Using convective aggregation to inform convection parametrization development

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Acknowledgement: Allison Wing, Catherine Stauffer, Jian-Feng Gu, and Kieran Pope

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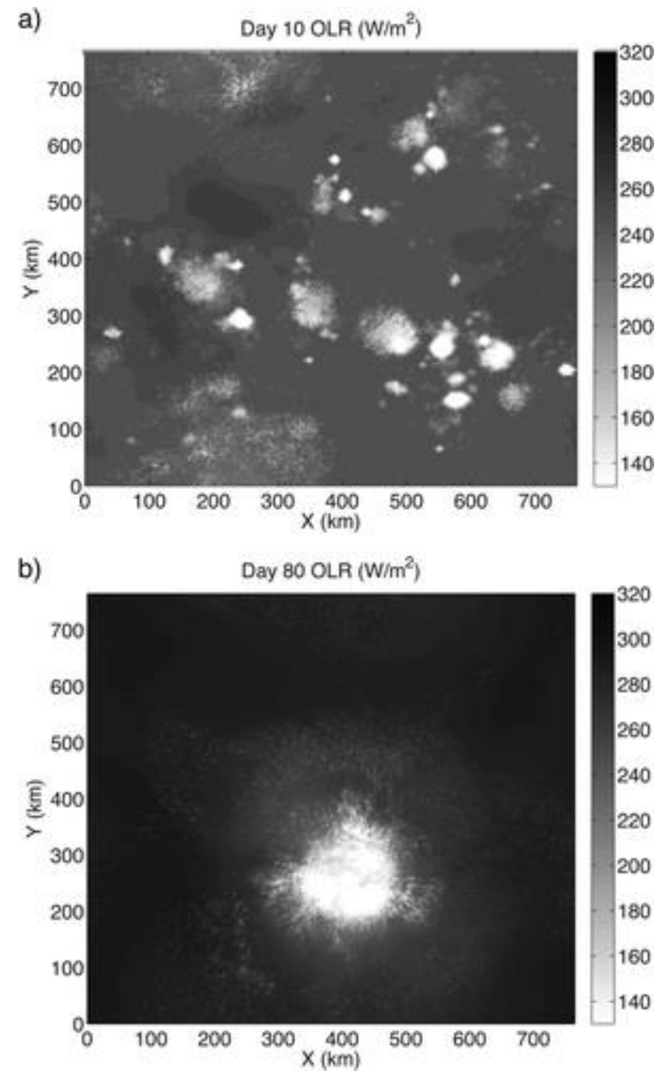
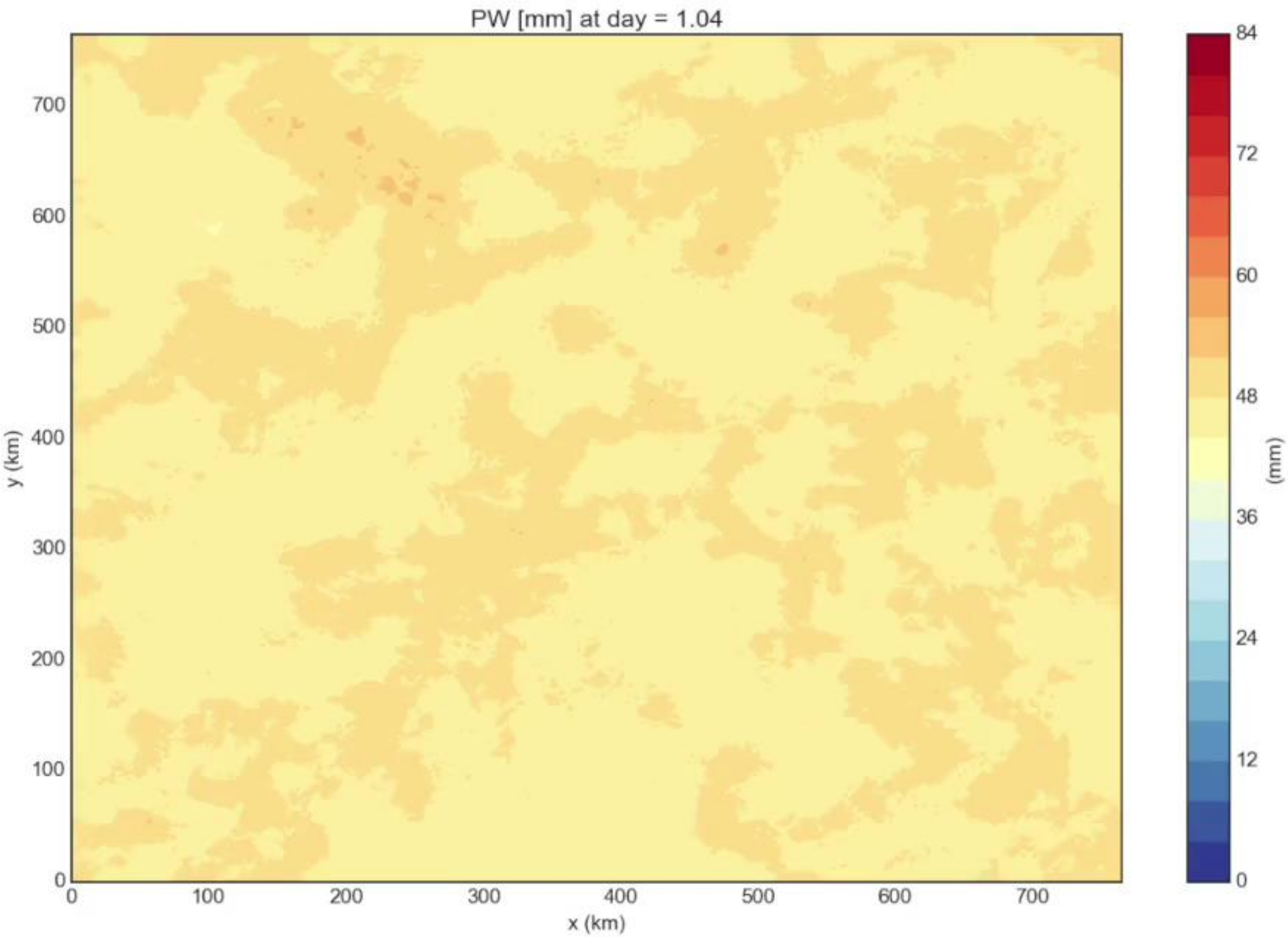
Convective self-aggregation

- the spontaneous spatial organization of convection in numerical simulations of radiative-convective equilibrium despite homogeneous boundary conditions and forcing (Wing et al. 2017)
- arises due to interactions among convection, radiation, environmental moisture, surface fluxes and circulation



Wing and Emanuel (2014)

Example from SAM, 3-km, 302 K SST



Patrizio and Randall (2019)

Aggregation in Observations

- Similar processes (i.e. moisture-convection feedbacks, radiation feedbacks, surface flux feedbacks) are important for observed phenomena:
  - The Madden-Julian Oscillation (MJO)
  - The Intertropical Convergence Zone (ITCZ)
  - Tropical Cyclogenesis

- Even at shorter time and space scales, some of these feedbacks appear to be important for maintaining organised convection against the often dis-aggregating tendency of vertical convective circulations (e.g. Holloway 2017)

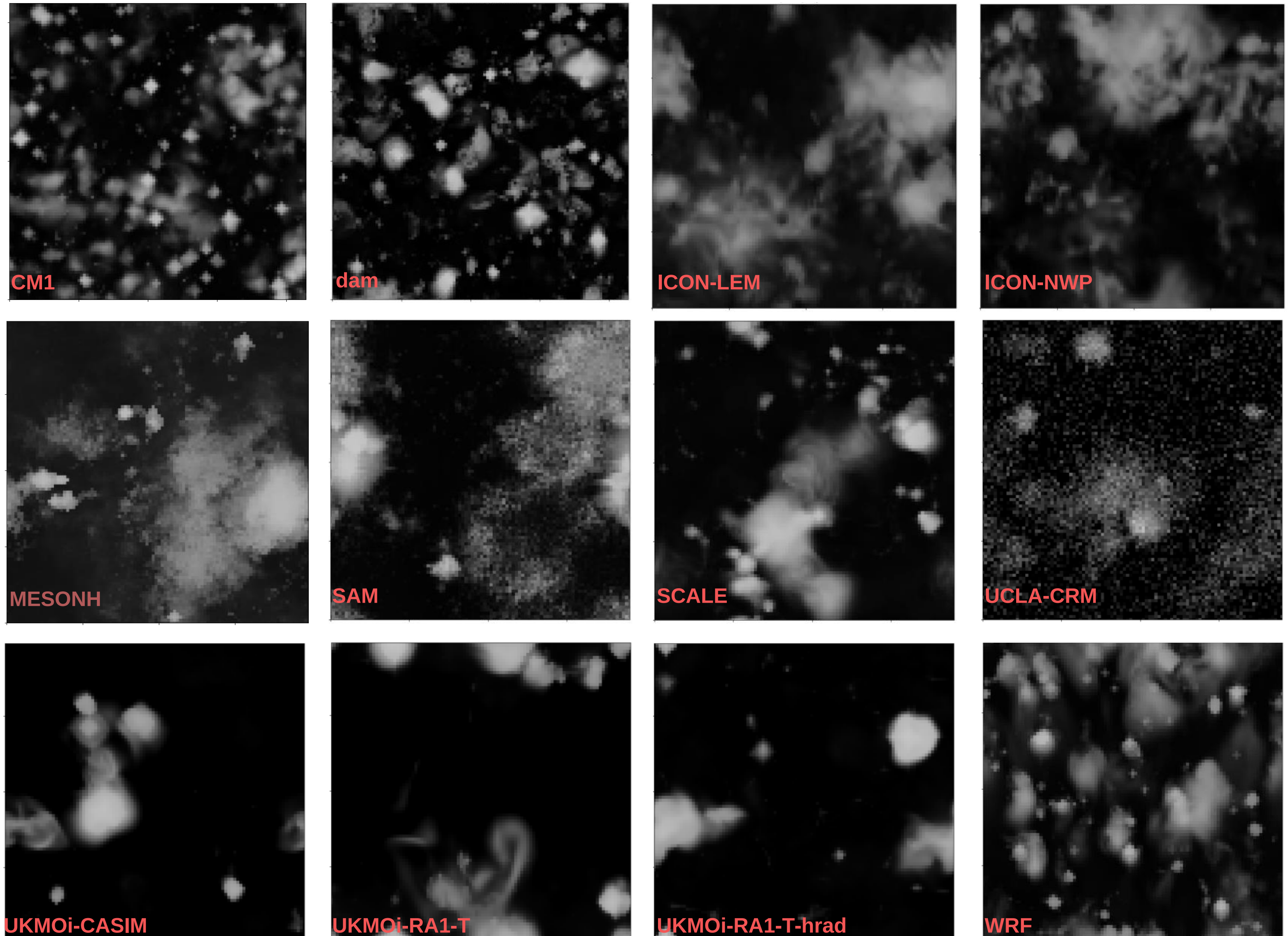
Holloway et al. (2017)

