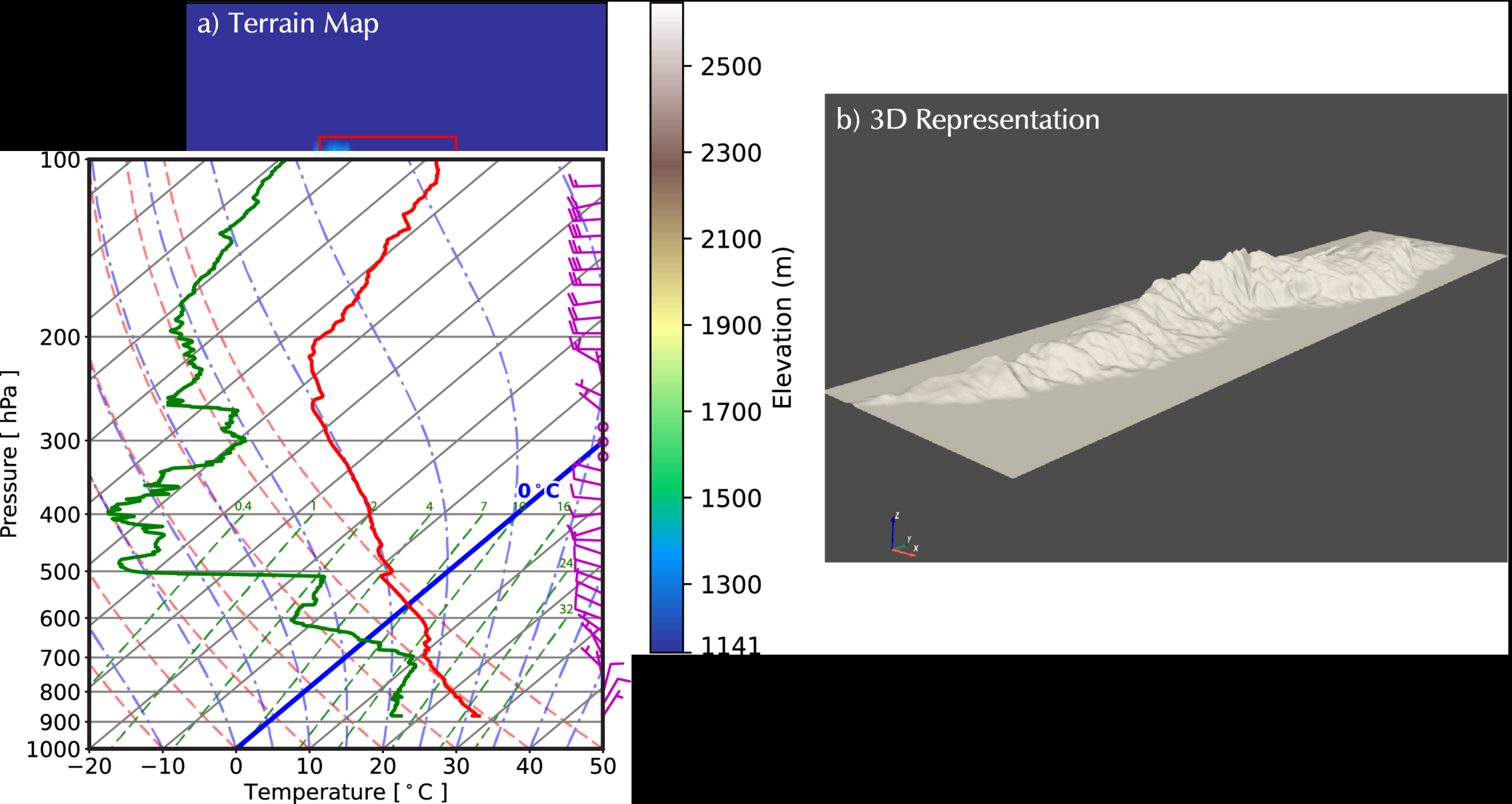

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