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Numerical diffusion and turbulent mixing in convective self-aggregation

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Centro Interuniversitario di Ricerca
sull'Inquinamento e sull'Ambiente - "Mauro Felli"

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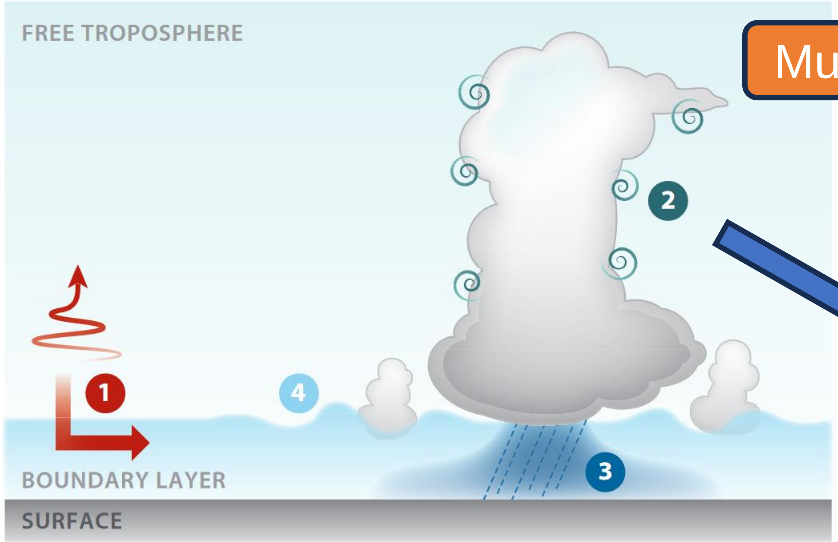
Introduction



Muller et al. 2022

Convective Self-Aggregation

MIXING

Moisture-Convection Feedback
Entrainment at cloud edges

PHYSICAL
(TURBULENT SUBGRID SCALE PARAMETRIZATION)

NUMERICAL
(ARTIFICIAL)

IMPLICIT
(by numerical schemes)

EXPLICIT
(by explicit filters)

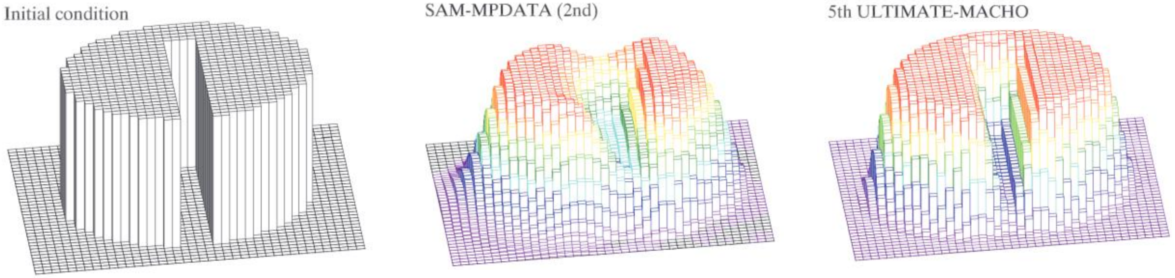
Ex: Smagorinsky model

$$K_h = (C_s l_h)^2 \overline{S}_\beta$$

$$l_h = (\Delta_x \Delta_y)^{1/2}$$

$$S_\beta = max\left[0, \left(\overline{S_{ij}}^2 - \frac{N^2}{Pr}\right)\right]^{1/2}$$

