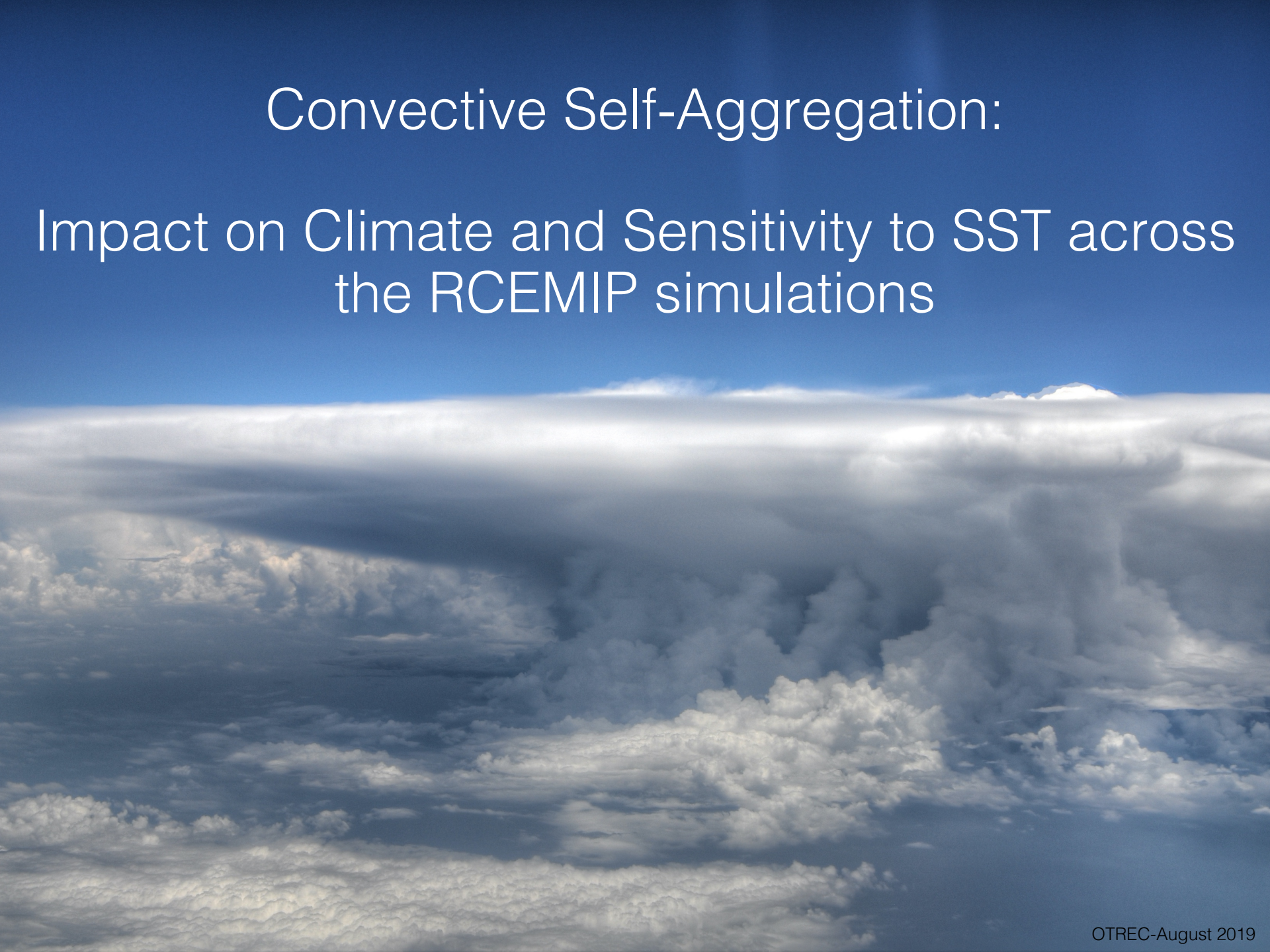
Convective Self-Aggregation:

Impact on Climate and Sensitivity to SST across the RCEMIP simulations



Convective Self-Aggregation:

Impact on Climate and Sensitivity to SST across the RCEMIP simulations

Allison Wing*, Catherine Stauffer

Kevin Reed, Tobias Becker, Min-Seop Ahn, Nathan Arnold, Sandrine Bony, Mark Branson, George Bryan, Jean-Pierre Chaboureau, Stephan de Roode, Kulkarni Gayatri, Cathy Hohenegger, I-Kuan Hu, Fredrik Jansson, Todd Jones, Marat Khairoutdinov, Daehyun Kim, Shuhei Matsugishi, Zane Martin, Brian Medeiros, Hiroaki Miura, Yumin Moon, Sebastian Mueller, Tomoki Ohno, Thara Prabhakaran, David Randall, Rosimar-Rios Berrios, Nicolas Rochetin, Romain Roehrig, David Romps, James Ruppert Jr., Masaki Satoh, Levi Silvers, Martin Singh, Bjorn Stevens, Lorenzo Tomassini, Chiel van Heerwaarden, Shuguang Wang, Ming Zhao

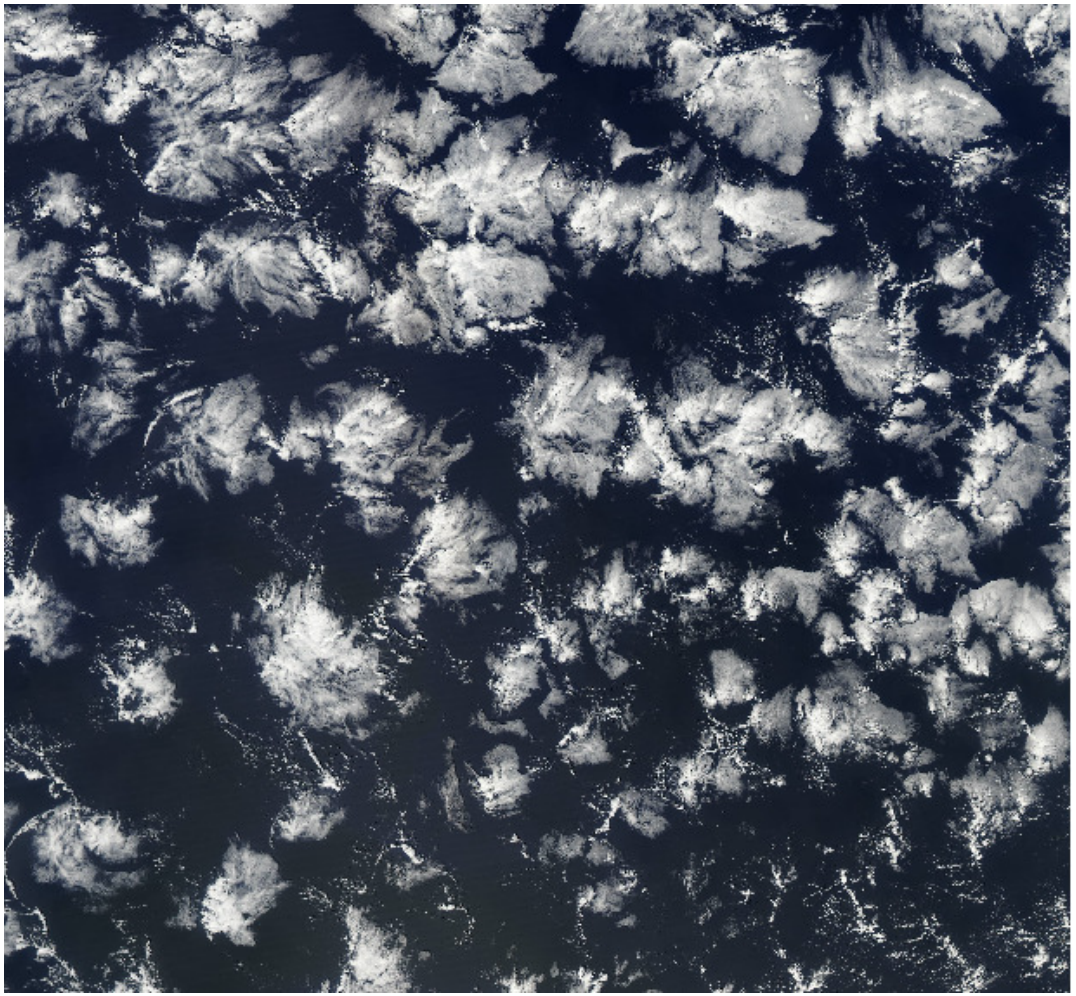
*Assistant Professor, Florida State University

Supported by NSF-AGS 1830724
Thanks to DKRZ for hosting data.

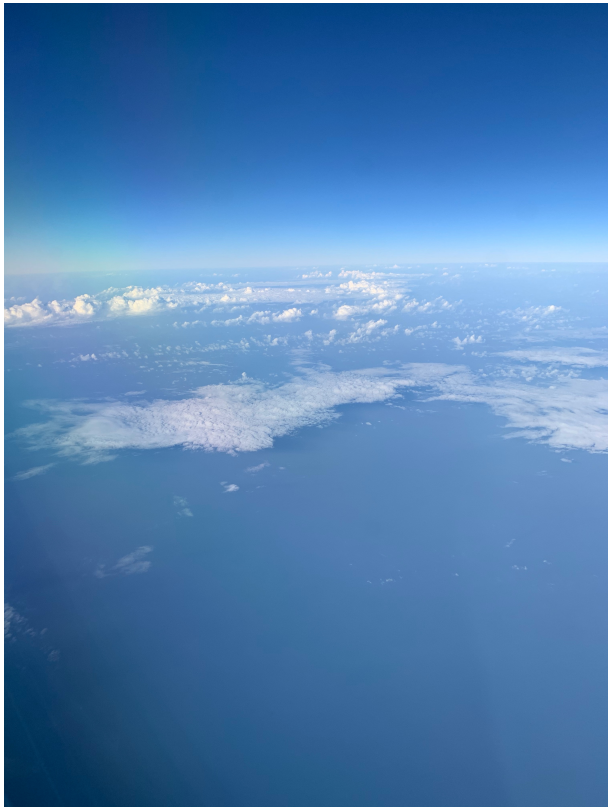
Sometimes tropical convection is isolated or scattered

