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Impacts of mixing by parameterized horizontal vorticity on clouds and precipitation in convection permitting simulations

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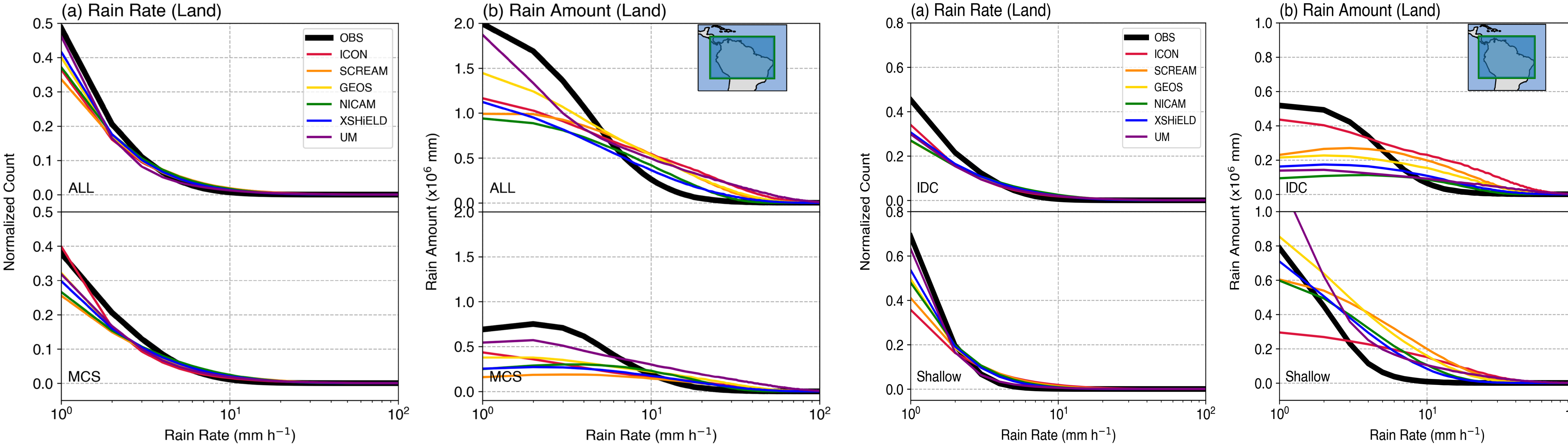
The Problem

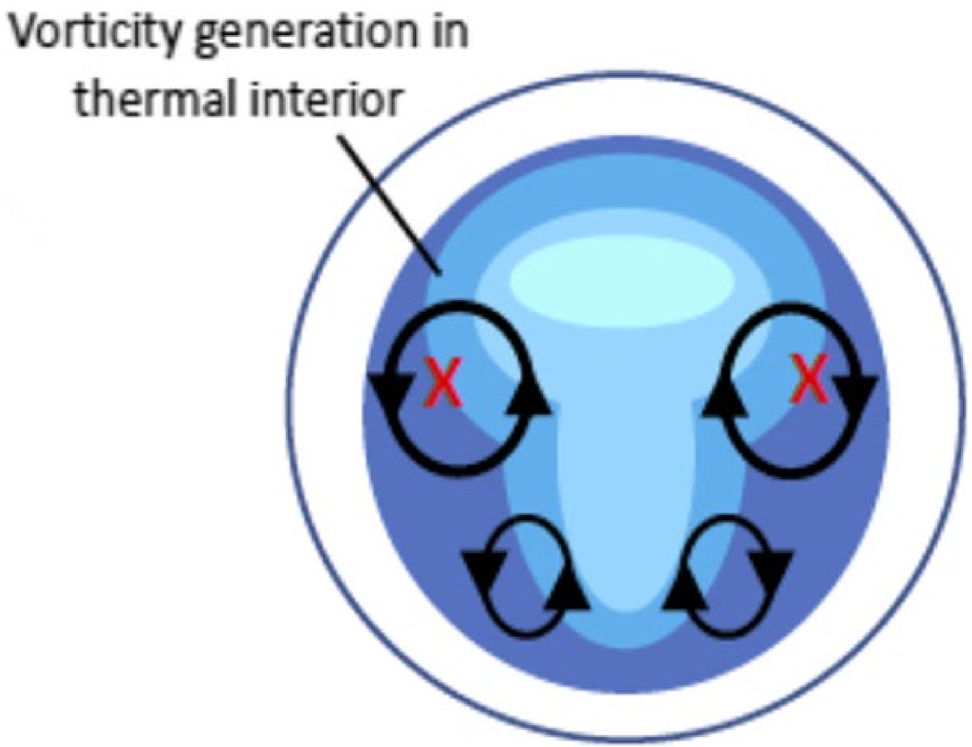
Precipitation statistics in DYAMOND global convective permitting simulations

- Convective permitting models typically overestimate convective rainfall intensity while underestimating the contributions of low intensity precipitation



