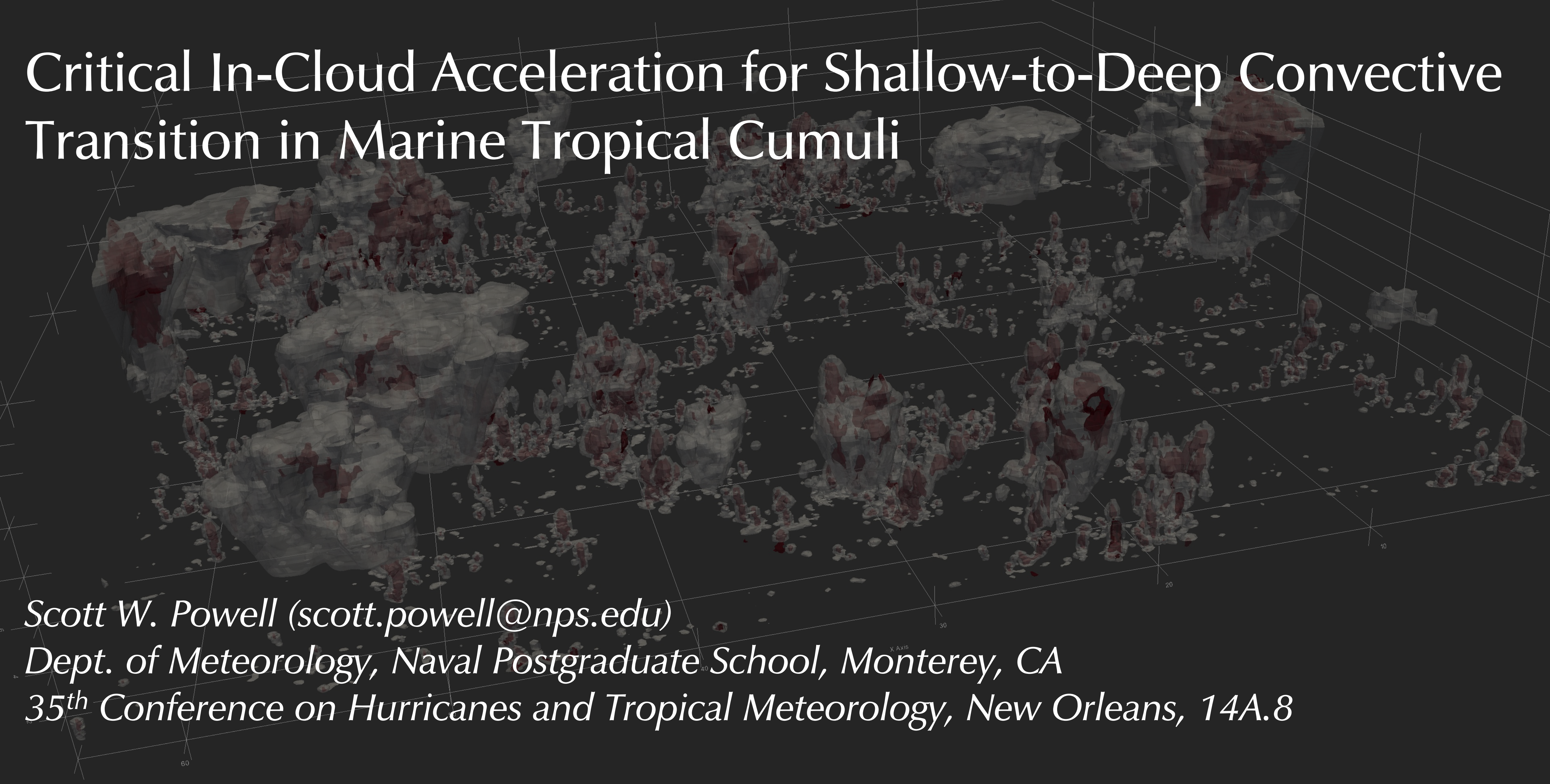
Critical In-Cloud Acceleration for Shallow-to-Deep Convective Transition in Marine Tropical Cumuli



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35th Conference on Hurricanes and Tropical Meteorology, New Orleans, 14A.8

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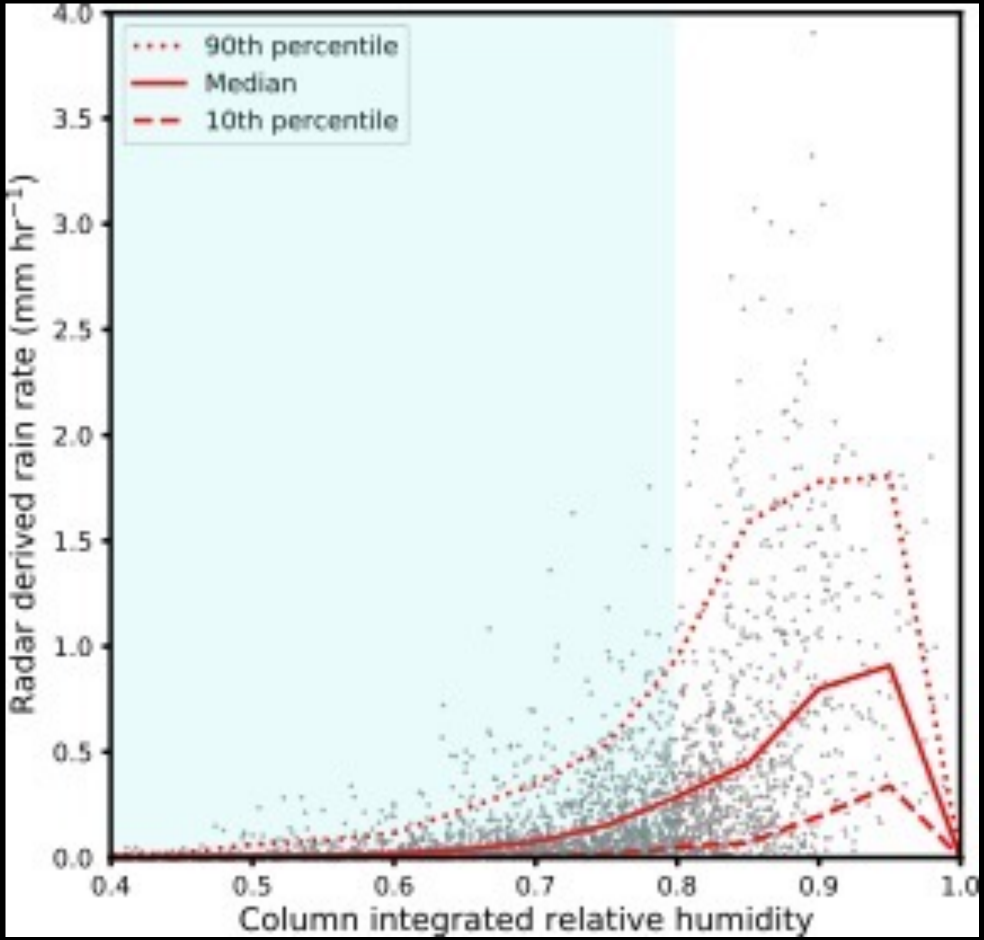
Tropospheric moisture is a necessary condition for deep convection and large rain rates, but by itself is not sufficient.

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



Powell (2019)

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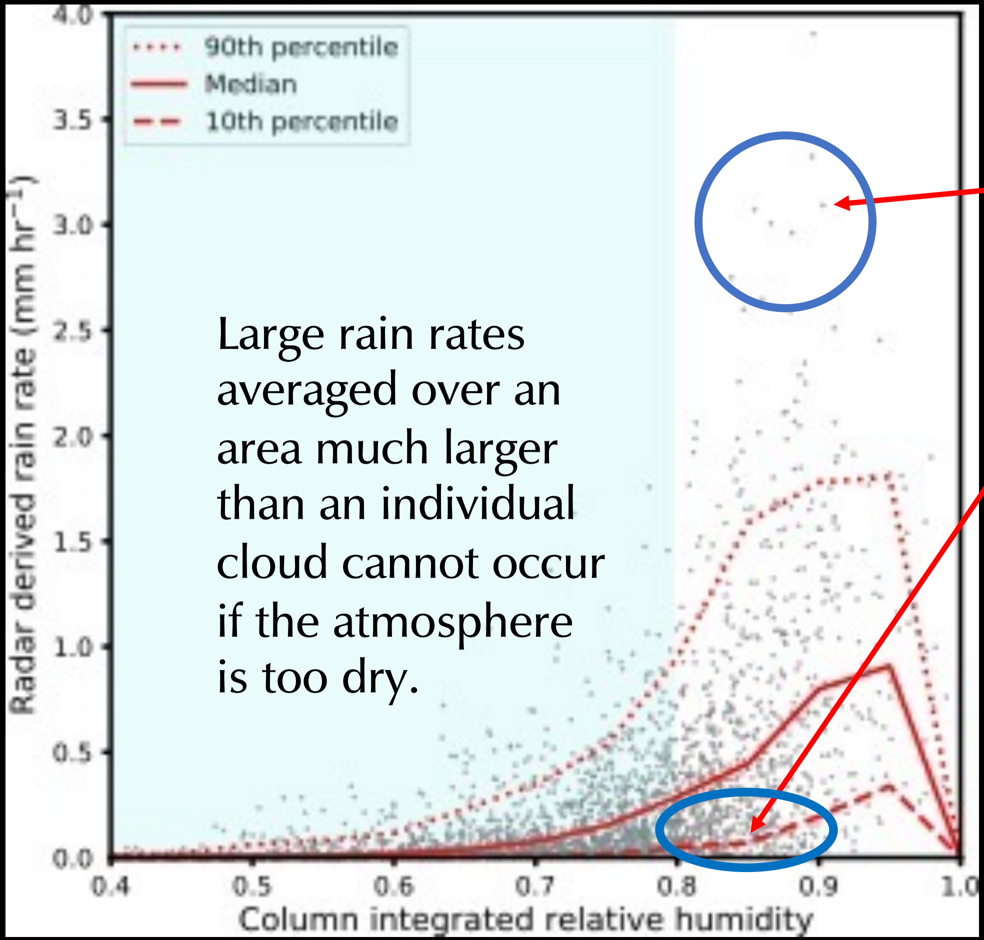

Column-relative humidity of 80% or greater is often considered sufficiently moist for widespread deep convection to occur, but rain rates in such an environment can range from very large to near zero!