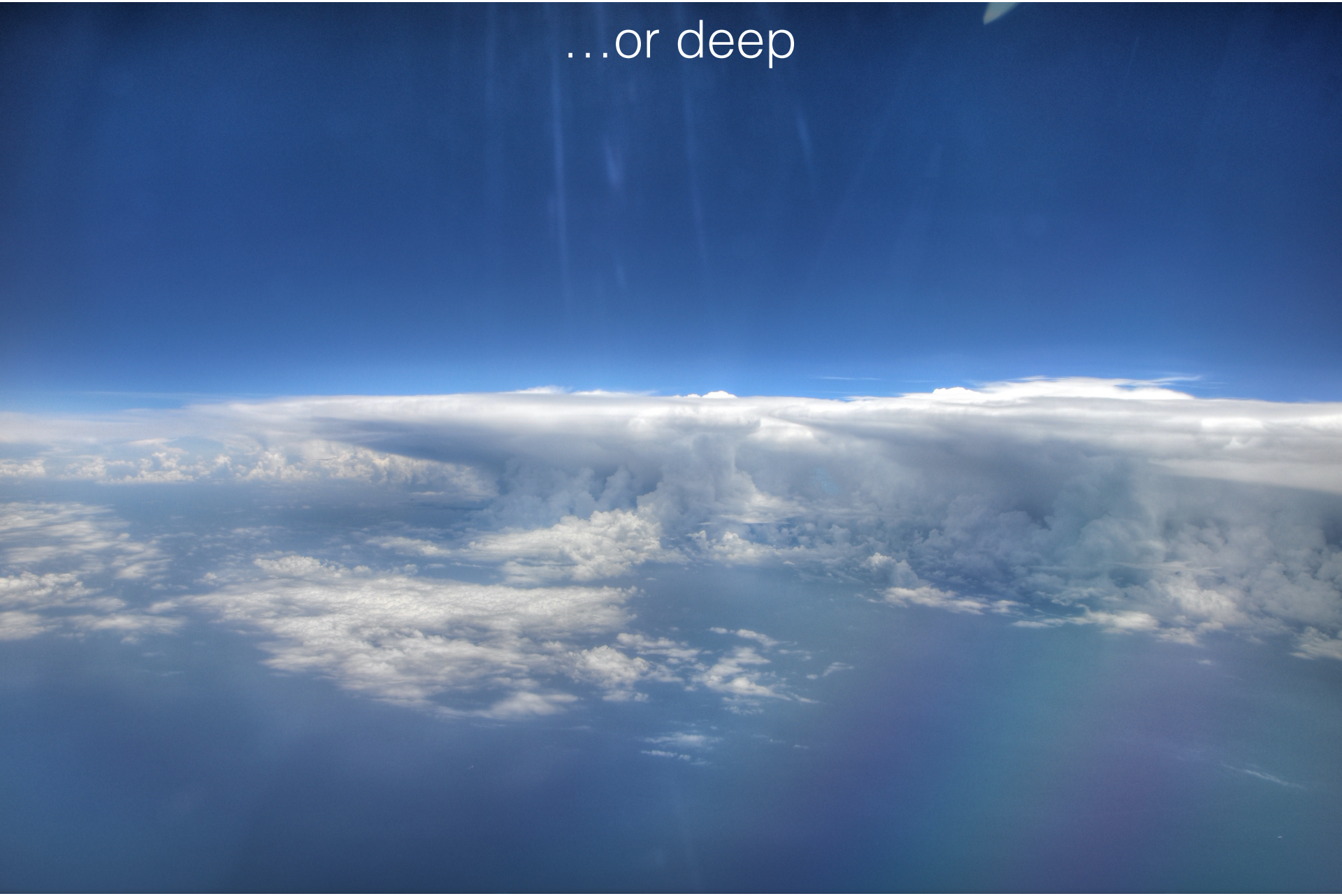
But often it is not

Convection may be organized, whether it is shallow…



EUREC4A HALO RF07 – 31Jan2020

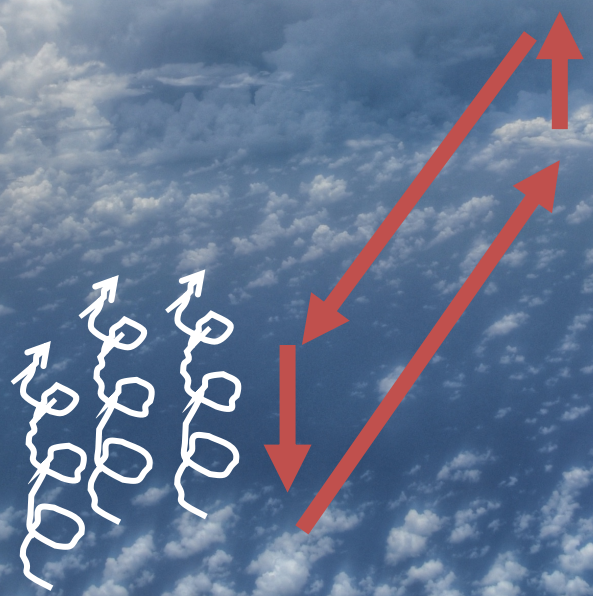



…or deep


OTREC-August 2019

Can shallow clouds drive radiatively-driven circulations?
EUREC4A

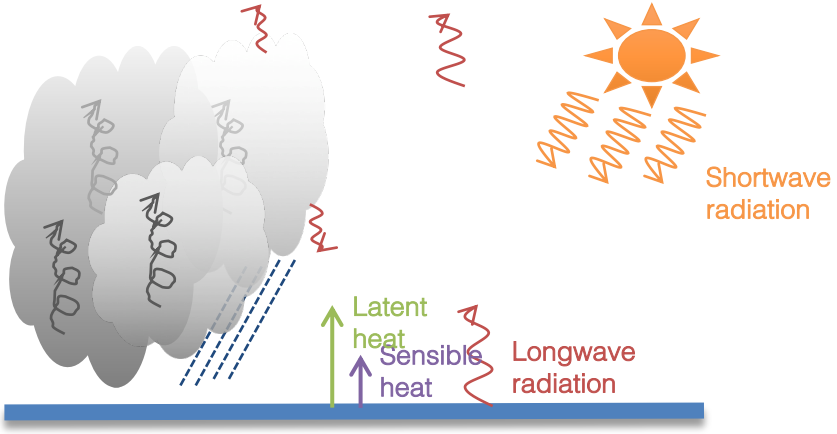
How do these circulations help deep convection organize?



Investigate convective self-aggregation in a multi-model ensemble of radiative-convective equilibrium

Radiative-Convective Equilibrium

A statistical equilibrium: balance between net radiative cooling and convective heating



"Time-honored idealization for understanding the tropical atmosphere and its sensitivity to relevant forcings"

Bretherton et al. (2005)

- Simplest possible way to phrase questions about climate
- Accessible by many model types
- Common baseline needed

RCEMIP:

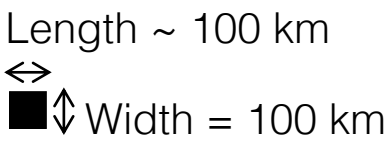
(1) Response of clouds to warming & climate sensitivity
(2) Convective self-aggregation
(3) Robustness of RCE state

RCEMIP Protocol

Two Sets of Simulations:

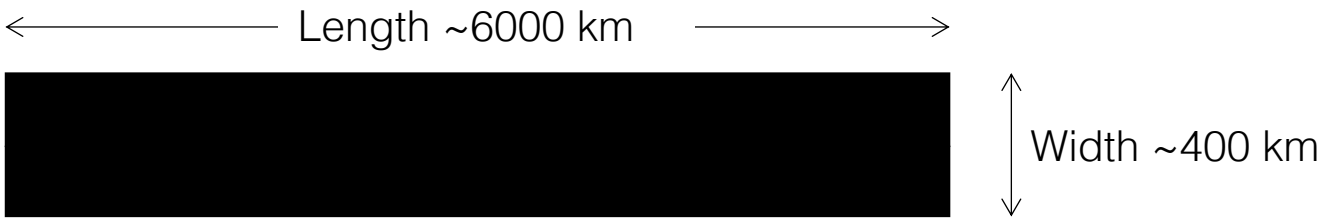
1. RCE_small (295 K, 300 K, 305 K)

- 100 km square for CRMs, 1 km horiz spacing
- Single column or small Earth for GCMs
- 200 m horiz spacing for LES



2. RCE_large (295 K, 300 K, 305 K)

- 6000 km x 400 km rectangle for CRMs, 3 km horiz spacing
- Global for GCMs, GCRMs

