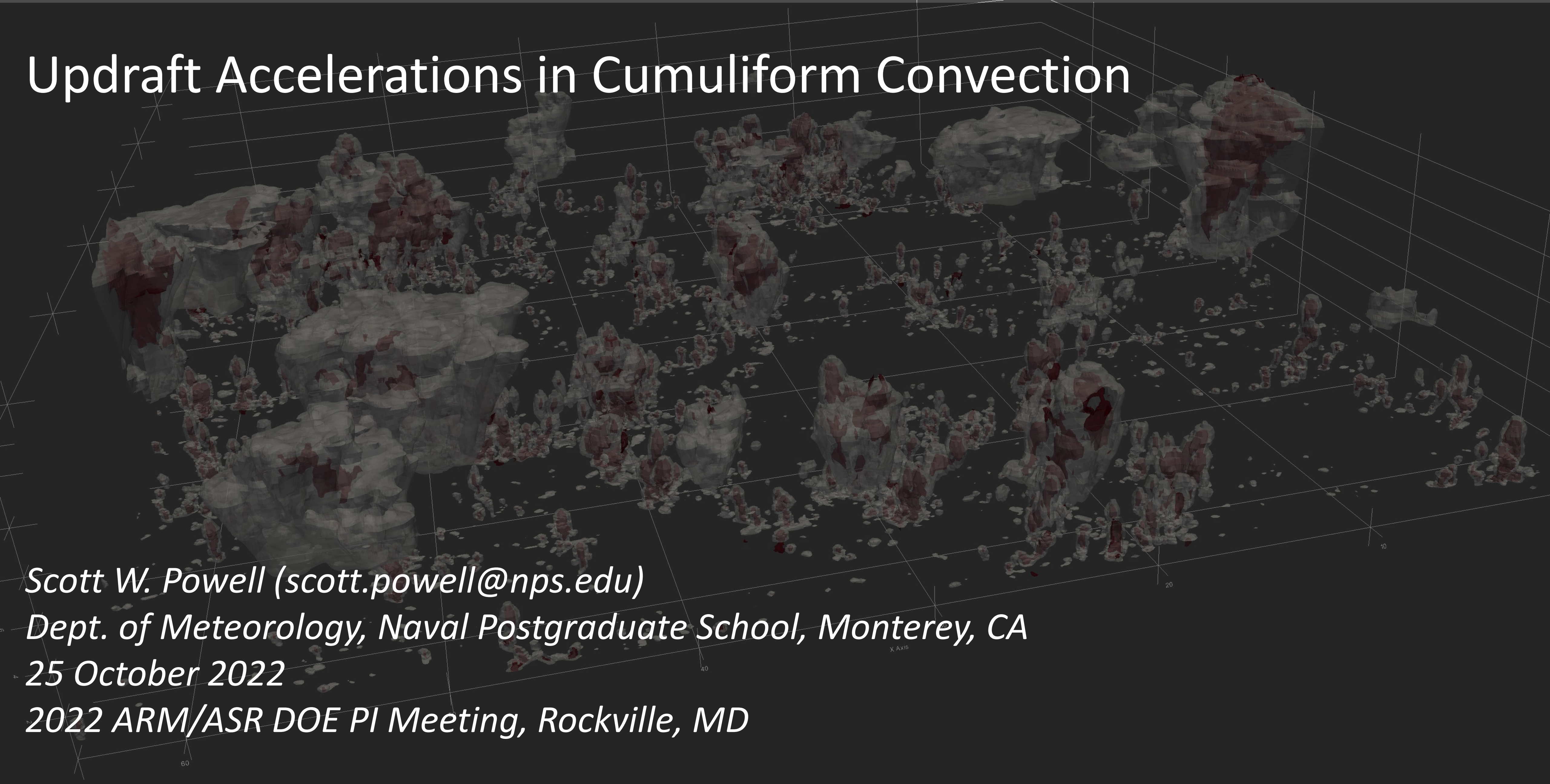
Updraft Accelerations in Cumuliform Convection



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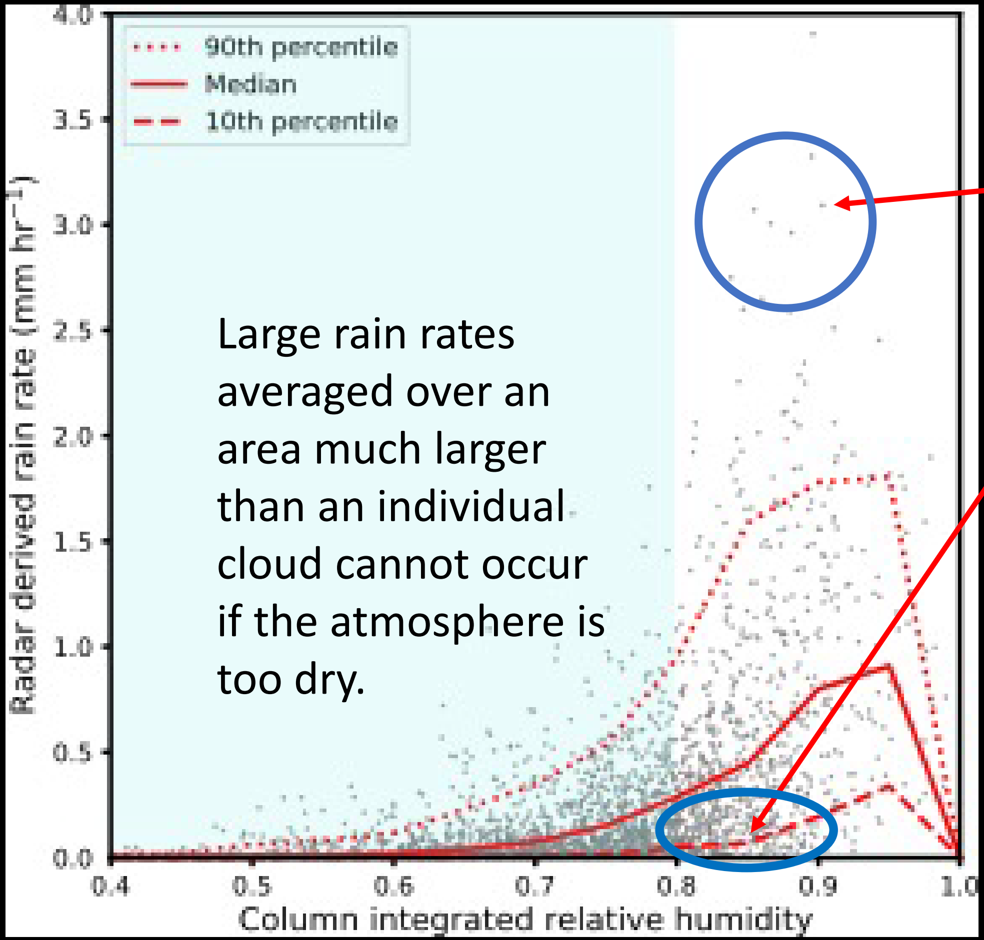
Why do we care?

Tropospheric moisture is a necessary condition for deep convection and large rain rates, but by itself is not sufficient.

Radar-derived rain rate vs sonde-derived CRH over tropical oceans



Column-relative humidity of 80% or greater is often considered sufficiently moist for widespread deep convection to occur, but rain rates in such an environment can range from very large to near zero!

What controls the when rain rate is zero versus large when the atmosphere is moist?

Powell (2019)

What *forces* convection?

Vertical Momentum Equation

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

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Archimedean buoyancy

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

Vertical Momentum Equation

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

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

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Vertical Pressure Gradient Accelerations

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"Effective buoyancy"

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Vertical Pressure Gradient Accelerations

Vertical gradient of dynamic perturbation pressure. Can be further separated into linear and nonlinear components:

$$-\frac{1}{\rho}\frac{\partial p'_D}{\partial z} = -\frac{1}{\rho}\frac{\partial p'_{D,L}}{\partial z} - \frac{1}{\rho}\frac{\partial p'_{D,NL}}{\partial z}$$

$$\nabla^2 p'_{D,L} \propto \frac{\partial \boldsymbol{u}_{H,0}}{\partial z} \cdot \nabla_H w$$