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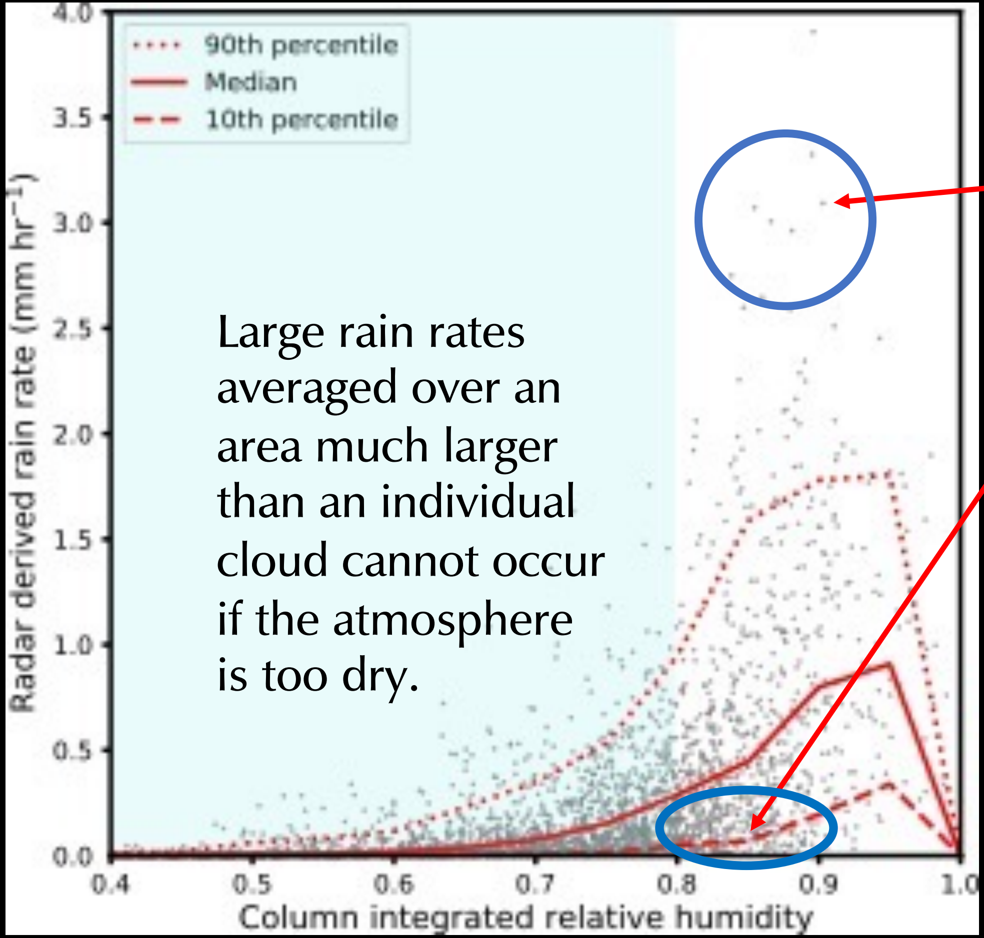

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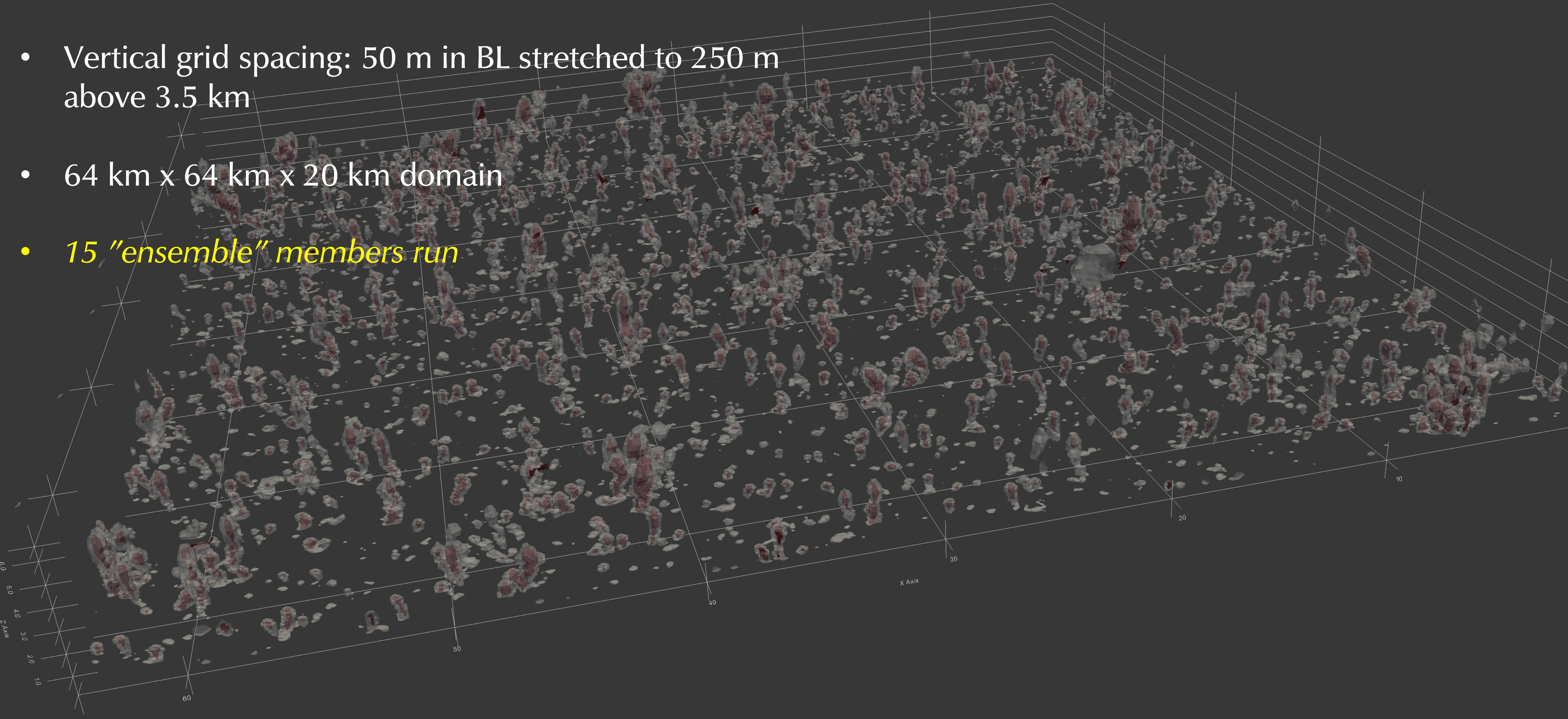
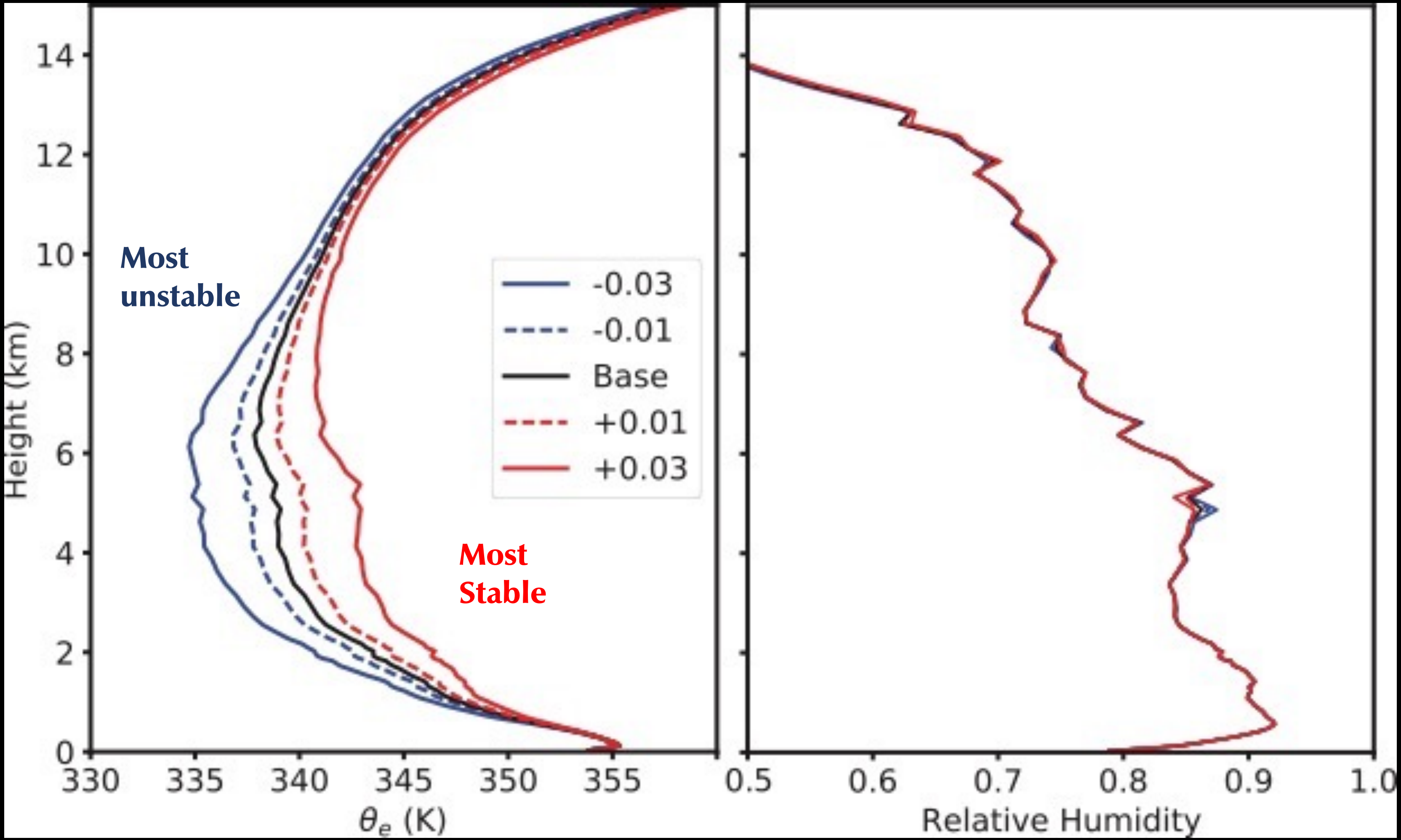
What controls the when rain rate is zero versus large when the atmosphere is moist?