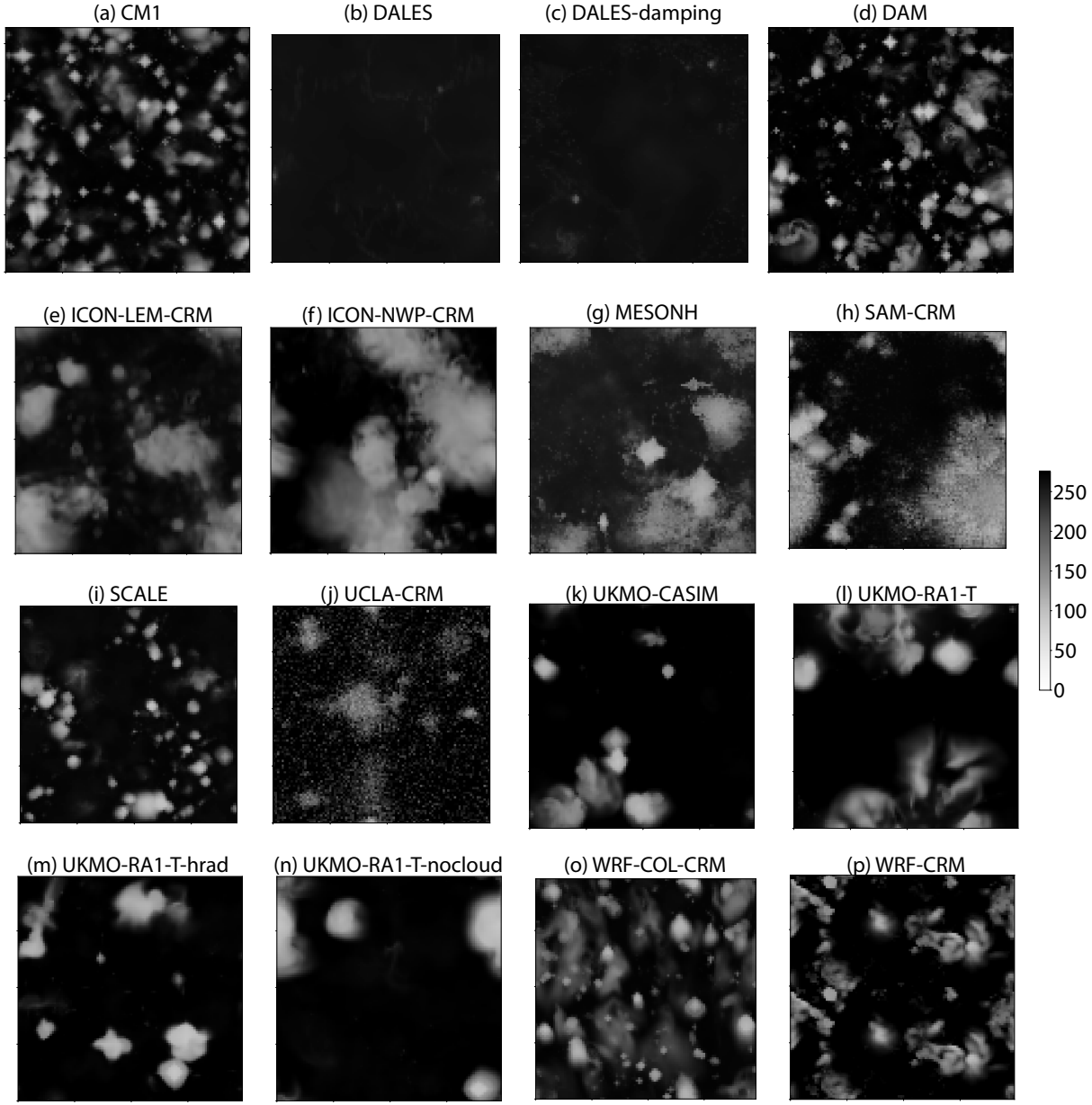


Aquaplanet, uniform insolation, uniform SST, initialized from random noise

Participation from 47 Models

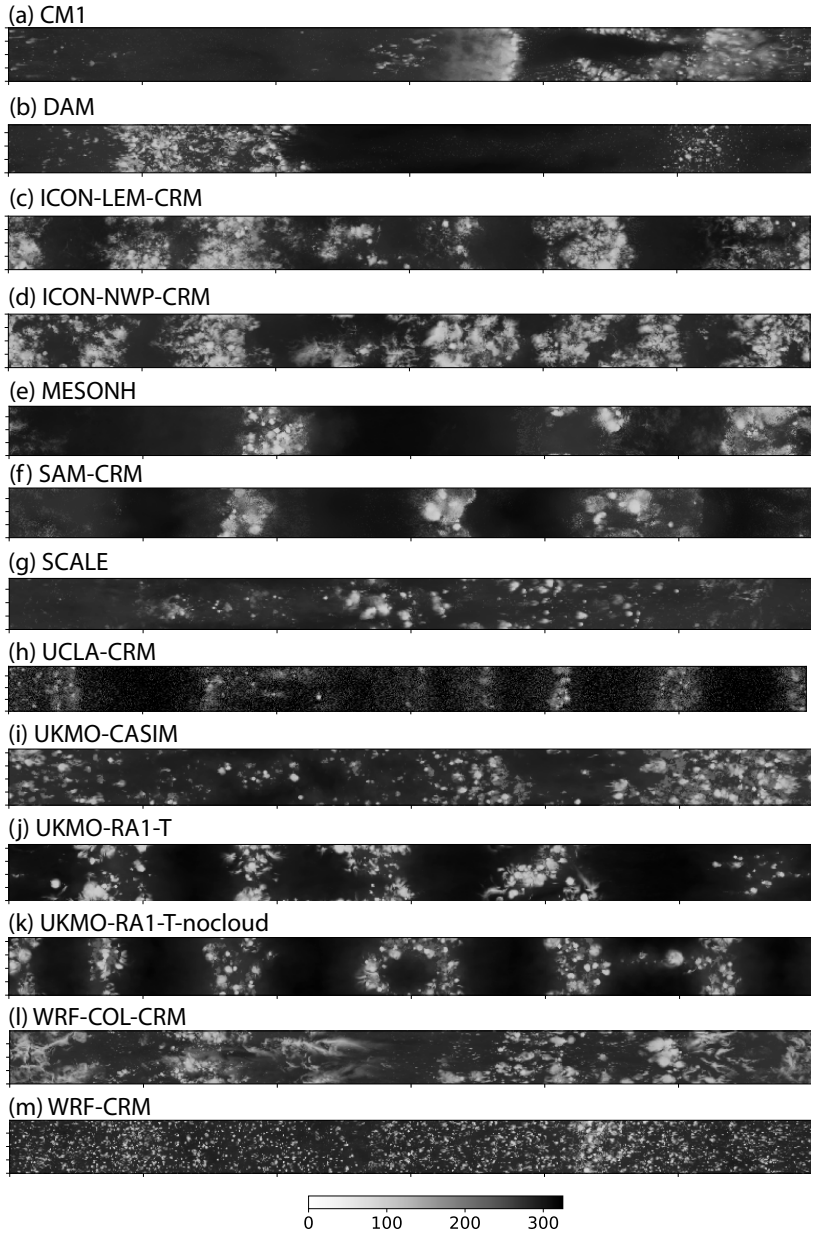
GCMs (16), CRMs (17), LES (6), GCRMs (3), SCMs (5)