Yamaguchi et al. 2011



Introduction

Greater subgrid-scale mixing

↓

Greater entrainment into updraft cores

↓

Stronger water vapor convection feedback

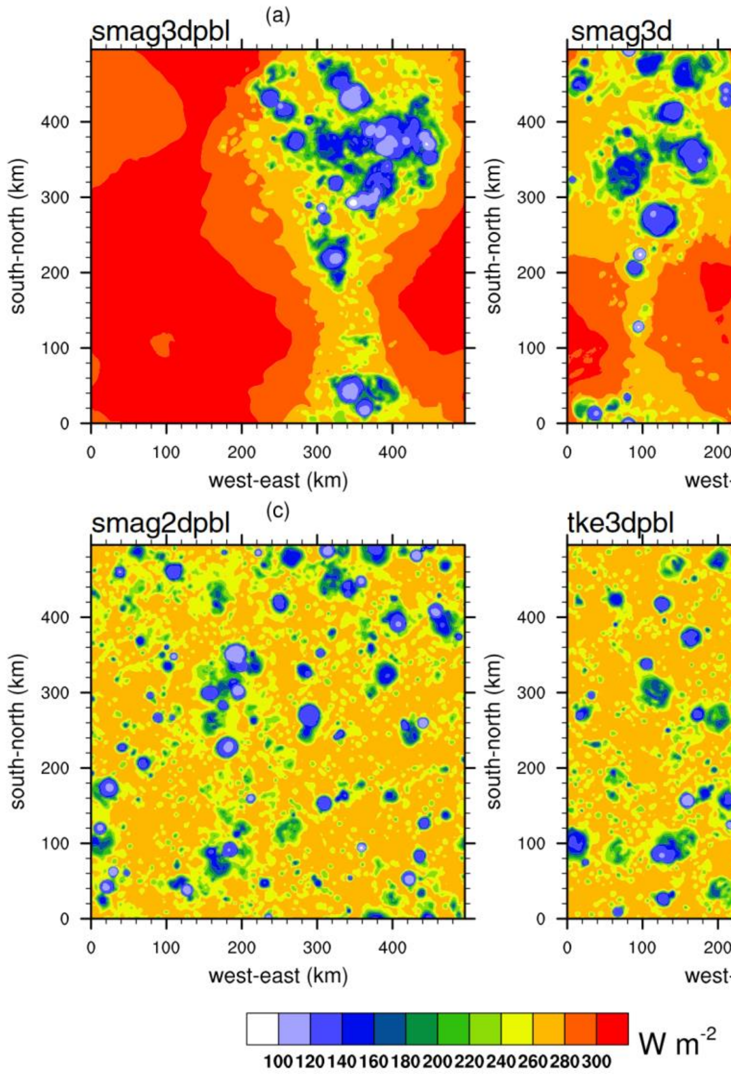
↓

<u>ALLOWING</u>
CSA to occur

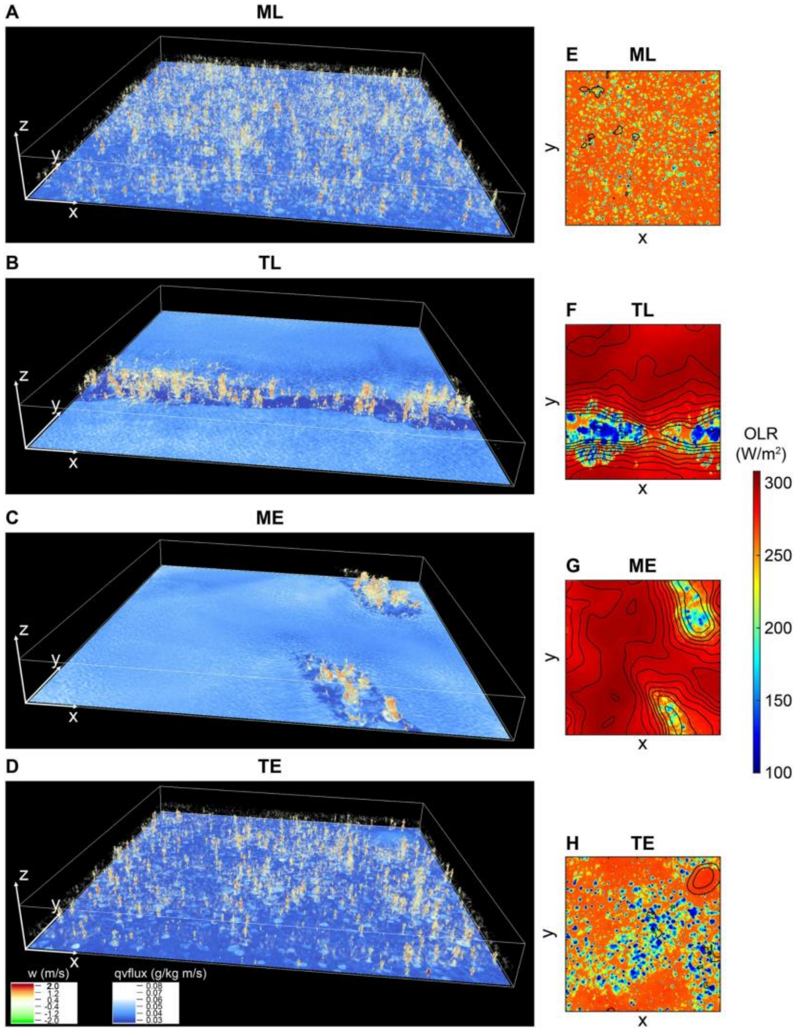
↓

Possible explanation for resolution dependence

WRF model, Tompkins and Semie (2017)

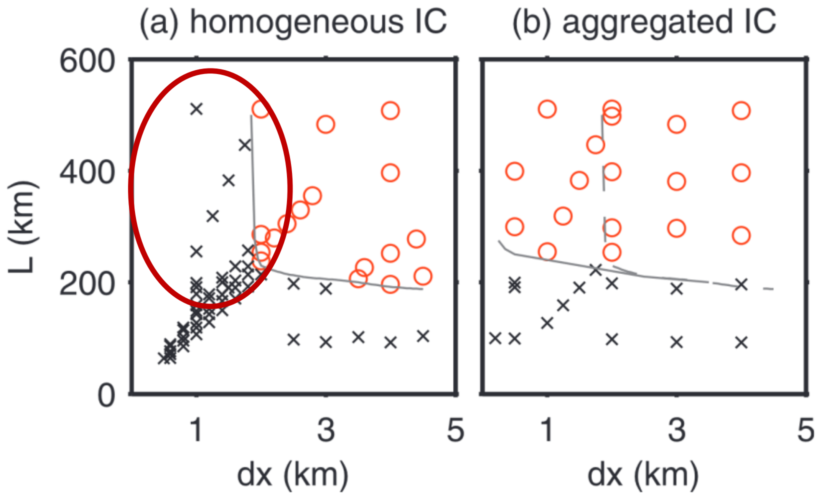


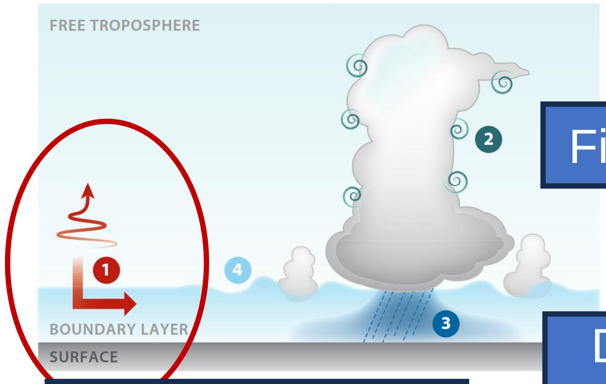
CM1 model, Shi and Fan (2021)



Introduction

SAM model, Muller and Held (2012)



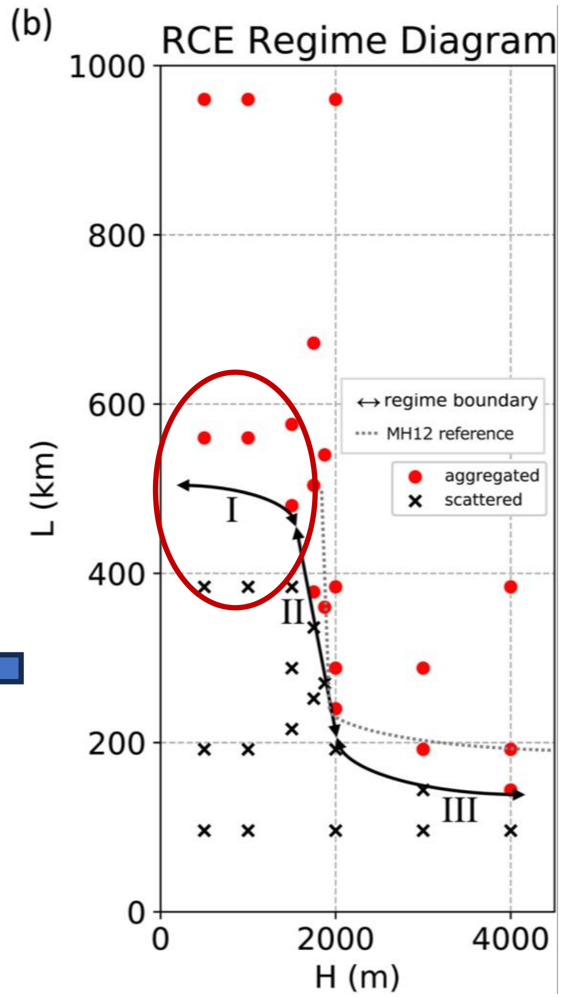


Finer resolution

Decrease low cloud amount

Decreasing Radiative Cooling

SCALE model, Yanase et al. (2020)

