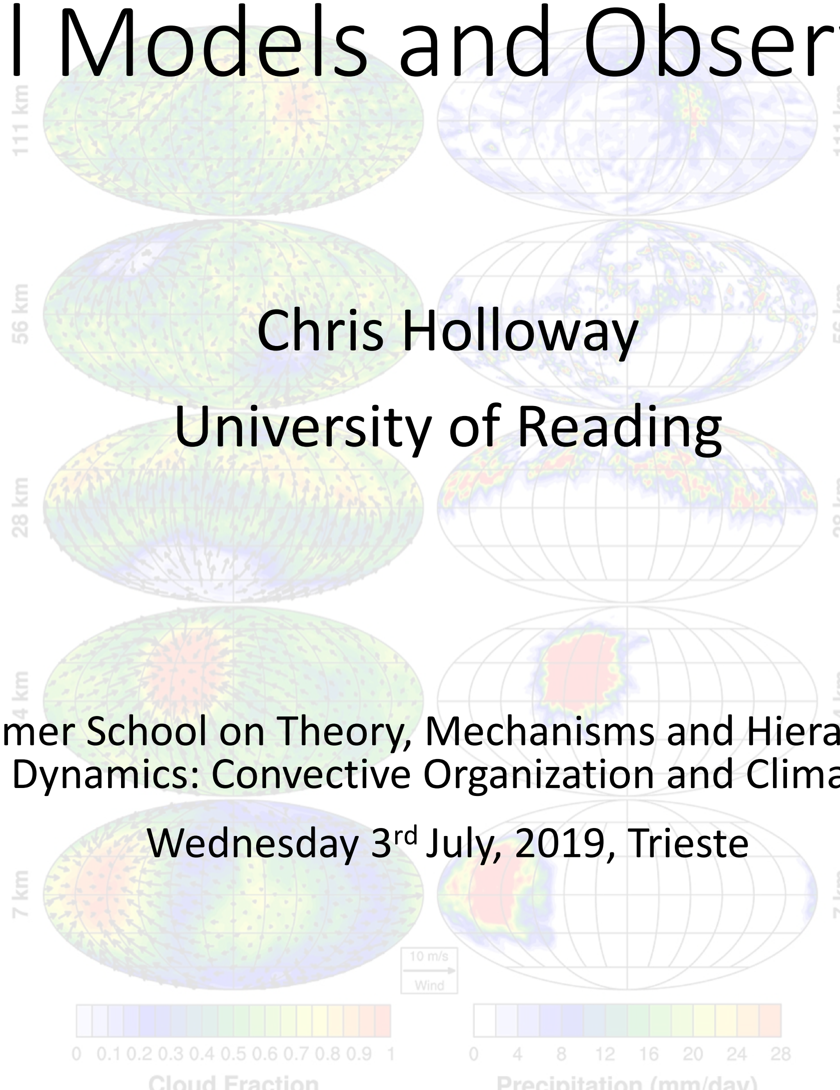
Convective Organisation in Global Models and Observations



Chris Holloway

University of Reading

2nd ICTP Summer School on Theory, Mechanisms and Hierarchical Modeling of Climate Dynamics: Convective Organization and Climate Sensitivity

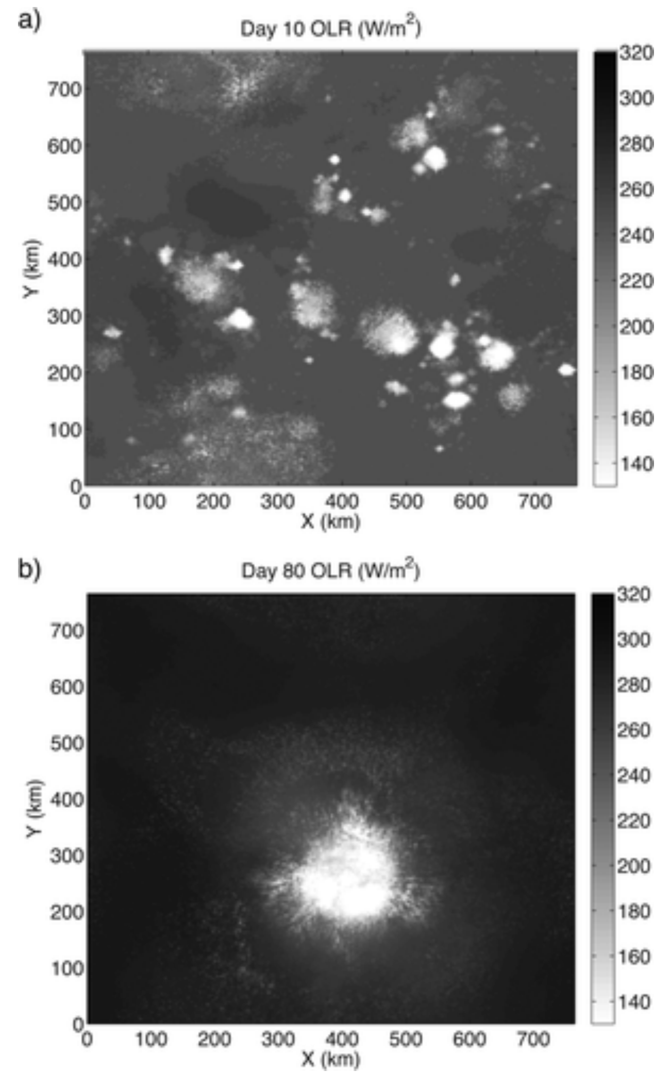
Wednesday 3rd July, 2019, Trieste

Outline

1. Examples of RCE in global models
2. organisation indices in global models
3. Implications of aggregation for large scales
4. Aggregation in observations
5. Questions

Review: 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)

RCE in global (coarse) models: Dependence on SST?