- Horizontal grid spacing: 100 m
- Vertical grid spacing: 50 m in BL stretched to 250 m above 3.5 km
- 64 km x 64 km x 20 km domain
- *15 "ensemble" members run*



Each line represents one of 5 different initial conditions used.



Vertical Momentum Equation

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

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Archimedean buoyancy

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

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

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

Vertical Momentum Equation

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

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

Archimedean buoyancy

Vertical Pressure Gradient Accelerations

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

Vertical Momentum Equation

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

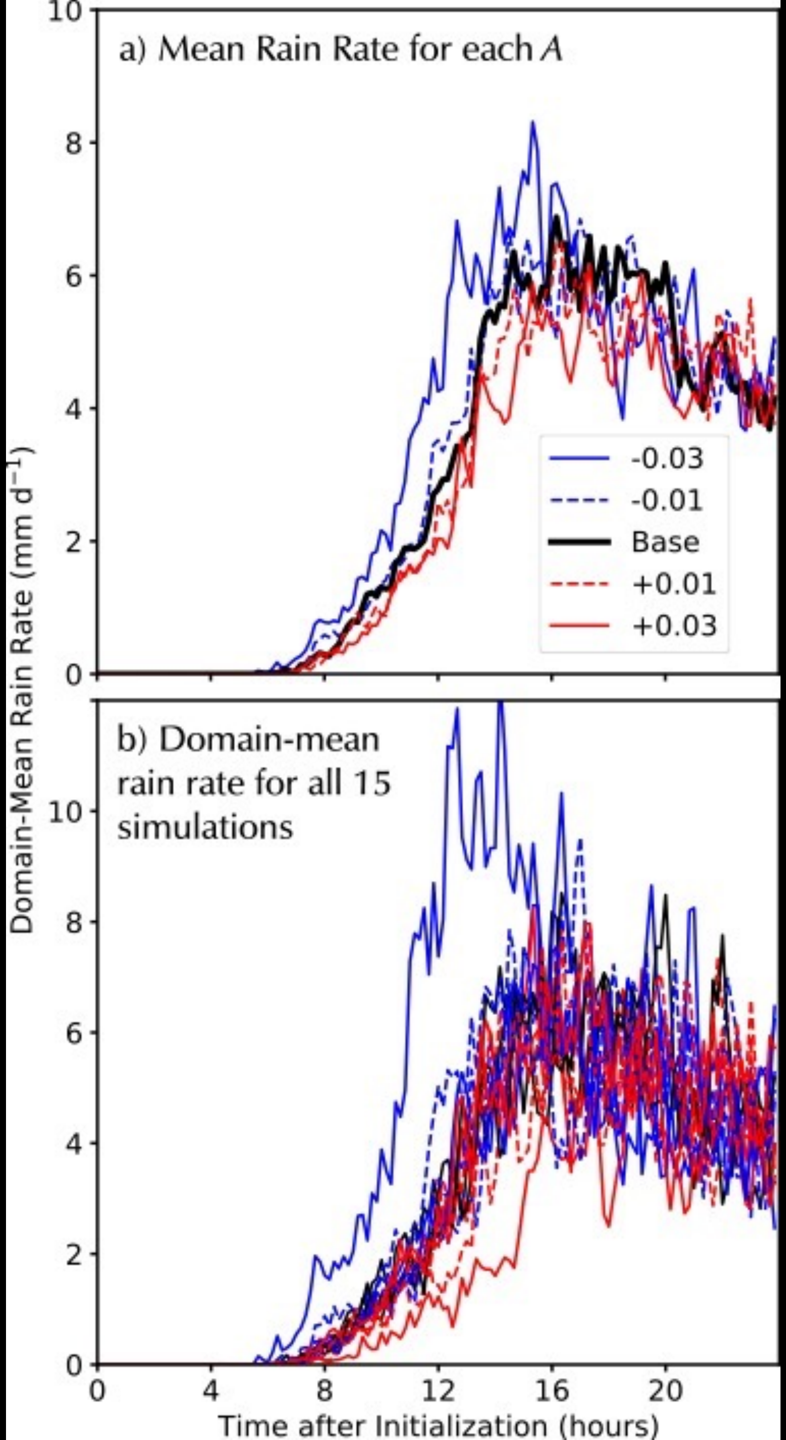
"Effective buoyancy"

