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Competing Effect of Radiative and Moisture Feedback in Convective Aggregation States in Two CRMs

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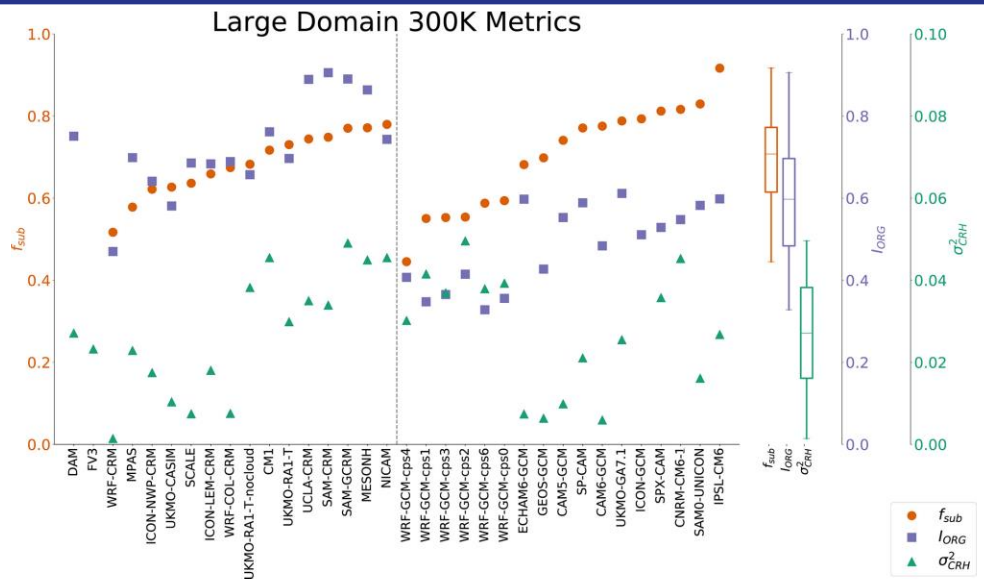
Introduction

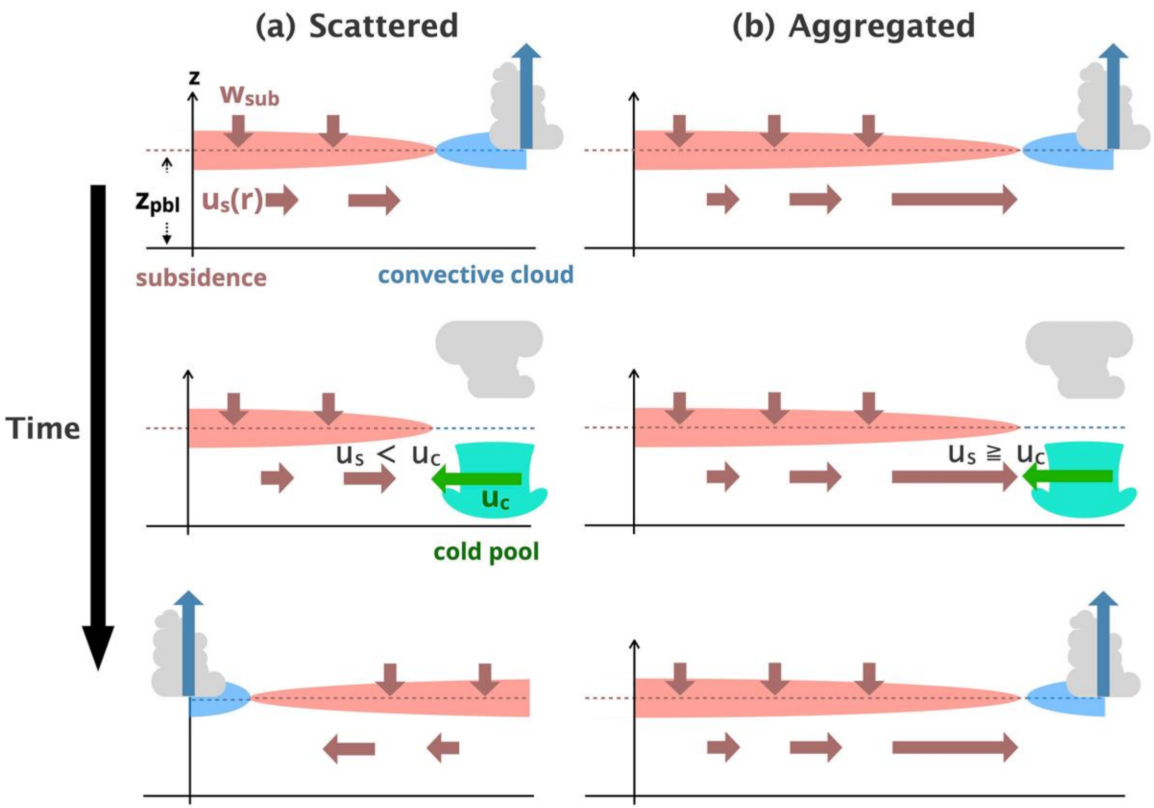
RCEMIP results showed that the wide range of equilibrated states can be due to differences in model physics and/or numerics.

Wing et al. 2020



Convective Self Aggregation

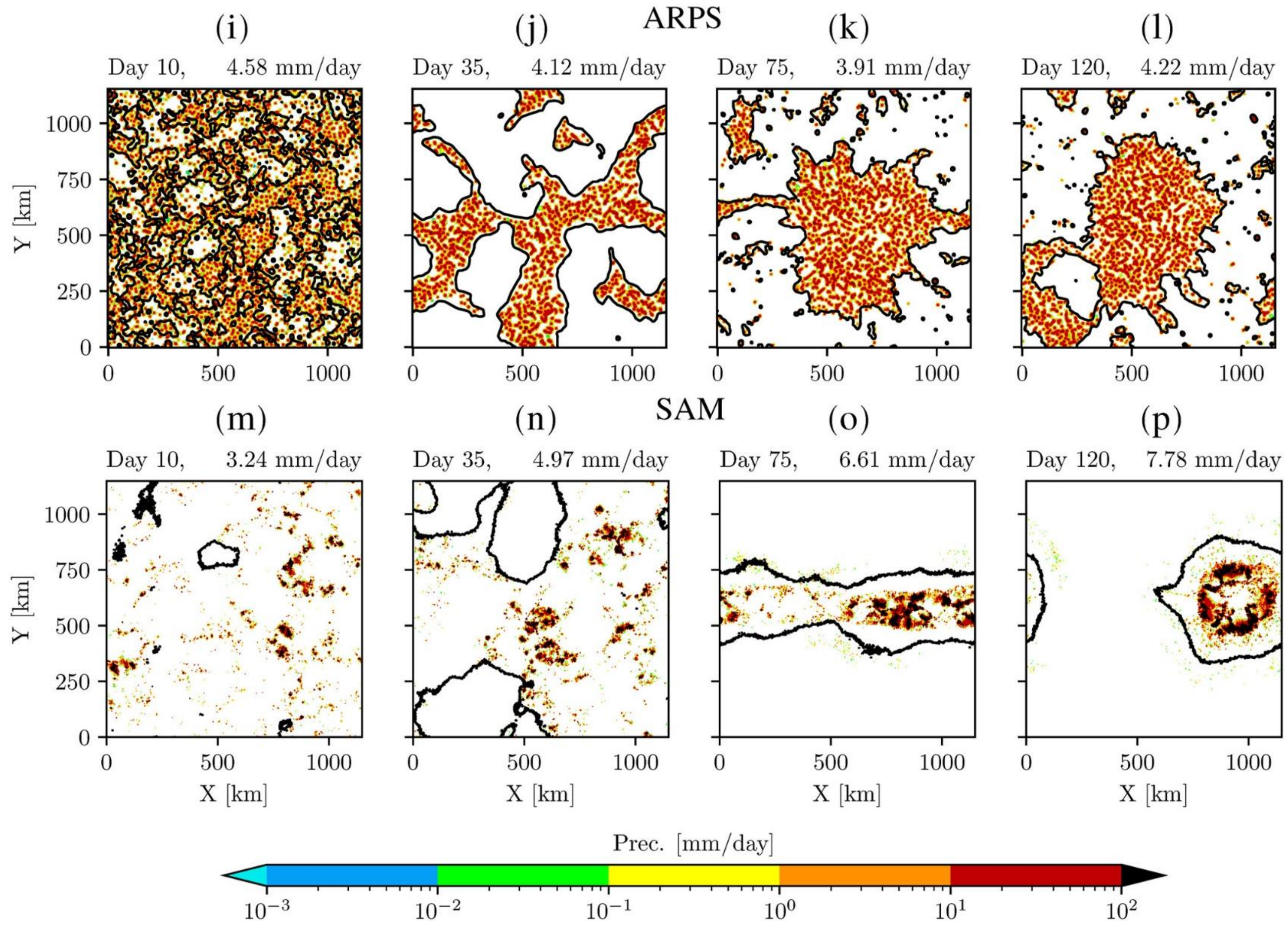
Radiative Feedback ⟷ Moisture Feedback



Yanase et al. 2020

Introduction

Which factors in the models are prevalent in aggregation? Can there be different sensitivities to the moisture and radiative feedback?



RCE simulations with Two Cloud Resolving Models **(CRM)**

- **ARPS** (The Advanced Regional Prediction System) model; similar to the most used Weather Research and Forecasting (WRF) model; (Xue et al., 2000, 2001)
- **SAM** (System of Atmospheric Modeling) model; (Khairoutdinov & Randall, 2003)

Numerical setup and Initialization

	SAM	ARPS
Model version	6.10.6	5.3.4
Δx (km)	3	3
Domain size (km)	1,152	1,152
Run time (days)	160	158
Radiation (fully interactive)	CAM version 3.0 Collins et al. (2006)	NASA/Goddard Chou (1990), Chou and Suarez (1994)
Microphysics	Original SAM single-moment Khairoutdinov and Randall (2003)	Warm-rain Kessler scheme Kessler (1969), Ice Lin scheme Lin et al. (1983)
Subgrid-scale mixing	First-order Smagorinsky	First-order Smagorinsky
Surface fluxes (Fully interactive)	Monin Obukhov similarity	Monin Obukhov similarity

Same initial conditions
(same profile of Temperature, humidity and pressure);