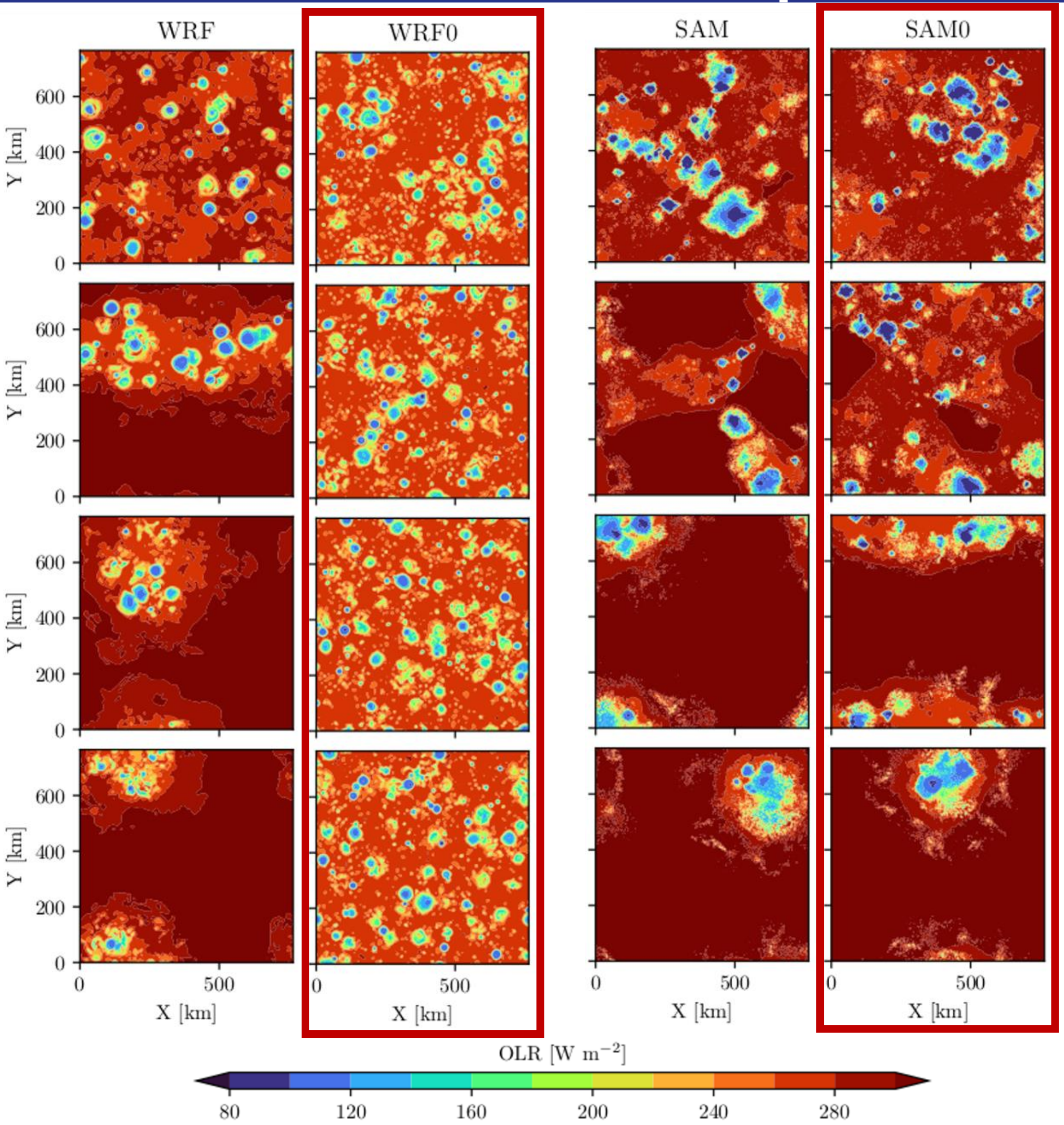


?

Why the role of mixing in CSA seems to be model dependent?

What happen to CSA if we completely switch off turbulent mixing in different models?

Numerical experiment



Physical parametrization

Parametrization	SAM	WRF
Radiation	CAM3 (Collins et al., 2006)	RRTMG (Iacono et al., 2008)
Microphysics	SAM1MOM (Khairoutdinov & Randall, 2003)	Purdue Lin (Chen & Sun, 2002)
Surface layer	Monin-Obukhov similarity	Revised MM5 similarity (Jiménez & Dudhia, 2012)
Subgrid-scale turbulence	3D Smagorinsky	3D Smagorinsky (Smagorinsky, 1963)
PBL	None	Yonsei University, YSU (Hong et al., 2006)

Numerical Schemes

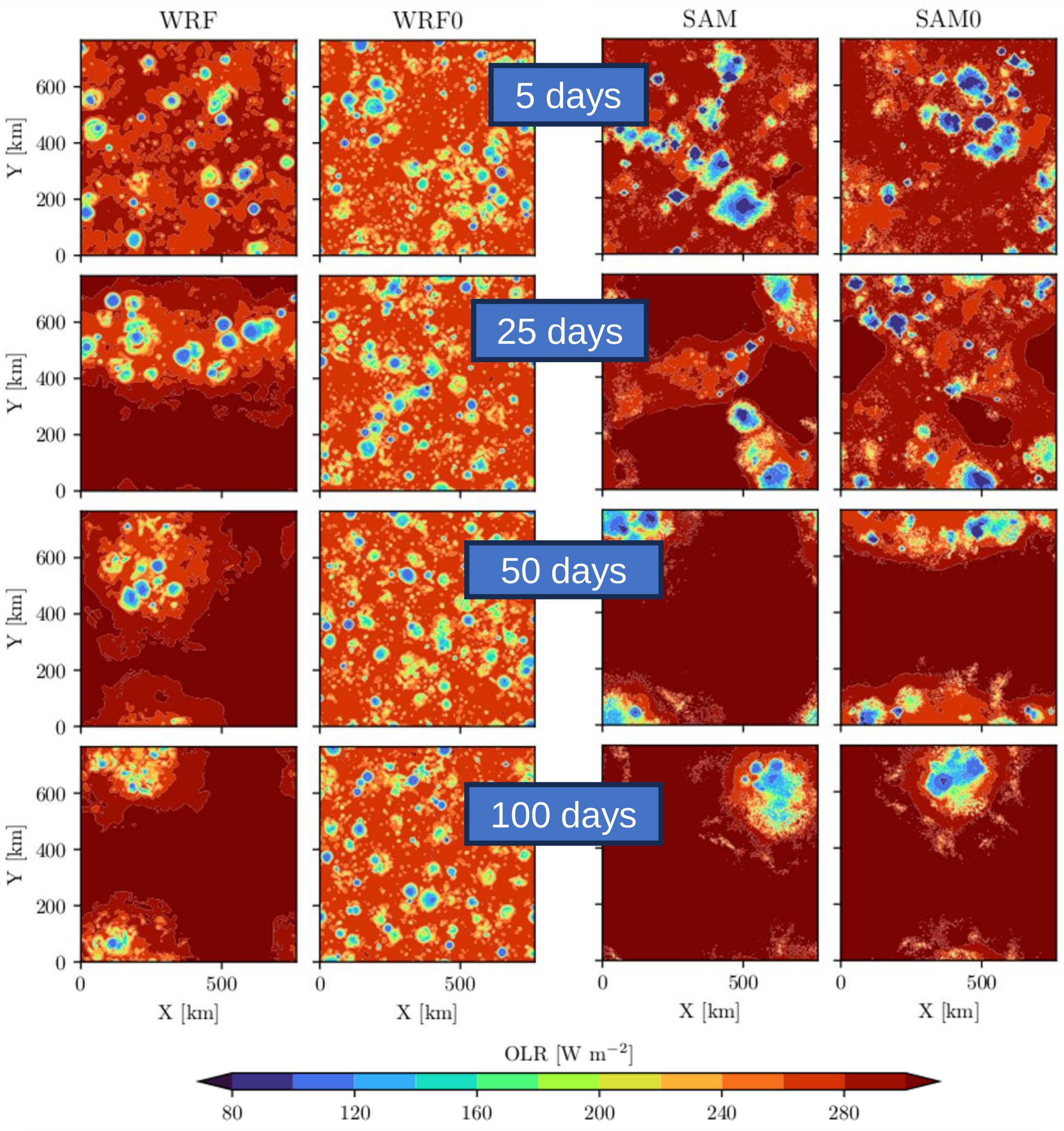
	SAM	WRF
Time Integration	Explicit 3rd order Adam-Bashfort scheme	Split-explicit 3rd order RK scheme (Wicker & Skamarock, 2002)
Momentum Advection	2nd order centered finite differences	5th order upwind-biased horizontal; 3rd order upwind-biased vertical
Scalar Advection	5th order ULTIMATE-MACHO scheme (Yamaguchi et al., 2011)	5th order upwind-biased horizontal; 3rd order upwind-biased vertical
Explicit mixing	None	6th order numerical diffusion

Cs=0 (No lateral mixing)