RCEMIP Overview

- Small domain (100x100 km bi-periodic, 1-km)
- large domain (long channel 6000x400 km, 3-km)
- Global models at operational grid spacing
- 295, 300, 305 K fixed SST
- No rotation, constant insolation
- Same initial sounding (for small domain)

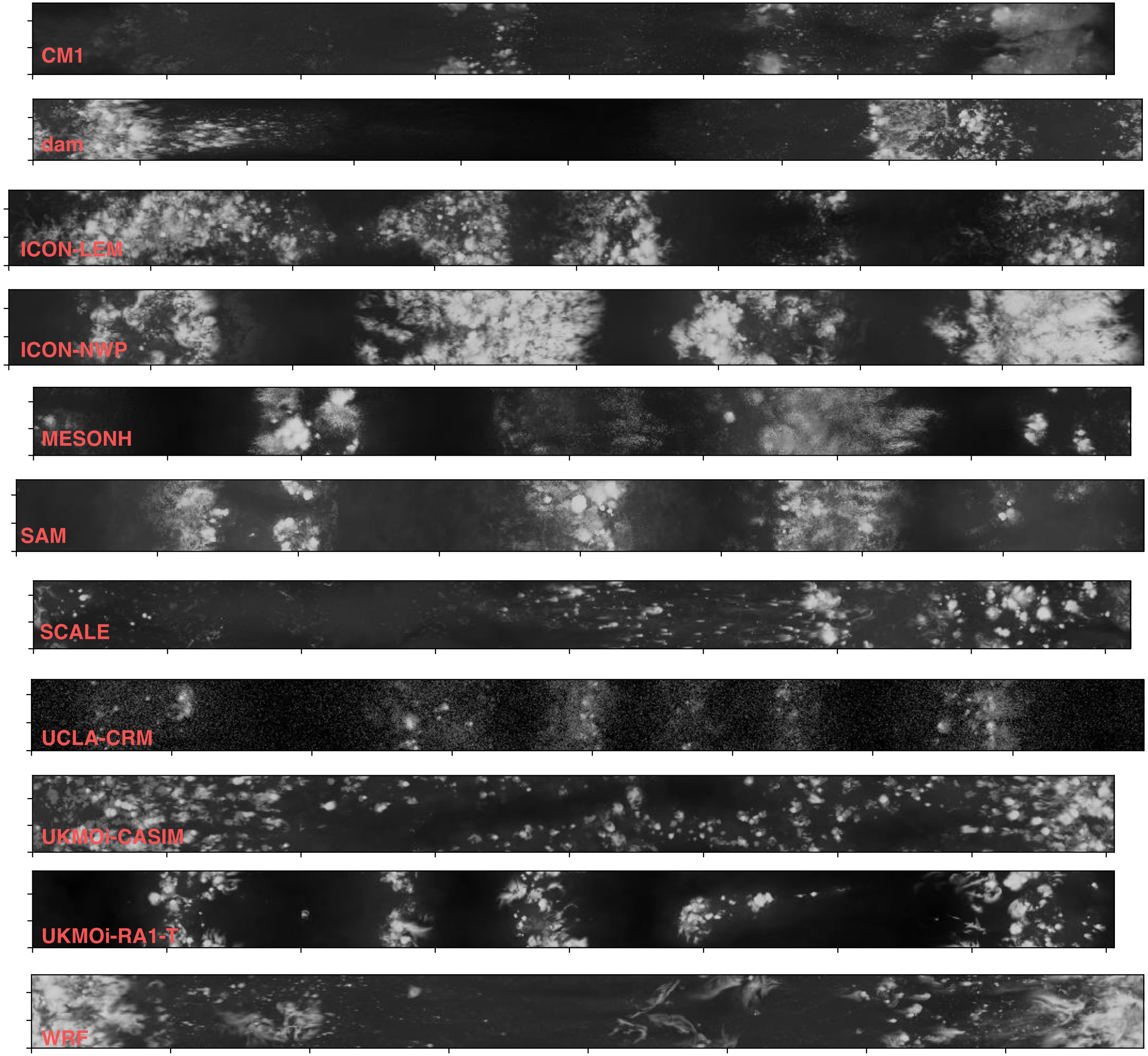
Wing et al. (2018)

OLR small domain, 300K CRMs, day 70



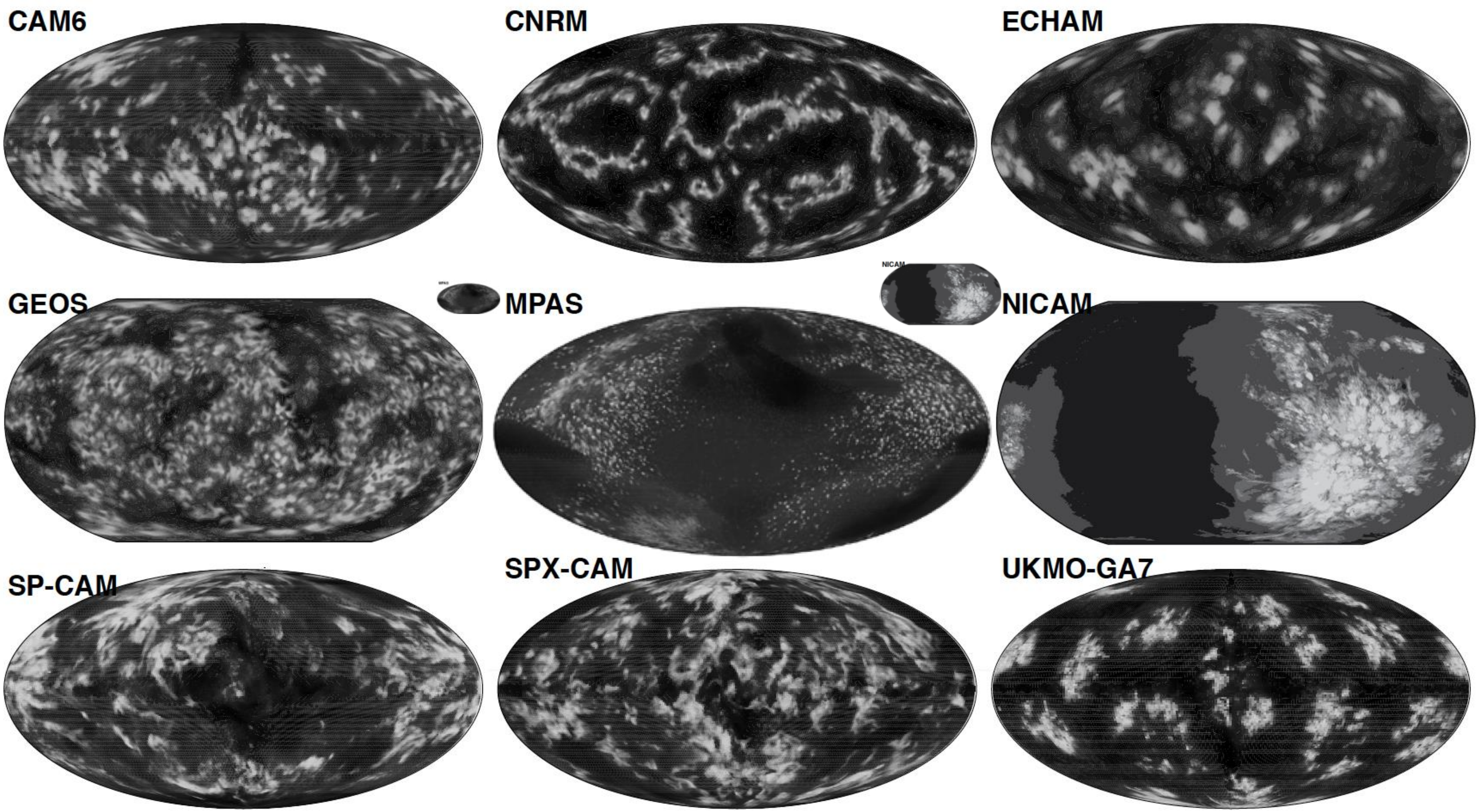
Courtesy of Catherine Stauffer and Allison Wing

