Substantial Convection and Precipitation Enhancements by Ultrafine Aerosol Particles

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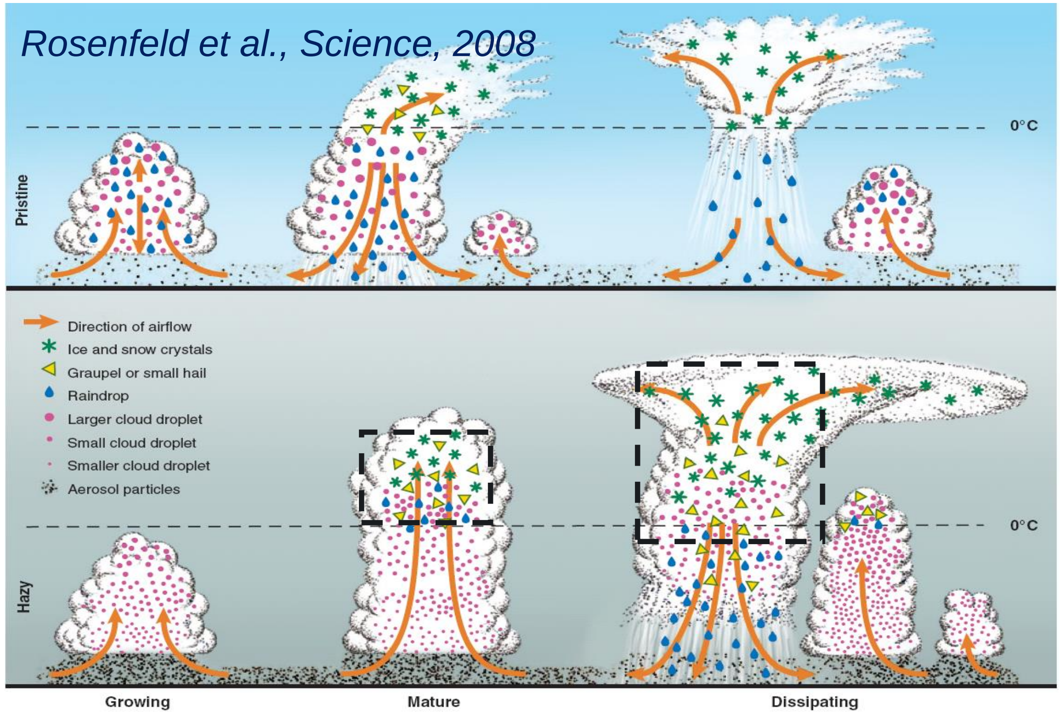
Convective invigoration

- **Andreae et al. (*Science*, 2004)**: **observed** delay in the onset of warm rain for pyro-clouds over Amazon in the **dry** season, hypothesizing convection can be invigorated due to the delay: **"cold-phase invigoration"**

Biomass burning: large particles



- **Fan et al. (*Science*, 2018): observed** drastically enhanced updraft velocity and precipitation for convective storms influenced by urban pollution plume at the **wet** season of Amazon, mainly through : **"warm-phase invigoration"**

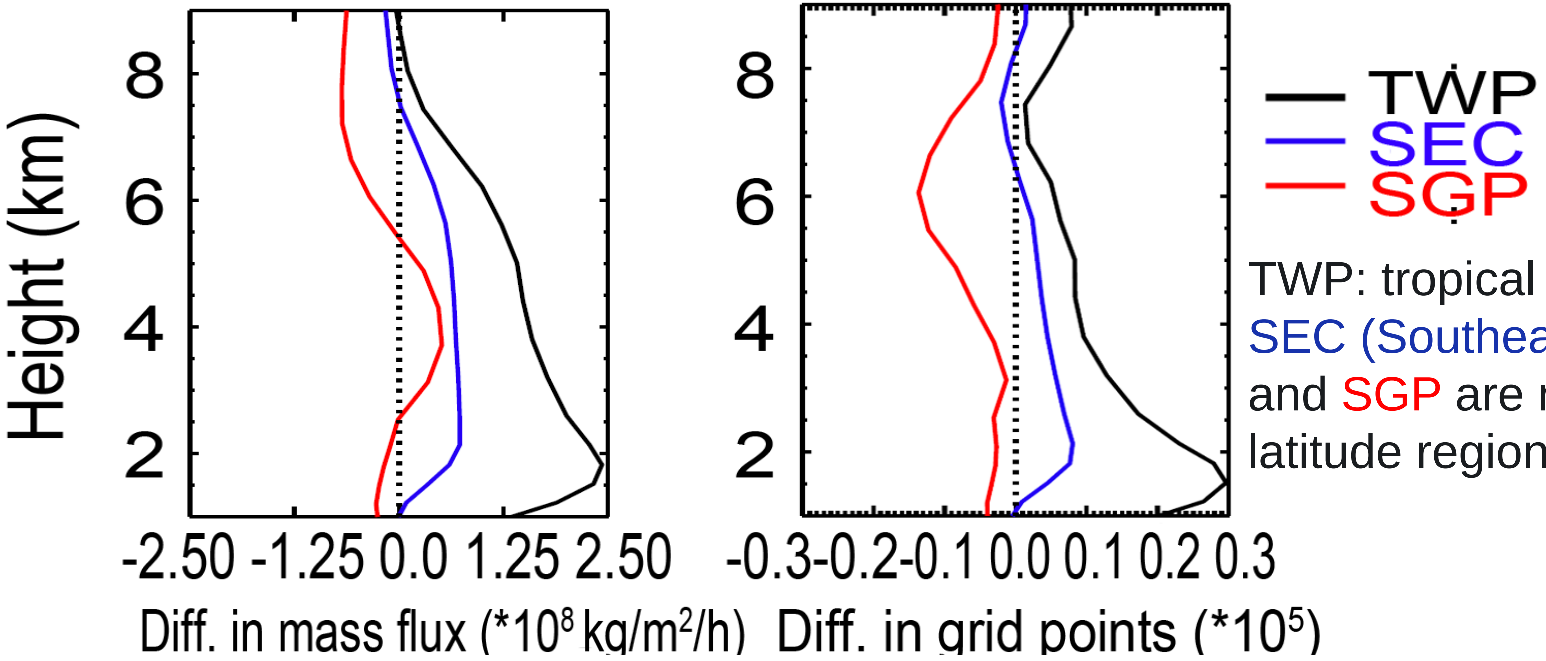
Urban pollution: small particles

- Many studies showed that meteorological factors such as wind shear, RH, and CAPE would modulate CCN impacts on DCCs (e.g., *Fan et al. 2007, 2009, Khain et al.2005, 2009, Storer et al., 2010, van den Heever et al. 2011, Lebo and Morrison 2014*).