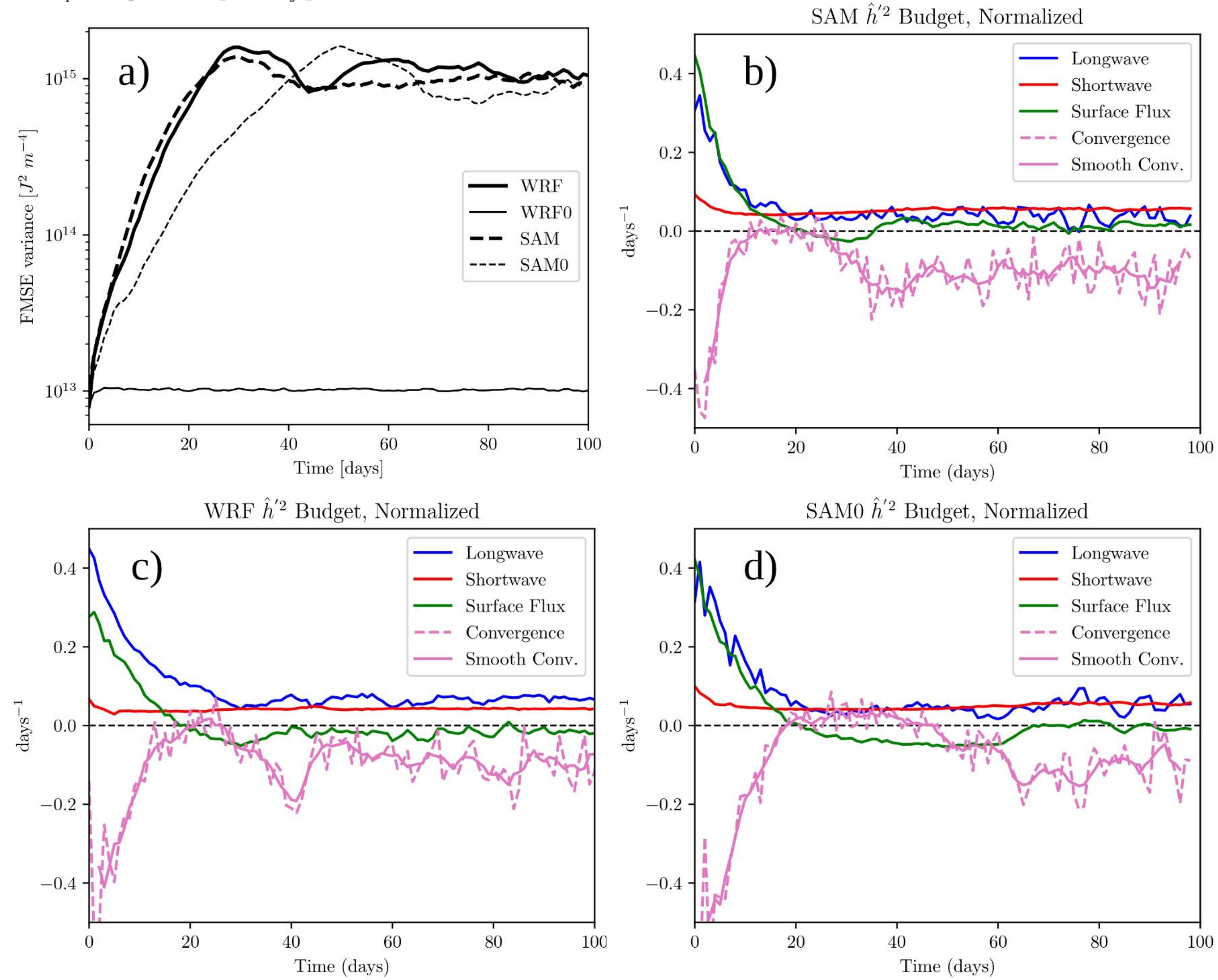
Domain: 768 x 768 km
Grid size: 3 km
SST 302 K

FMSE variance budget

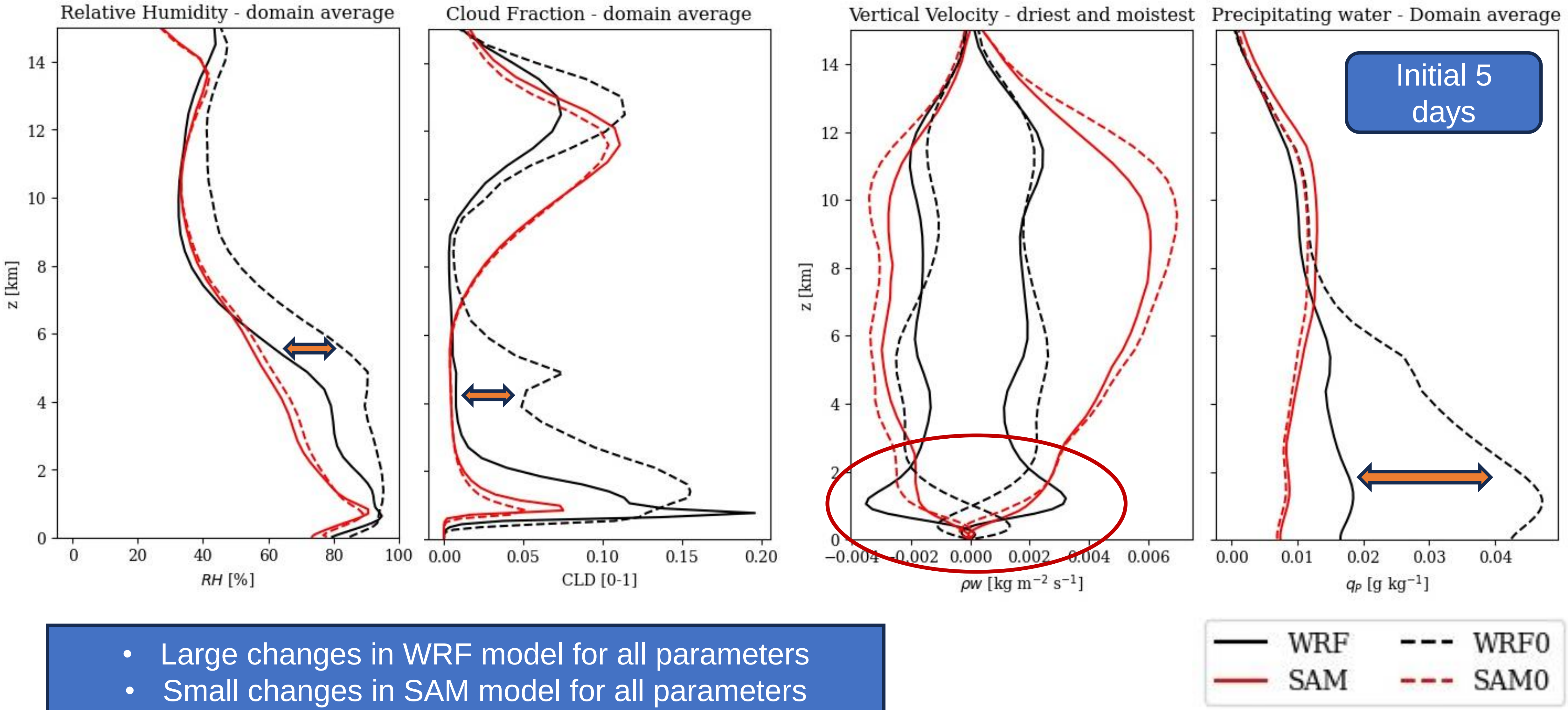
$$\frac{1}{2}\frac{\partial \widehat{h}'^2}{\partial t} = SEF'\widehat{h}' + NetSW'\widehat{h}' + NetLW'\widehat{h}' - \widehat{h}'\nabla_h \cdot \widehat{\vec{u}h}$$