OLR large domain, 300K CRMs, day 70



Courtesy of Catherine Stauffer and Allison Wing

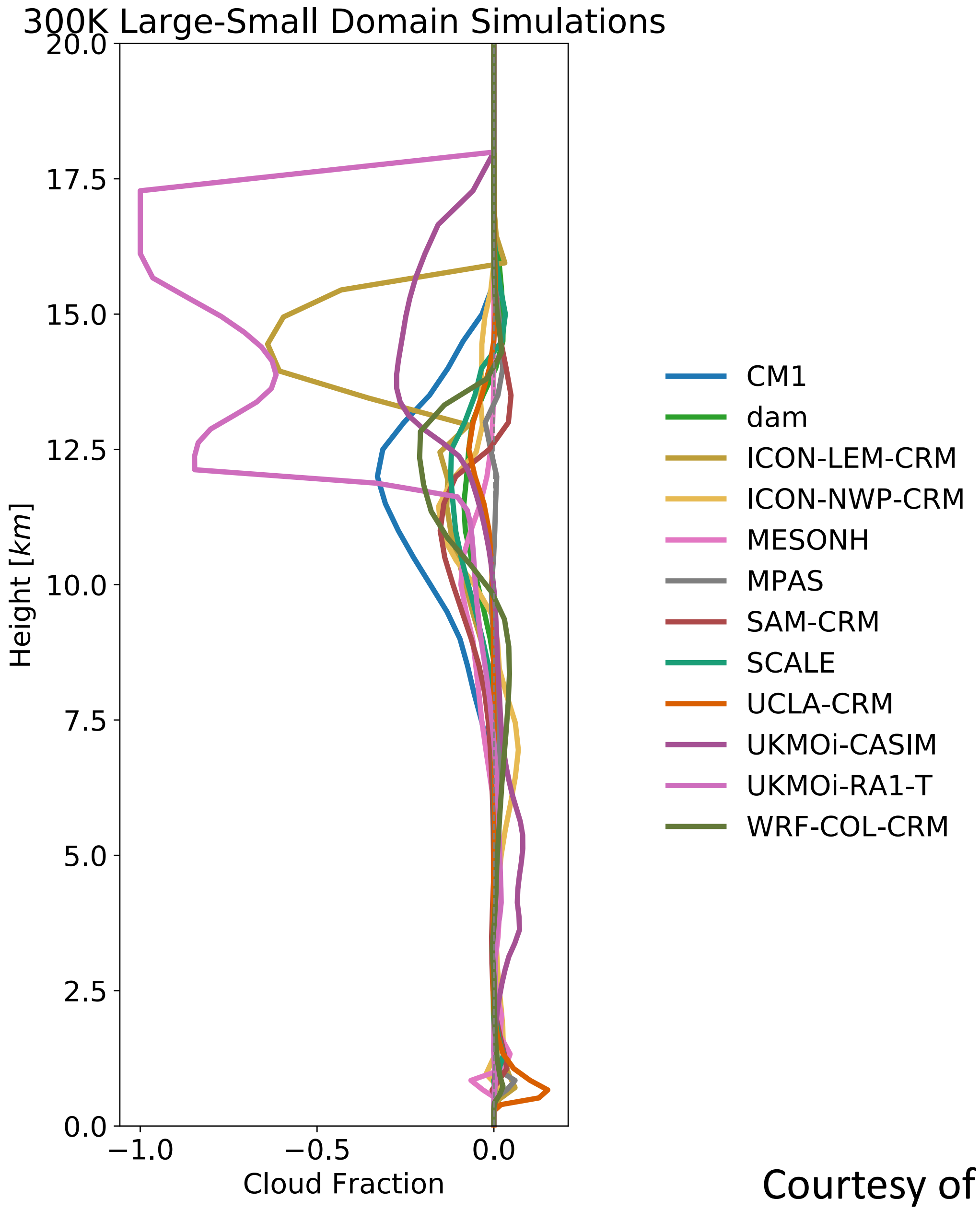
OLR global models, 300K CRMs, day 1000



Note: MPAS ($R_e/8$) and NICAM ($R_e/4$) are 4km small-planet GCRMs

Courtesy of Catherine Stauffer and Allison Wing

Effects of aggregation: cloud fraction

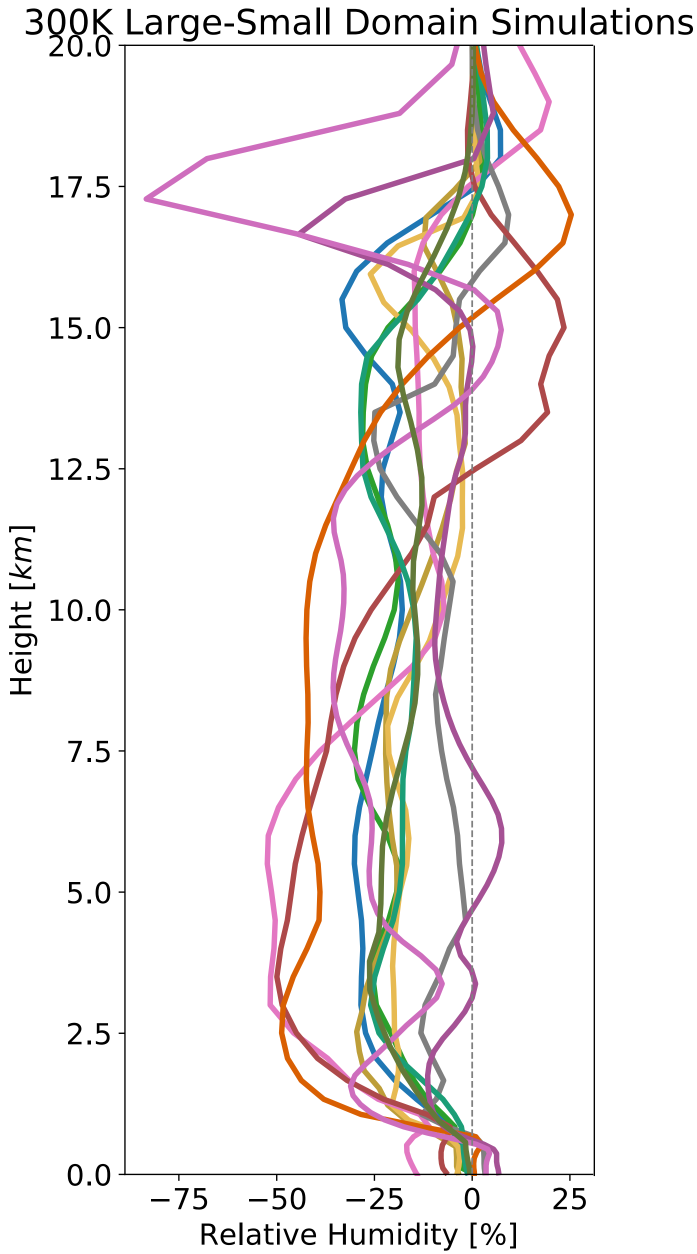


All simulations have a reduction in high cloud fraction with aggregation.

Most seem to have an increase in low clouds.

