Investigating Cloud Feedbacks in Earth System Models

Brian Soden (PI)

Gabriel Vecchi (Co-I)

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Feedbacks Involving Clouds, Radiation, and Circulation

Questions:

i) Is convective aggregation important in the presence of *realistic boundary conditions*?

ii) How do cloud-circulation feedbacks influence *weather extremes*?

iii) How do cloud-circulation feedbacks influence *climate and climate sensitivity*?

iv) How can observations be used to *evaluate the representation* of these feedbacks?

High-Resolution Global Modeling Studies

Feedback Suppression Experiments

- **Preliminary studies using GFDL HiRAM Atmospheric Model (~0.5°)**
  - **Working on implementing in E3SM/CAM5 and GFDL ESM2.1/AM4**

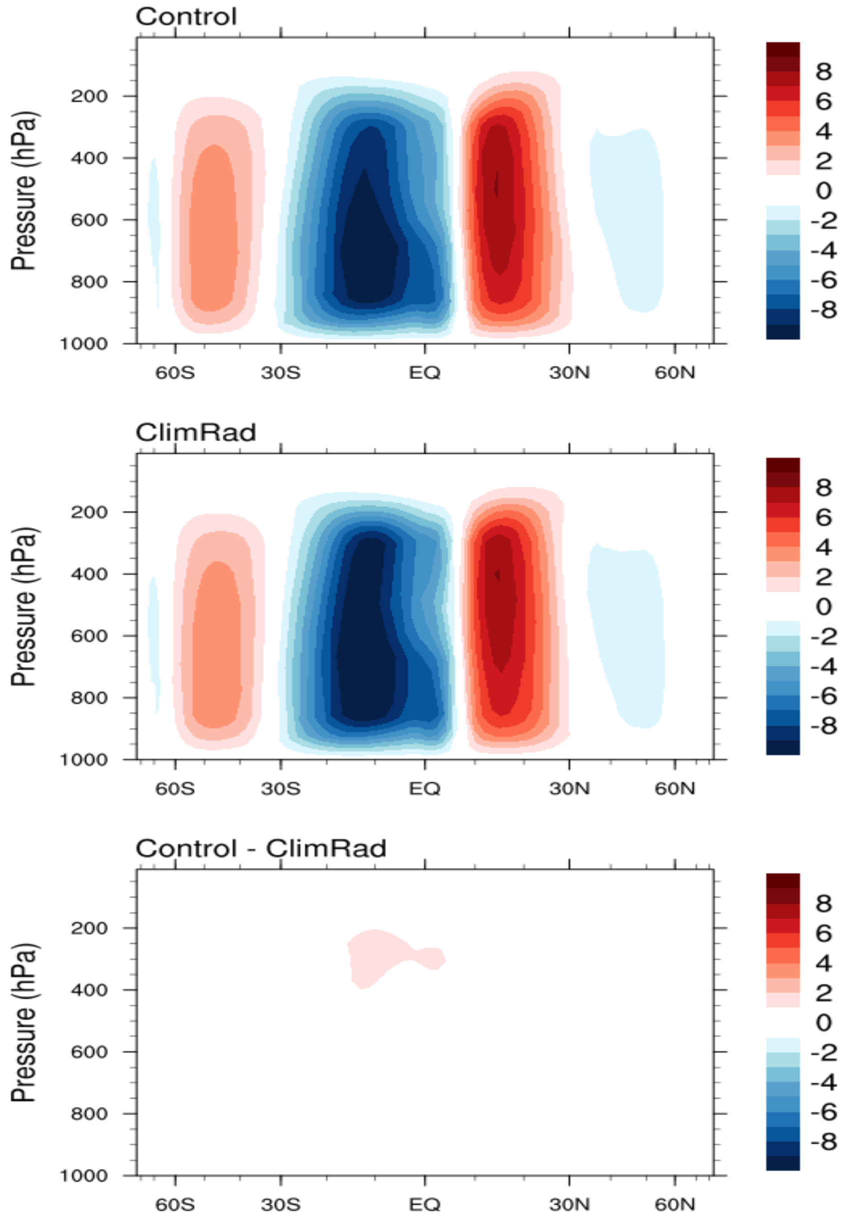
- **Suppress synoptic-scale coupling of radiation and dynamics by prescribing seasonally-varying climatology of radiative heating from Control run (ClimRad).**