Outgoing Longwave Radiation, Day 80: CRMs



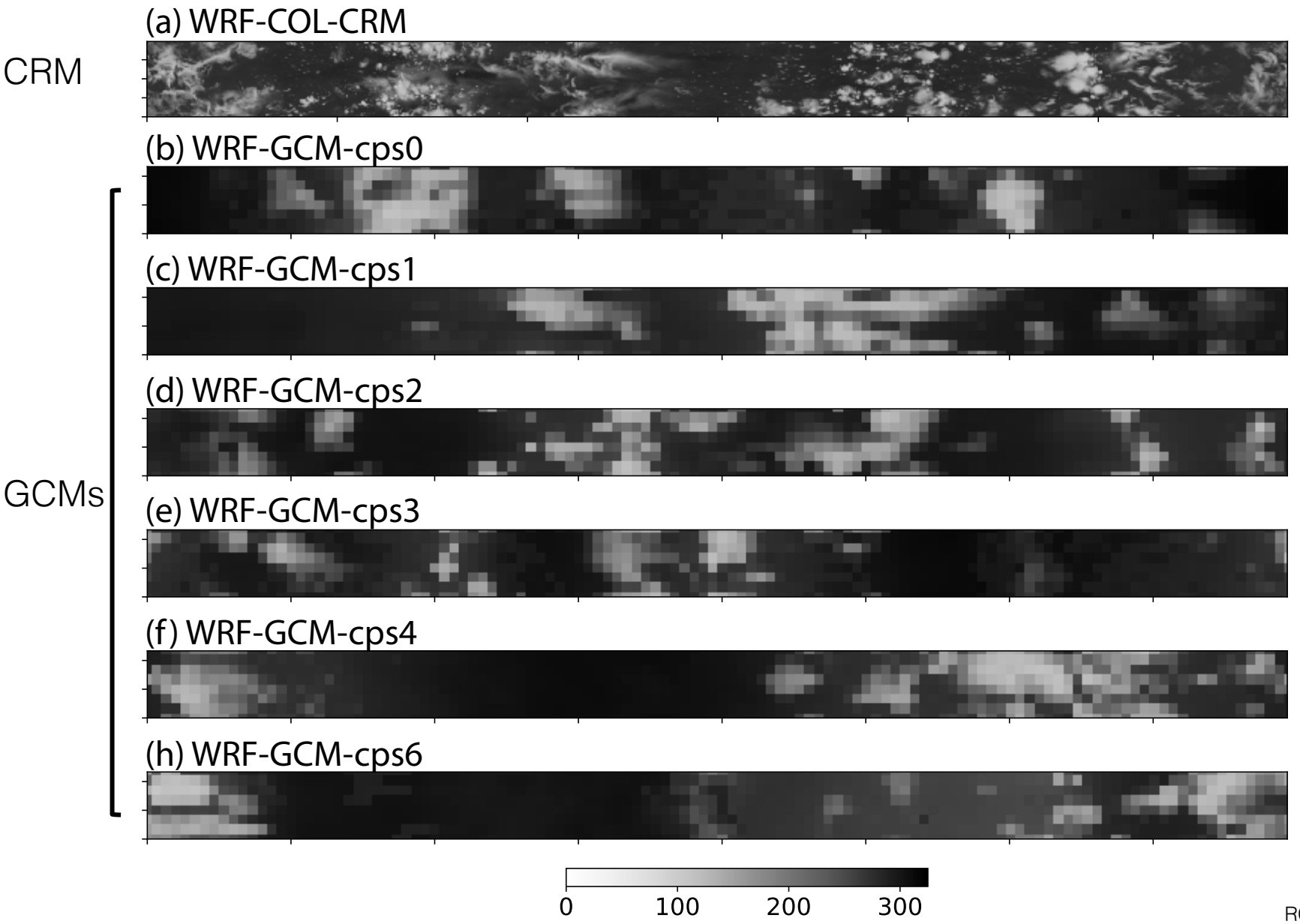
RCE_small300

Outgoing Longwave Radiation, Day 80: CRMs



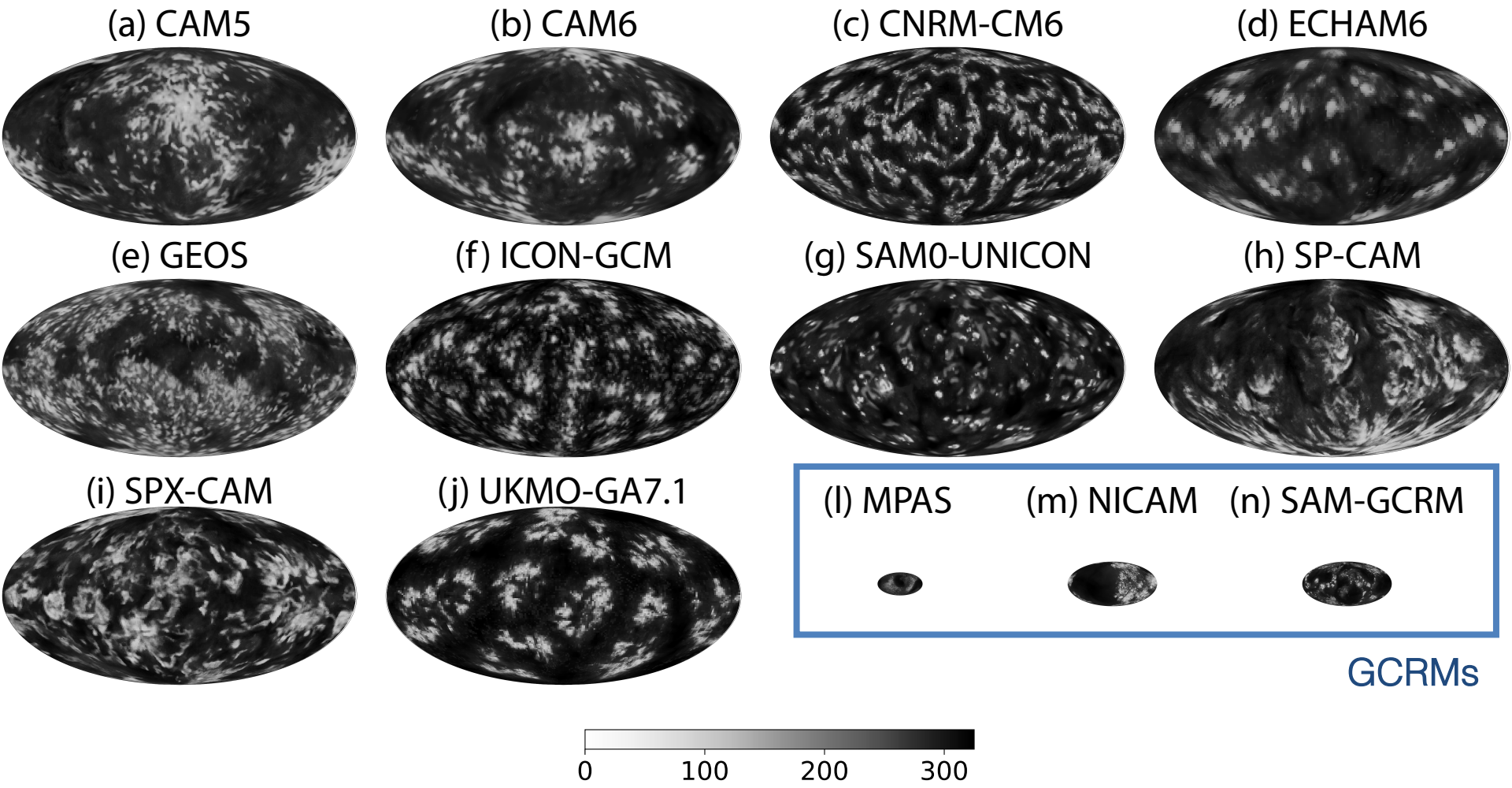
RCE_large300

Outgoing Longwave Radiation, Day 80: WRF

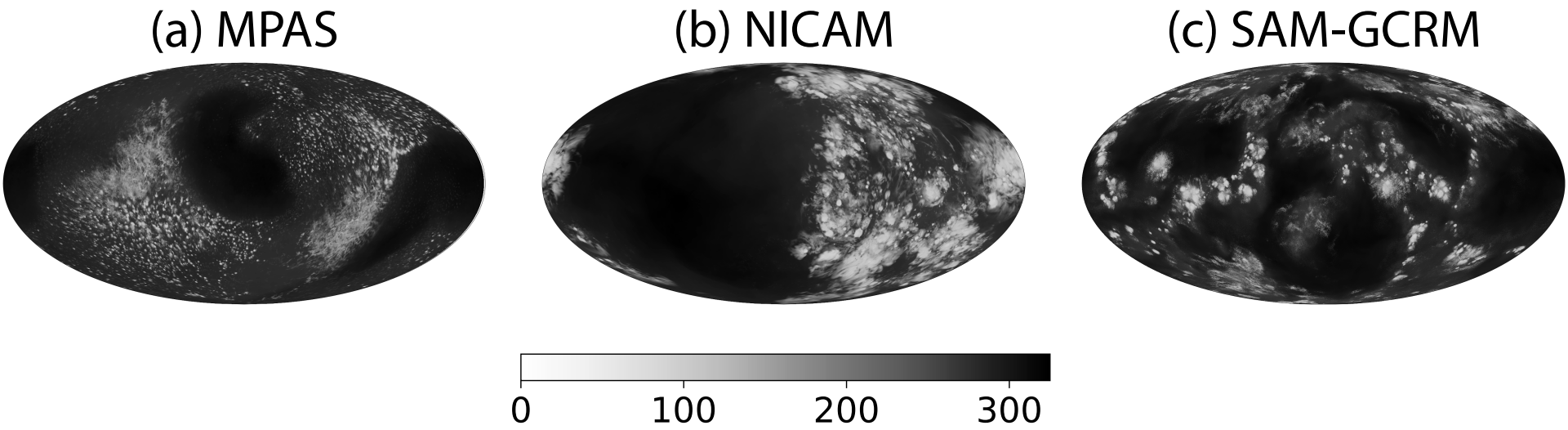


RCE_large300

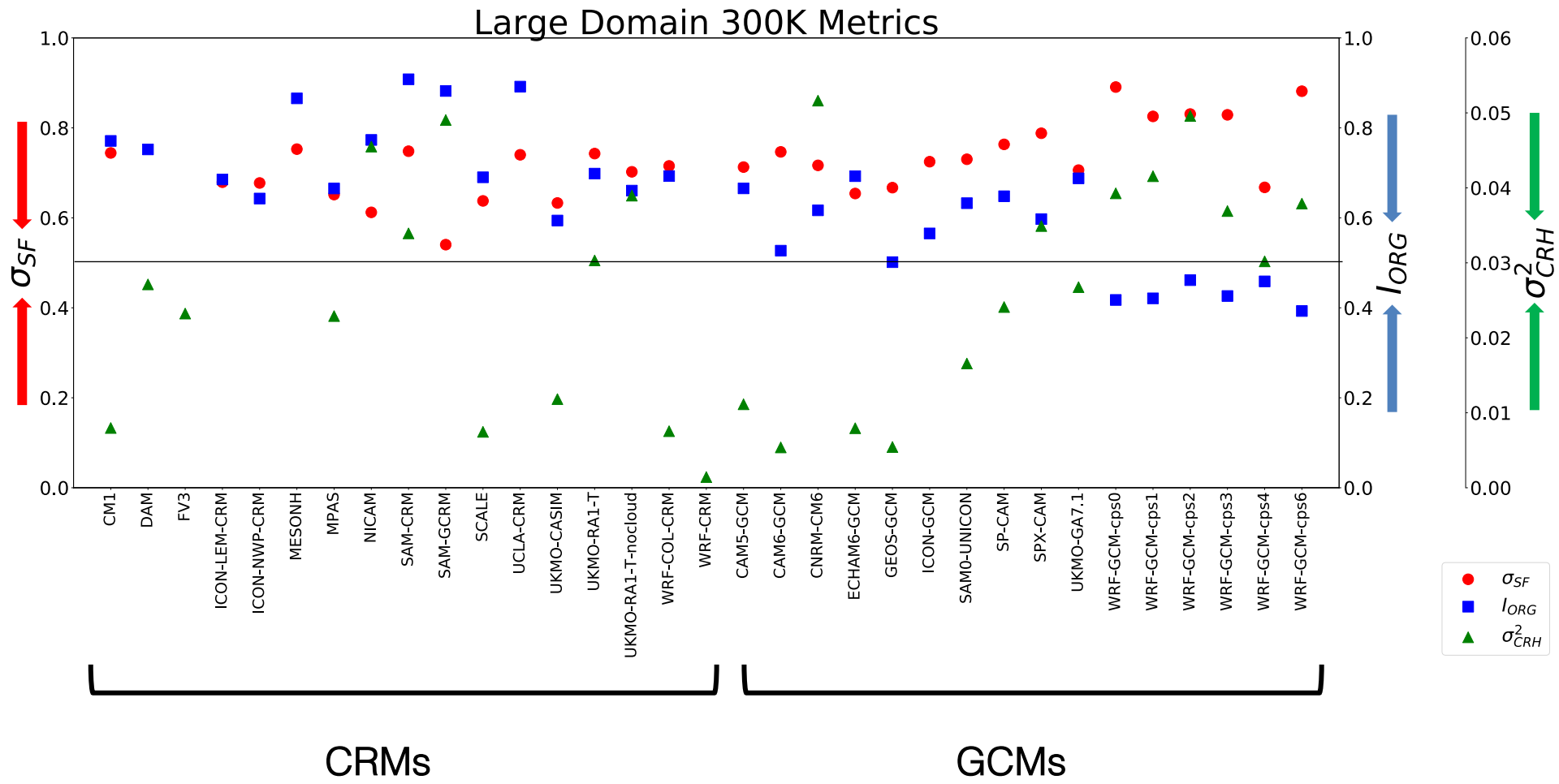
Outgoing Longwave Radiation, Day 80: GCMS



Outgoing Longwave Radiation, Day 80: GCRMS

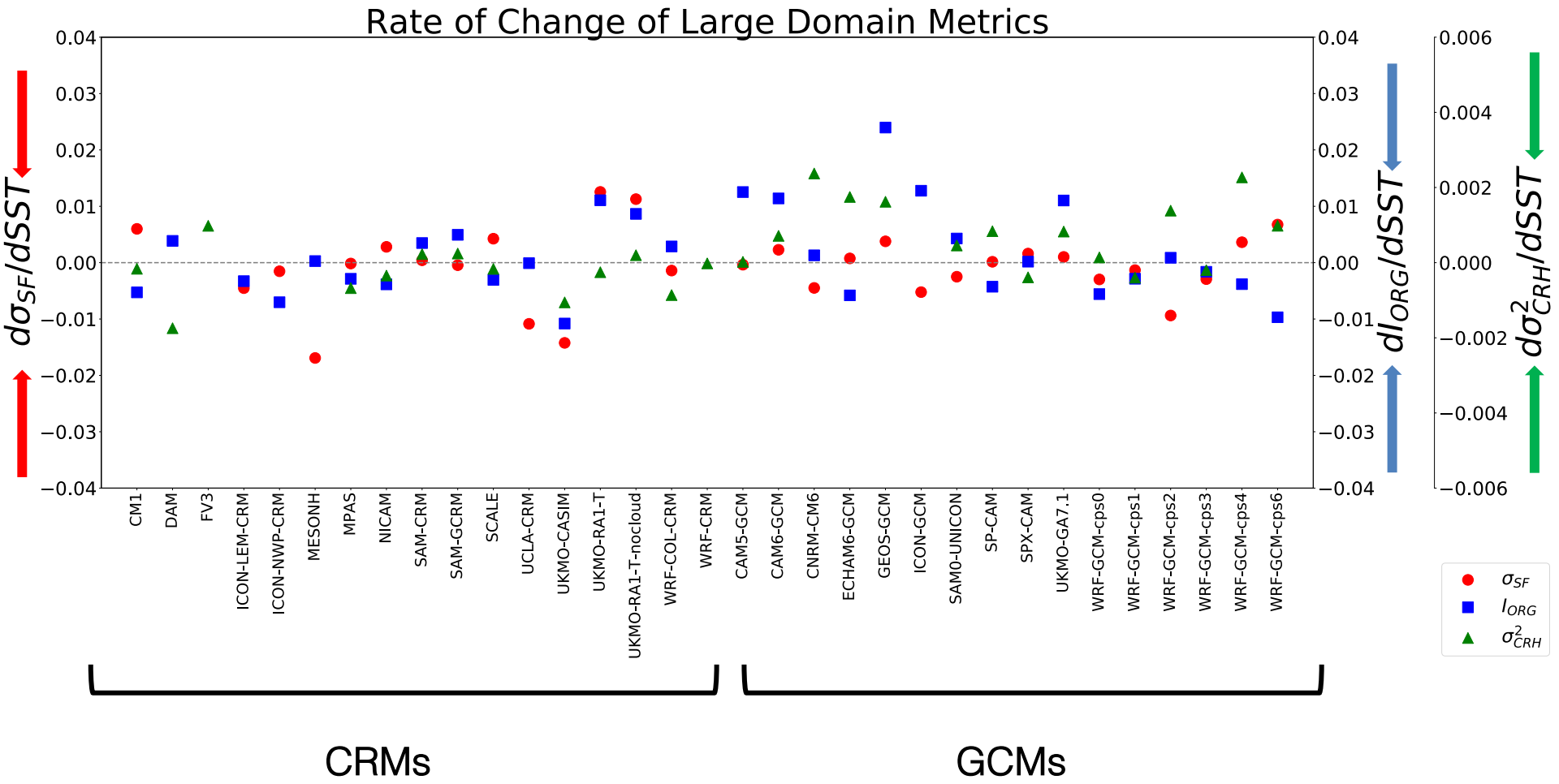


Large Domain Simulations are Aggregated!



RCE_large300

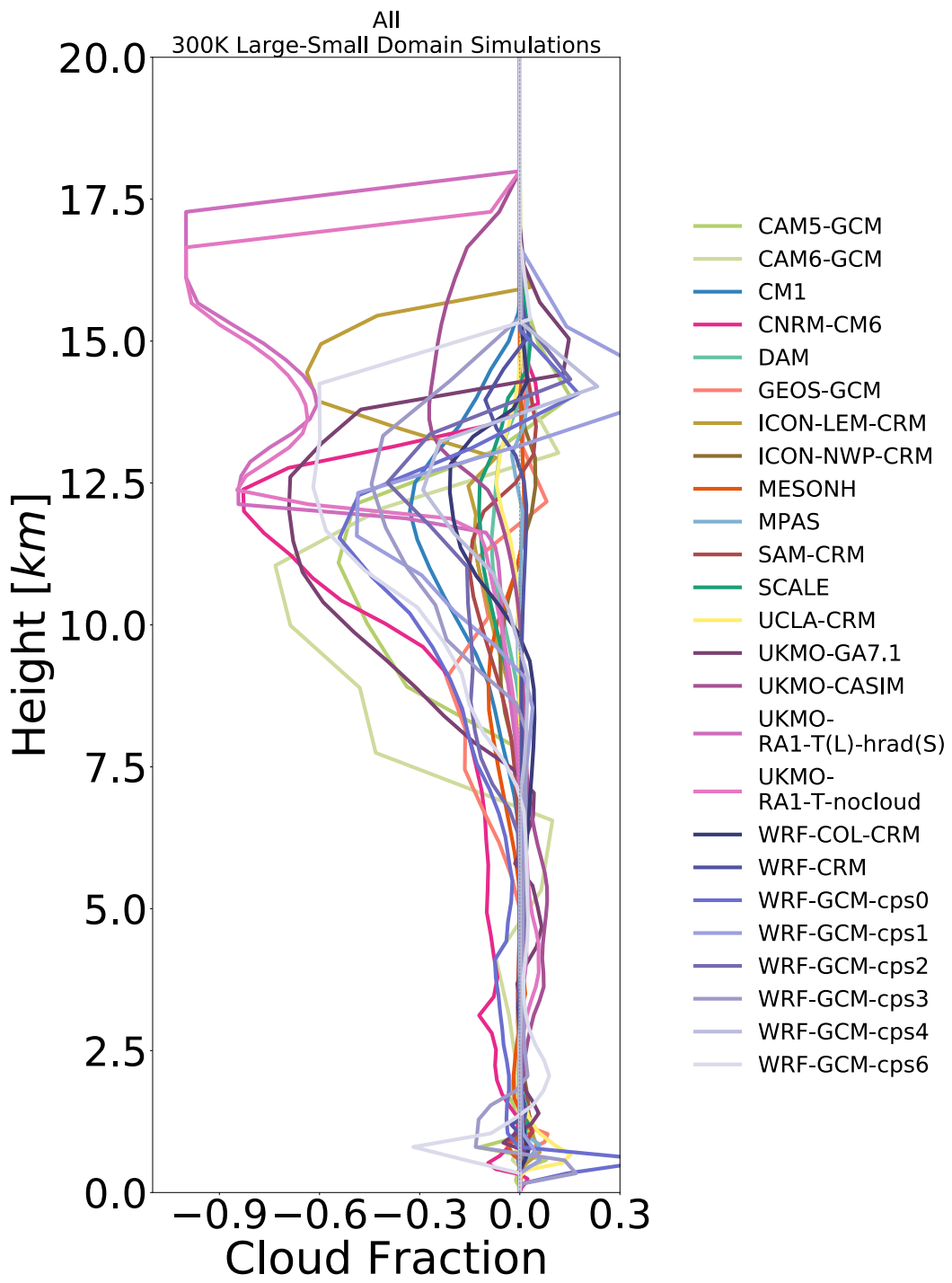
Half the simulations have an increase in aggregation with warming, half have a decrease



How does self-aggregation impact the mean state?

