The Unreasonable Efficiency of Total Rain Evaporation Removal in Triggering Convective Self-Aggregation

Yi-Ling Hwong & Caroline Muller

5 September 2023, Trieste, Italy

3rd Workshop on Cloud Organisation and Precipitation Extremes - WCO3

Institute of Science and Technology Austria

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 101034413

Background

- Convection self-aggregates in RCE experiments devoid of external forcings
- Generally mechanism: physical processes that generate a shallow circulation which leads to an upgradient transport of MSE from dry to moist region
- Radiative feedback crucial, surface flux feedback favourable

Background

- Convection self-aggregates in RCE experiments devoid of external forcings
- Generally mechanism: physical processes that generate a shallow circulation leading to an upgradient transport of MSE from dry to moist region
- Radiative feedback crucial, surface flux feedback favourable
- Intriguingly, self-aggregation can also occur ***without*** radiative feedback if rain evaporation is removed in the boundary layer (Muller & Bony, 2015; Holloway & Woolnough, 2916)
    - "moisture-memory aggregation"

Background

- Are cold pools causing this phenomenon?
  - Cold pools hinder aggregation by increasing mixing between dry and moist areas in the PBL
  - Removing rain evaporation removes cold pools ⇒ aggregation (e.g., Jeevanjee & Romps, 2013)
- No clear consensus

Research questions

- How does convective self-aggregation (CSA) change when rain evaporation is removed or reduced in the PBL?
- Which physical processes are involved in the development of this type of CSA?

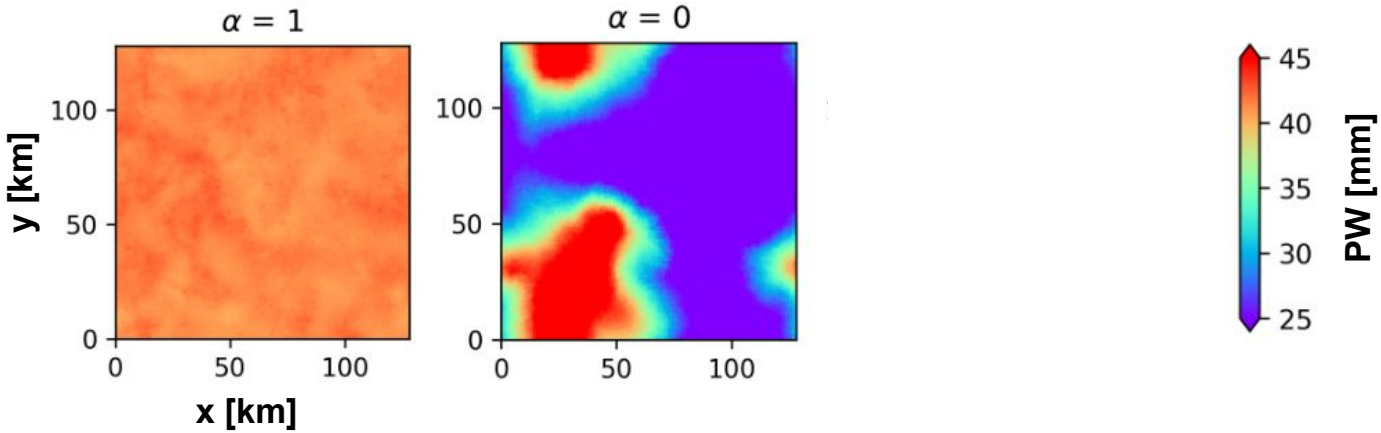
Methods

- 3D radiative-convective equilibrium (RCE) simulations in SAM
- Domain size L = 128 km, Δx = 1 km
- Horizontally homogenised radiation and surface fluxes
- Ocean surface, SST = 301 K
- Progressively reduce rain evaporation in lowest 1 km by multiplying $q_{p,evap}$ with a factor α = [1, 0.8, 0.6, 0.4, 0.2, 0]

Aggregation (precipitable water)

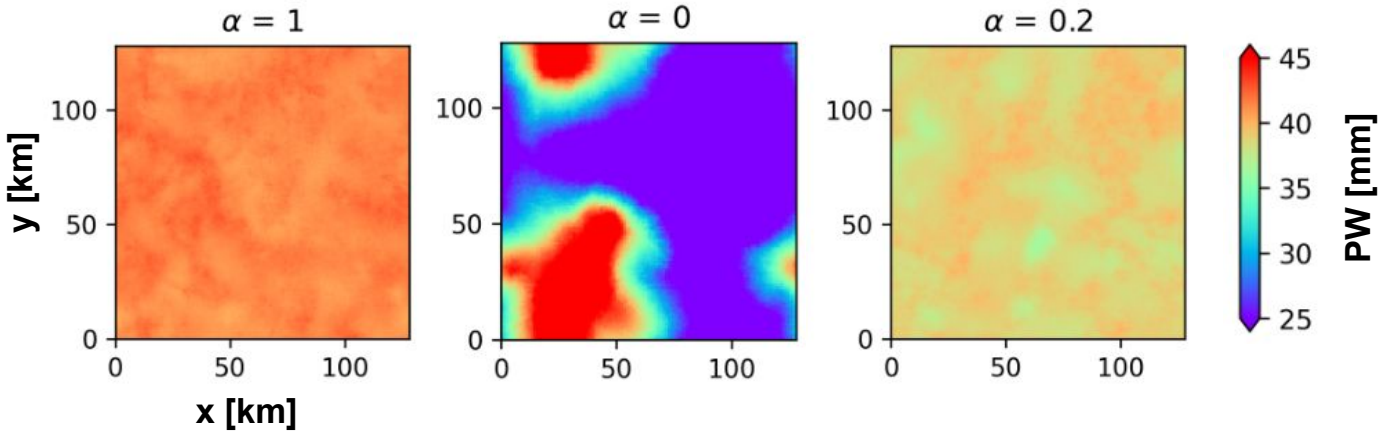
Aggregation (precipitable water)

Aggregation (precipitable water)