Warm and humid tropics – much larger convective invigoration than mid-latitudes

Diff. in vertical Mass flux between polluted and clean conditions

Diff. in updraft area between clean and polluted conditions



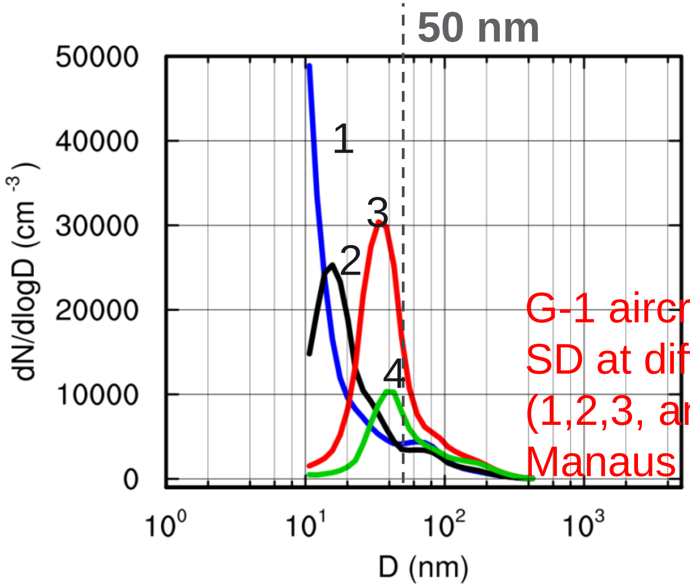
TWP: tropical region
SEC (Southeast China) and SGP are mid-latitude regions

Fan et al., PNAS, 2013

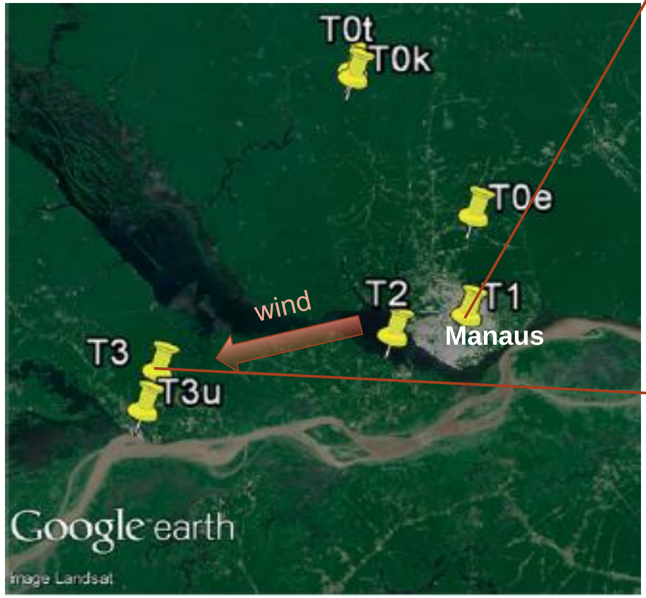
- Many modeling studies (Fan et al. 2007; 2013, Storer and van den Heever 2013, Sheffield et al. 2015, Khain et al. 2008, 2012) showed significant convective invigoration in tropics due to enhanced condensational heating.

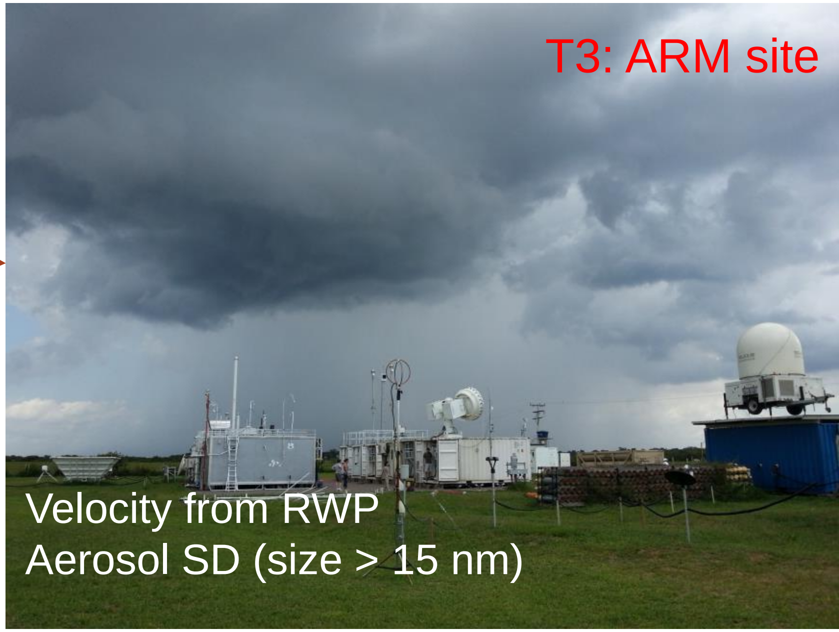
Uniqueness of GoAmazon

- Unique field campaign design to disentangle aerosol impacts from the impact of meteorological variables.
- Unique observational data: convective intensity from RWP and aerosol size distribution from 10 nm.
- Manifest the role of ultrafine aerosol particles (<50 nm; UAP) from urban plumes, generally thought be too small to be activated



G-1 aircraft obs. of aerosol SD at different locations (1,2,3, and 4) influenced by Manaus plume