$$h = c_pT + gz + L_vq_v - L_fq_i$$



The onset of aggregation

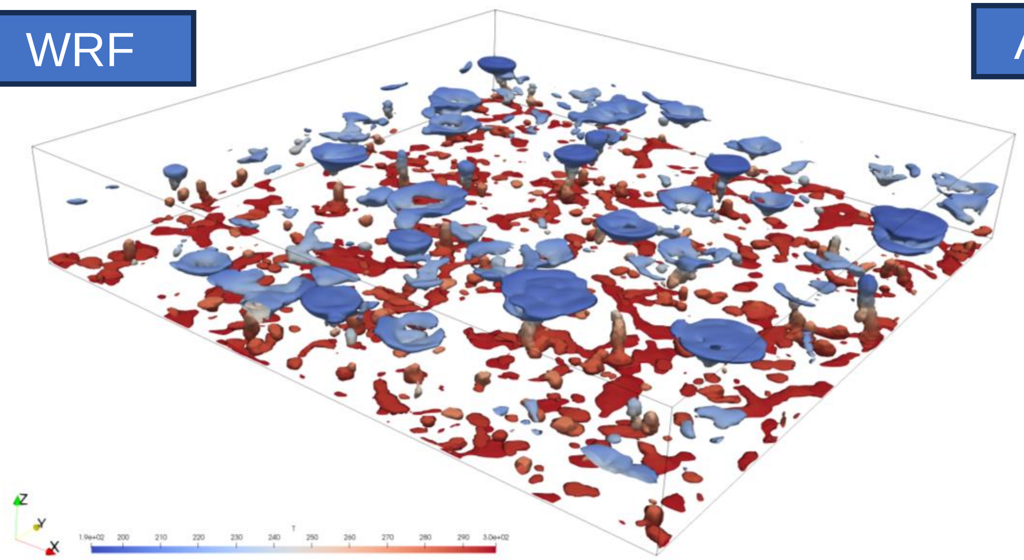


- Large changes in WRF model for all parameters
- Small changes in SAM model for all parameters