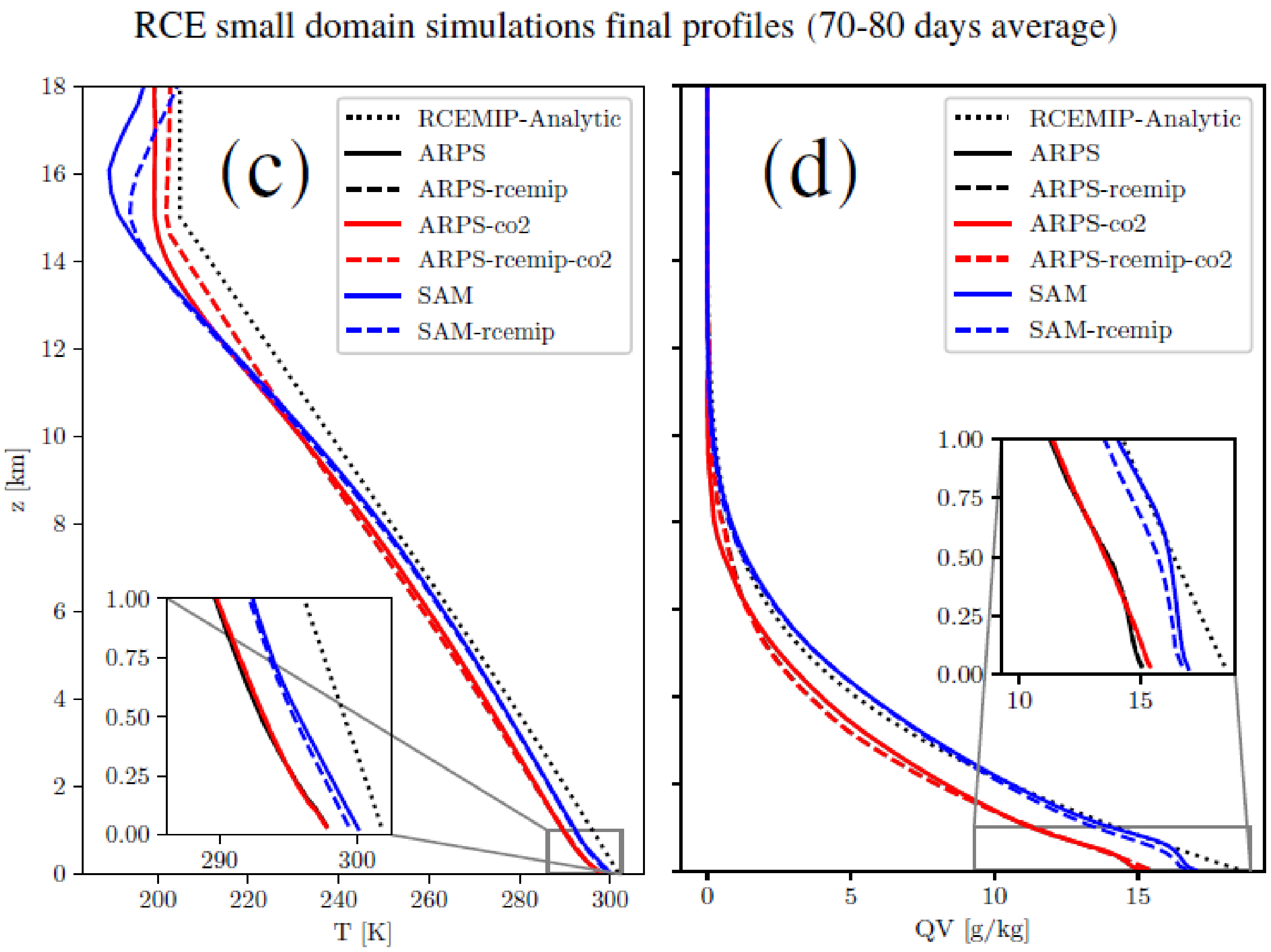
Same turbulence physics and different radiation and microphysics schemes;

Domain: 1152 km^2
Grid size: 3 km
SST 302 K

Numerical setup and Initialization

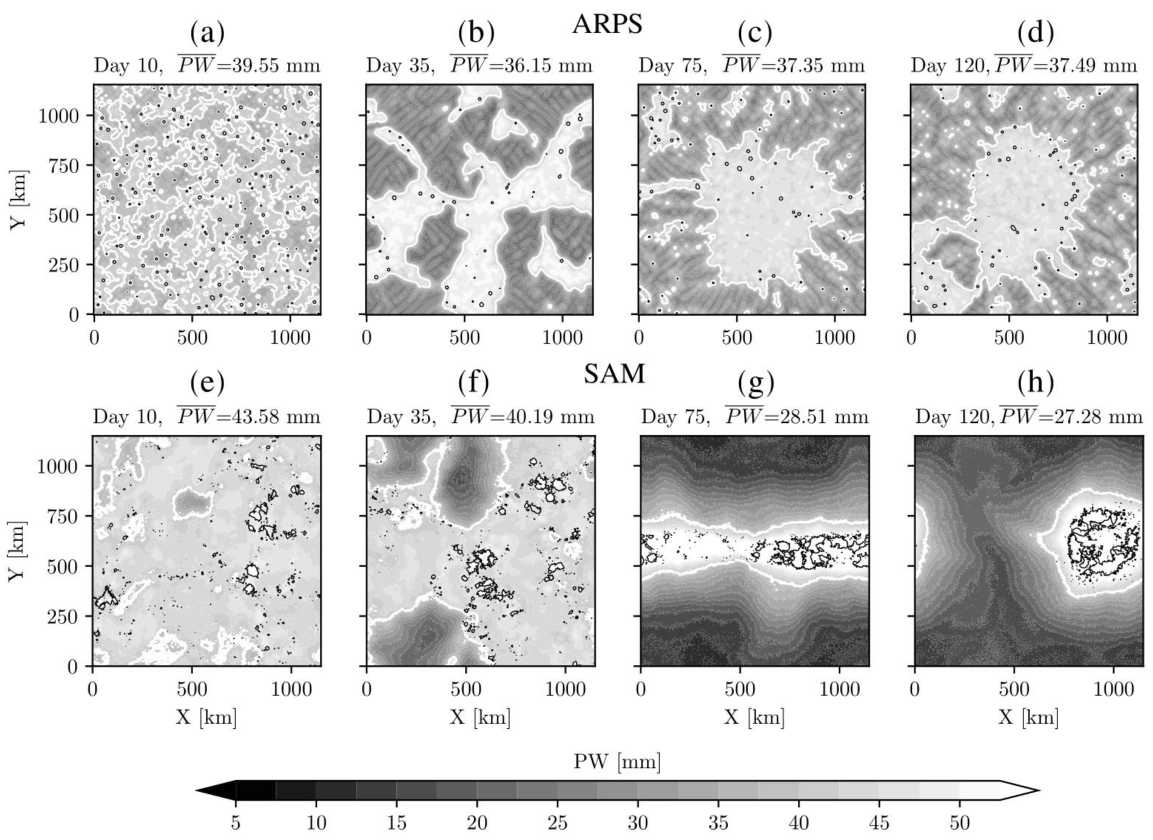
The initial conditions of ARPS and SAM large simulations correspond to the **final equilibrium states of small domain RCE simulations**

The Initial state of ARPS **is colder and drier than the initial state of** SAM

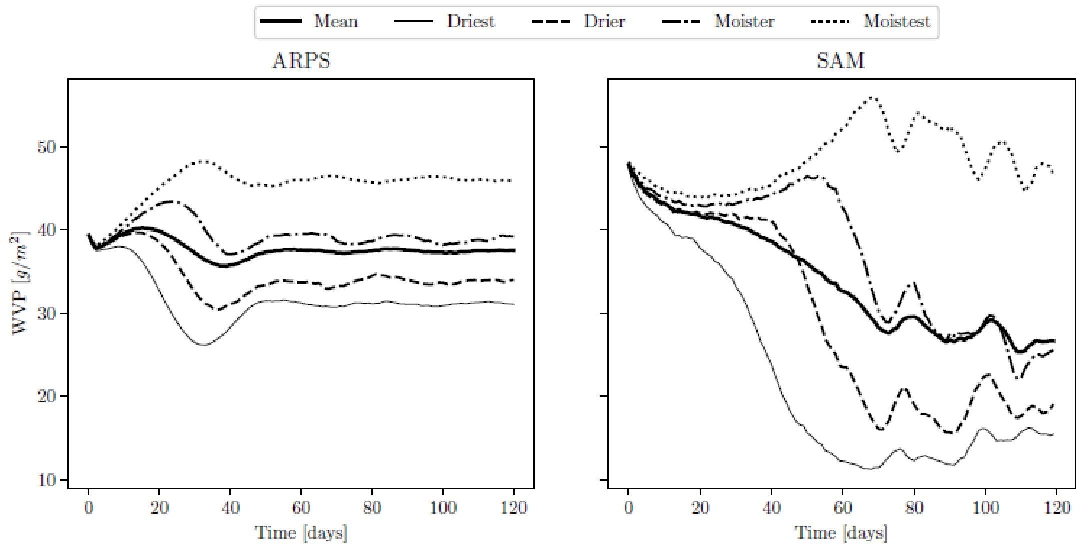


Statistics of Convective Organization

Time evolution of Precipitable Water



Moisture-sorted time series of the daily averaged Water Vapor Path



In both models the **convection spontaneuosly organizes**. However, it happens with different timing and **SAM final state is warmer, drier than the ARPS one**

Statistics of Convective Organization

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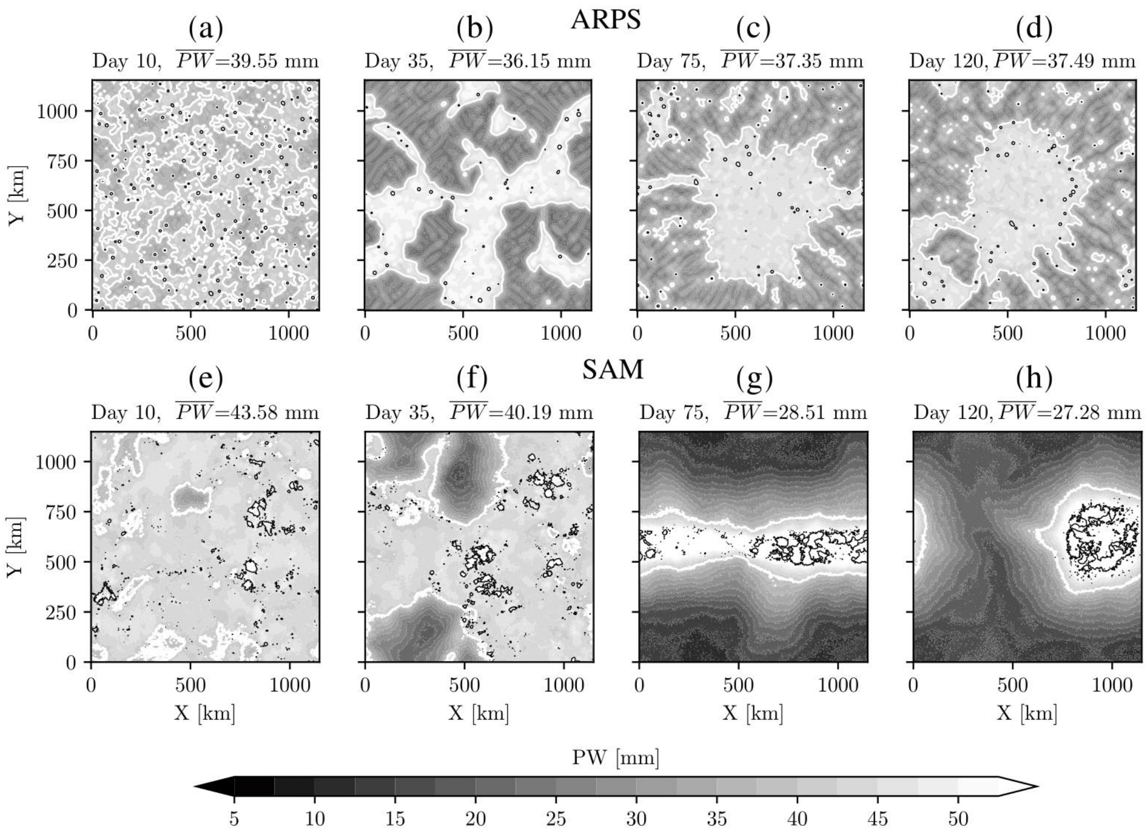

