On the Role of Convective Aggregation in Climate: Observational and Modeling Perspectives

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with :
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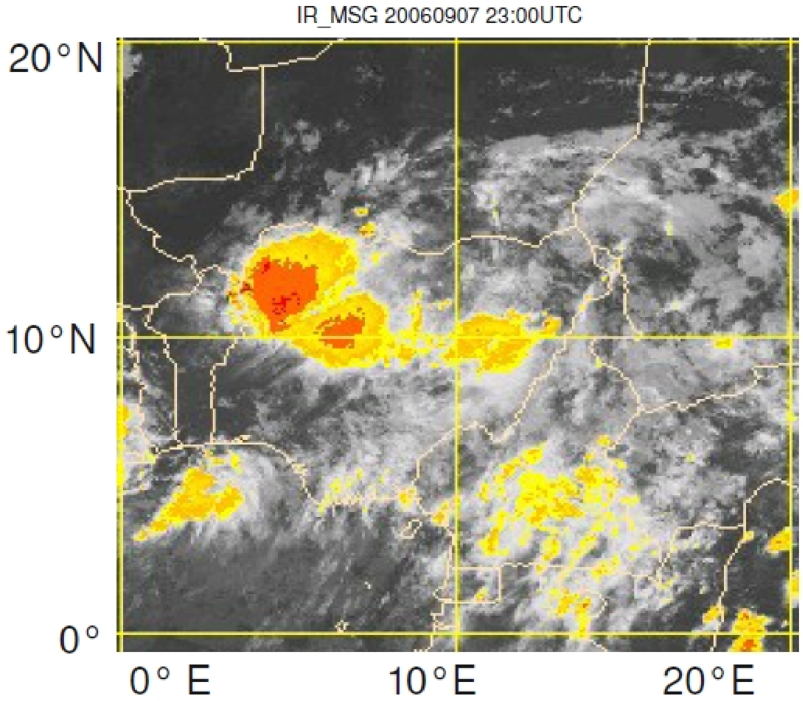
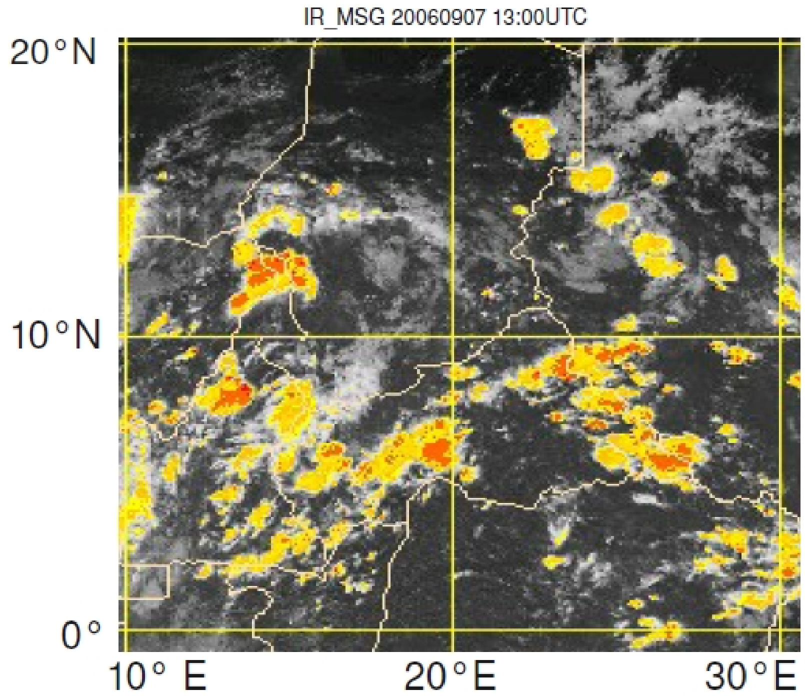
Organization of tropical convection





- What difference does is make for the Earth's climate ?

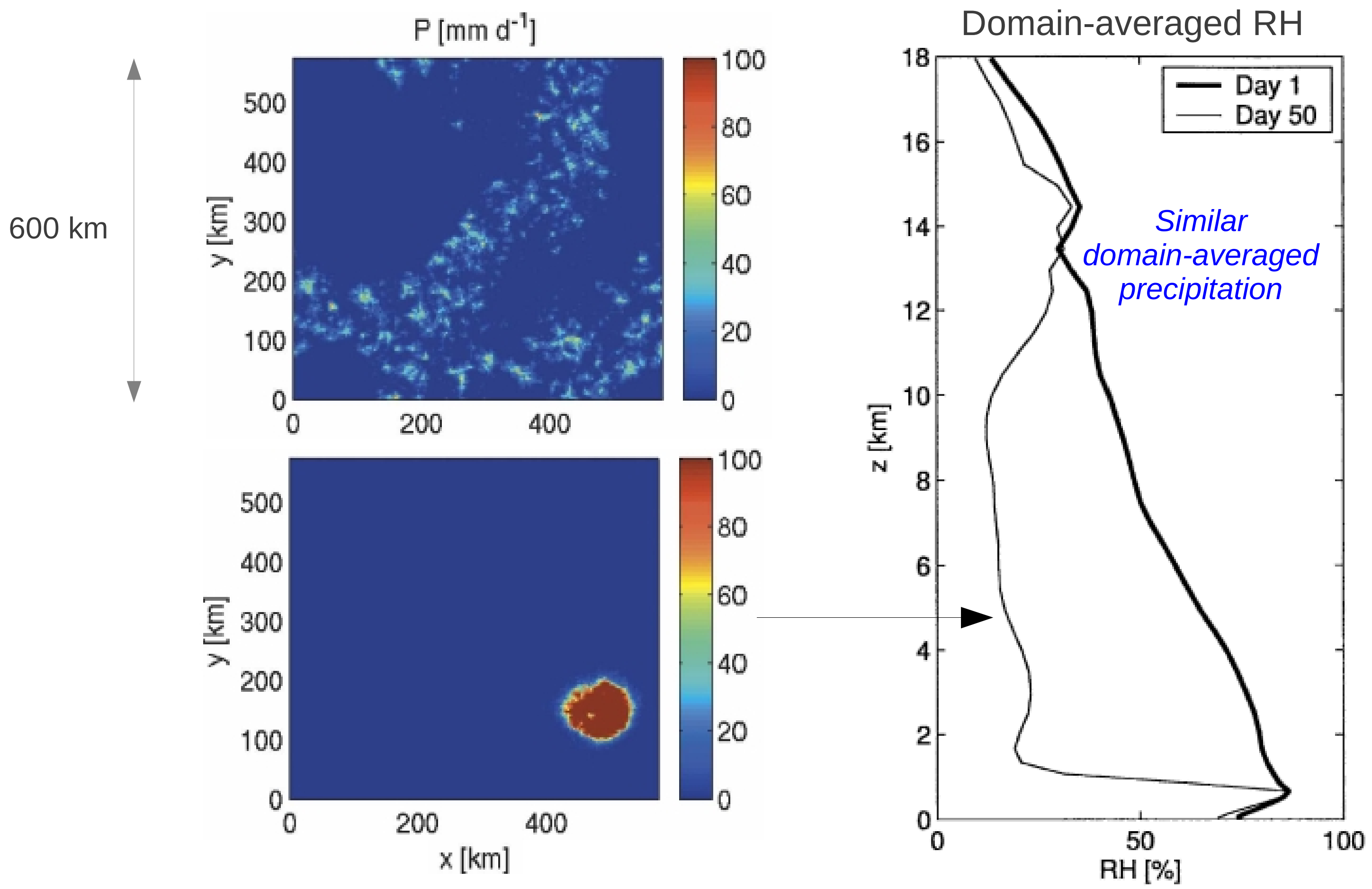
- Investigation using :

  (1) Observations

  (2) General Circulation Model

Idealized Radiative-Convective Equilibrium studies :

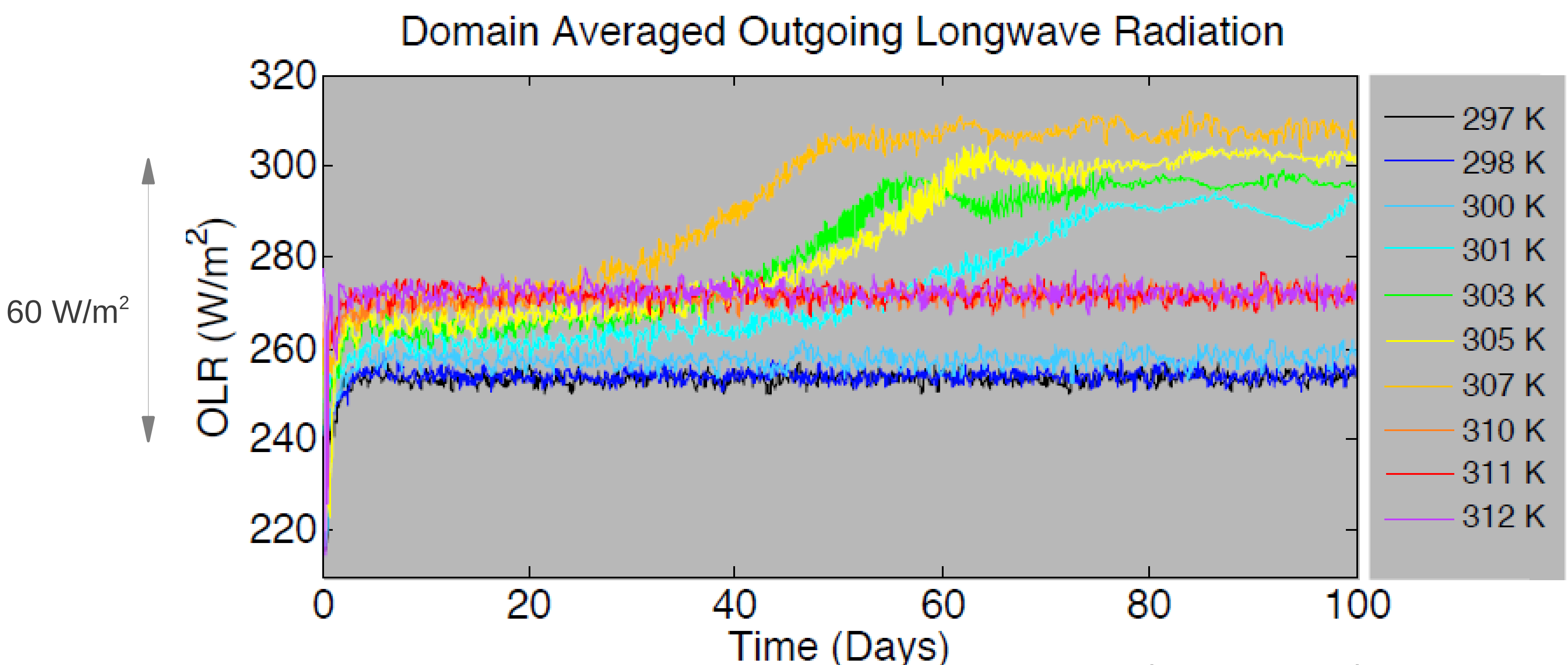
(1) may matter for the large-scale atmospheric state