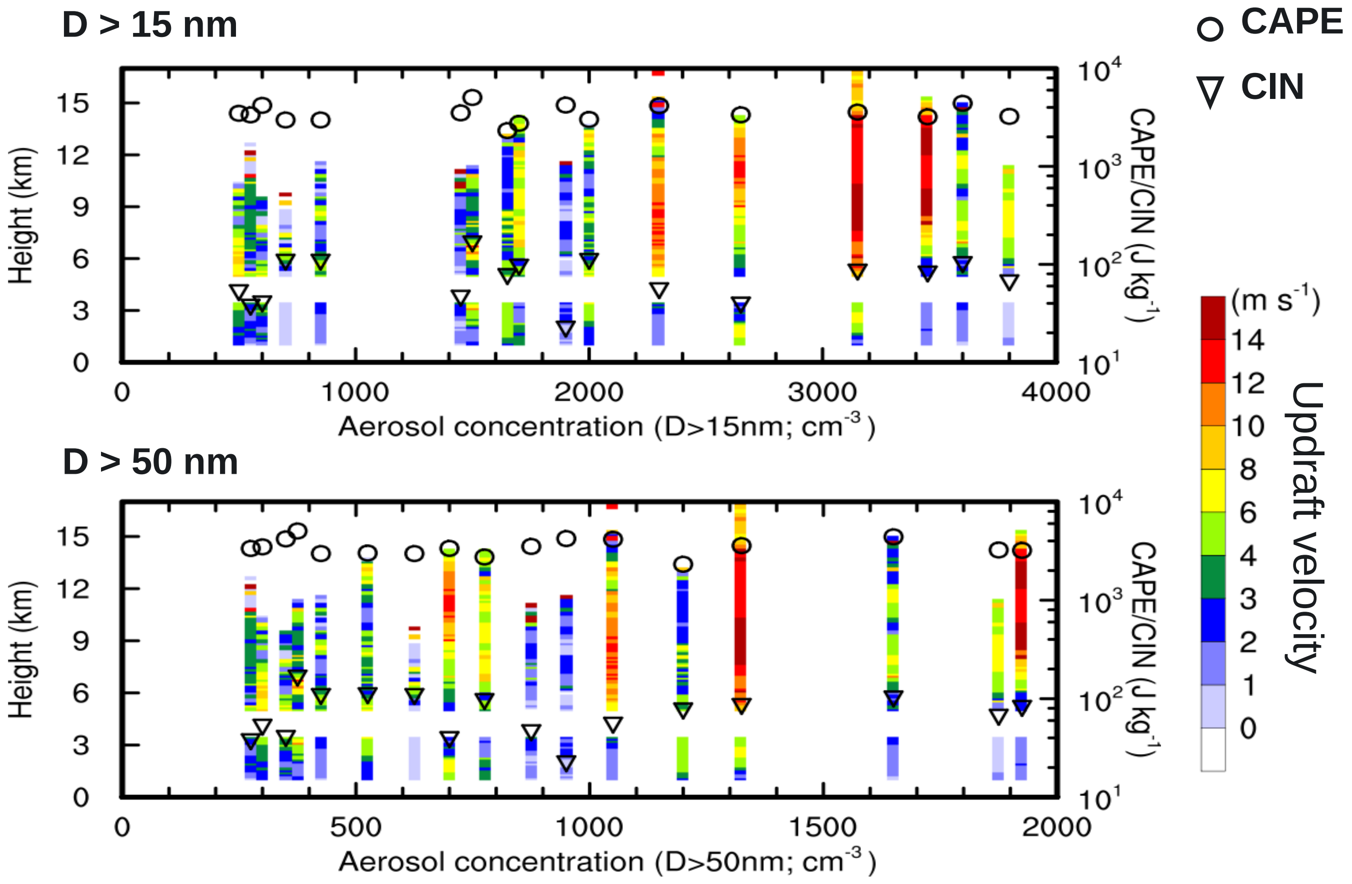




Observed enhancement of convective intensity and precipitation by aerosols

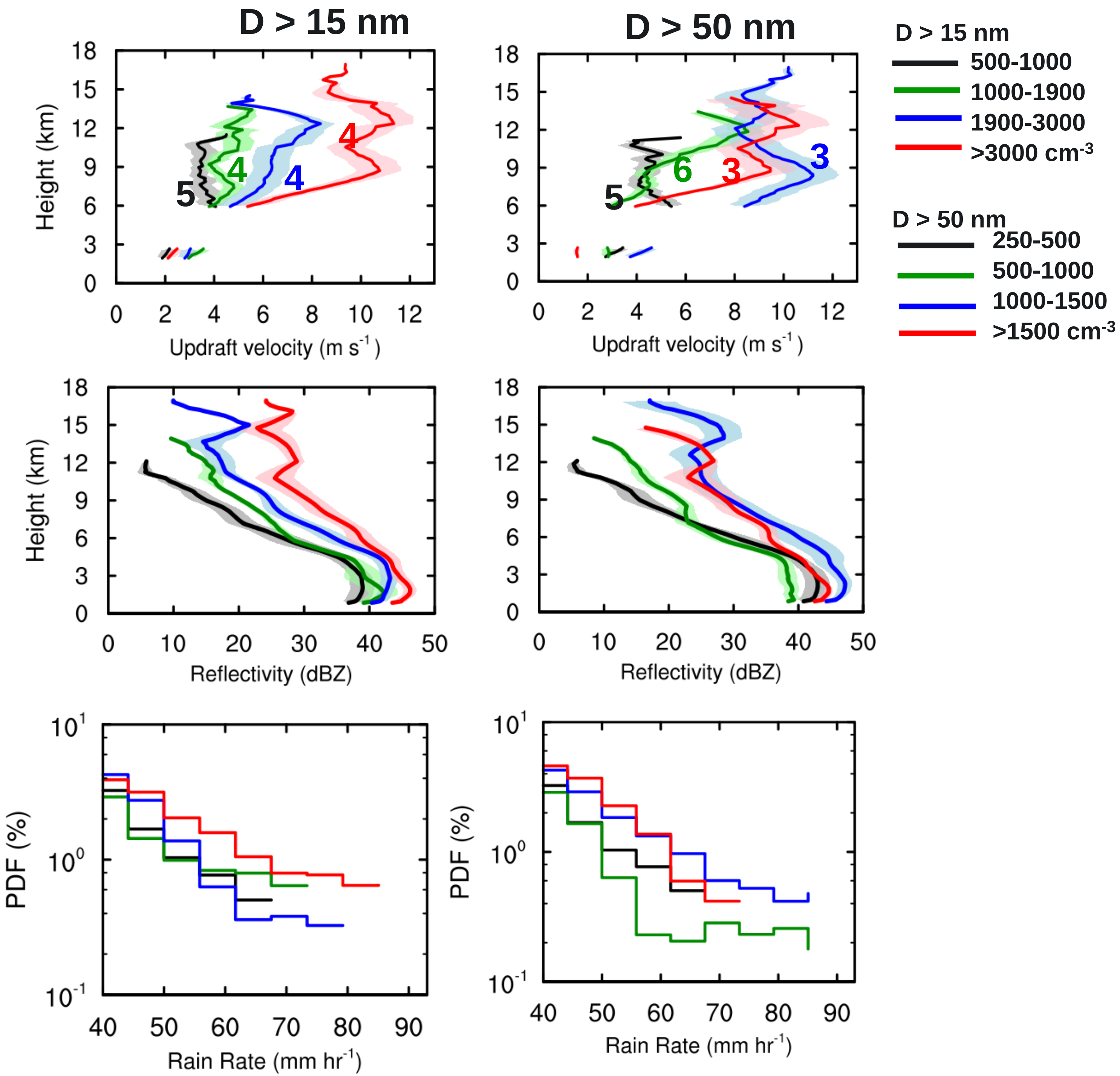
Carefully selected the locally-occurring storm cases from the 2014 wet season over March-May: 17 DCCs with valid aerosol and convective core measurements

- Updraft velocity increases with an increase of aerosols counting *D* > 15 nm.
- However, the relationship with aerosols does not hold well when excluding aerosols smaller than 50 nm.



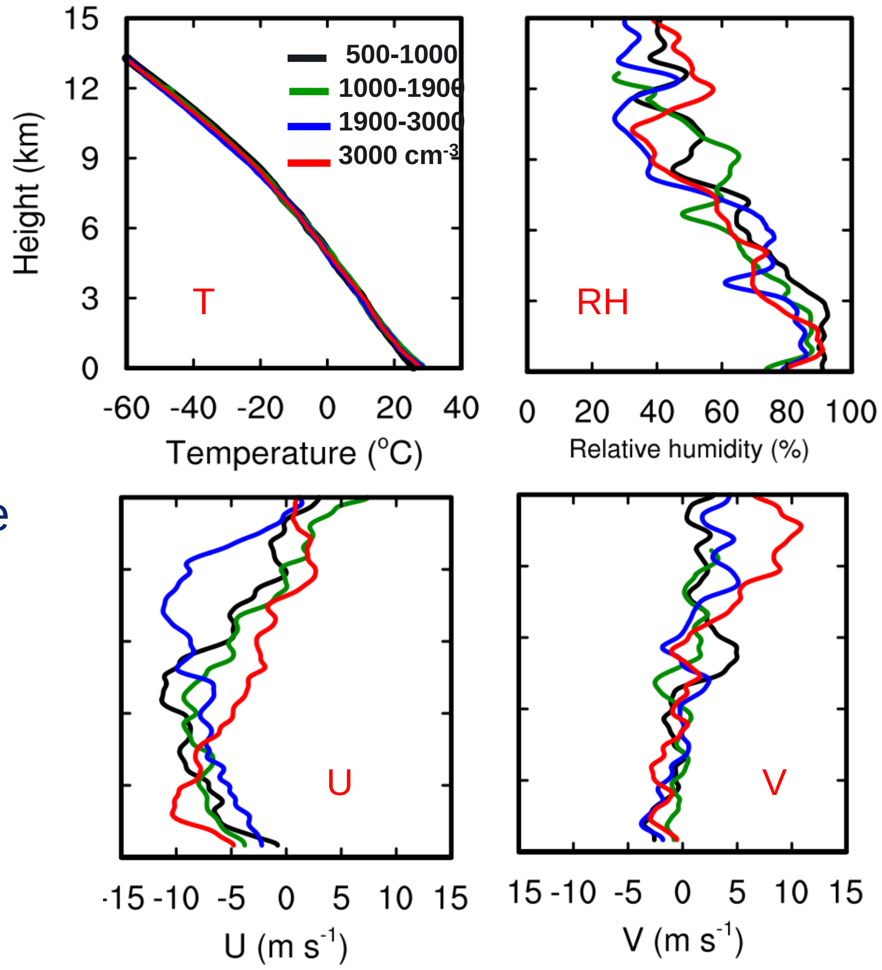
Further quantify the effect from the low to high aerosol groups