- **Advantages:**
  - **Realistic spatial gradients in SST, winds, moisture, etc.**
  - **TC-permitting resolution, with realistic TC climatology**
  - **Little change in climatological mean state (e.g., circulation, precipitation, etc.)**
  - **Easy to implement**
  - **Can easily manipulate coupling in different vertical levels**

Zhang, B. et al., 2020: The role of radiative interactions in tropical cyclone development under realistic boundary conditions, under review J. Climate.

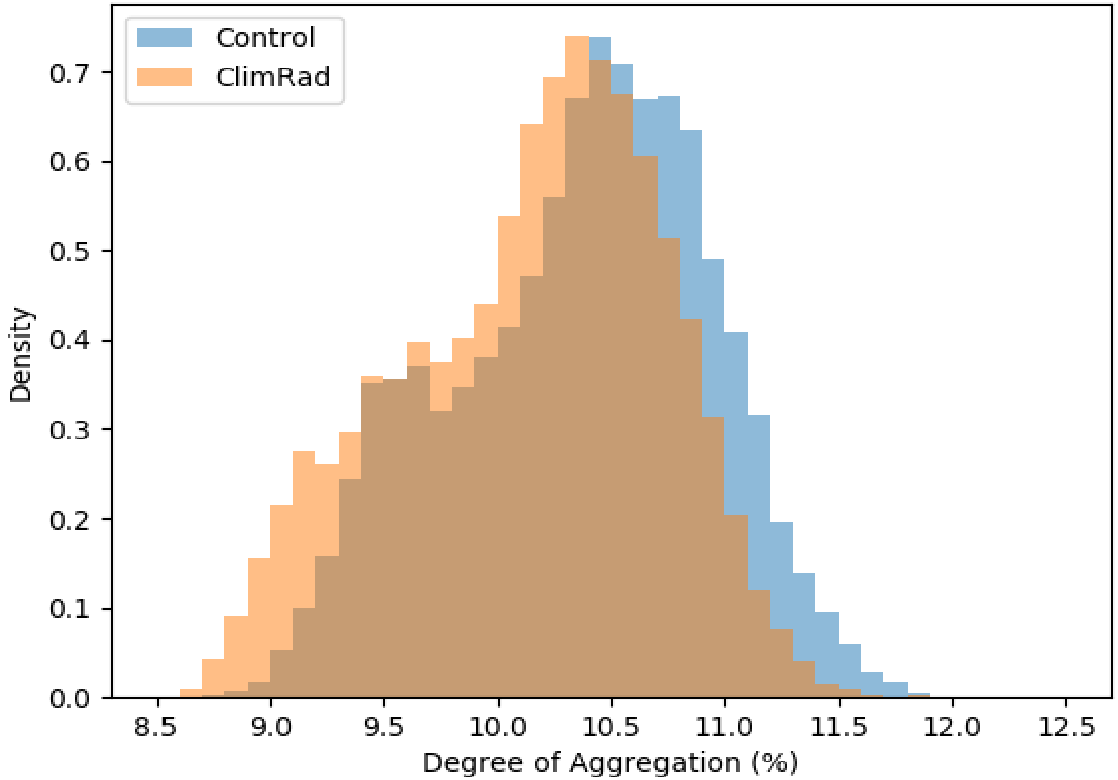
Zhang, B. et al., 2020: The impact of radiative interactions on convective organization and climate feedbacks, in preparation