Bretherton, Blossey and Khairoutdinov, JAS, 2005

Idealized Radiative-Convective Equilibrium studies :

(2) may matter for Climate Sensitivity



Wing & Emanuel, JAMES, 2014
Khairoutdinov & Emanuel, AMS, 2010

Easier occurrence of convective aggregation at high temperatures → Drying of the free troposphere and enhanced OLR → Negative feedback under global warming ?

CRM results might be sensitive to
experimental design, resolution, size of the domain, model physics, etc

What do Observations Suggest ?

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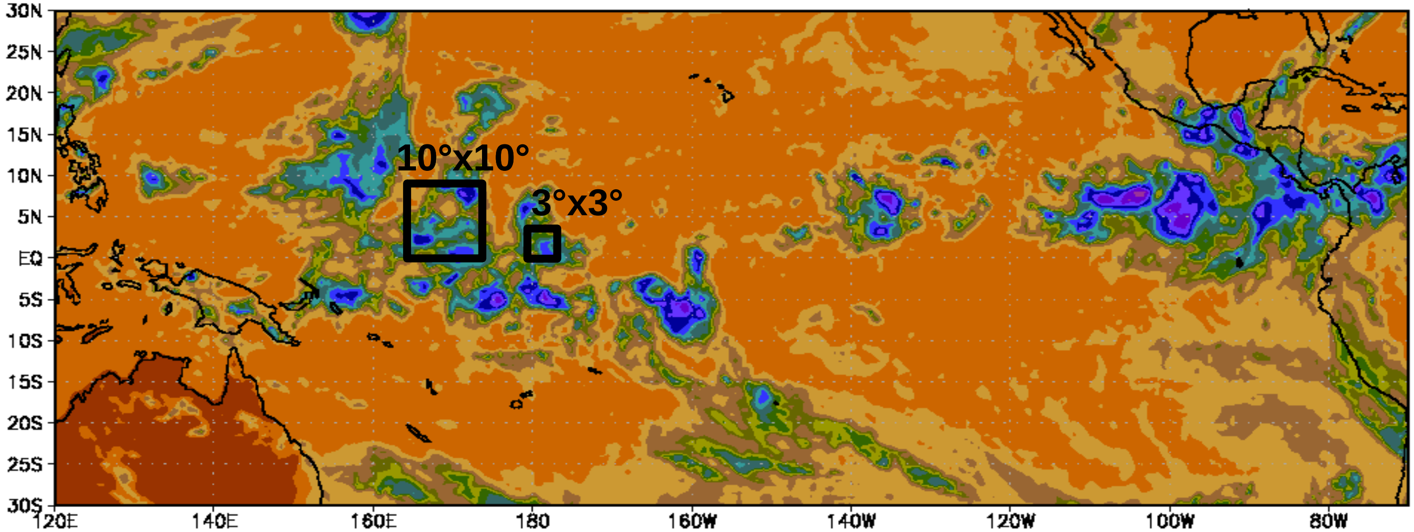
experimental design, resolution, size of the domain, model physics, etc

What do Observations Suggest ?



1. Characterize convective aggregation using geostationnary satellite data through a simple index

2. For given domain-averaged precipitation and large-scale forcings :

Investigate statistical relationships between the degree of aggregation
of deep convection and the large-scale atmospheric state

3. Consider two domain sizes : 10 ° x 10 ° or 3° x 3° (synoptic vs mesoscale organization)

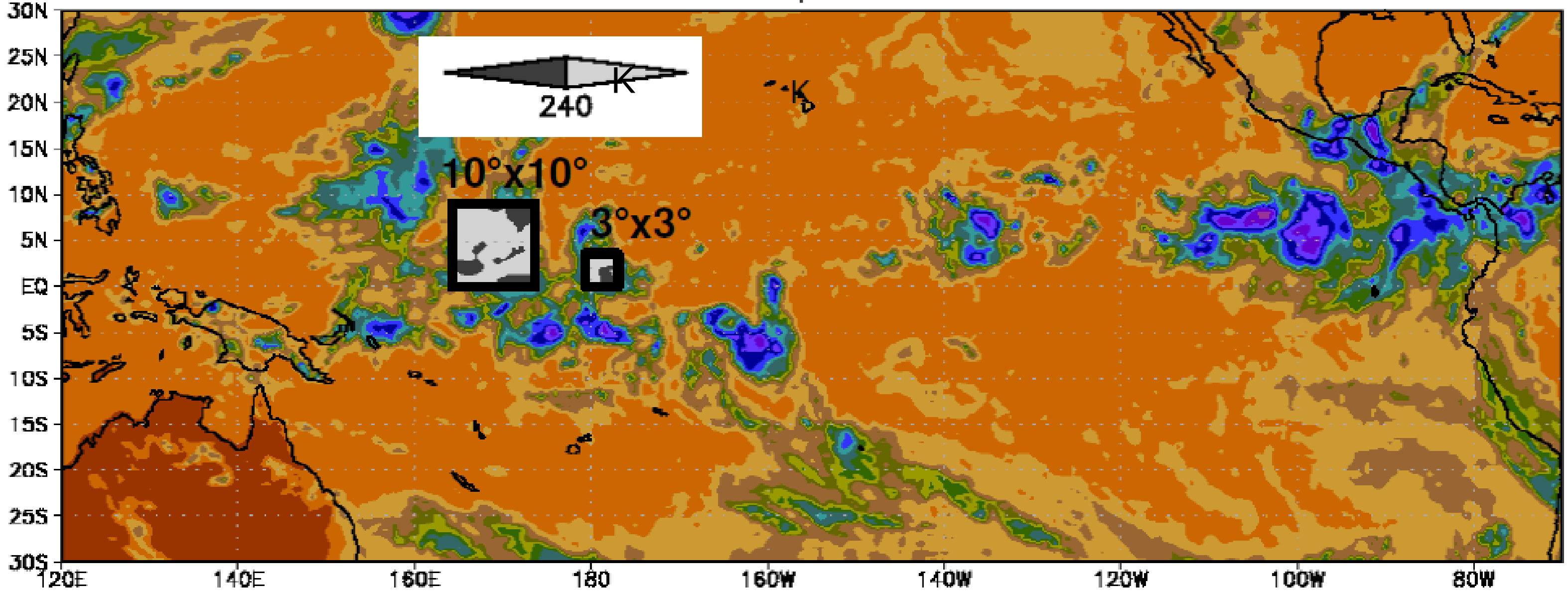
Tobin, Bony & Roca, J. Climate (2012) ; Tobin et al., JAMES (2013)

Datasets

Name	Variable	Spatial resolution	Temporal sampling	Period	Reference
CLAUS	IR brightness temperature	0.5°	3 hourly	1983–2005	Hodges et al. (2000)
HOAPS	Surface rain	1°	Twice daily	1988–2005	Andersson et al. (2010)
	Precipitable water				
	Surface sensible heat flux				
	Surface latent heat flux				
	Sea surface temperature				
	10-m wind speed				
	Air–sea difference in humidity				
ERA-Interim	RH	0.75° 37 levels	6 hourly	1989–present	Simmons et al. 2007
	Vertical velocity	0.75° 37 levels	6 hourly	1989–present	
AIRS	RH	1°	Twice daily	2002–present	Aumann et al. 2003
OLR-NOAA	OLR	2.5°	Daily	1976–present	Liebmann and Smith 1996
CERES	OLR	5°	Daily	2000–04	http://ceres.larc.nasa.gov/
	Reflected shortwave				
METEOSAT	IR & WV Tb	5 km	30 min	1991-2006	
ISCCP-FD	Radiative fluxes	2.5°	3 hourly	1998-2005	Zhang et al. 2004
ISCCP-DX	Cloud top pressure, optical thickness	30 km	3 hourly	1998-2005	Rossow and Schiffer 1999