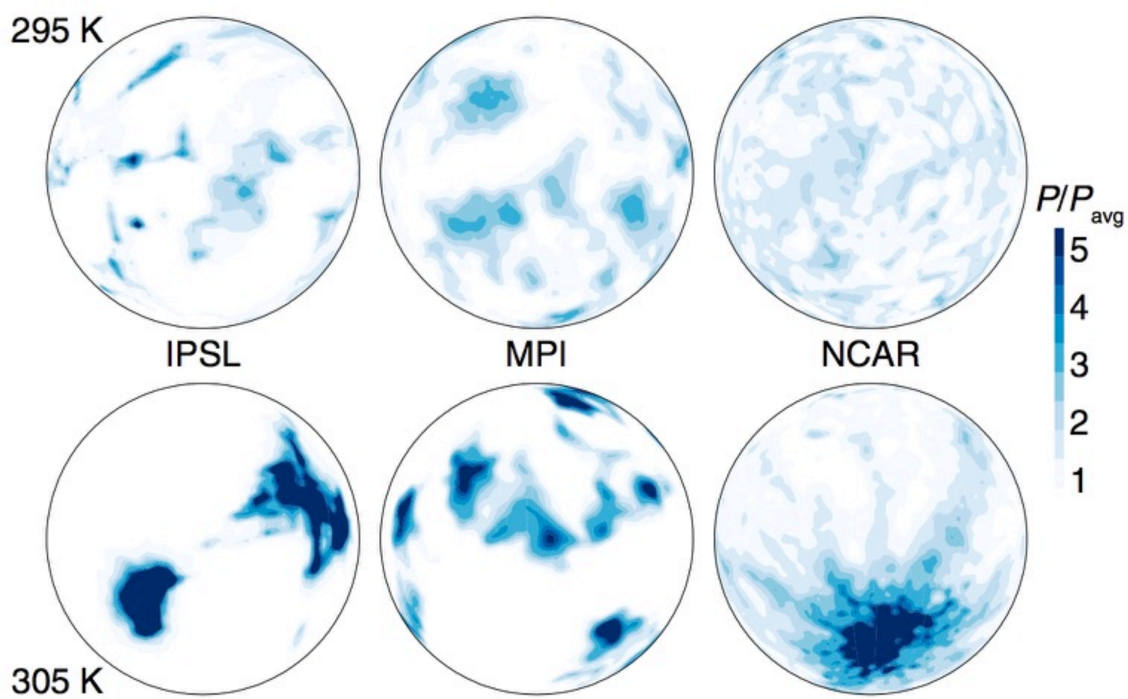


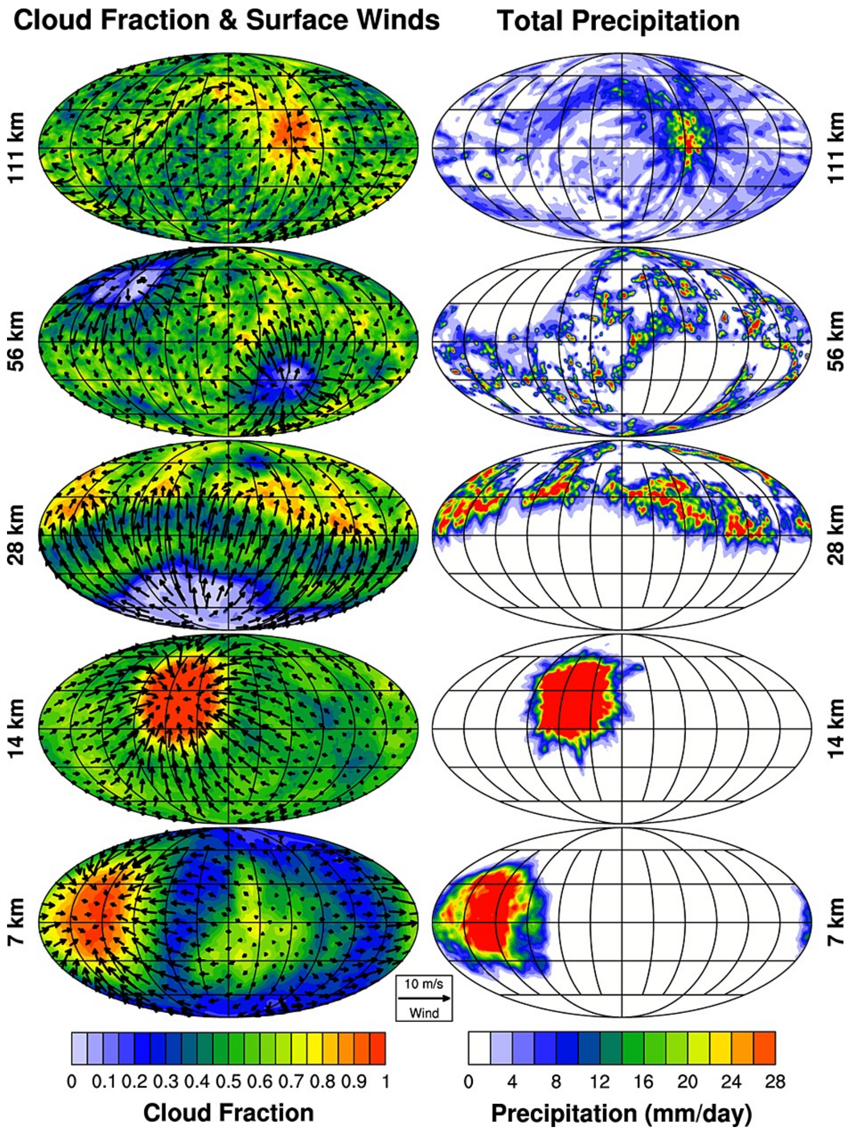
Fig. 1. Monthly precipitation (normalized by its global mean value) predicted by the IPSL, MPI, and NCAR GCMs in RCE simulations forced by an SST of (*Top*) 295 K and (*Bottom*) 305 K.

Fixed SST, no rotation, constant insolation with a diurnal cycle (usually)

self-aggregation is more pronounced at high SSTs, with a narrowing of rainy areas

Bony et al. (2016)

Dependence on resolution?

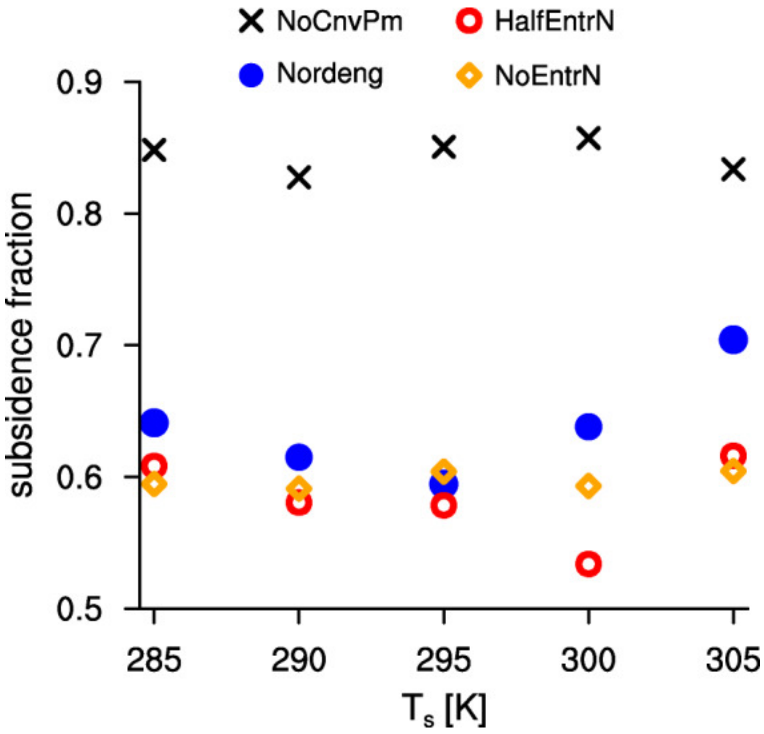


For CAM5 model: aggregation becomes stronger with finer grid scale. Note that planetary radius scale varies going down column from 1 to 1/16.

Reed and Medeiros (2015)

Dependence on convection representation and entrainment?

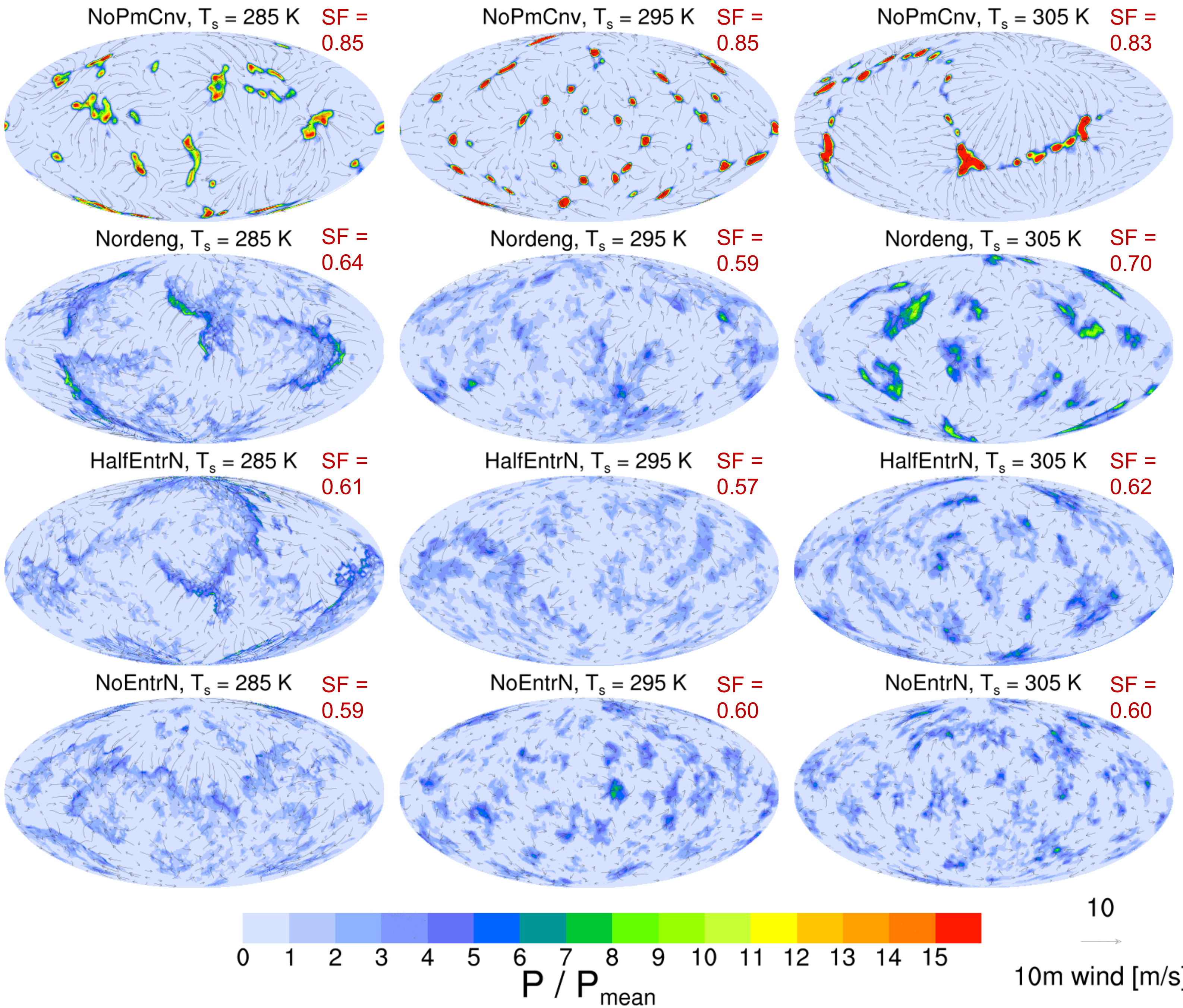
Becker et al. (2017) find that convective parameterisation (on/off, and entrainment mixing value) affect SST dependence of aggregation in a global model (ECHAM 6.3) at ~200 km grid spacing:



They also find that WISHE (wind-evaporation feedback) is important at low SSTs (with parameterised convection) but not at high SSTs, where evaporation is higher in dry regions.

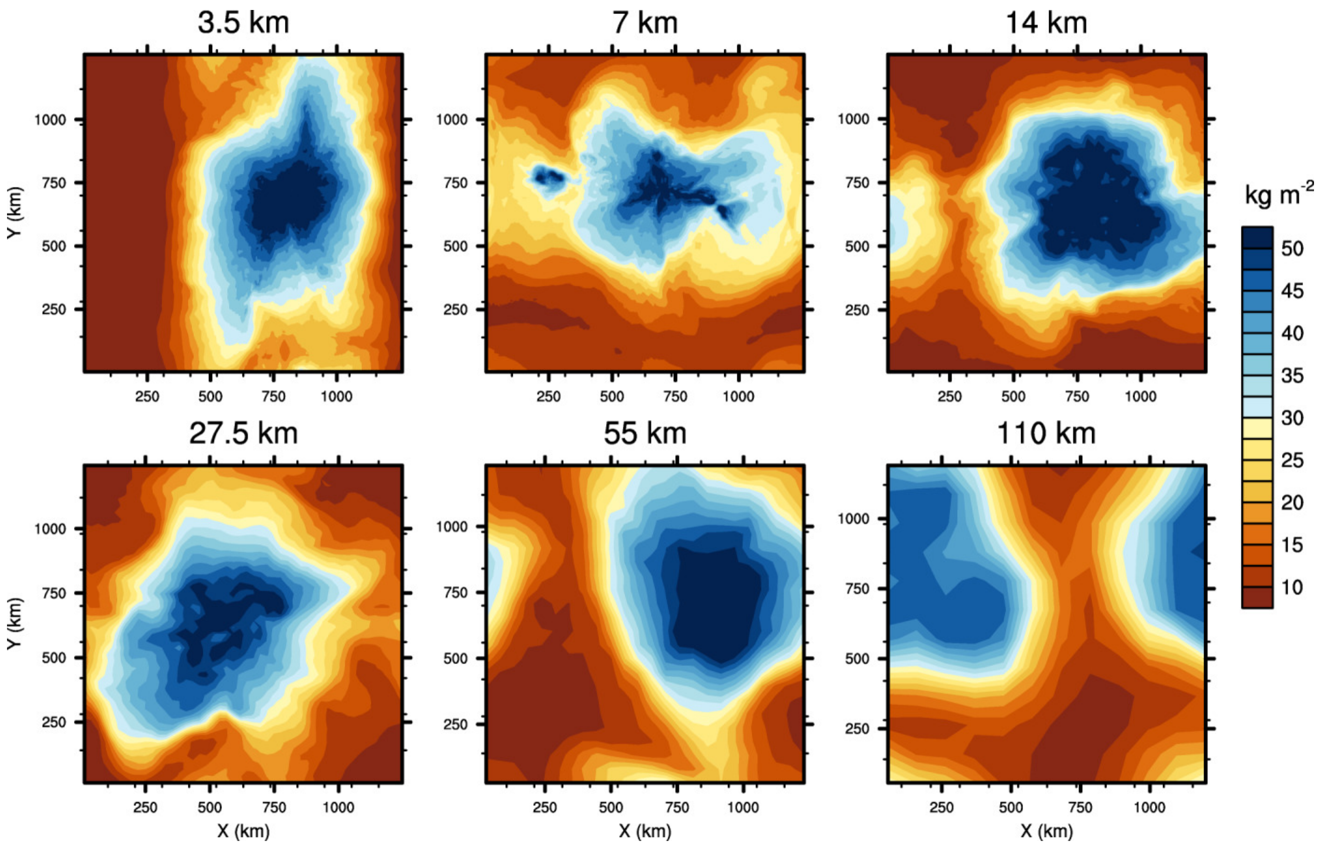
On the other hand, moisture-convection feedbacks become more important at higher SSTs because larger saturation deficits lead to more dry air dilution per mixing amount.

Precipitation and 10 m wind field in last simulated year, day 1



Becker et al. (2017)

Dependence on resolution (flat domain)?