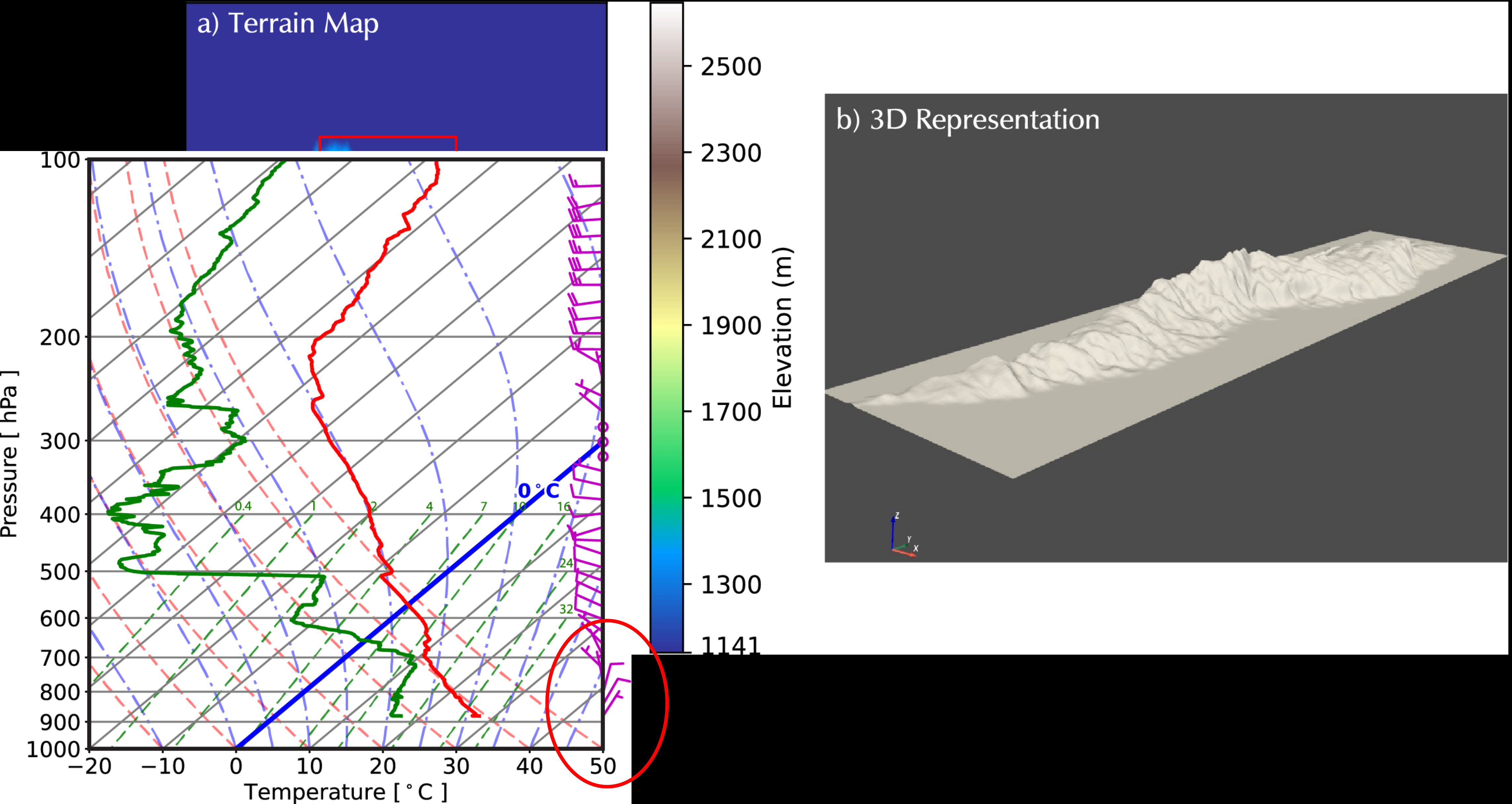