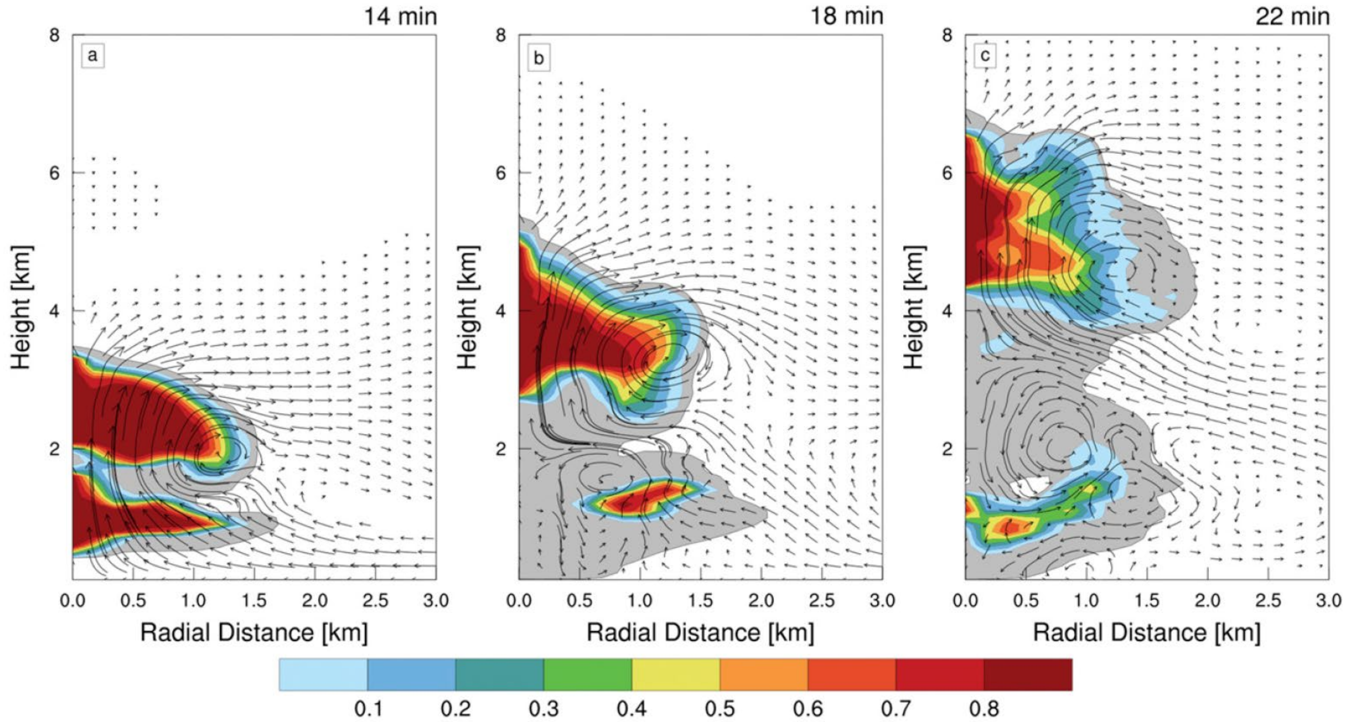
Precipitation statistics from observations (thick black line) and simulations (color lines) over Amazon region from DYAMOND convective permitting simulations.

Horizontal vorticity in LES modelled convection



From Morrison et al (2020)

System for Atmospheric Modeling (SAM) 100-m



From Hannah W. (2018)

- Latent heating in moist thermals lead to horizontal buoyancy gradients and hence baroclinic vorticity generation (Morrison et al. 2020, Peters et al. 2021)

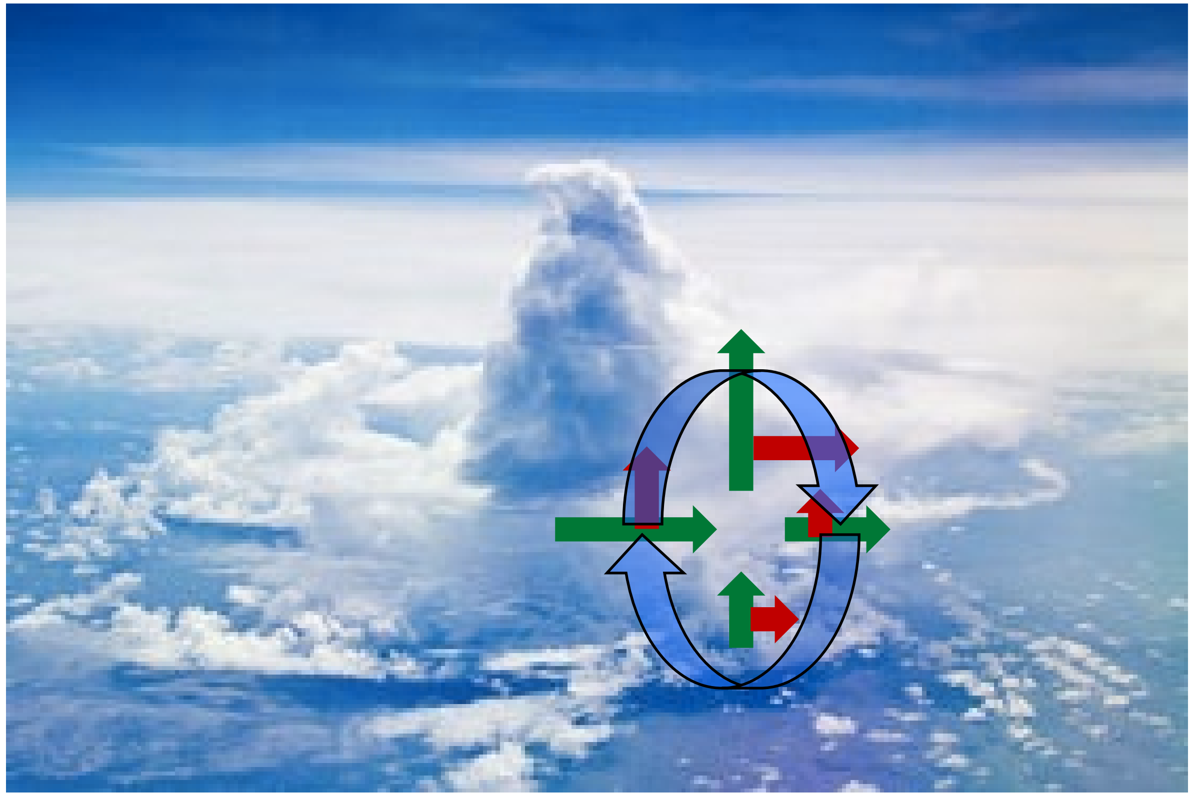
- In climate models with weak mixing shallow convective updrafts grow deeper and precipitate more efficiently. With stronger lateral mixing, more humidity is detrained into the cloud layer, the convective updrafts lose buoyancy faster, and therefore precipitate less efficiently.

