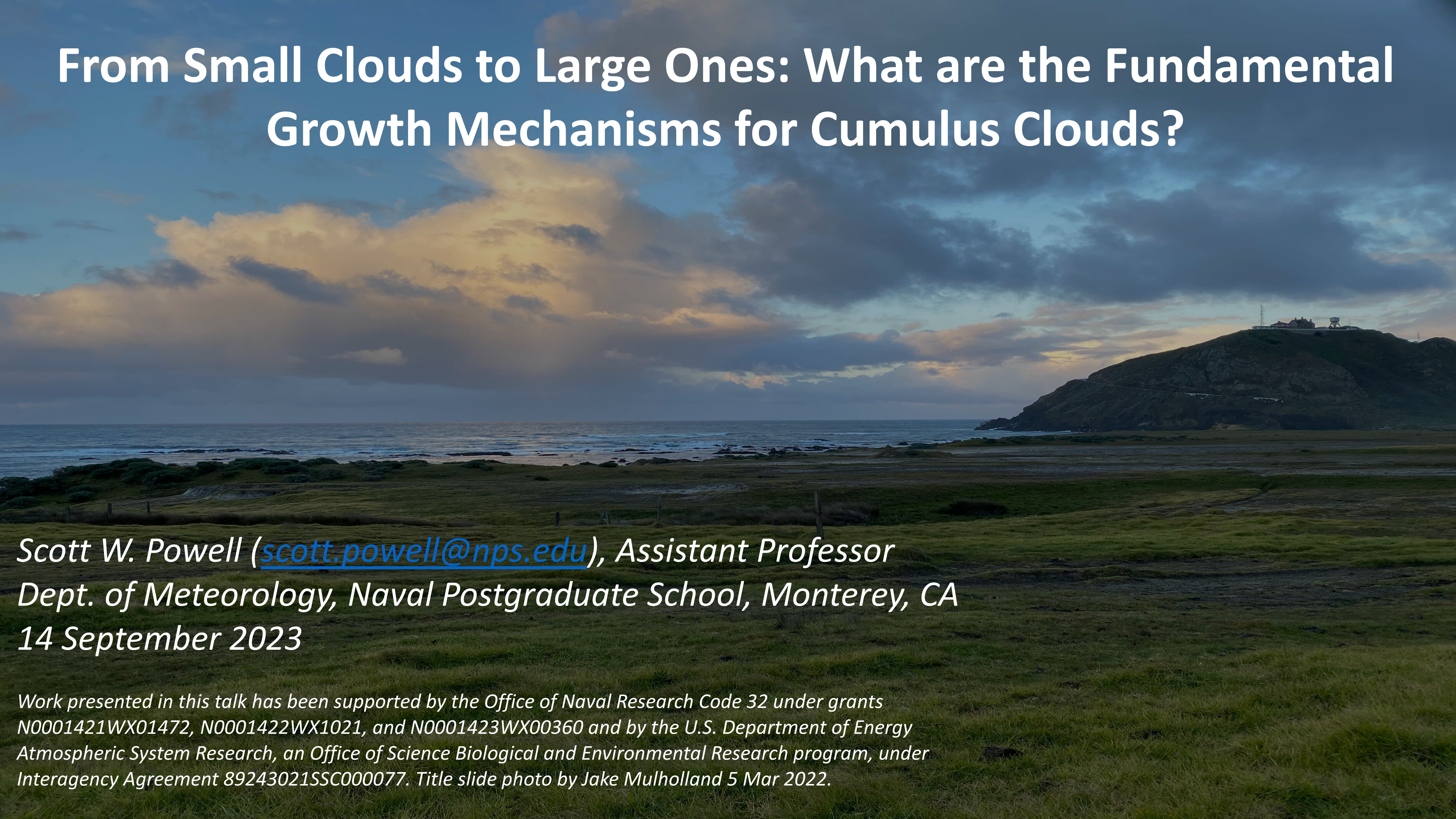

From Small Clouds to Large Ones: What are the Fundamental Growth Mechanisms for Cumulus Clouds?

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14 September 2023

Work presented in this talk has been supported by the Office of Naval Research Code 32 under grants N0001421WX01472, N0001422WX1021, and N0001423WX00360 and 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 by Jake Mulholland 5 Mar 2022.

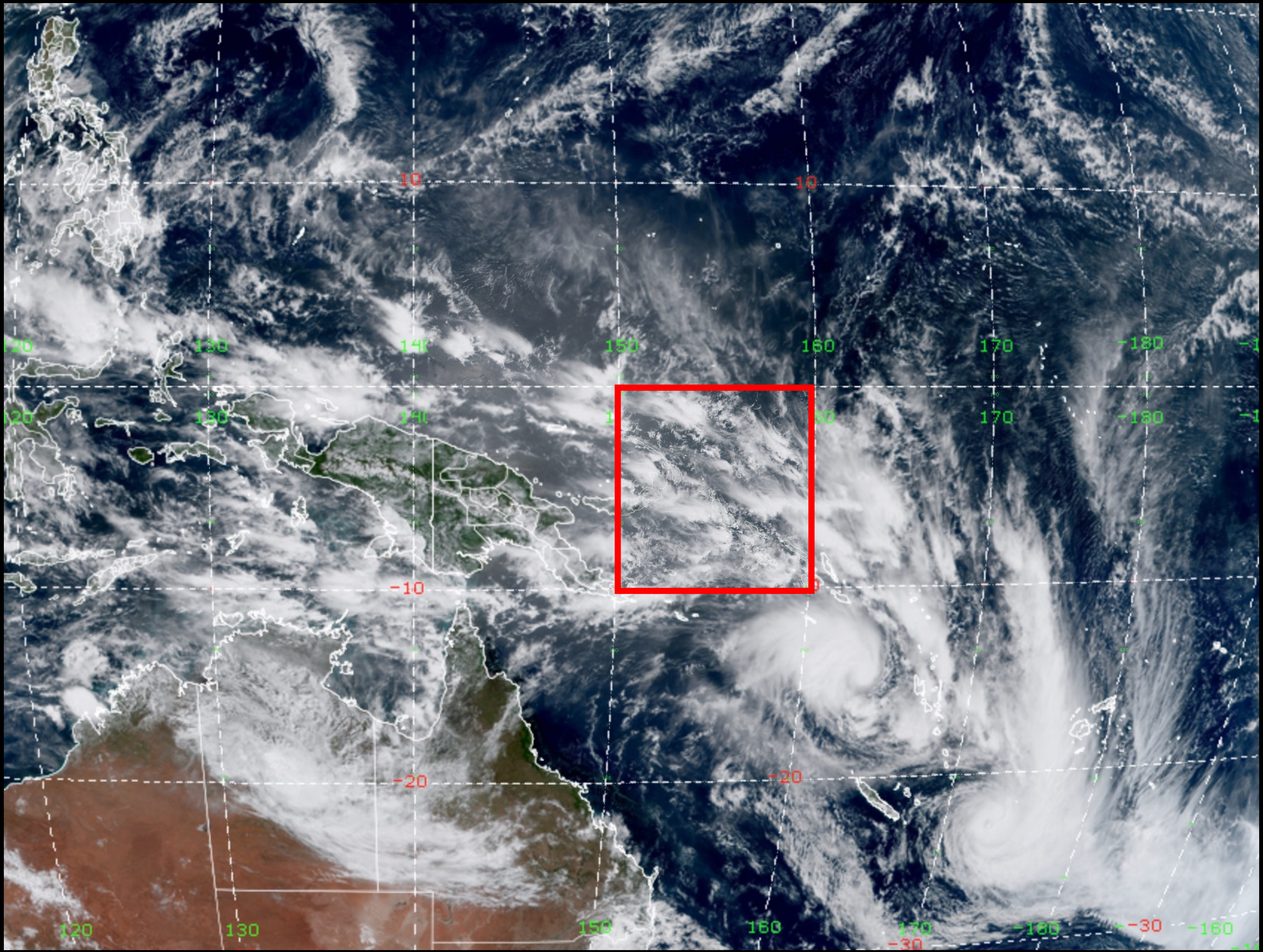


Image from
Himawari-9
0200 2
March 2023
(CSU/CIRA)