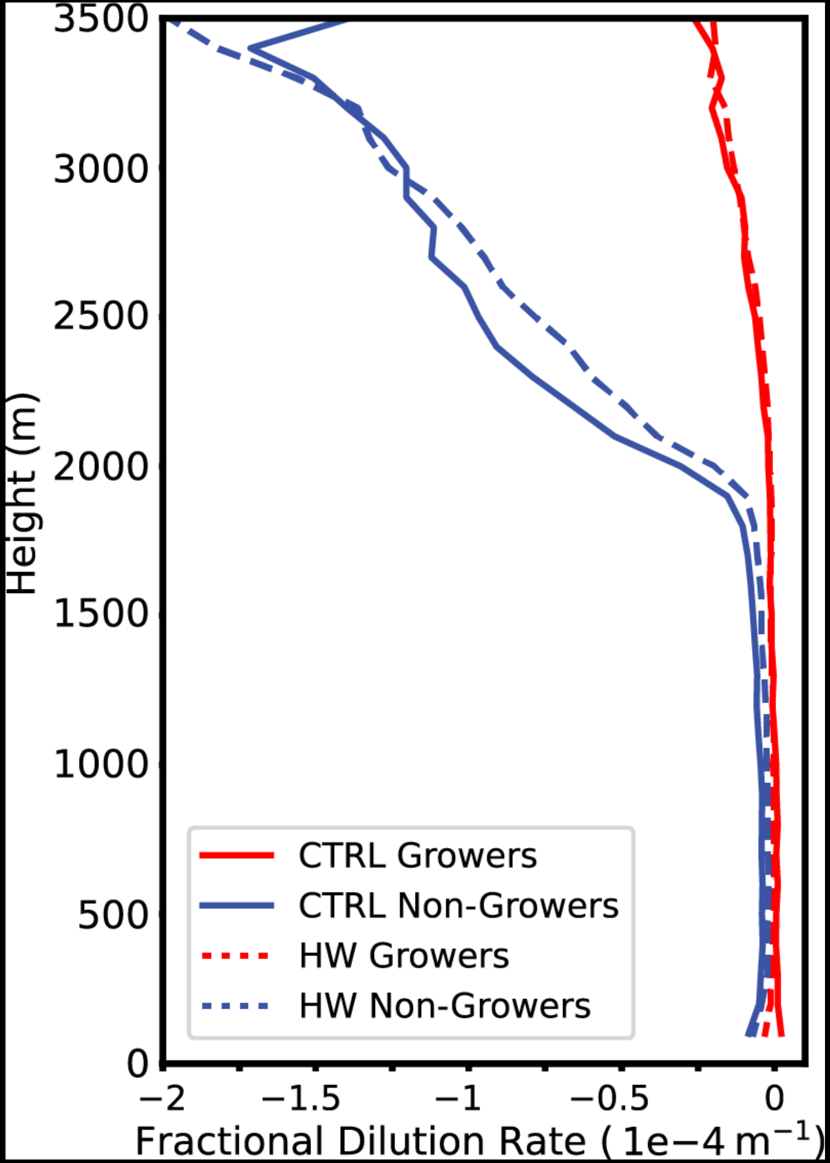
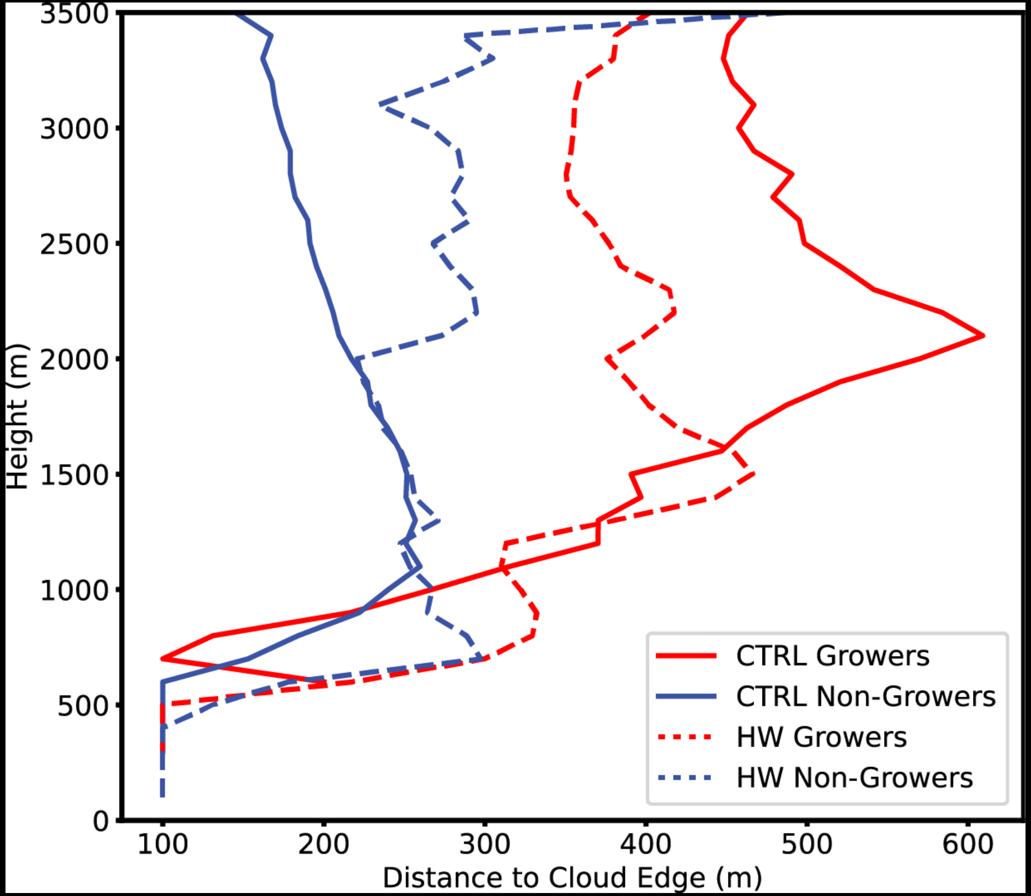