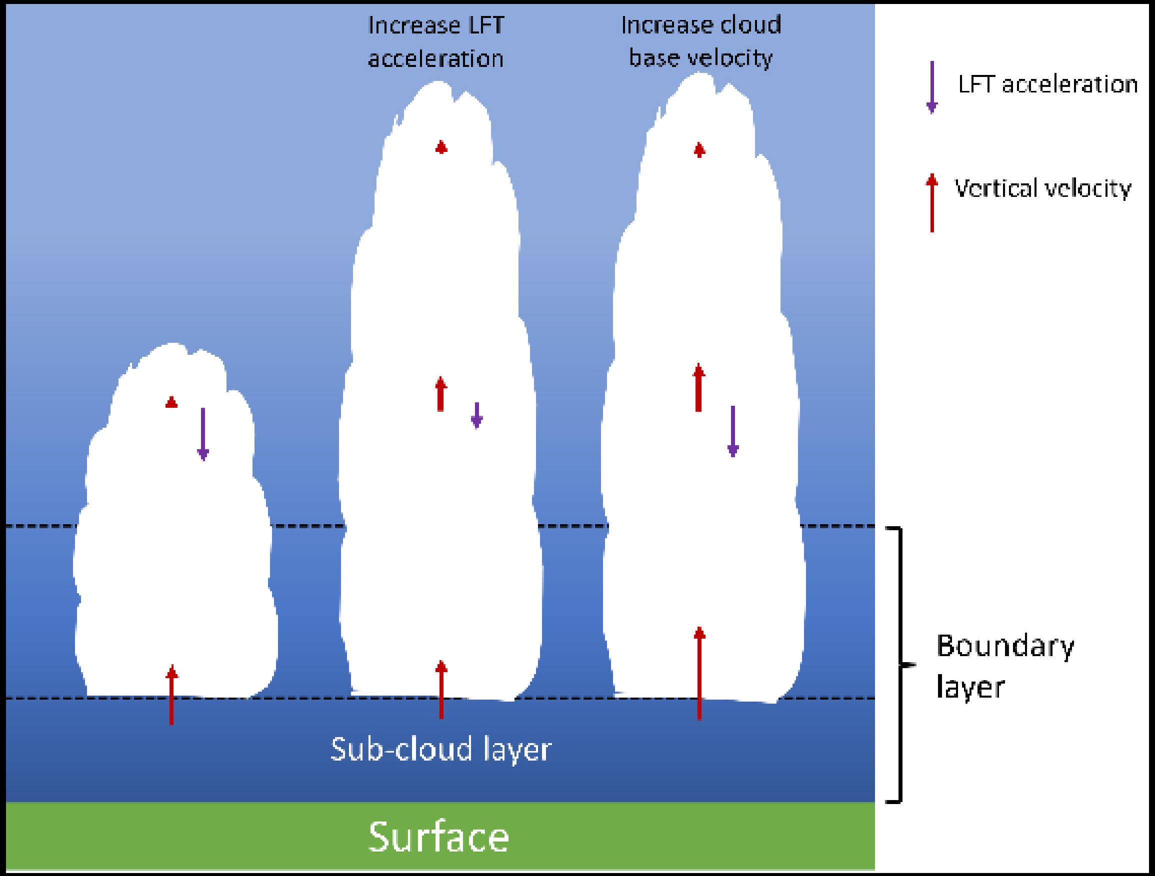
$$\nabla^2 p'_{D,NL} \propto \text{ext.} + \text{shear}$$

Which clouds grow vs. do not grow?

- Do growers have larger initial *w* or do they experience more upward/less downward acceleration (or both)?

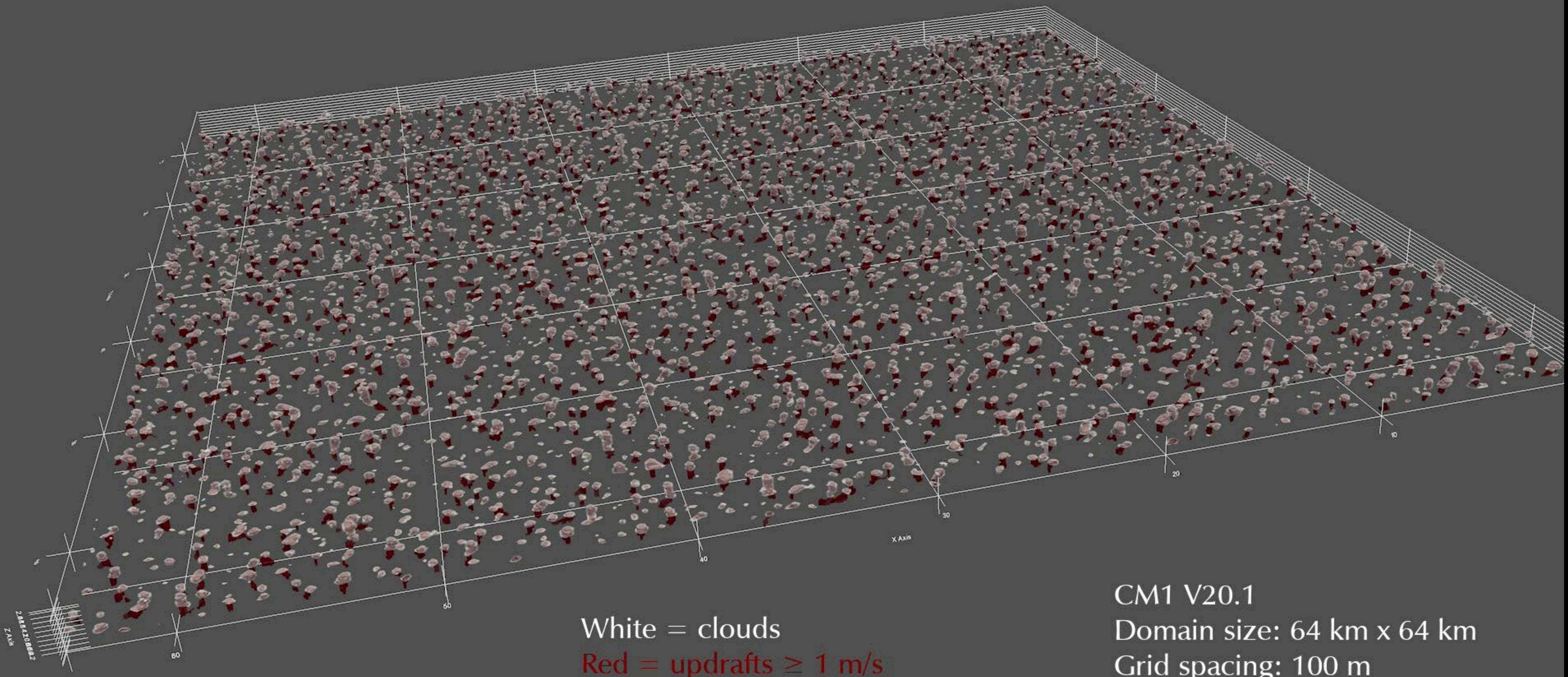
- This is extremely challenging to answer with observations alone (although techniques like photogrammetry can help some within limited volumes).

- If D*w*/D*t* is most important, we would like to decompose it to determine what causes downward acceleration.