Courtesy of Catherine Stauffer and Allison Wing

Effects of aggregation: relative humidity

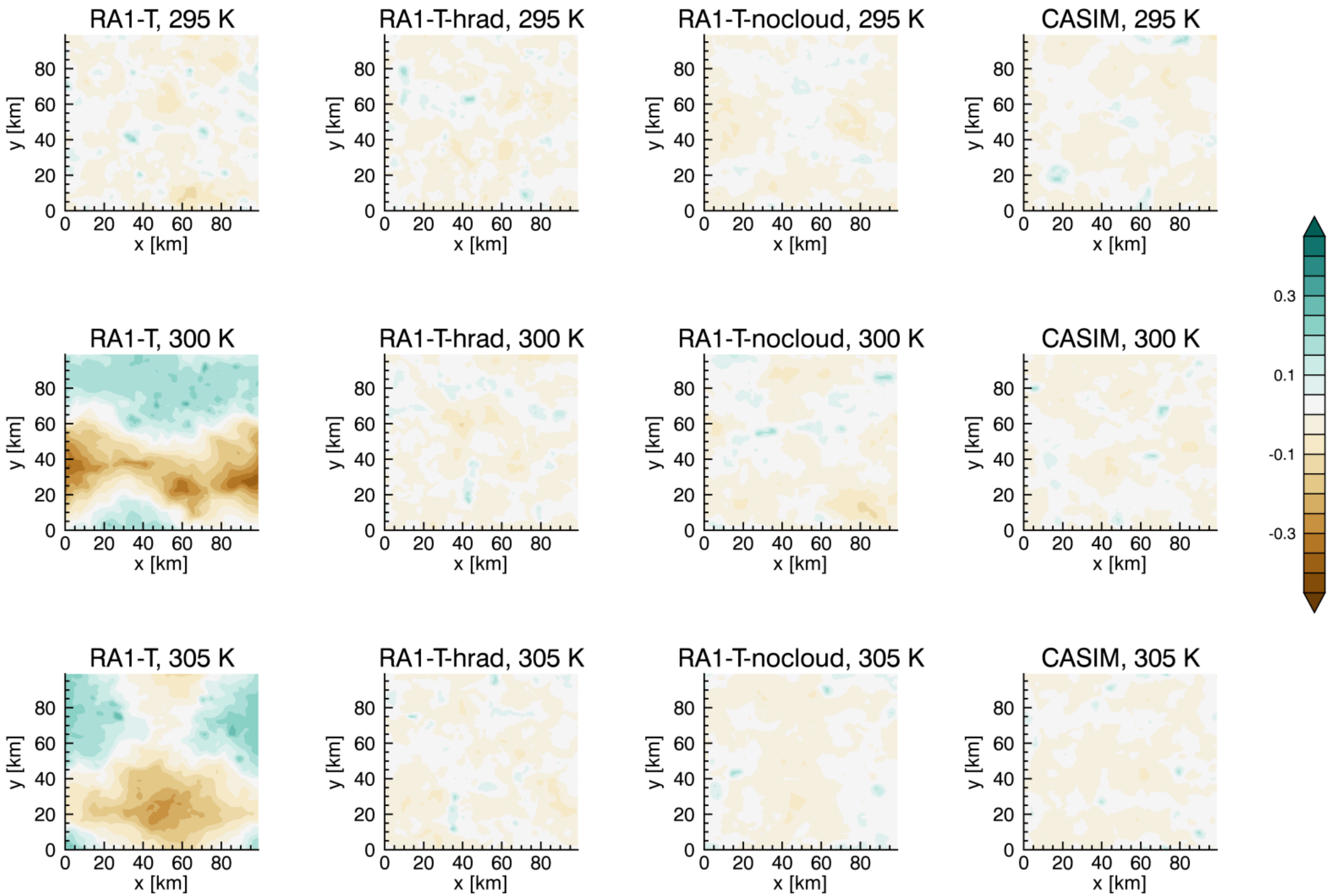


All simulations have a reduction of relative humidity with aggregation.

Courtesy of Catherine Stauffer and Allison Wing

Small Domain, CRH (CWV / domain mean CWVsat)

Day 100, CRH anomalies from domain mean



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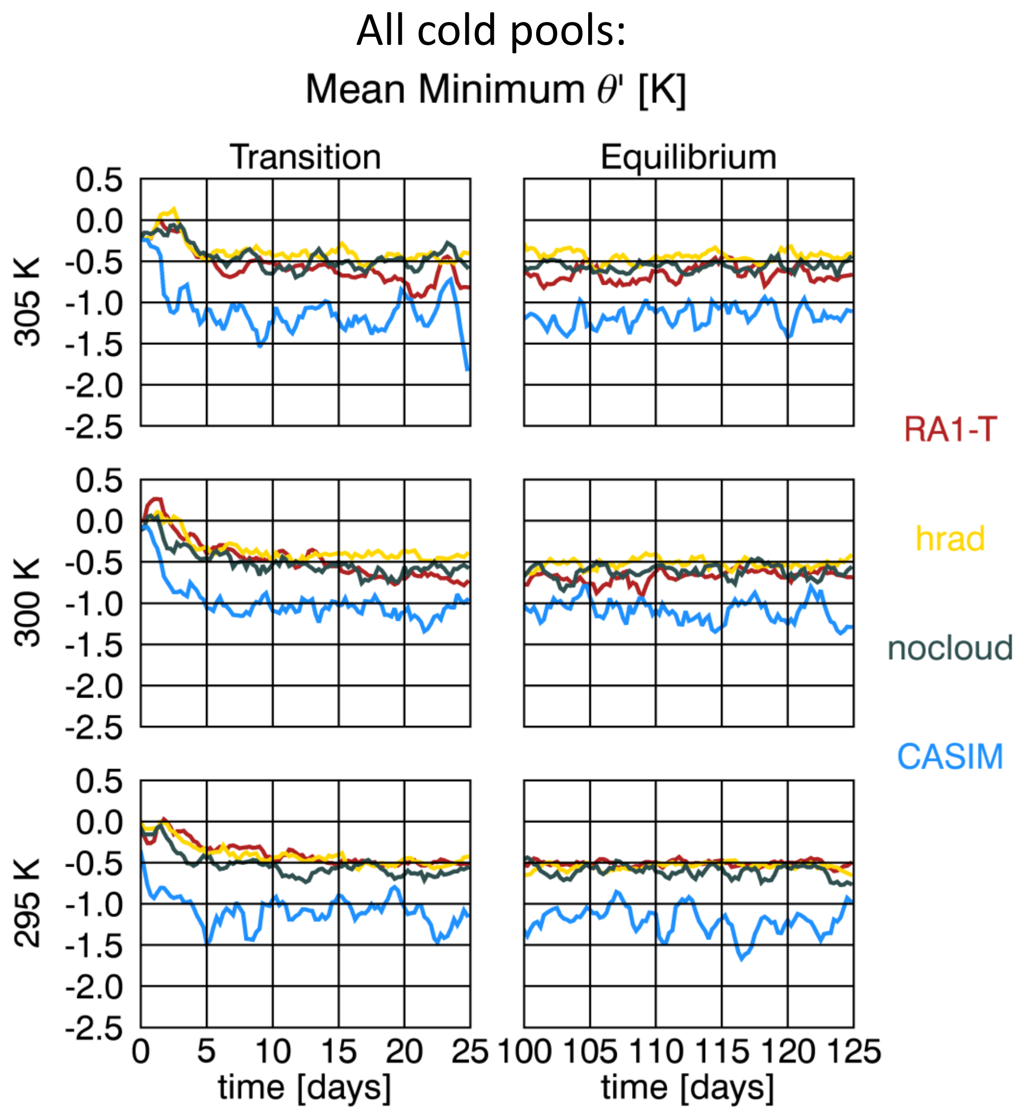
Small Domain, cold pools stronger in CASIM



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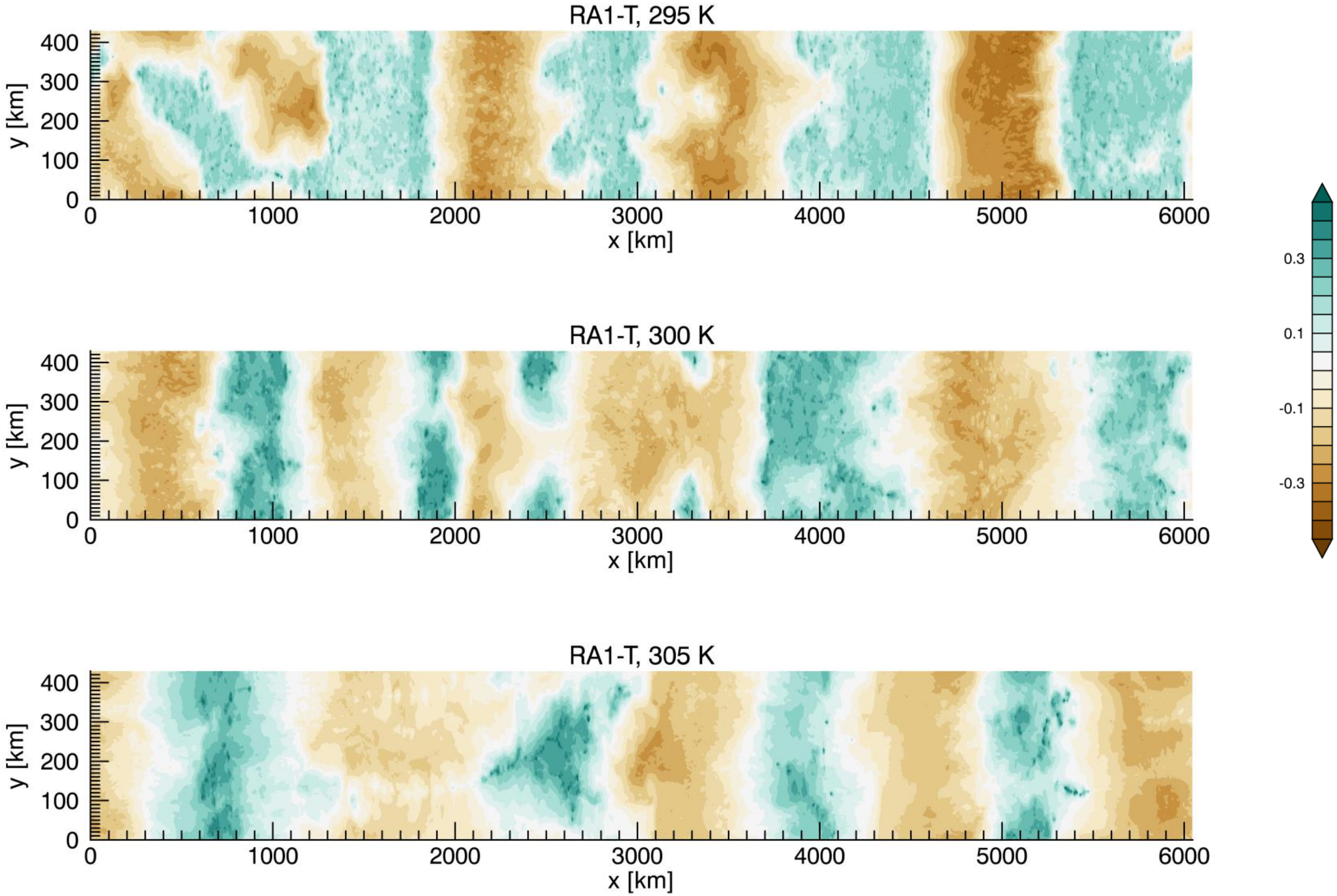
Large Domain, CRH