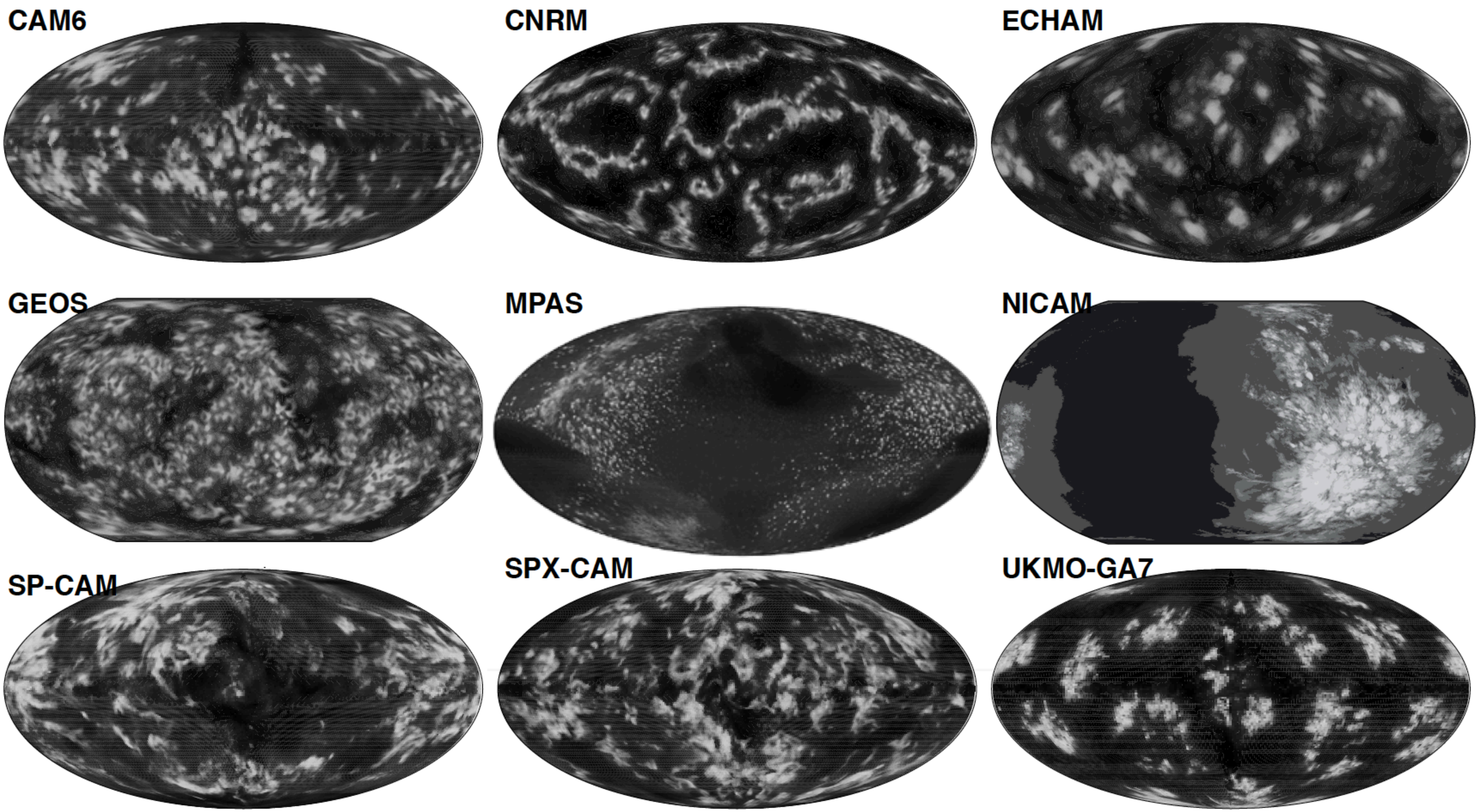


GEOS Column water vapour (CWV), flat doubly periodic domain: aggregation differs somewhat with resolution but not systematically.

Note that 3.5 km is mainly explicit convection, 7 km is “gray zone”.

Arnold and Putnam (2018)

Global models, OLR day 1000, RCEMIP 300 K SST



Courtesy of Allison Wing

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

Organisation indices for global models

- Review: Subsiding fraction (SF) (Coppin and Bony 2015): the fractional area of the globe covered by **large-scale** (coarse grid or horiz. avg.) and ~day-mean subsidence in the mid-troposphere (e.g. 500 hPa or tropospheric-mean)
- SF is close to 0.5 when convection is disaggregated, but can be much higher when aggregated
- Dry area fraction (DAF) is the area fraction covered by very low precipitation.

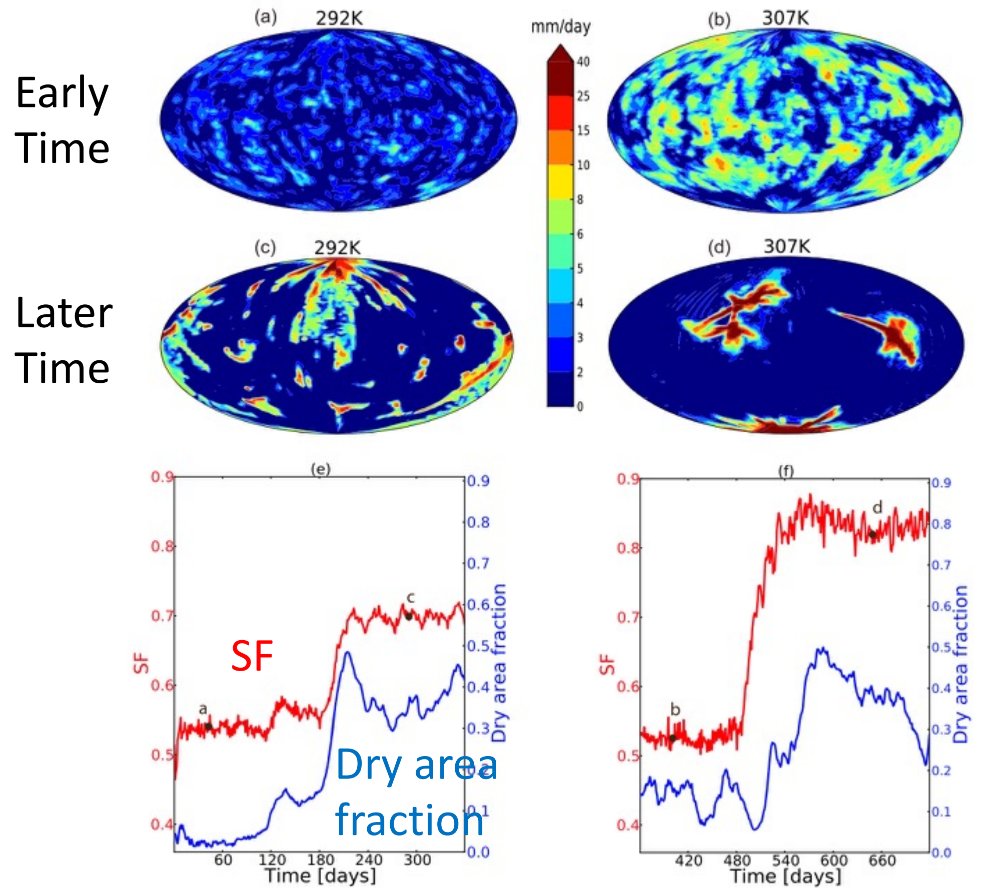
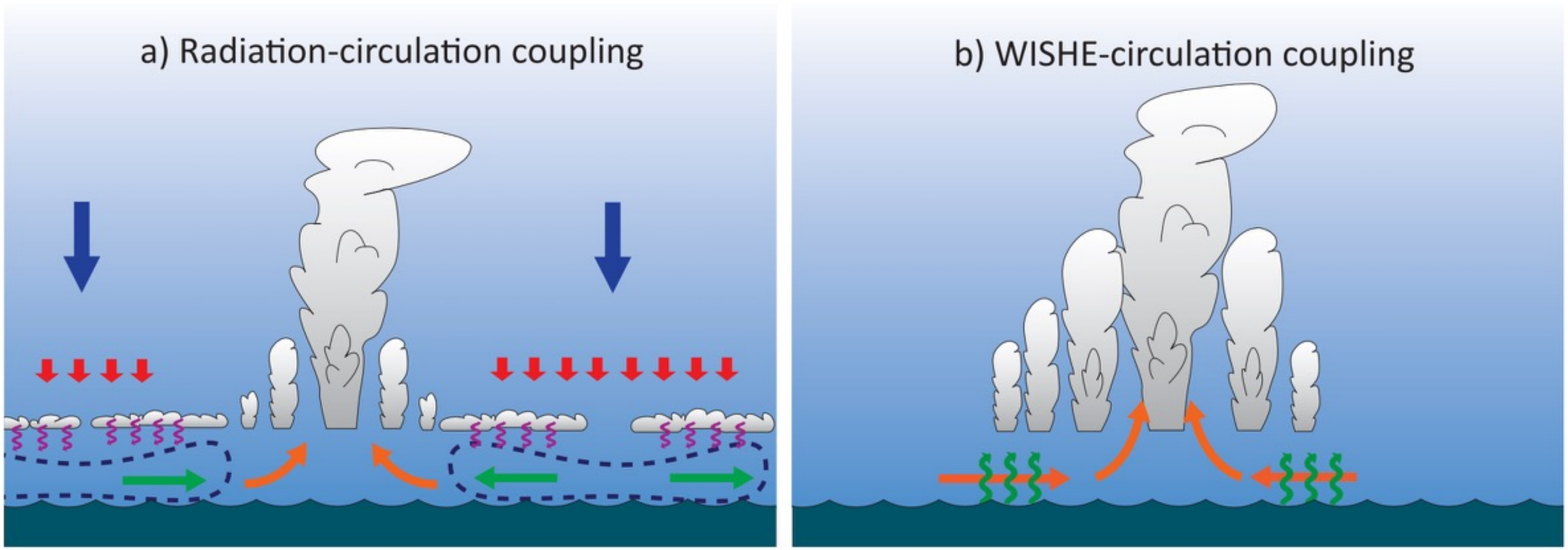


Figure 1. Global snapshots of precipitation for disaggregated convection at (a) day 40 at 292 K and (b) day 400 at 307 K, and for aggregated convection at the same SSTs (respectively, (c) at day 290 and (d) at day 650). Temporal evolution of subsiding fraction (SF, red) and proportion of dry areas (blue) for the reference simulations at (e) 292 K and (f) 307 K. The approximate timing of the snapshots shown on Figures 1a–1d is reported on Figures 1e and 1f.