Hypothesis: Dilution/detrainment in convective permitting simulations might be too weak because horizontal vorticity associated with thermals is not resolved

Approach: A simple parameterization is developed to:

- Introduce additional horizontal vorticity (rotation) to the resolved 3D wind, and
- use the modified wind to advect momentum, moisture and temperature.

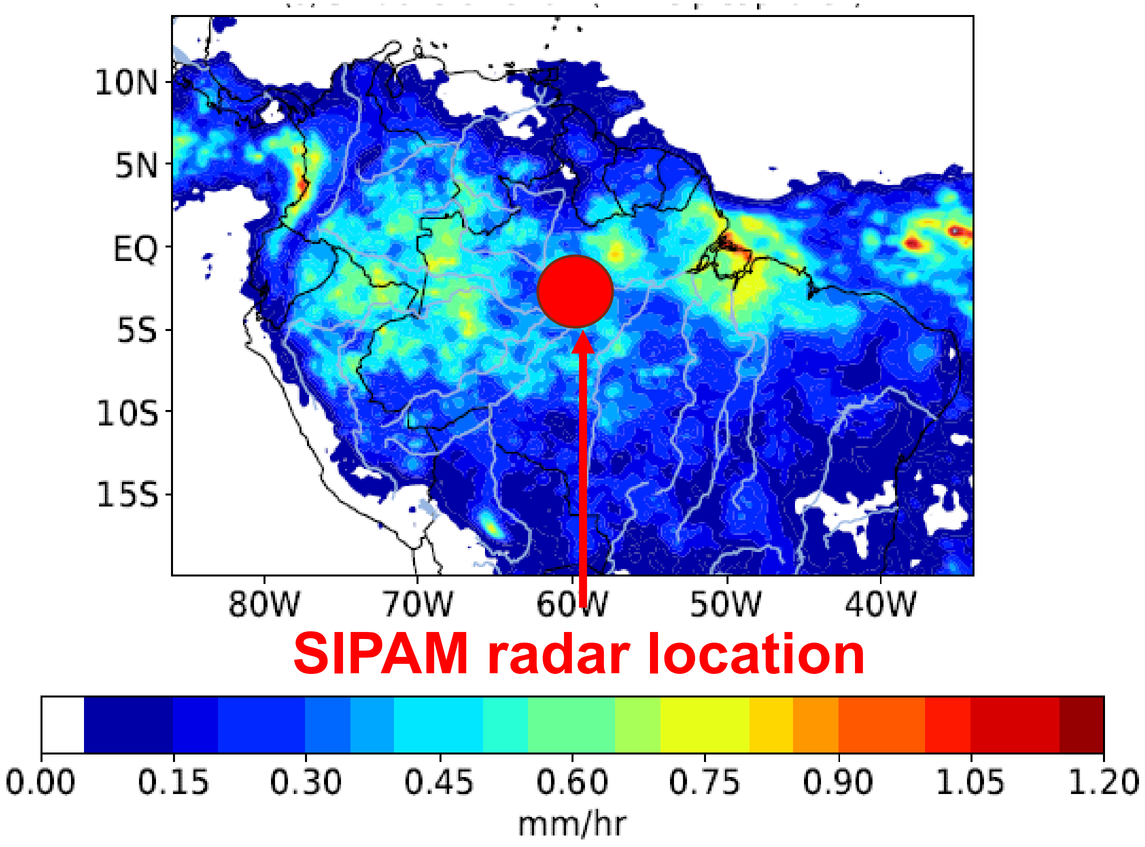
$$\begin{bmatrix} w_r \\ \boldsymbol{v}_r \end{bmatrix} = \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{bmatrix} \begin{bmatrix} w \\ \boldsymbol{v} \end{bmatrix}$$



φ the angle of rotation is a tunable parameter. For small φ, $\varphi \sim \sin(\varphi)$ approximating the fractional change in the magnitude of vertical and horizontal components of the wind.