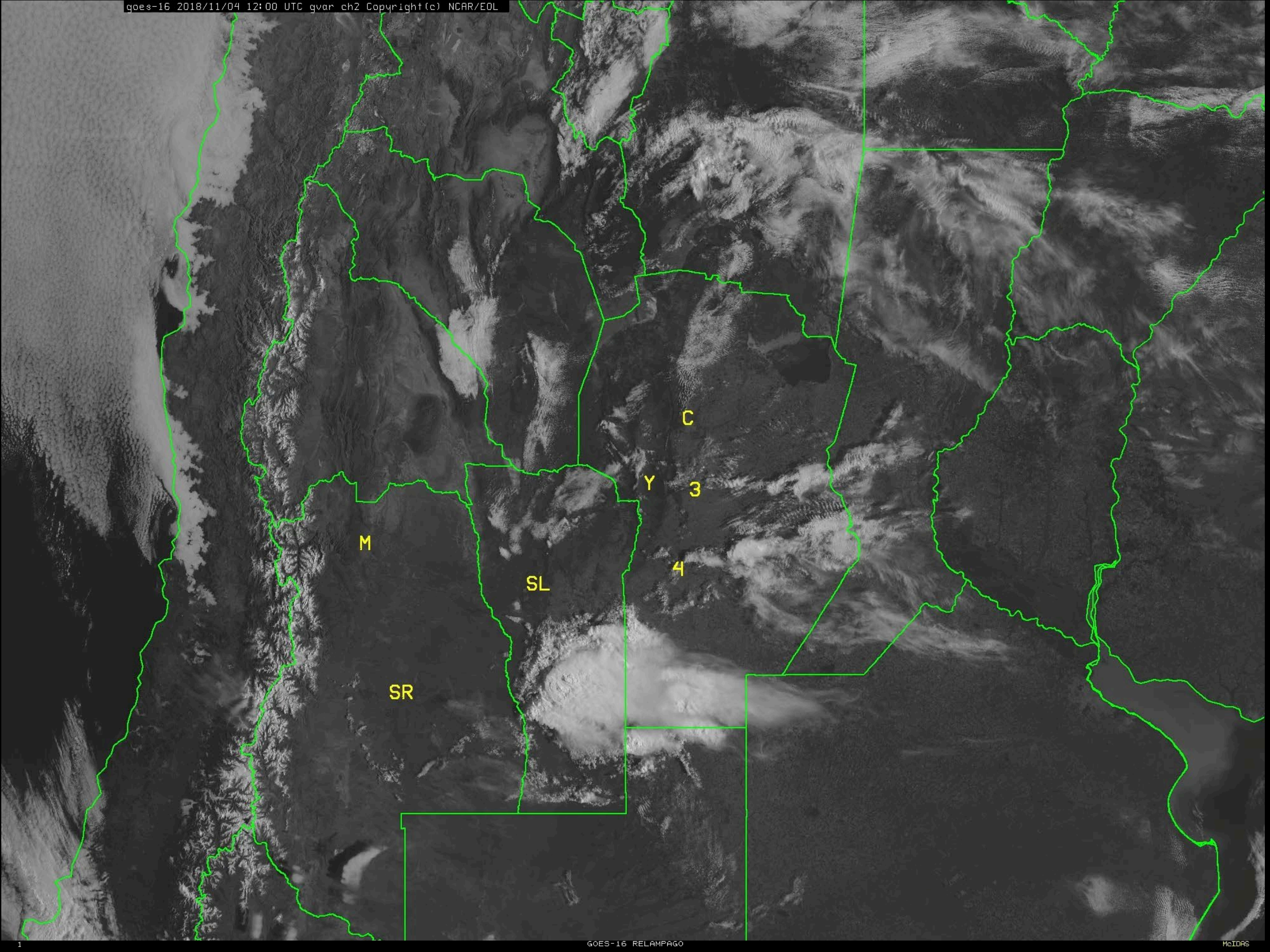
Tropical Ocean

Images made with PyVista
Sullivan et al. (2019)



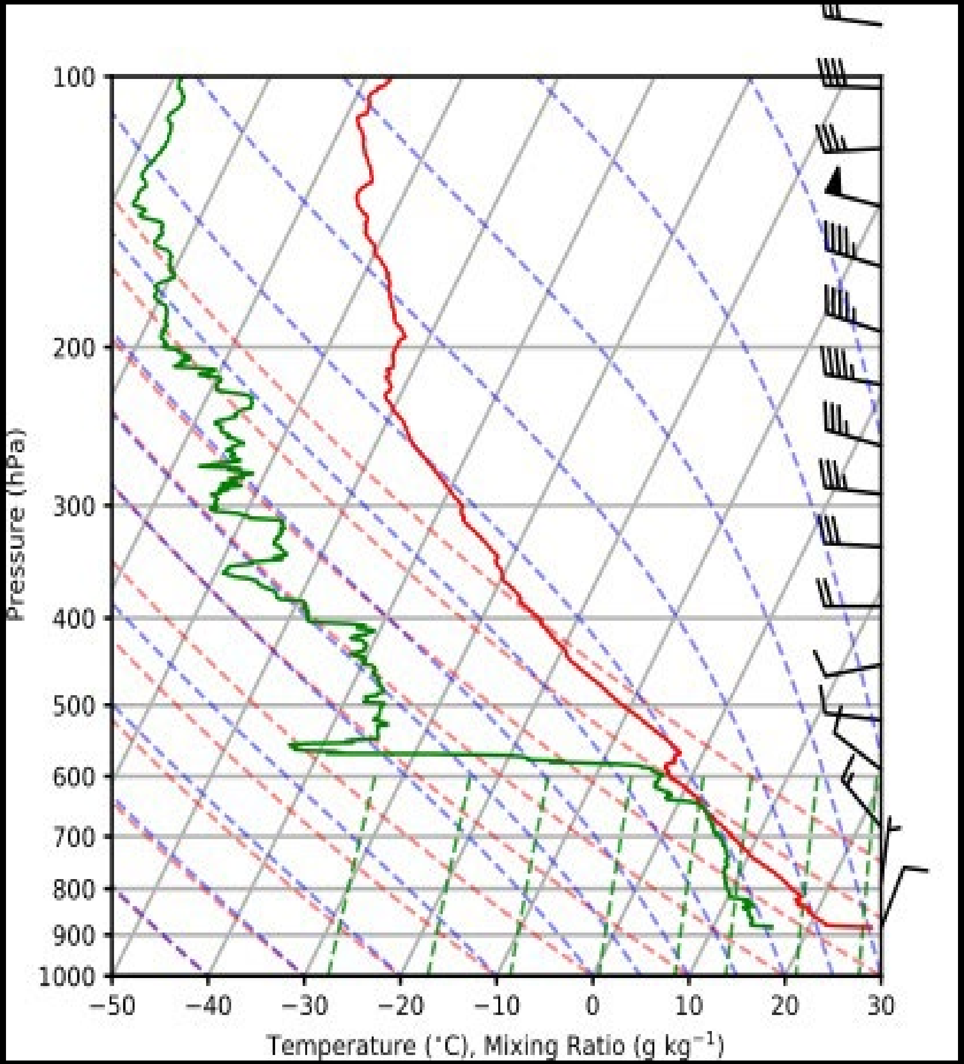
White = clouds
Red = updrafts ≥ 1 m/s
In boundary layer only updrafts ≥ 1 m/s connected to cloudy uprafts are shown.

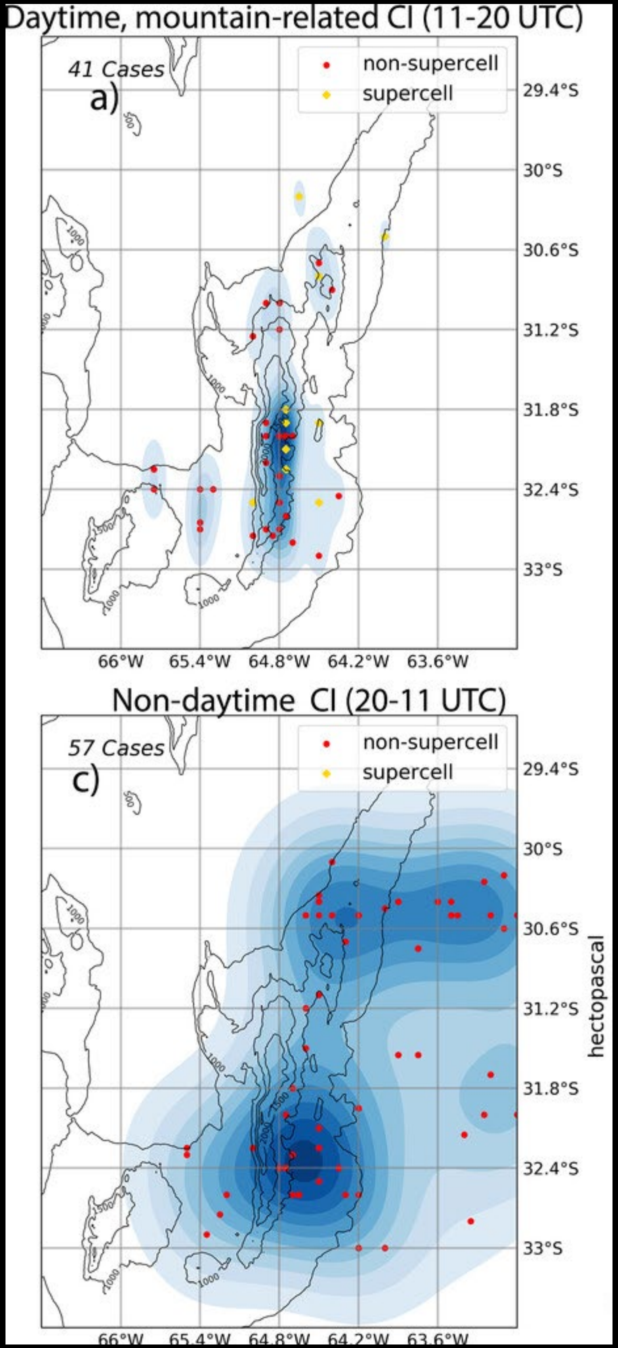
CM1 V20.1
Domain size: 64 km x 64 km
Grid spacing: 100 m
Initial Conditions: Moist DYNAMO sounding with BL *T* perturbations