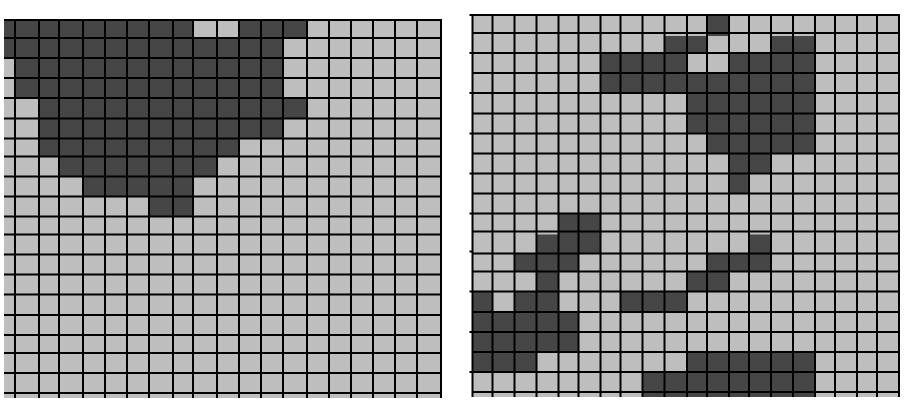
Characterization of Convective Aggregation

30S-30N tropical oceans



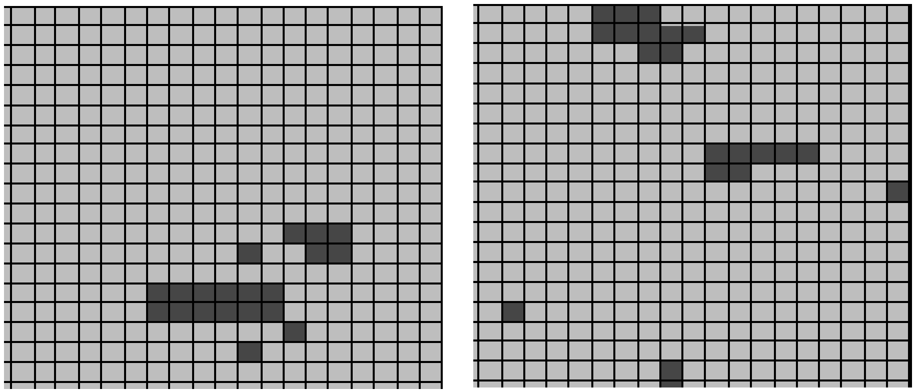
Number of convective clusters

10° or 3°



Tb threshold : 240 K

Clumping of convective clusters



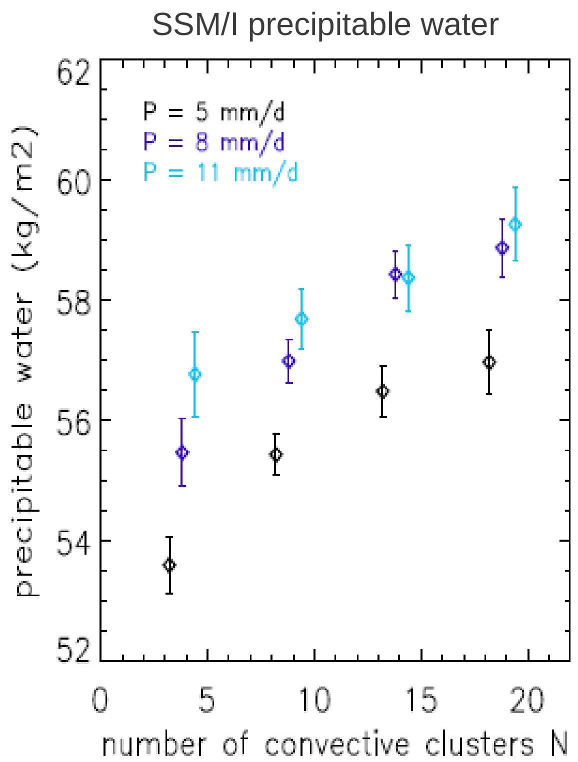
$$D_0 = (d_0 \ldots x d_i x \ldots d_n)^{1/n}$$

Gauvrit et Delahaye , 2006

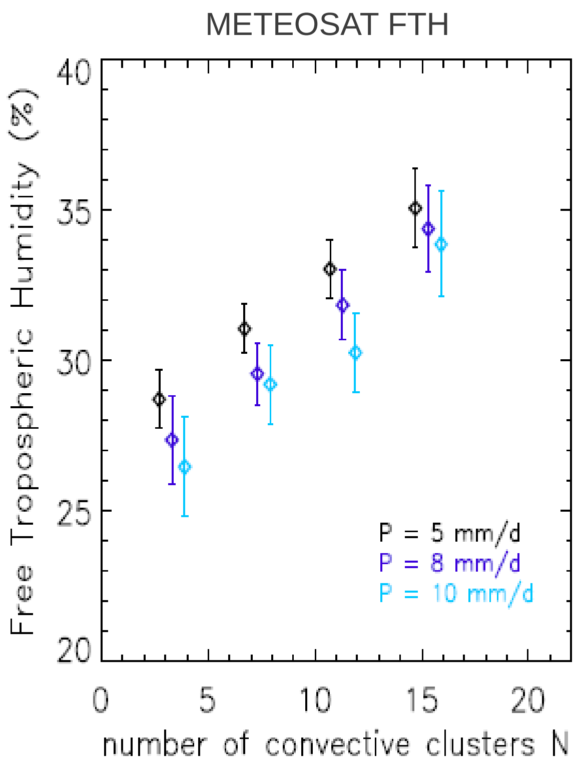
Water Vapor

For given domain-averaged precipitation and LS forcings :

more convective aggregation ◄—► drier free troposphere



more aggregation



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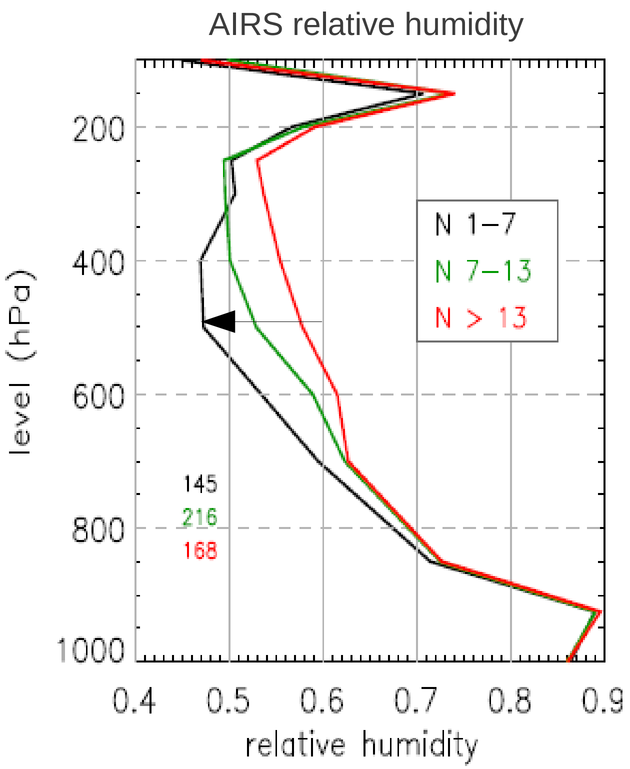
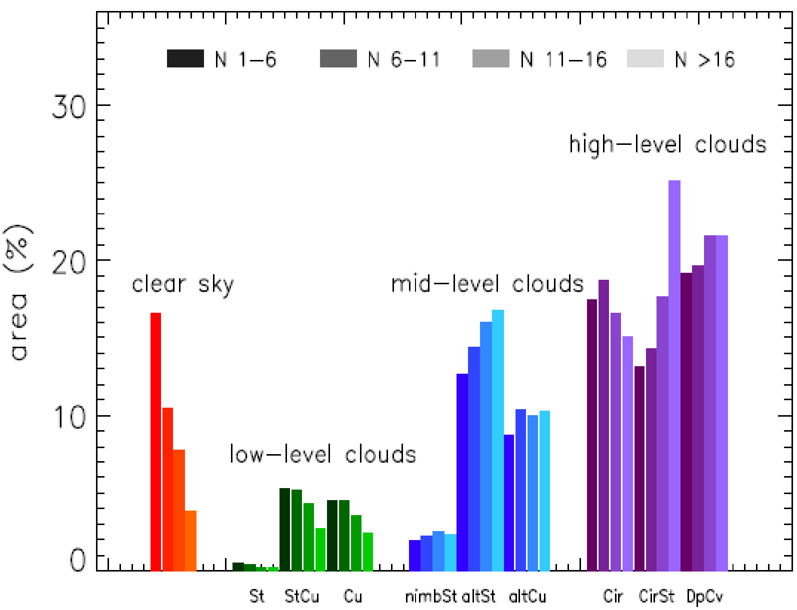


Radiation

For given domain-averaged precipitation and LS forcings :

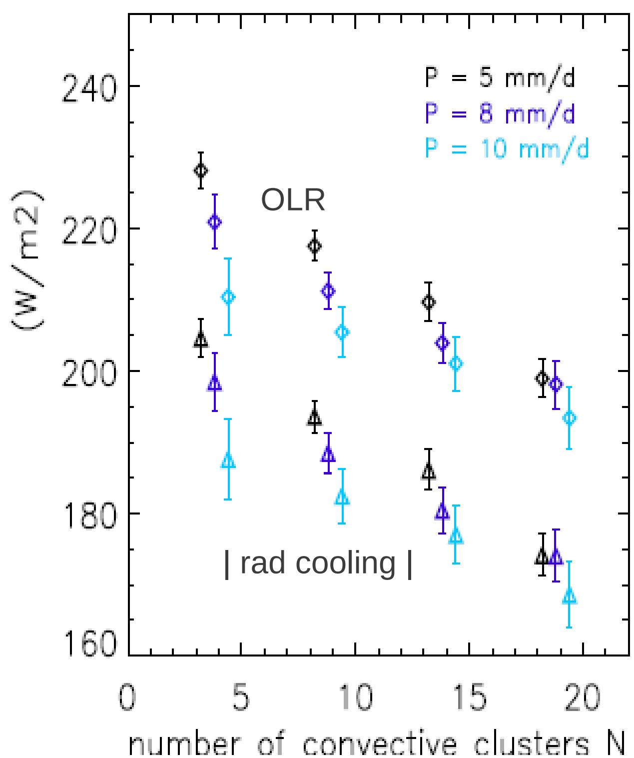
more convective aggregation ←→ more radiative cooling,
more OLR, less albedo
less clouds in the free troposphere