Vertical Pressure Gradient Accelerations

Domain-mean rain rates

"Ensemble" mean

Each simulation



Domain-mean rain rates

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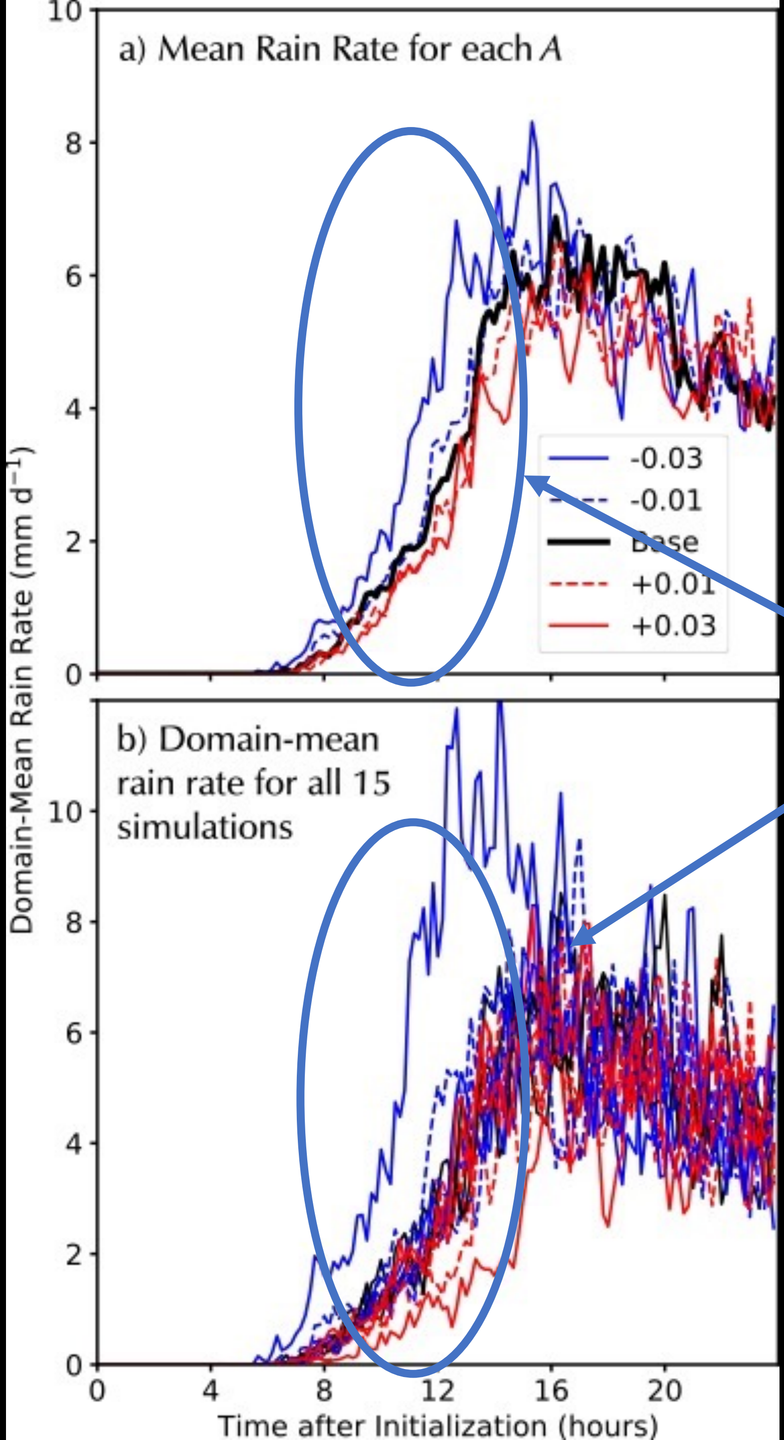
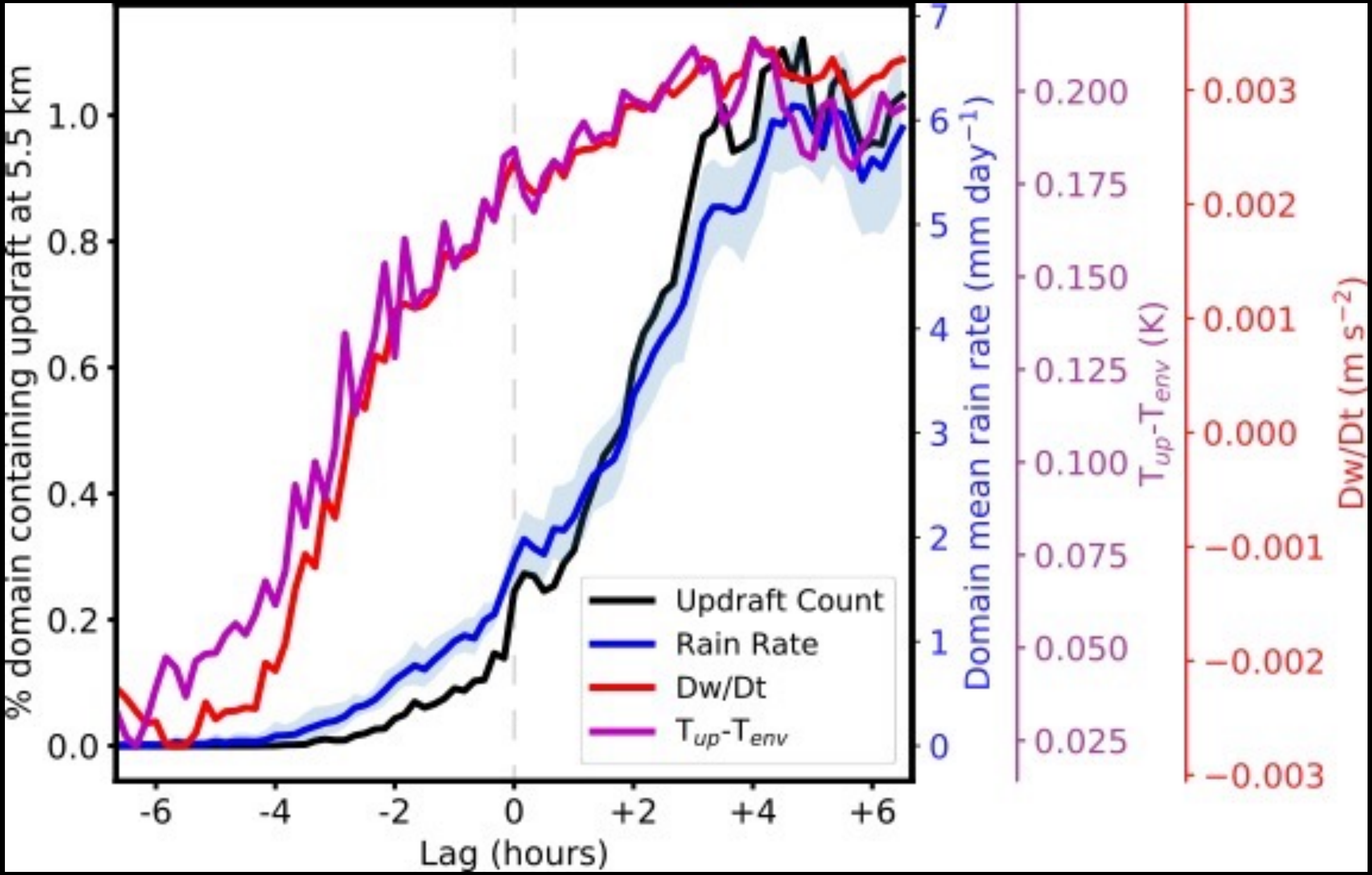
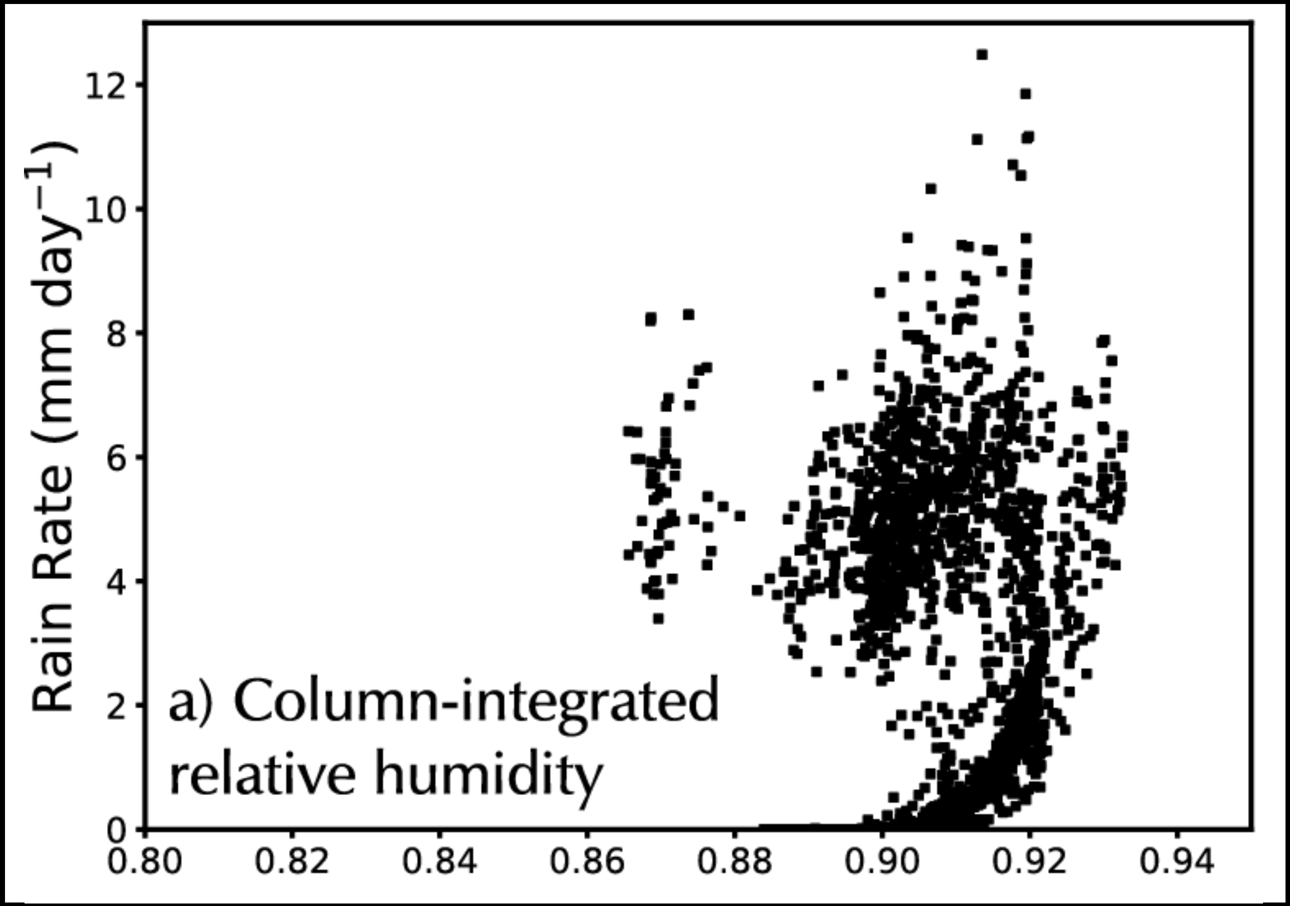
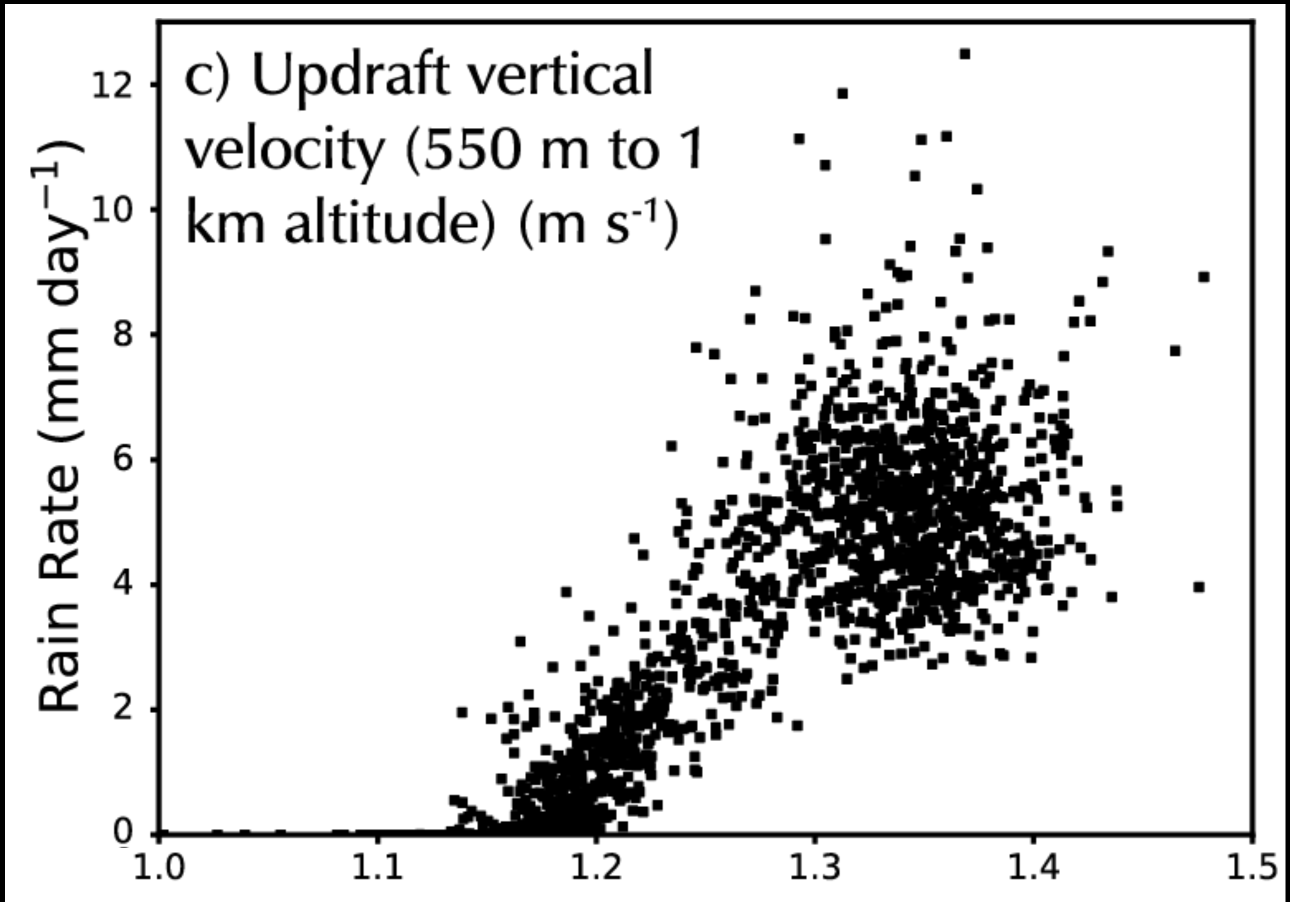
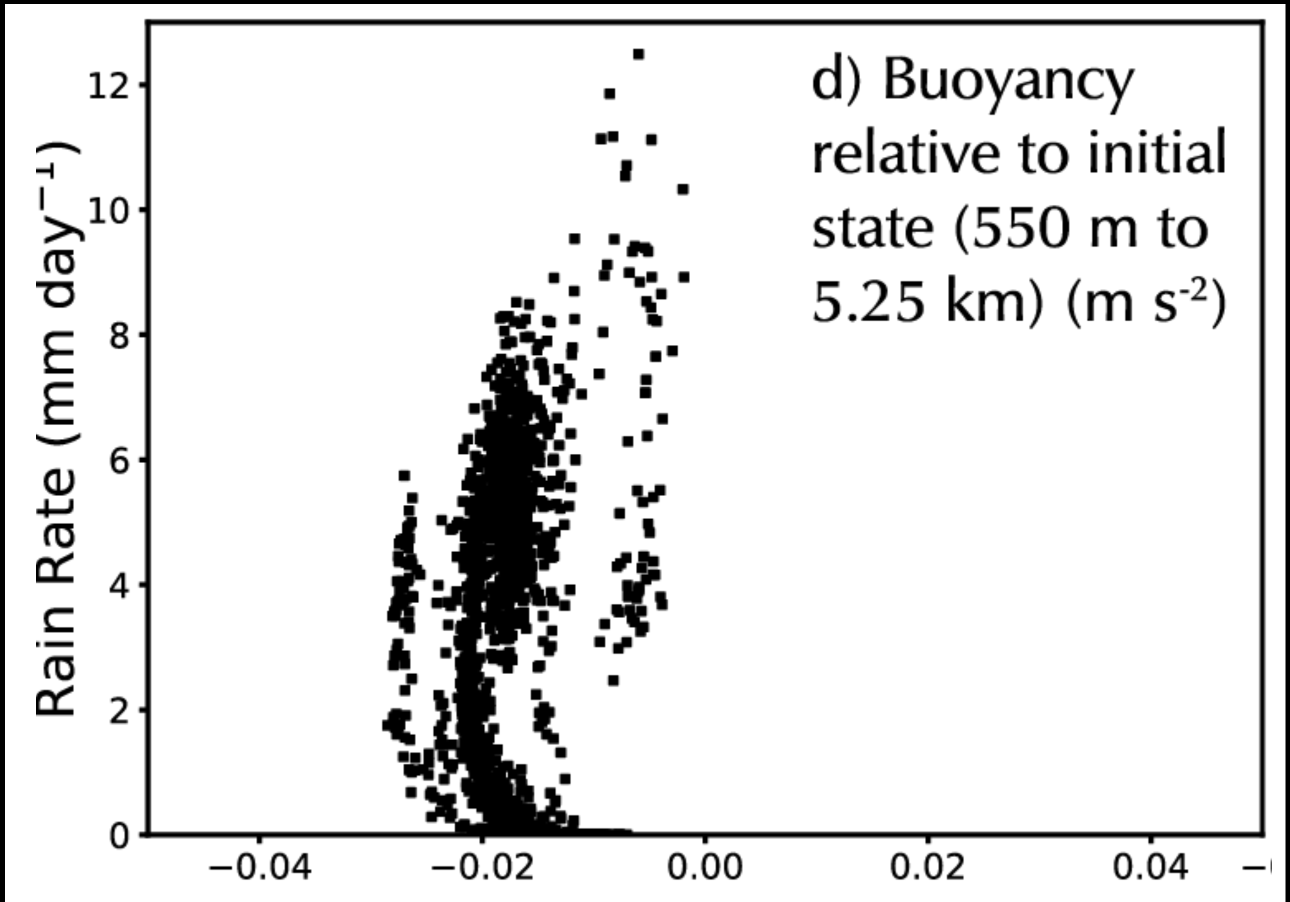