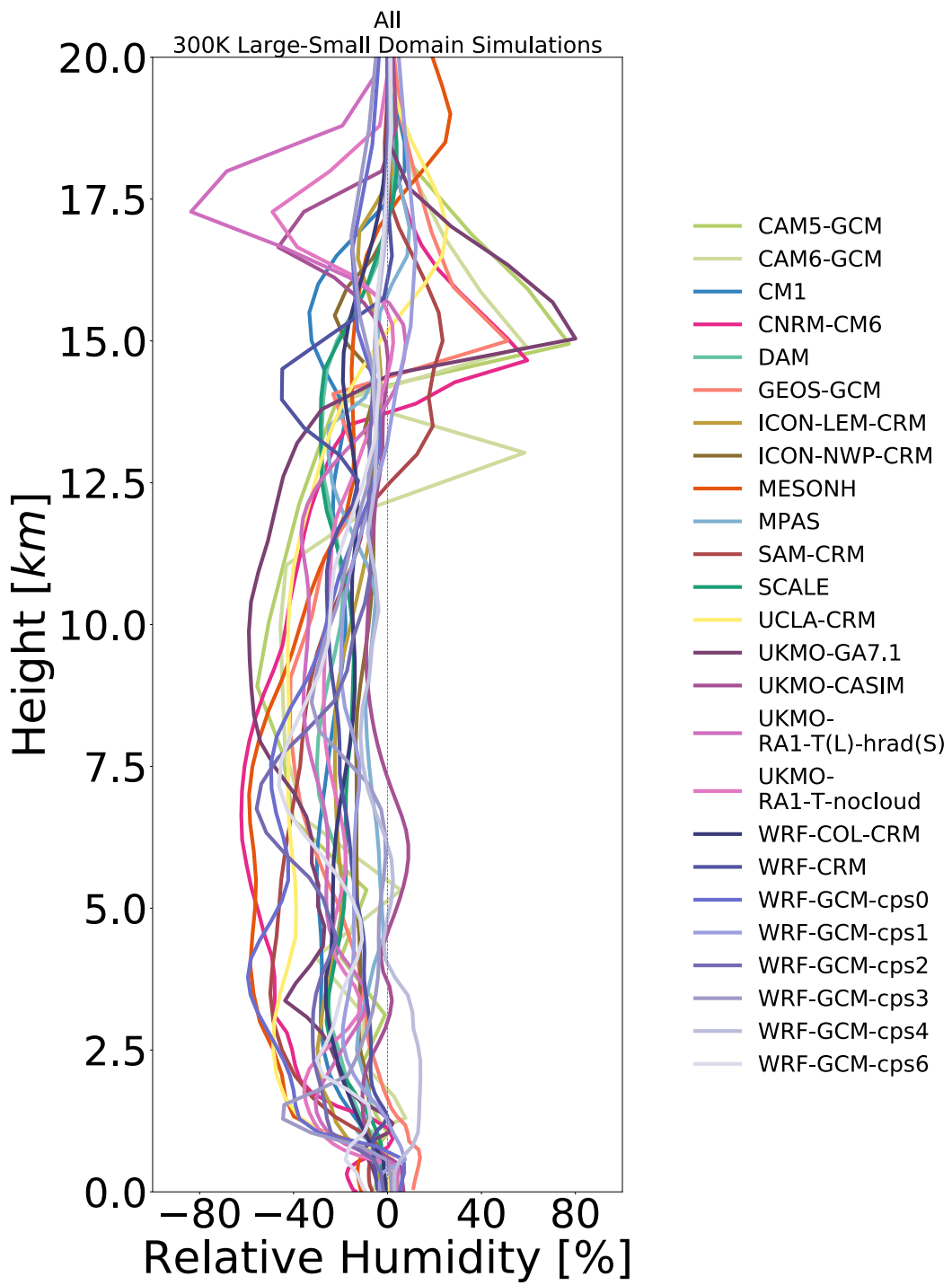
How does self-aggregation impact the mean state?

Compare small & large simulations



Reduction in high cloud fraction with aggregation

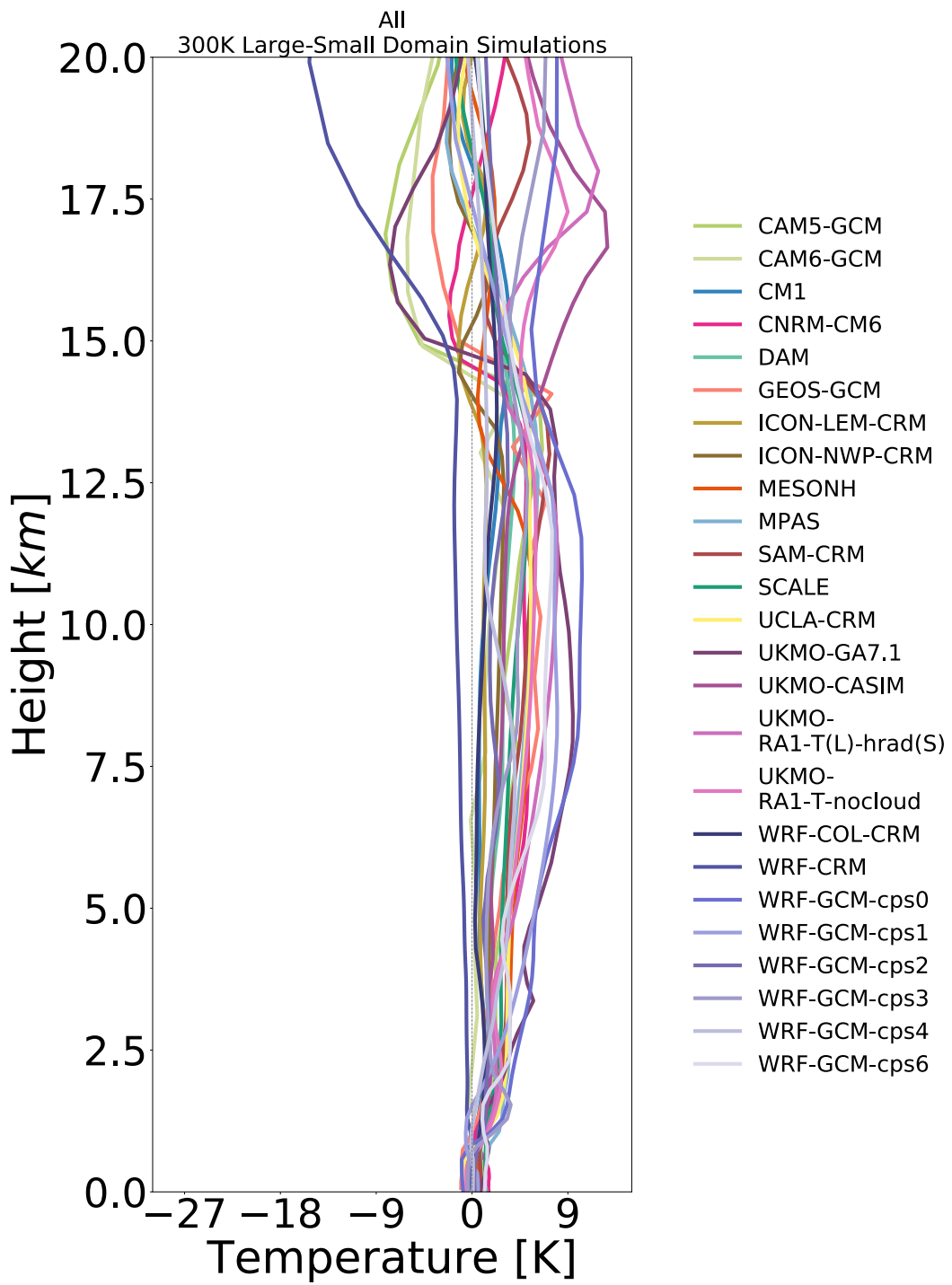
RCE_large300 – RCE_small300



Aggregated - Unaggregated

Reduction in relative humidity with aggregation

RCE_large300 – RCE_small300



Aggregated - Unaggregated

Increase in temperature with aggregation

RCE_large300 – RCE_small300

With aggregation…

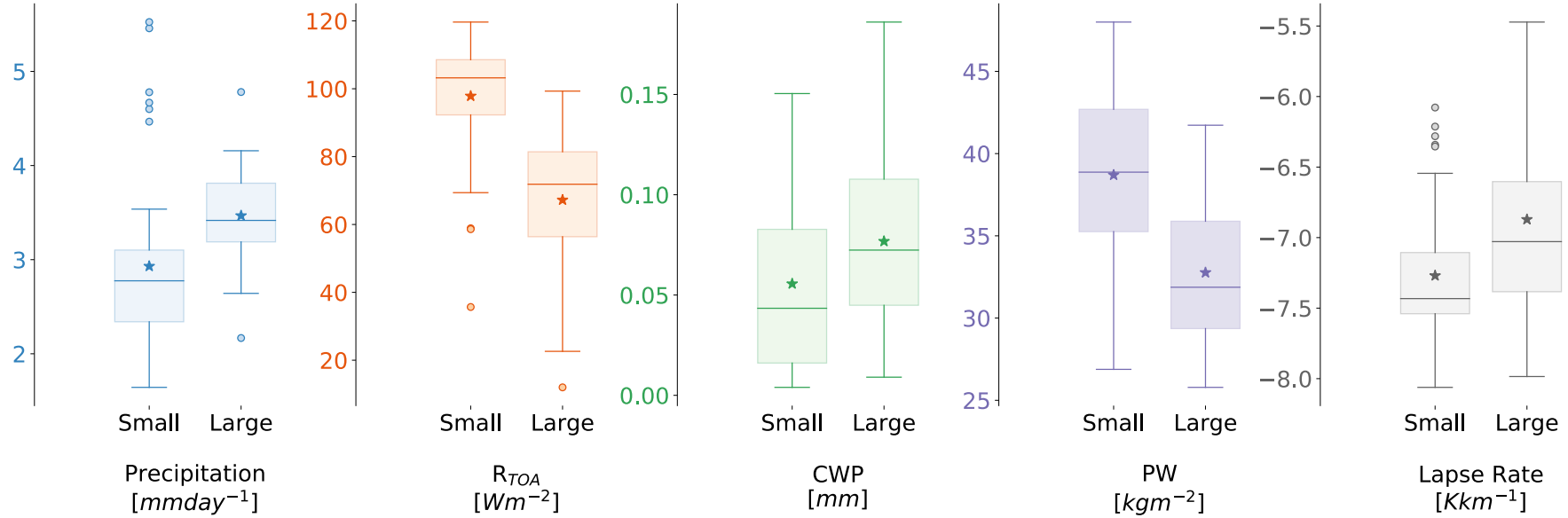
more rain

less radiation into column at TOA (*more cooling to space*)

more condensed water?

drier

more stable



RCE_large300, RCE_small300

Self-aggregation impacts the climate

Self-aggregation impacts the climate

Does self-aggregation impact climate sensitivity?