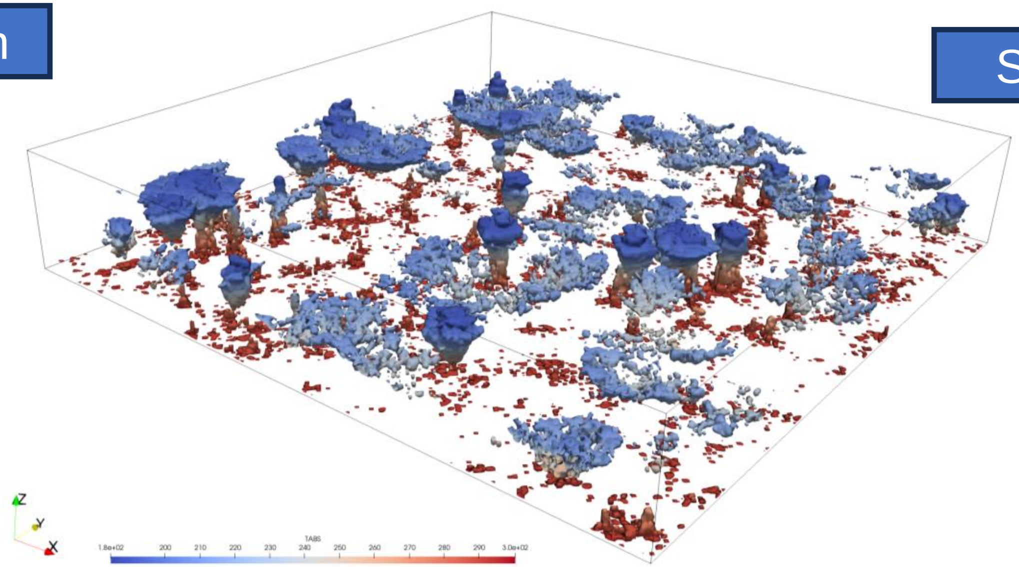
The onset of aggregation

After 18 h

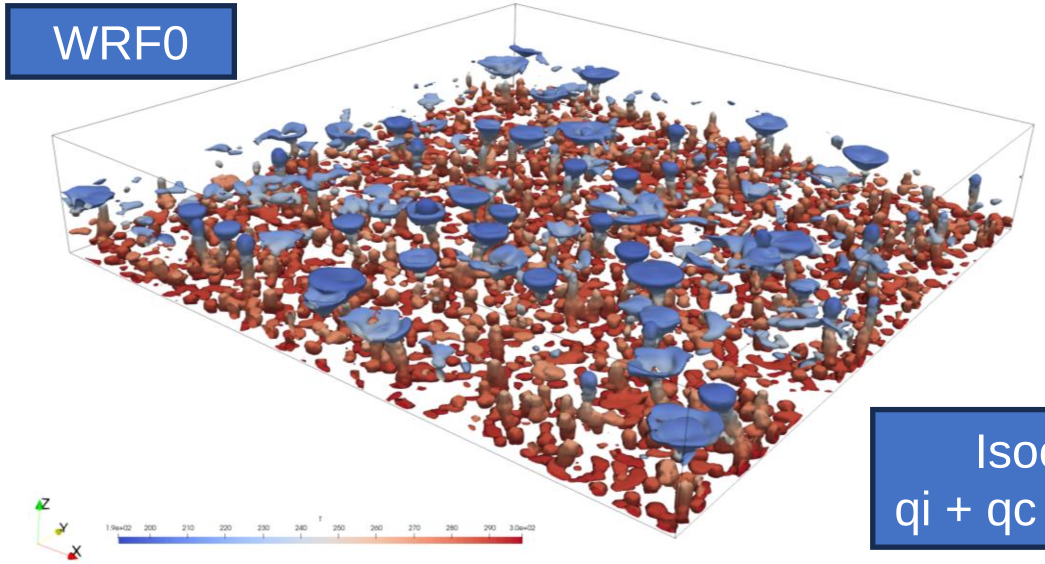
WRF



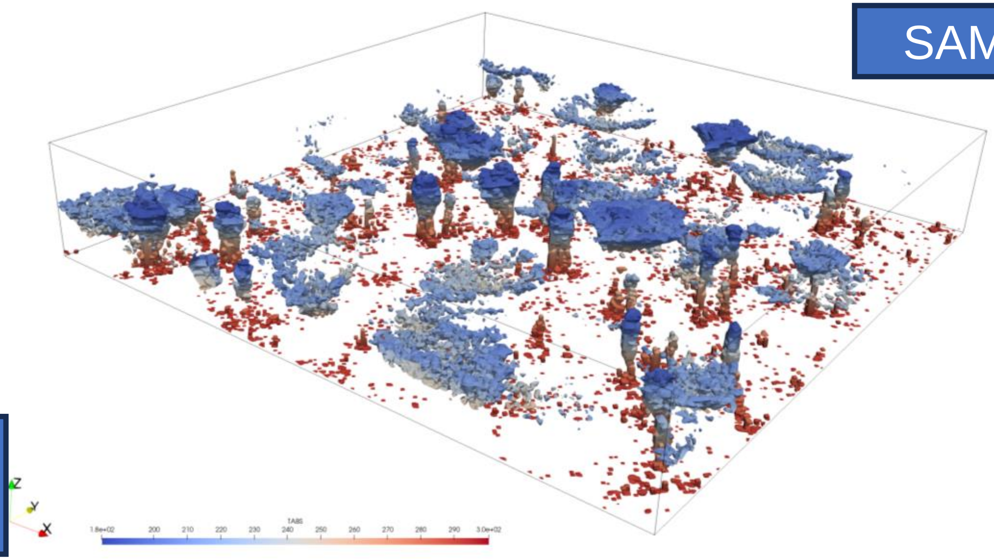
SAM



WRF0



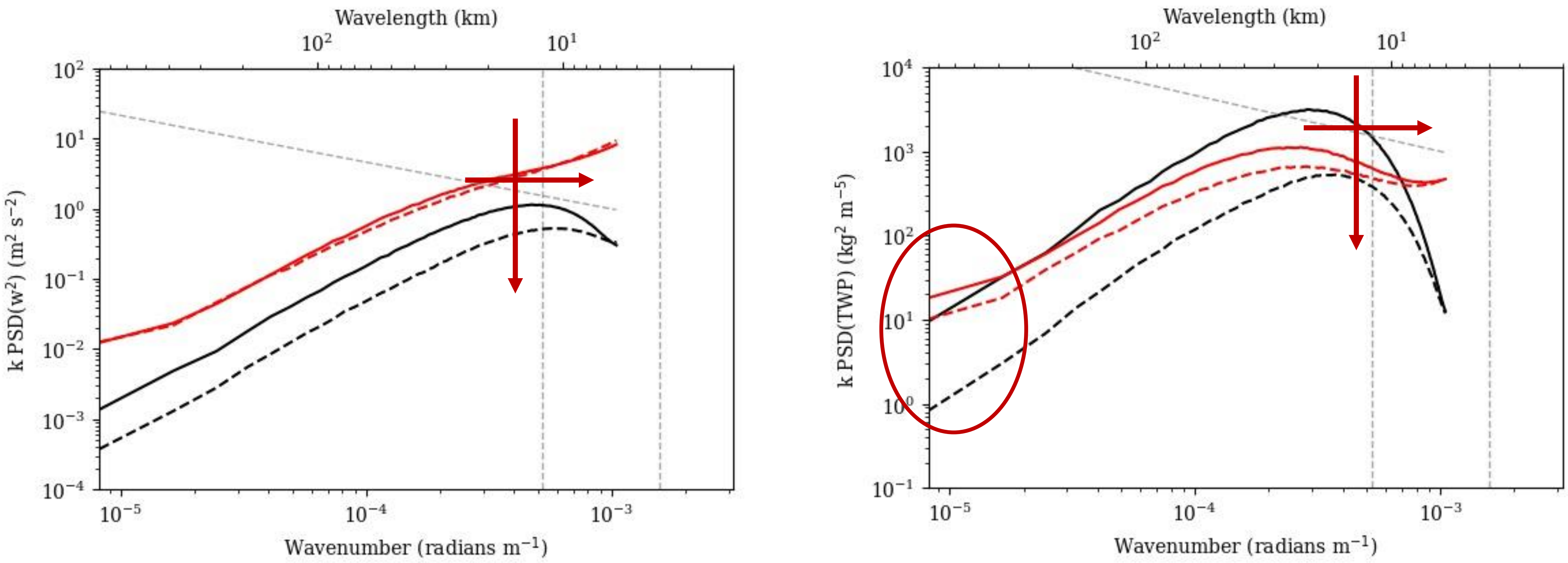
SAM0



Isocontours
qi + qc =0.001 g/kg

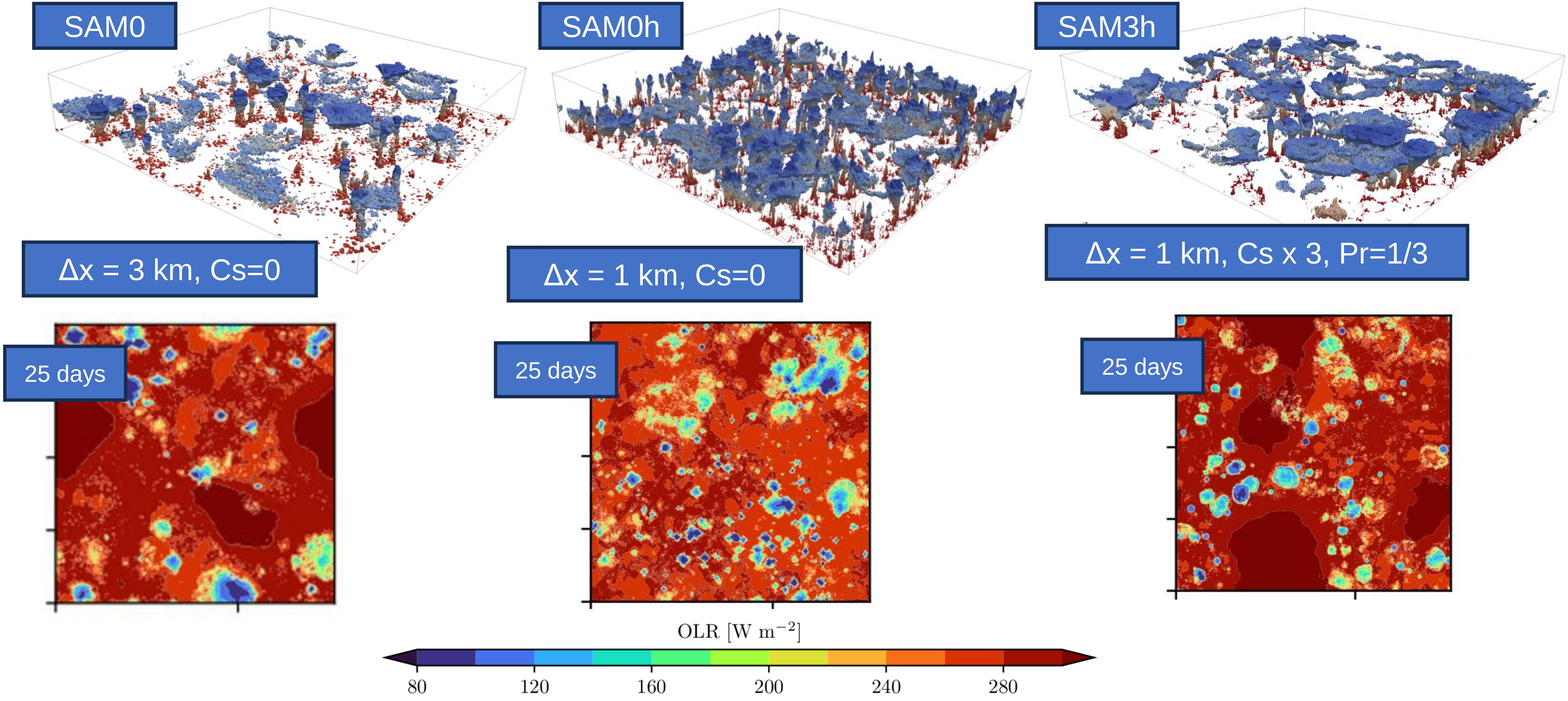
Energy spectra

Energy spectra between 3 and 10 km (initial 5 days)