- Ultrafine aerosol particles smaller than 50 nm (**UAP$_{<50}$**) might be responsible for intensified convection and precipitation, not the aerosol particles larger than 50 nm (**CCN$_{>50}$**)

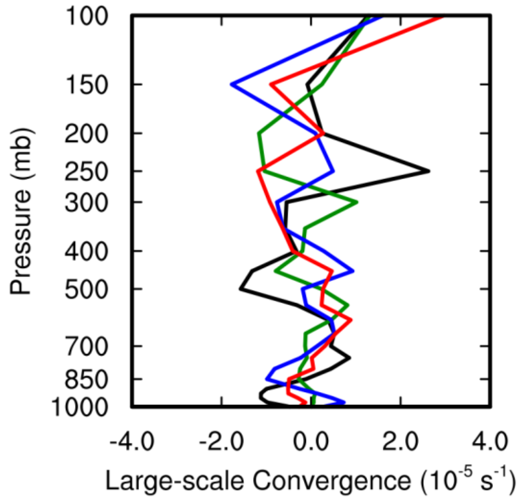


Isolate aerosol effects from meteorological factors

D >15 nm: **pre-storm environment**



Large-scale convergence

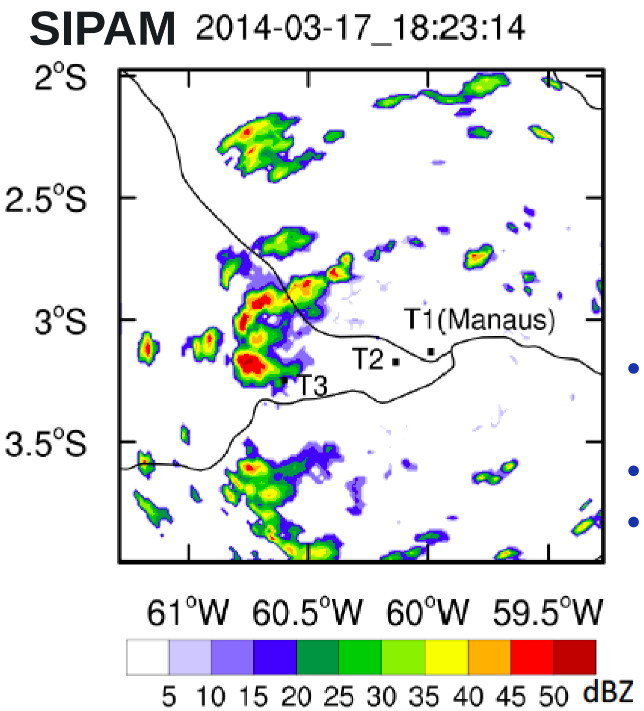


- Profiles of T, RH, and U- and V- wind as well as large-scale convergence indicate that none of them correlates with an increase of updraft intensity as UAP<50 increases.

WRF-SBM model simulations at cloud-resolving scale (0.5 km)

- To see if model can simulate such substantial enhancements in convection
- To reveal the mechanisms responsible for such large invigoration by $UAP_{<50}$

Conducted WRF with spectral-bin microphysics (WRF-SBM) for a typical wet season convective event on 17 March 2014 (0.5 km resolution)

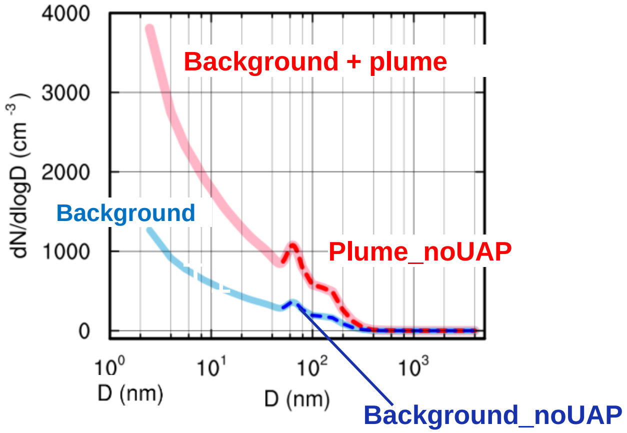


- Weak wind shear
- High CAPE
- Winds were northeasterly at the 850 hPa level

Background: Manaus background ($820\ cm^{-3}$ UAP $+130\ cm^{-3}$ $CCN_{>50}$)

Background + plume: Manaus background with Manaus plume ($2460\ cm^{-3}$ UAP $+390\ cm^{-3}$ CCN $_{>50}$ for Manaus)

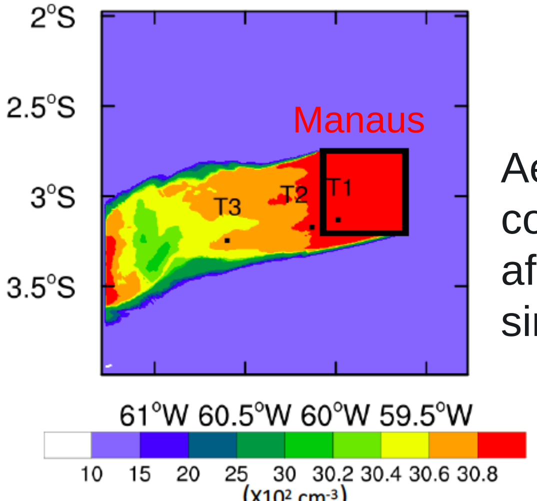
Background_noUAP and **Plume_noUAP** are the corresponding cases by removing UAP



NOTE

Background_noUAP represents Amazon pristine environment

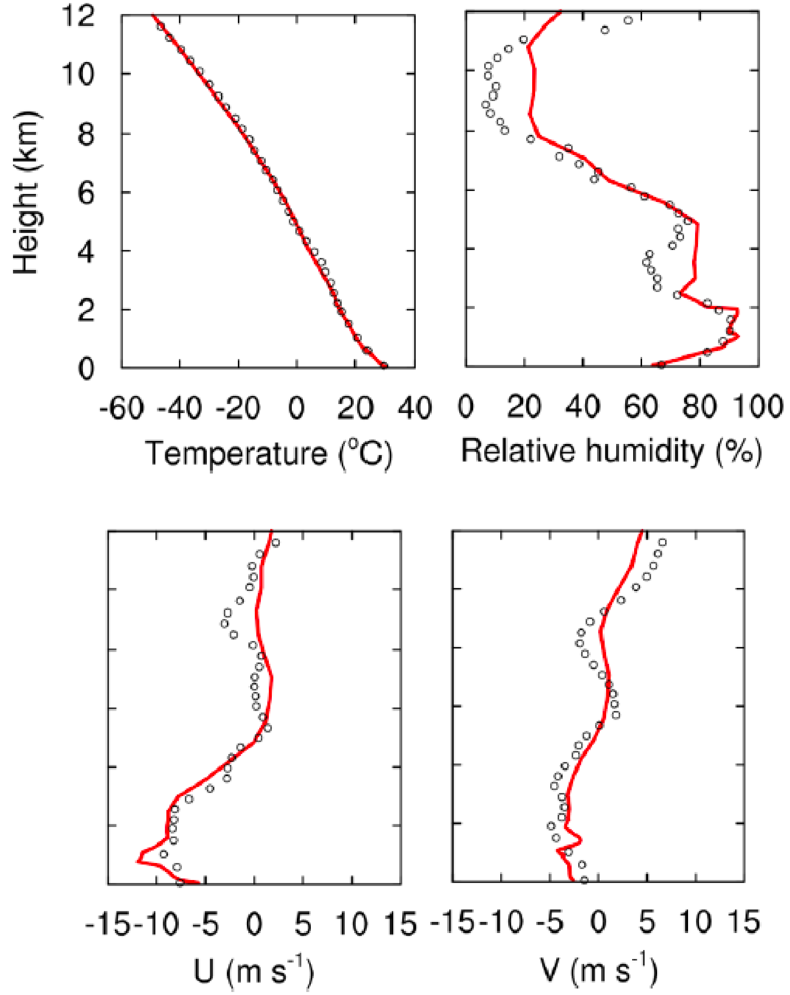
Background+plume represents current urban plume affected condition