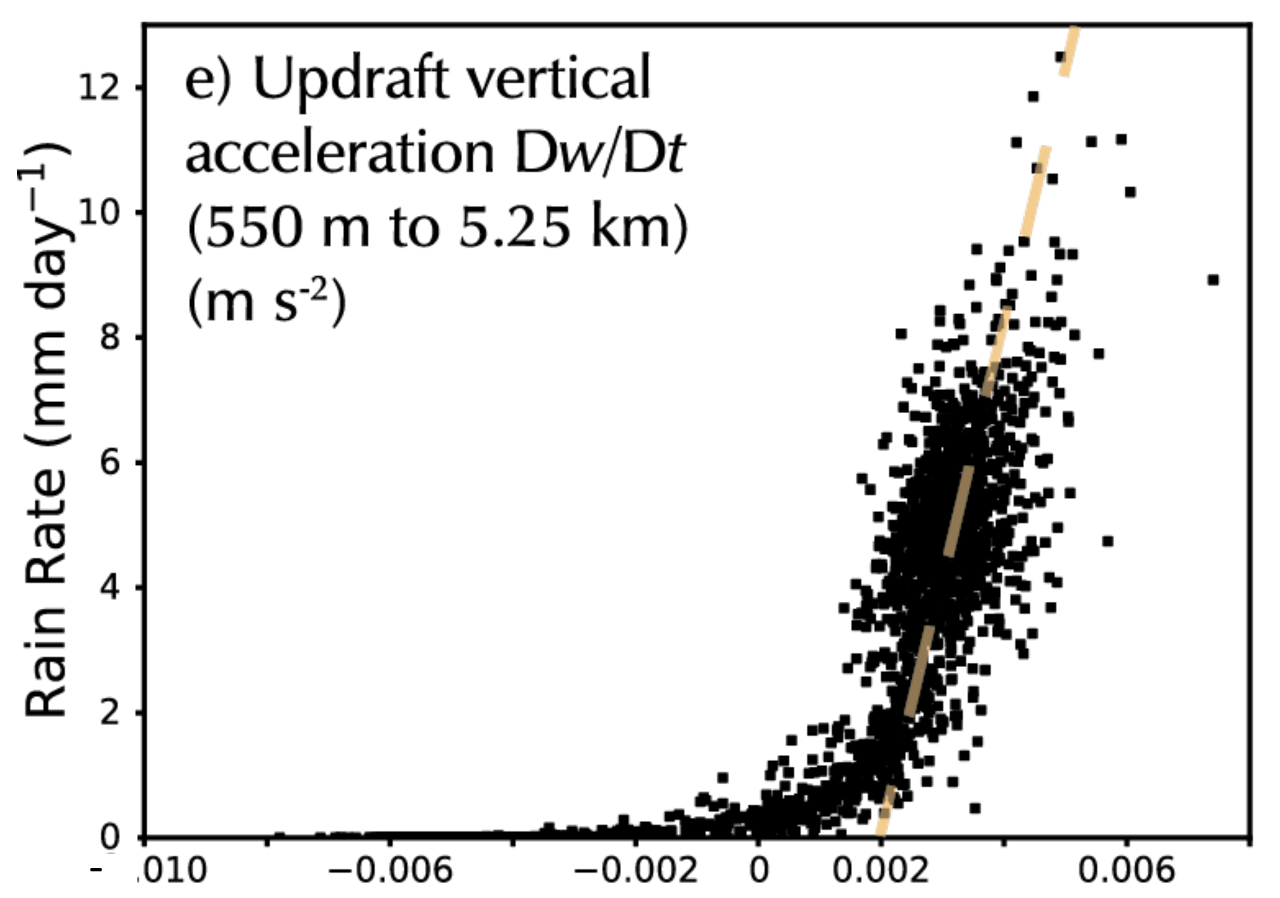
What happens during the period when the domain-mean rain rate rapidly increases?