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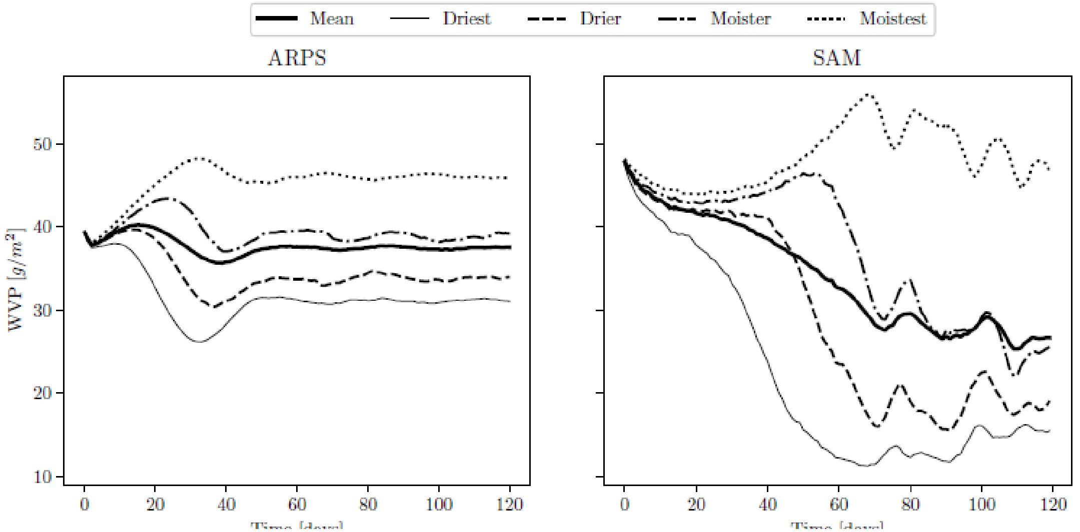
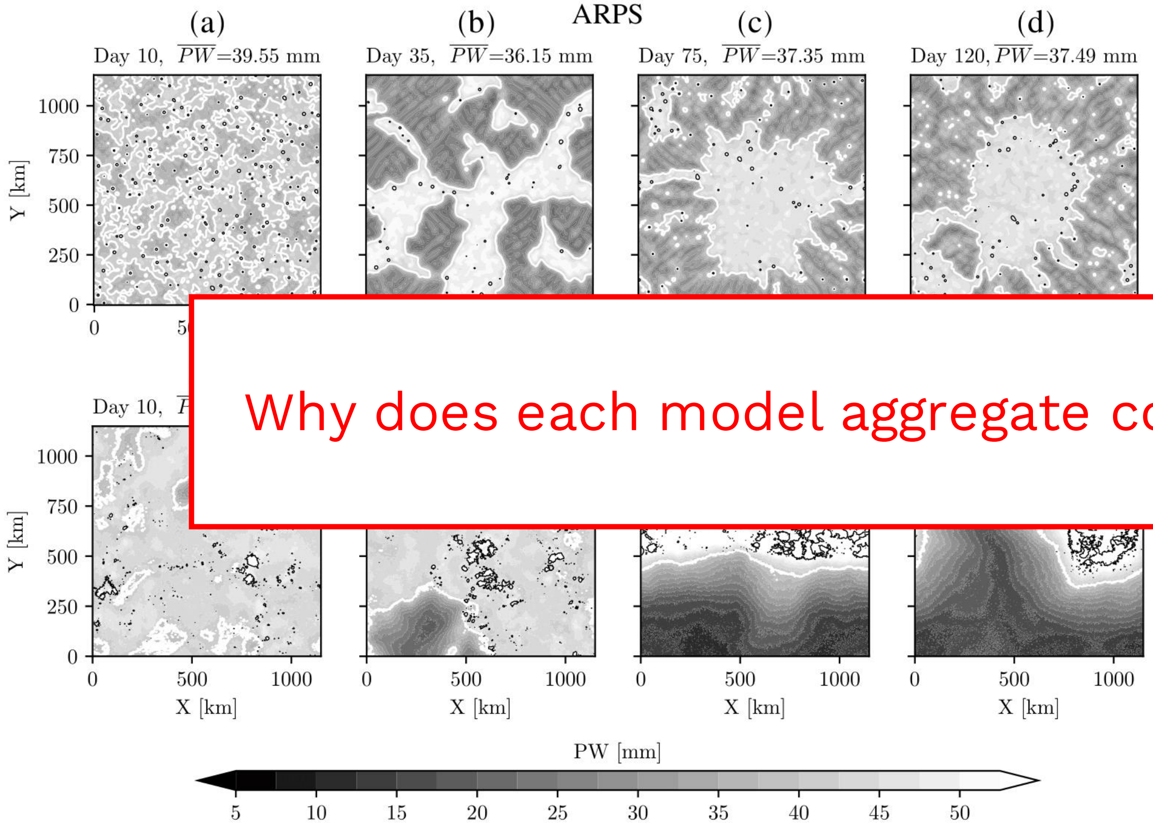


Var	Unit	SAM	ARPS
Iorg	– (Tompkins & Semie, 2017)	0.9	0.6
σ^2_{CRH}	– (Coppin & Bony, 2015)	0.04	0.02
f_{sub}	– (Wing & Cronin, 2016)	0.74	0.66

SAM final state is more oganized than ARPS final state

Statistics of Convective Organization

Time evolution of Precipitable Water



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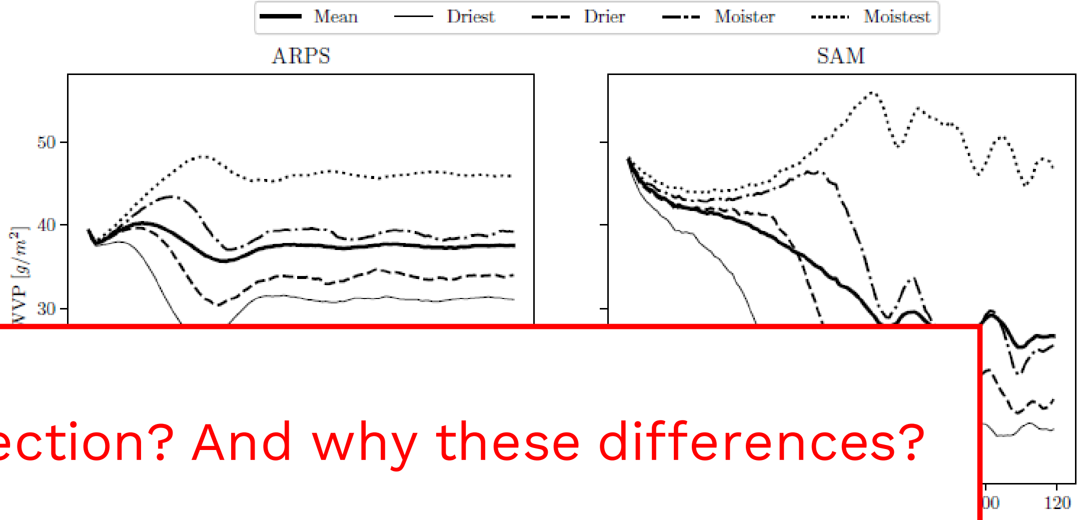

Why does each model aggregate convection? And why these differences?

SAM final state is more oganized than ARPS final state

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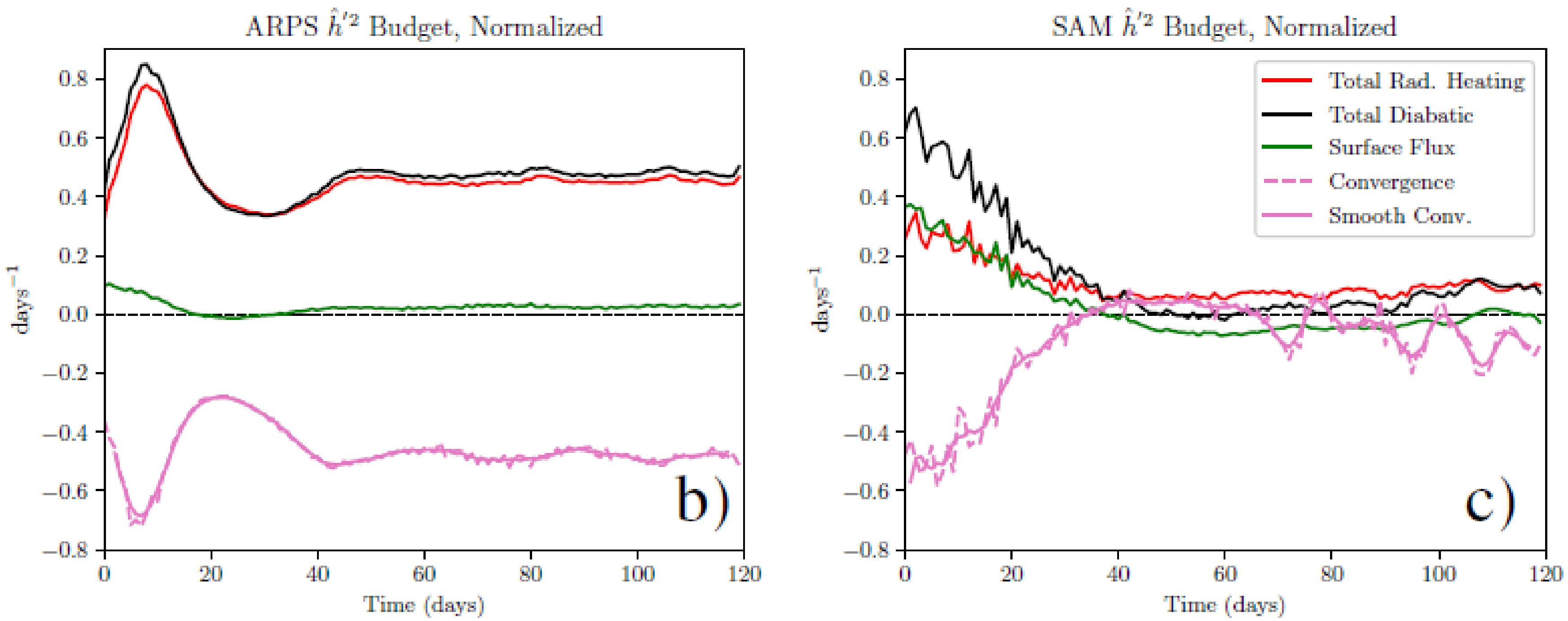
Cloud Properties and Organization Feedback

Convective organization in both models is characterized **by the by the increase of the <u>spatial variance of the vertically integrated Frozen Moist Static Energy (FMSE).</u>** In order to quantify the feedback mechanisms leading to such an increase we compute the budget of the FMSE (Wing and Emanuel (2014))

$$\frac{1}{2}\frac{\partial \widehat{h}'^2}{\partial t} = THF'\widehat{h}' + RAD'\widehat{h}' - \widehat{h}'\nabla_h \cdot \widehat{\vec{\mathbf{u}}h}$$



Time evolution of the domain mean terms in the FMSE budget, each normalized by {h′2}, with units of day−1, for ARPS and SAM, respectively.

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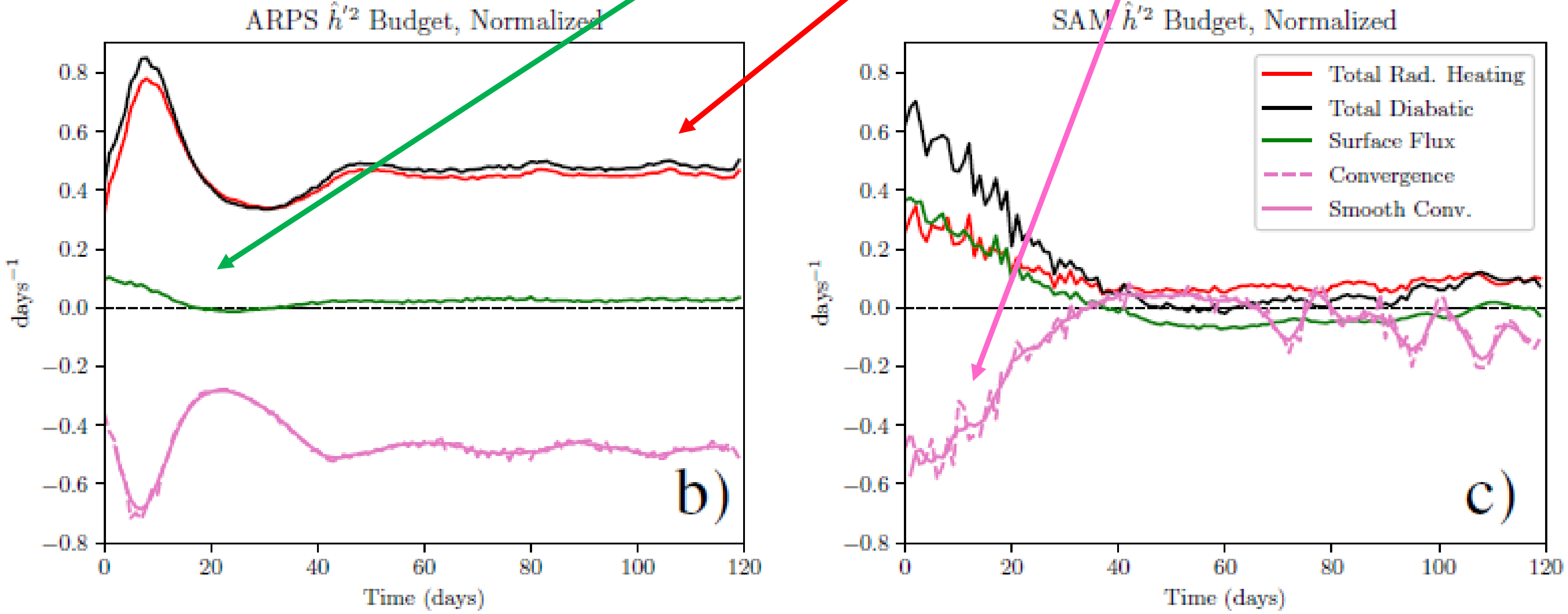