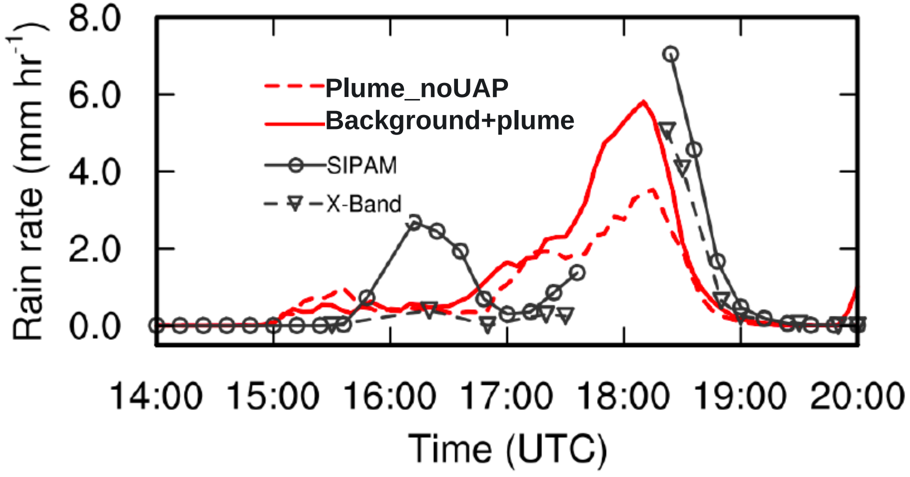
Aerosol concentration after 1-day simulation

Validation of the baseline run: Background + plume

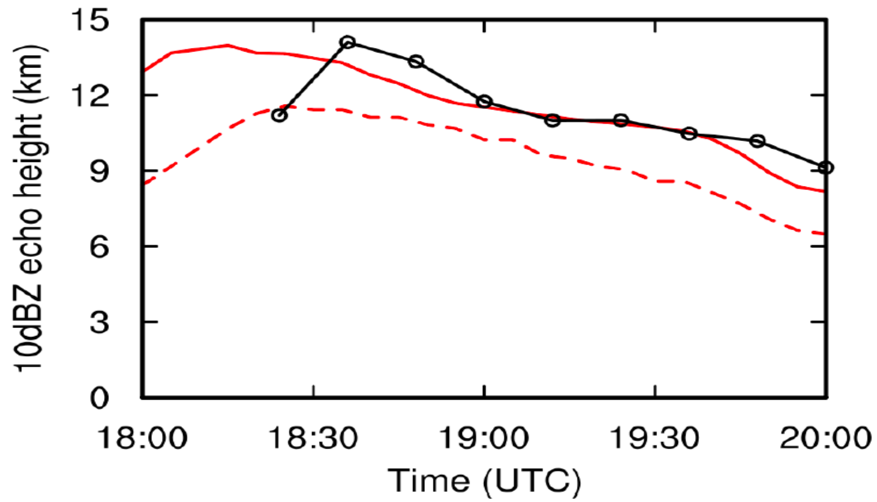
Pre-storm meteorology



Rain rate at 2.5 km



10 dBZ echo top height

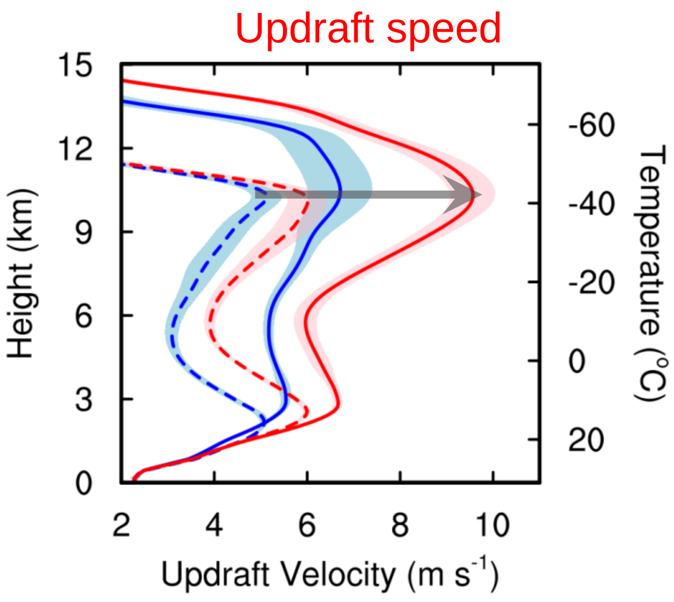


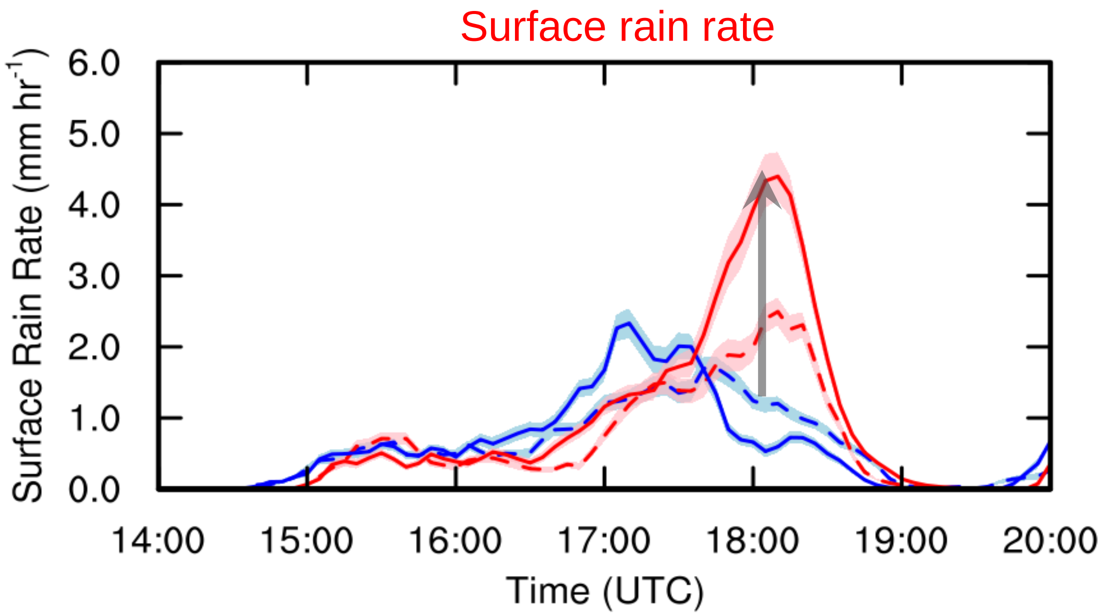
Similarly large enhancement from model simulations