Bazemore and Powell (2024)

Fractional dilution rate

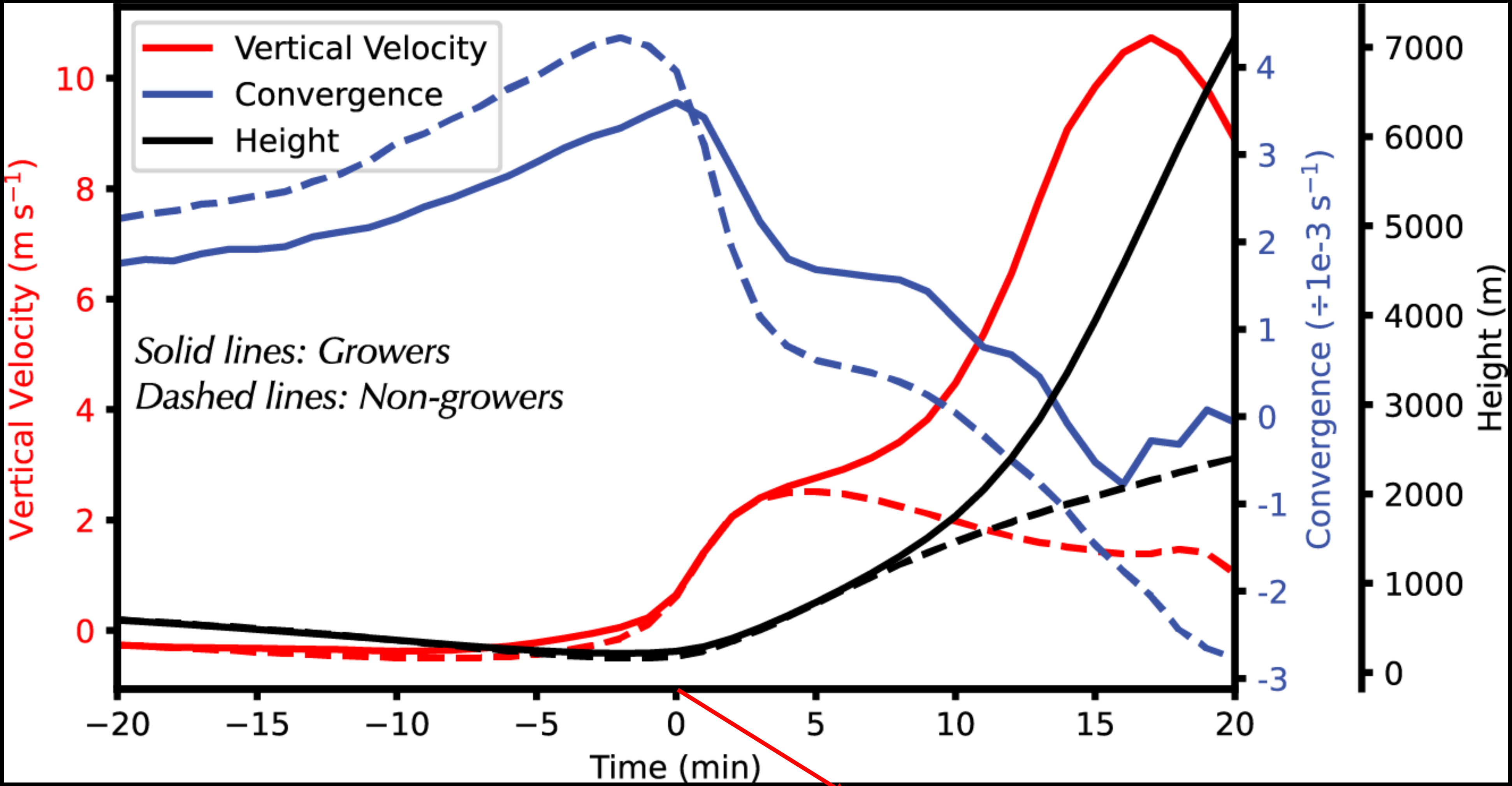


Distance to nearest cloud edge



Bazemore and Powell (2024)