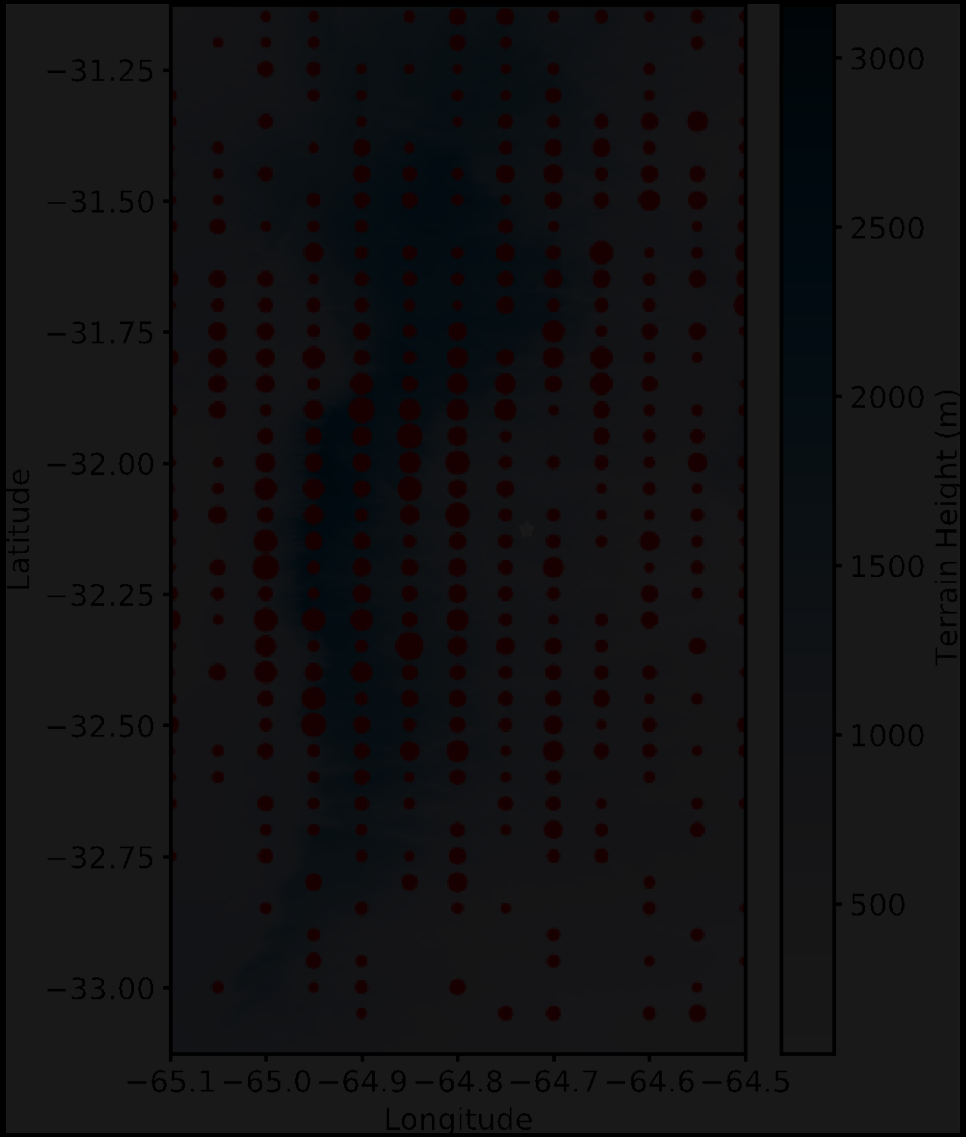


4 November 2018: GOES-16 (1200–2100 UTC)

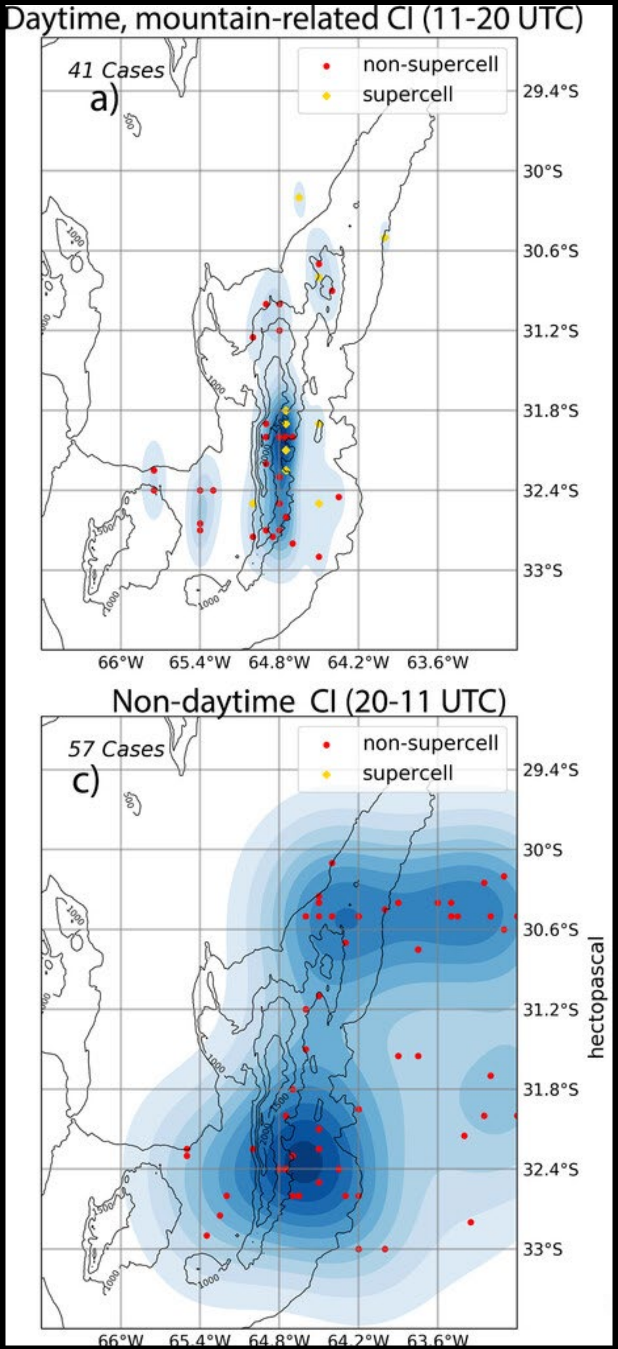
AMF 1800 UTC Sounding

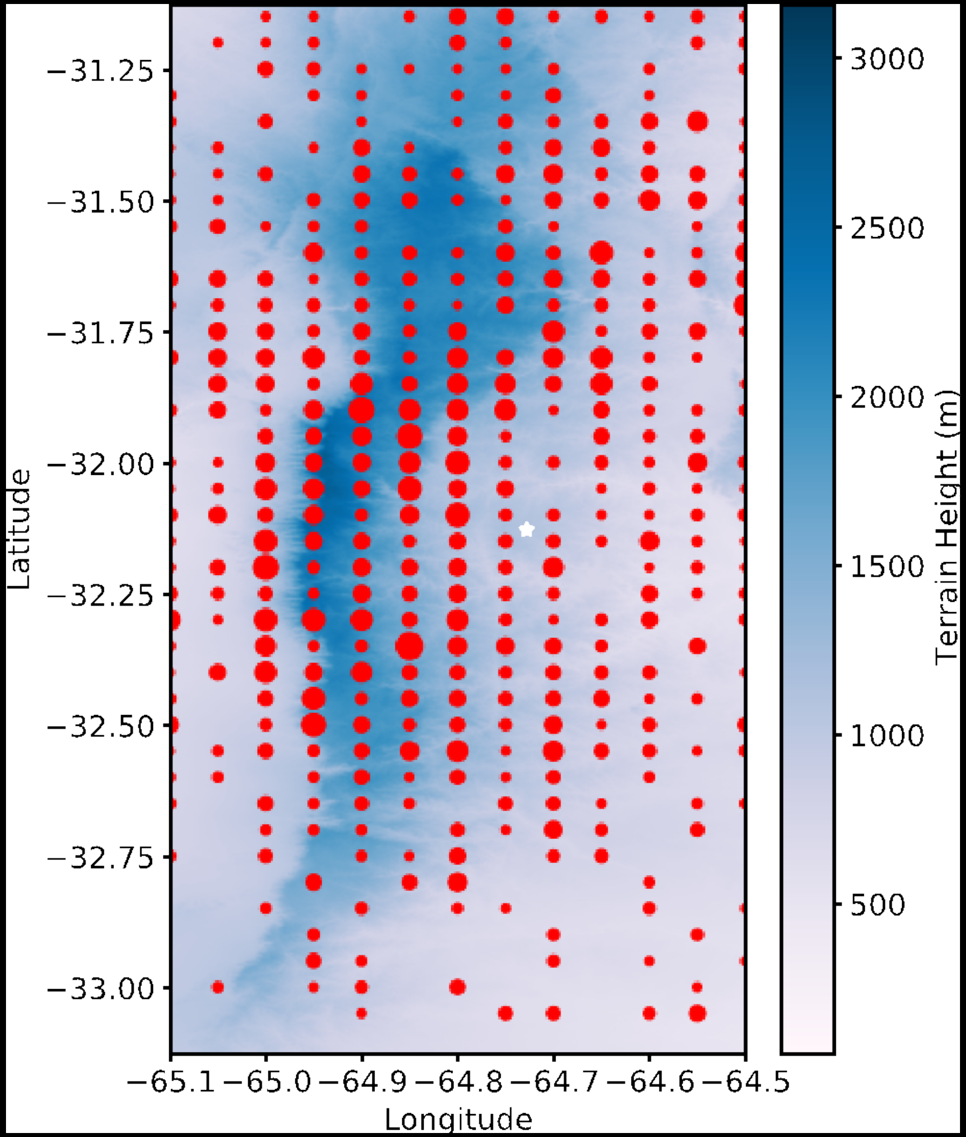






Singh et al. (2022)