Day 100, CRH anomalies from domain mean



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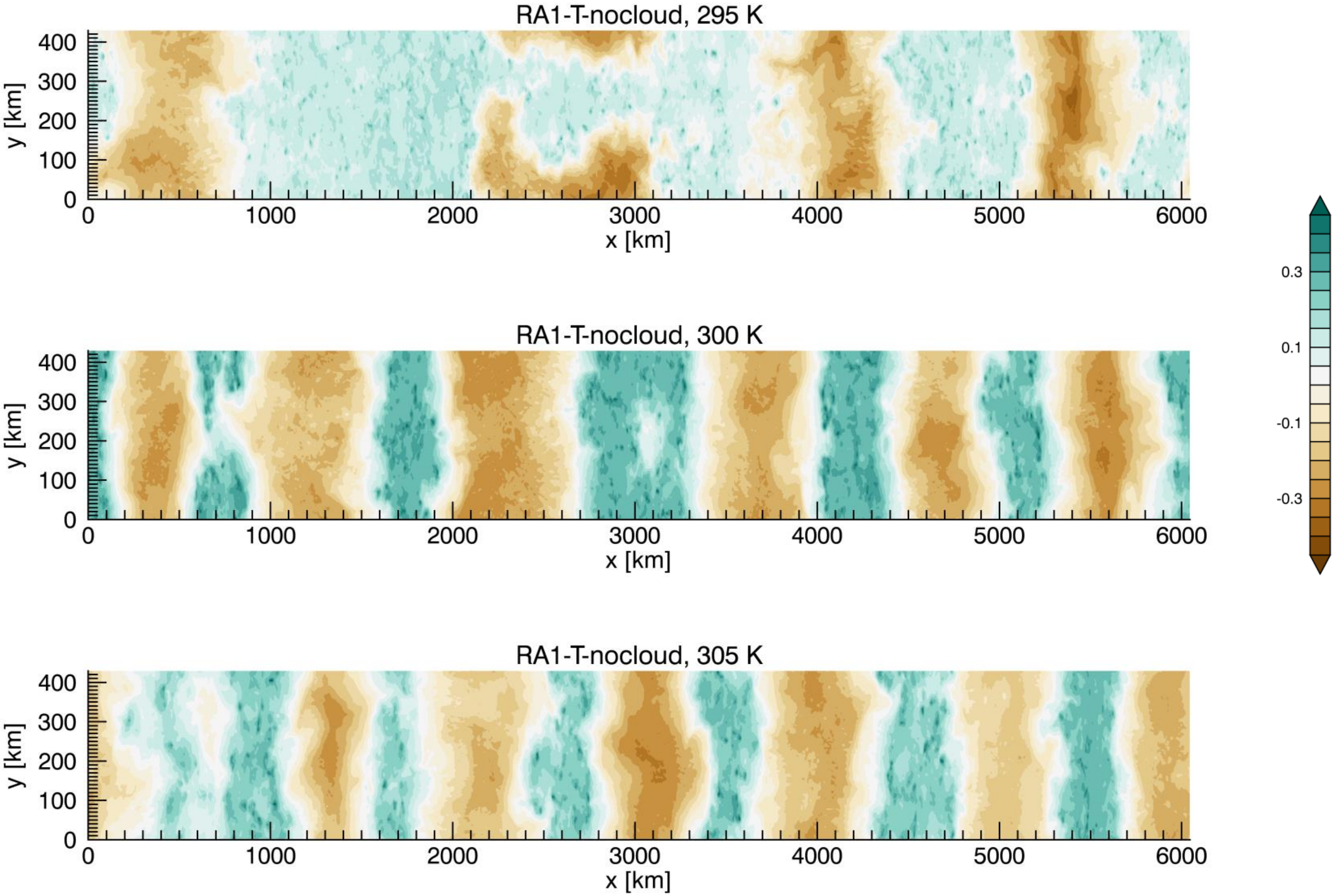
Large Domain, CRH

Day 100, CRH anomalies from domain mean



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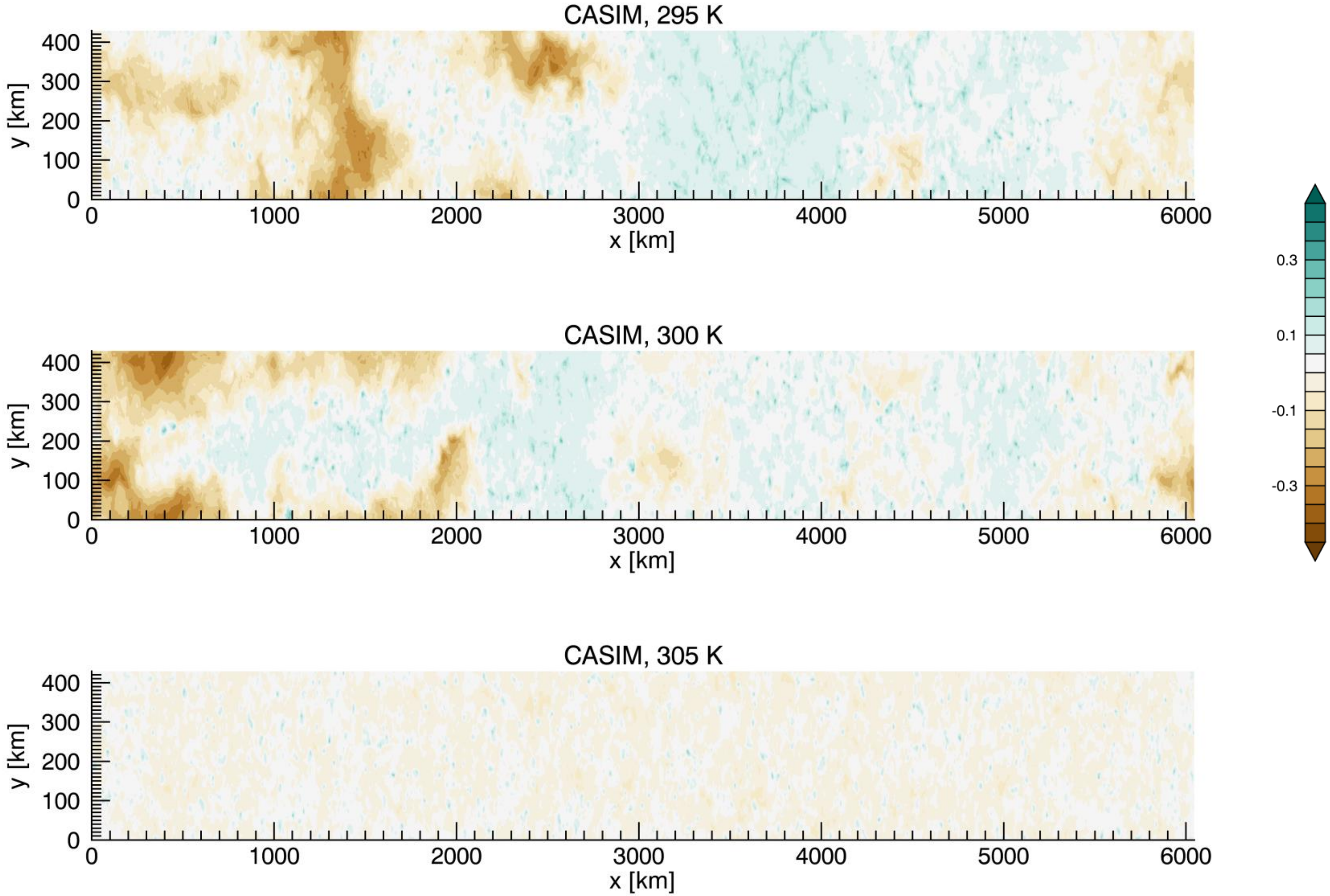
Large Domain, CRH