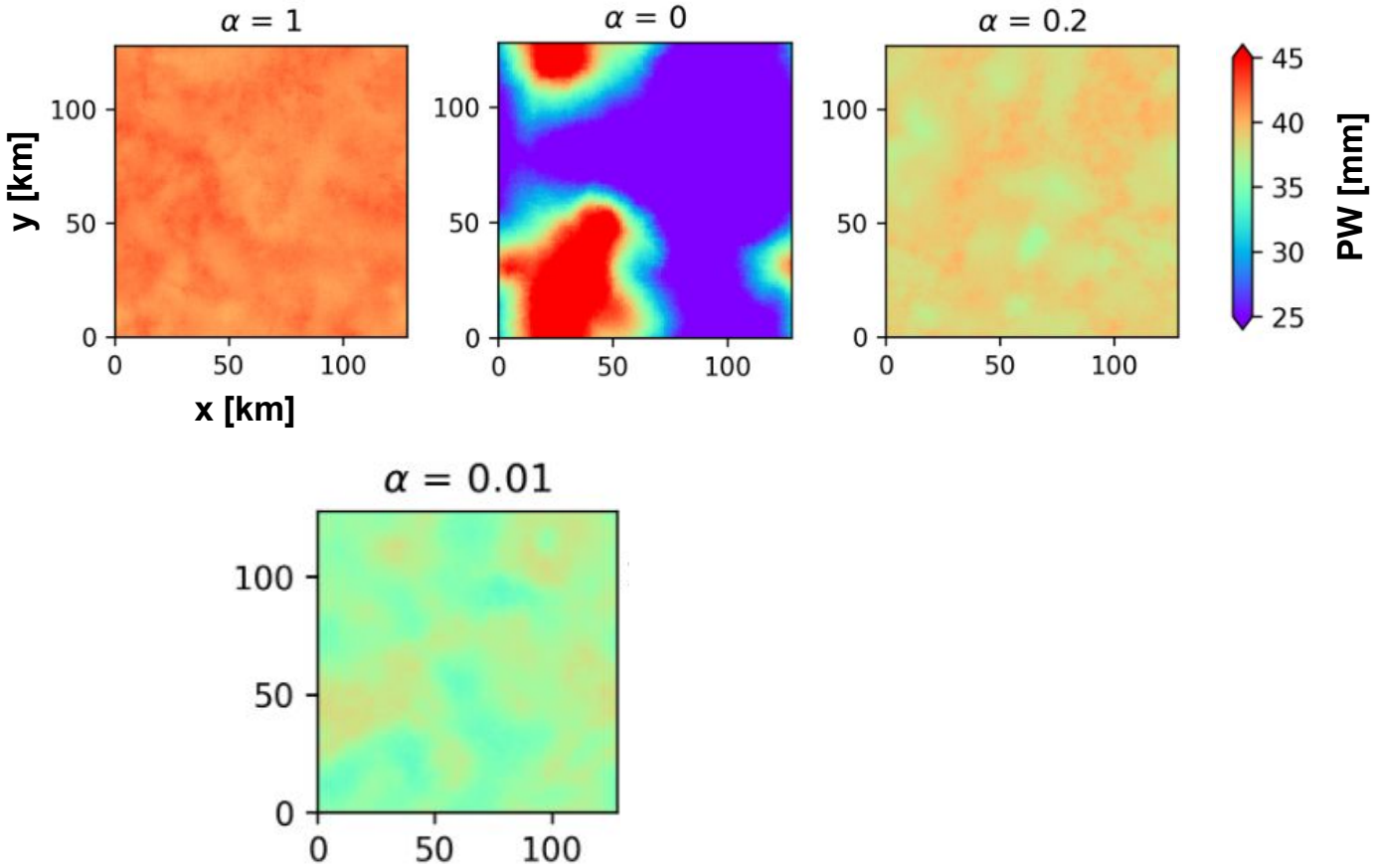
Aggregation (precipitable water)

Intriguingly ...



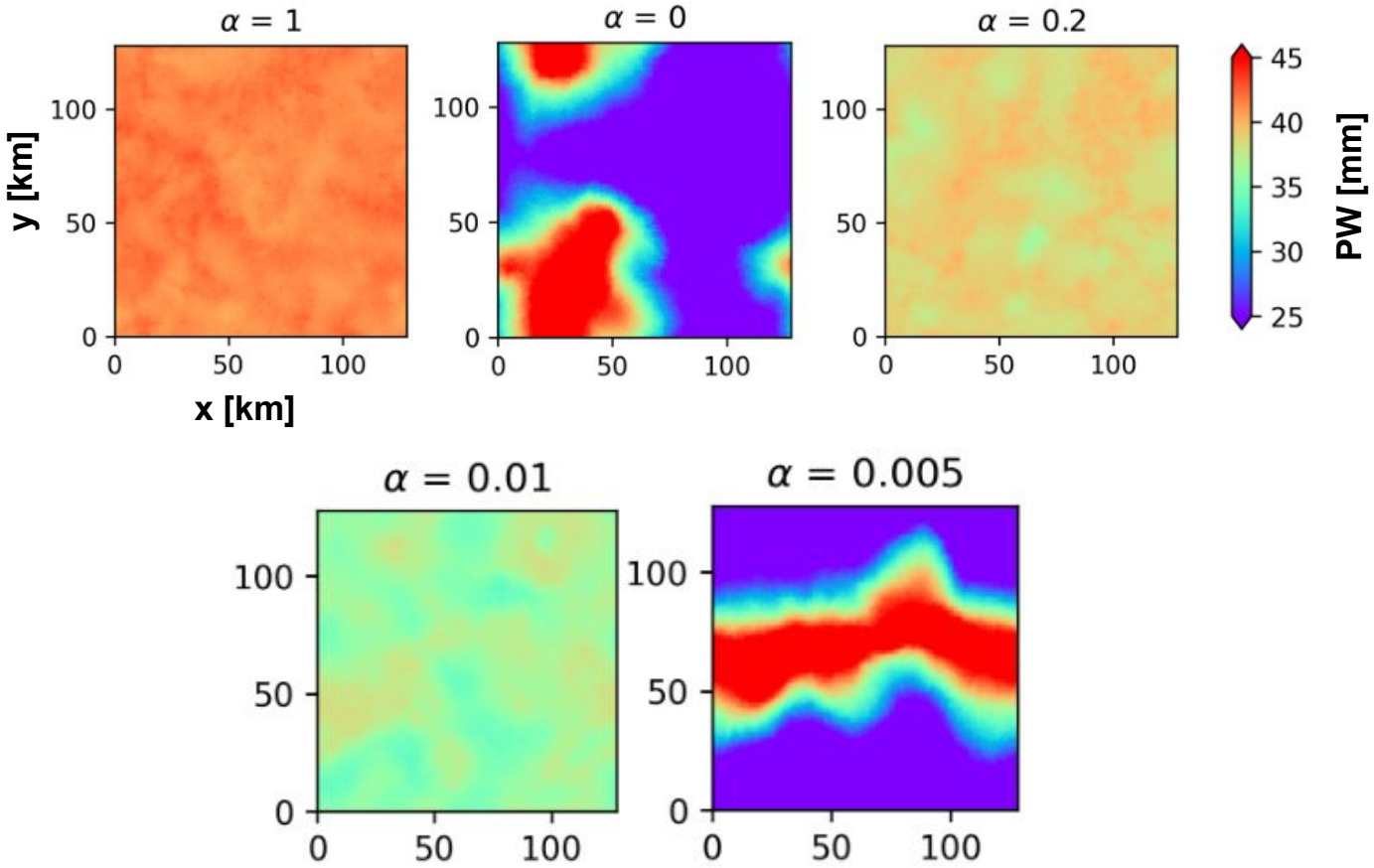
Aggregation (precipitable water)