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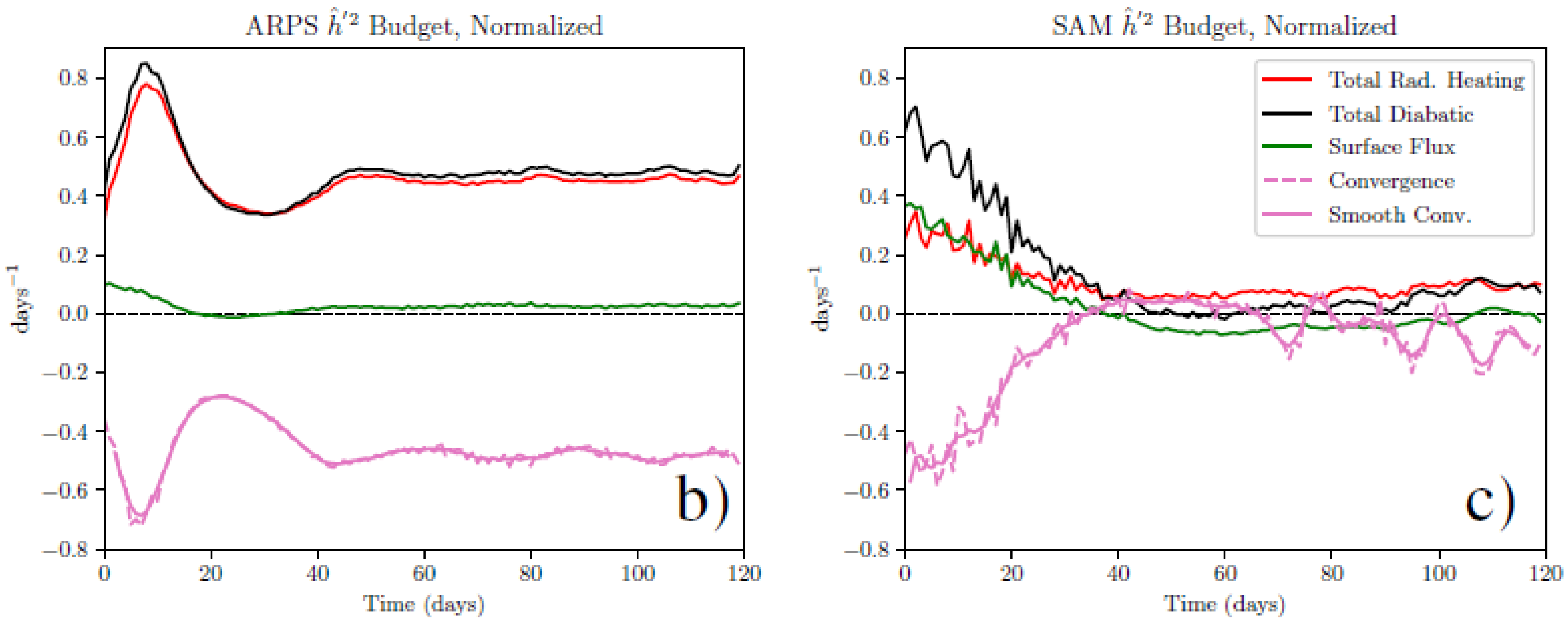

In SAM for the first 40 days, the **total diabatic term** (**surface fluxes** and **radiative fluxes** (shortwave and longwave)) contributes to organization;

Cloud Properties and Organization Feedback

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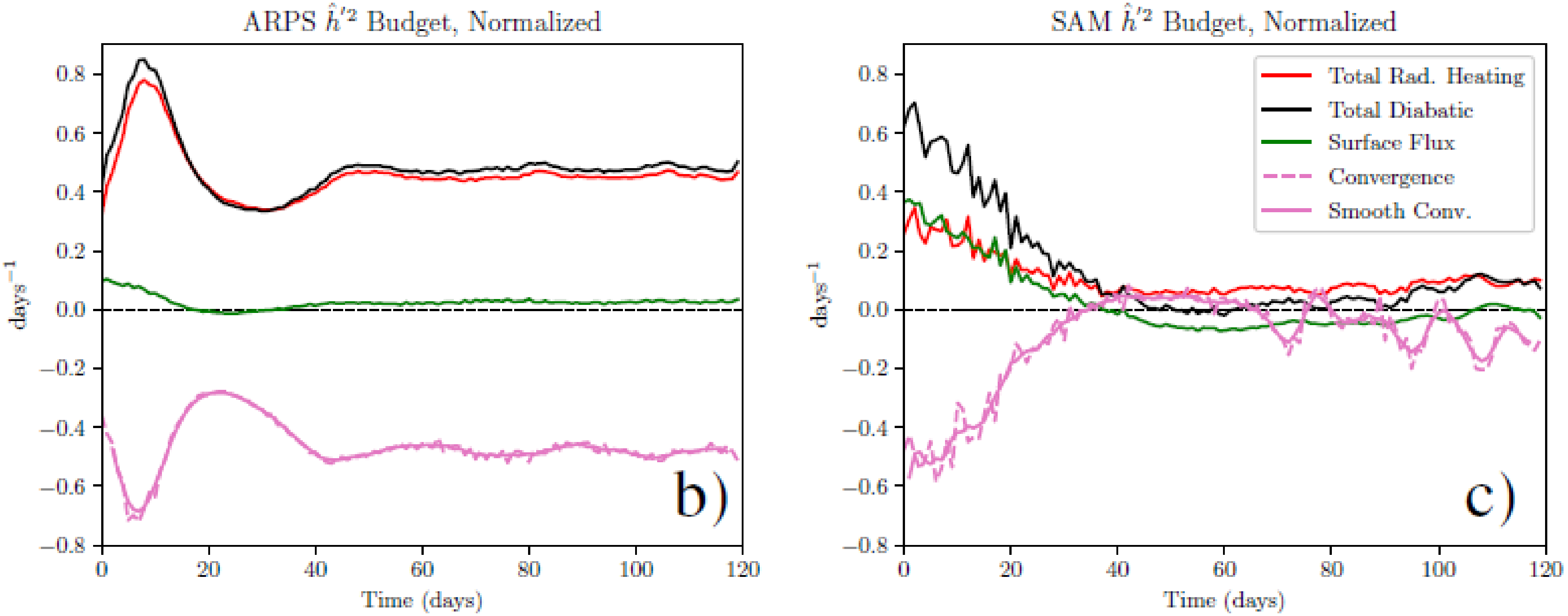

Then in SAM, after the 40th day, the **convergence** acts as the main source of organization maintenance, when the total diabatic term tends toward zero

Cloud Properties and Organization Feedback

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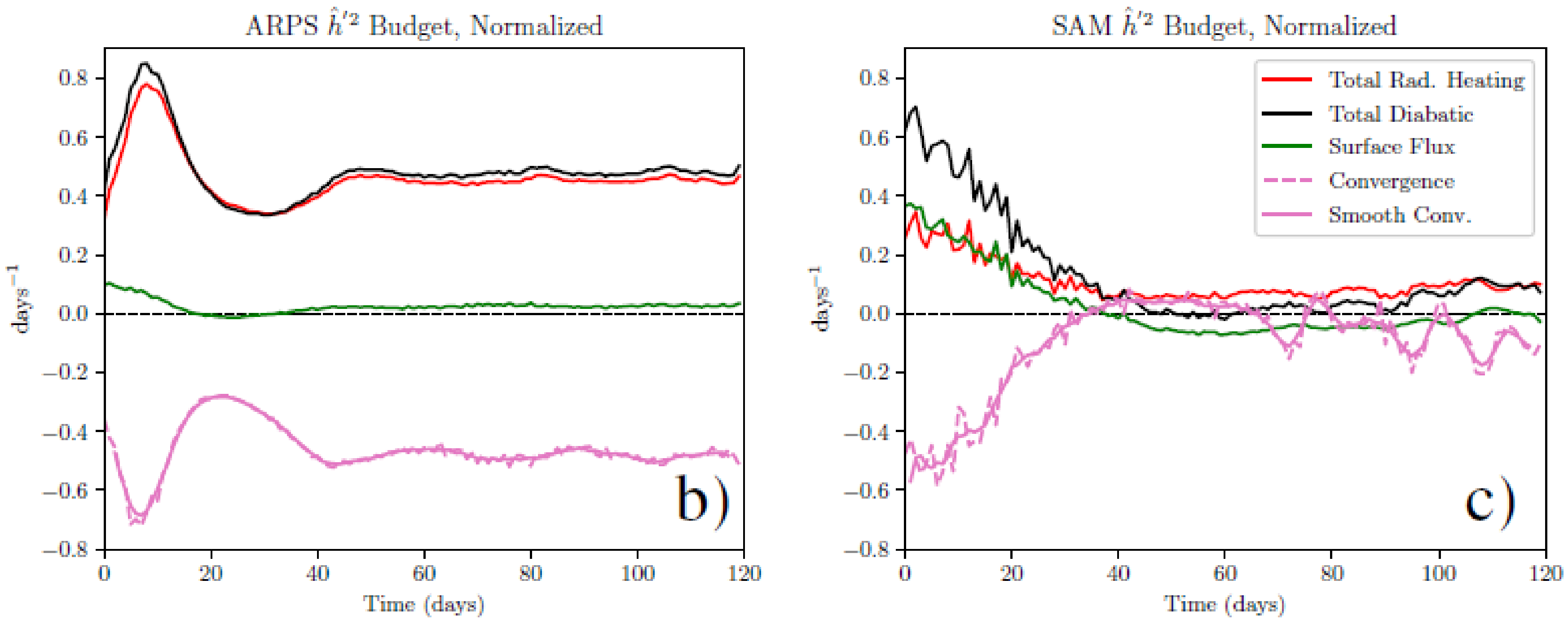
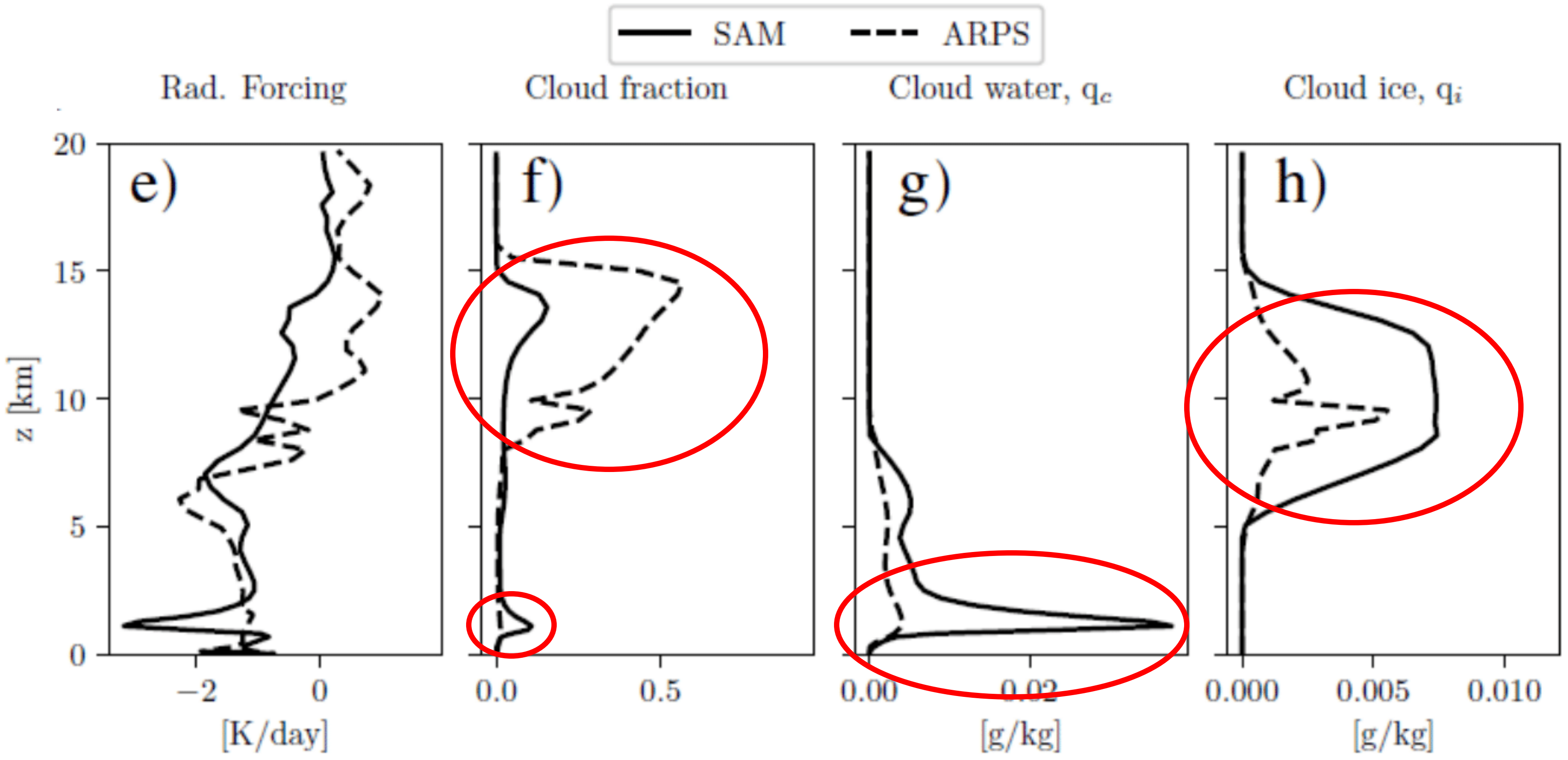