Self-aggregation impacts the climate

Does self-aggregation impact climate sensitivity?

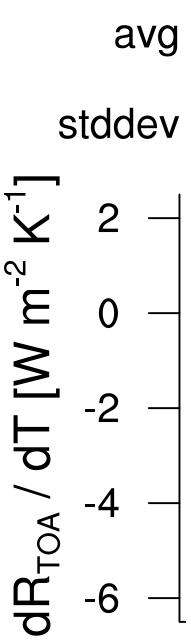
What is the climate sensitivity in the RCEMIP simulations?

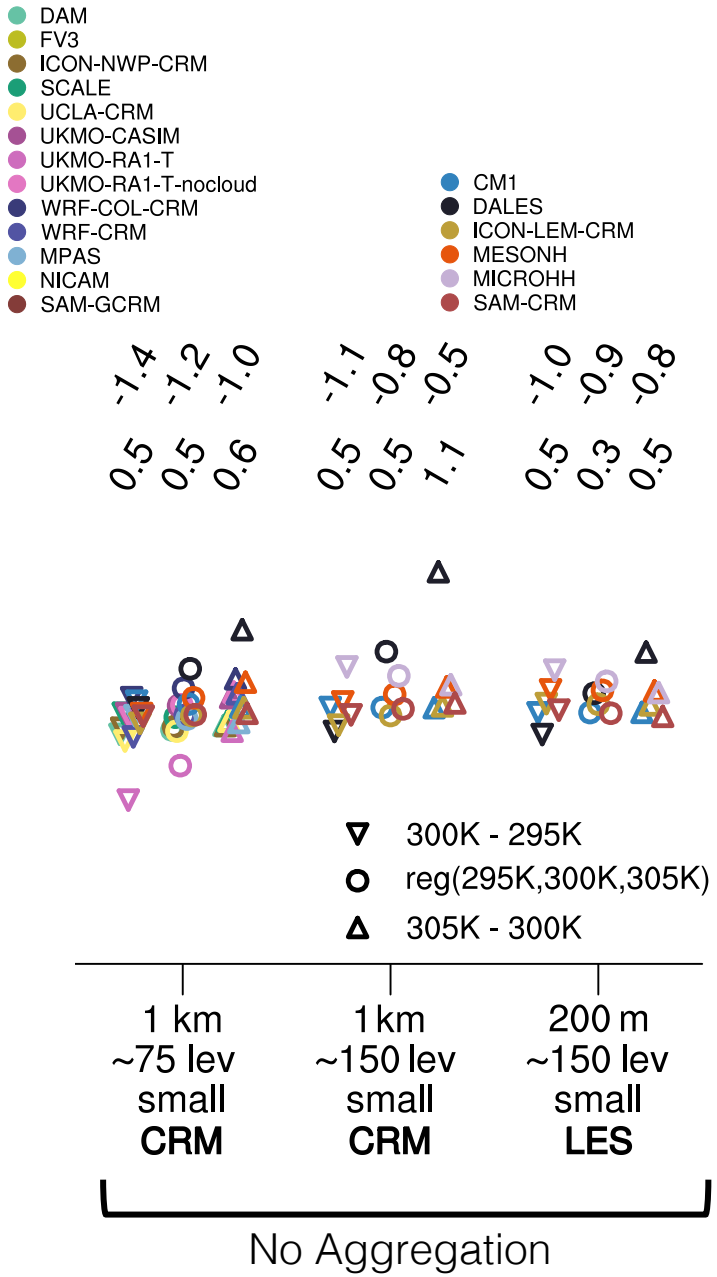
Net climate feedback parameter

$$\lambda = \frac{dR_{\mathrm{TOA}}}{dT}$$

Equilibrium climate sensitivity

$$\mathrm{ECS} = \frac{F_{2\mathrm{xCO2}}}{\lambda}$$



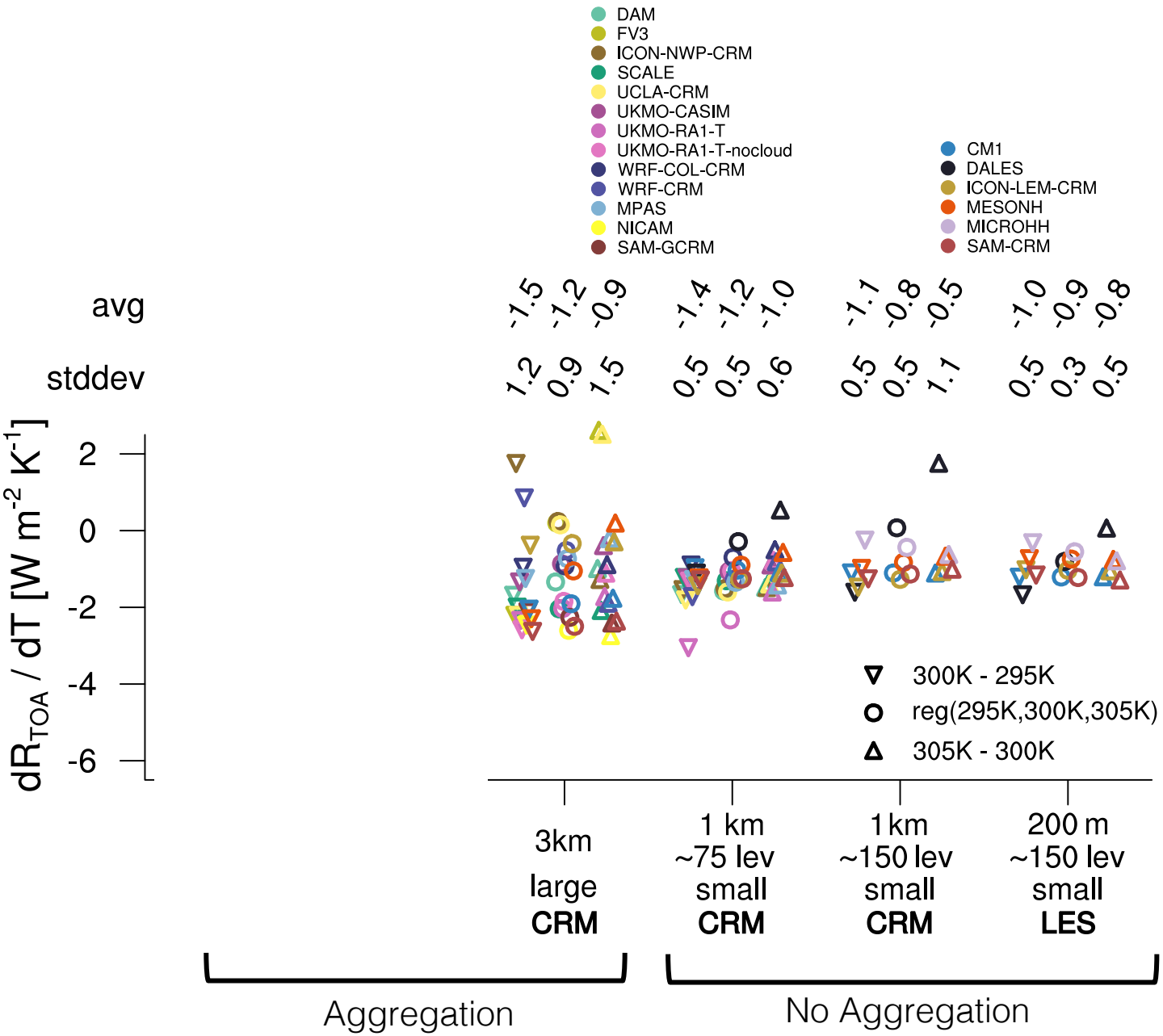


small domain CRMs / LES:

high climate sensitivity

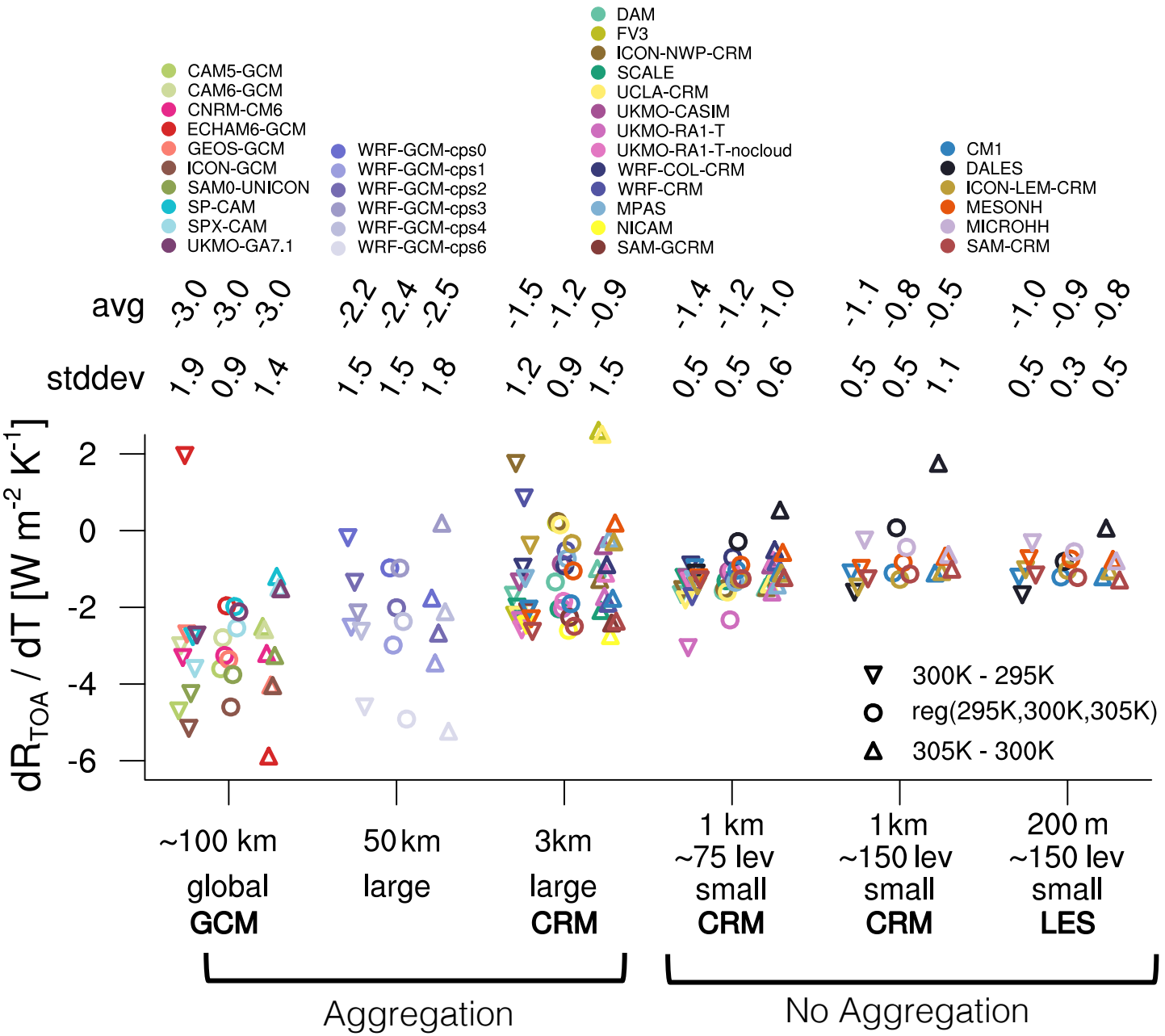
spread(models) > spread(setups)