ISCCP cloud type classification

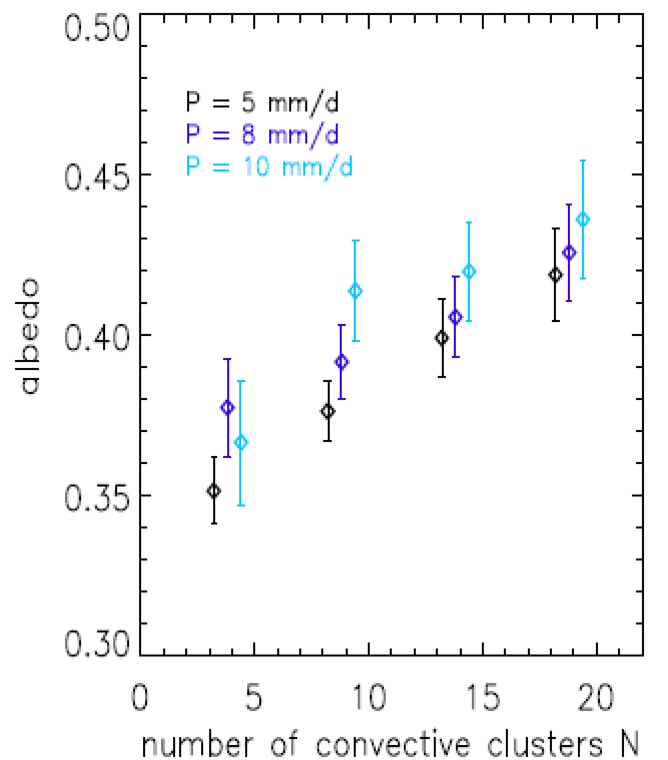


more clear-sky
less middle & upper-level clouds
confirmed by CloudSat-CALIPSO data
(pers. comm. Chris Holloway)

OLR & radiative cooling
(NOAA, ISCCP-FD or METEOSAT)

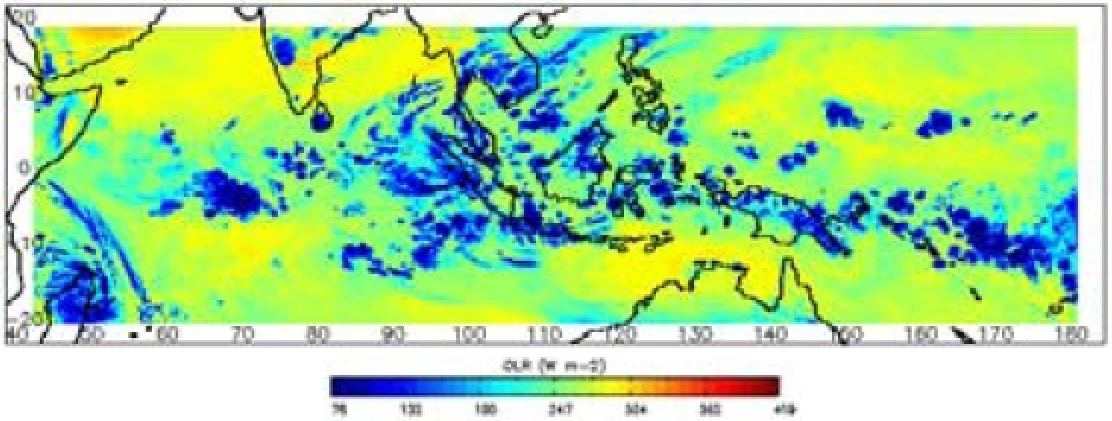


planetary albedo
(ISCCP-FD)

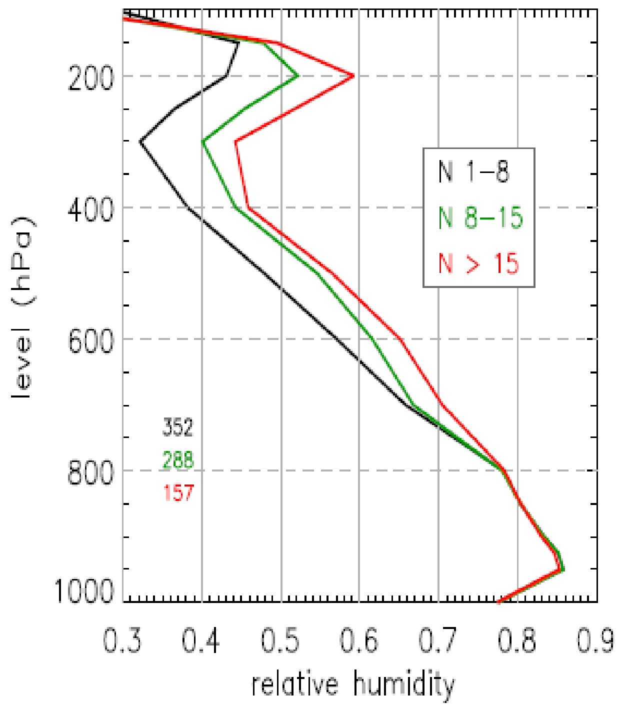


Observed Behavior Reproduced by (at least) one Cloud Resolving Model

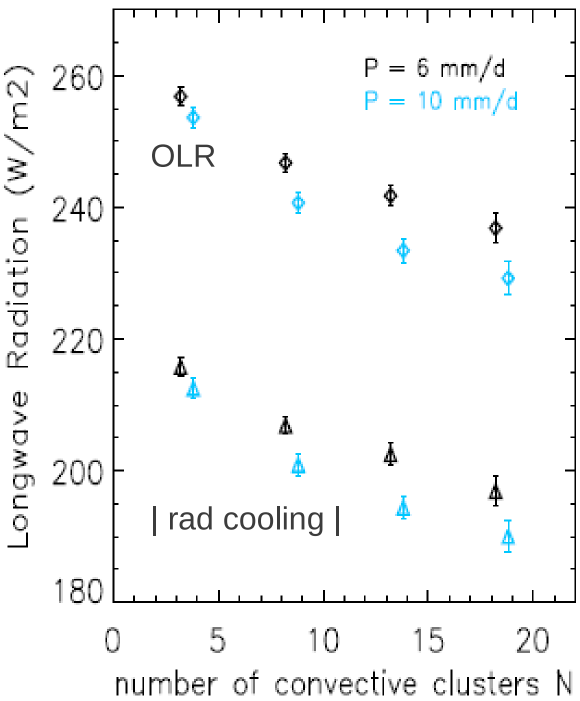
CASCADE CRM simulation (4km 3D Smag)



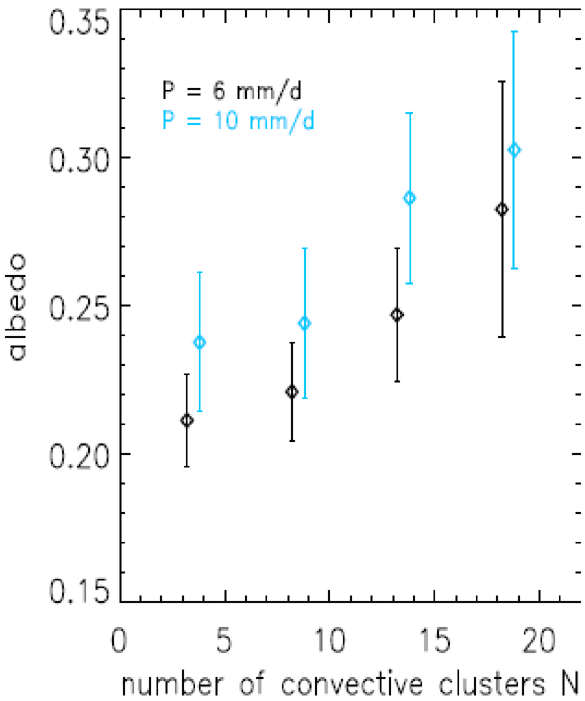
relative humidity



OLR & radiative cooling



planetary albedo



Lessons from Observations (1)

- For given large-scale forcings and precipitation :
  different states of convective aggregation are not equivalent in terms of water and energetics.

- Clustered convection is associated with a drier free troposphere, less cloudiness,
  an increase of OLR and of the atmospheric radiative cooling.