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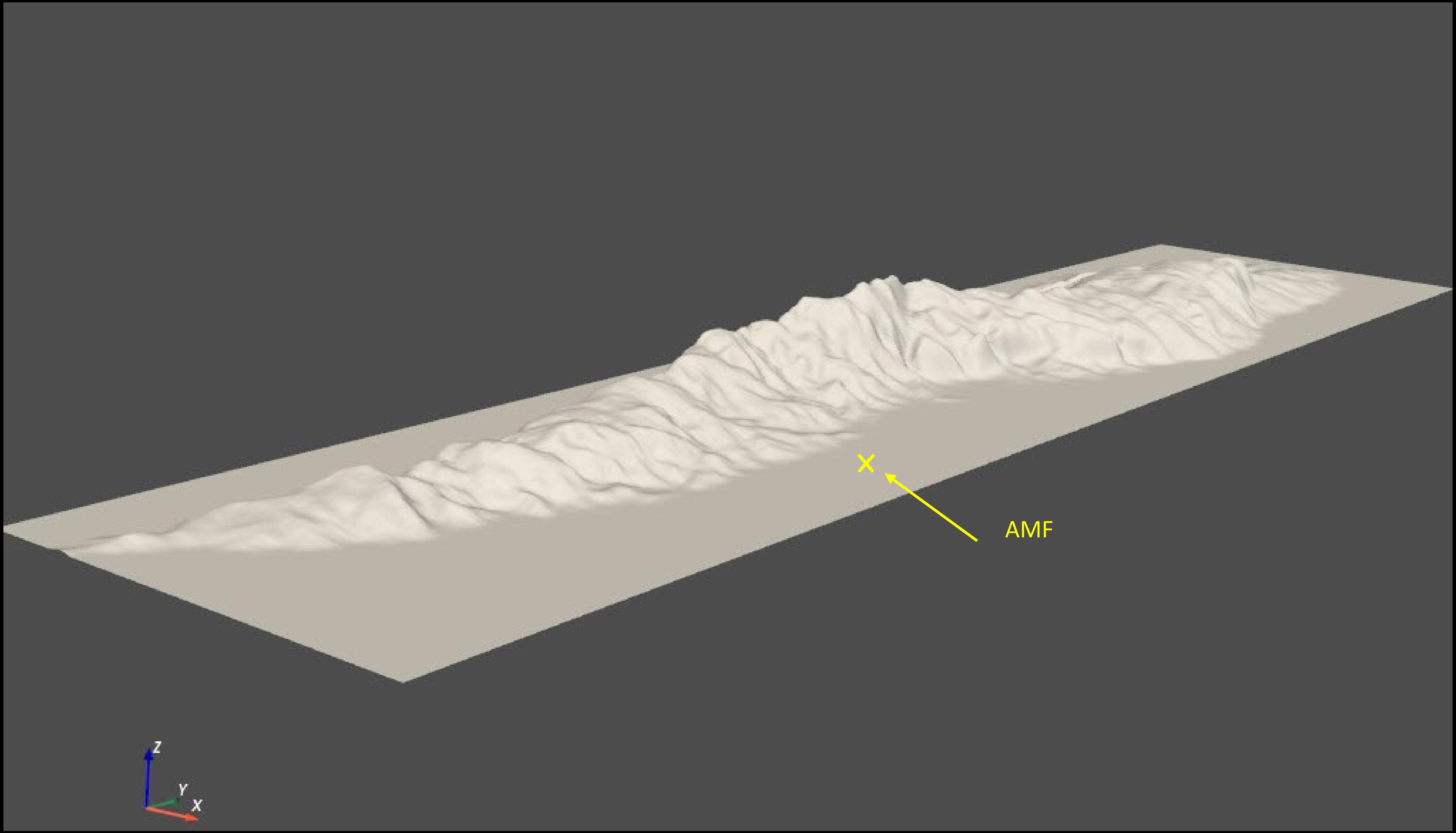