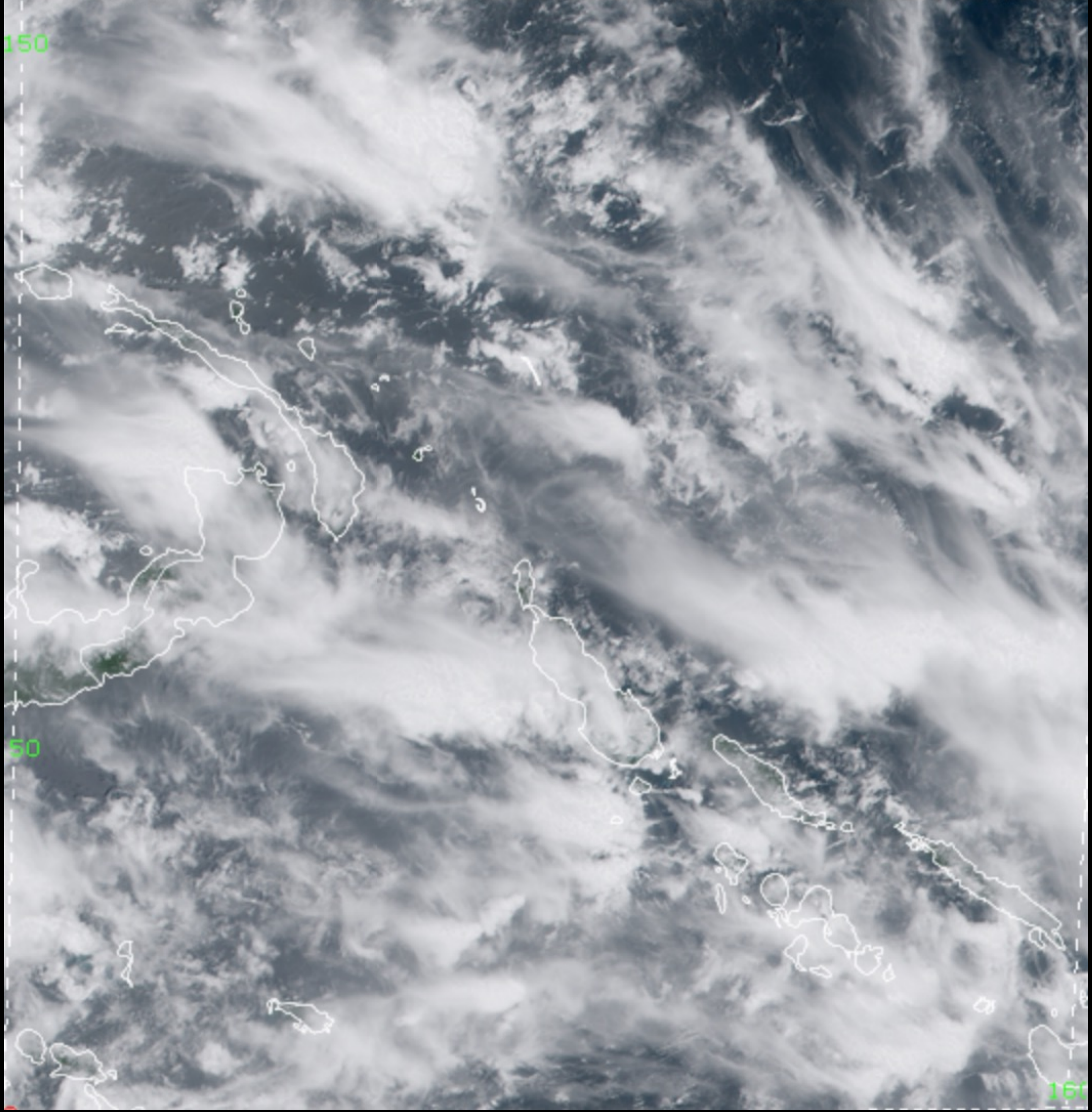
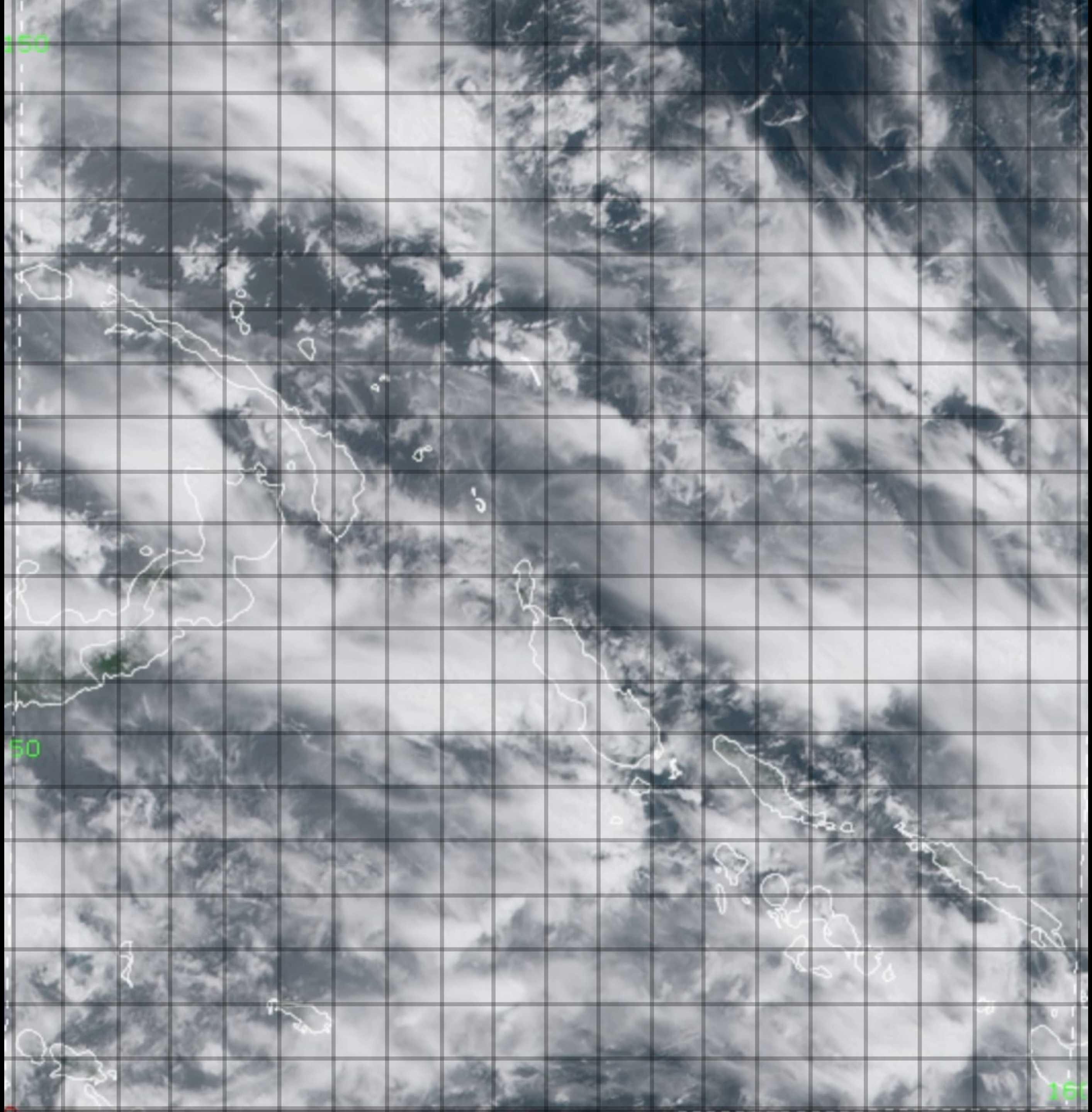


Image from Himawari-9 0200 2 March 2023 (CSU/CIRA)



Animation from CSU/CIRA 0200–0400 2 March 2023

Why does our understanding and modeling of large-scale dynamics depend on individual clouds?

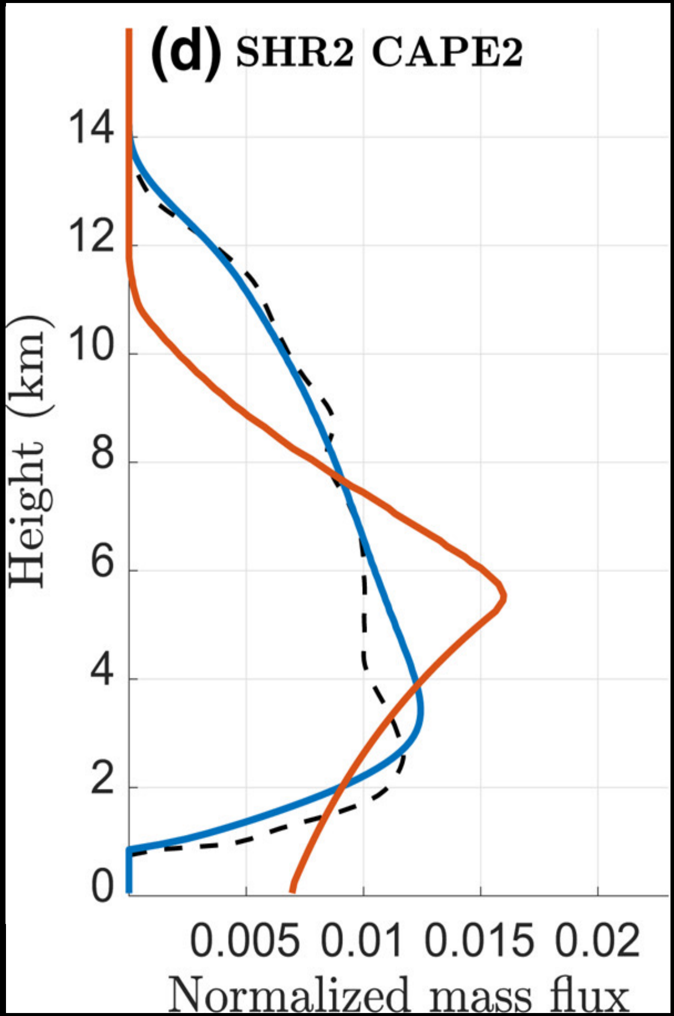
Cumulus parameterization depends on the thermodynamic properties of atmosphere, makes some questionable assumptions about vertical mass flux, and does poorly at accounting for the life cycle of convection.