High-Resolution Global Modeling Studies



- Both models have very similar climatological mean states; large-scale circulation, global precipitation, etc.
- Forcing with climatological radiation (ClimRad) does not alter mean state, but rather alters the character of "weather" events that compose the mean.
- Two models with similar "climates" (and model physics), but different "weather"

High-Resolution Global Modeling Studies

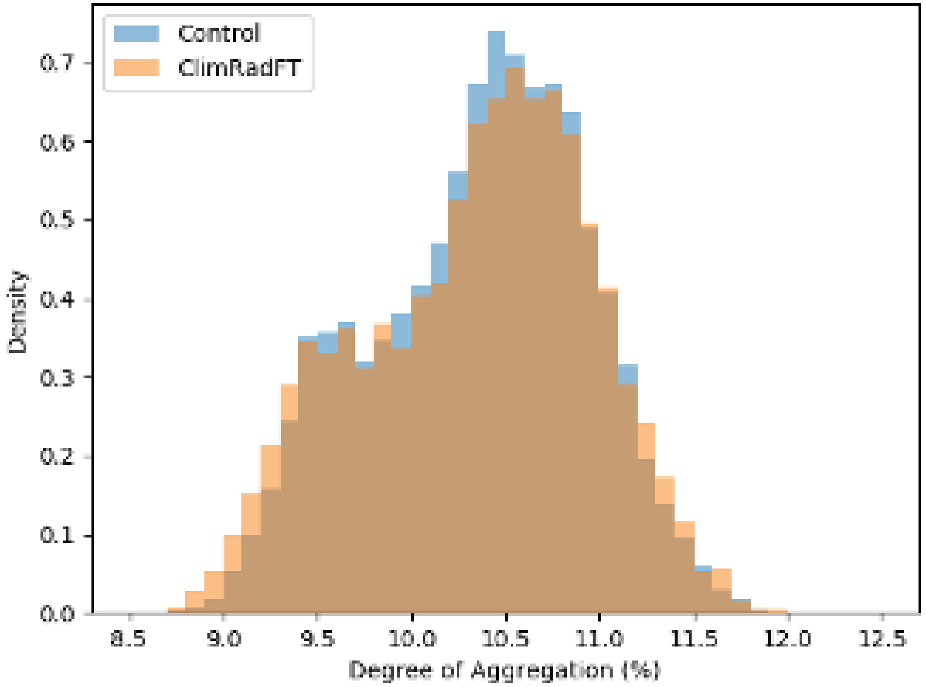


Suppressing synoptic-scale coupling of radiation and dynamics reduces convective aggregation.

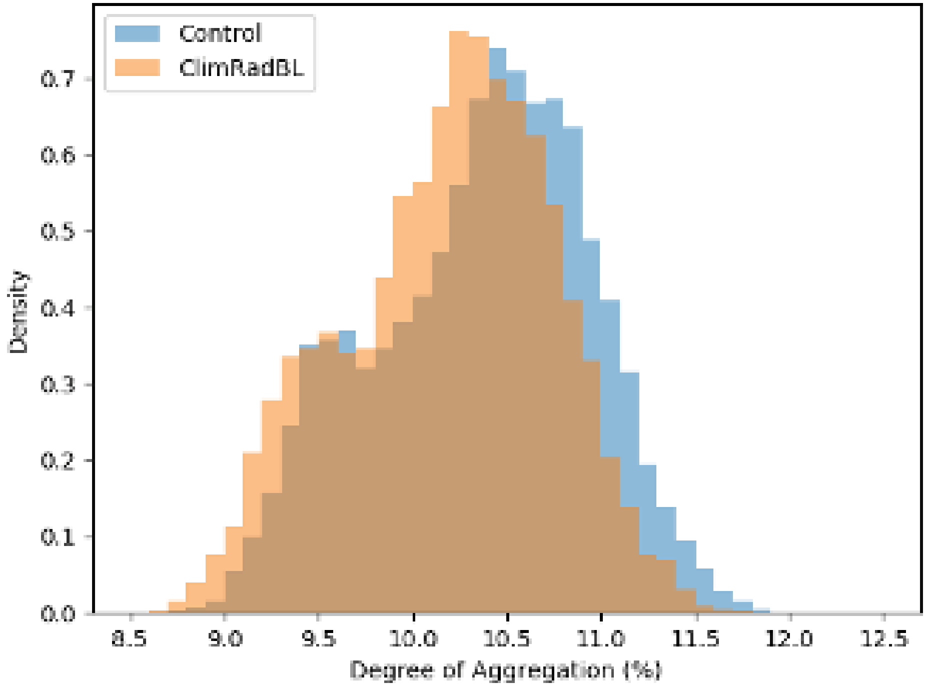
Radiative feedback on aggregation is important even in the presence of realistic boundary conditions.