In ARPS the **total diabatic term** is always highly positive, with the **radiative heating** being dominant on the surface fluxes. The **convergence** term is always negative.

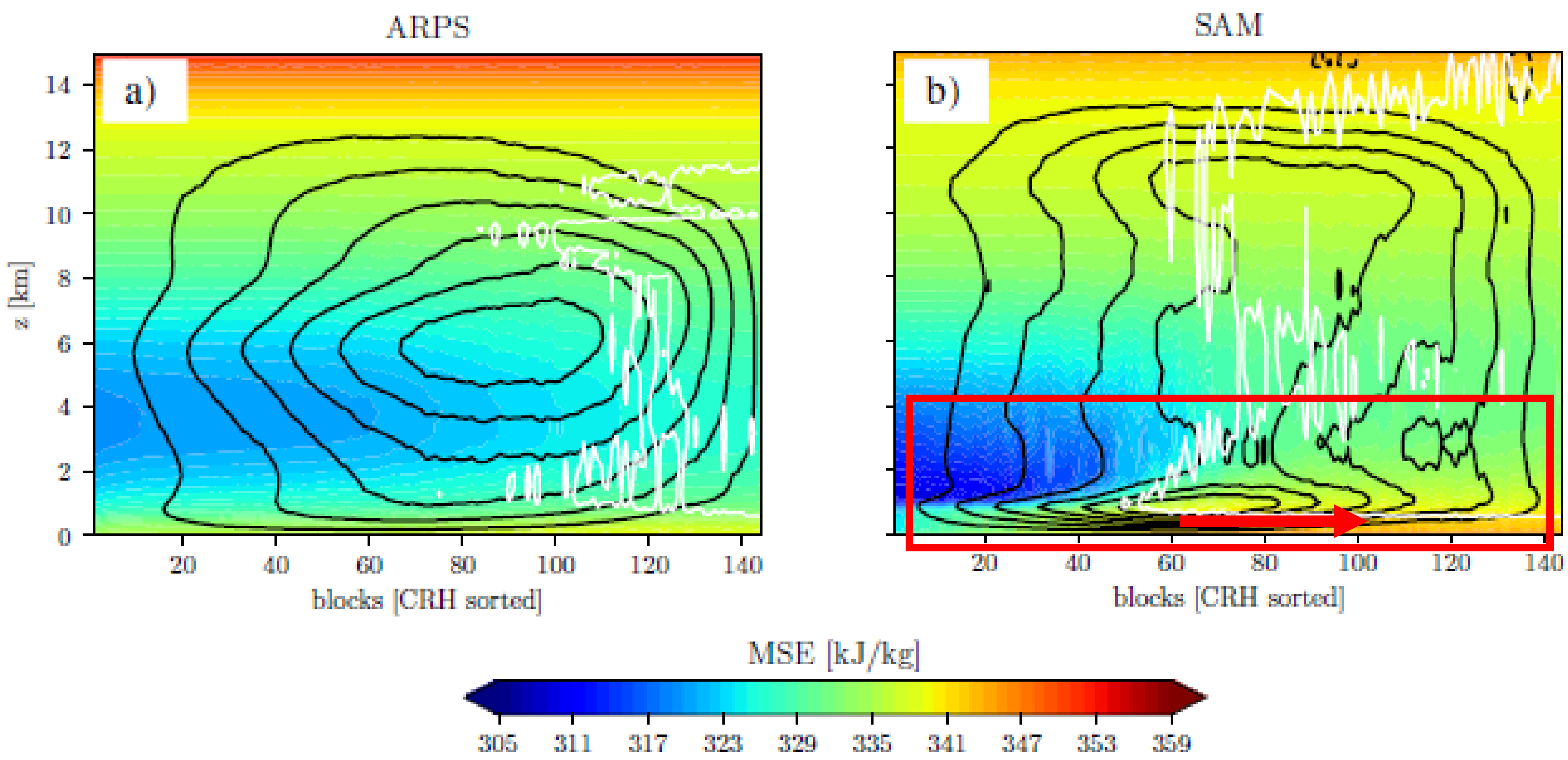
Cloud Properties and Organization Feedback

Cloud Properties at Equilibrium



- In SAM the presence **thick layer of shallow clouds** has developed linked to the indirect longwave feedback
- In ARPS presence of thick **high icy anvil clouds** linked to the positive longwave feedback

Cloud Properties and Organization Feedback



CRH sorted columns values of FMSE and stream function Ψ (Bretherton et al., 2005), derived as the horizontal integral over vertical velocity

- In SAM the longwave radiation exerts an indirect feedback, where the **longwave cooling in dry regions** generates a **shallow circulation between dry and moist regions** (**positive convergence term**)
- In ARPS the circulation is less bottom-heavy and **this never happens**

The role of Cold Pools

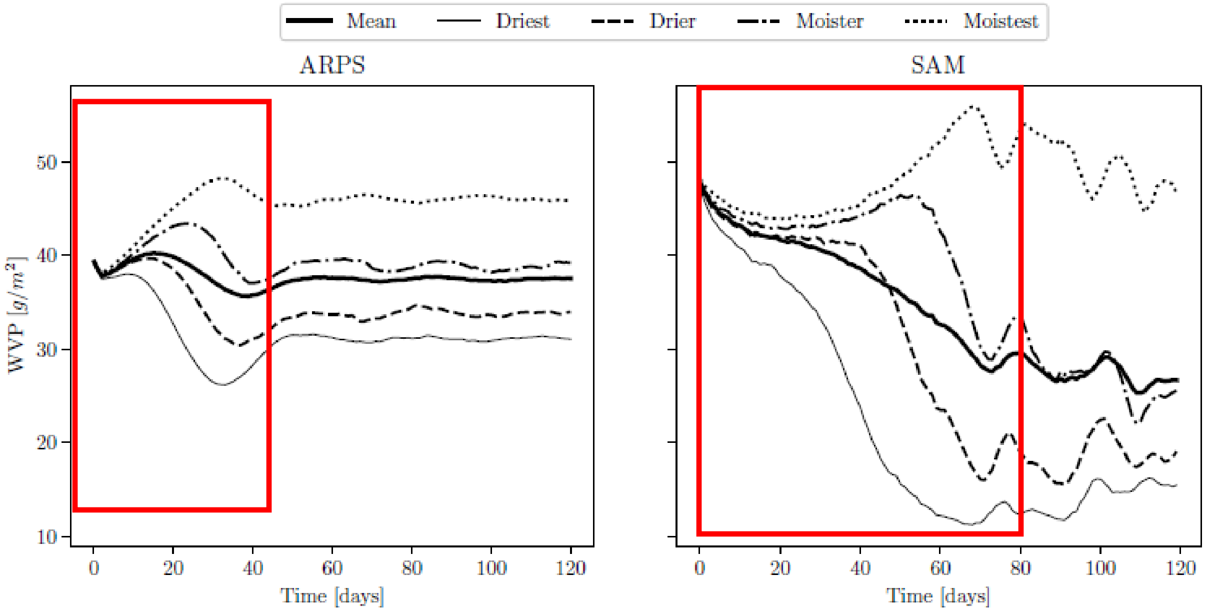
ARPS presents a faster aggregation process compared to SAM

⇩

faster aggregation is found by suppressing rain evaporation

⇩

Therefore, weakening evaporation-driven downdraft and cold pools



The role of Cold Pools

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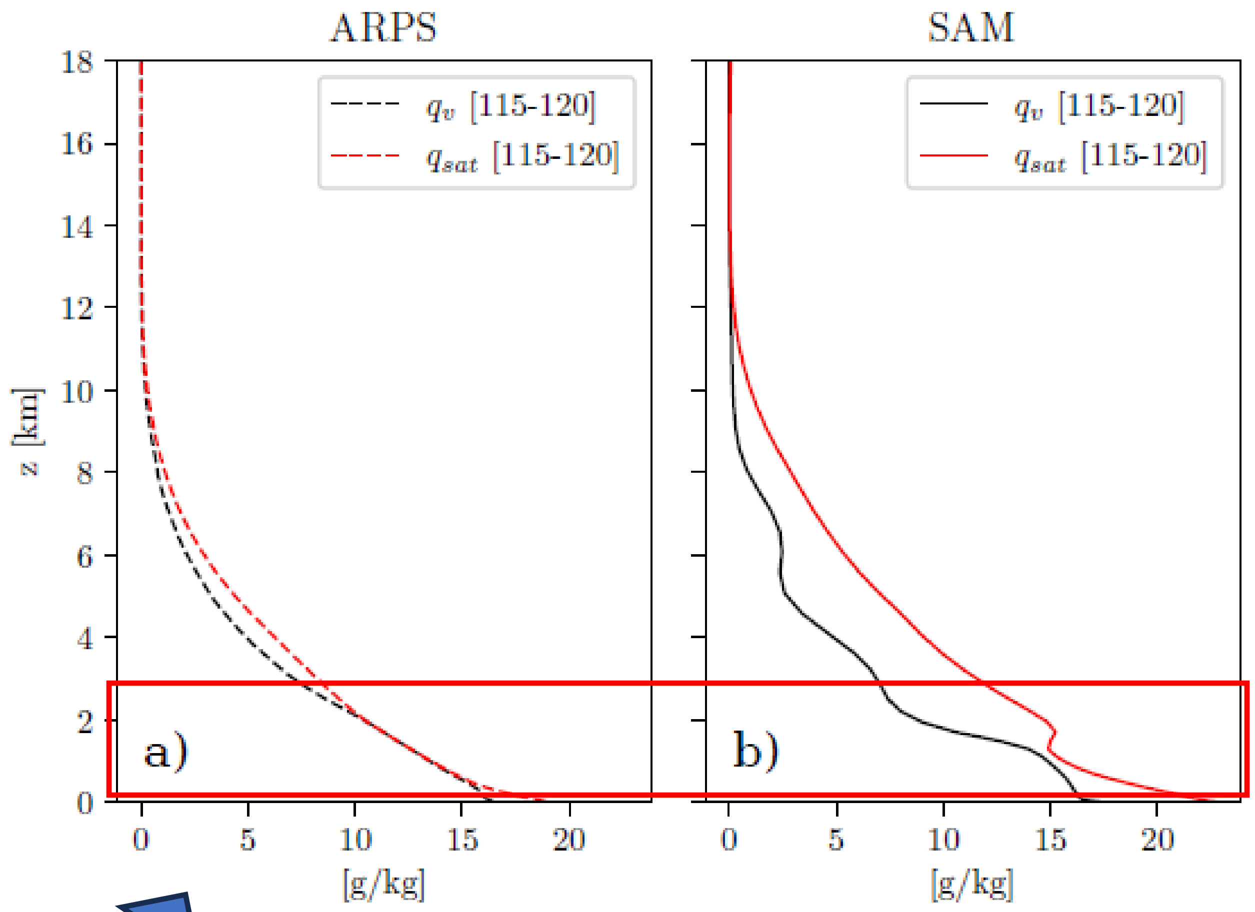
This may occur when the sub-cloud layer is nearly saturated and rain cannot evaporate (Wing et al., 2017).