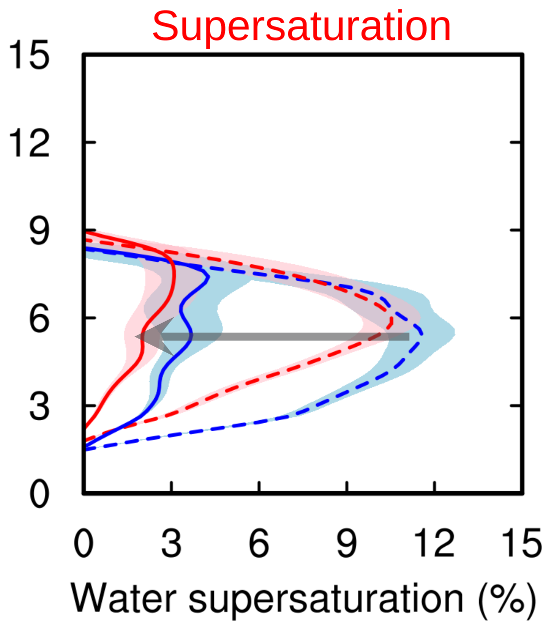
- Background
- Background_noUAP
- Background+plume
- Plume_noUAP

Background_noUAP represents Amazon pristine environment

Background+plume represents current urban plume affected condition





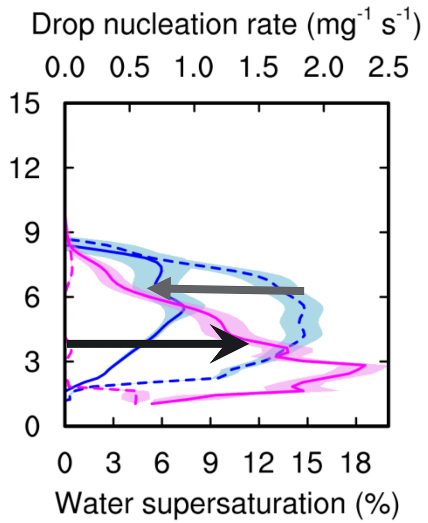


- The observed **large enhancements** in convective intensity and precipitation by $UAP_{<50}$ from Manaus pollution plume are reproduced.
- Corresponding to drastic decrease in **supersaturation**