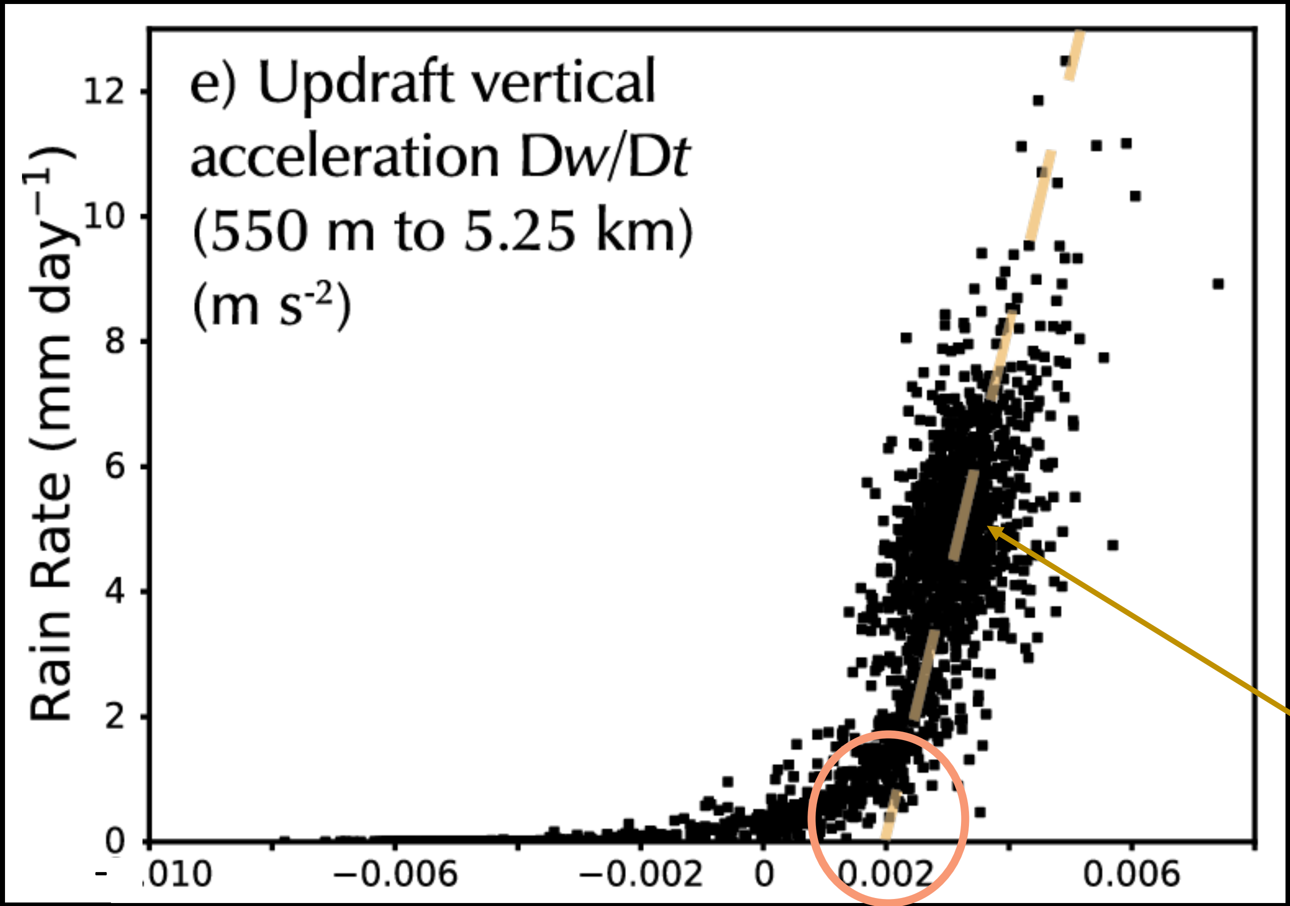

% domain containing updraft at 5.5 km
Lag (hours)
Domain mean rain rate (mm day^{-1})
T_{up}-T_{env} (K)
Dw/Dt (m s^{-2})
Updraft Count
Rain Rate
Dw/Dt
T_{up}-T_{env}
-6
-4
-2
0
+2
+4
+6
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
7
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
−0.003
−0.002
−0.001
0.000
0.001
0.002
0.003


a) Column-integrated
relative humidity
Rain Rate (mm day^{-1})
0
2
4
6
8
10
12
0.80
0.82
0.84
0.86
0.88
0.90
0.92
0.94


c) Updraft vertical velocity (550 m to 1 km altitude) (m s-1)
Rain Rate (mm day−1)
0
2
4
6
8
10
12
1.0
1.1
1.2
1.3
1.4
1.5


d) Buoyancy relative to initial state (550 m to 5.25 km) (m s-2)
Rain Rate (mm day⁻¹)
12
10
8
6
4
2
0
−0.04
−0.02
0.00
0.02
0.04

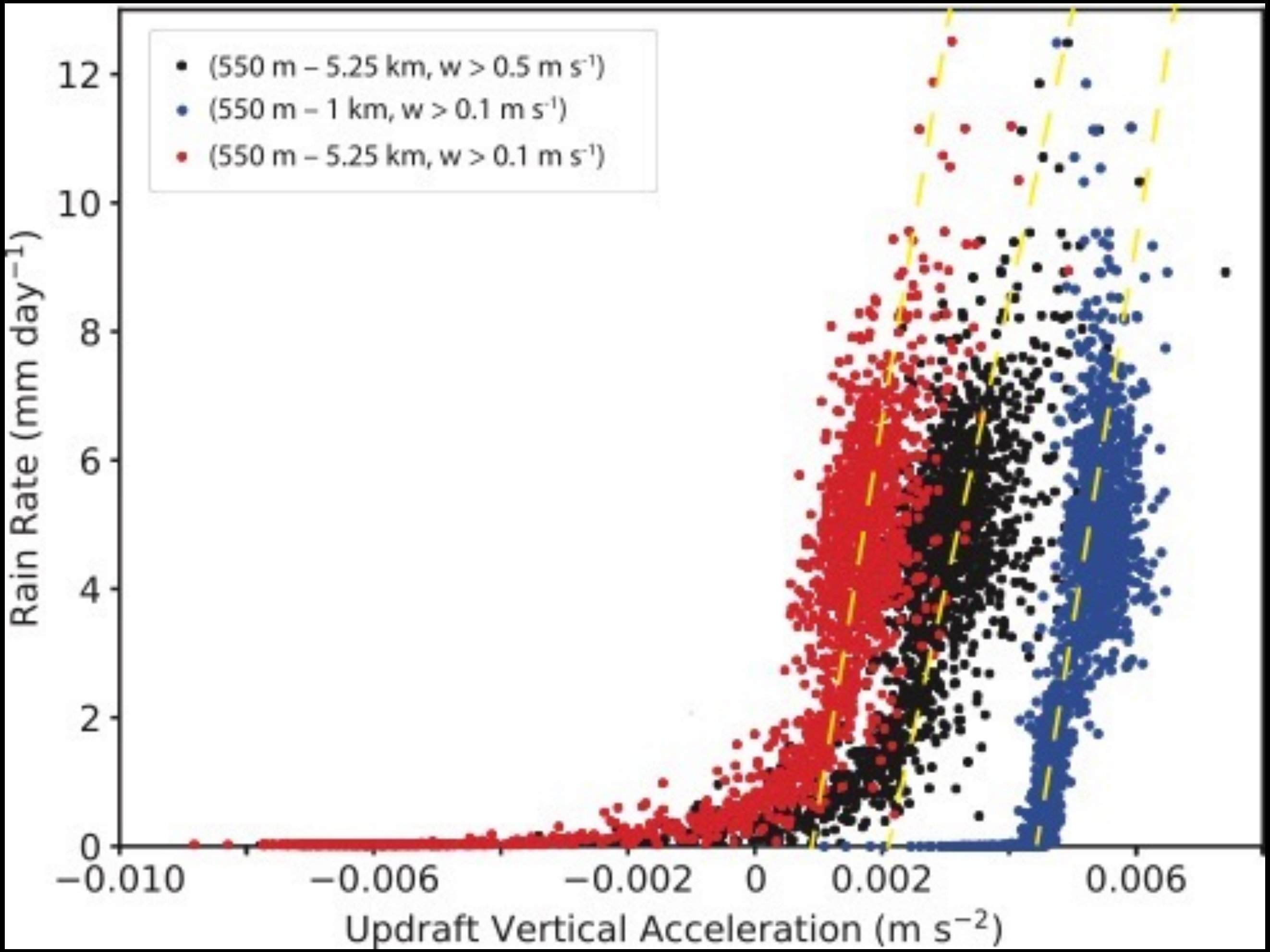

e) Updraft vertical
acceleration Dw/Dt
(550 m to 5.25 km)
(m s-2)
Rain Rate (mm day−1)
12
10
8
6
4
2
0
-.010
−0.006
−0.002
0
0.002
0.006