Peters et al. (2021)

Red: Cumulus parameterization

Black: LES

Blue: Revised treatment of mass flux



Poor parameterization of mass flux and detrainment leads to misrepresentation of radiative heating profiles! Major impact on MJO maintenance and propagation. Focus of new NOAA/CVP project.

Peters et al. (2021)

Red: Cumulus parameterization

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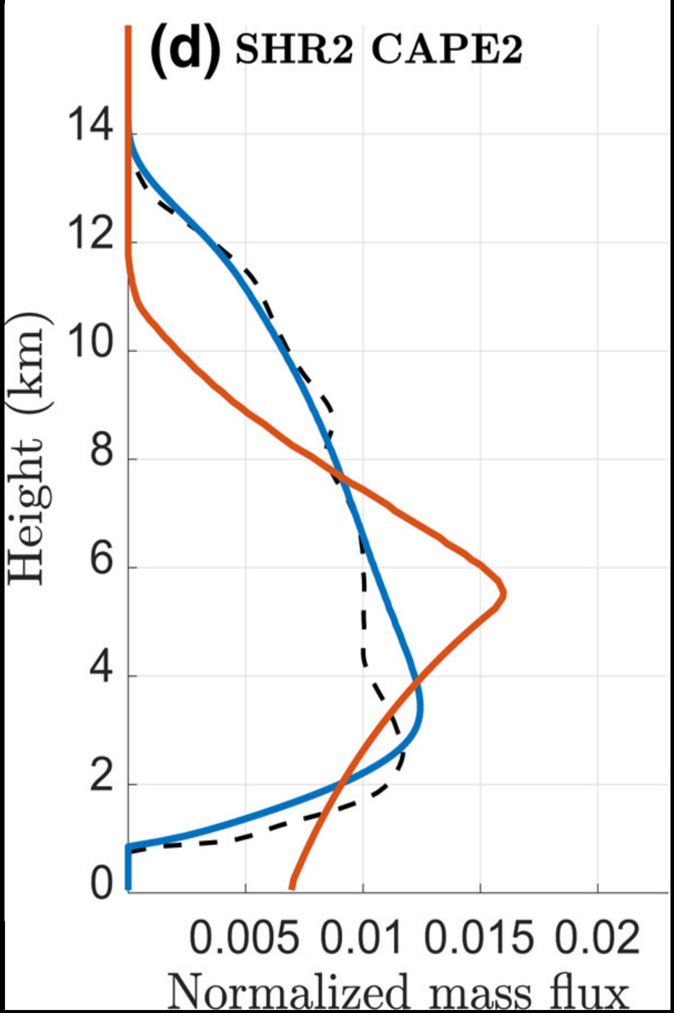
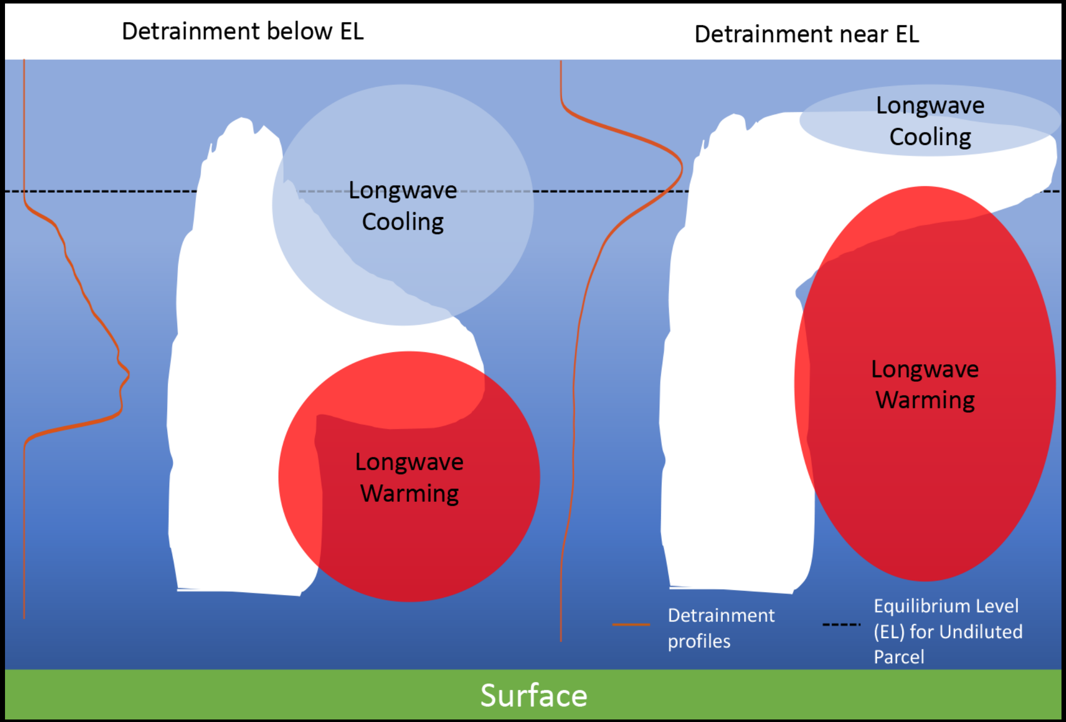




Poor parameterization of mass flux and detrainment leads to misrepresentation of radiative heating profiles! Major impact on MJO maintenance and propagation.

What *forces* convection to deepen?

Vertical Momentum Equation

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

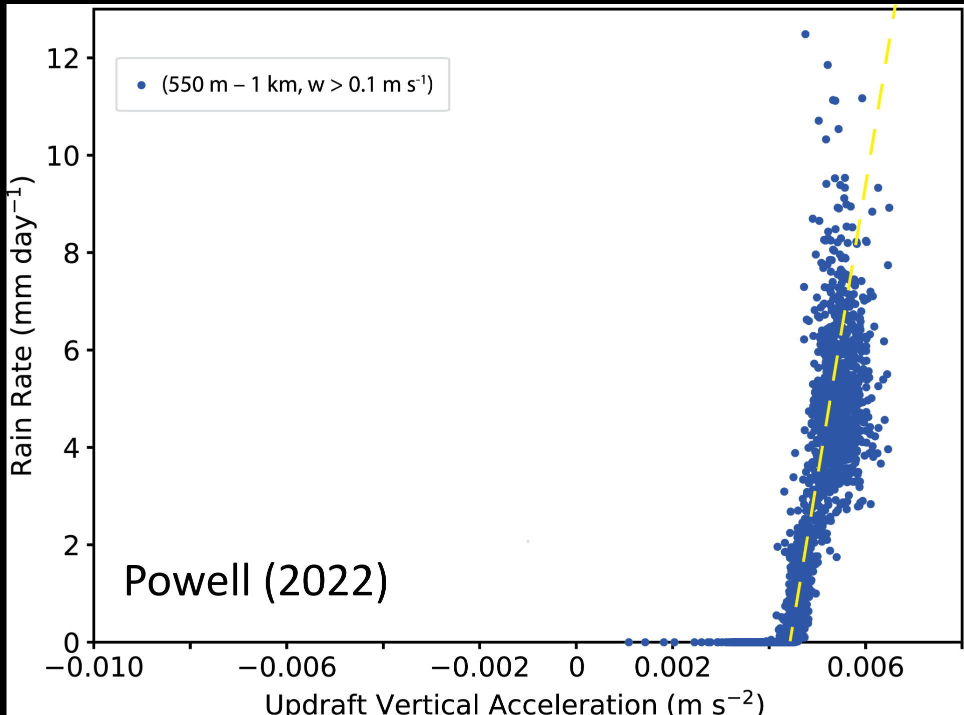
$$\frac{Dw}{Dt} \approx -\frac{1}{\rho}\frac{\partial p'_D}{\partial z} - \frac{1}{\rho}\frac{\partial p'_B}{\partial z} + B$$