Intriguingly ...



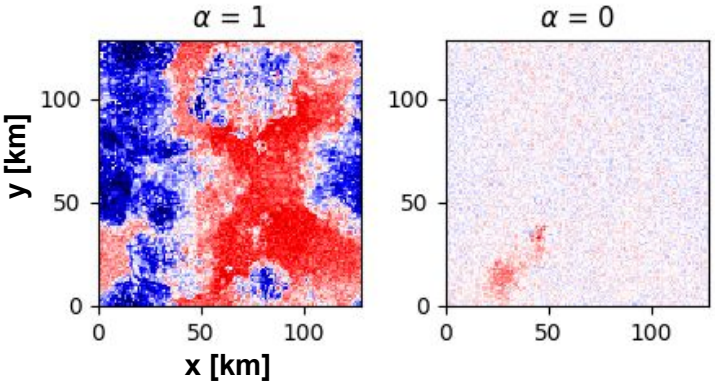
Aggregation (precipitable water)

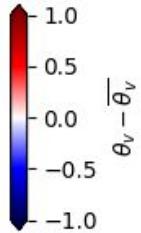
Intriguingly ...



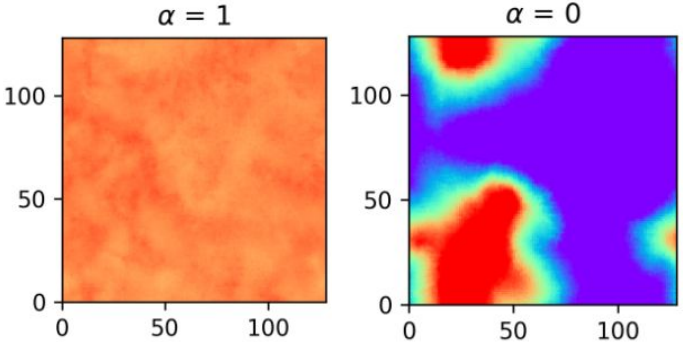
Cold pools?

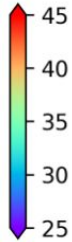
Cold pools





PW



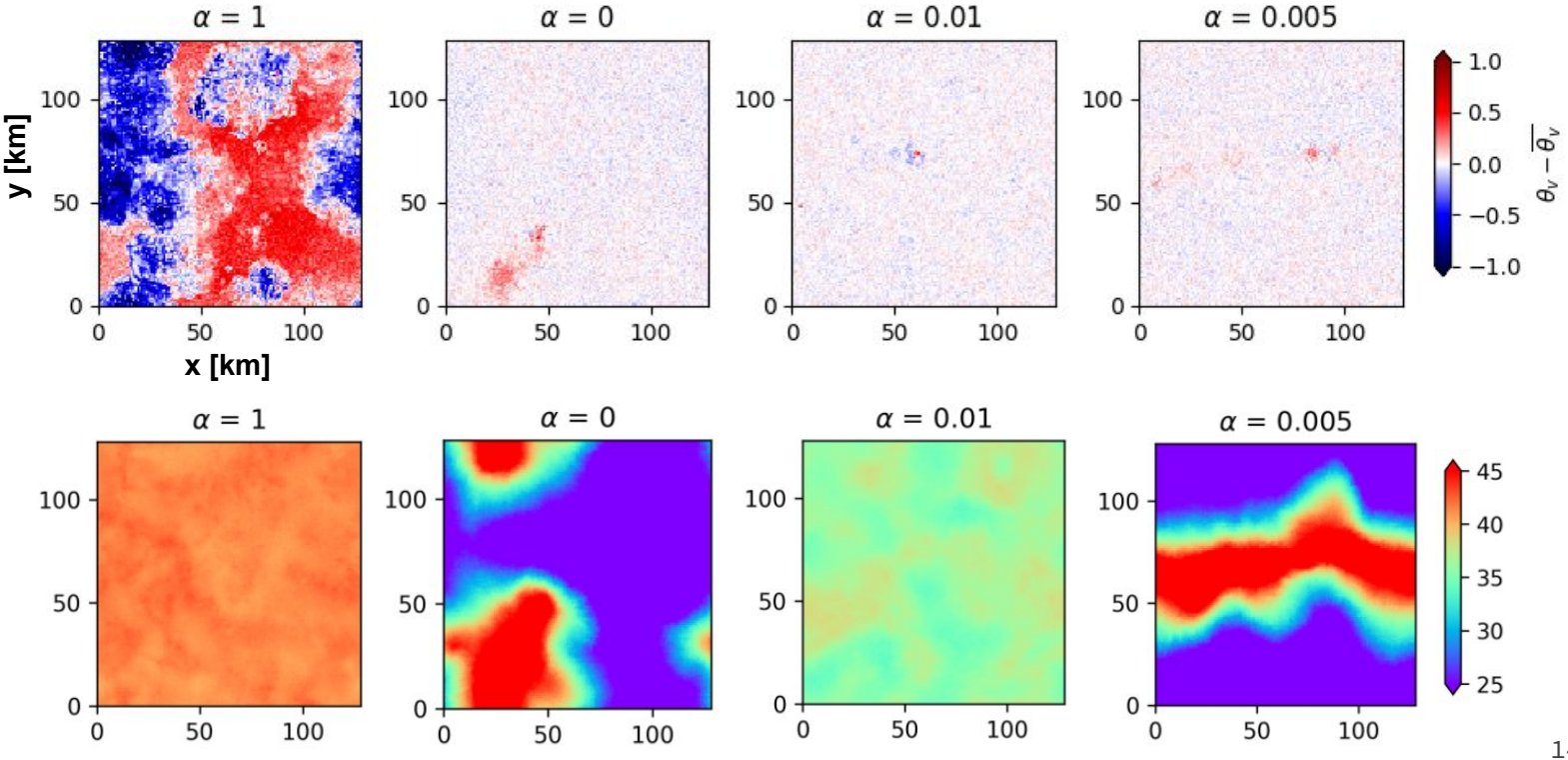


Cold pools?