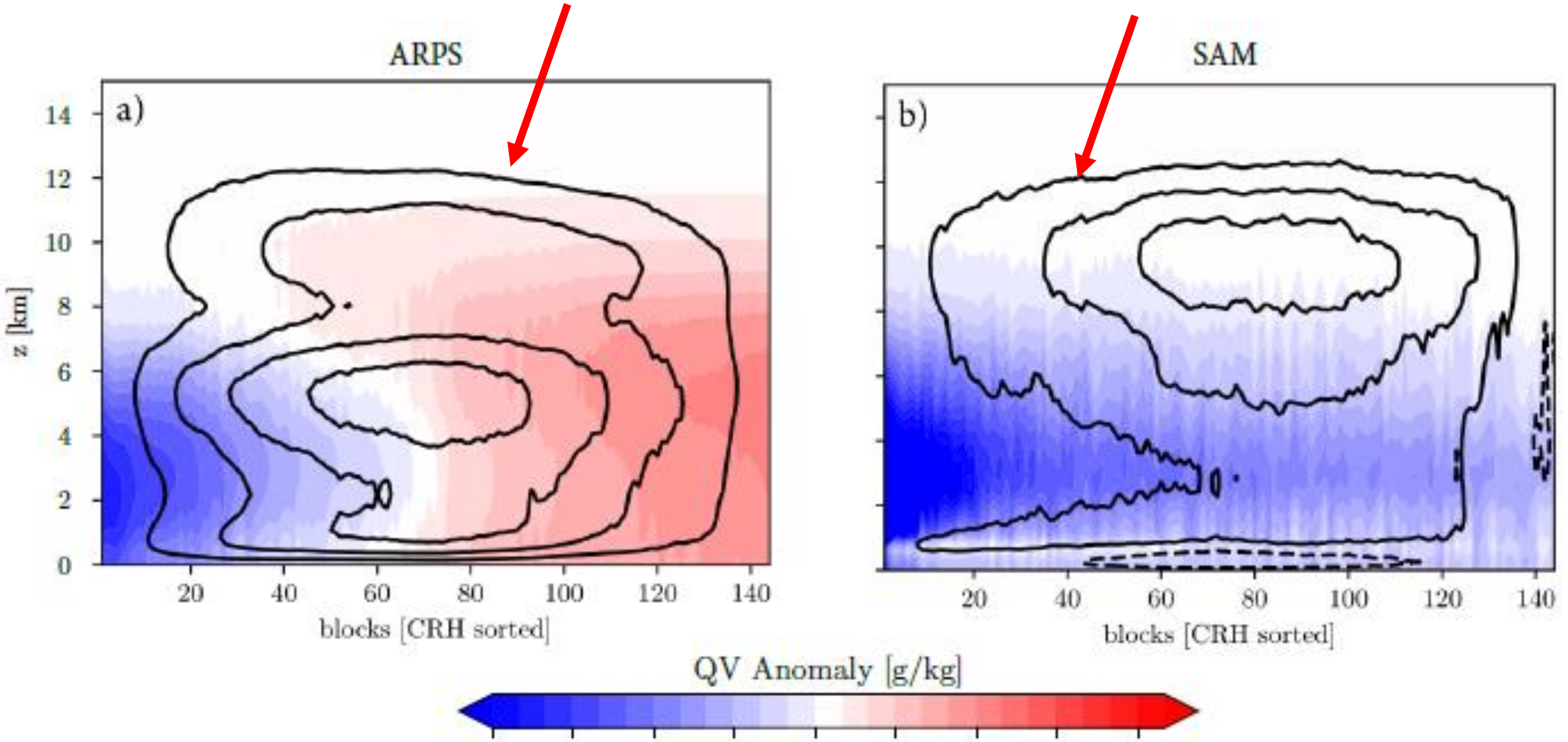


Vertical profiles of saturation water vapor mixing ratio (q_{sat}) and water vapor mixing ratio (q_v) over cloudy grid points

The role of Cold Pools

Cold pools slow down the organization process by increasing low-level mixing between moist and dry regions (Jeevanjee & Romps, 2013)

convection remains active in the same moist regions throughout the simulation



Specific humidity (qv) anomaly from the initial day of simulation (qv_0) (days 20-25)

"Moisture memory aggregation" and localization of convection in ARPS compared to SAM

Mechanism behind Organization

ARPS

larger anvil and the presence of many dry regions

strong differential heating between moist and dry zones

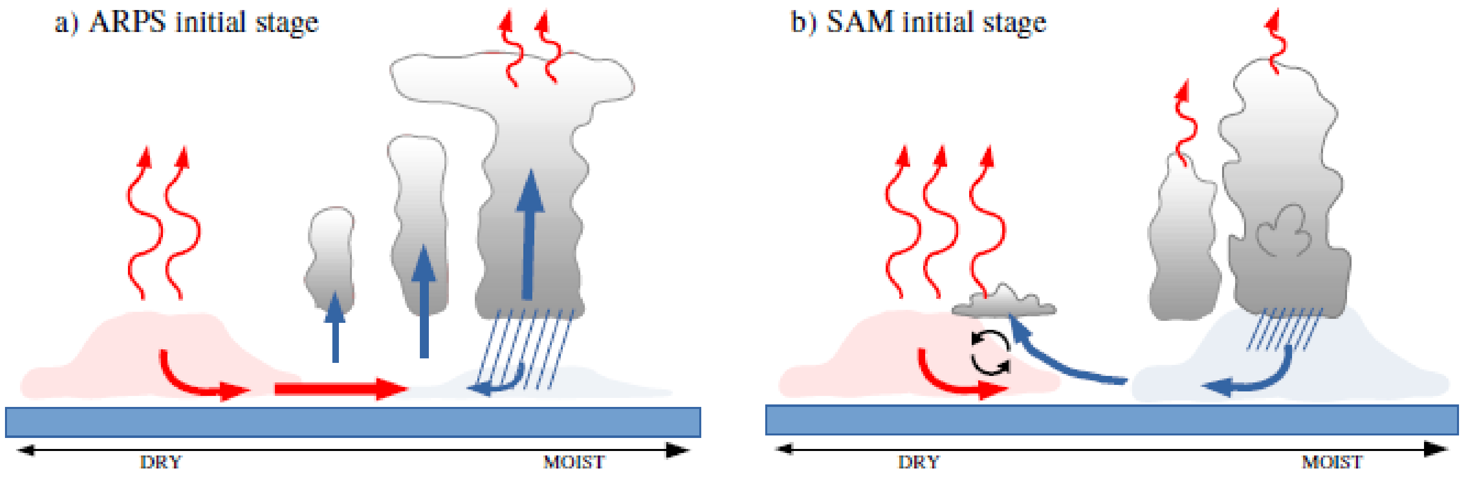
weaker cold pools are not able to transport moisture inside the dry region

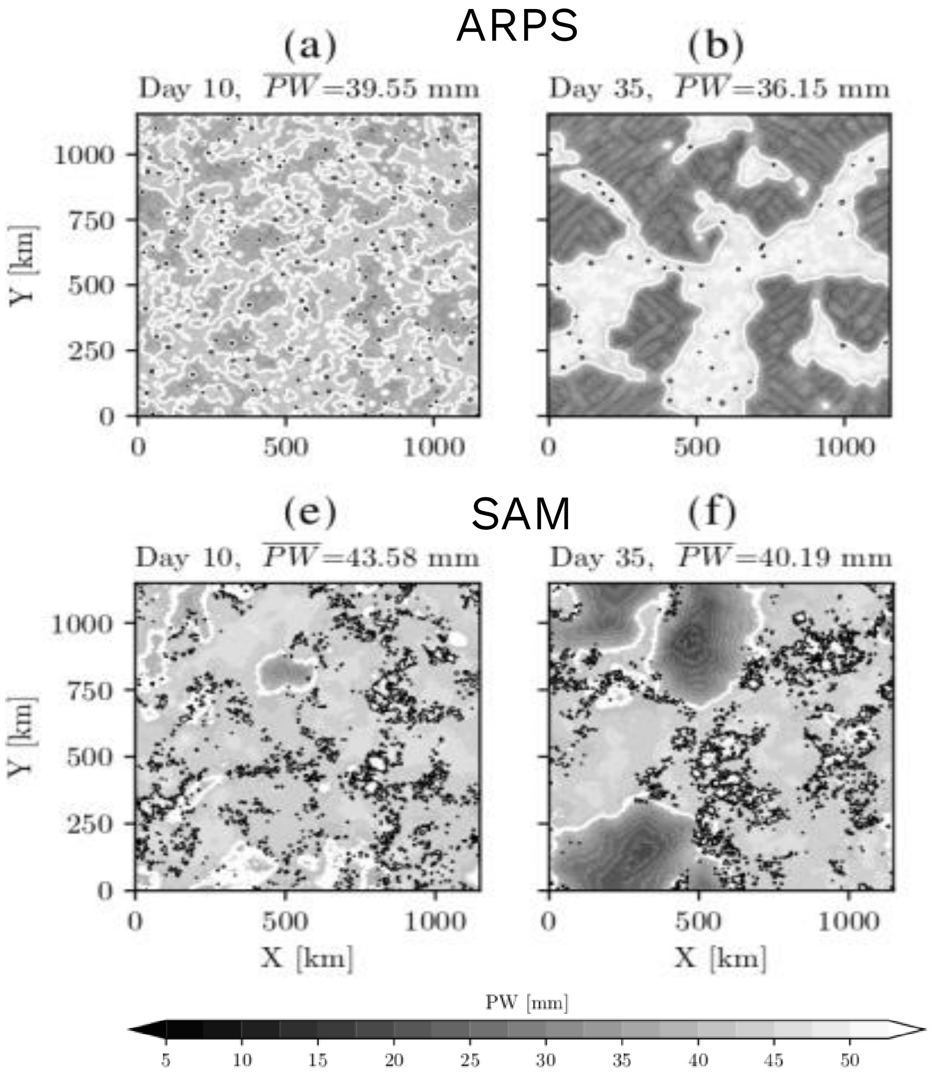
SAM

stronger cold pools are able to transport moisture inside the dry regions

moisten the boundary layer by low-level mixing

create shallow clouds in the dry regions





Mechanism behind Organization

ARPS

moist zones get saturated due to weaker low-level mixing of the BL

evaporatively-driven cold pools are switched off

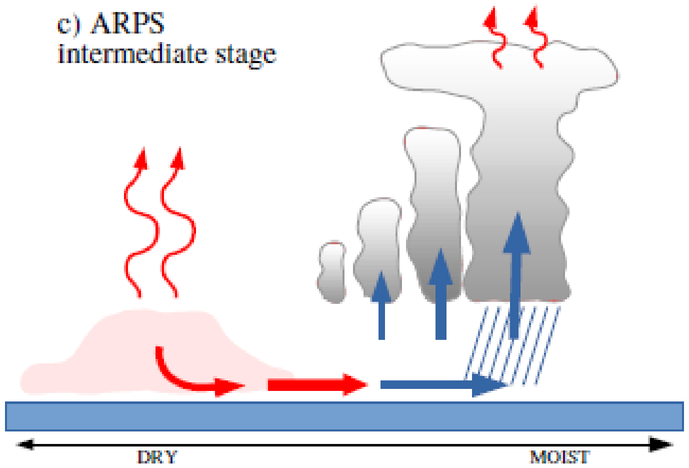
direct longwave feedback maintains the moist (dry) region moister (drier)