Archimedean buoyancy

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

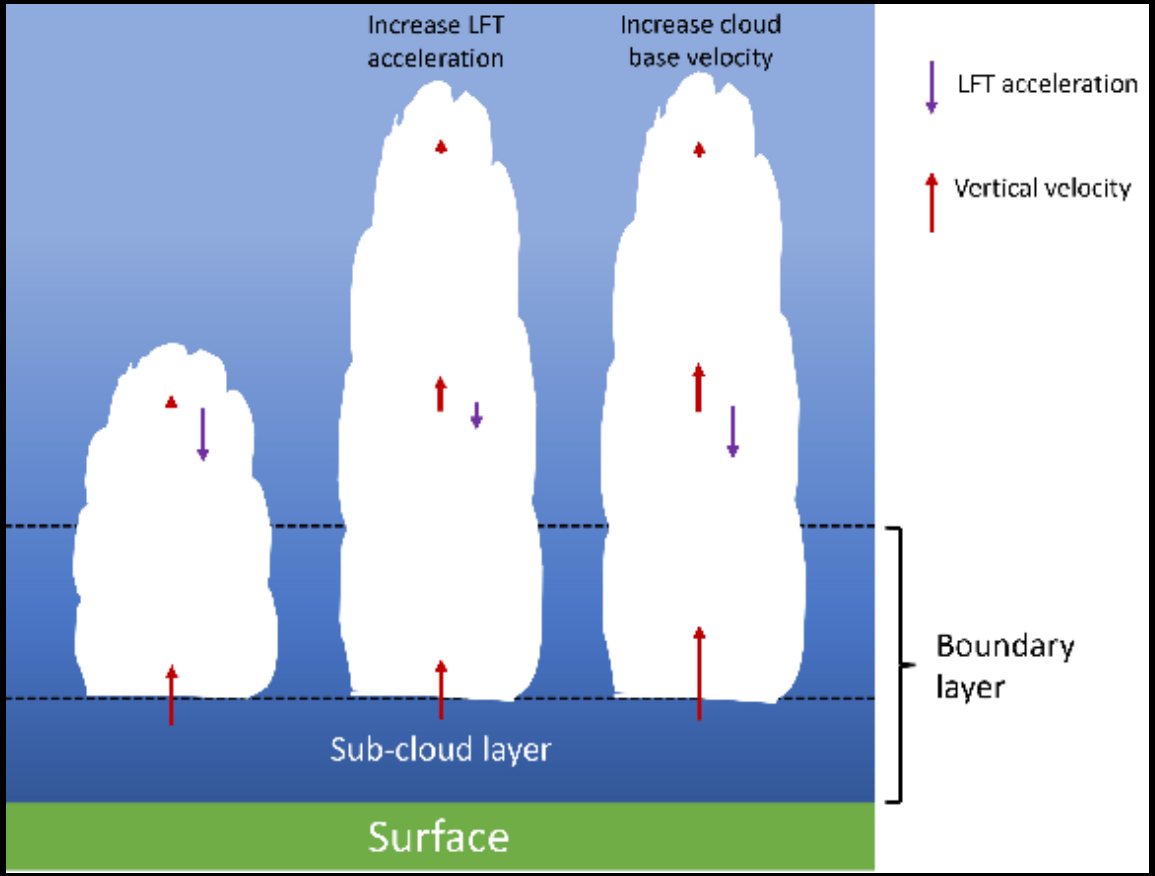
Vertical gradient of dynamic perturbation pressure.

Vertical Pressure Gradient Accelerations



Which clouds grow vs. do not grow?

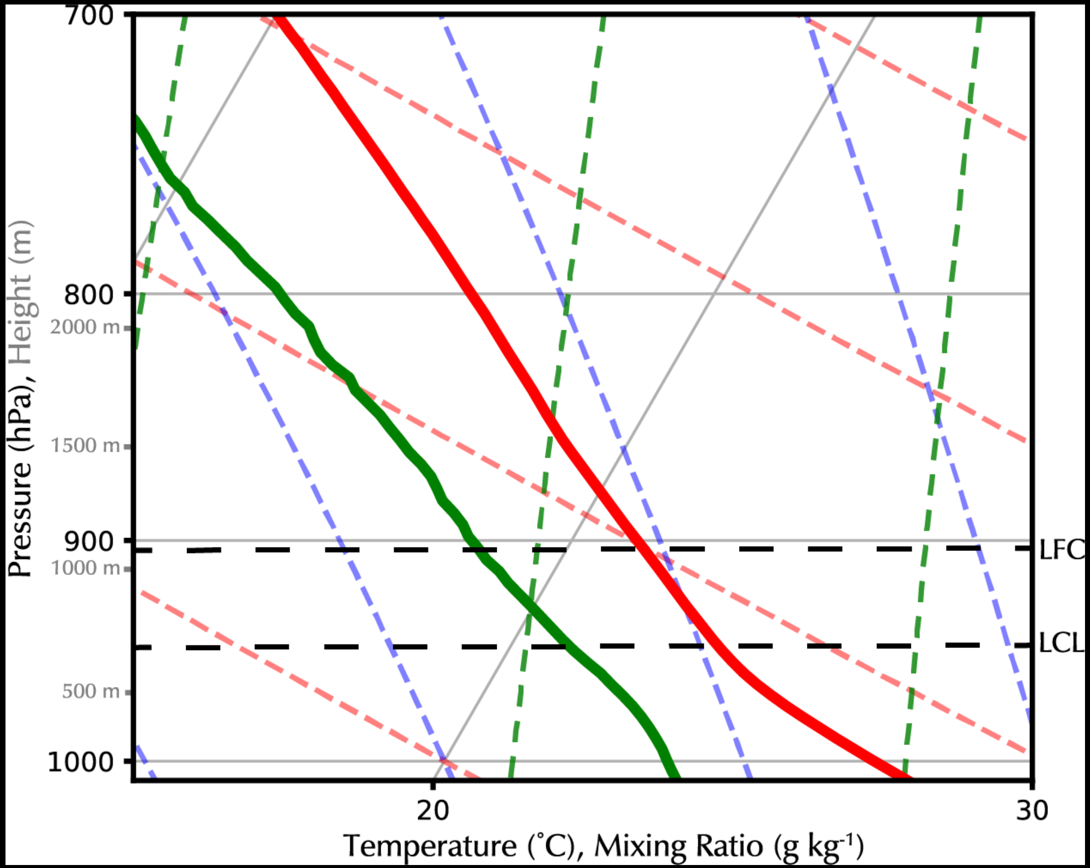
- Do growers have larger initial *w* or do they experience more upward/less downward acceleration (or both)?
- This is extremely challenging to answer with observations alone (although techniques like photogrammetry can help some within limited volumes).
- If D*w*/D*t* is most important, we would like to decompose it to determine what causes downward acceleration.



Powell (2022, 2023)

Cloud Model 1 (CM1) configuration:
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 (2023)



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

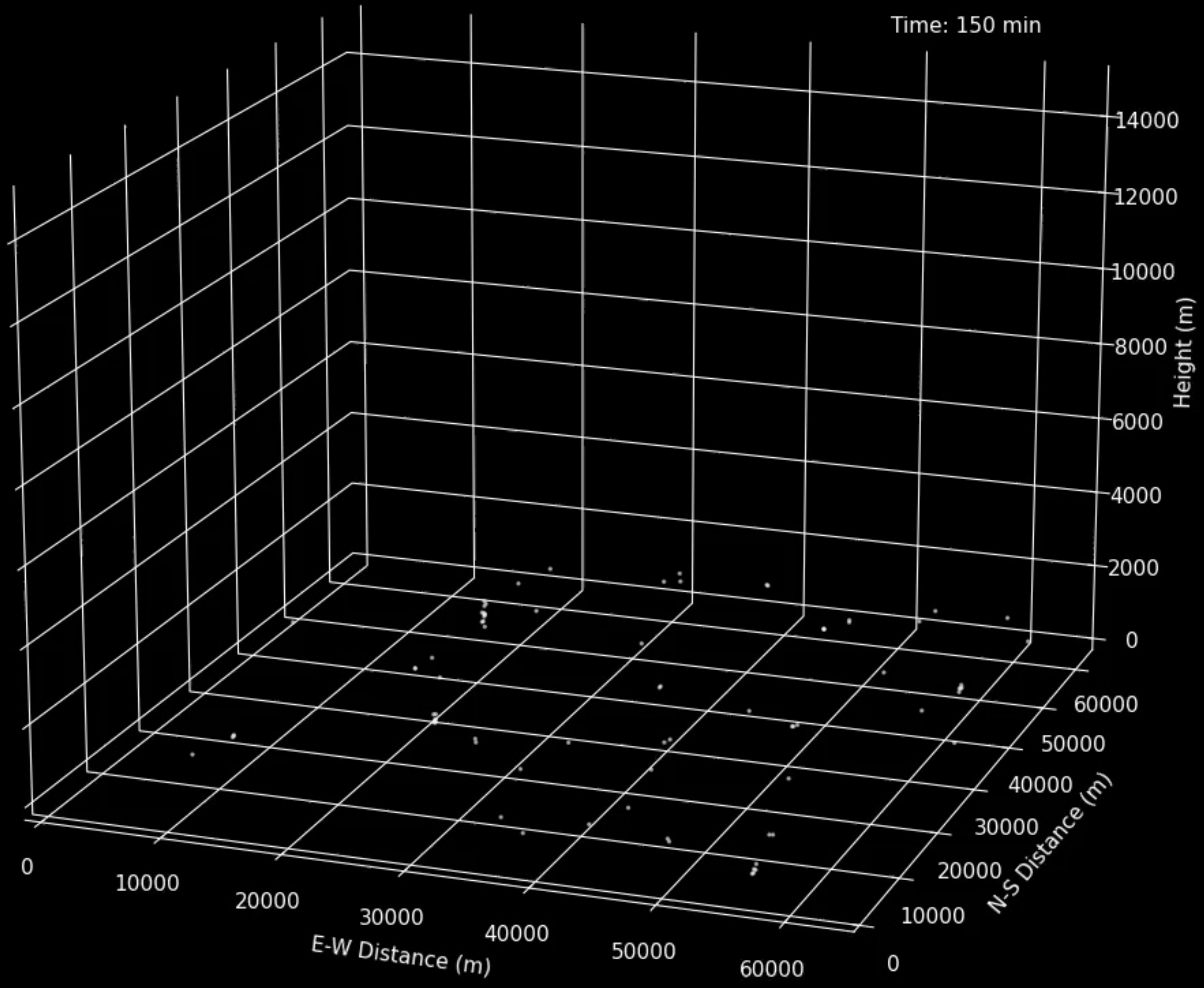
- 10,240,000 parcel trajectories analyzed
- Over 5 Tb of output for just one simulation

- 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.