Do not have cold pools, but one aggregates and the other does not

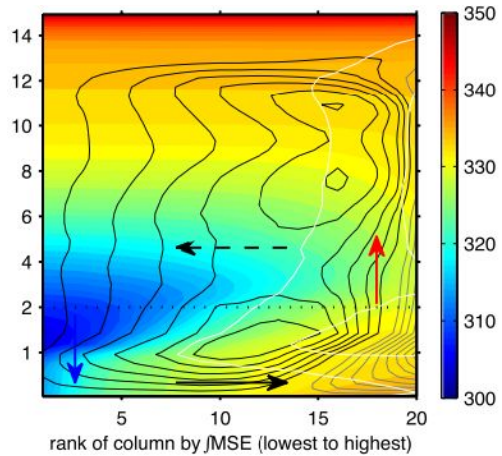
Cold pools

PW



Shallow circulation

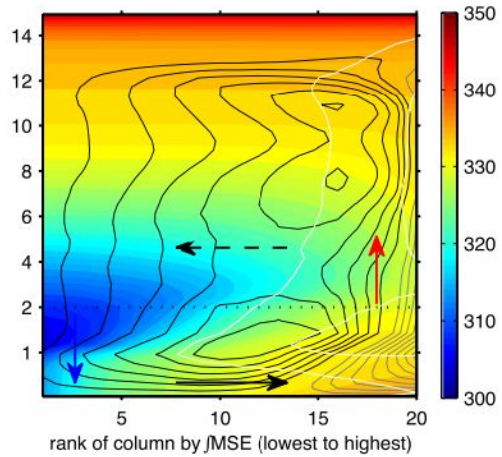
- Radiatively-driven aggregation (i.e., with interactive radiation) is driven by a shallow circulation that transports MSE upgradient
  - differential radiative cooling ⇒ dry region gets drier ⇒ dry region expands ⇒ aggregation



Muller & Bony (2015)

Shallow circulation

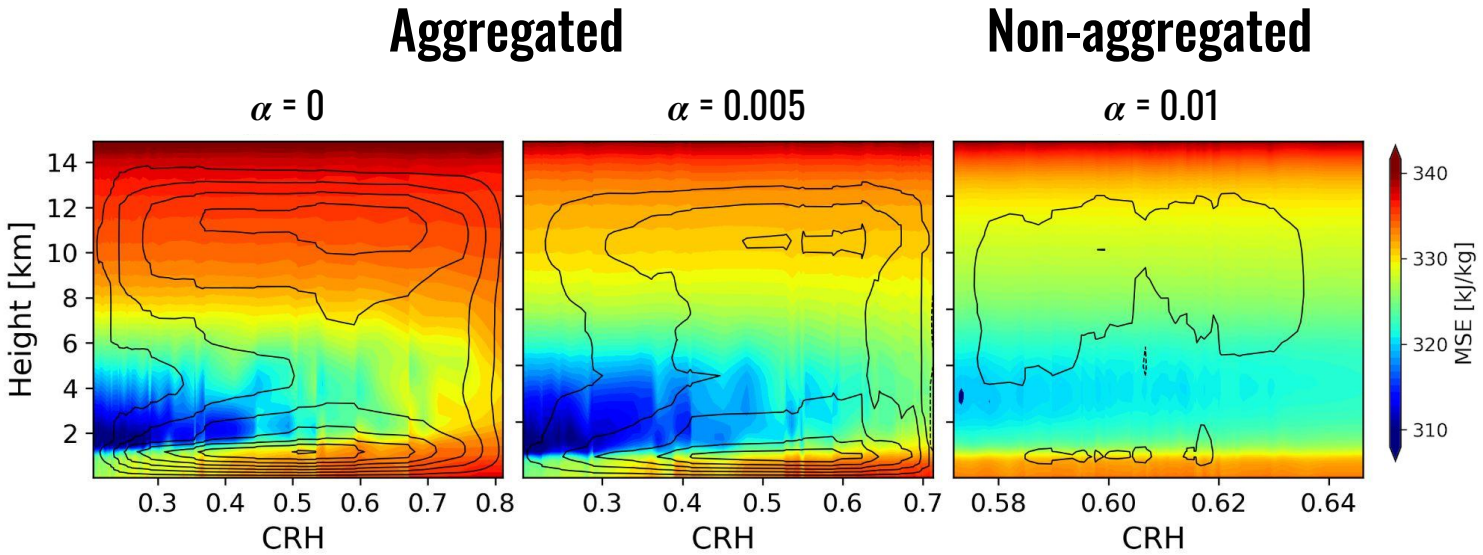
- Radiatively-driven aggregation (i.e., with interactive radiation) is driven by a shallow circulation that transports MSE upgradient
  - differential radiative cooling ⇒ dry region gets drier ⇒ dry region expands ⇒ aggregation



Muller & Bony (2015)