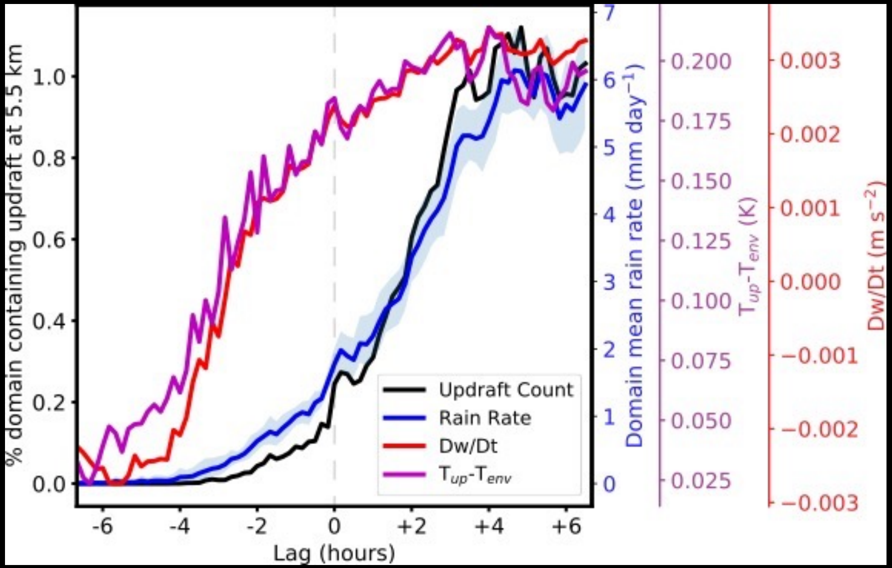


Linear increase in rain rate above critical acceleration

Critical Acceleration

The "critical value" of D*w*/D*t* is sensitive to how an updraft is defined or the layer in which D*w*/D*t* is considered.

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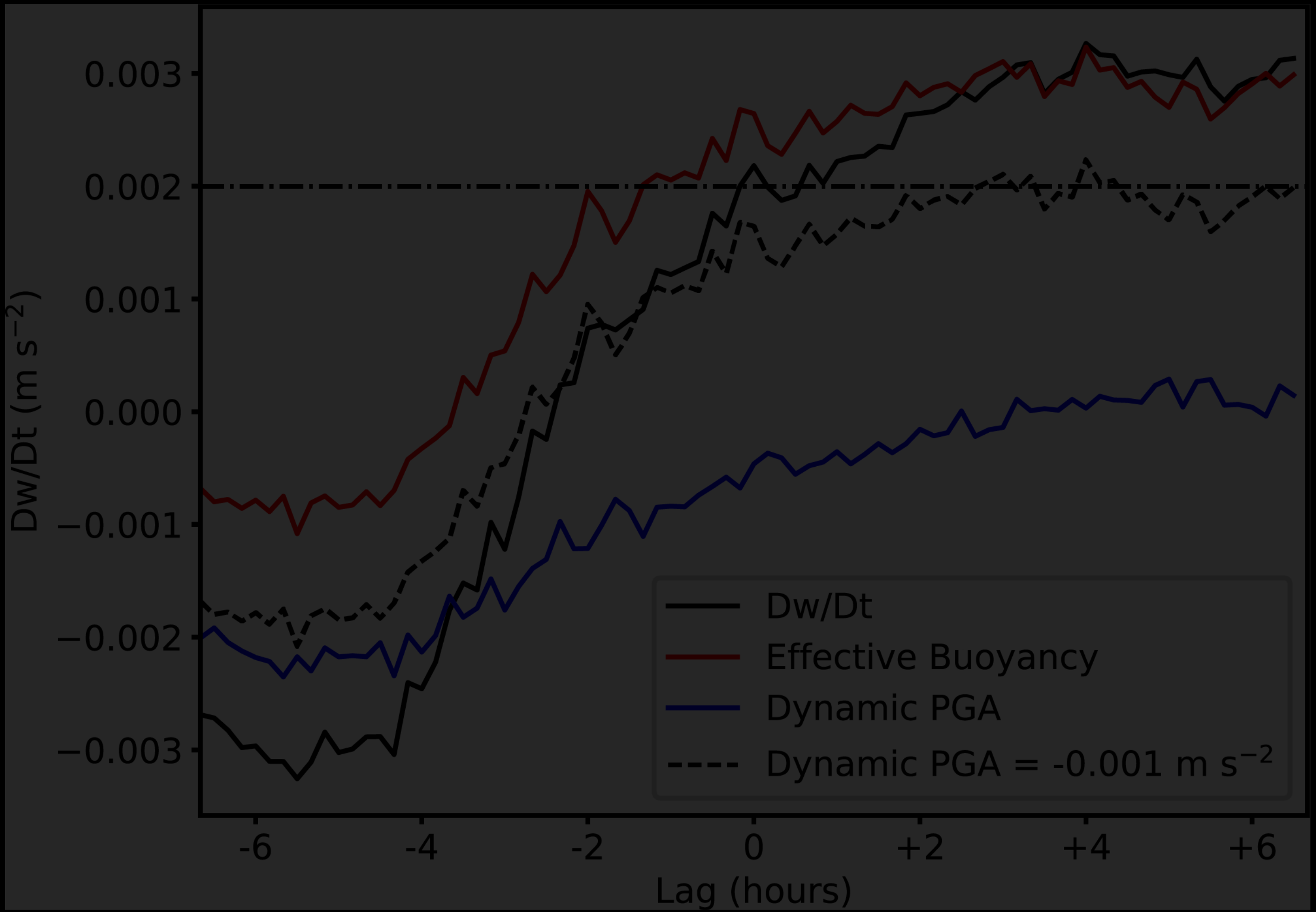
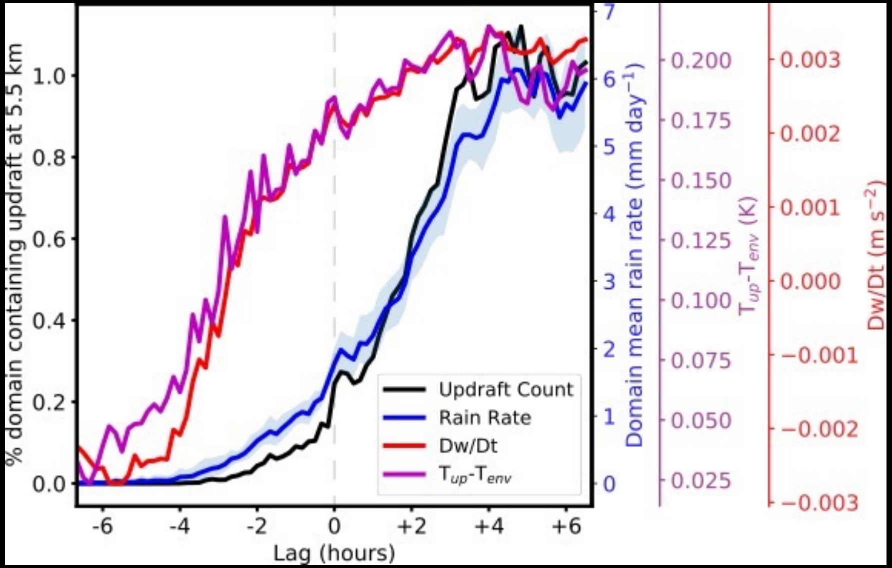
Domain mean rain rate (mm day^{-1})
T_{up}-T_{env} (K)
Dw/Dt (m s^{-2})
Lag (hours)
Updraft Count
Rain Rate
Dw/Dt
T_{up}-T_{env}


Dw/Dt (m s^{-2})
Lag (hours)
Dw/Dt
Effective Buoyancy
Dynamic PGA
Dynamic PGA = -0.001 m s^{-2}