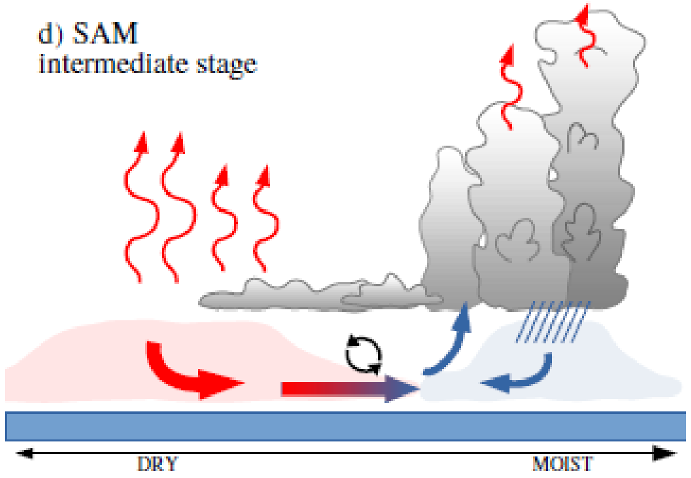
SAM

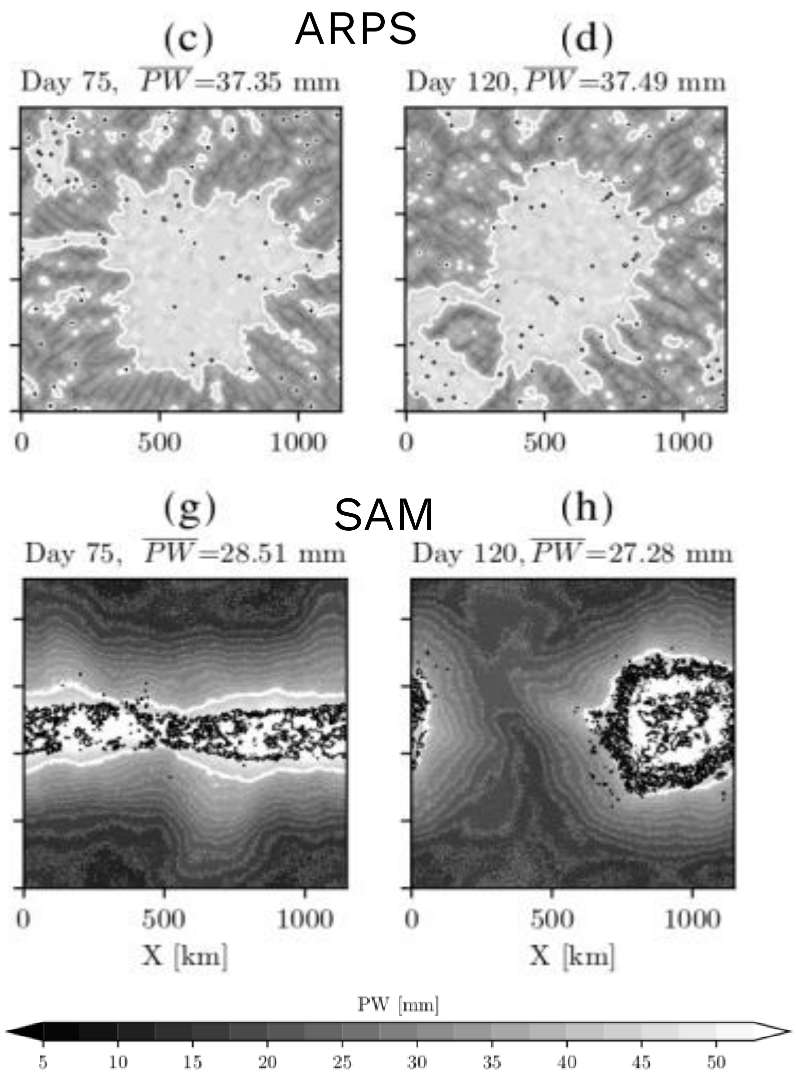
radiatively-driven cold pools have become strong

high MSE stored at the boundary of the dry regions, **is transported into the moist regions**

The **up-gradient** MSE **circulation ends** when the **driest region has lost all its water vapor**







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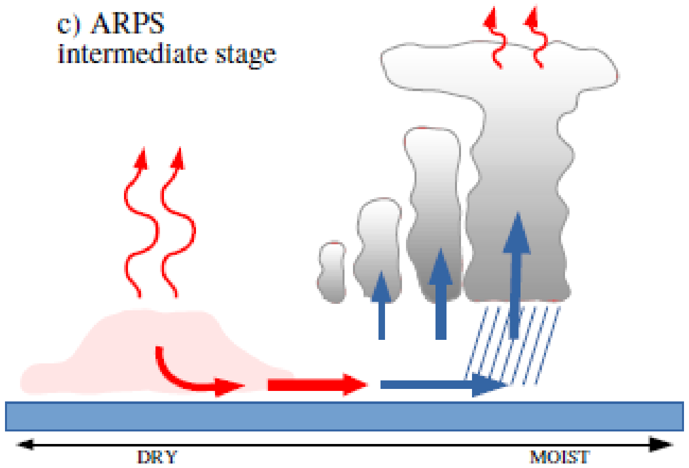

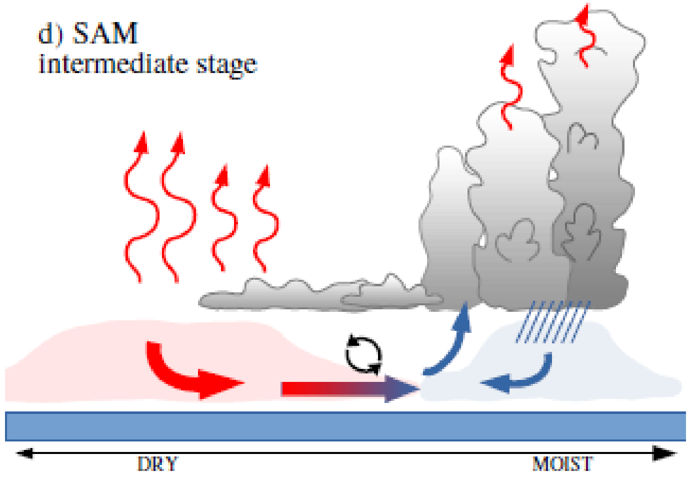

From this point forward (after day 70 in SAM), the expansion (contraction) of moist regions alternates with the contraction (expansion) of dry regions due to **competition between radiatively and evaporatively-driven cold pools.**

Conclusion and Further development

- **A saturated sub-cloud layer is found to spontaneously occur in the radiative-convective equilibrium simulation** of the Advanced Regional Prediction System model;
- **The closer the sub-cloud layer to saturation, the lower the degree of aggregation and the weaker its effect on the average domain statistics**;
- The appearance of an **up-gradient moist static energy circulation which expand dry regions needs a strong cold pool effect** to generate low clouds;
- **There is a chance that this effect, found in these two models, could be found also in other CRMs,** so we will proceed with the analysis of other RCEMIP models;

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Many Thanks for your Attention!

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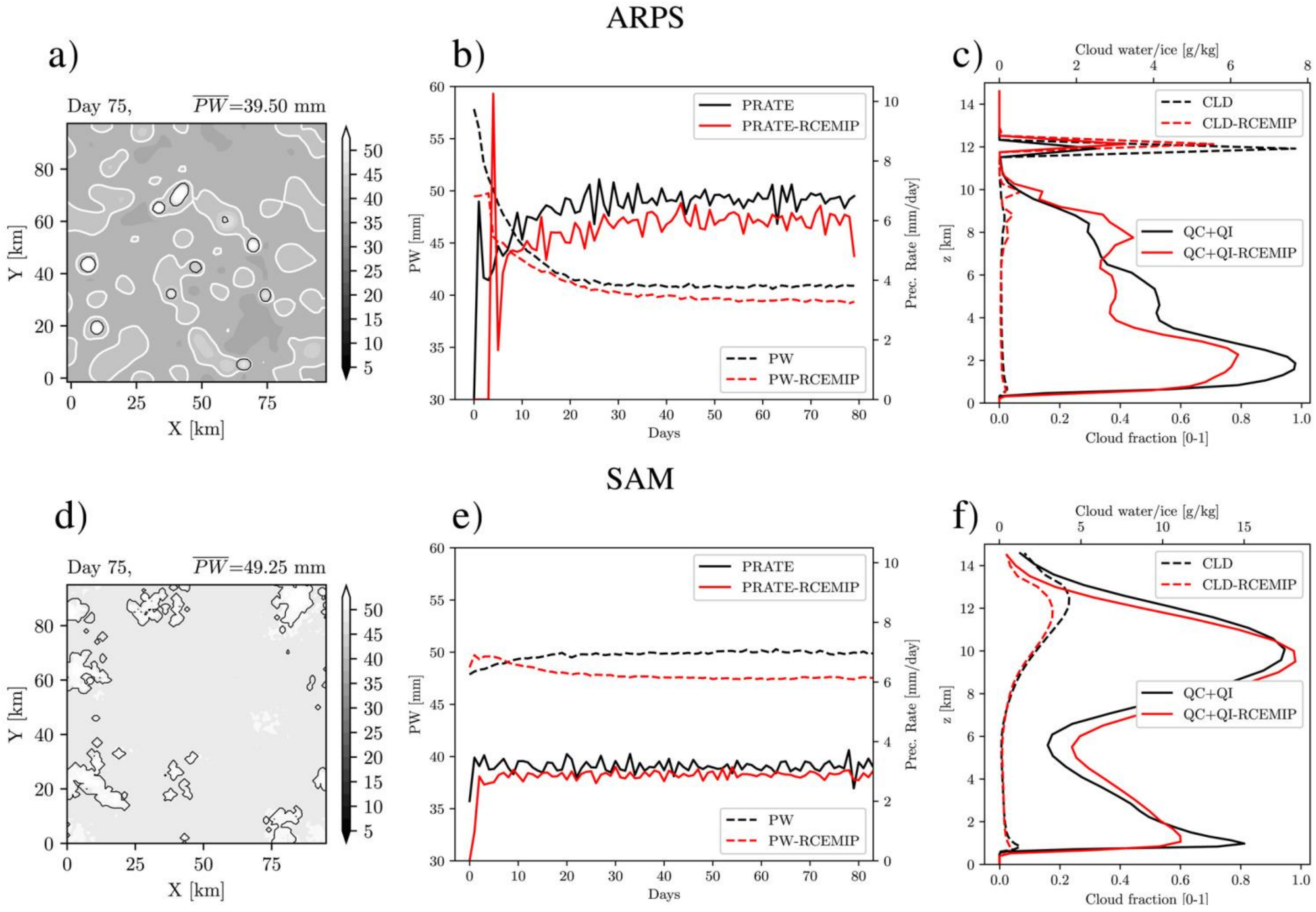
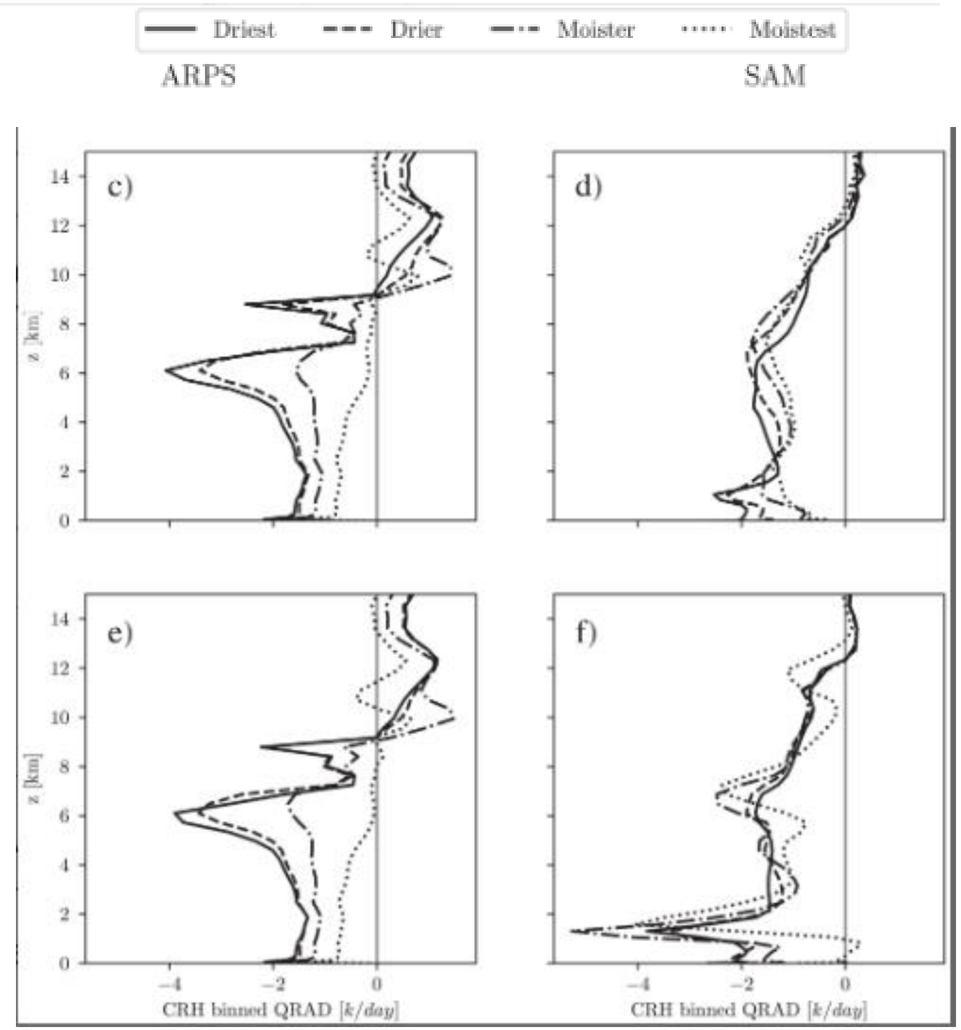
First published: 23 January 2023 | https://doi.org/10.1029/2022MS003323