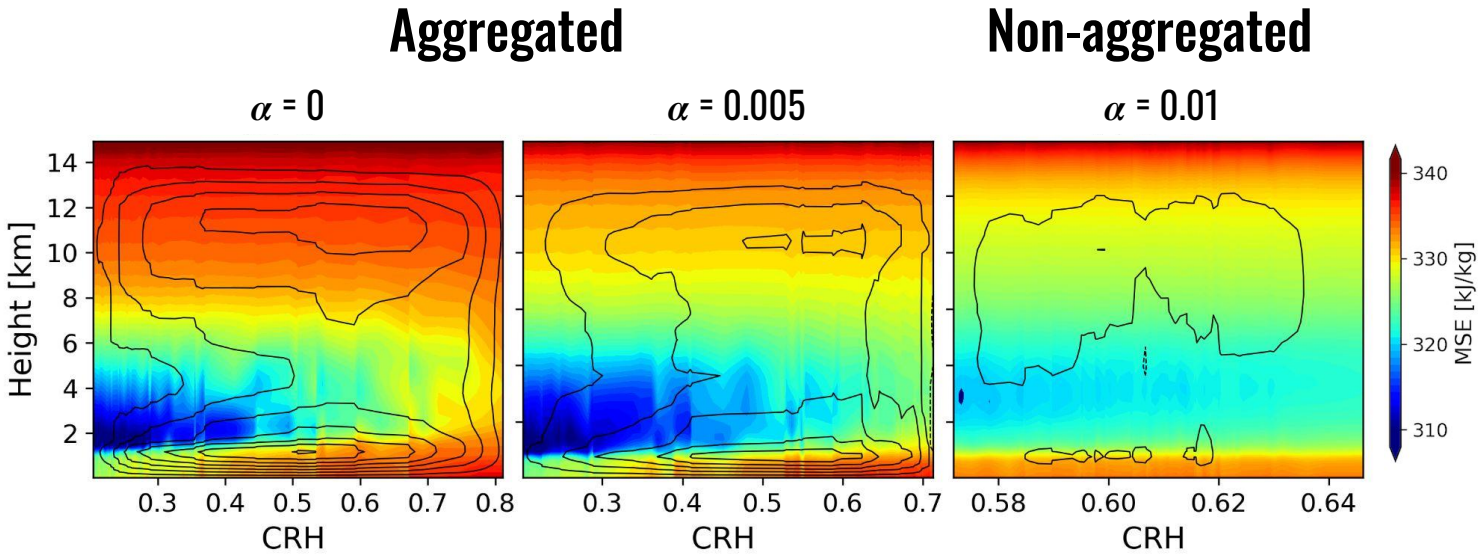
In our case radiation is horizontally homogenised, is this shallow circulation still present?

Yes it is …



** averaged over final 5 days*

Yes it is …



What is driving this shallow circulation, if not radiation?

Buoyancy

- High surface pressure (P_{sfc}) anomaly of dry region builds up a divergent flow that drives the shallow circulation required for aggregation to occur (Yang, 2018; Shamekh et al., 2020)
- Assuming weak temperature gradient in the FT, P_{sfc} anomaly is related to the boundary layer buoyancy (density) anomaly (Yang, 2018):

$$b = g\frac{\theta_v'}{\overline{\theta_v}} = g\left(\frac{\theta'}{\overline{\theta'}} + \frac{\epsilon q'}{1+\epsilon\bar{q}}\right)$$

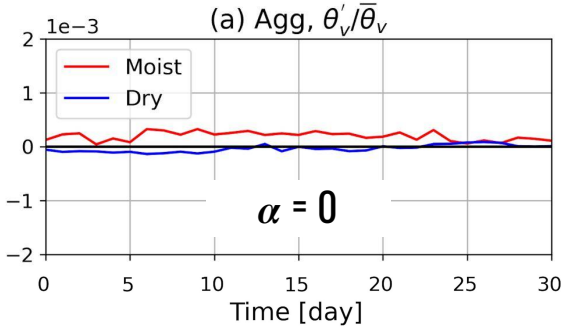
Temperature contribution

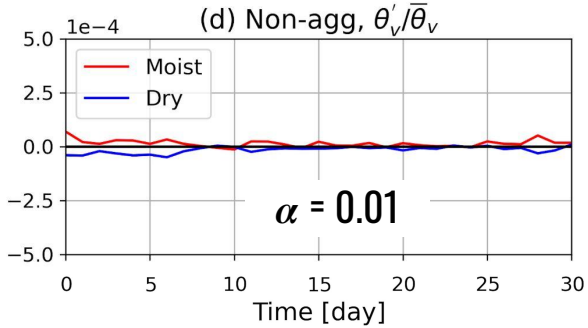
Moisture contribution

Buoyancy

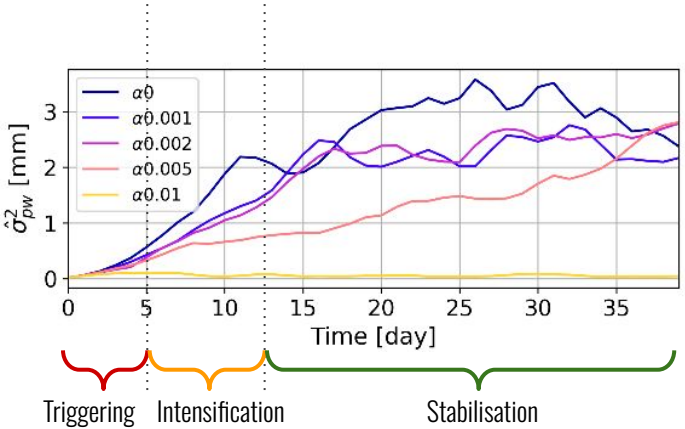
- Reducing rain evaporation:
  - reduce evaporative cooling (net heating effect)
  - reduce evaporative moistening (net drying effect)
- Two opposing buoyancy effects, which one plays a dominant role in self-aggregation?

Buoyancy (θ'_v)