Time series of convergence, w, and height of parcel



$t = 0$: Time when parcel first had $w \geq 1$ m s^{-1}

Conclusions

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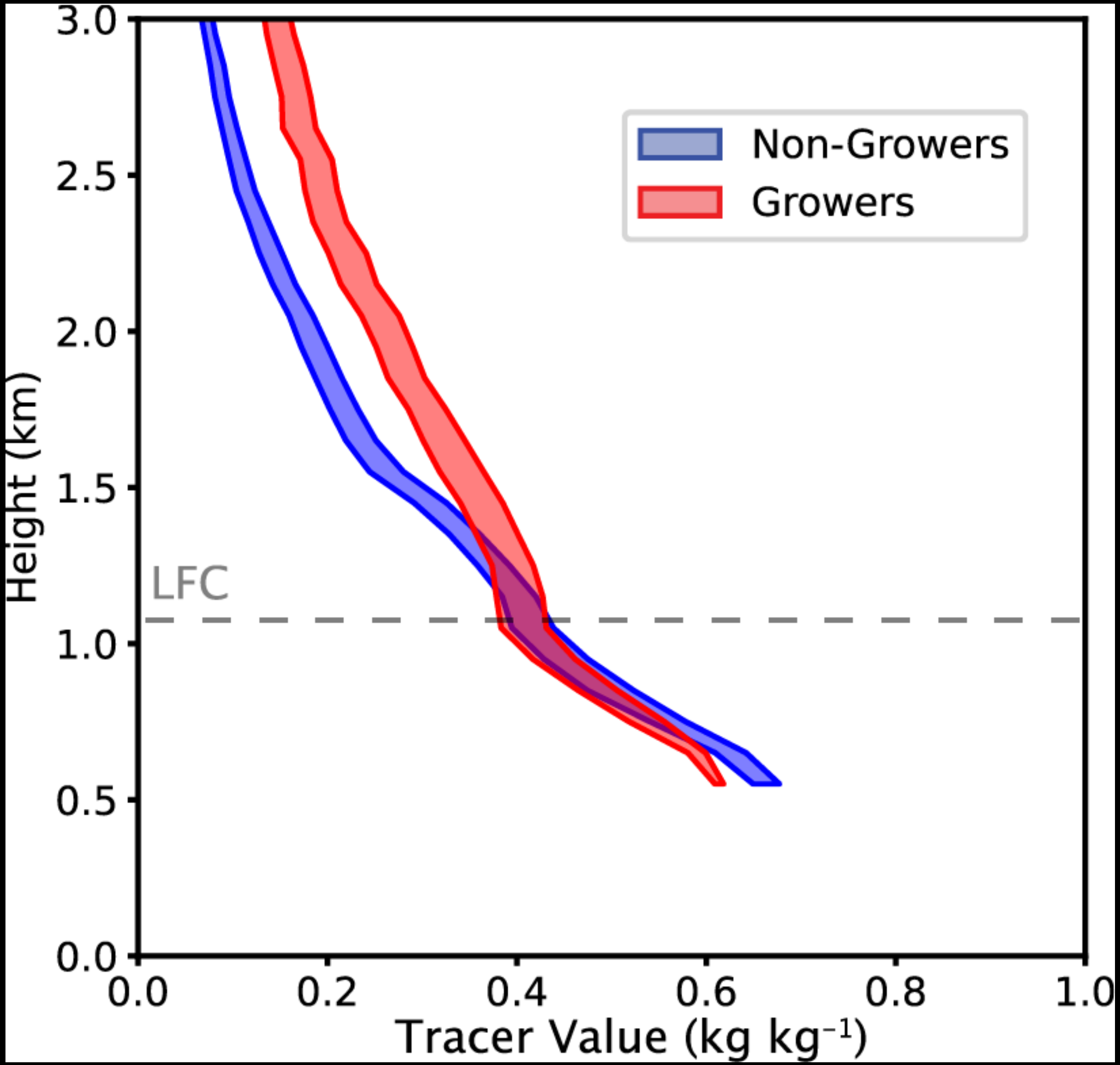
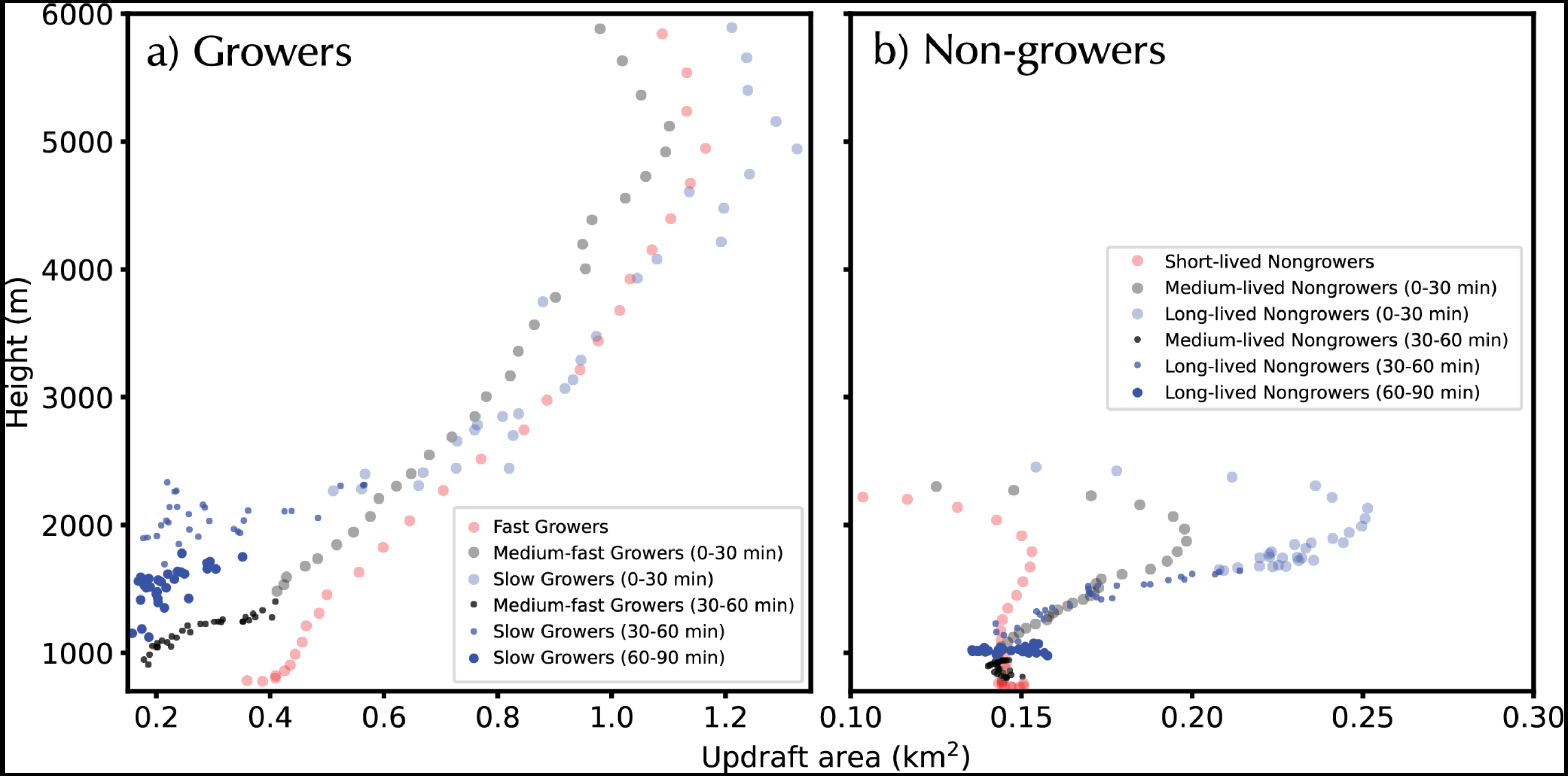
Conclusions

- Obviously, thermodynamic profile is very important factor for determining if deep convection can develop, but…
- There are other “tunable knobs” as well: Vertical wind shear, updraft size, and probably others.
- What controls the size?
  - Convergence seems to be important. But is it a cause or consequence of convection?
  - Moisture ″preconditioning″ by weak convection may actually matter on short time scales by allowing successive clouds to grow wider. Just a hypothesis for now.