Day 100, CRH anomalies from domain mean



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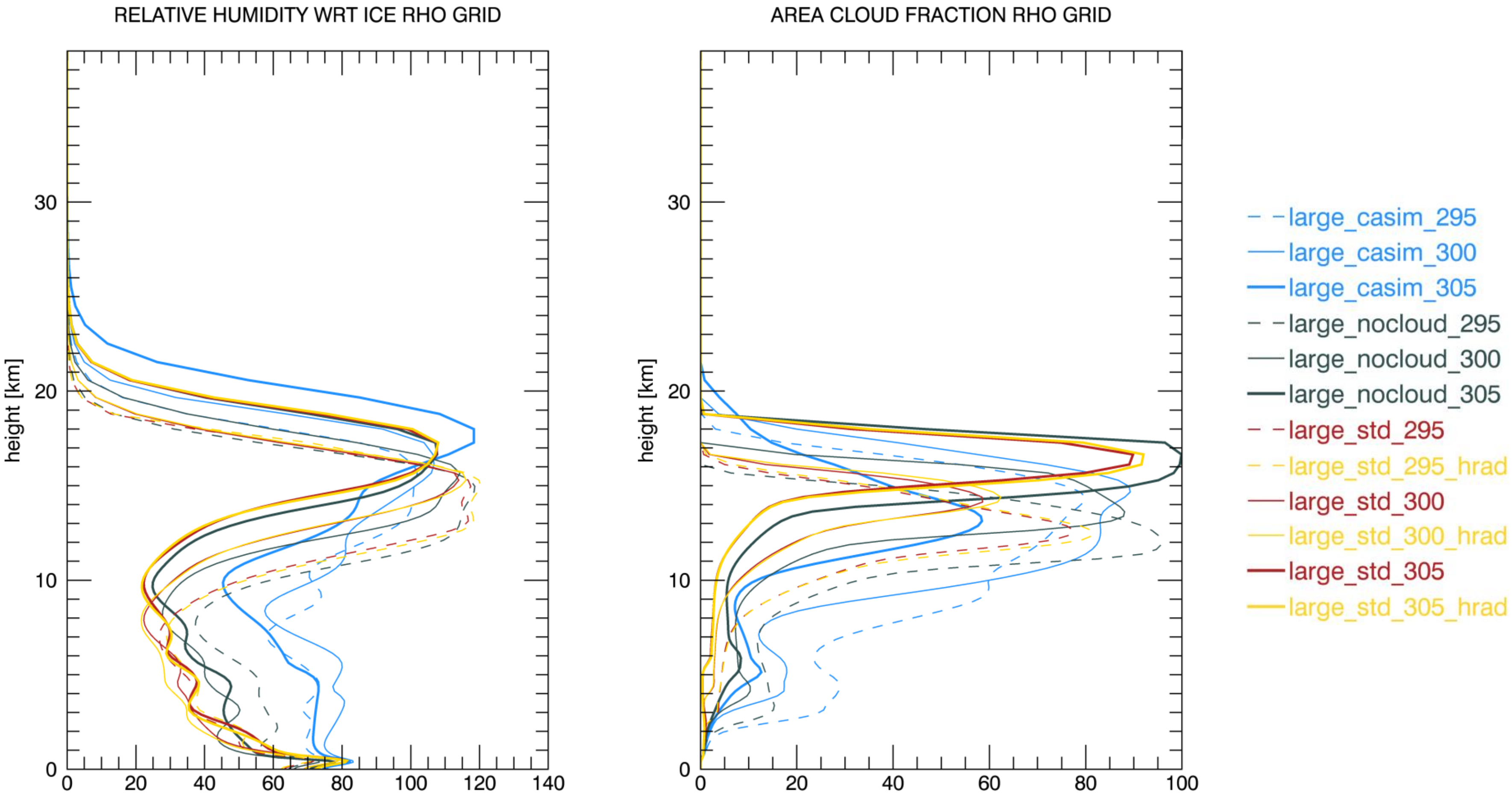
Large Domain, RH and cloud fraction



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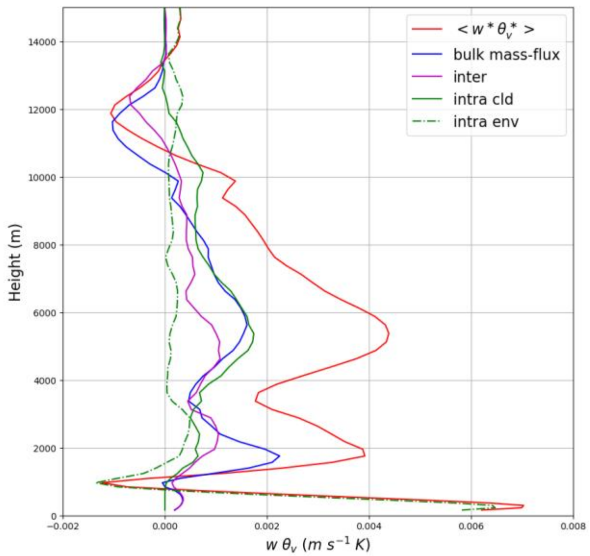
Pathways to use these simulations to aid parameterisation development

Jian-Feng Gu, Todd Jones, ParaCon

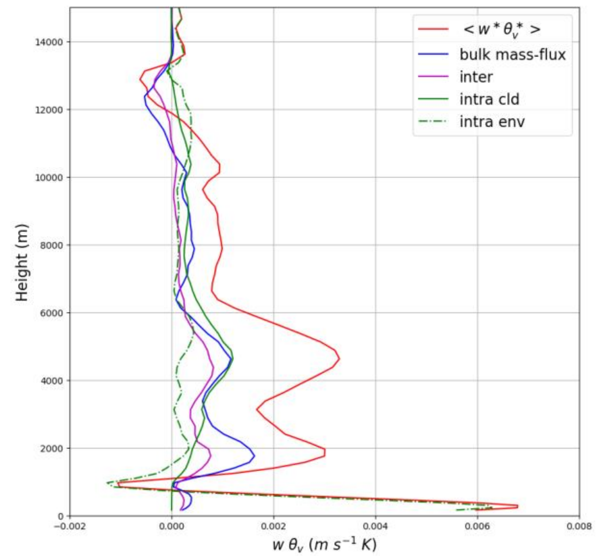
300 K SST, small 100x100 km domain, MetUM RCEMIP simulations

Not aggregrated
(homogenised radiation)



Bulk mass flux approximation (ud: top 0.5%)

Aggregrated
(interactive radiation)



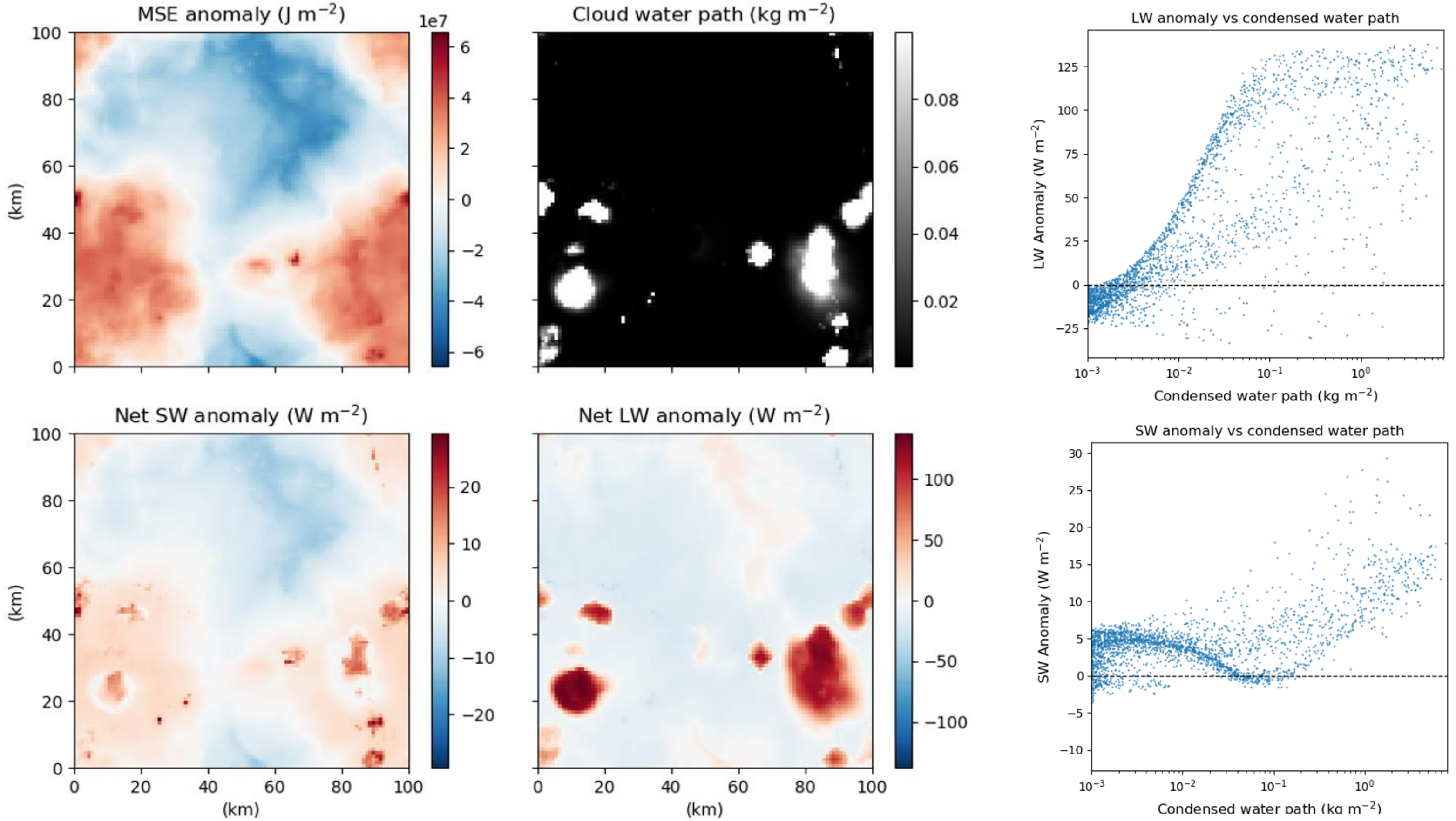
Bulk mass flux approximation (ud: top 0.5%)