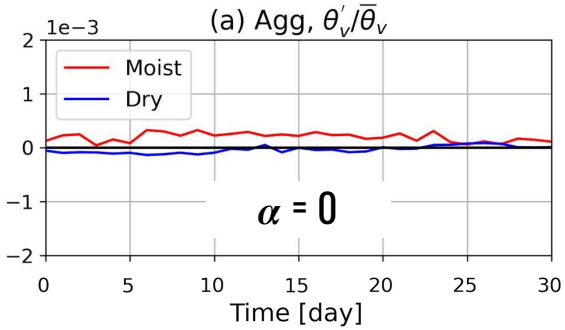


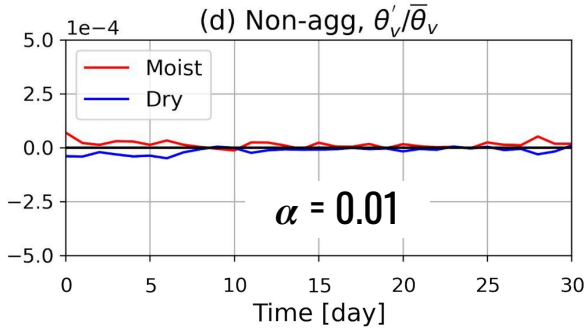


Aggregation index

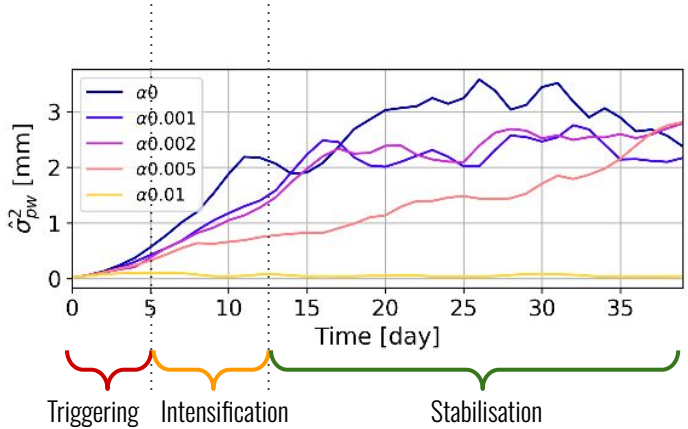


Buoyancy (θ'_v)

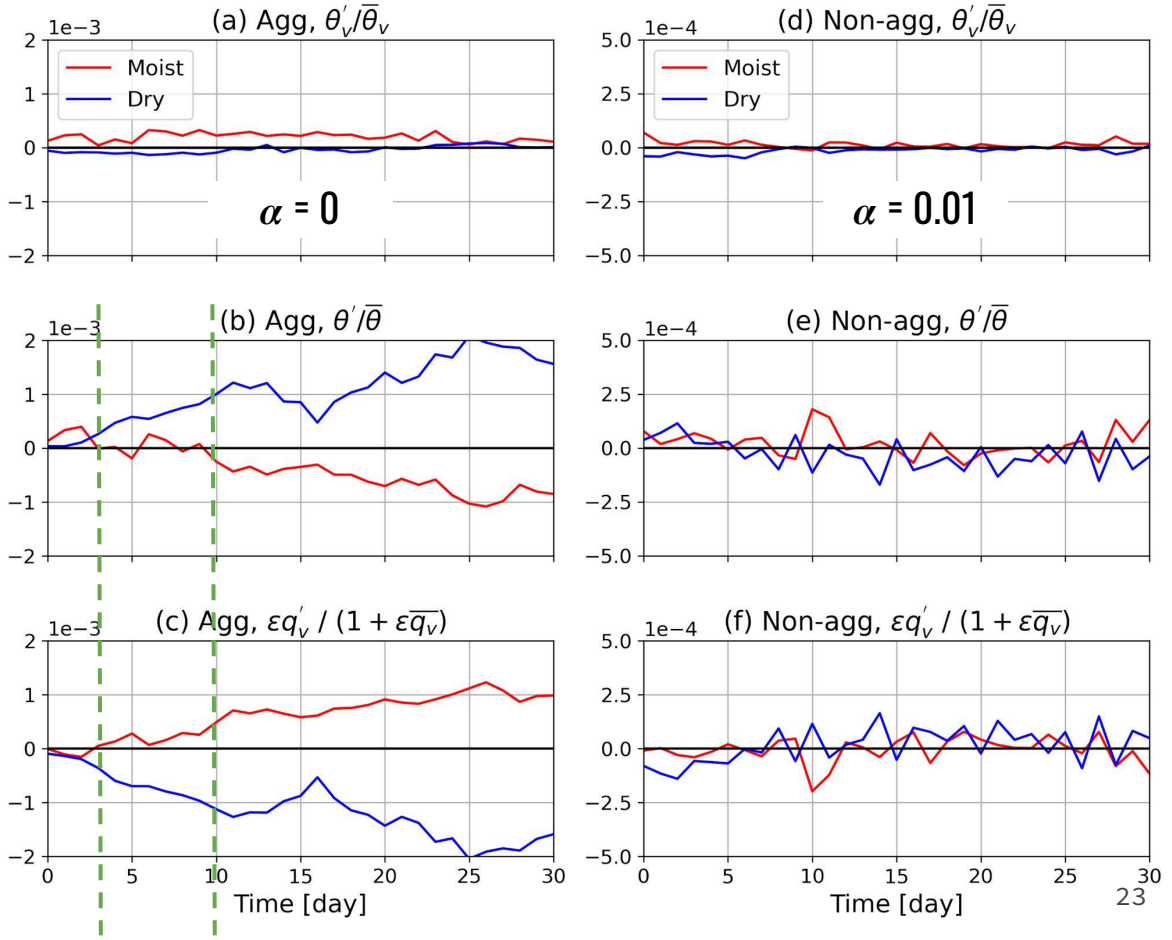




Aggregation index



Buoyancy (θ'_v)