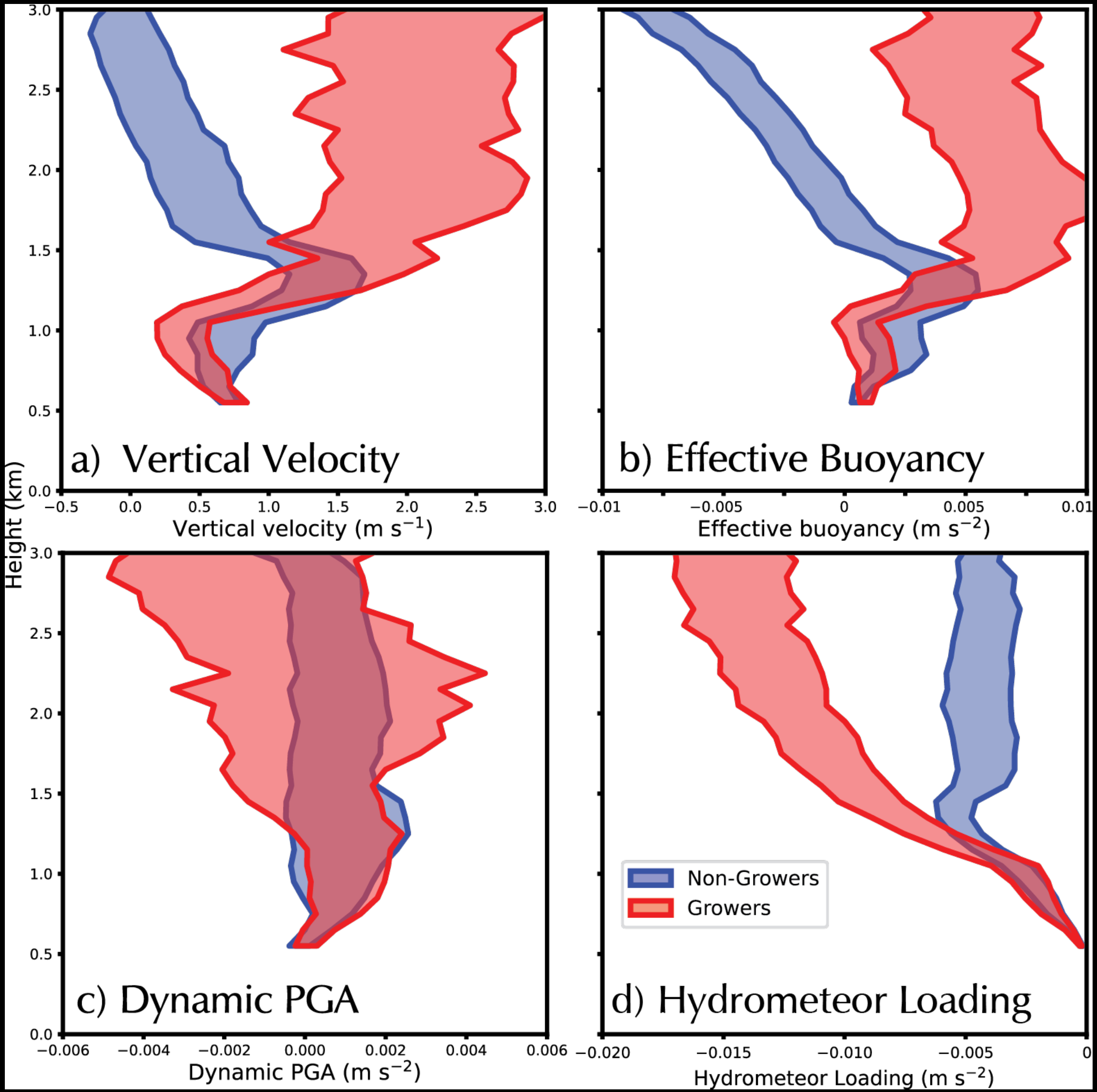
Powell (2023)

Red: Growers
Blue: Non-Growers

Parcel trajectories only shown when in cloud.

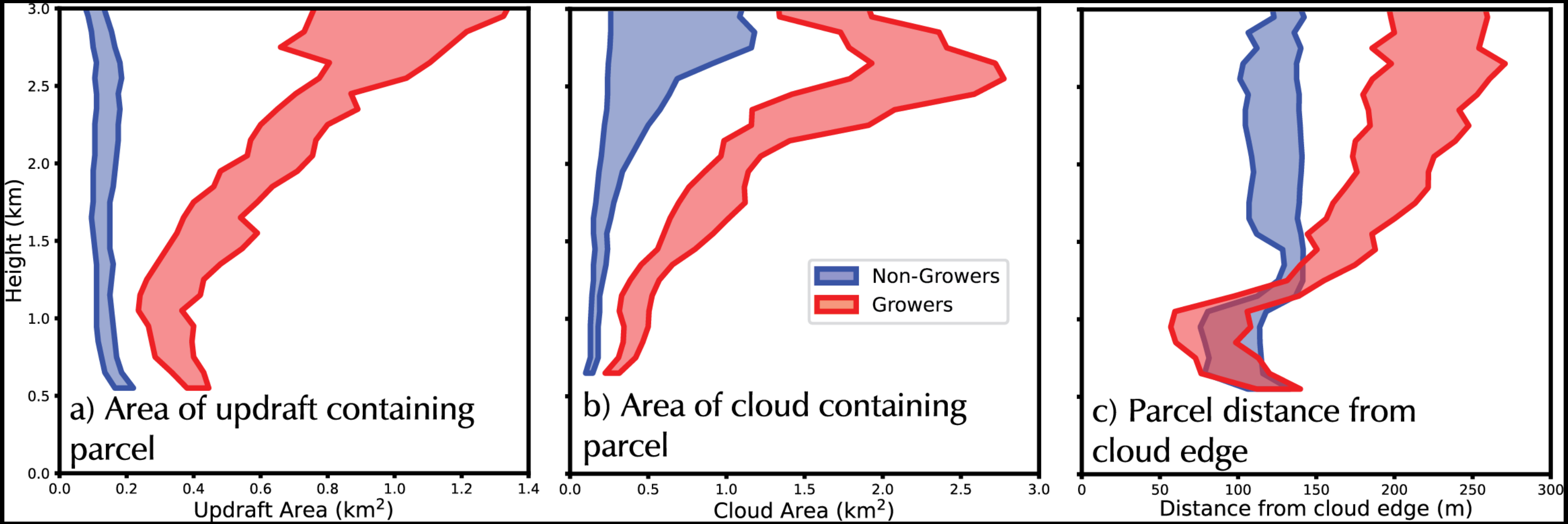


Powell (2023)