How Do Radiative Processes Enhance Convective Aggregation?

ClimRadFT: Climatological Radiation
in Free Tropopsphere

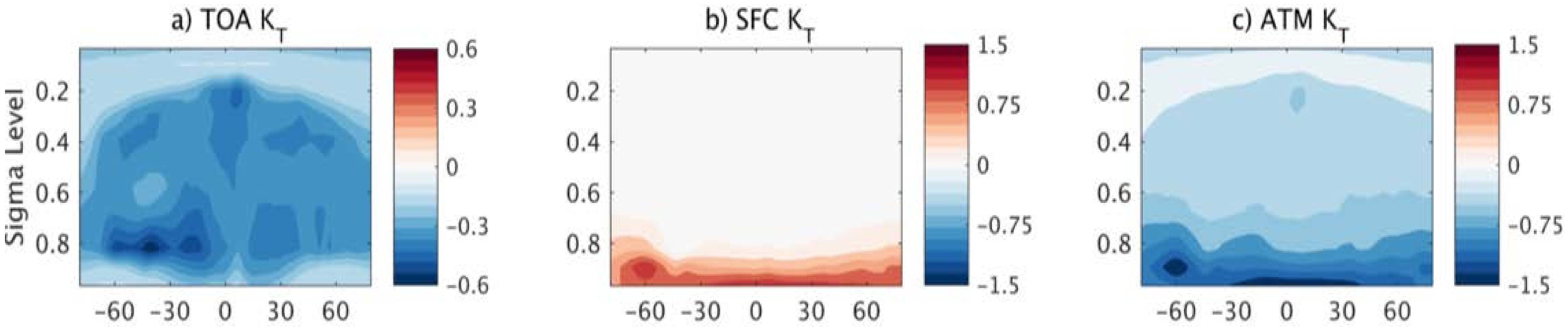


ClimRadBL: Climatological Radiation
in Boundary Layer



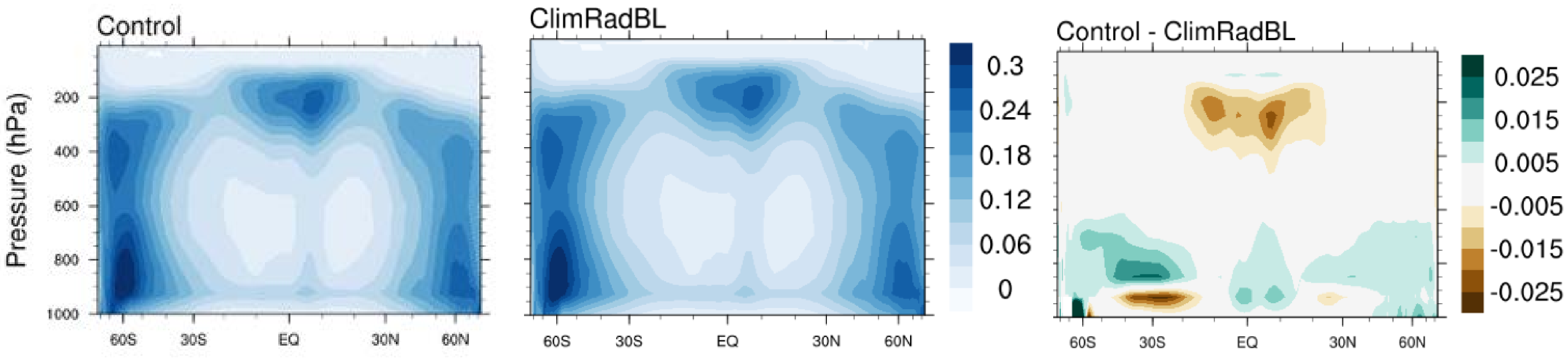
Coupling between radiation and dynamics in *boundary layer*,
not *free troposphere*, governs convective aggregation.