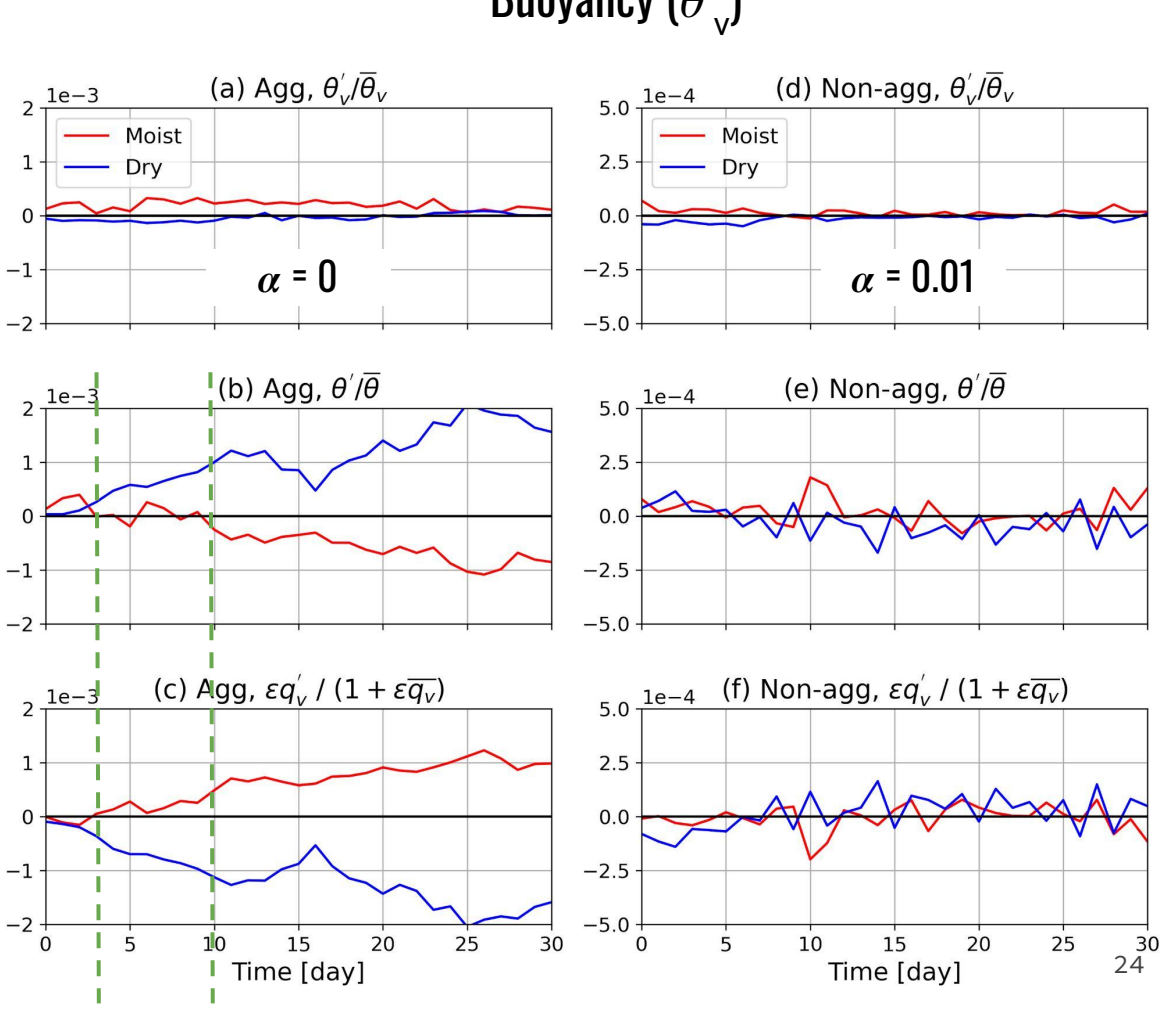


Convective heating of moist patch triggers CSA

Dry subsidence intrusion into PBL of dry region intensifies CSA

Competing T and q_v effects in mature phase of CSA

Very small α required (almost total rain evap. removal)



Convective heating of moist patch triggers CSA

↓

Dry subsidence intrusion into PBL of dry region intensifies CSA

↓

Competing T and q_v effects in mature phase of CSA

↓

Very small α required (almost total rain evap. removal)

- Moisture-memory aggregation ⇒ convectively-driven aggregation?

Convective heating of moist patch triggers CSA

↓

Dry subsidence intrusion into PBL of dry region intensifies CSA

↓

Competing T and q_v effects in mature phase of CSA

↓

Very small α required (almost total rain evap. removal)

- Moisture-memory aggregation ⇒ convectively-driven aggregation?
- How is it different from radiatively-driven aggregation?

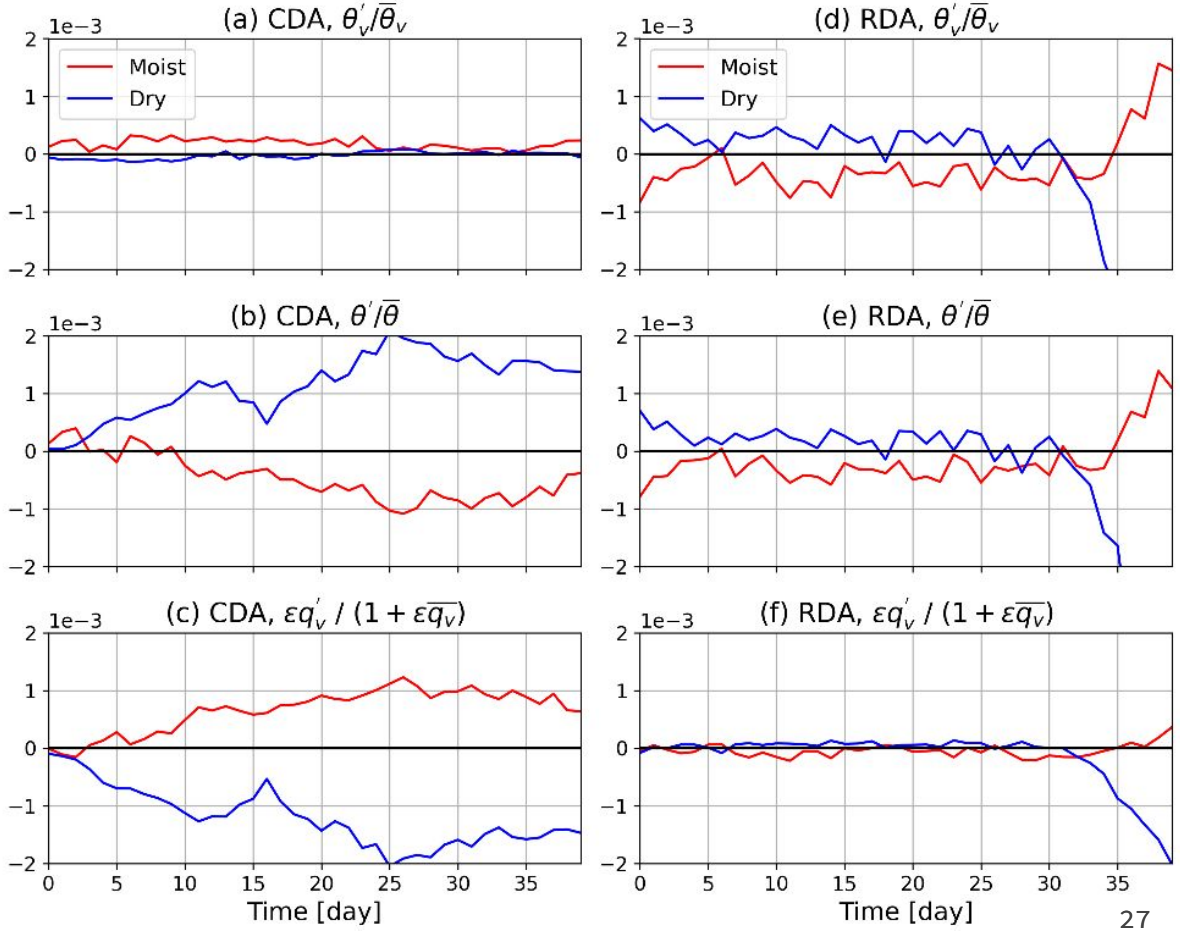
Radiative cooling of dry patch triggers CSA