Small domain simulations



In ARPS after a few days of simulation, the small domain is entirely covered by a very thin anvil cloud which remains there until the end of the simulation

Cooling and heating

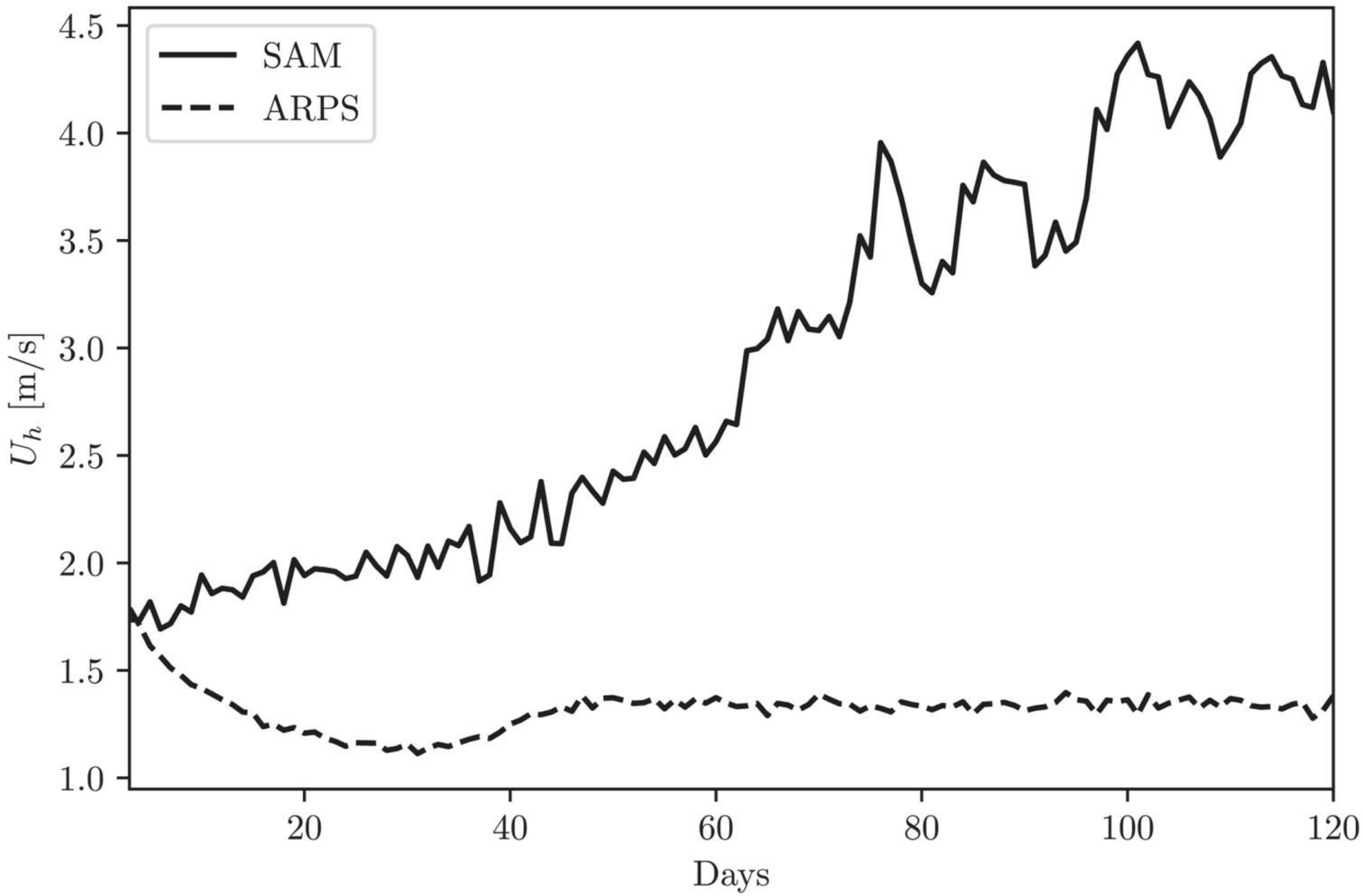


Differences in Cooling and heating of the middle and upper troposphere:

ARPS -> warming inside moist columns and cooling in the dry columns

SAM -> low level cooling in the dry regions

Radiatively driven aggregation?

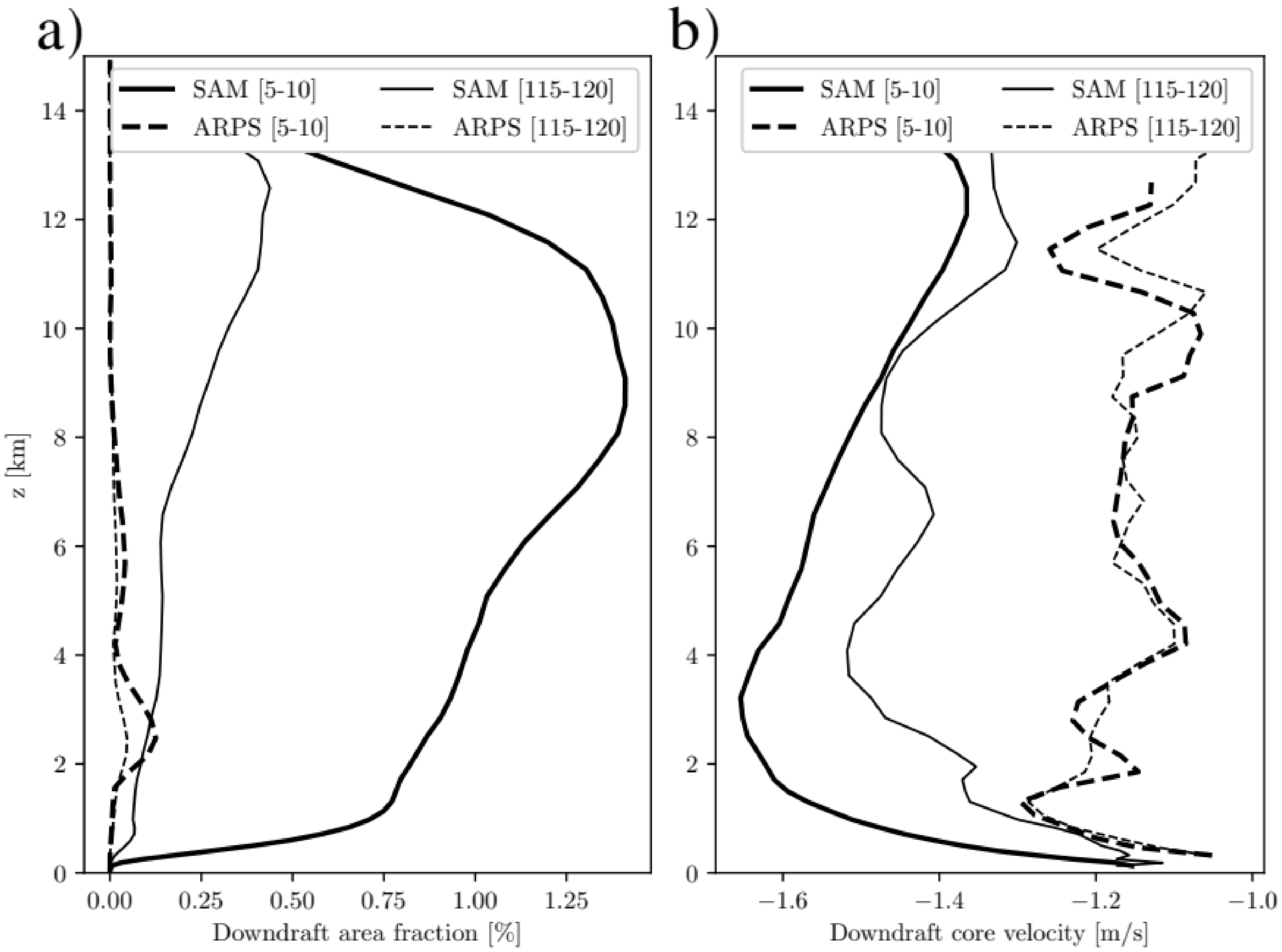


Differences in bottom layer wind speed at the boundary between the moist and the dry regions (Windmiller & Craig (2019)):

ARPS -> almost constant

SAM -> increases in time

Downdrafts area fraction and core velocity



The saturation of the sub-cloud layer in ARPS directly influences the downdrafts properties

ARPS downdrafts are weaker than those in SAM and they cover a smaller fraction of the domain