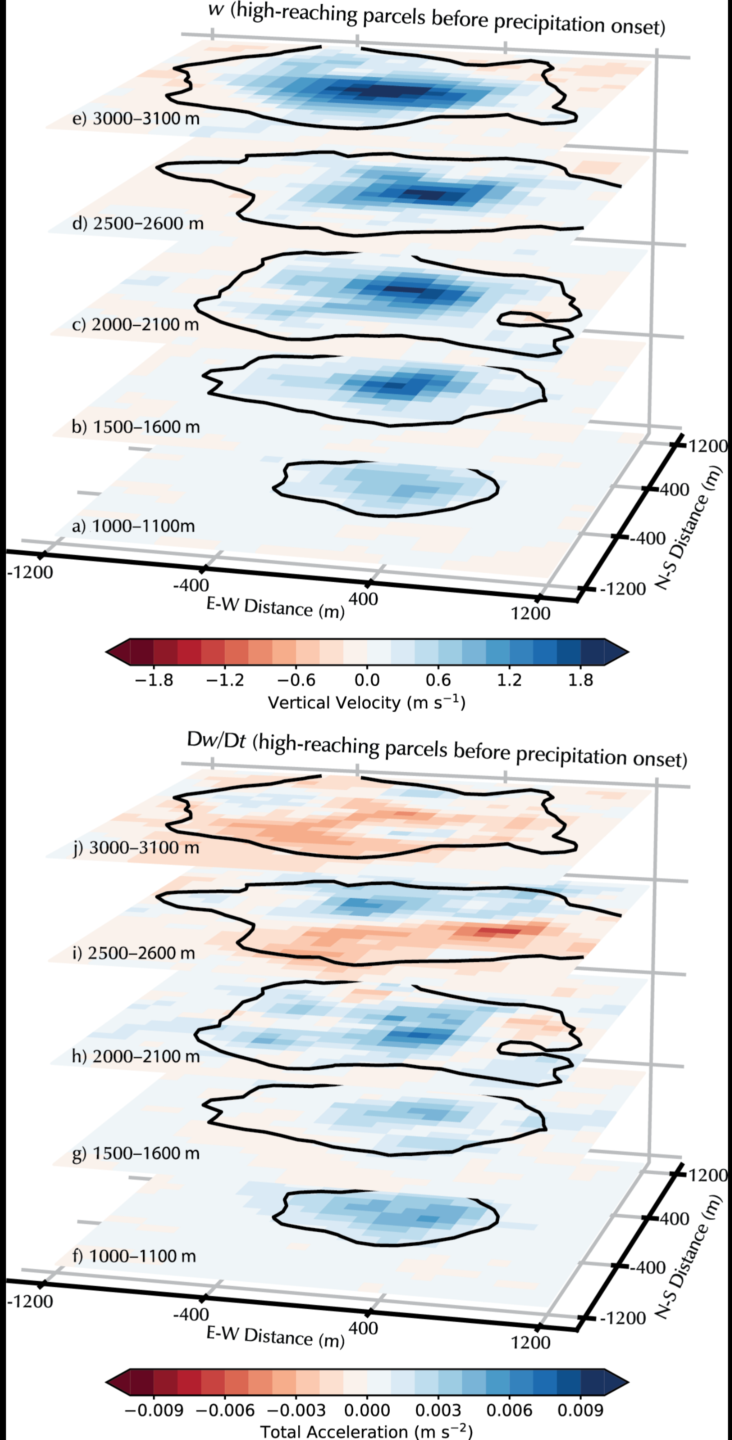


Non-Growers
Growers
LFC
Height (km)
Tracer Value (kg kg⁻¹)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.0
0.2
0.4
0.6
0.8
1.0