Coppin and Bony (2015)

Different mechanisms for different SSTs?



Low SST

High SST

Coppin and Bony (2015)

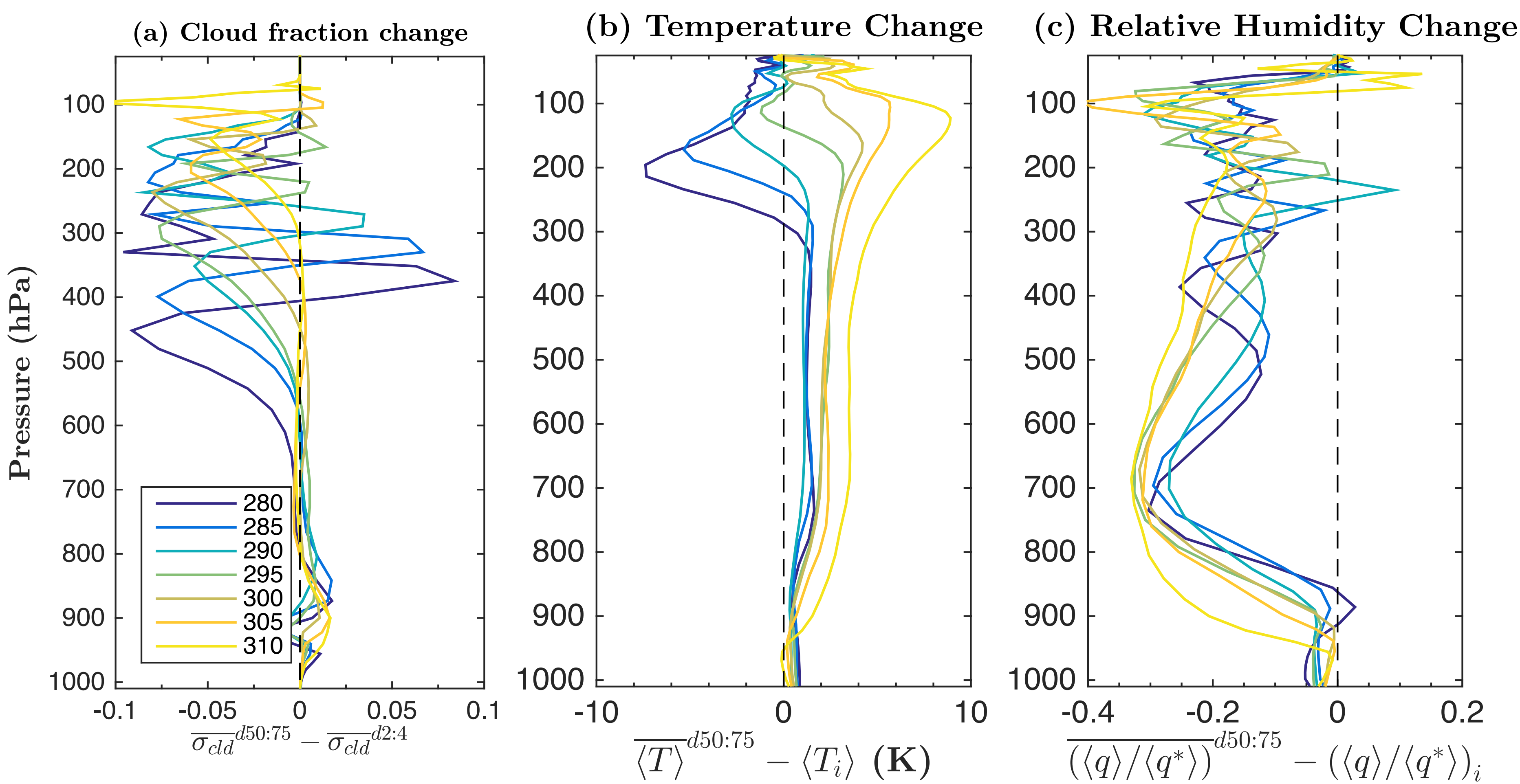
Possible implications of aggregation for climate

(Some introduction before Thursday's lecture on aggregation and climate)

(Note: the rest of this lecture includes limited-area CRMs and observations, not just global models)

Courtesy of Allison Wing

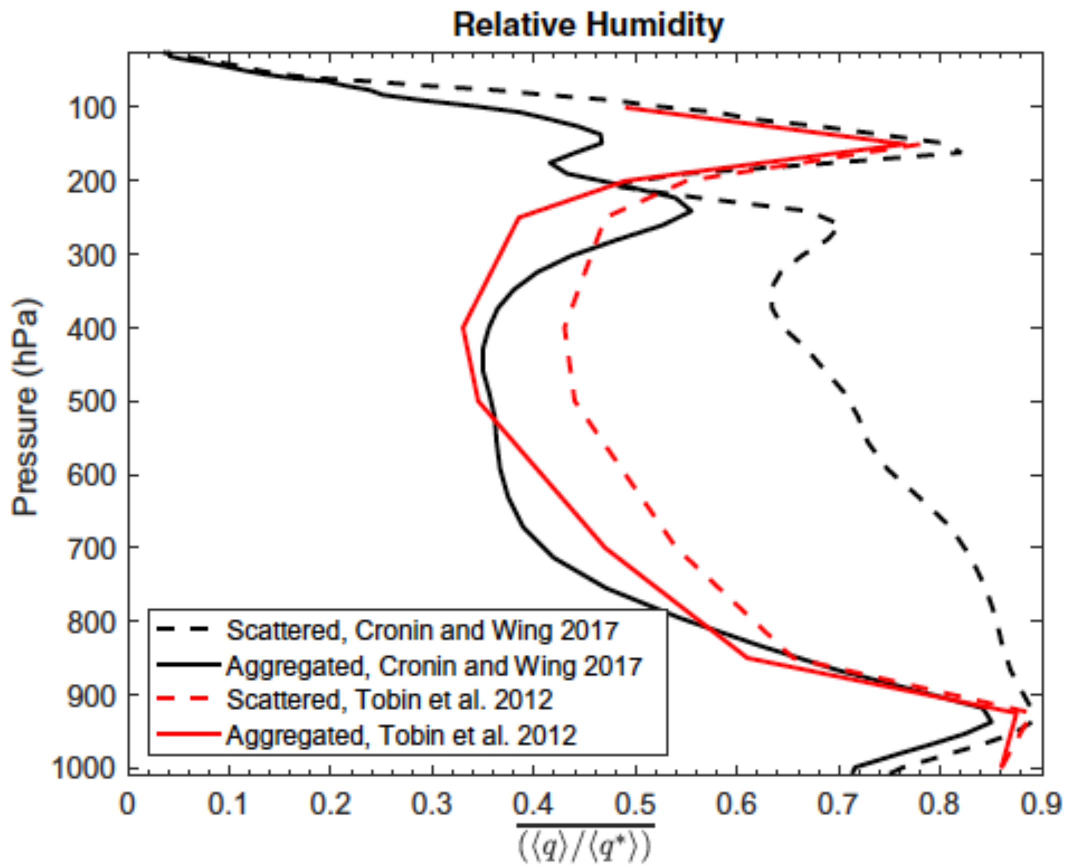
Decrease in high clouds, warming, drying with aggregation



Courtesy of Allison Wing

Wing and Cronin (2016)