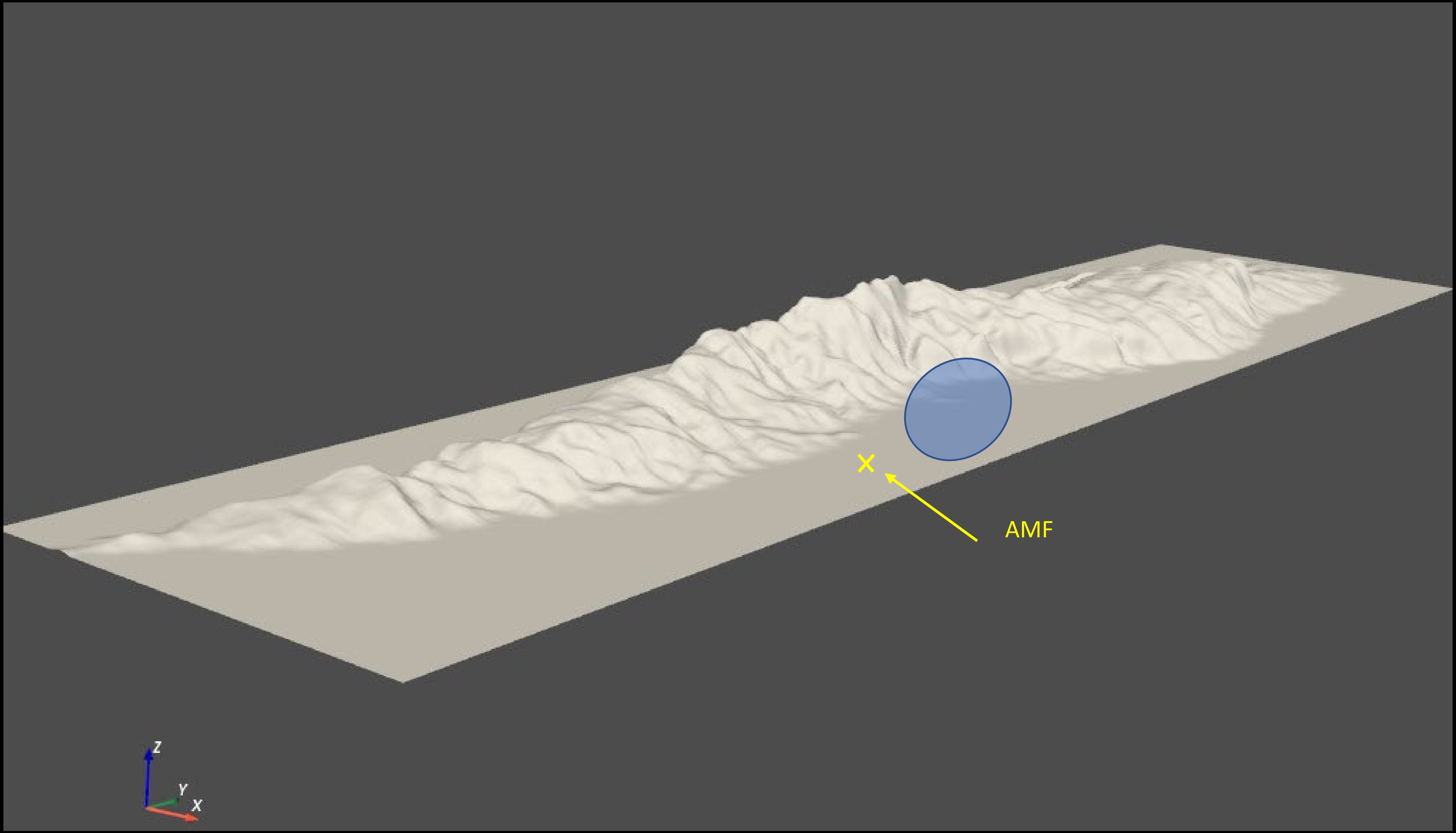
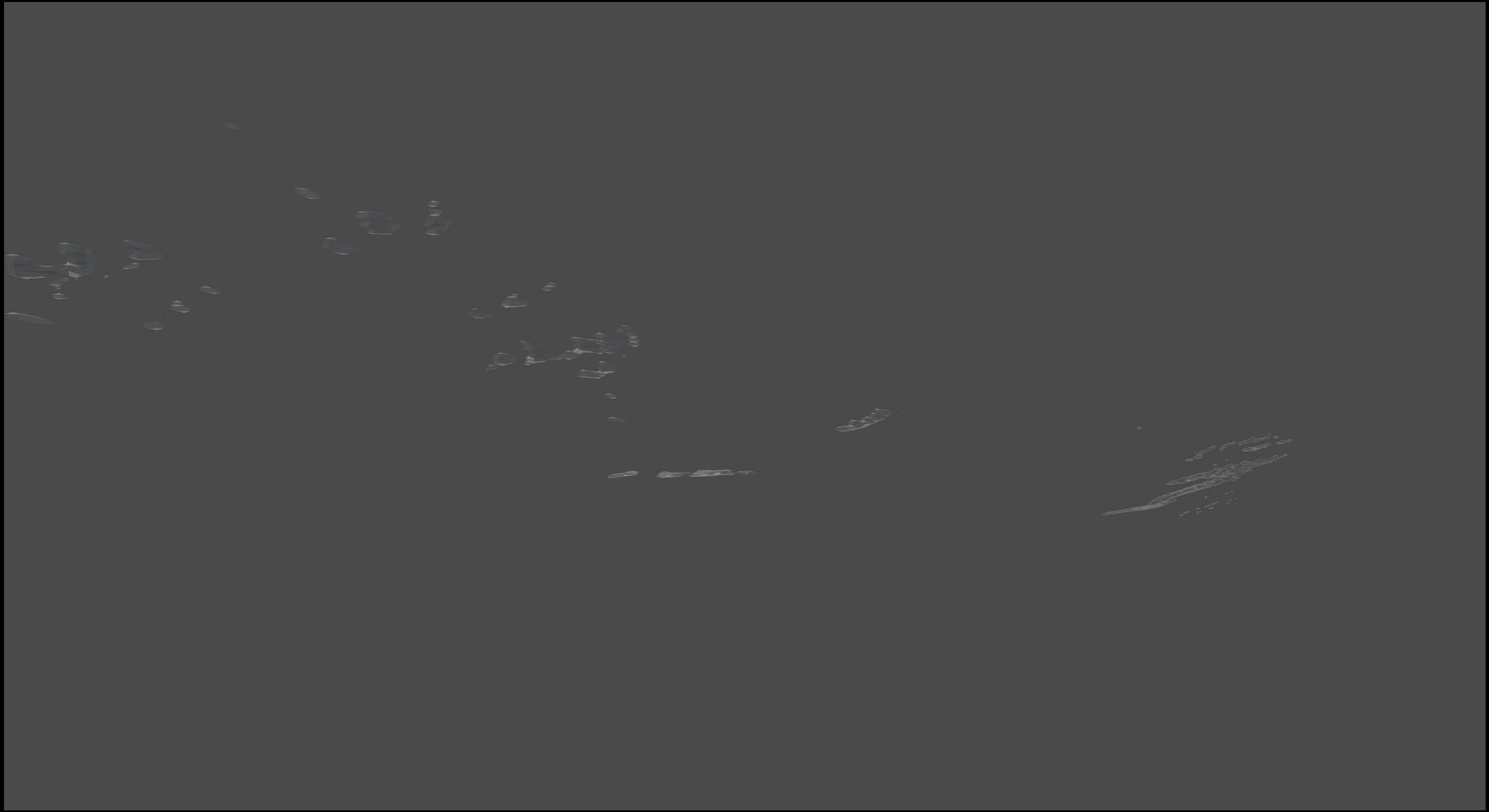
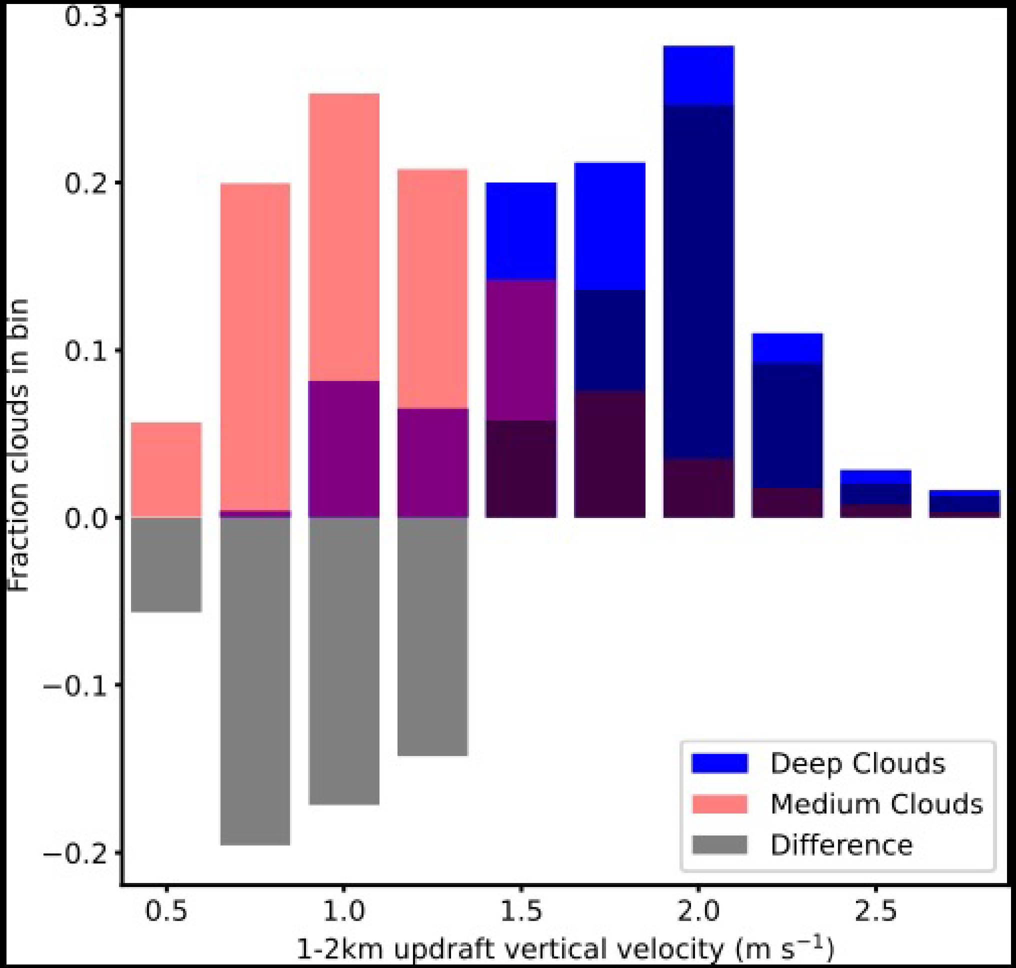