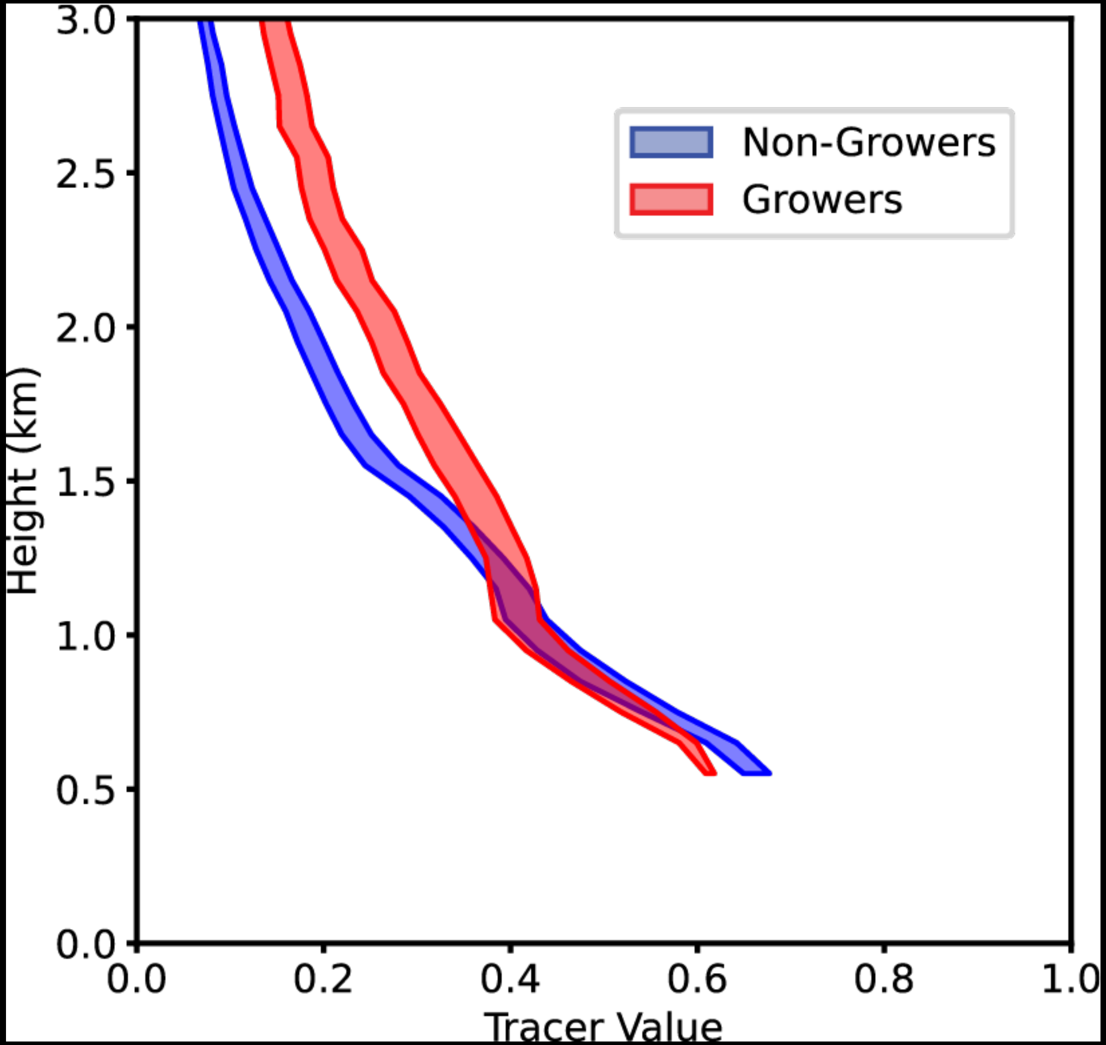
Shaded regions indicated 95% confidence interval of median.

Powell (2023)



Shaded regions indicated 95% confidence interval of median.

Powell (2023)



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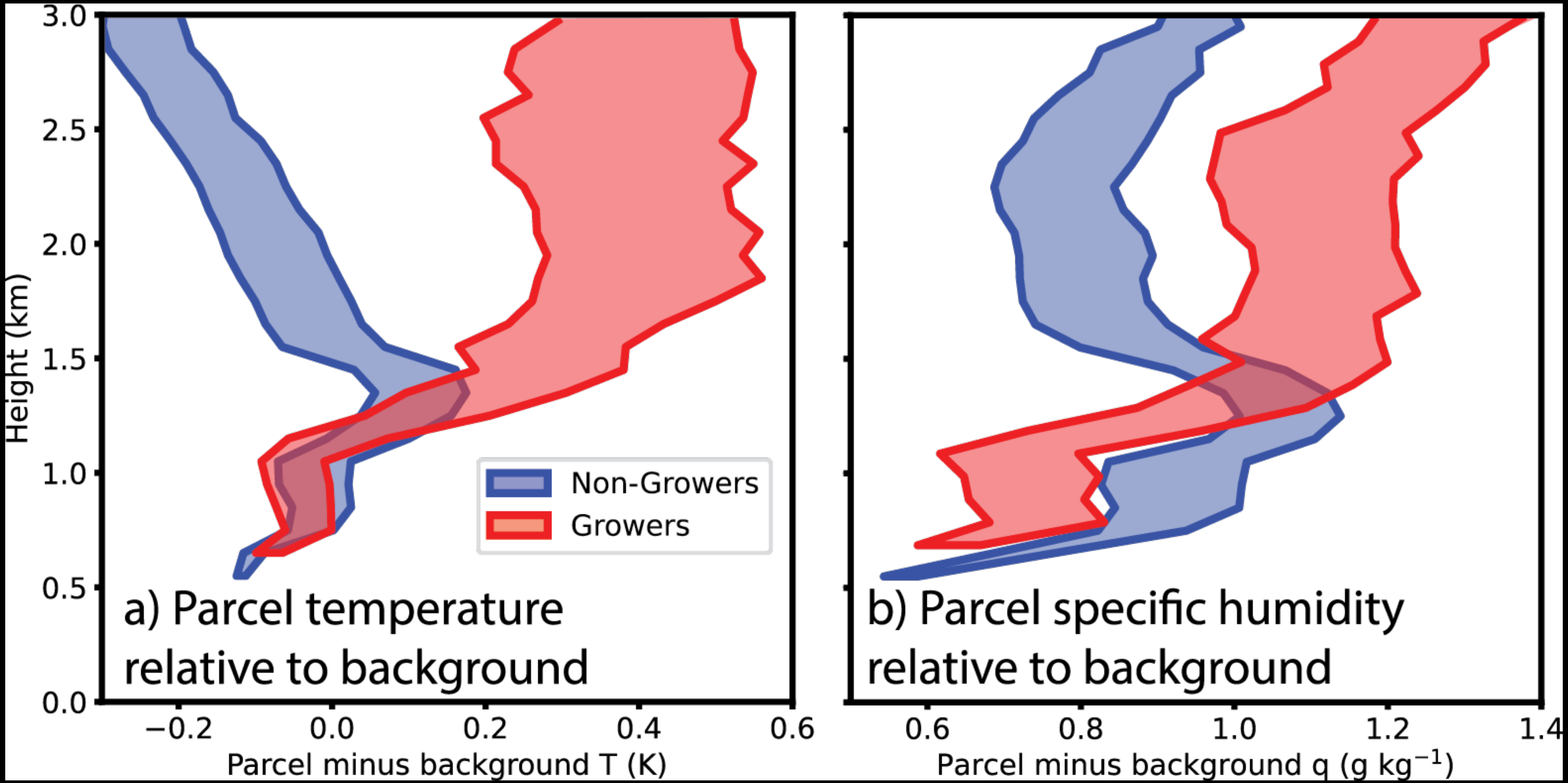
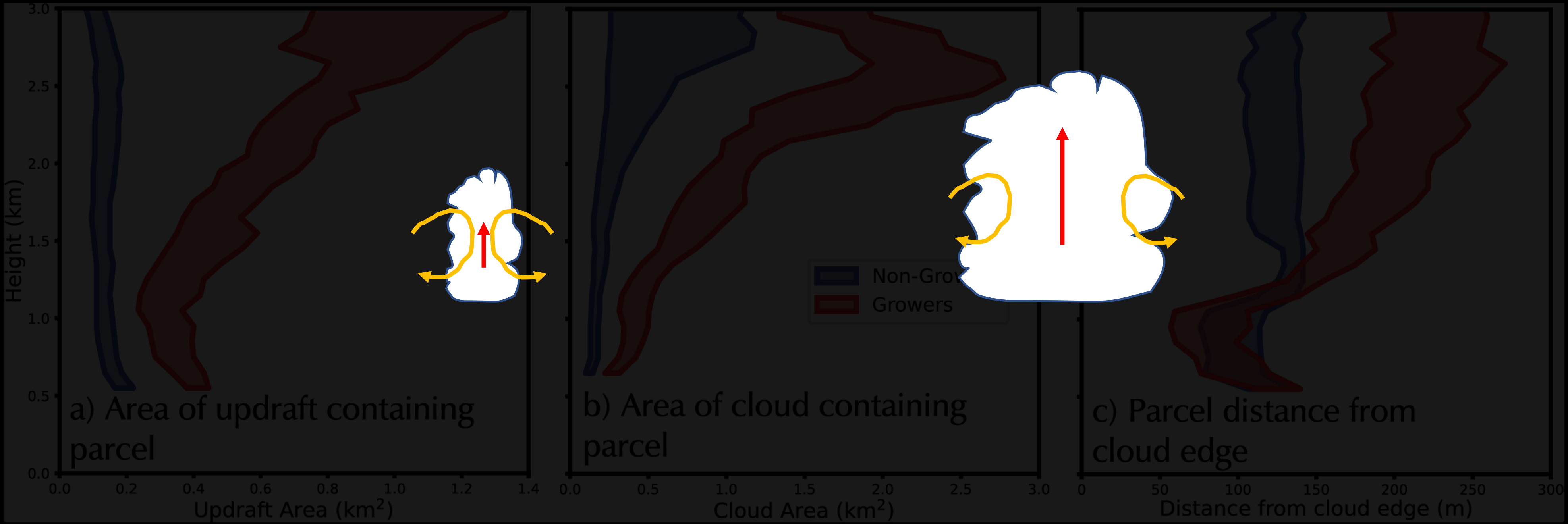
Powell (2023)



Shaded regions indicated 95% confidence interval of median.