How Do Radiative Processes Enhance Convective Aggregation?



Column integrated radiative cooling of atmosphere is dominated by temperature, water vapor and clouds fluctuations in boundary layer, not free troposphere.

Impact of Convective Aggregation on Clouds



More aggregation

Less aggregation

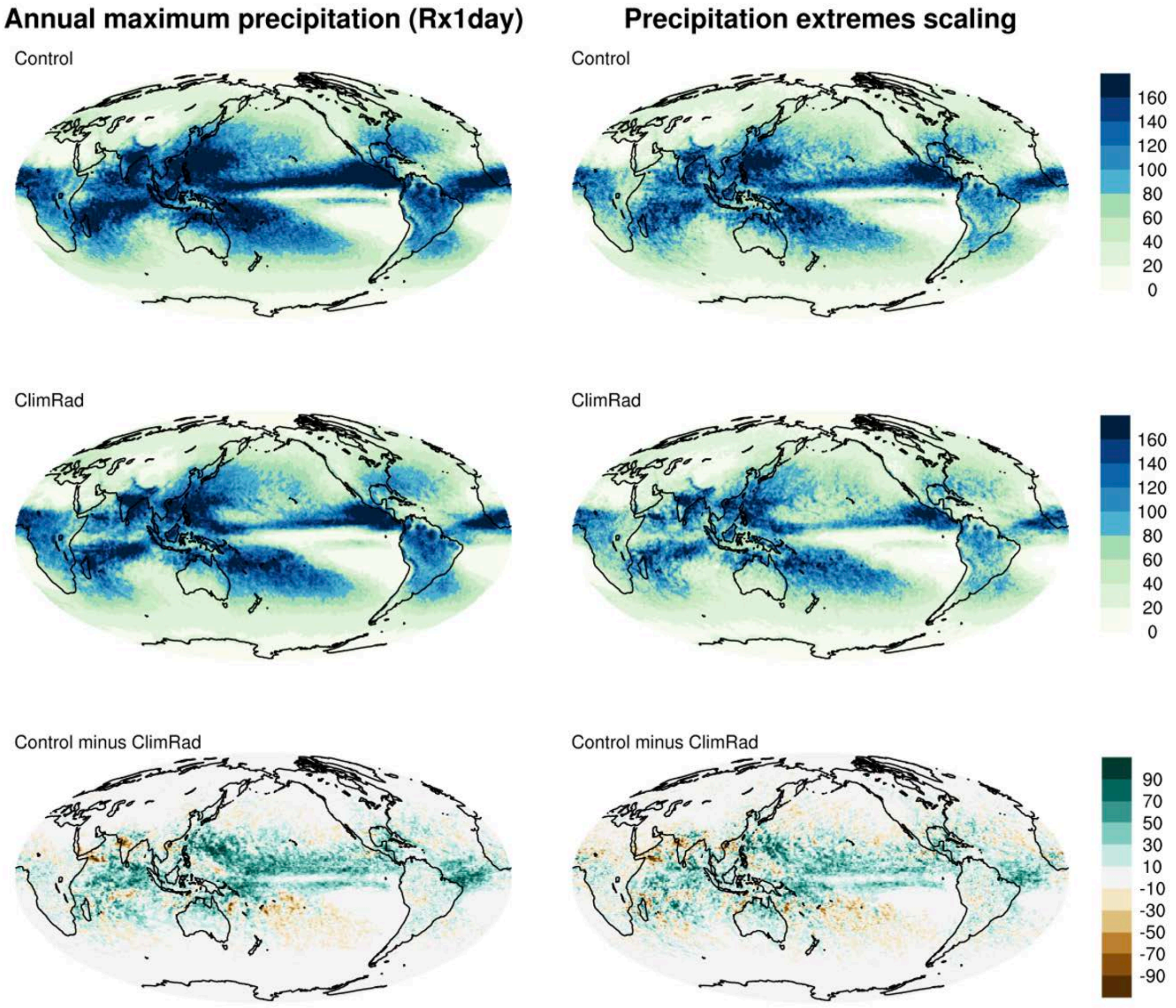
Convective aggregation reduces upper level clouds in ITCZ, increases subtropical low clouds, dries tropical free troposphere.