AMF
Z
Y
X


AMF
Z
Y
X

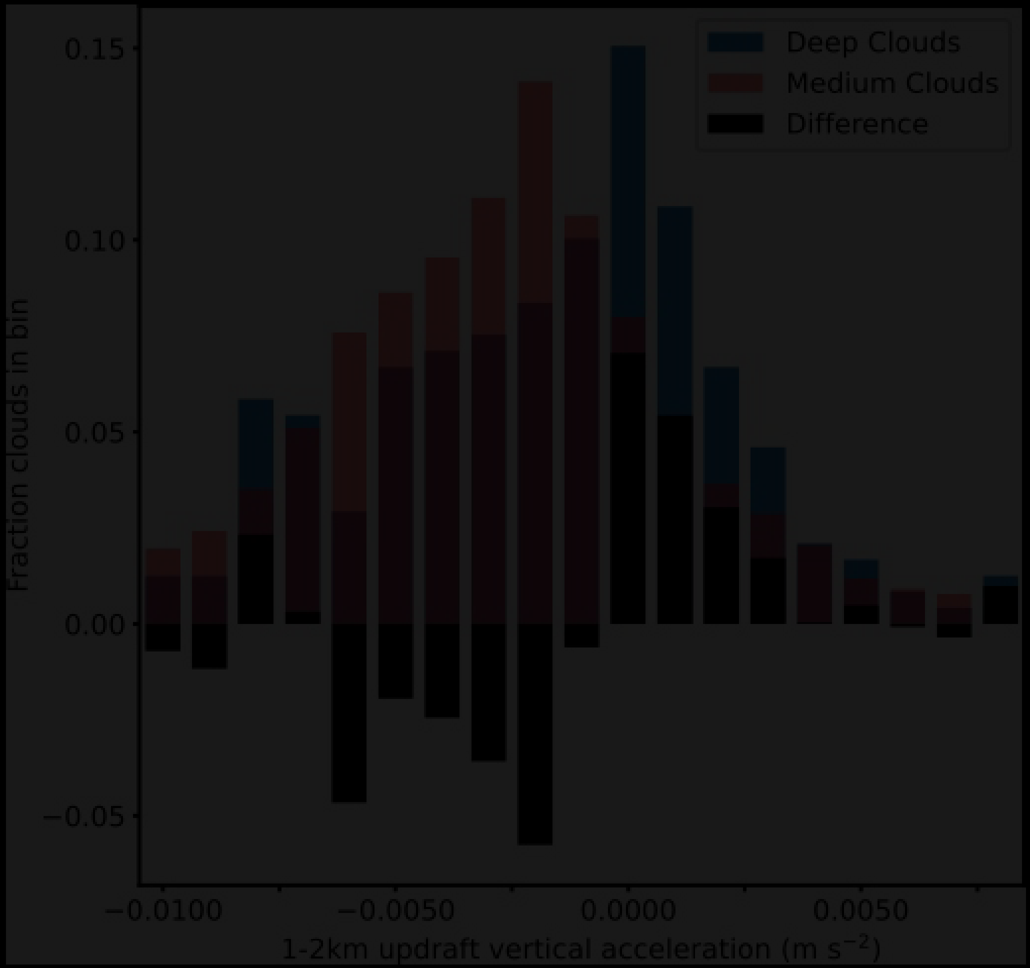
CACTI



1–2 km Vertical Velocity



1–2 km Vertical Updraft Acceleration



CACTI

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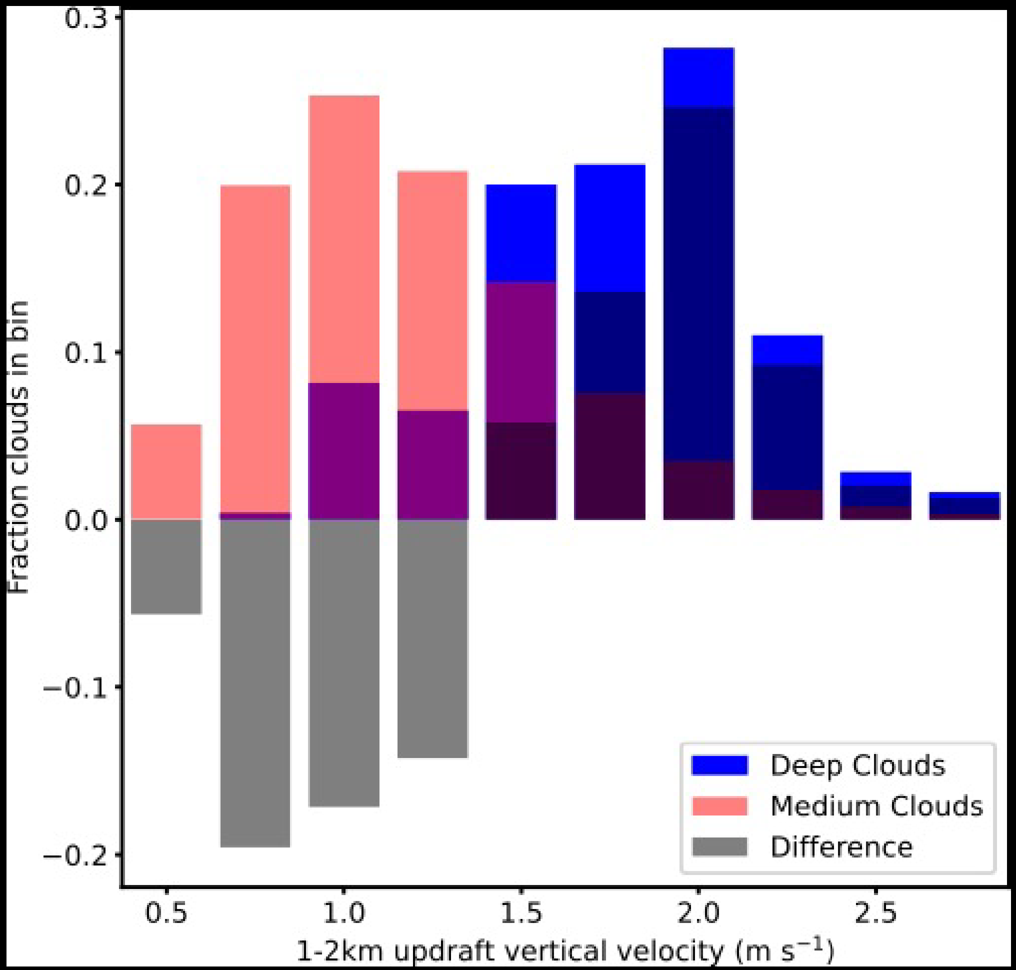

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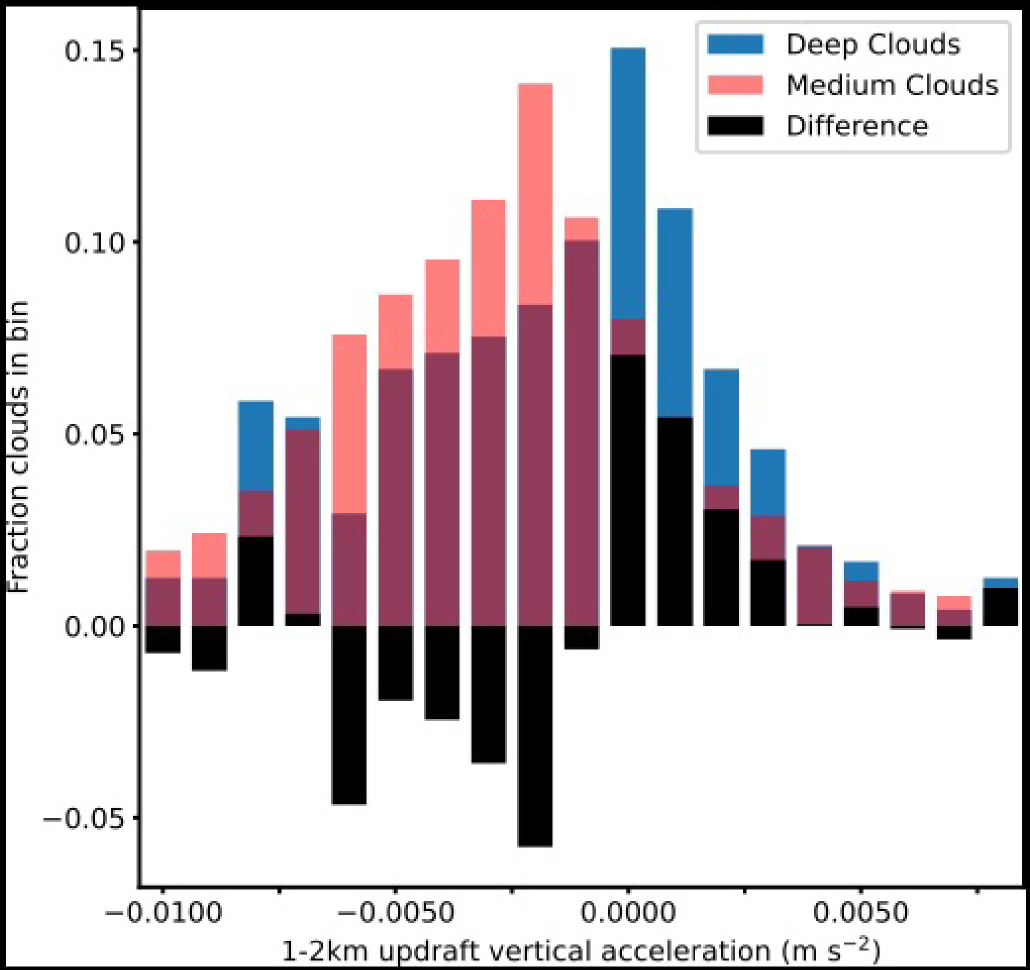
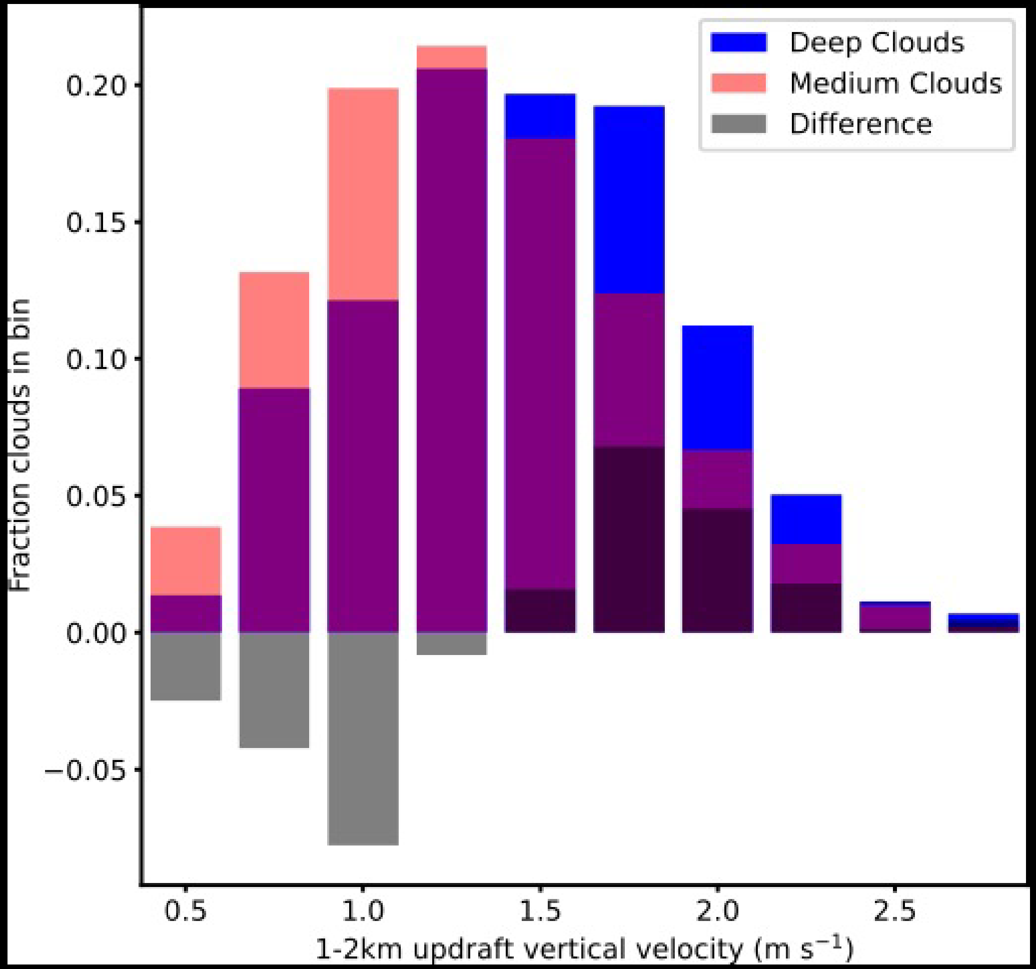