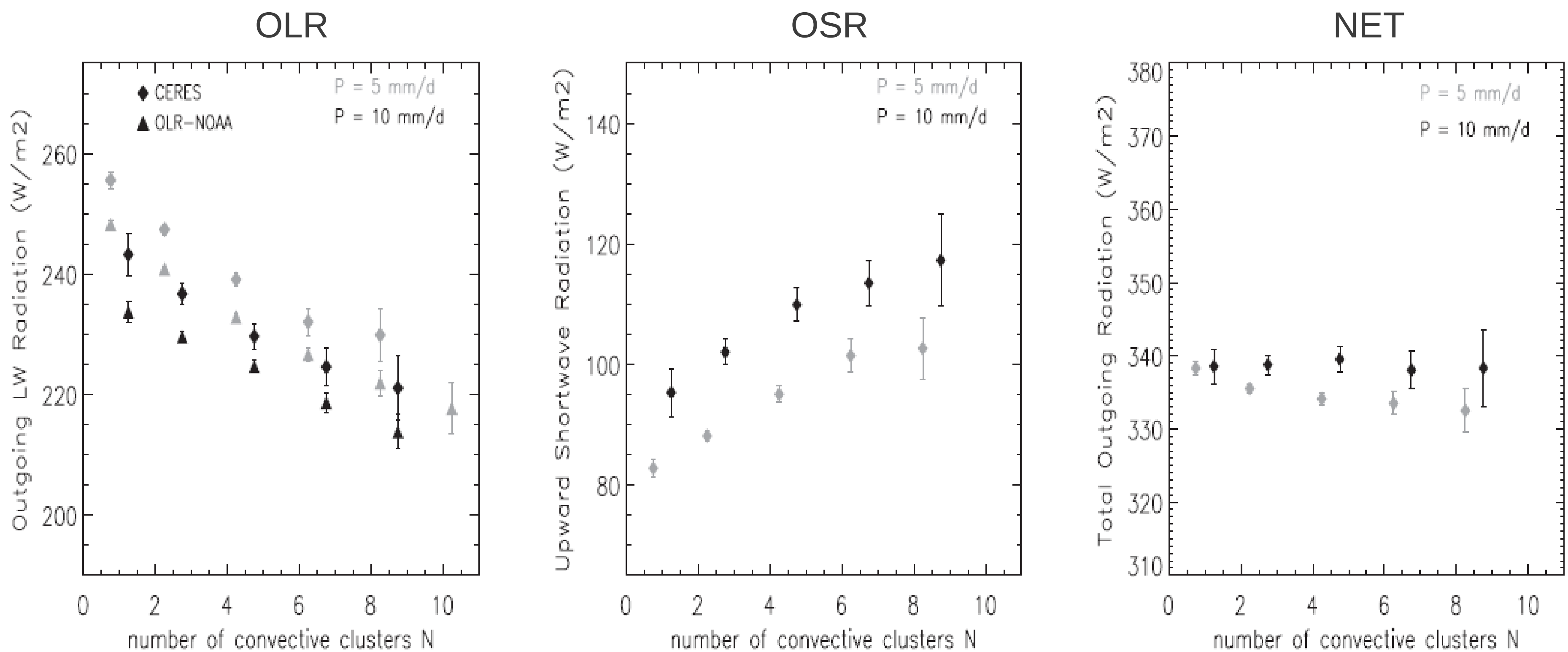
- The modulation is significant (several tens of W/m2, several kg/m2)

- Observed both at the synoptic scale and at the mesoscale

Implications ?

Implications for Climate Sensitivity

Does a change in convective aggregation modulate the NET radiation budget at TOA ?



- No observational evidence for a strong effect
- But the compensation of LW and SW variations may not hold any more in a warmer climate

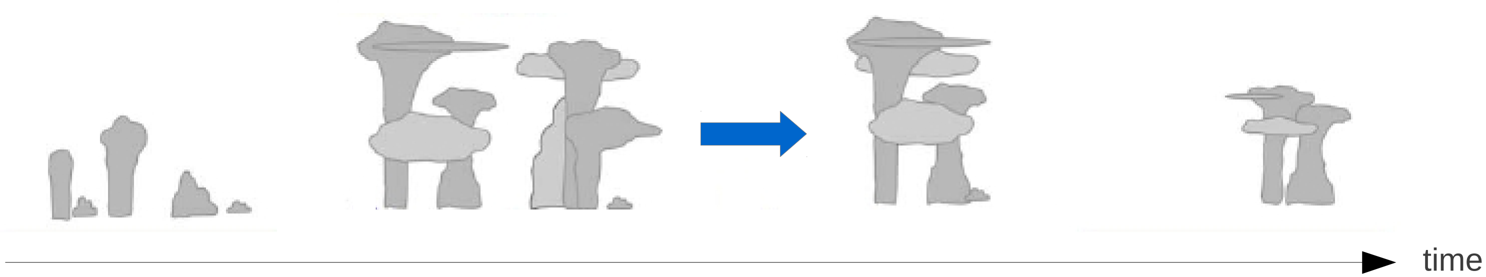
Implications for the Atmospheric Energy Budget

Observational evidence that changes in aggregation are associated with substantial changes in the moist static energy input into the atmospheric column (LH + SH + Rad)

especially changes in mesoscale organization

Scattered convection :
MSE forcing builds up
Favors large-scale ascent

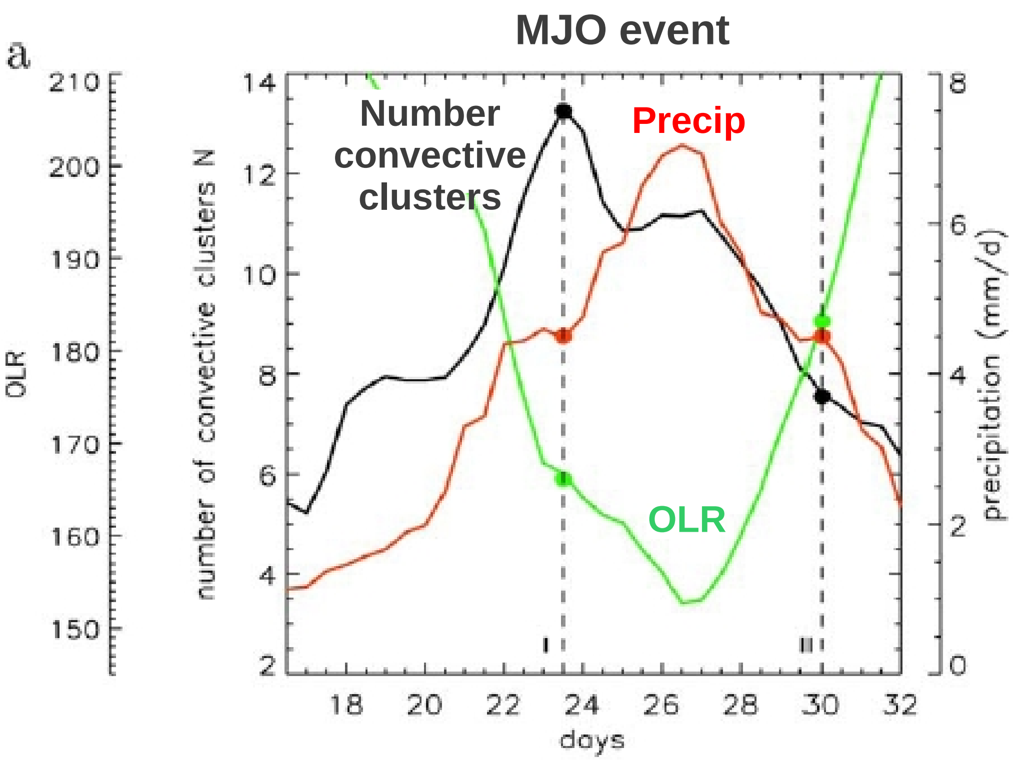
Aggregated convection :
MSE forcing decreases
Weakens large-scale ascent

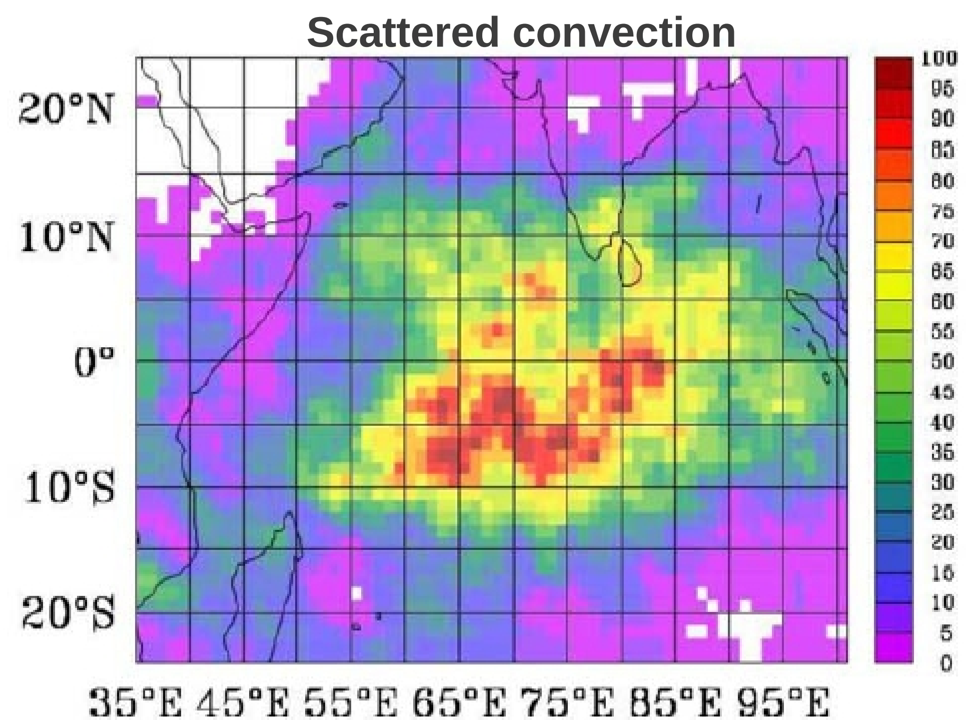


Suggests an active role in the large-scale circulation

Tropical Intra-Seasonal Variability

- Convective aggregation exhibits intra-seasonal variations :
- During active phase : more scattered convection *before* the peak of precipitation than *after*
- Favors the build-up of column-integrated MSE before the peak, and the decrease or discharge during and after the peak (cf Maloney 2009)