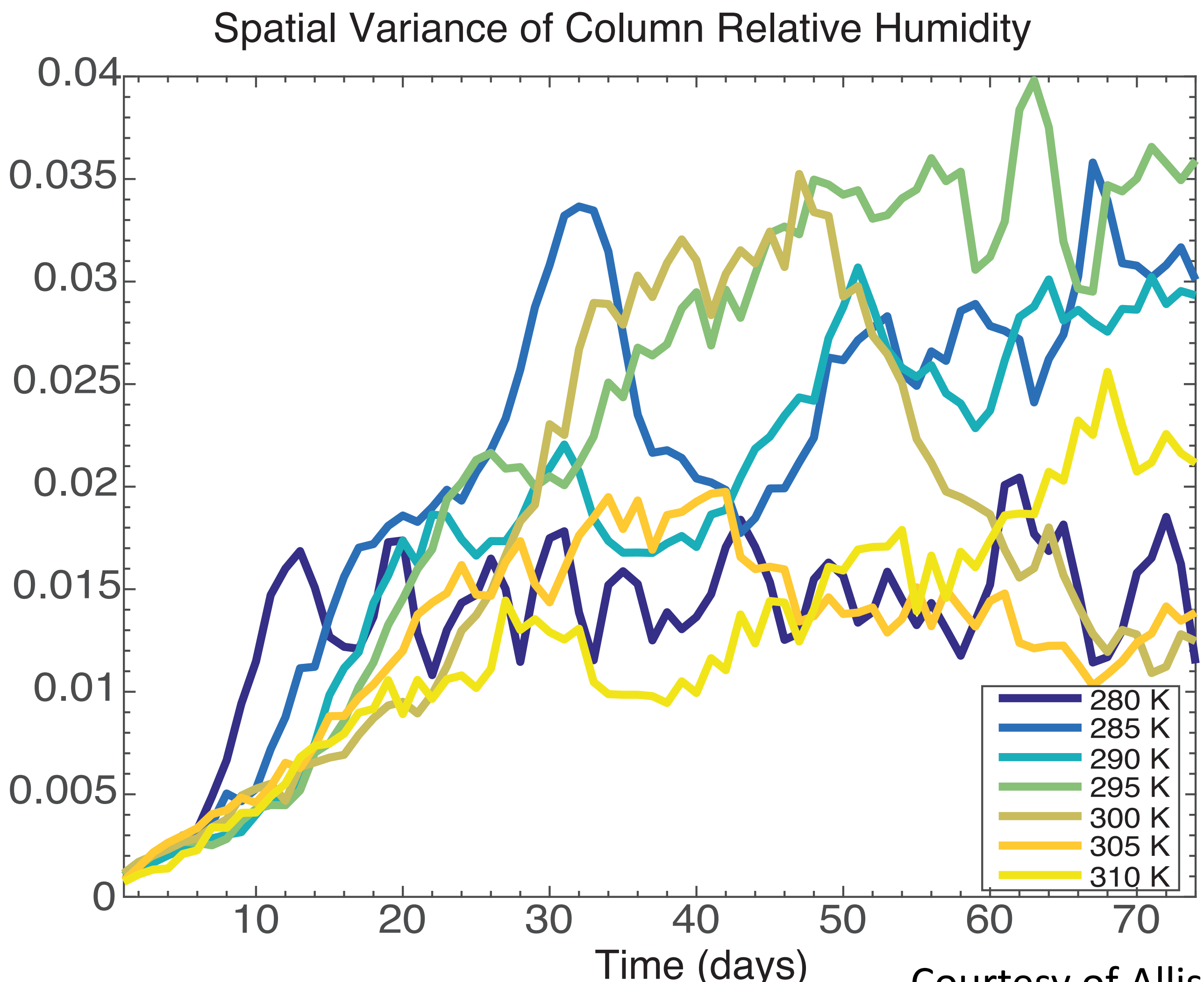
Drying of mean state under more aggregated conditions seen in self-aggregation simulations *and* observations of aggregated convection



Courtesy of Allison Wing

Wing (2019)

Increased humidity variance: dry regions get drier, moist regions get moister

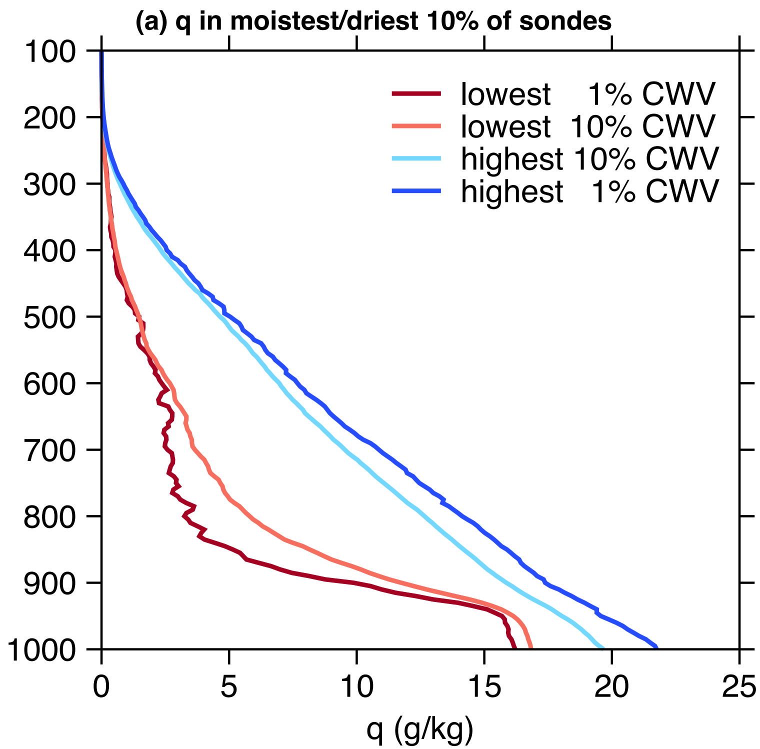


Courtesy of Allison Wing

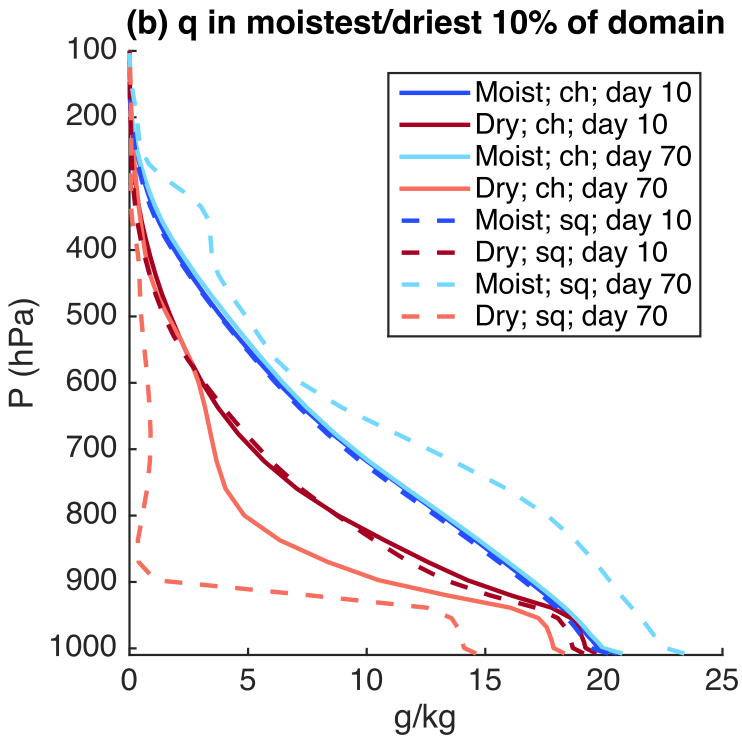
Wing (2019)

Humidity variability in aggregated channel simulations resembles observed humidity variability