LES models with similar spread as at coarser resolution



large domain CRMs:

spread significantly larger



GCMs:

spread even larger

low mean climate sensitivity

Wide spread in climate sensitivity

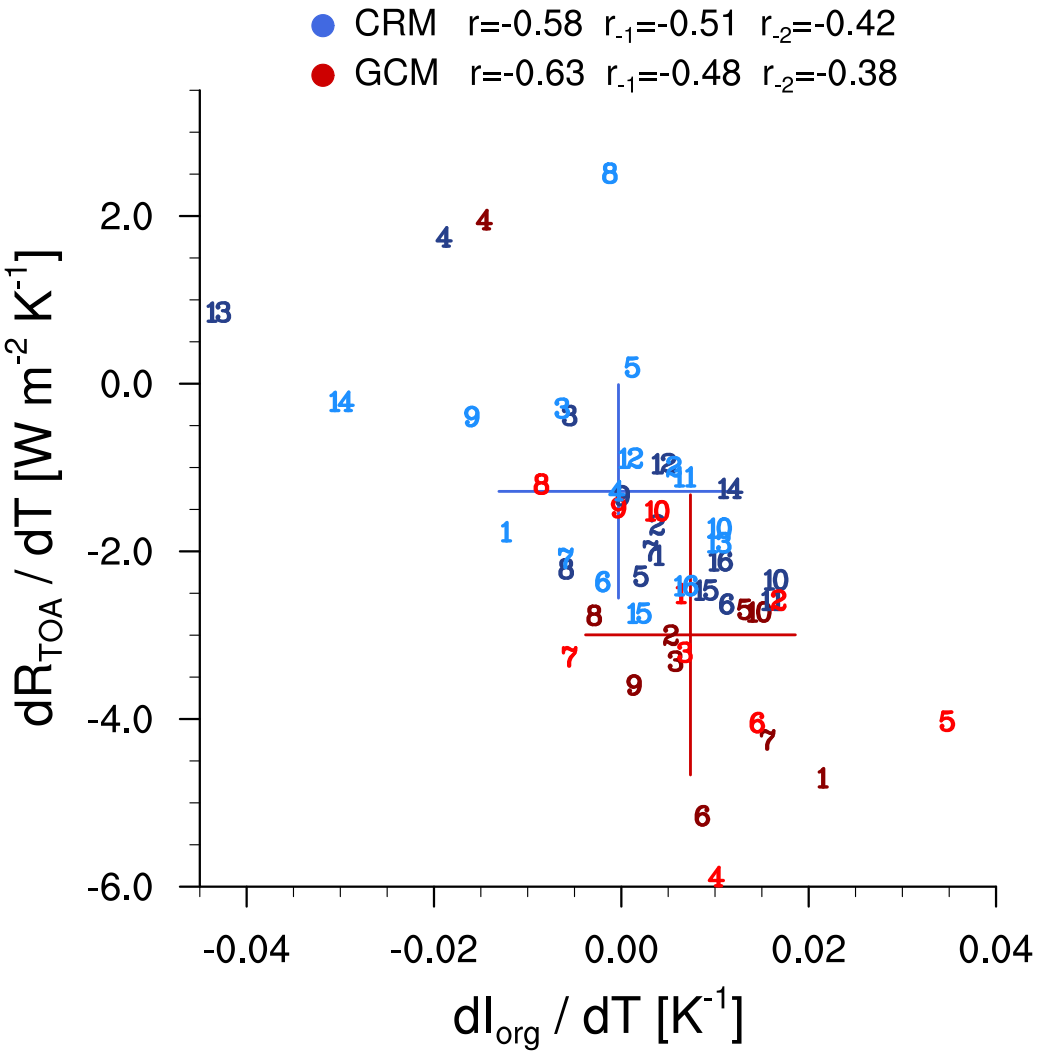
Wide spread in climate sensitivity
Wide spread in self-aggregation

Wide spread in climate sensitivity
Wide spread in self-aggregation
Wide spread in changes in self-aggregation with warming

Wide spread in climate sensitivity
Wide spread in self-aggregation
Wide spread in changes in self-aggregation with warming

Do changes in self-aggregation with warming explain the intermodel spread in climate sensitivity?

Extreme changes in aggregation are related to extreme climate sensitivities



CRMs

1 CM1
2 DAM
3 ICON-LEM-CRM
4 ICON-NWP-CRM
5 MESONH
6 SAM-CRM
7 SCALE
8 UCLA-CRM
9 UKMO-CASIM
10 UKMO-RA1-T
11 UKMO-RA1-T-nocloud
12 WRF-COL-CRM
13 WRF-CRM
14 MPAS
15 NICAM
16 SAM-GCRM

GCMs

1 CAM5-GCM
2 CAM6-GCM
3 CNRM-CM6
4 ECHAM6-GCM
5 GEOS-GCM
6 ICON-GCM
7 SAM0-UNICON
8 SP-CAM
9 SPX-CAM
10 UKMO-GA7.1

dark color: 300 K - 295 K

bright color: 305 K - 300 K

Conclusions

- All models self-aggregate to some extent in the large domain
- Wide variability in spatial structure & degree of aggregation
- Half models have an increase in aggregation with warming, half have a decrease

- All models indicate decrease in high clouds, drying, warming, increased cooling to space with aggregation

- Climate sensitivity is overall smaller and has more spread in large, aggregated simulations compared to small

- Extreme changes in self-aggregation with warming lead to extreme climate sensitivities*

- Climate sensitivity is overall smaller in GCMs than in CRMs because GCMs have more self-aggregation with warming*

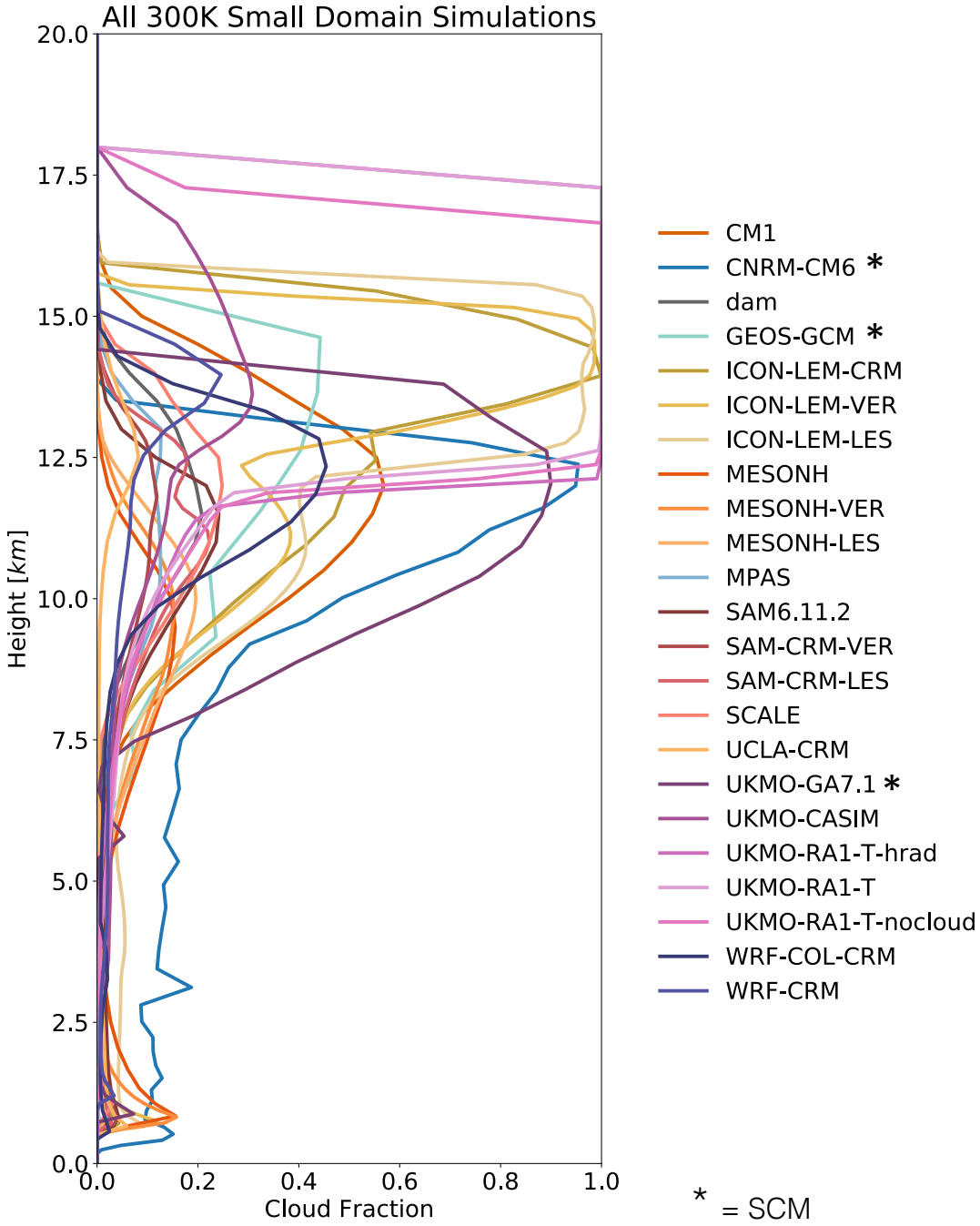
*changes in shallow clouds are also important

http://myweb.fsu.edu/awing/rcemip.html

Participation from 47 Models

GCMs (16), CRMs (17), LES (6), GCRMs (3), SCMs (5)

GCMs	CRMs	LES	GCRMs	SCMs
CAM5	DALES	CM1	MPAS	CNRM-CM6
CAM6	DAM	DALES	NICAM	GEOS5
CNRM-CM6	CM1	ICON-LEM	SAM	SCAM5
ECHAM6	GFDL FV3	MESONH		SCAM6
GEOS5	ICON-LEM	MicroHH		UKMO GA7
ICON-A	ICON-NWP	SAM		
SAM0-UNICON	MESO-NH			
SP-CAM	MicroHH			
SPX-CAM	SAM			
UKMO GA7	SCALE			
WRF 3.5.1* (x 6)	UCLA-CRM			
	UKMOi v11.1 RA1-T			
	UKMOi v11.1 RA1-T-nocloud			
	UKMOi v11.1 RA1-T-hrad			
	UKMOi v11.1 CASIM			
	WRF 3.9.1			
	WRF 3.5.1			