Qualitatively consistent with idealized, CRM studies (Wing et al. 2020) and observations (Bony et al. 2020)

Convective Aggregation and Precipitation Extremes

More Aggregation

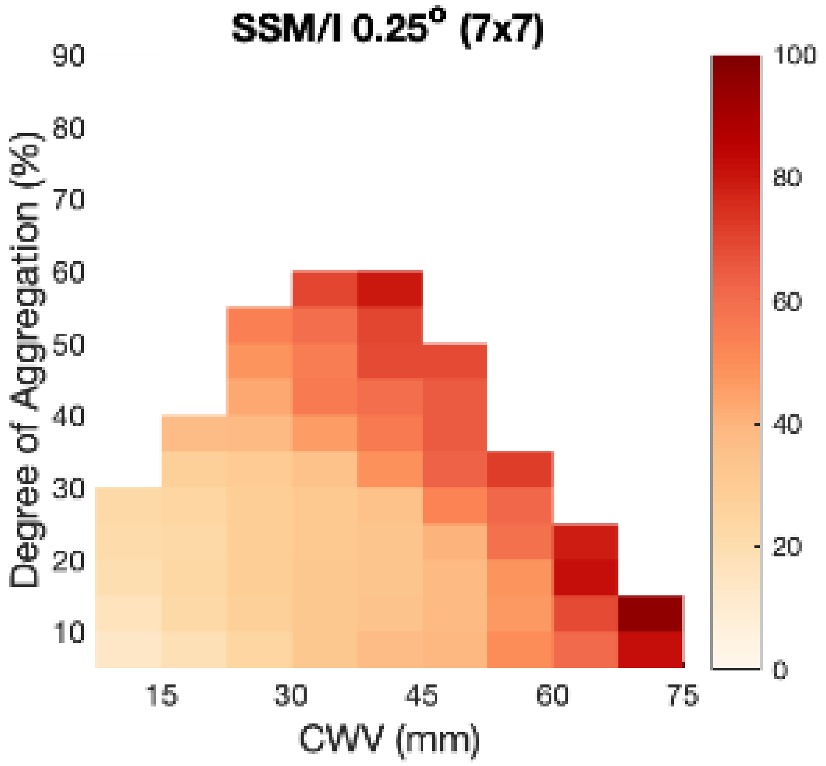
Less Aggregation



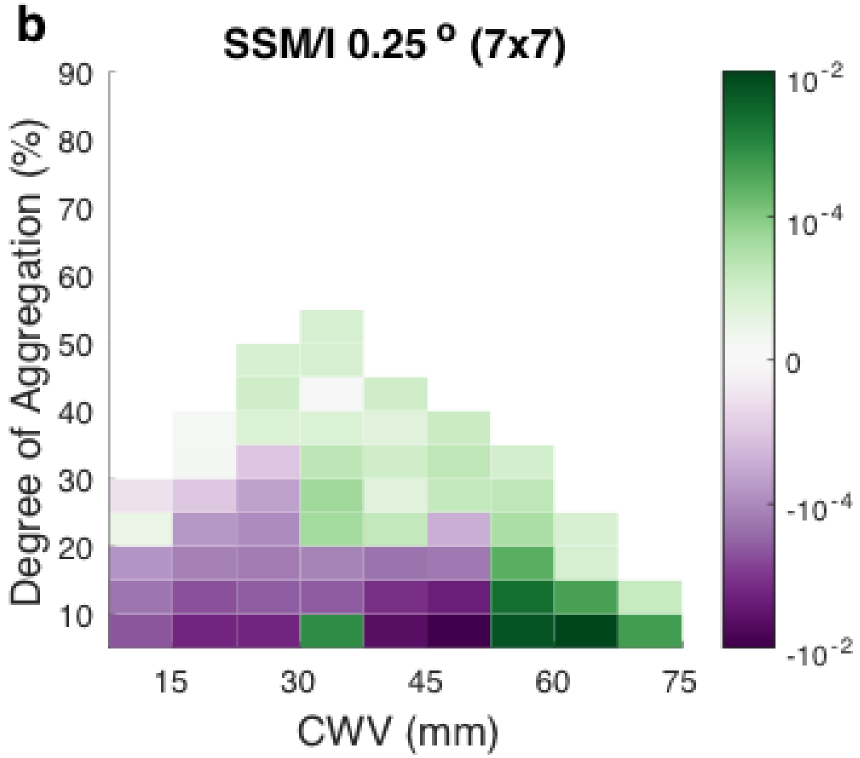
Increased convective aggregation enhances precipitation extremes (no change in mean precipitation)