Cloud-radiation interactions

Kieran Pope's PhD project

(supervised by Chris Holloway, Thorwald Stein, Todd Jones and Michael Whitall)

305 K SST, small 100x100 km domain



Summary and Ways Forward

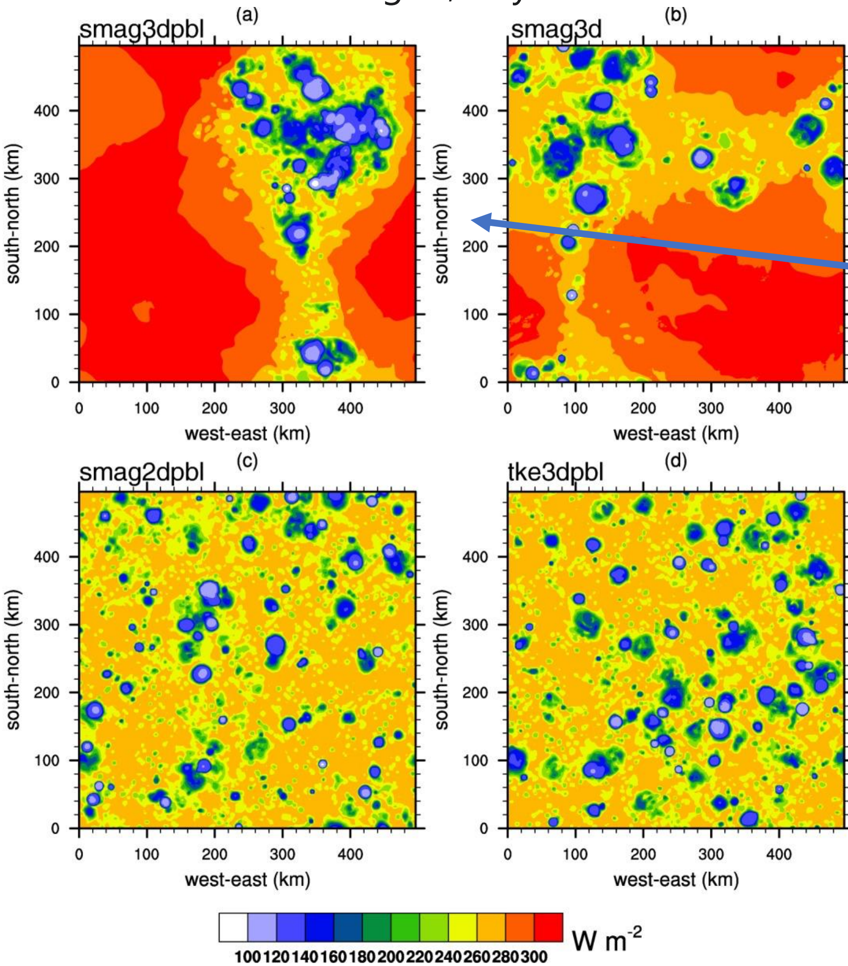
- Observations show some agreement with self-aggregation processes, e.g. anvil cloud radiative warming has a positive effect on organisation.
- RCEMIP has the potential to interrogate the ability of models to simulate convection-circulation-environment relationships across different resolutions and SSTs.
- Possible pathways toward using this kind of framework to inform convection parametrization development.
  - Run coarse model with parameterised convection on same large domain as CRMs
  - Investigate processes that are important for feedbacks in self-aggregation, connect with biases in coarse runs (Kieran Pope's PhD on cloud-radiation interactions)
  - Plume/entrainment/convection characteristics in LES/CRM RCE that differ in aggregated versus dis-aggregated state (Jian-Feng Gu's work on plumes, Tobias Becker's talk)

Questions for ParaCon

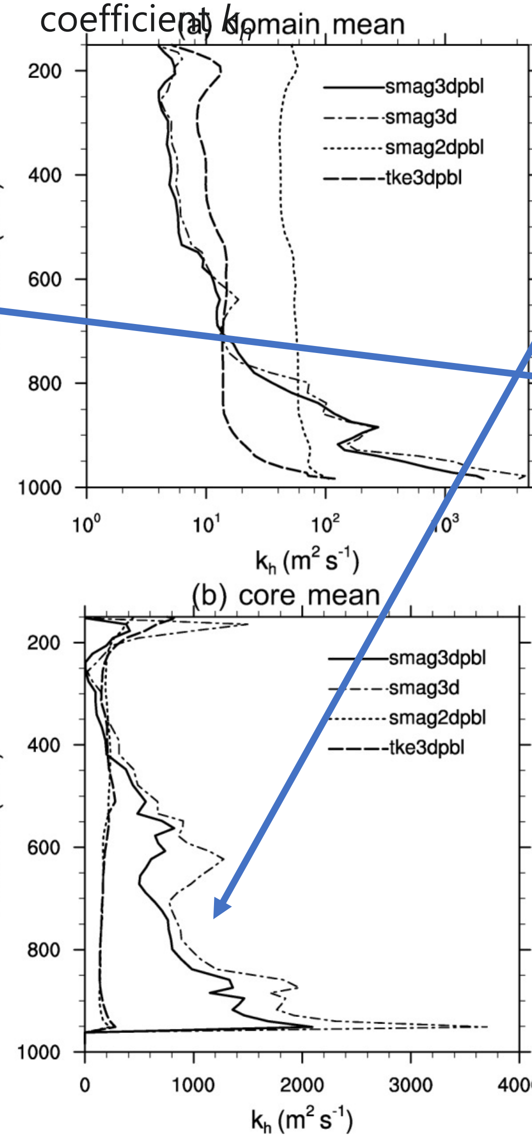
1. Are aggregation and related processes important to parameterize (at “subgrid” scales)?
2. Is aggregation and related large-scale organization represented in coarse models with parameterized convection, and how is this sensitive to resolution?
3. What can we learn from self-aggregation studies that can inform our efforts to improve the representation of convection in models, particularly in the grey zone?

Convective Mixing allows Aggregation

2 km grid, Day 70 OLR



mean horizontal mixing coefficient k_h



The runs with larger mixing in the convective cores are the ones which show self-aggregation. Larger sensitivity to environmental moisture.

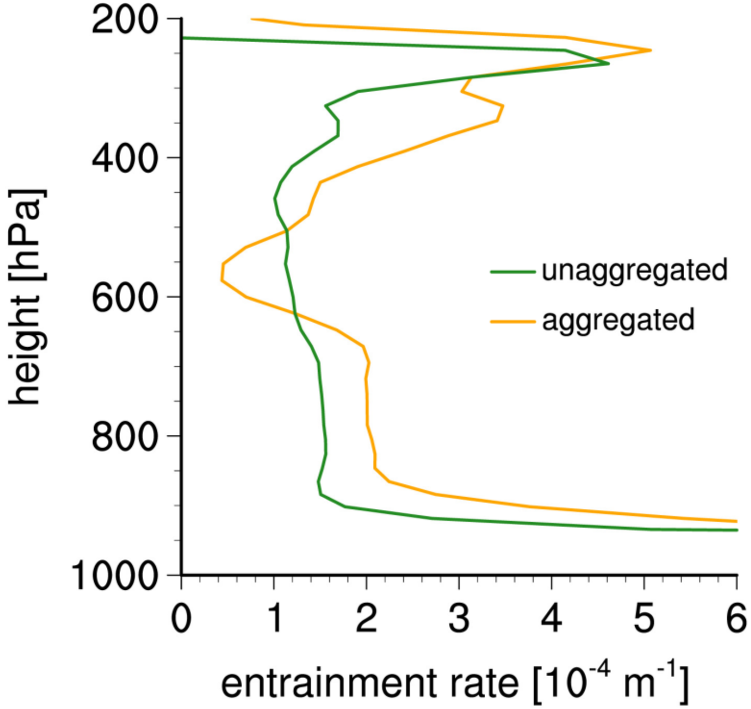
Still need diabatic feedbacks (e.g. cloud radiation).

Links to MJO: increased entrainment also improves MJO.