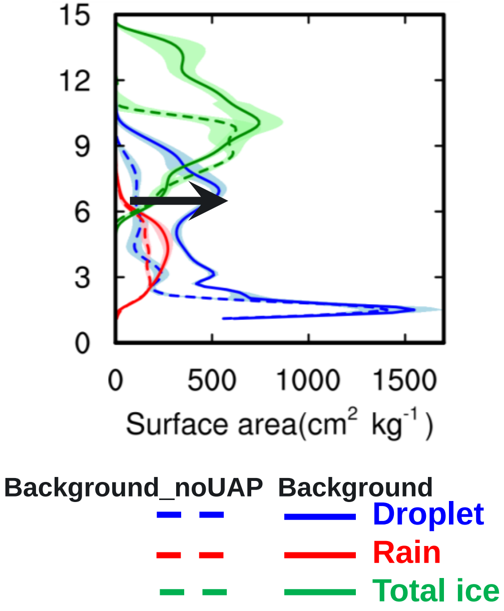
Mechanism

Use **Background** (solid) and **Background_noUAP (dashed)** to illustrate

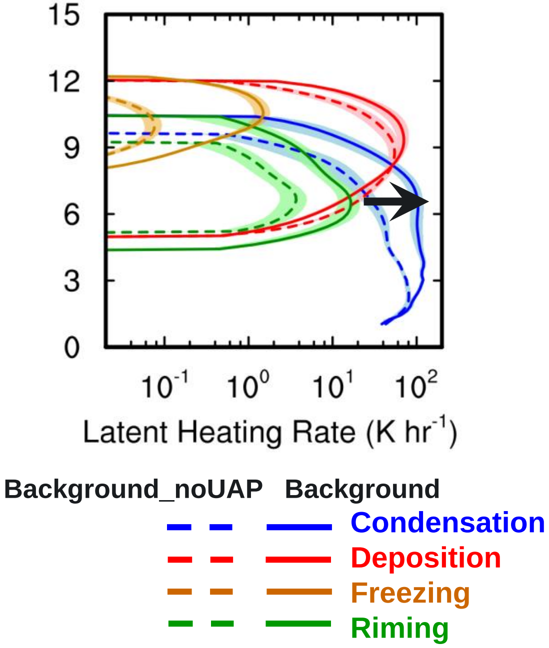
Drop nucleation rate



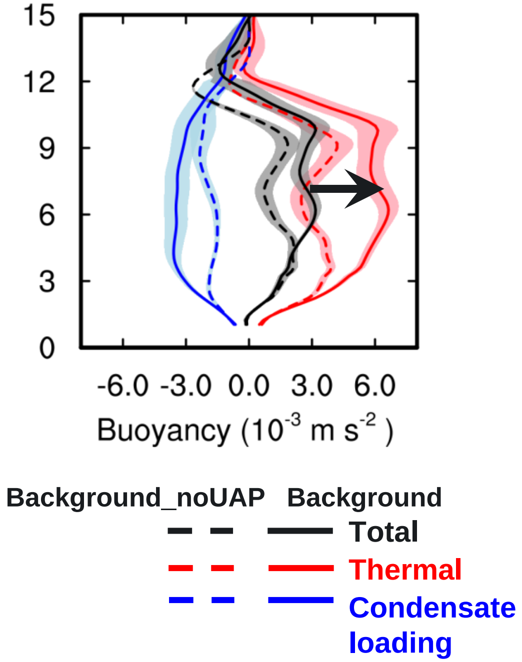
Surface area

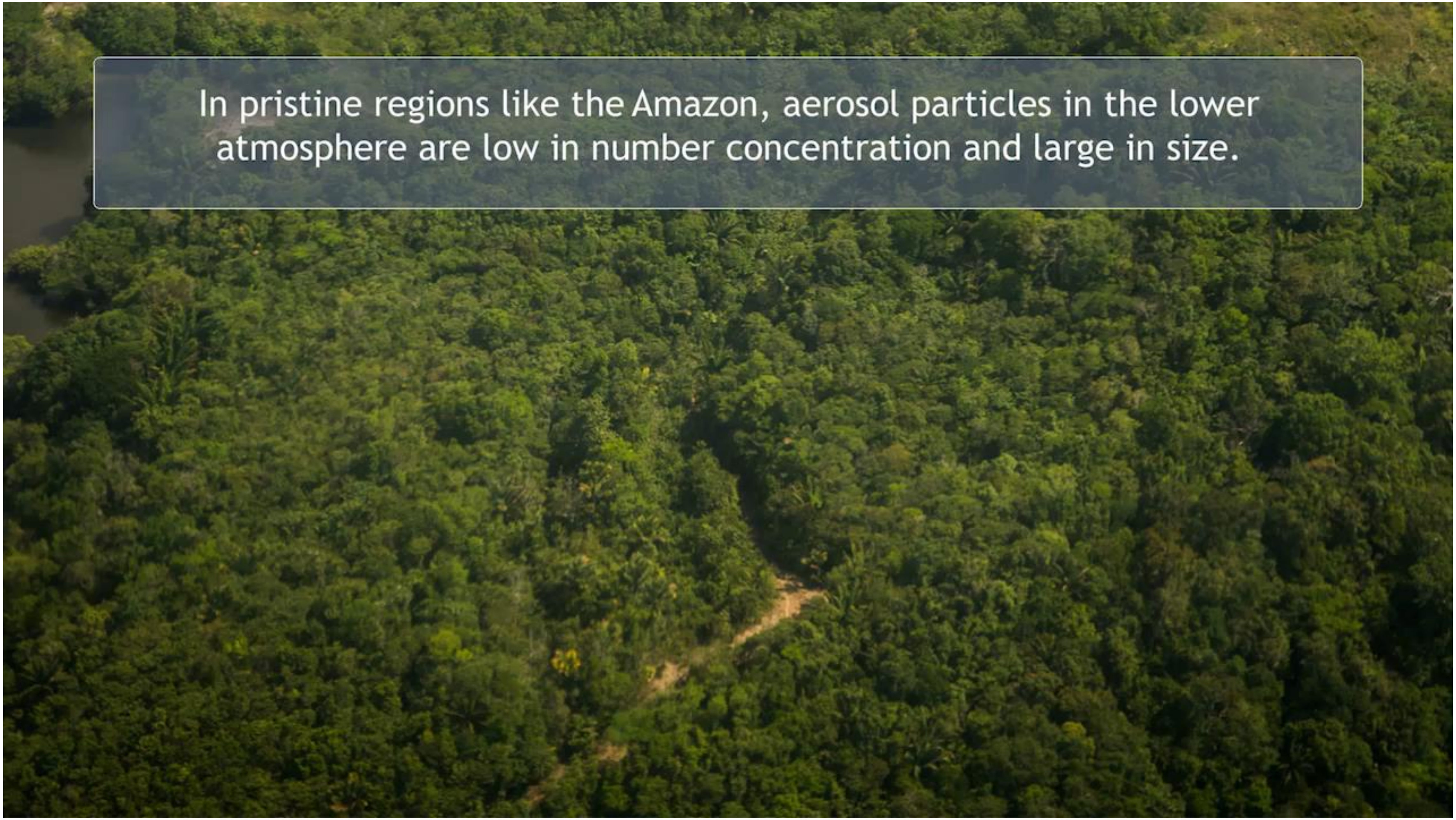


Latent heat



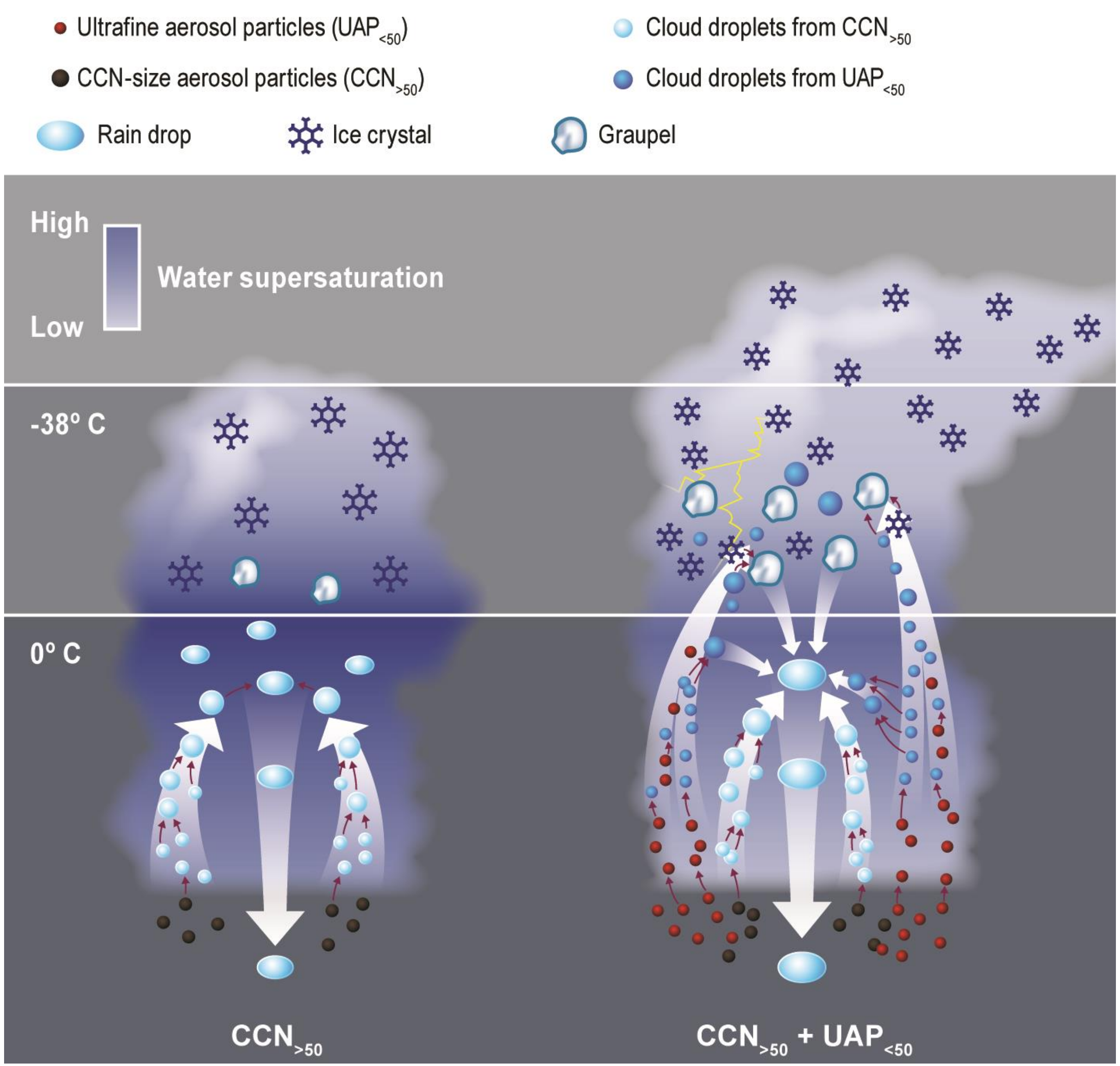
Buoyancy




In pristine regions like the Amazon, aerosol particles in the lower atmosphere are low in number concentration and large in size.

Features of "warm-phase invigoration"

- **Does not delay rain or suppress warm rain** (in contrast to the effect of $CCN_{>50}$)
- The effect is **much more powerful** compared to "cold-phase invigoration" because (a) the enhanced heat is much larger and (b) the heating is at the lower part of storm clouds.