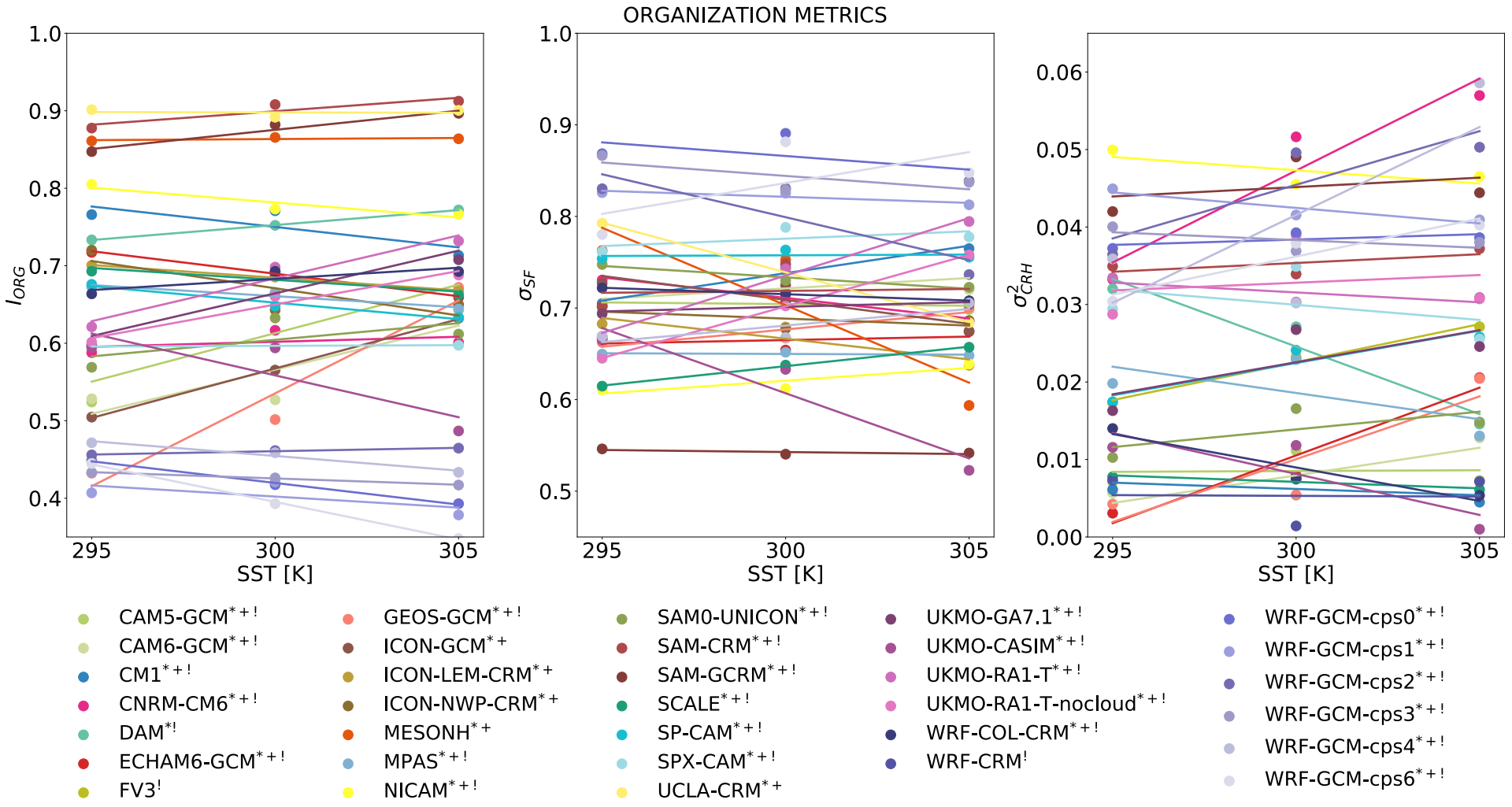


* = SCM

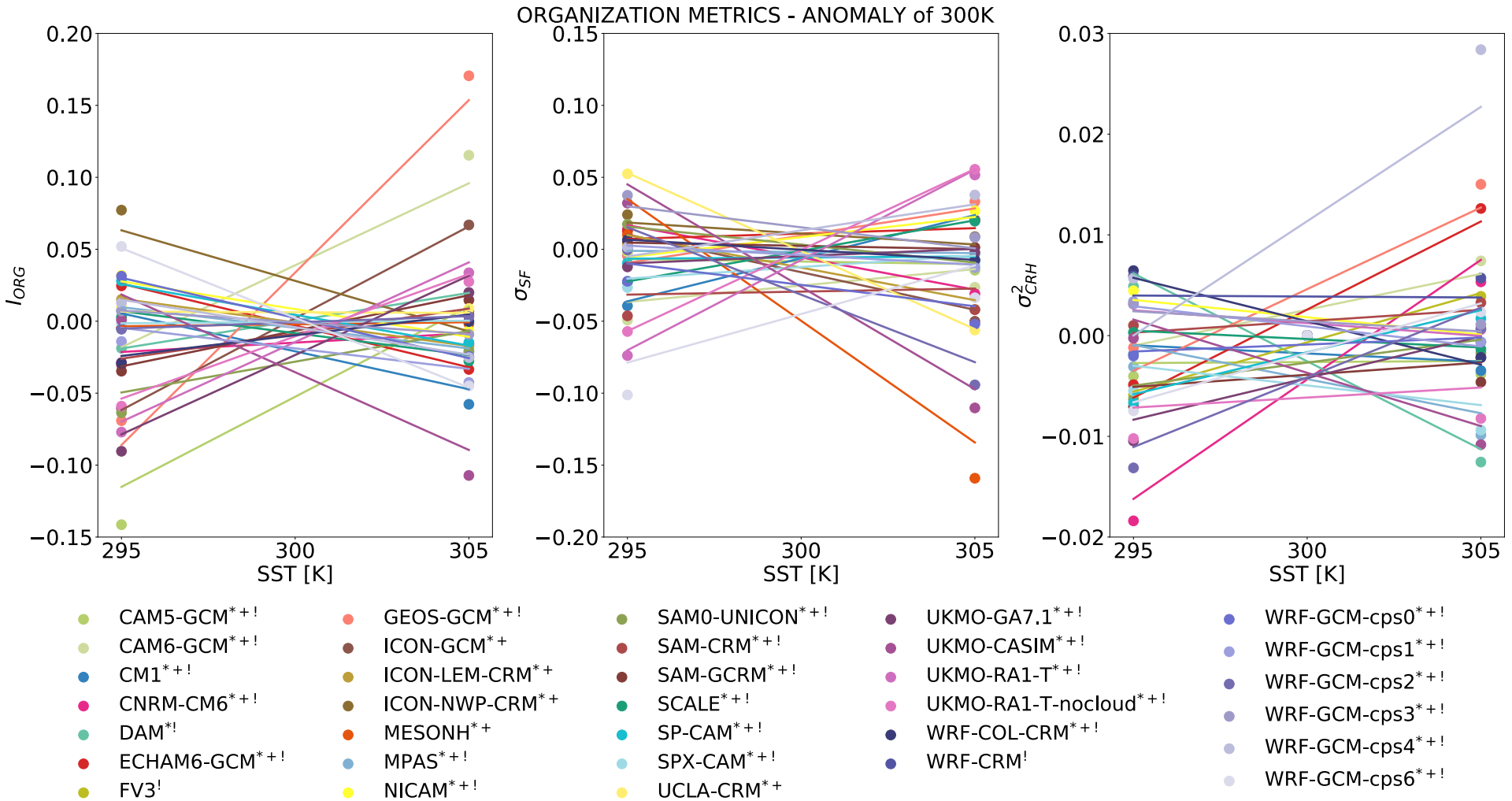
Large variability in cloud fraction profiles across simulations

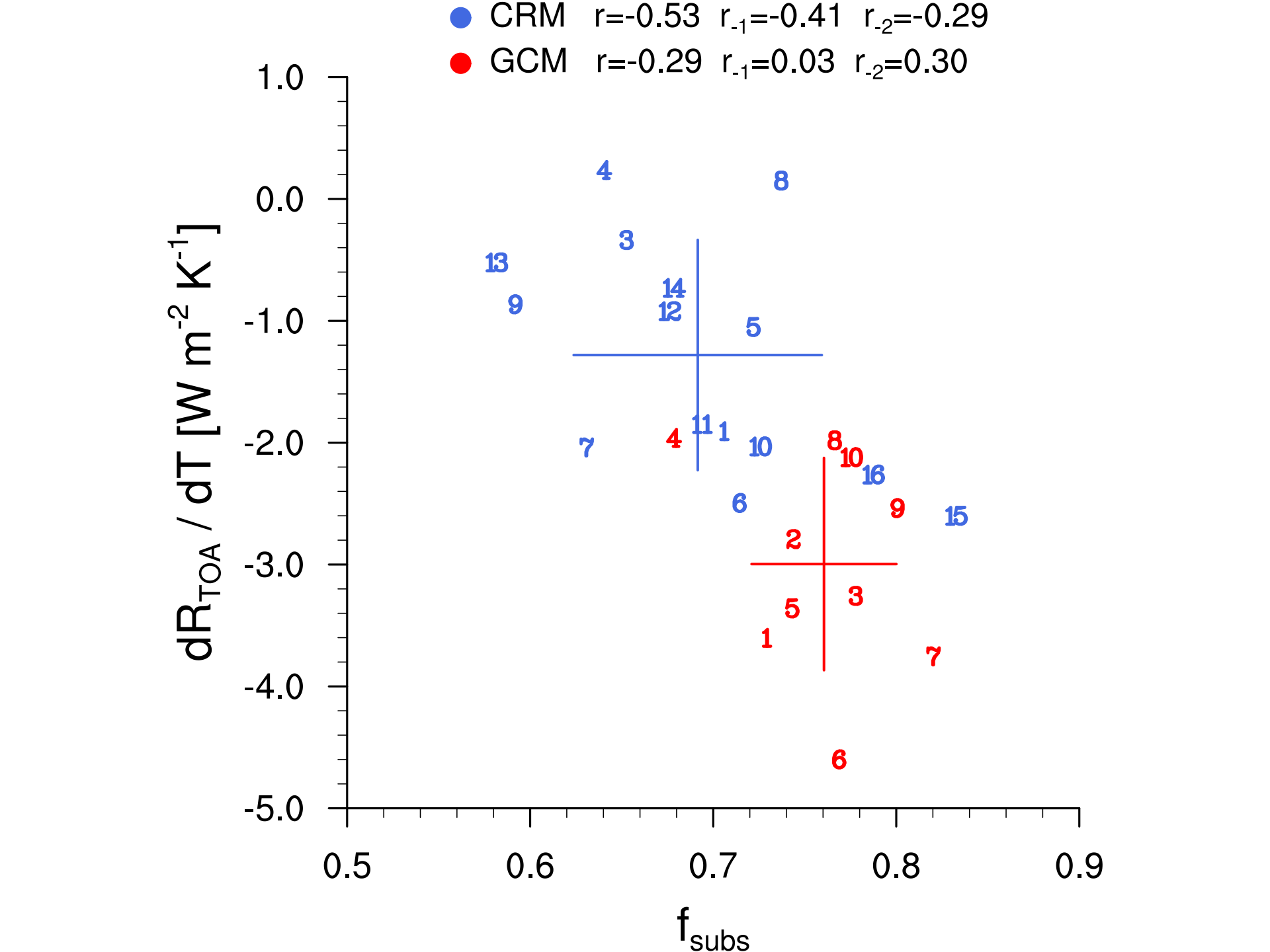
Definition of "cloud":
Cloud condensate > $\min(1 \times 10^{-5}\ g\ g^{-1}, 0.01 * q_{sat})$
or
output of cloud scheme

Widely varying degrees of aggregation



Widely varying response of aggregation to warming




CRM r=-0.53 r_-1=-0.41 r_-2=-0.29
GCM r=-0.29 r_-1=0.03 r_-2=0.30
dR_TOA / dT [W m^-2 K^-1]
f_subs
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
0.5
0.6
0.7
0.8
0.9
4
8
3
13
14
9
12
5
11
1
7
4
10
8
10
16
6
9
15
2
3
5
1
7
6