Changes in convective aggregation likely to amplify MJO dynamics

Lessons from Observations (2)

- No significant sensitivity of the observed TOA radiation budget to convective aggregation
  (in the current climate at least)

- However, by modulating the MSE budget of the atmosphere :
  convective aggregation may play an active role in the large-scale dynamics (e.g. MJO)

- Impact of mesoscale organization of convection ;
  missing degree of freedom in convective parameterization ?
  climate models presumably underestimate the coupling between clouds and circulation

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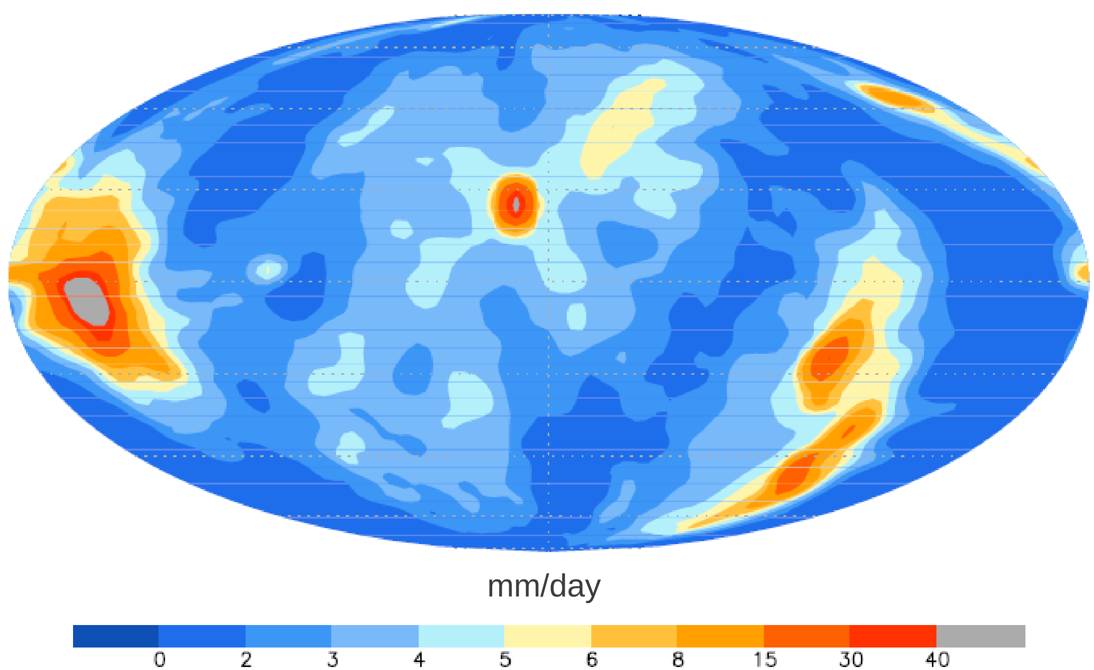
Does the larger-scale (resolved) organization impact the global climate ?

Large-scale convective organization in GCM simulations

IPSL-CM5A-LR GCM run in a Radiative-Convective Equilibrium configuration
(cf Held, Zhao & Wyman 2007 ; Popke, Stevens & Voigt 2013)

Non-rotating aquaplanet, globally-uniform insolation and SST (prescribed)

RCE, uniform SST (300 K)



Thanks to
Aiko Voigt
&
David Coppin

Spontaneous emergence of a large-scale convective organization & circulation

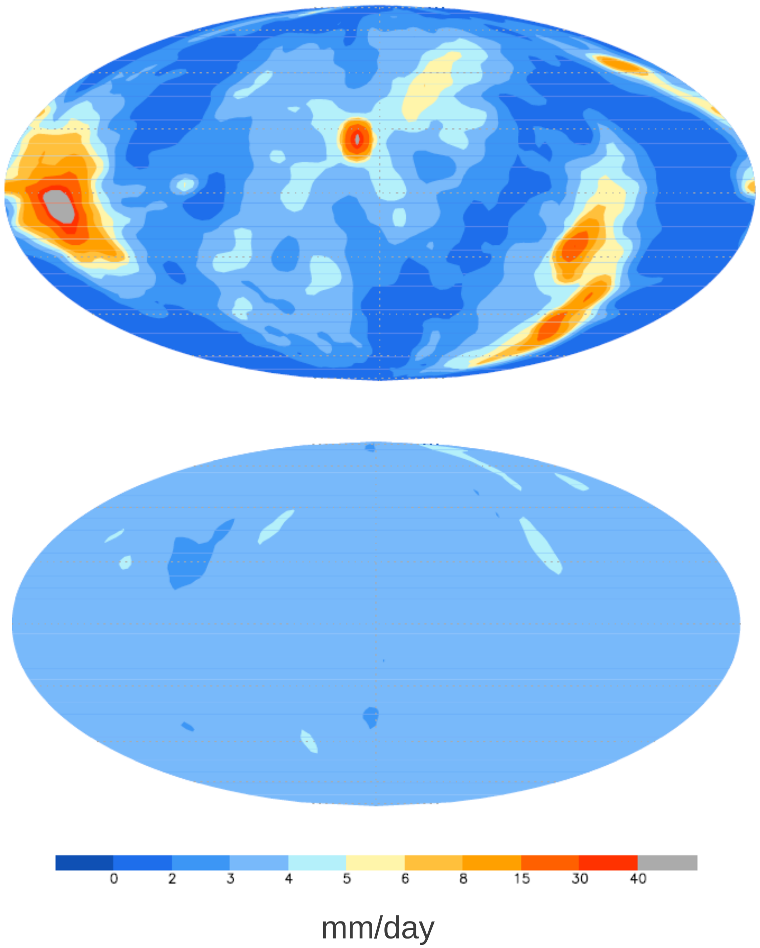
Sensitivity to processes ? Impact on the mean state ?
NB : preliminary results

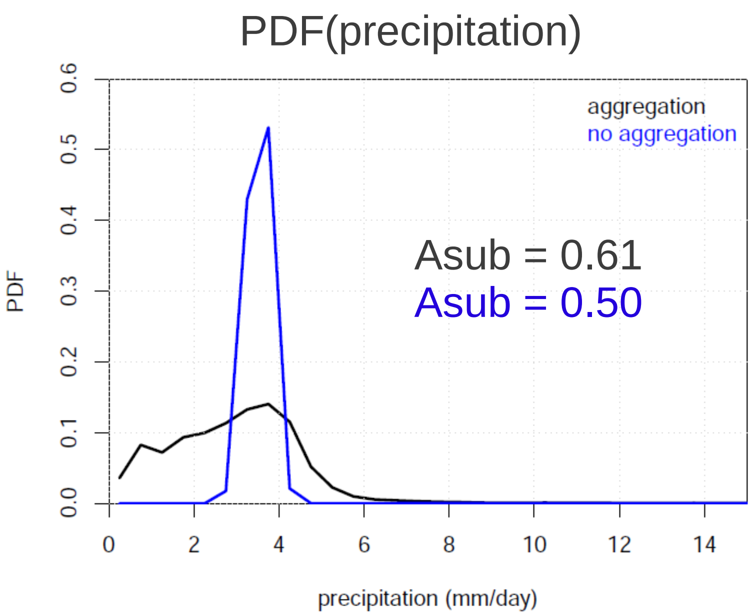
Dependence on model physics, *e.g.* cloud-radiative effects