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T$_{up}$-T$_{env}$ (K)
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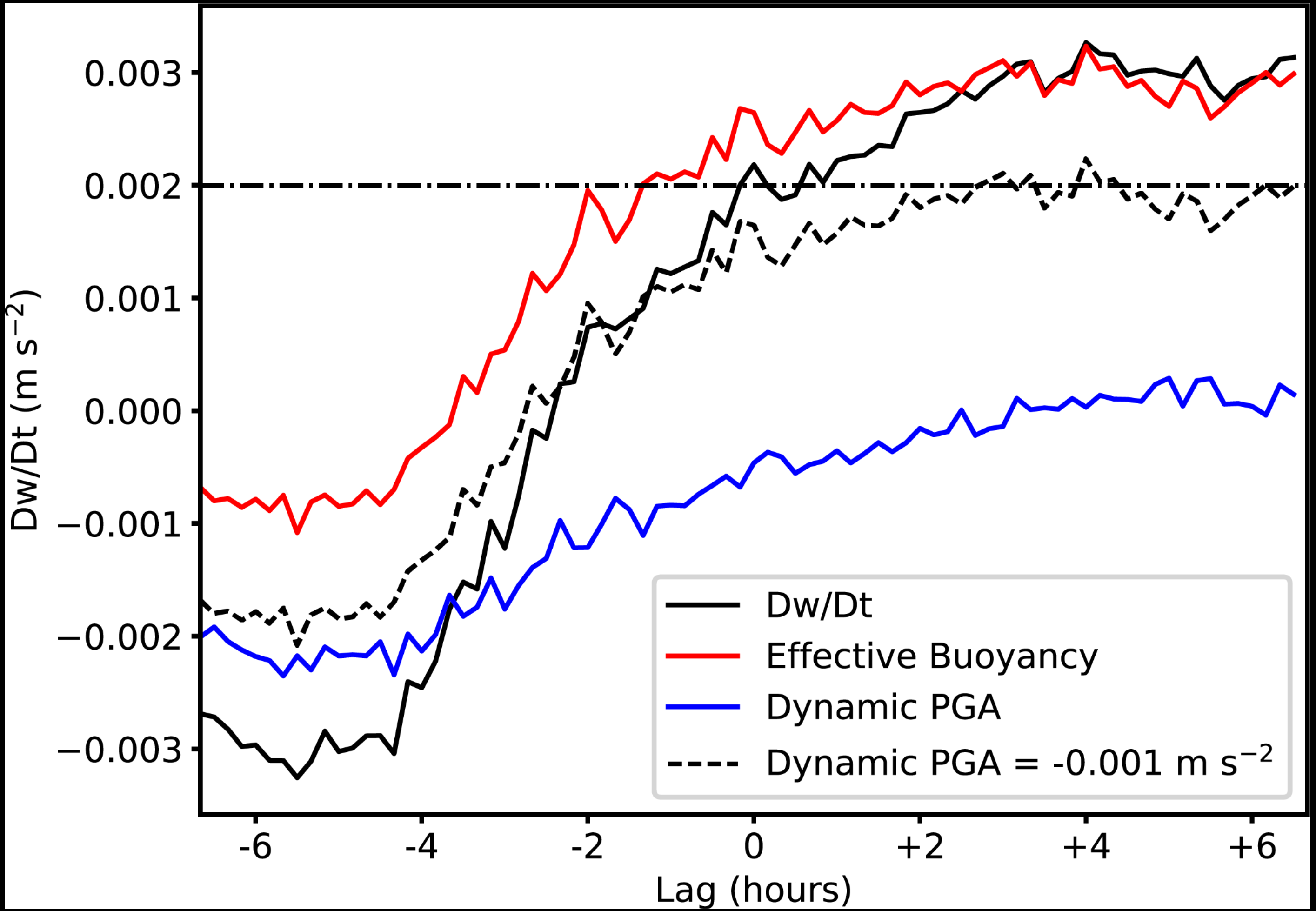
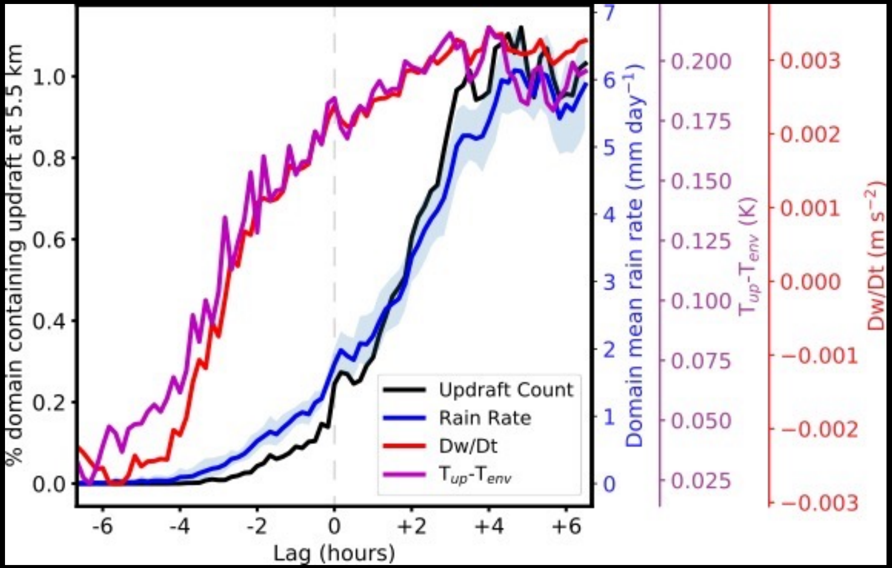
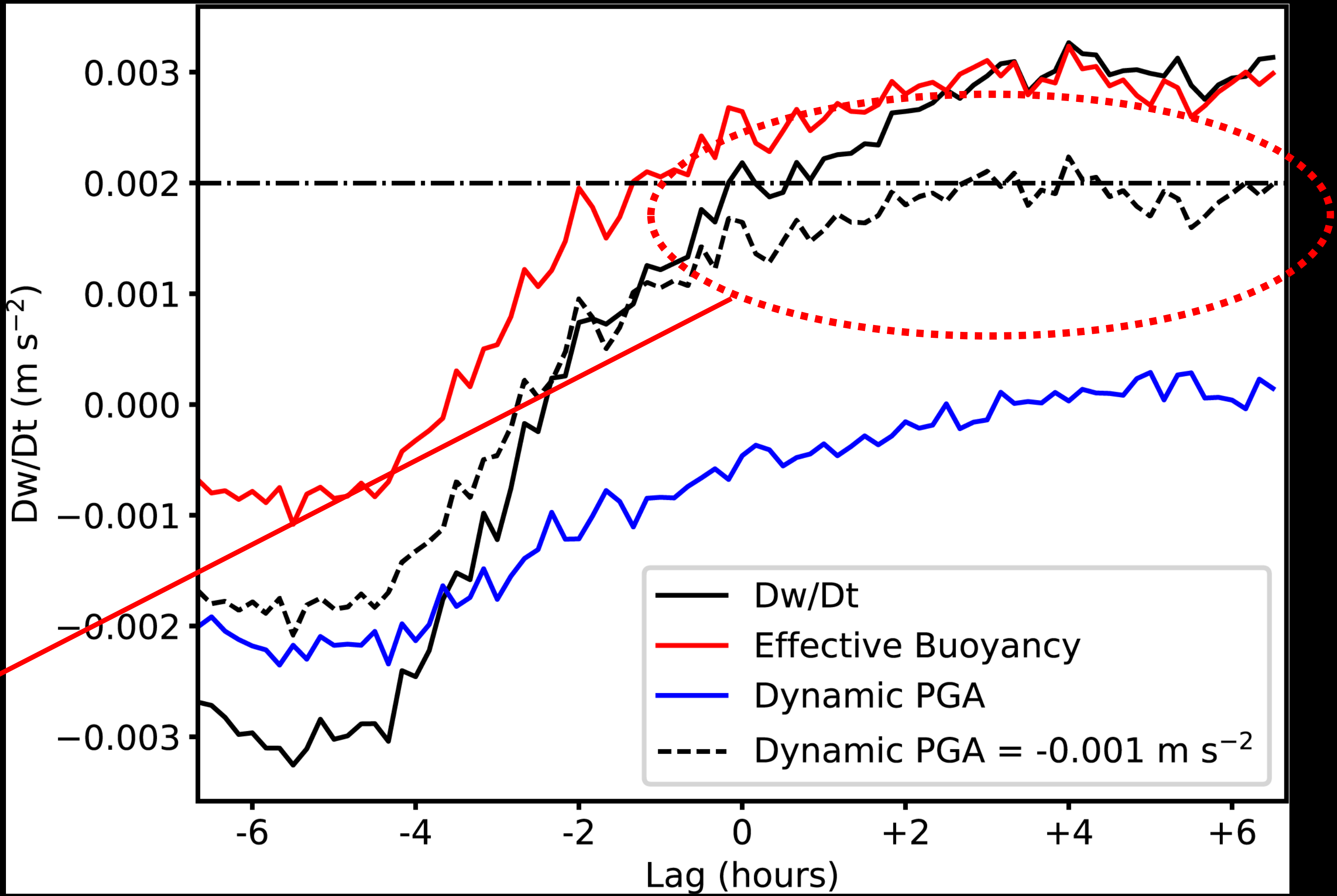
Updraft Count
Rain Rate
Dw/Dt
T$_{up}$-T$_{env}$
Lag (hours)



Dw/Dt (m s^{-2})
Dw/Dt
Effective Buoyancy
Dynamic PGA
Dynamic PGA = -0.001 m s^{-2}
Lag (hours)





Dw/Dt if the Dynamic PGA term is set to -0.001 m s^{-2}. It barely reaches the critical Dw/Dt!

Conclusions

Thermodynamic properties of the atmosphere are not the only important factors for shallow to deep transition of convection.

- Within a simulated small domain, cumulus transition into deep convection when a "critical" value of updraft acceleration is reached.
    - Not shown here: The "critical process" associated with the critical acceleration is probably convection penetrating the 0°C level, at least over tropical oceans.
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