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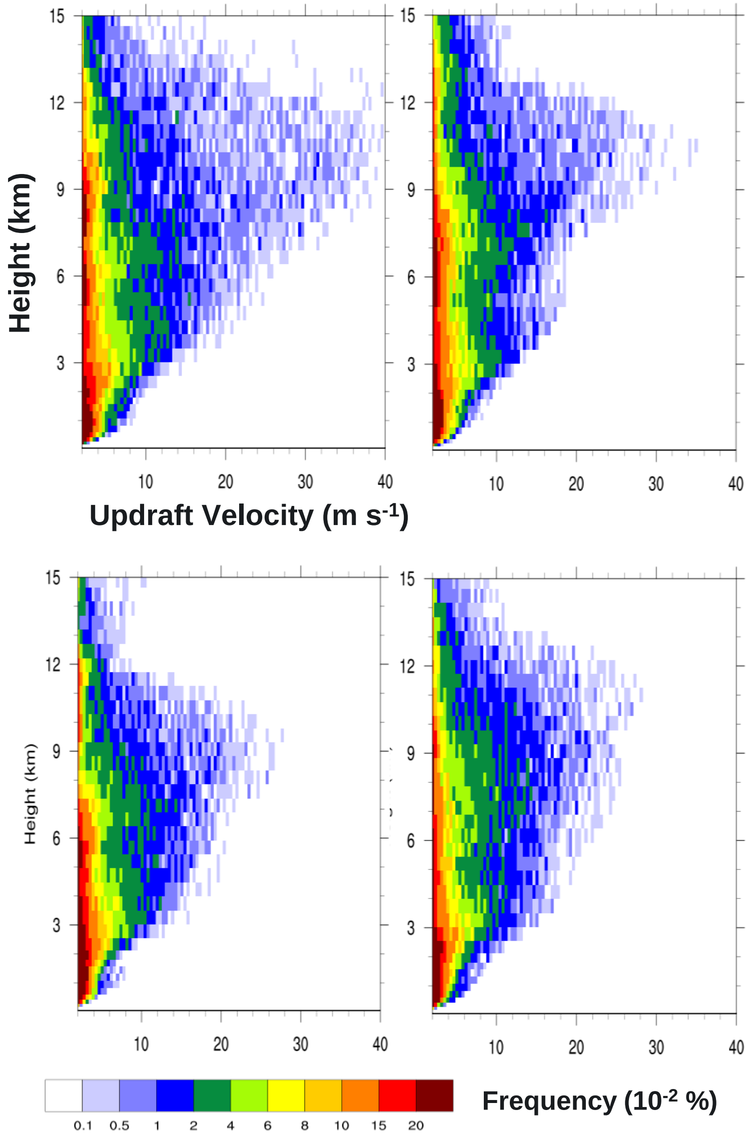
Key factors for model to simulate convective invigoration

- Predict aerosol size distribution including small mode (No fixed aerosol or droplet number)
- Resolve updrafts and predict supersaturation (No saturation adjustment)
- **Droplet condensation and evaporation depend on supersaturation and droplet surface area** (No saturation adjustment).

WRF-Chem with SBM | WRF-Chem with Morr



With anthropogenic aerosols

Without anthropogenic aerosols

The problem with the piggybacking approach in examining feedback to dynamics

- Grabowski, JAS (2015) and Grabowski Morrison, JAS (2016) denied invigoration with the piggybacking approach as below:

D: Driving. P: Piggybacking. H: High CCN. L: Low CCN

Pair 1:

D_LowCCN = dyn_L + micro_L
– P_HighCCN = dyn_L + micro_H – not a realistic run

= Microphysical effect under **dyn_L** due to increasing CCN from Low to High CCN …. **(a)**

Pair 2:

D_HighCCN = dyn_H + micro_H
– P_LowCCN = dyn_H + micro_L – not a realistic run

= Microphysical effect under **dyn_H** due to decreasing CCN from High to Low CCN …. **(b)**

If **(a)** and **(b)** are are opposite in signs and magnitudes are the same, it only means that the microphysical effect is the same under **dyn_H** as under **dyn_L**. We **can not** infer anything about relative magnitudes of **dyn_H** and **dyn_L.**

The dynamics effect = D_HighCCN – D_LowCCN

Ensemble simulations is a solution for more robust feedback to dynamics!

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Summary Significance

This finding implies that from **pre-industrial times to the present day**, small aerosols from human activity may have significantly influenced storms **in warm and humid places through "warm-phase invigoration"**.

The work would push the **atmospheric observation field to make progress** in measuring convective microphysics, vertical motion, and supersaturation in storms, all of which are very challenging.

Also would stimulate **more field campaigns over the warm and humid regions** to tackle this problem more robustly and systematically.

Wildfire impact

Geophysical Research Letters

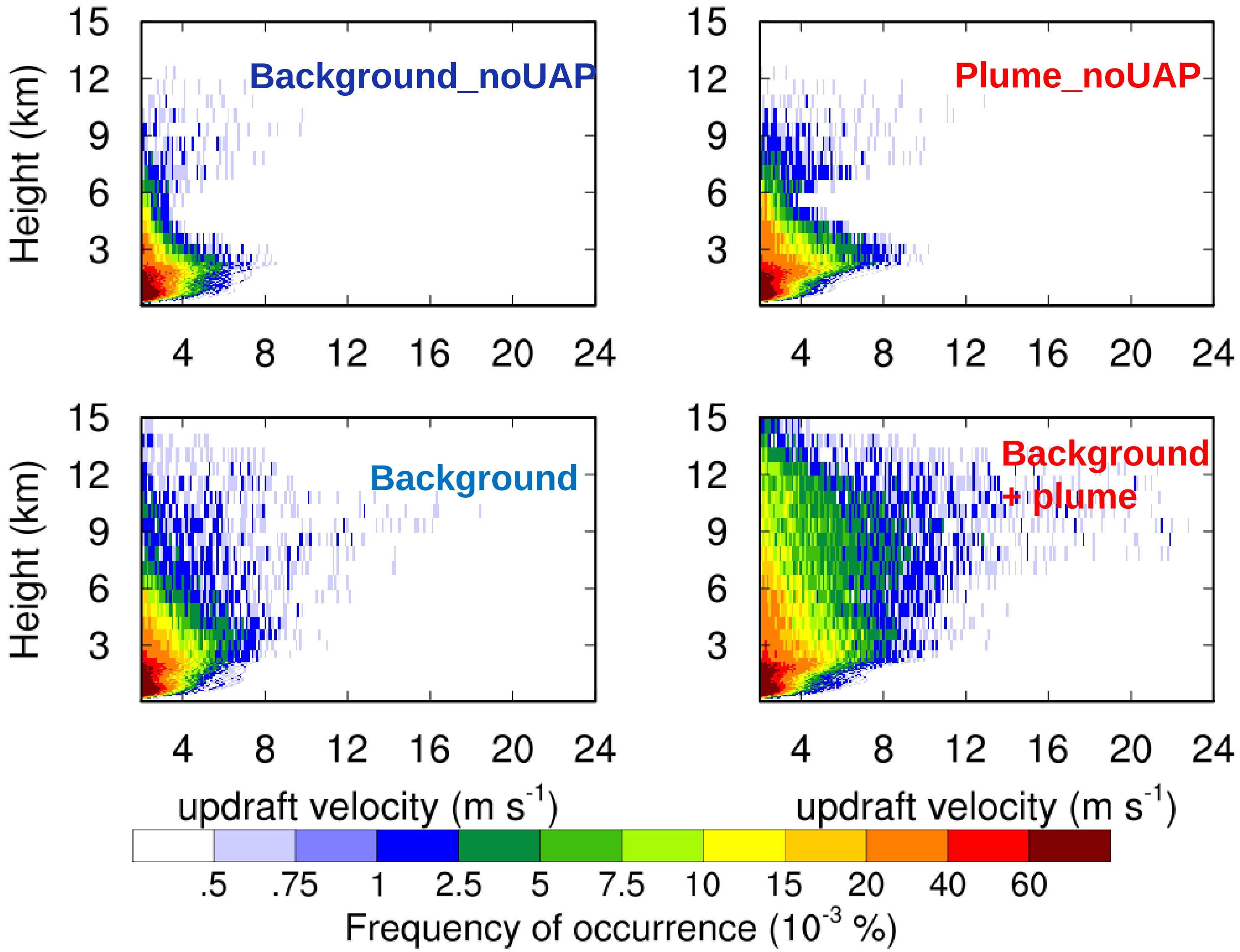
Research Letter | Open Access

Wildfire Impact on Environmental Thermodynamics and Severe Convective Storms

Yuwei Zhang, Jiwen Fan, Timothy Logan, Zhanqing Li, Cameron R. Homeyer

First published: 15 August 2019 | https://doi.org/10.1029/2019GL084534

PDF of updraft velocity



Effect of latent heat increase at different levels