Narrow cloud: Diluted updraft

Wide cloud: More protected from environmental air

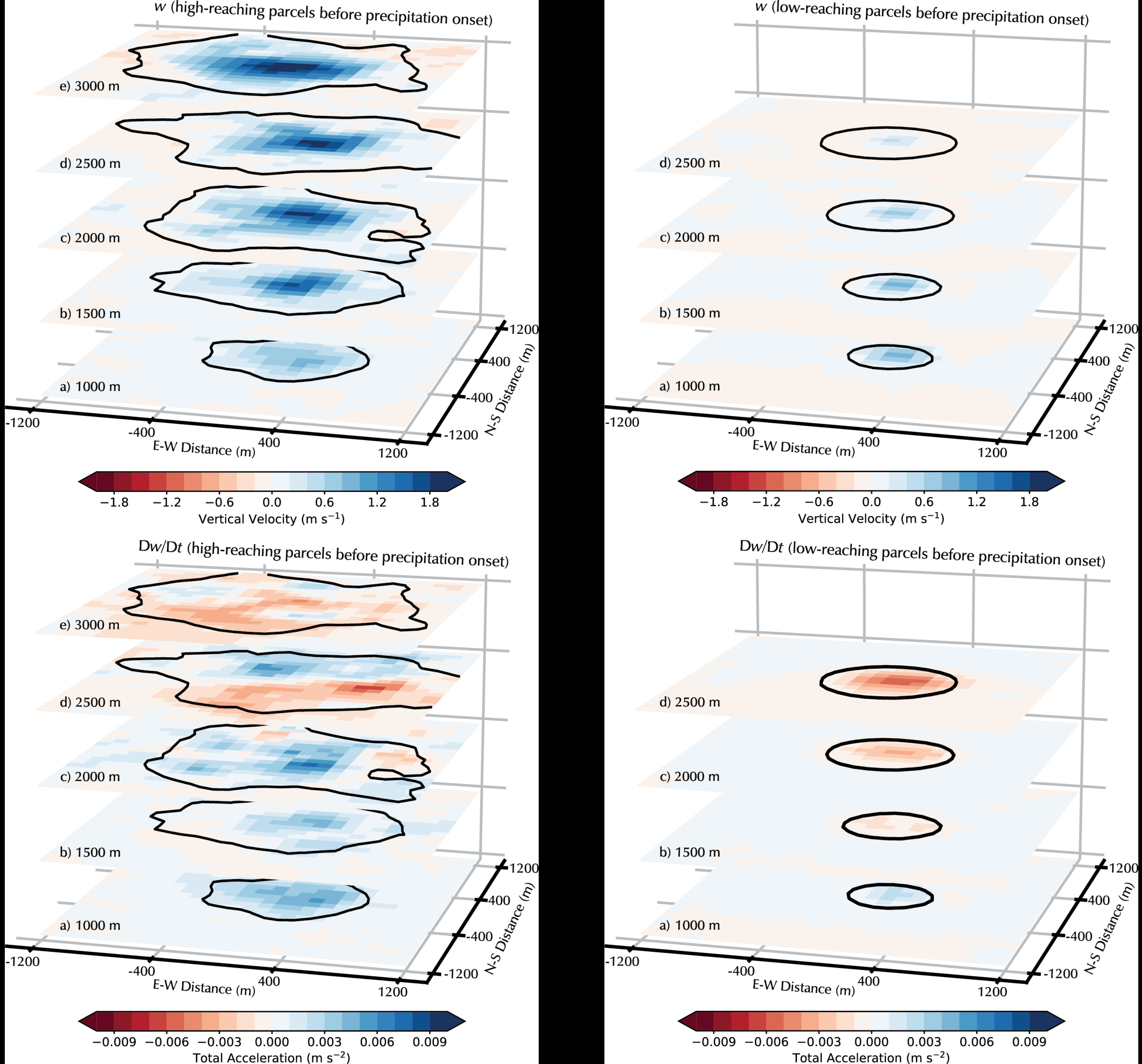


Shaded regions indicated 95% confidence interval of median.

Powell (2023)

Vertical Velocity

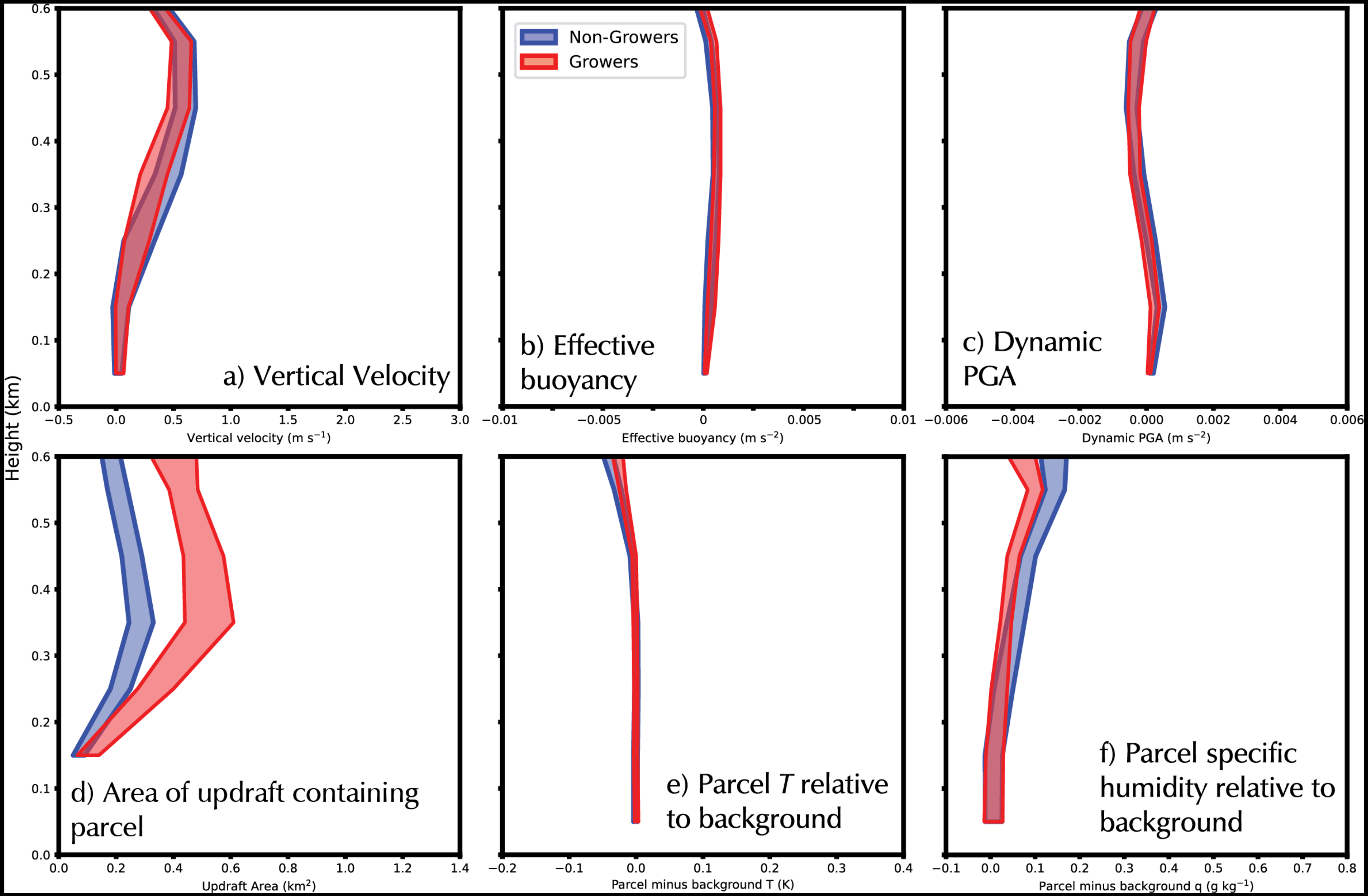
Vertical Acceleration (Dw/Dt)