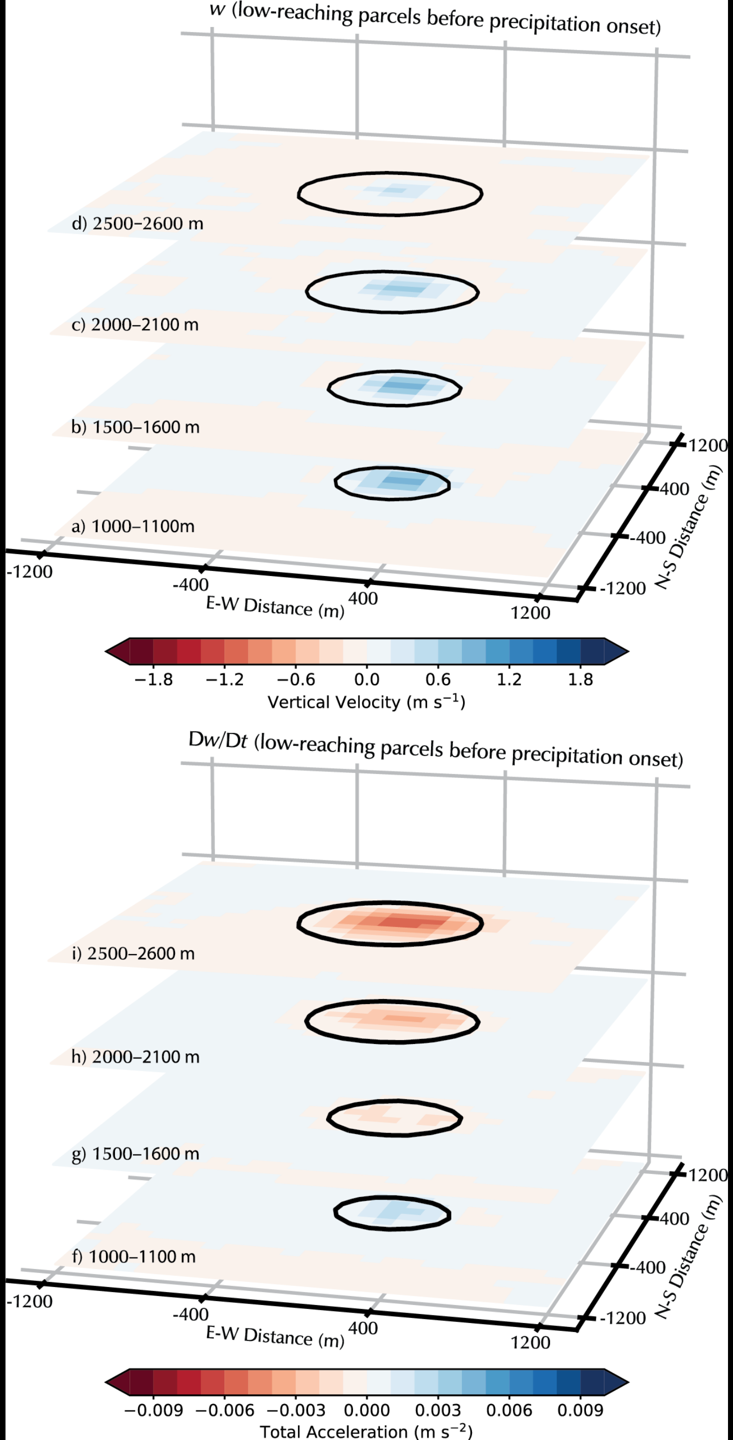


a) Growers
b) Non-growers
Height (m)
Updraft area (km^2)
6000
5000
4000
3000
2000
1000
0.2
0.4
0.6
0.8
1.0
1.2
0.10
0.15
0.20
0.25
0.30
Fast Growers
Medium-fast Growers (0-30 min)
Slow Growers (0-30 min)
Medium-fast Growers (30-60 min)
Slow Growers (30-60 min)
Slow Growers (60-90 min)
Short-lived Nongrowers
Medium-lived Nongrowers (0-30 min)
Long-lived Nongrowers (0-30 min)
Medium-lived Nongrowers (30-60 min)
Long-lived Nongrowers (30-60 min)
Long-lived Nongrowers (60-90 min)

Ascending Parcels (growers)



Non-Ascending Parcels (non-growers)



Powell (2024)