Tropical Ocean

1–2 km Vertical Velocity



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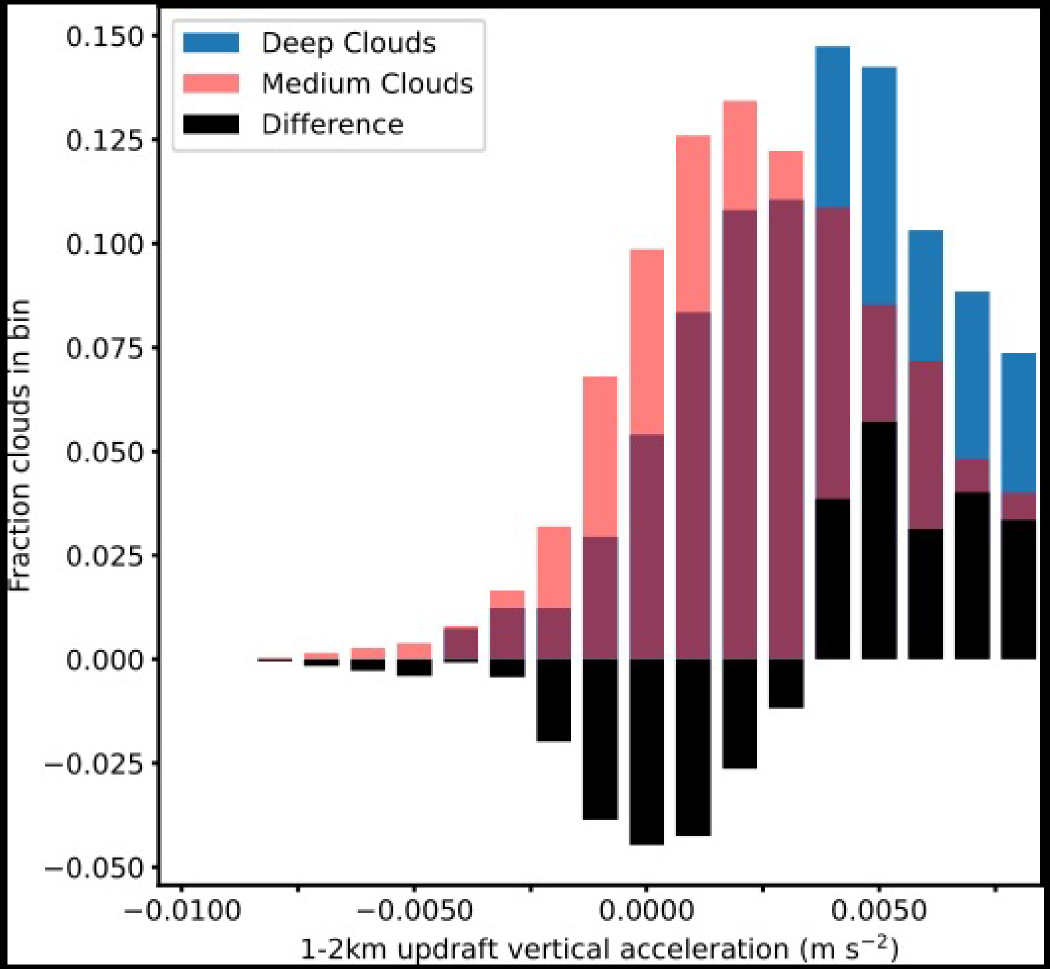
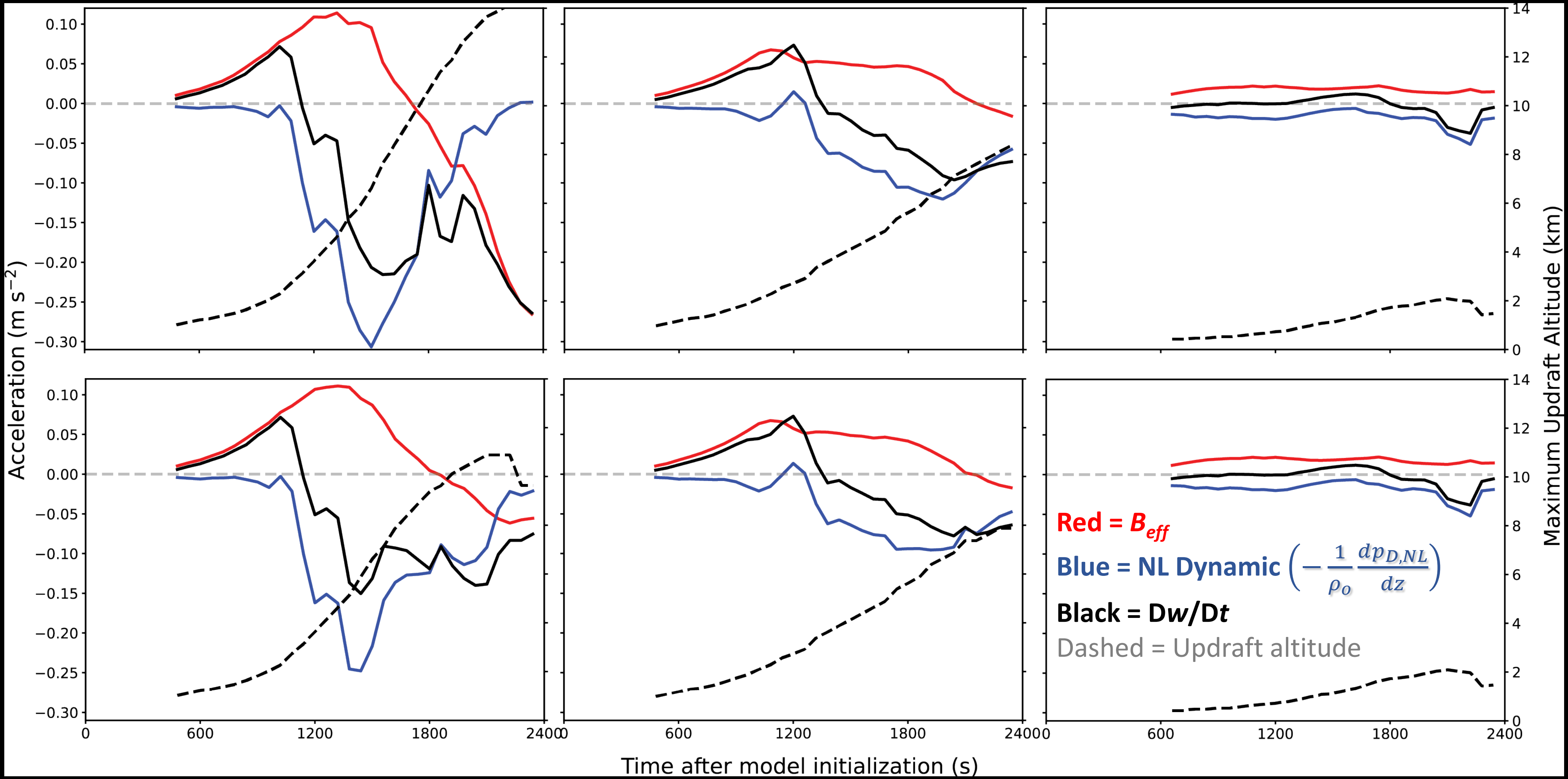


Very Idealized CACTI-like (no terrain; single warm bubble)

Increasing 0–2.5 km Shear

See poster on Thursday AM.

Increasing 2.5–10 km Shear



Conclusions

- Distributions of in-cloud updraft vertical velocity *and* acceleration at low levels in cloud (1–2 km altitude) differ between growing and non-growing cells.

- Simulated updrafts in low-level vertically sheared environments experience enough downward acceleration due to dynamic pressure perturbation gradients to overcome buoyancy and significantly hinder growth of updrafts.

- Main challenge: Tracking updrafts in 3D. How do we objectively identify updrafts in order to track them?

- Main need: Clear air motions and thermodynamic properties in sub-cloud layer?