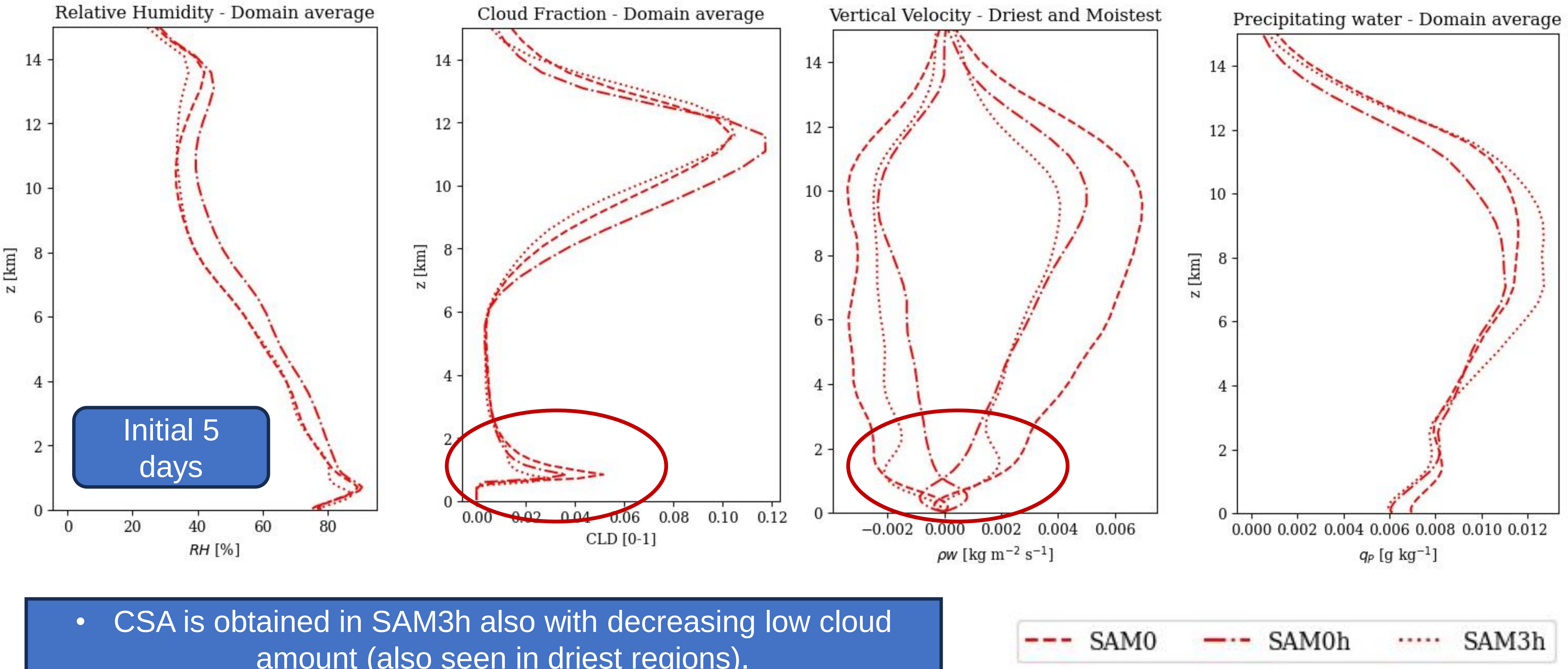


- Smaller turbulent mixing cause structure of smaller size and less energetic
- Smaller size updrafts causes a decrease in TWP variance at larger scales

Sensitivity to horizontal resolution



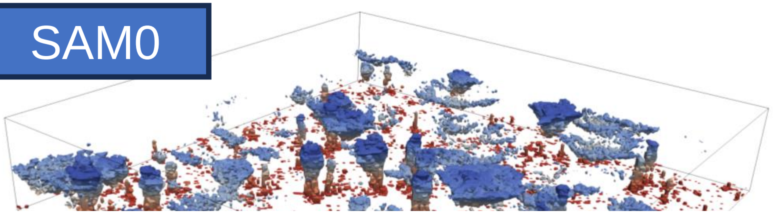
Sensitivity to horizontal resolution



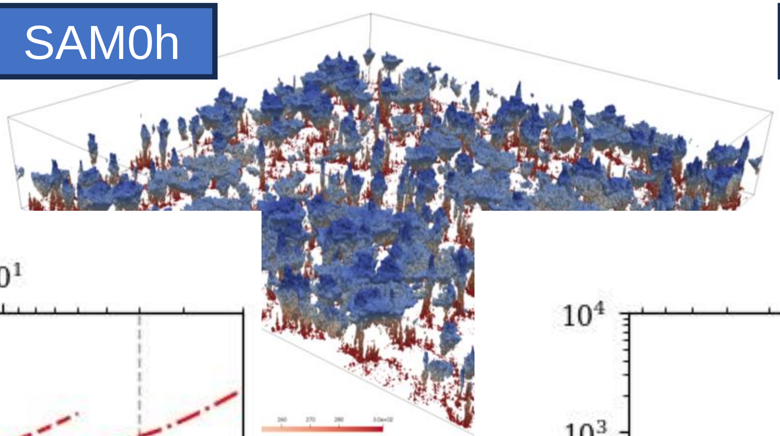
- CSA is obtained in SAM3h also with decreasing low cloud amount (also seen in driest regions).
- Large changes in the low level circulation