Precipitation

with
cloud-radiative
effects

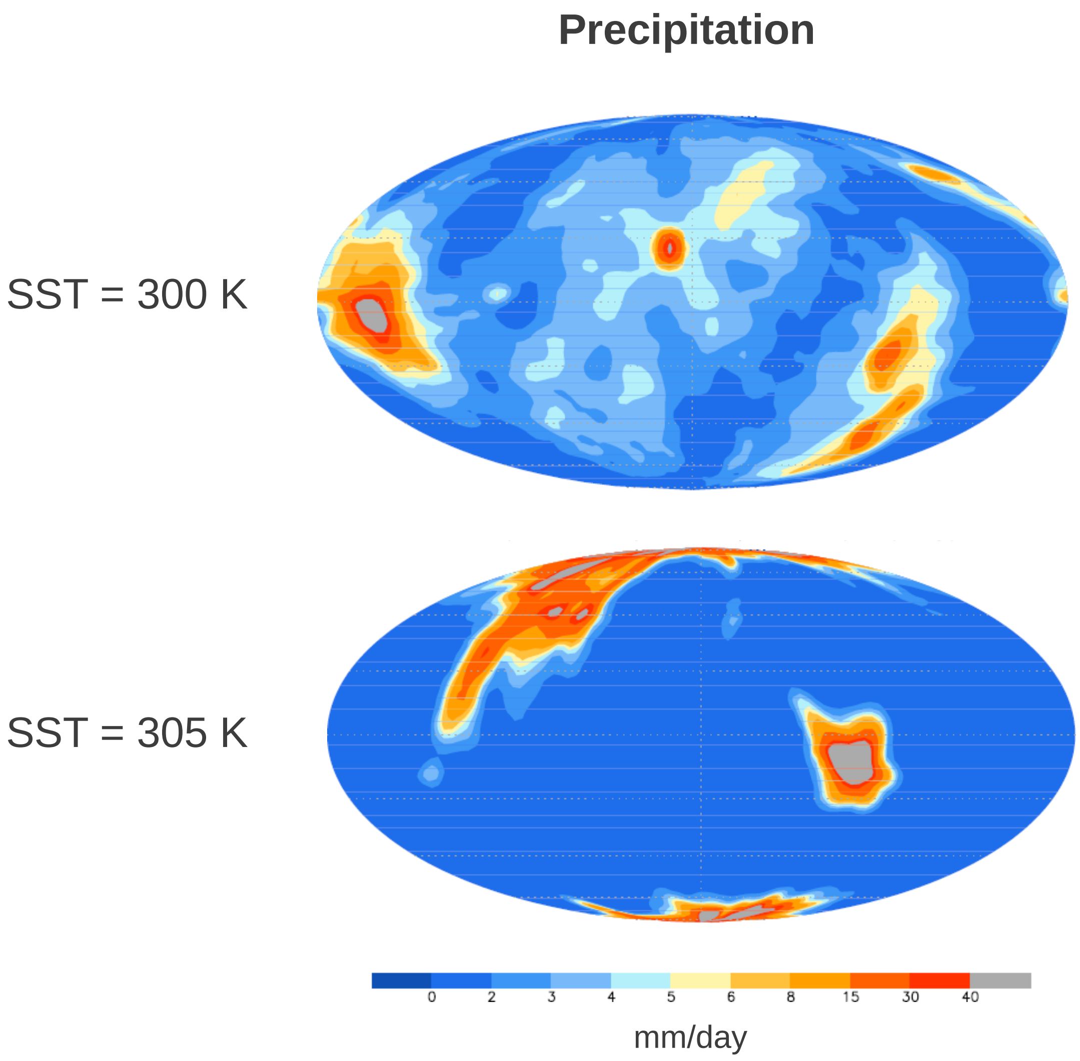
without
cloud-radiative
effects

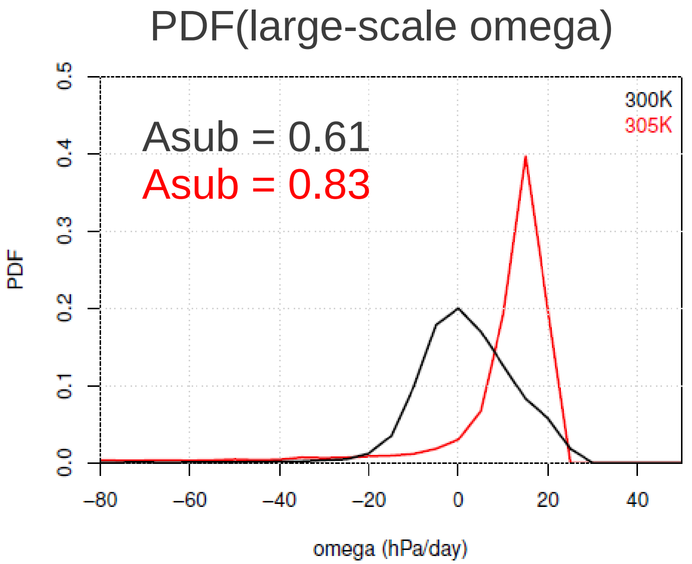




Cloud-radiative effects in the free troposphere crucial

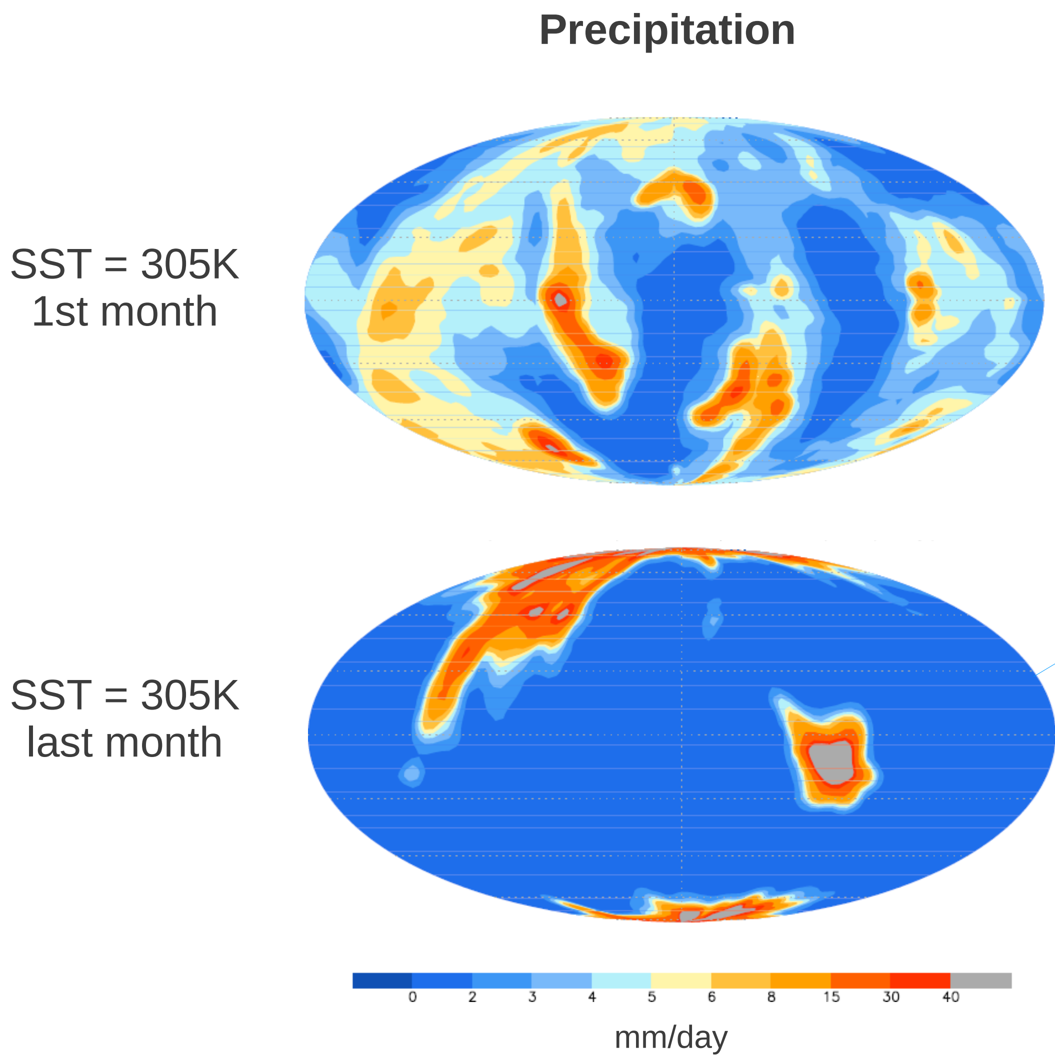
Dependence on temperature

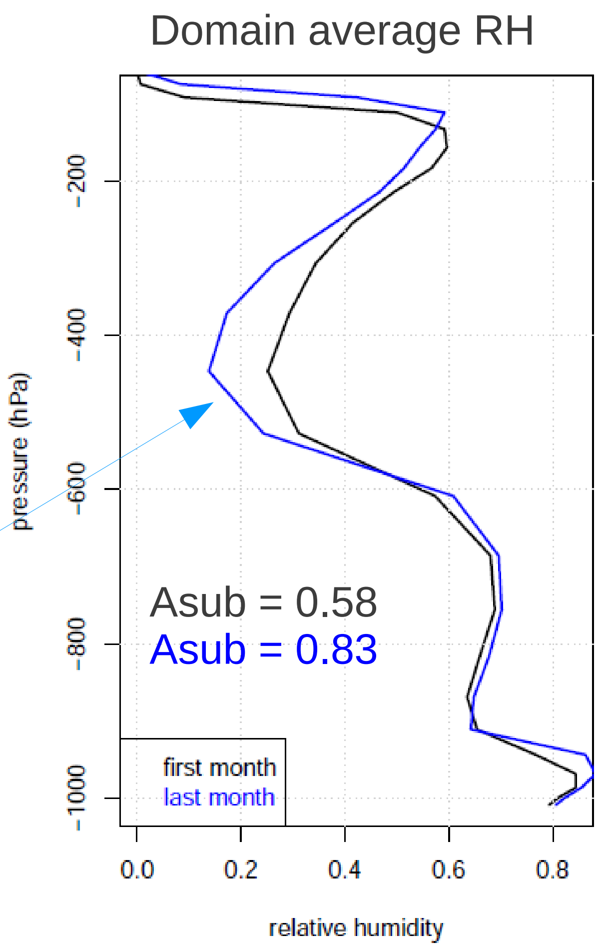




More aggregation at higher SSTs

Impact on the mean state



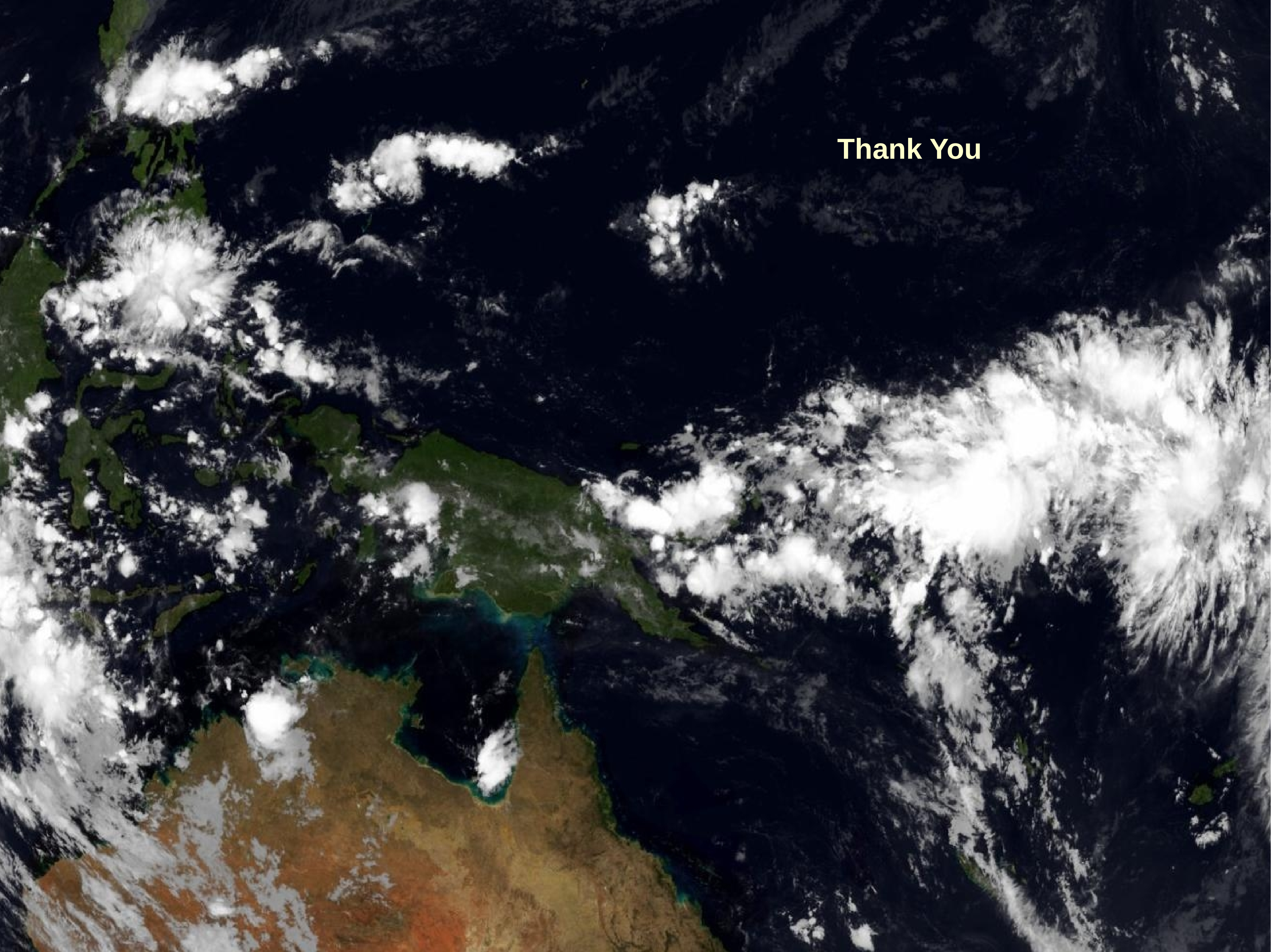


Impact on the global-mean relative humidity & radiative cooling

Lessons from GCM simulations of RCE

- In RCE, a large-scale convective organization and circulation :
  - can arise spontaneously
  - depends on model physics (e.g. cloud-radiative effects)
  - depends on temperature