↓

Dry subsidence intrusion into PBL of dry region intensifies CSA

↓

T and q_v effects both support CSA in mature phase



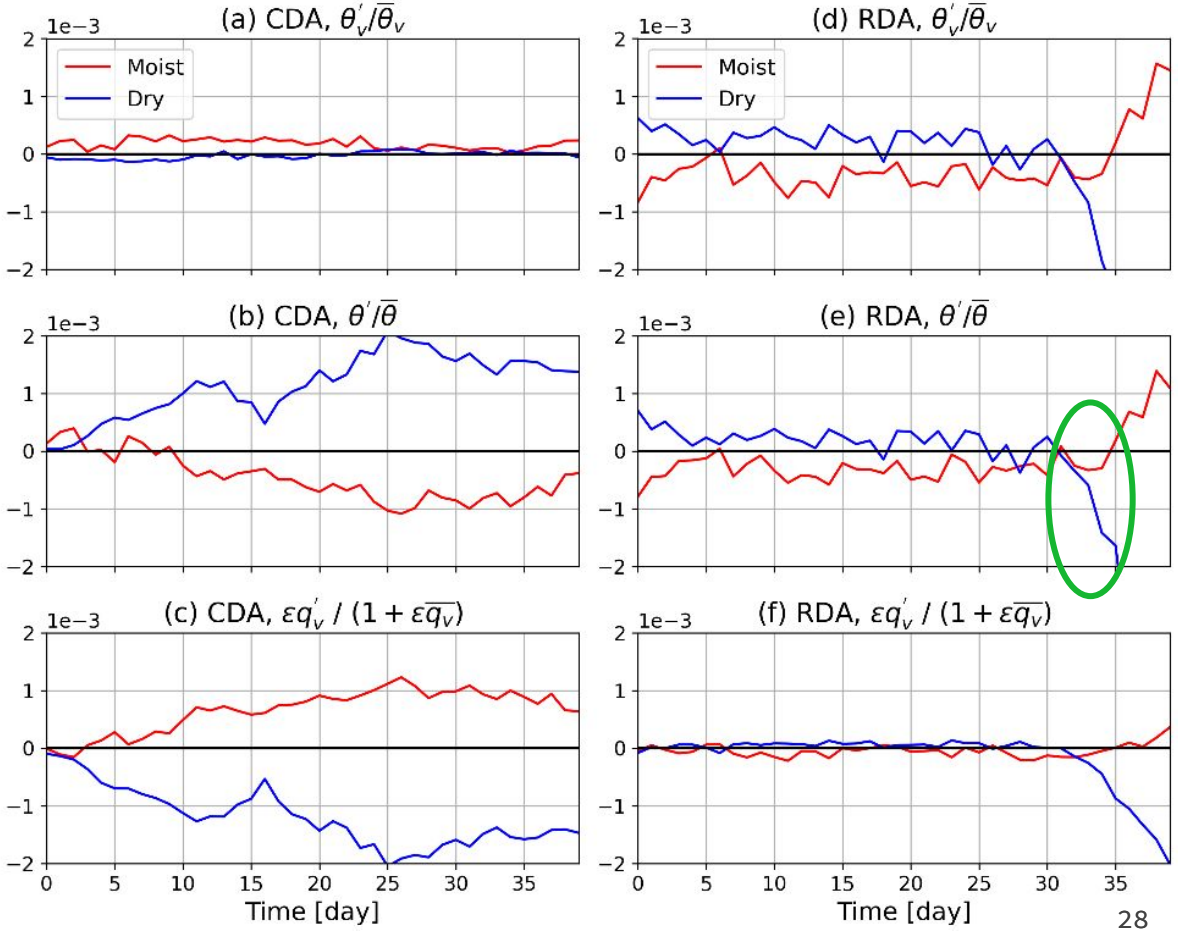
Radiative cooling of dry patch triggers CSA

↓

Dry subsidence intrusion into PBL of dry region intensifies CSA

↓

T and q_v effects both support CSA in mature phase



Summary

Convectively-Driven Aggregation (CDA)	Radiatively-Driven Aggregation (RDA)
Convective heating of moist patch triggers aggregation	Radiative cooling of dry patch is the first-mover of aggregation
Dry subsidence (virtual effect) intrusion into PBL of dry patch intensifies aggregation	Dry subsidence (virtual effect) intrusion into PBL of dry patch intensifies aggregation
Moist and dry patches work in tandem	Dry patch driven
Aggregation occurs quickly	Aggregation occurs slowly
T and q_v effects oppose each other in mature phase	T and q_v effects work together in mature phase

Summary

Convectively-Driven Aggregation (CDA)	Radiatively-Driven Aggregation (RDA)
Convective heating of moist patch triggers aggregation	Radiative cooling of dry patch is the first-mover of aggregation
Dry subsidence (virtual effect) intrusion into PBL of dry patch intensifies aggregation	Dry subsidence (virtual effect) intrusion into PBL of dry patch intensifies aggregation
Moist and dry patches work in tandem	Dry patch driven
Aggregation occurs quickly	Aggregation occurs slowly
T and q_v effects oppose each other in mature phase	T and q_v effects work together in mature phase

(almost) total rain evaporation removal needed as ignition during triggering phase, and to counter the opposing T and q_v effects in mature phase

“The unreasonable efficiency of mathematics in science is a gift we neither understand nor deserve.”

— Eugene Wigner (winner of Nobel prize in Physics 1963)

"The unreasonable efficiency of mathematics in science is a gift we neither understand nor deserve."

— Eugene Wigner (winner of Nobel prize in Physics 1963)

"The unreasonable efficiency of total rain evaporation removal in triggering self-aggregation is a gift we should neither expect nor accept."