Sensitivity to horizontal resolution

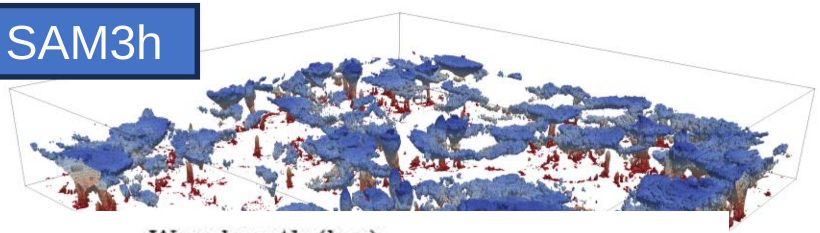
SAM0

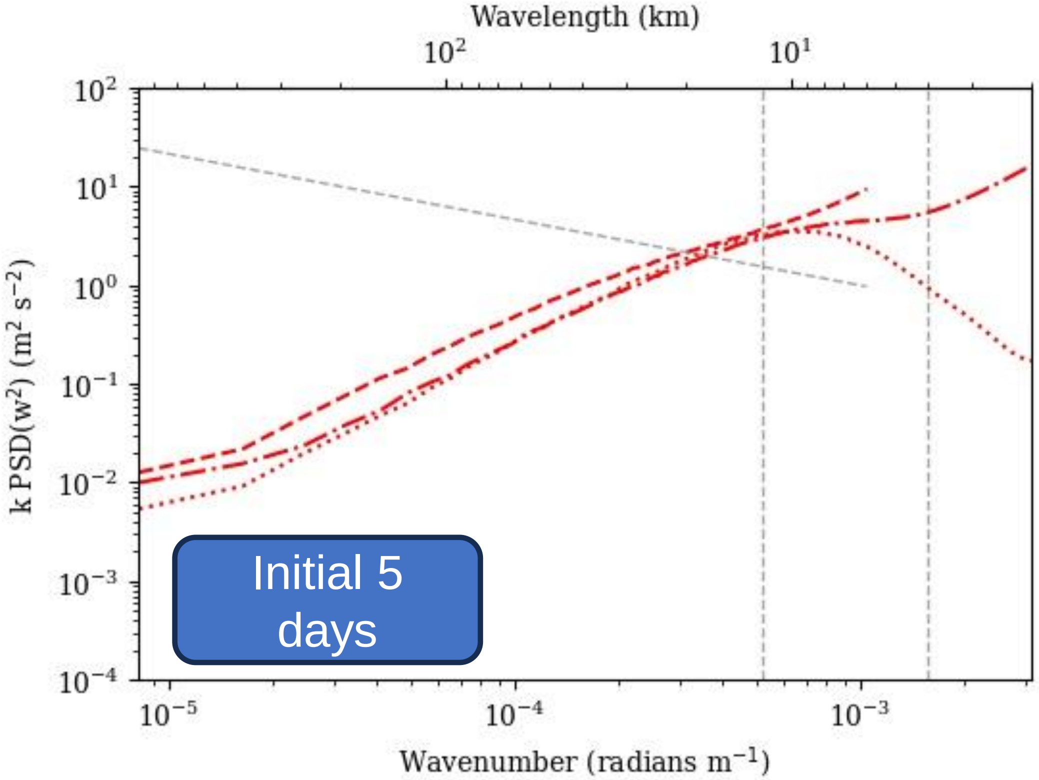


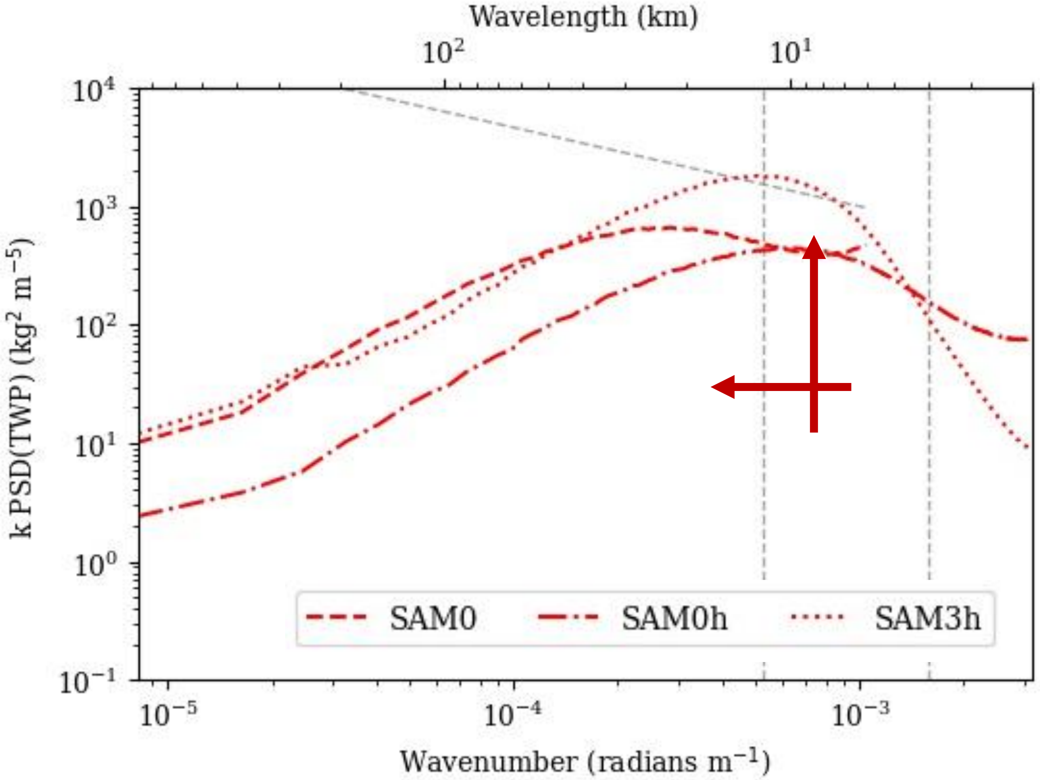
SAM0h



SAM3h

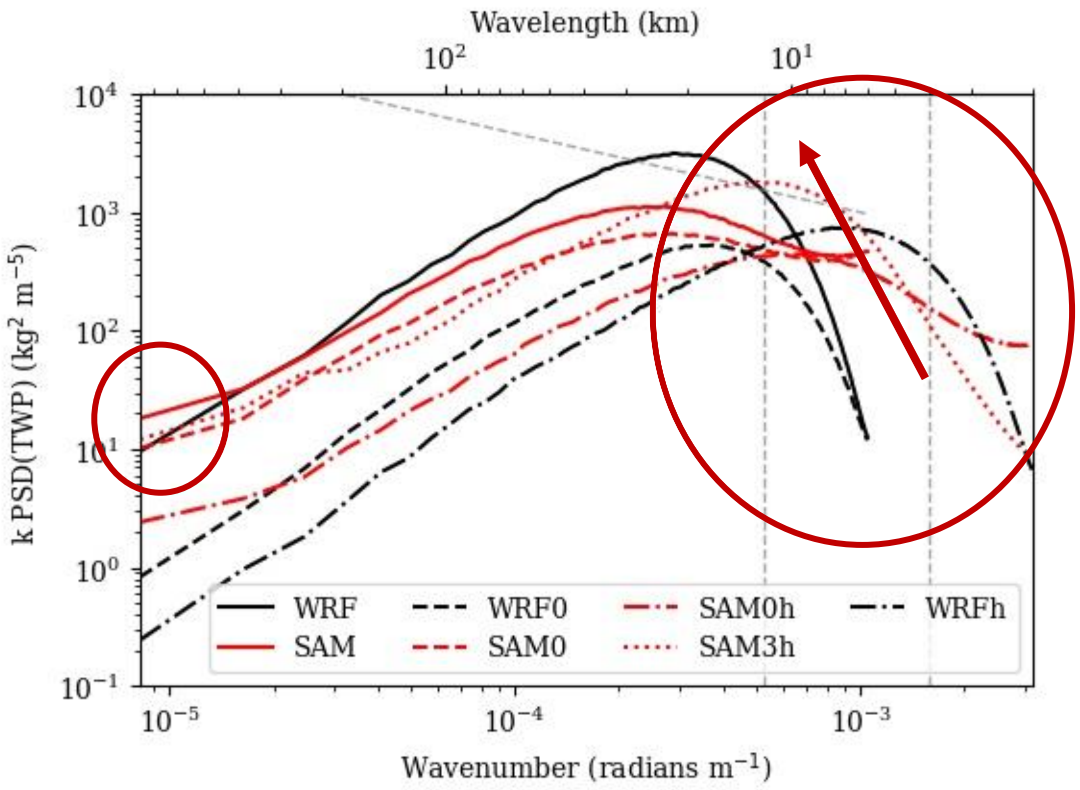






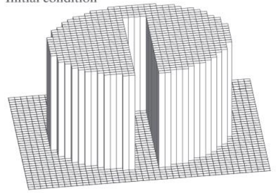
- SAM3h has a spectrum more similar to that of WRF
- Reintroducing large turbulent mixing at finer resolution ricreates larger and energetic structures.

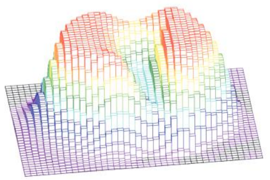
Conclusions



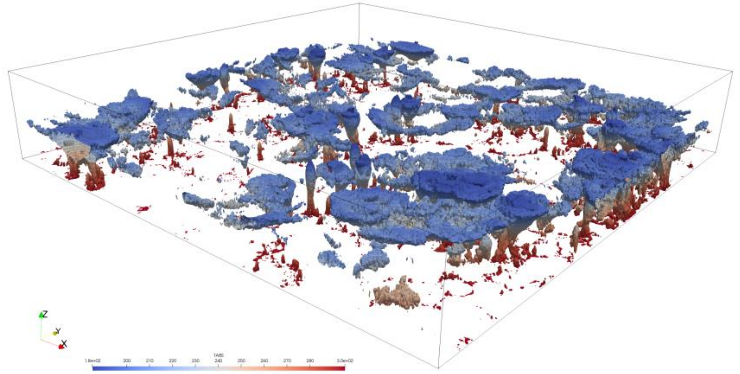
Why the role of mixing in CSA seems to be model dependent?

Because at <u>COARSE RESOLUTION</u> also <u>NUMERICAL MIXING</u> becomes relevant!!





Shaping the SIZE and the ENERGY of updrafts



<u>LARGER DISSIPATION</u> at small scales (either provided by turbulent mixing or numerical filters) causes <u>LARGER AND MORE ENERGETIC UPDRAFTS</u> which are able to trigger CSA and create <u>LARGE-SCALE HUMIDITY PERTURBATIONS</u> even at finer resolutions.

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Paper under review in JAMES (preprint online):
"Numerical diffusion and turbulent mixing in convective self-aggregation"

THANKS FOR YOUR ATTENTION!

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