Nauru Radiosondes



RCE Simulations



Courtesy of Allison Wing

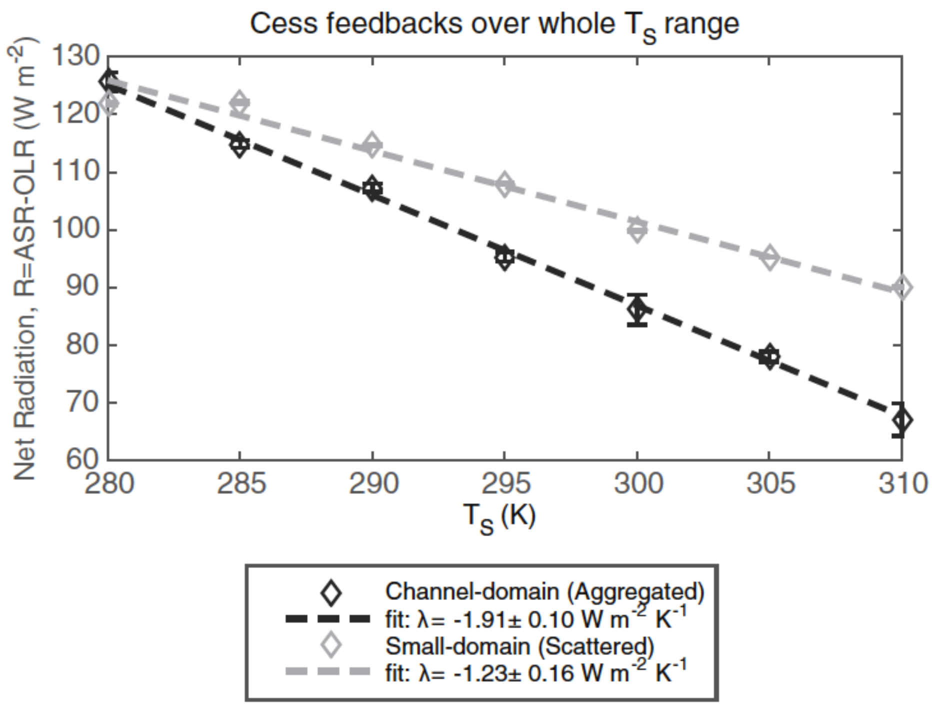
Holloway et al. (2017)

Why might self-aggregation be important for climate?

Self-aggregation...
warms and dries mean state,
reduces high clouds,
enhances dryness of dry regions,
might be temperature dependent

Courtesy of Allison Wing

Aggregation modestly reduces climate sensitivity*



- Net feedback over whole SST range more negative in channel than square
  - Implies lower climate sensitivity when aggregated (in channel)
  - Contributions from both non-cloud and cloud feedbacks
- Caveat: large variability across simulations

* more on this in Thursday's lecture

Courtesy of Allison Wing

Cronin and Wing (2017)

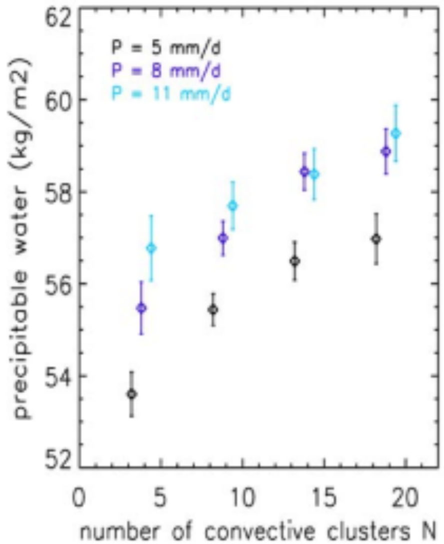
Aggregation in Observations

- 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

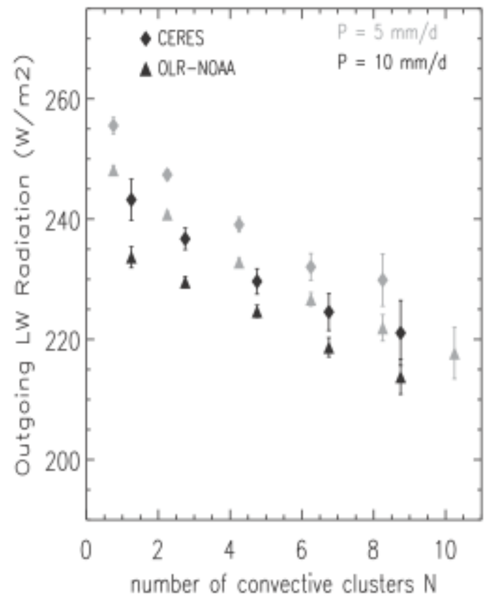
- Even at shorter time and space scales, some of these feedbacks appear to be important for maintaining organised convection against the often dis-aggregating tendency of vertical convective circulations (e.g. Holloway 2017)

Holloway et al. (2017)

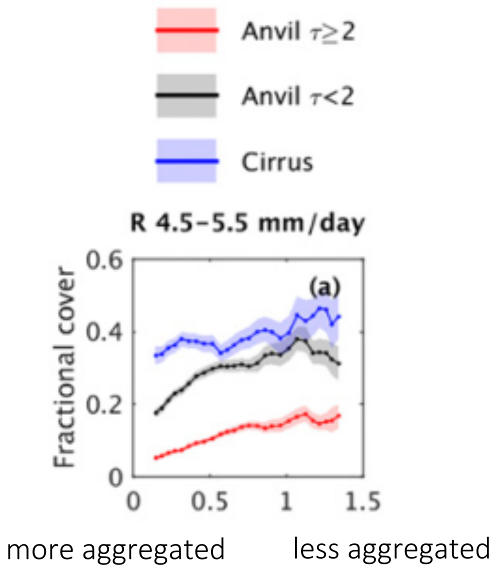
Convective aggregation in observations



Tobin et al. 2013



Tobin et al. 2012



Stein et al. 2017

Review: There is agreement between models and observations that as convection becomes aggregated (clumped into fewer moist regions), the subsidence regions become dryer, resulting in *a dryer large-scale mean environment*.

This drying, and a reduction of upper-tropospheric stratiform cloud, leads to *larger OLR* and *stronger atmospheric cooling*.

Observational perspectives on aggregation processes

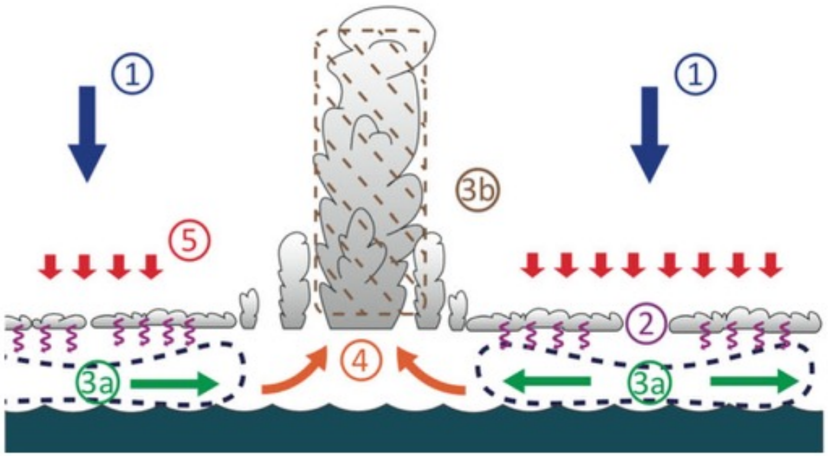


Figure adapted from Coppin and Bony 2015

Initiation processes, such as *radiatively-driven cold pools* and related shallow overturning circulations (above), are one obvious observational target.

Maintenance processes may be easier to study in observations (already aggregated convection). Likely links to the *MJO* and *tropical cyclones*, with feedbacks involving convection, clouds, moisture, radiation, and surface fluxes being important.

Further work is needed on ocean coupling effects in models and observations.