Design of Simulations

Simulation Domain and IMERG Precipitation



Three 4-km grid spacing WRF V4.0 simulations are performed over Amazon domain.

- CONTROL
- HVMIXING10 (10 rotation, ~ 17% change)
- HVMIXING15 (15 degrees ~ 26%)

Month-long April 2014 simulations forced by FNL lateral boundary conditions.

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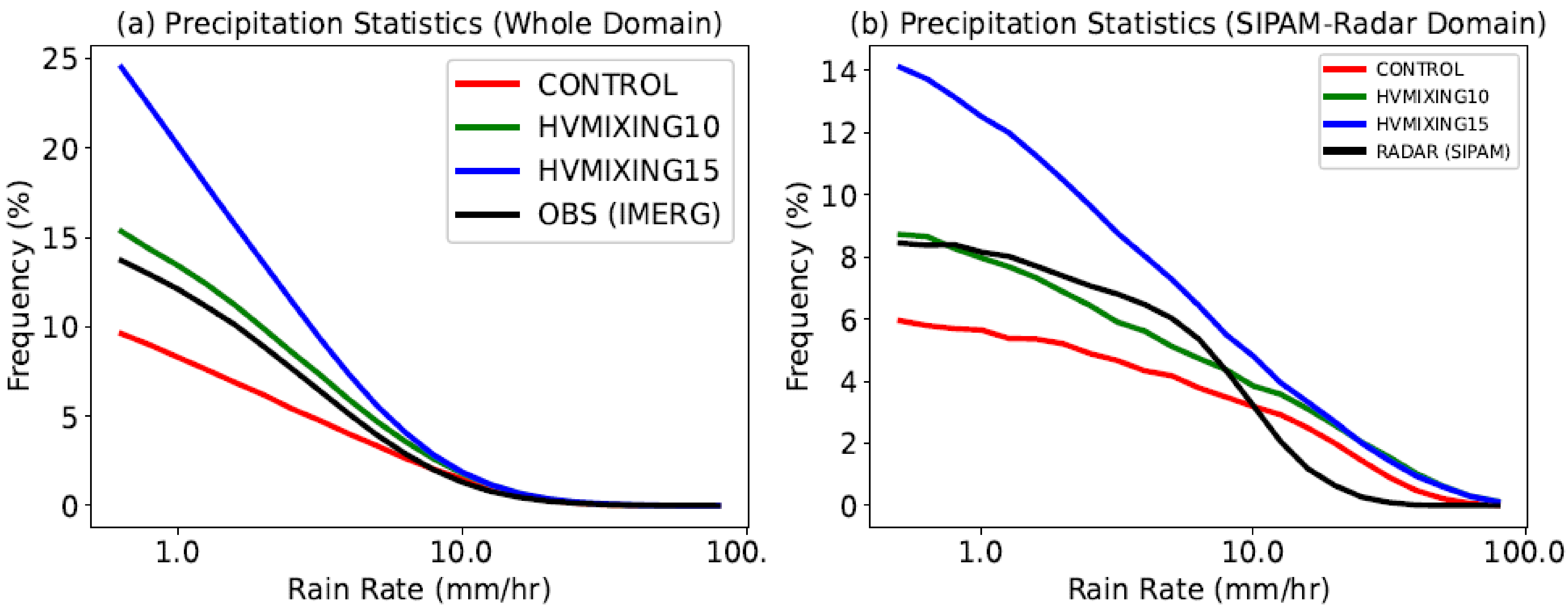
Results

Precipitation Statistics from the HVMIXING Simulations



- HVMIXING increases the frequency of low-intensity precipitation (<10mm/hr).