Growing Clouds

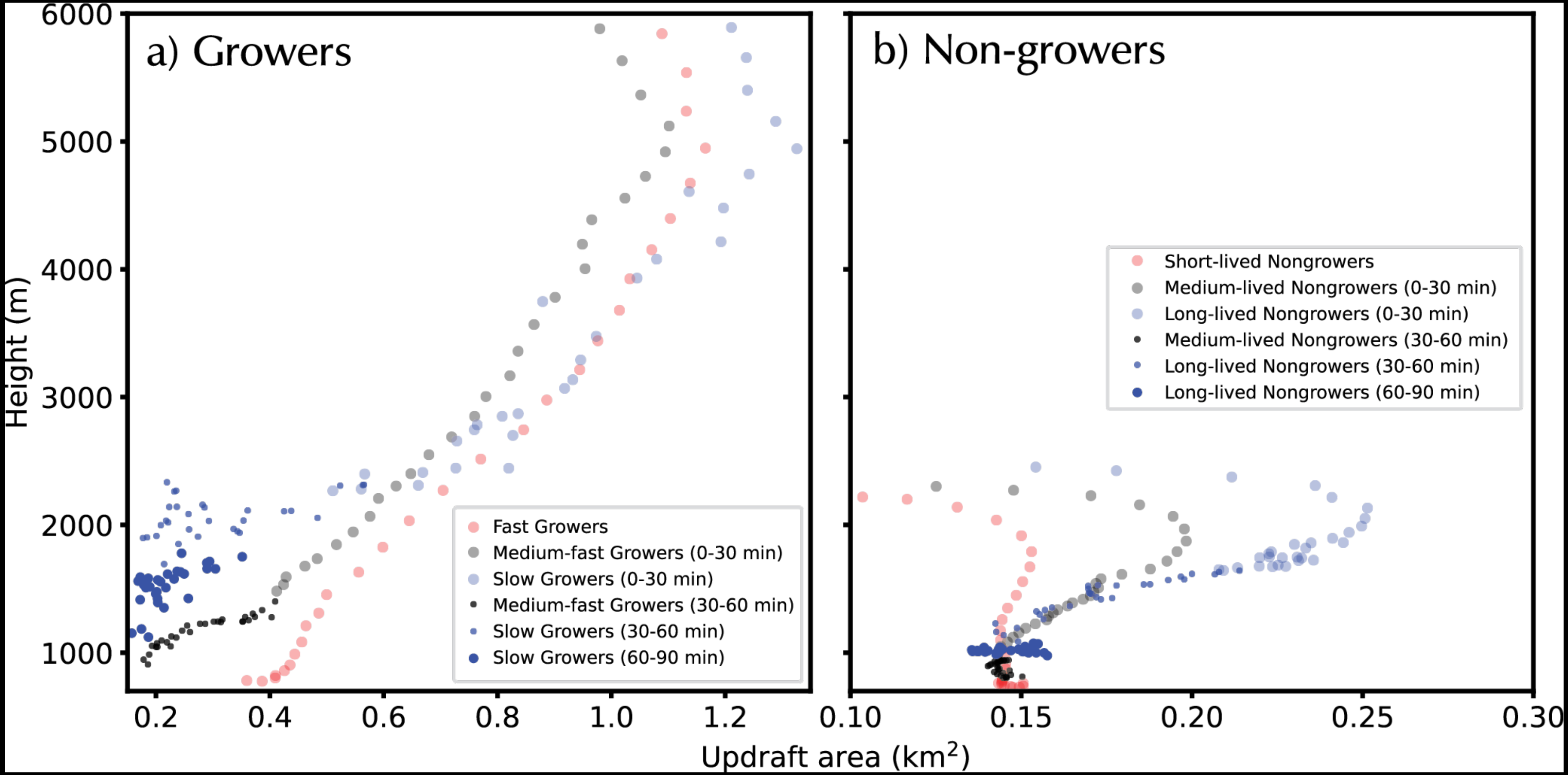
Non-Growing Clouds

Powell (2023)



Shaded regions indicated 95% confidence interval of median.

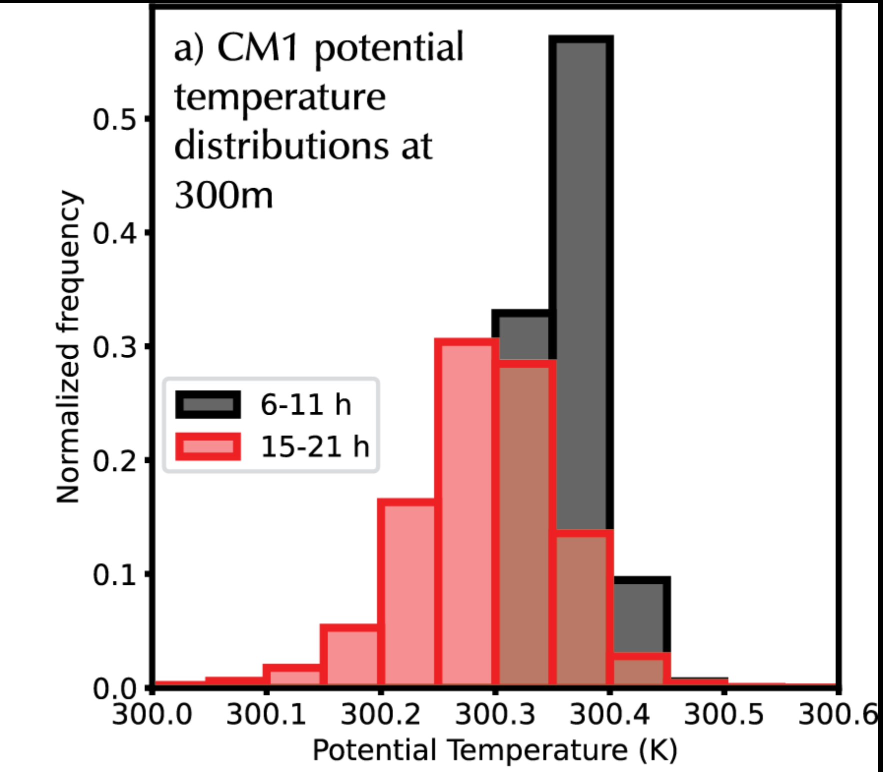
Powell (2023)

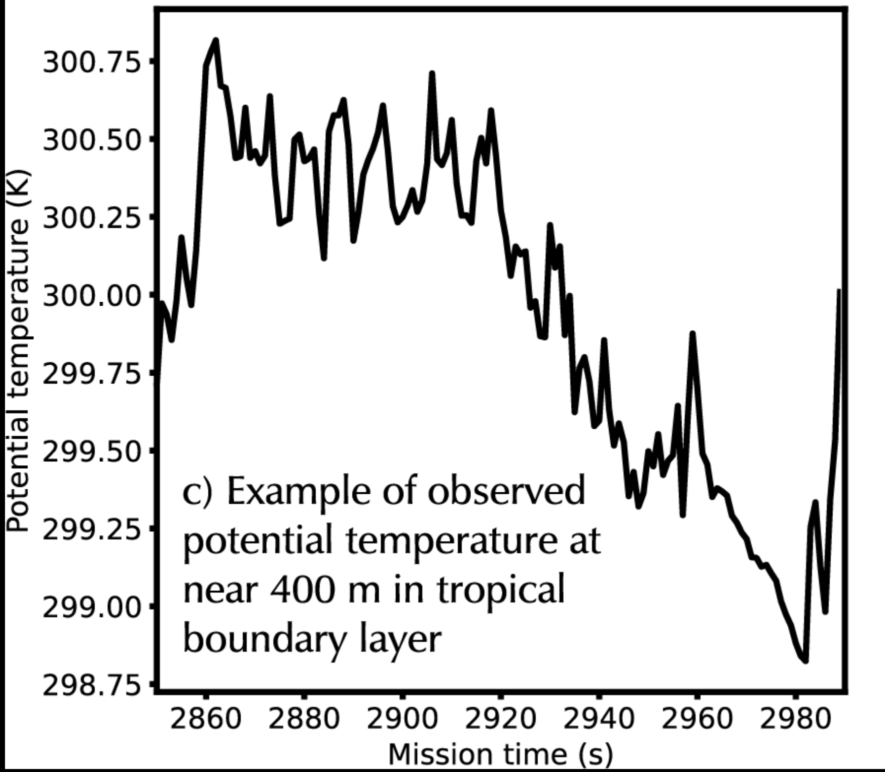


Parcels did not ascend rapidly until they were contained in an updraft that exceeded a certain size. In this simulation, this was 0.4–0.6 km^2.

This critical size is not "one-size-fits-all"! In nature, it probably depends on environmental conditions.

Powell (2023)





Boundary layer temperature distributions in the model are much narrower than in observations.

Therefore, although these results indicate importance of eddy updraft size, they cannot assess importance of BL temperature on evolution of eddy into cloud!

Conclusions

- The size of individual clouds and updrafts as they rise out of the sub-cloud layer is one control on their eventual fate. However, models do not have total fidelity to nature. How important are boundary layer temperature or humidity variability (or other quantities)?

- Parcels that reach the upper troposphere are diluted less in-cloud after they rise out of the boundary layer.

- Cause and effect remains unclear. Are updrafts wider because their size is reinforced by existing clouds (perhaps that initially partially because their environment was moist)? Or do boundary layer processes control the size of incipient updraft eddies independently of cloud dynamics?