Aggregation in a warming climate

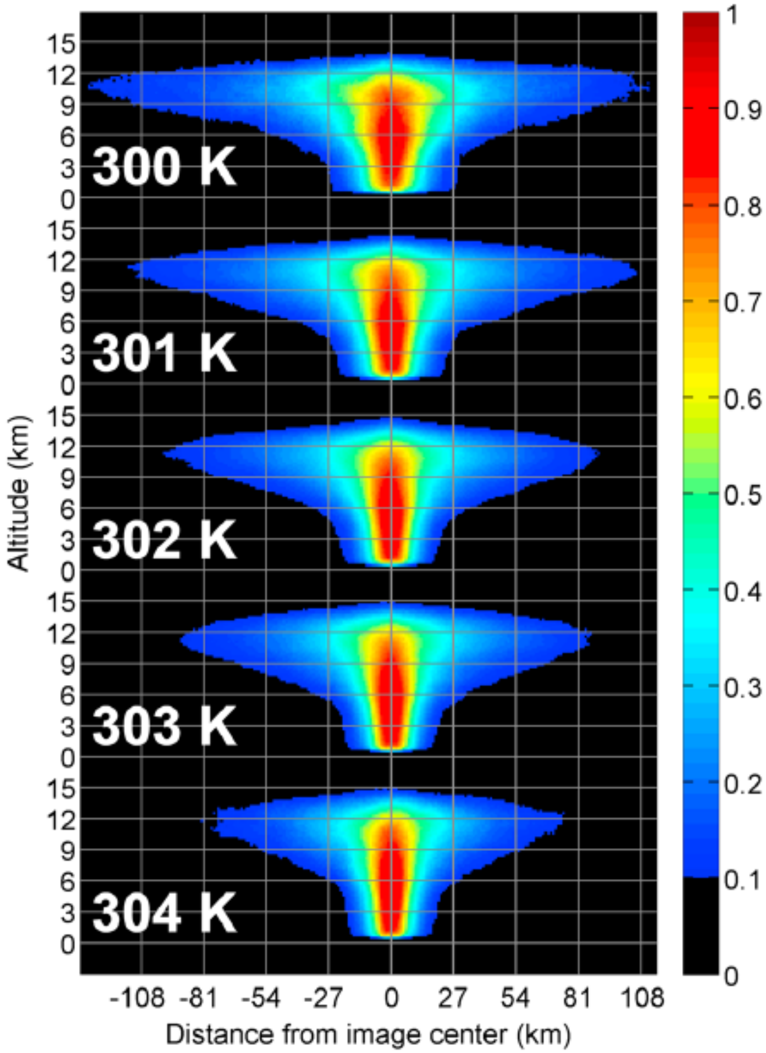


Figure from Igel et al. 2014, *JGR Atmos.*

Recent work suggests potential sensitivity of aggregation processes to SST and climate change.

For instance, the “stability-iris” effect (Bony et al, 2016) predicts smaller anvil fractions in a warmer climate.

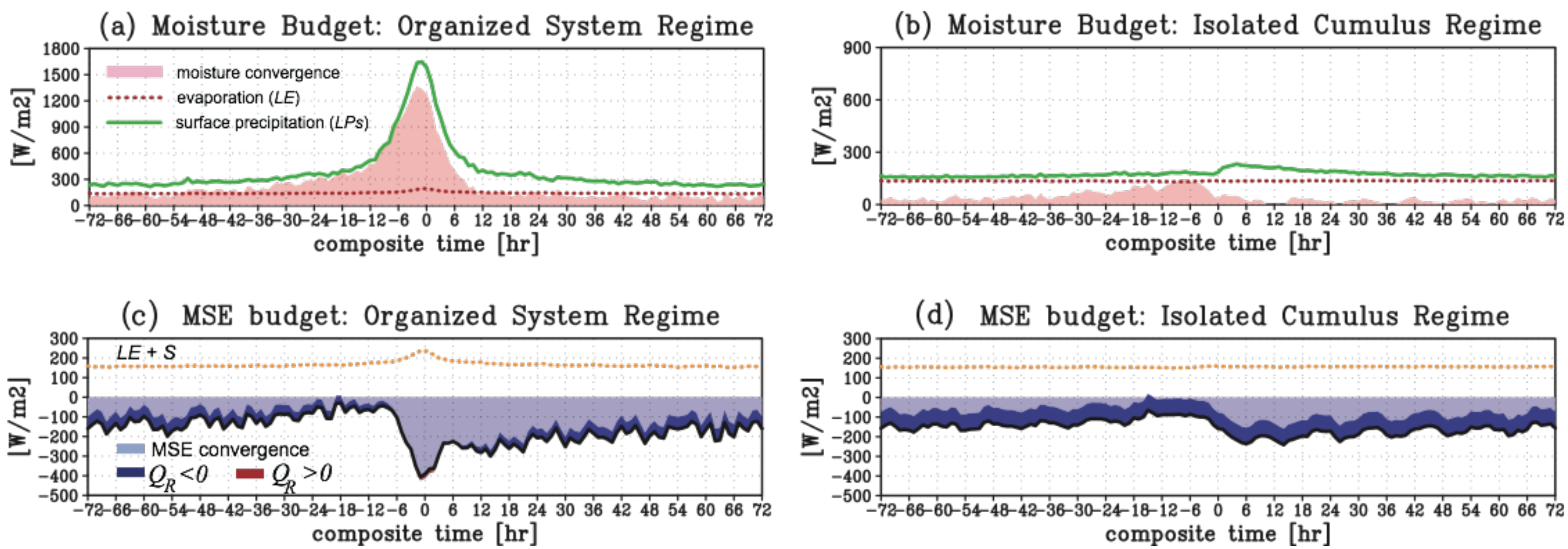
Igel et al. (2014, *JGR Atmos.*) shows an observational dependence of anvil size on *local* SST (left).

However, modelling challenges include expense in resolving both large-scale circulations and convective processes as well as more complex processes such as ocean coupling.

There are also challenges in using observations, including short data records.

Future observational aspirations

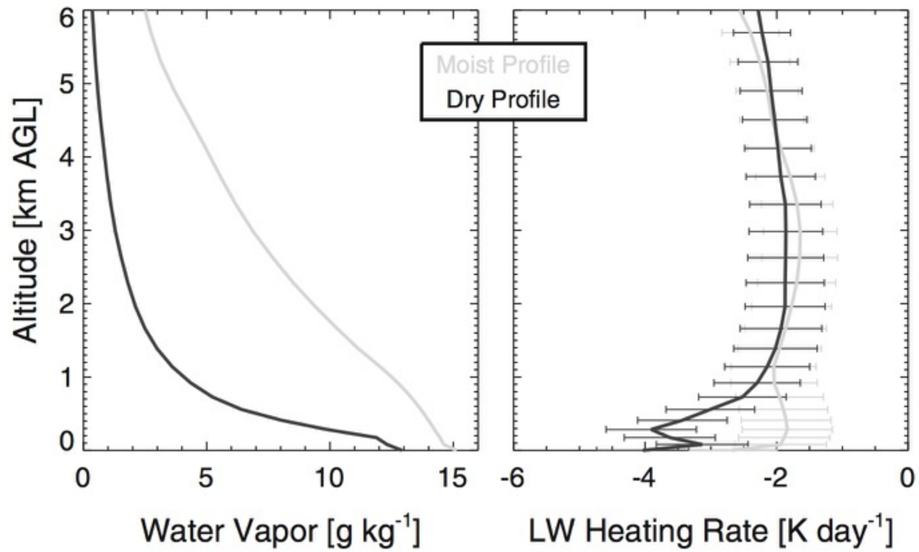
Evolution of convective organization using satellite data



Holloway et al. 2017

Future observational aspirations

Feasibility of a ground-based observational network



Water vapor profiles from a dry (black) and moist (gray) region of an aggregated idealized simulation.

Corresponding calculated longwave heating profiles, with estimated uncertainties for hypothetical radiometer measurements.

Holloway et al. 2017

Summary

- Global models in non-rotating RCE show a range of self-aggregation behavior
- One metric developed specifically for global models is the subsiding fraction
- More aggregated conditions mean not only more organisation of convective elements but also changes to the mean state (in simulations *and* observations):
  - Mean drying
  - Increased spatial humidity variance
  - Reduced high cloud fraction
  - Increased mean OLR
  - Increased mean atmospheric cooling rate
- Self-aggregation in models may be relevant for real-world phenomena such as the MJO, the ITCZ, and tropical cyclogenesis, and might affect climate sensitivity …

Questions

- How might coupling to an ocean model affect these global RCE simulations?
- How might rotation affect these simulations?
- Is self-aggregation typically stronger for:
  - Global or “flat” simulations?
  - Explicit or parameterised convection?
  - Fine resolution or coarse resolution?
- What might be some objections to the idea that self-aggregation is analogous to observed tropical convective organisation?

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