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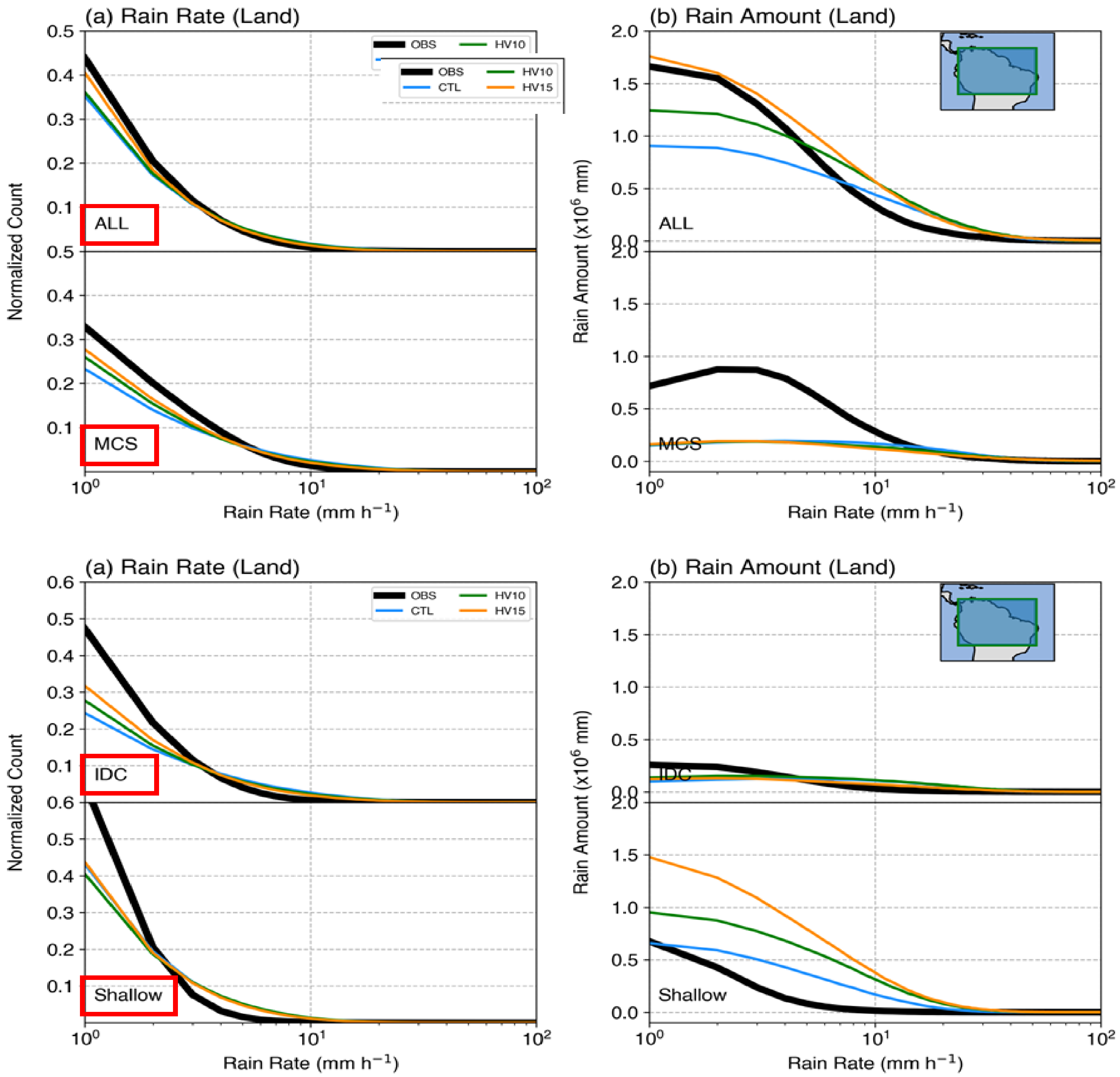
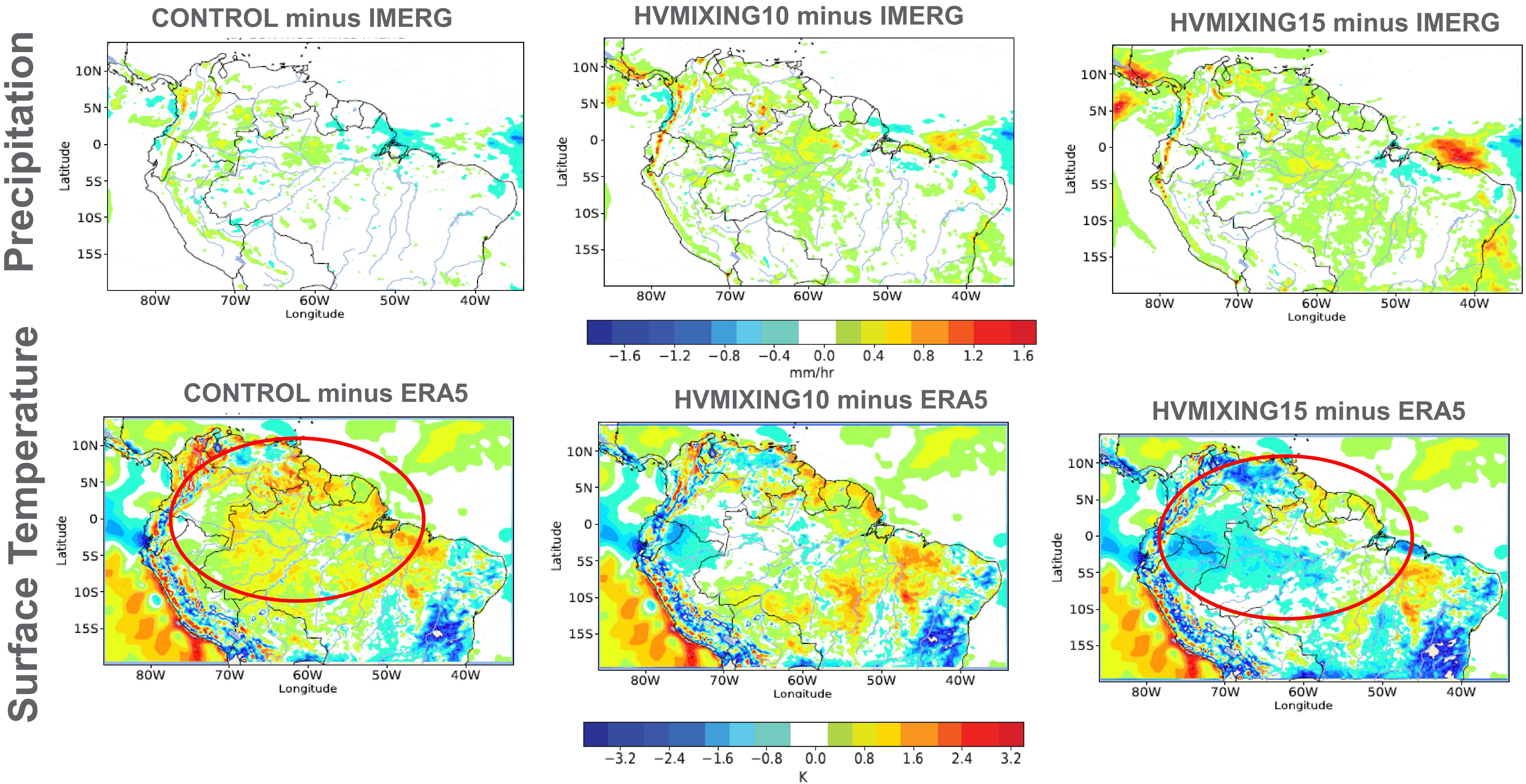
Rain Rate PDF