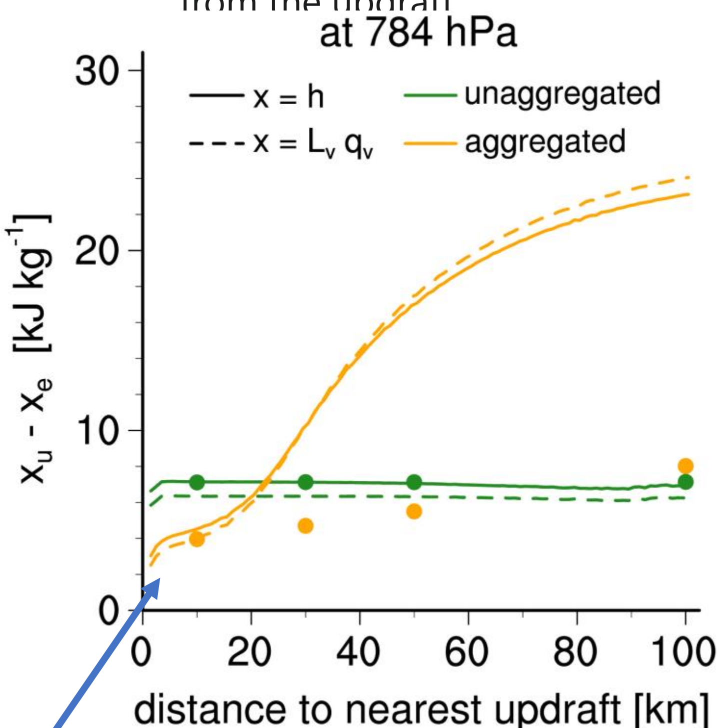
Tompkins and Semie (2017)

Aggregation mitigates Convective Mixing effects

1 km grid, used tracers to estimate bulk entrainment at 10-km scale



Moist static energy difference between updraft mean and the environment at a given distance from the updraft



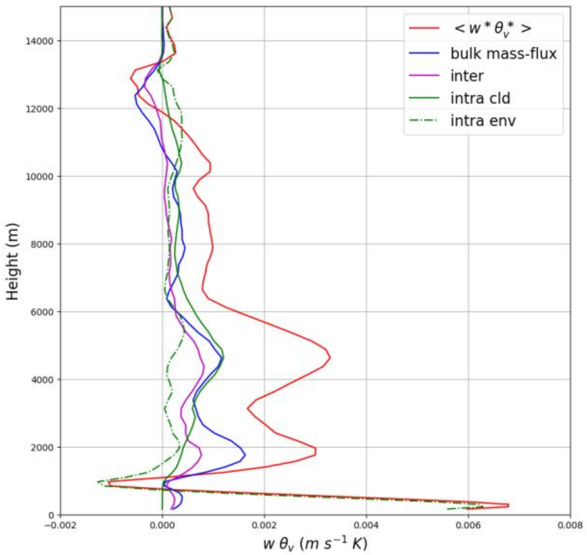
The protective "moist shell" effect dominates here, so updrafts are less diluted by entrainment in aggregated conditions

Becker et al. (2018)

Questions for ParaCon

1. Are aggregation and related processes important to parameterize (at “subgrid” scales)?
   a. At “subgrid” scales we need to represent key processes, including convective mixing, cloud and moisture radiation effects (if grid scale is not sufficient), and subgrid cloud latent heating (especially shallow convection).
   b. In coarse models (grid length > 10 km) this likely includes the partition of the subgrid environment into: (i) the near-environment around updrafts, and (ii) the outer environment.
2. Is aggregation and related large-scale organization represented in coarse models with parameterized convection, and how is this sensitive to resolution?

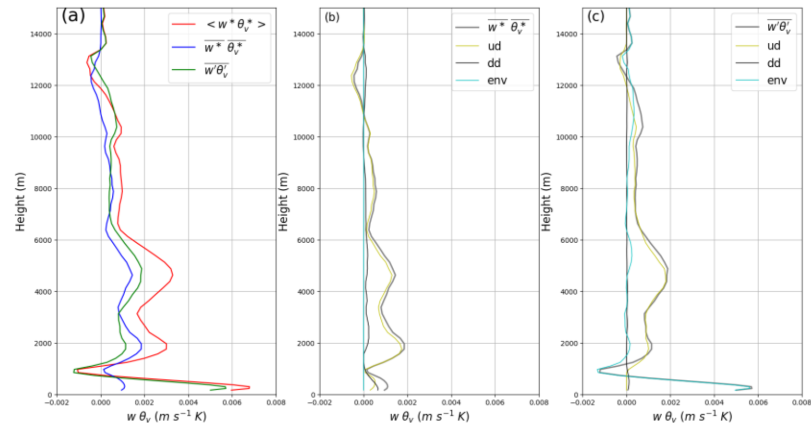
   Aggregation does occur, tends to be weaker in coarser models (but not always).
3. What can we learn from self-aggregation studies that can inform our efforts to improve representations of convection in models, particularly in the grey zone?
   a. We need to consider near-environment of updrafts (and not just in “aggregation” context, but also for other types of organisation).
   b. Cold pools can inhibit aggregation; need to be careful with cold pool parametrisations.
   c. Still work to do using higher resolutions and more complex surface boundaries: ocean coupling, land surface.



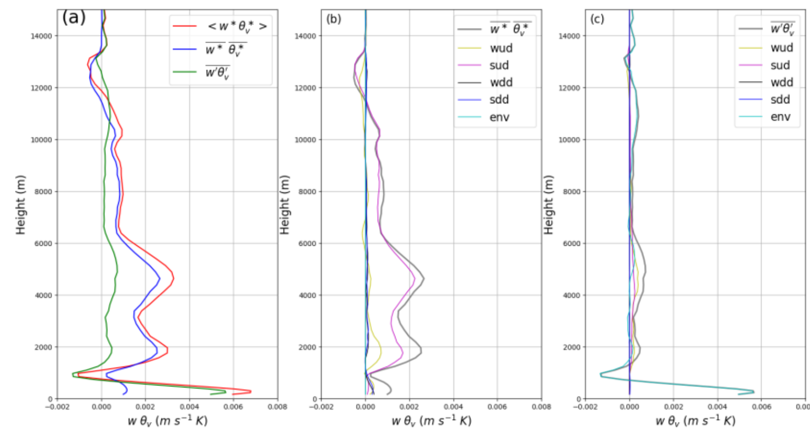
Bulk mass flux approximation (ud: top 0.5%)

RCEMIP:

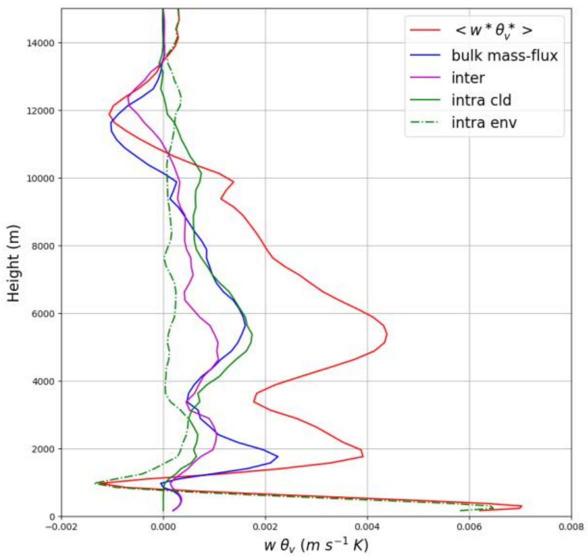
small domain
100km*100km*40km (100*100*98)
SST=300K;
self-aggregate



bulk plume (ud&dd: top 0.5%)



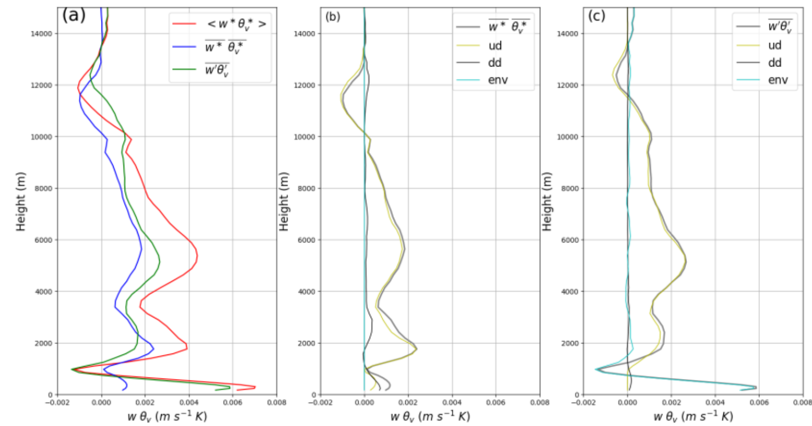
Core-cloak representation
(core: top 0.1%; cloak: top 0.5-0.1%)



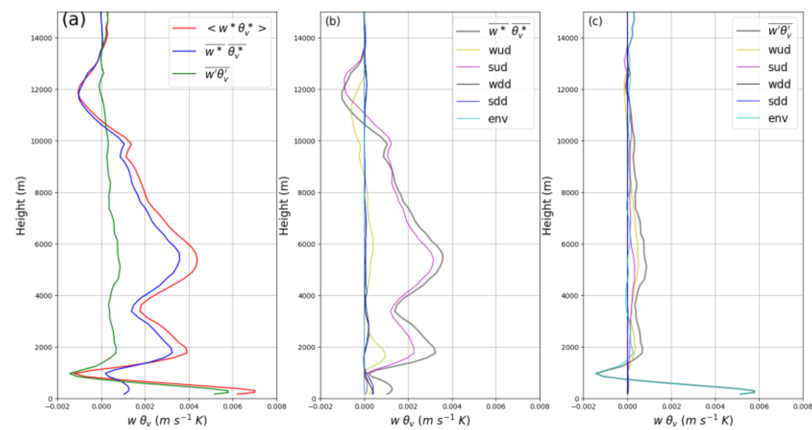
Bulk mass flux approximation (ud: top 0.5%)

RCEMIP:

small domain
100km*100km*40km (100*100*98)
SST=300K;
homogeneous radiation
non-aggregate;



bulk plume (ud&dd: top 0.5%)



Core-cloak representation
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