  - impacts the global mean state

- As emphasized by Held et al. (2007) and Popke et al. (2013), GCMs in a radiative-convective equilibrium constitute promising tools to explore :
  - underlying physical processes
  - impact on climate
  - bridge conceptual and realistic frameworks

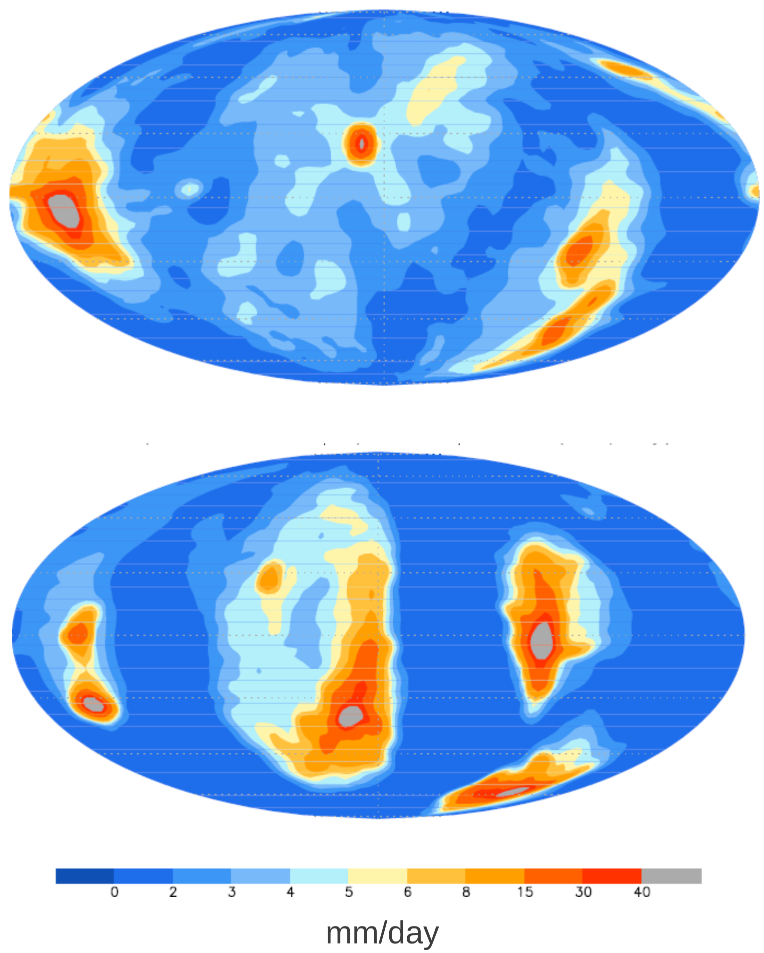

Thank You

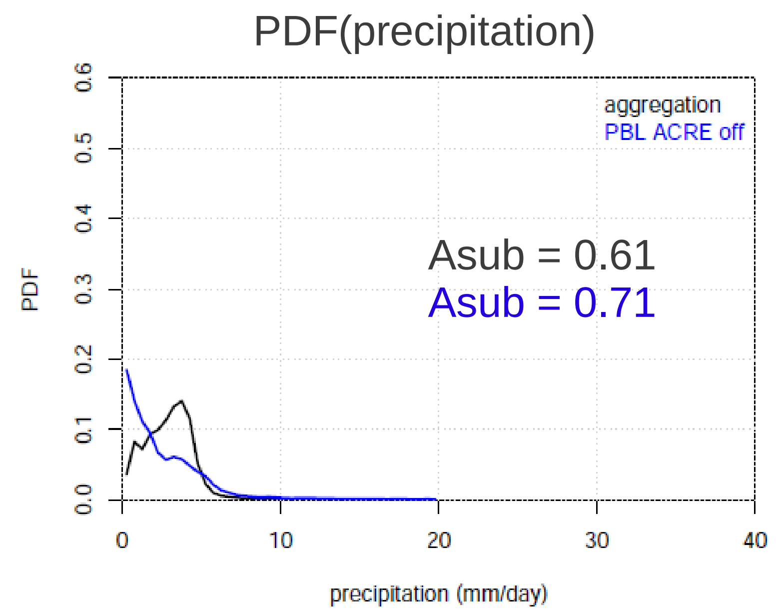
Dependence of the large-scale convective organization on cloud processes

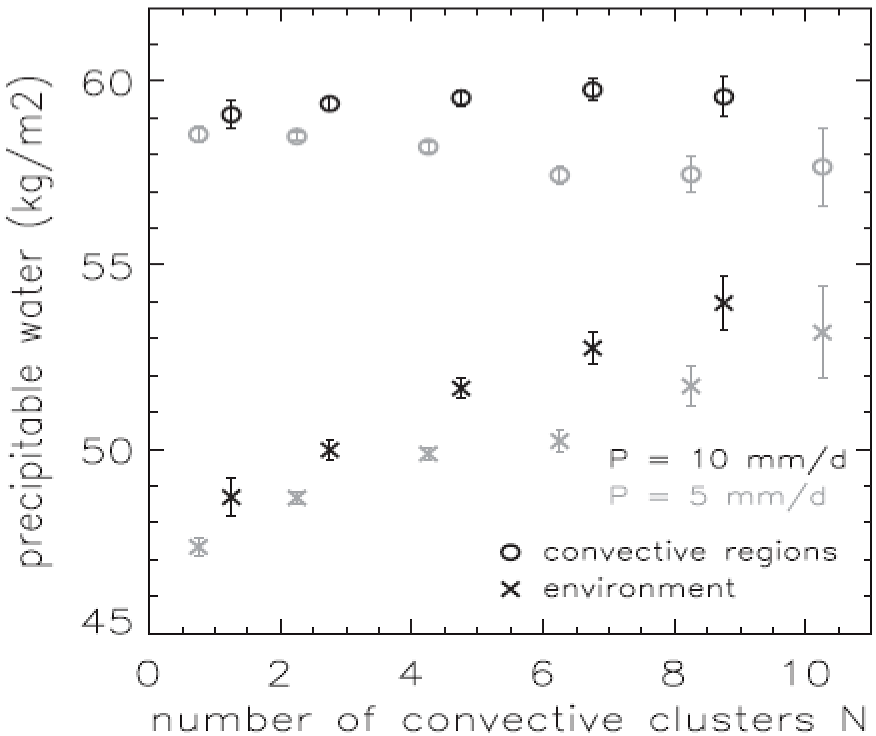
Precipitation

with
cloud-radiative
effects

without
cloud-radiative
effects
in the PBL







precipitable water (kg/m2)
number of convective clusters N
P = 10 mm/d
P = 5 mm/d
convective regions
environment
45
50
55
60
0
2
4
6
8
10