Rain Amount by Rain Rate



- Changes of Rain Rate PDF & Amount largely from shallow/congestus

Impacts on land surface temperature

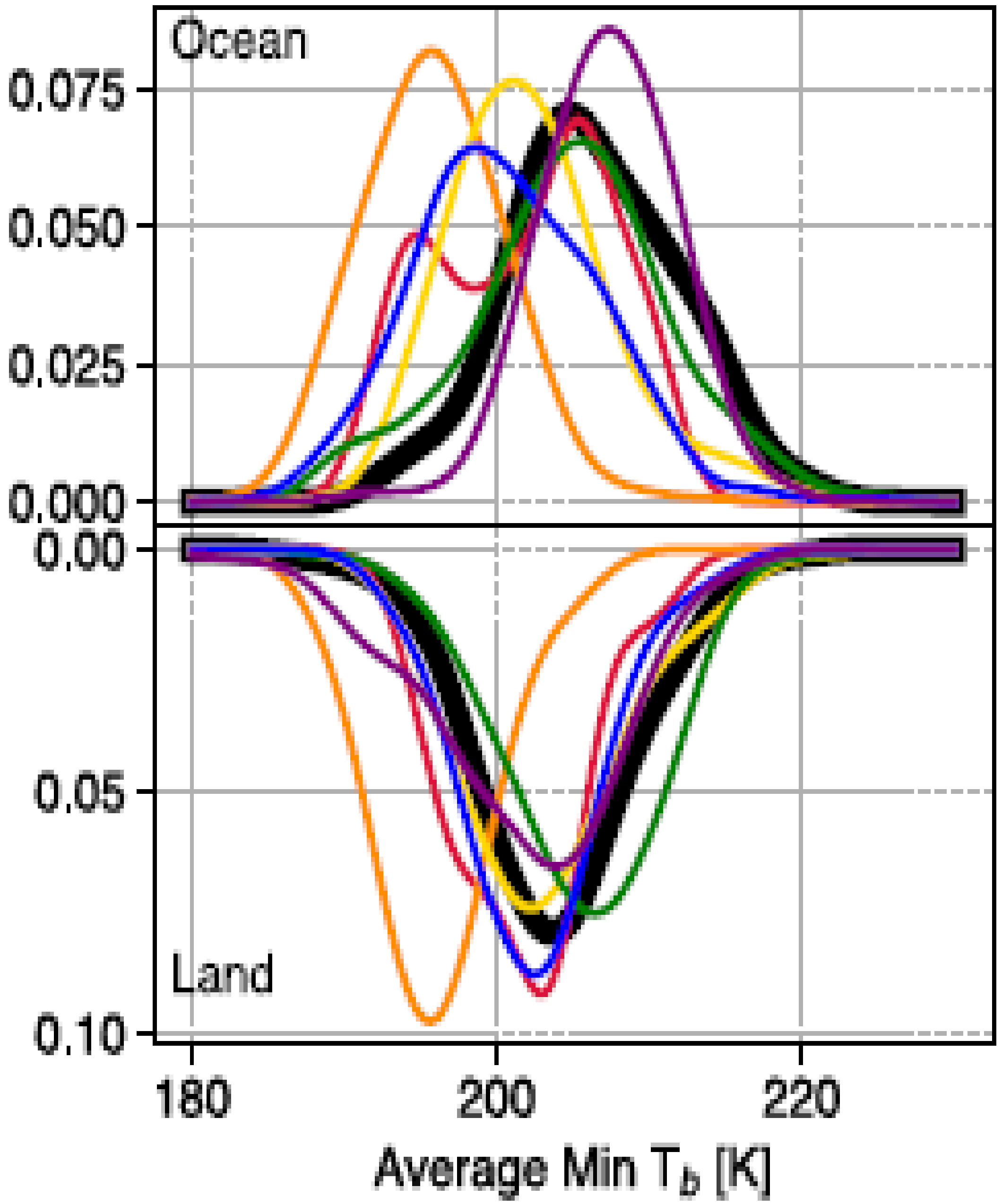


- More wide-spread precipitation is accompanied by land surface cooling reducing the warm bias over Amazon. Excessive coverage of precipitation on the other hand can switch the warm (positive) bias to

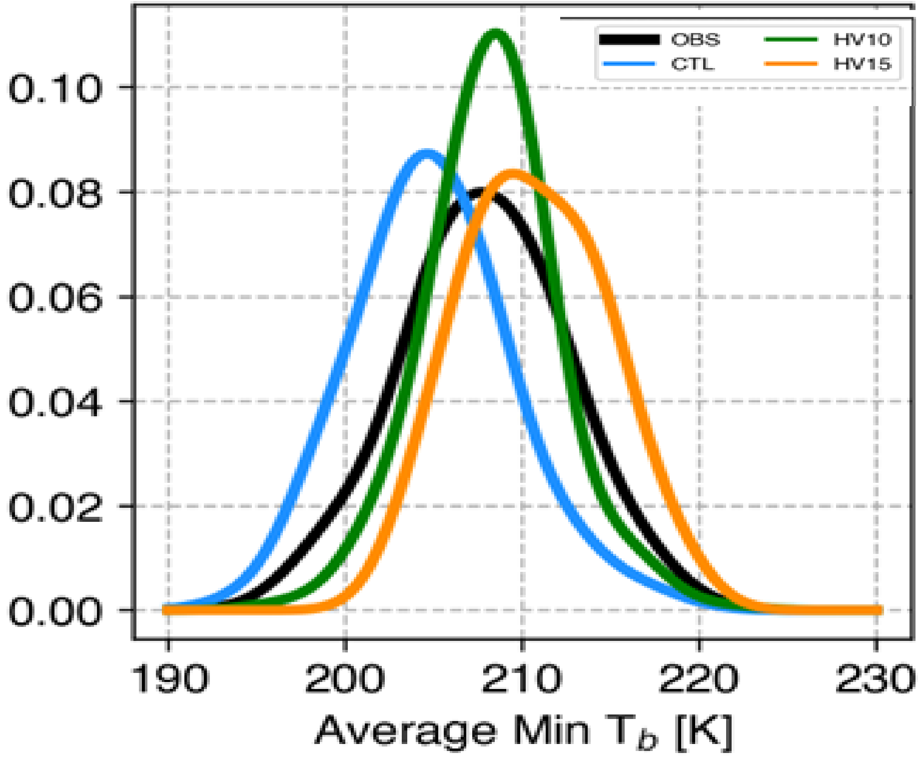
The Vertical Structure of Convection

Brightness temperature of MCSs

DYAMOND simulations



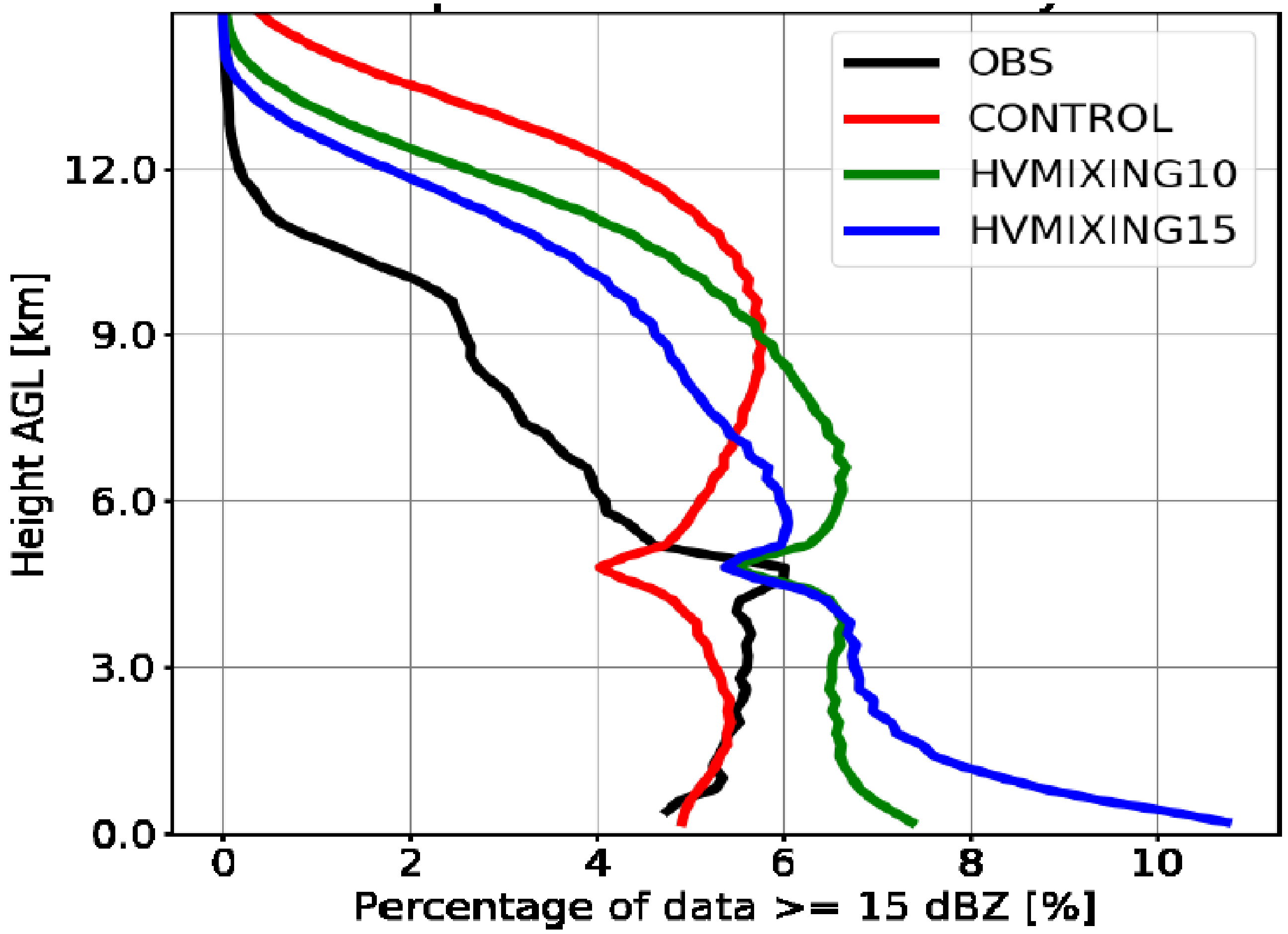
HVMIXING simulations



- MCSs from most DIAMOND global convective permitting simulations deeper (have cooler brightness temperature) than satellite observations
- The parameterized mixing reduces the depth of convection

Echo-top height

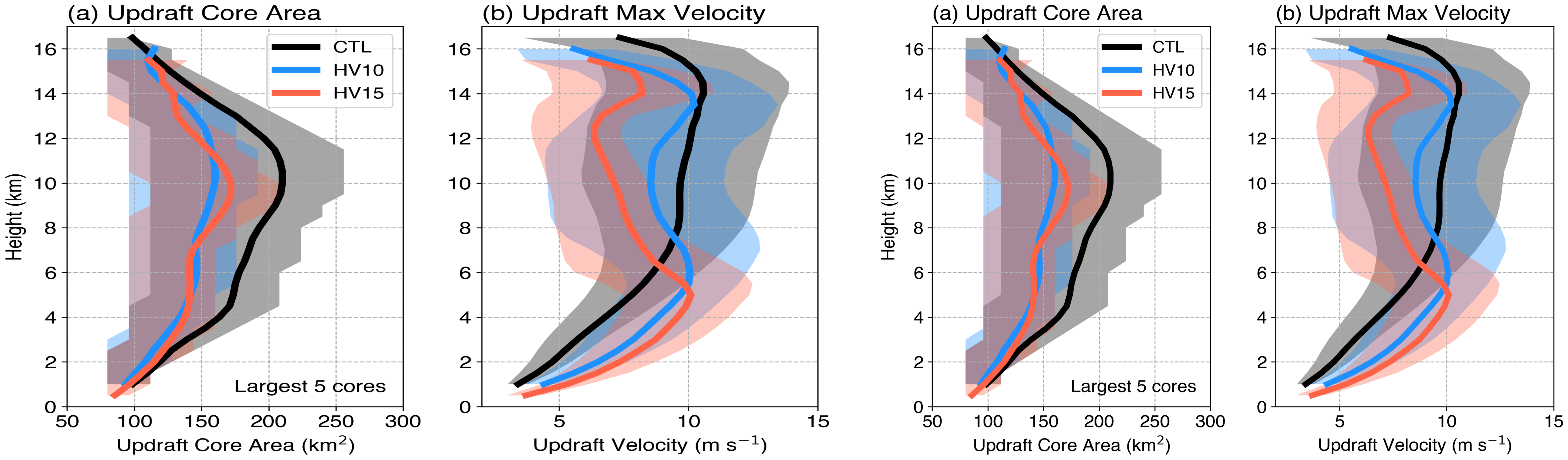
CFAD (Contoured Frequency with Altitudes Diagram)



- The steep increase for HVMIXING15 below 1.5 km echoes the enhanced precipitation near Manaus
- Stronger mixing enhances convection below 7 km and weakens the clouds in the upper-troposphere

Radar wind profiler @ ARM T3. Total samples for each altitudes: - Obs: 2881 (every 30 sec) x 30 (days) - Model: 697 (hourly) x 57 (x-dim) x 57 (y-dim)

Statistics of Updrafts in MCSs



- Narrower, weaker above 8 km but stronger below
- More cores to keep up with mass flux

Summary and ongoing work

LES

↓

Simple Parameterizations

↓

In-situ and Satellite observations, Reanalysis

↓ **constraints on parameters**

Improvements in Convection Permitting Modeling

Examination of impacts of such mixing on E3SMV2-RRM simulations