Convective Aggregation and Precipitation Extremes

Precipitation Rate Percentiles



Frequency of Occurrence
(El Nino – La Nina)

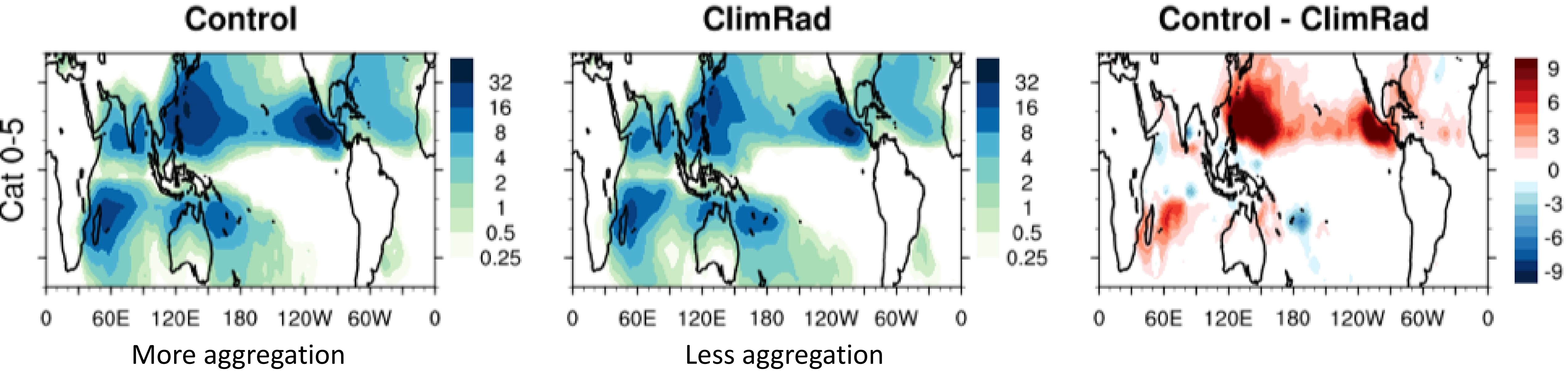


Observations show:

1) **Increased precipitation intensity as aggregation increases**
2) **Increased aggregation in El Nino (warm) relative to La Nina (cold)**

Dai and Soden (2020)

Convective Aggregation and Tropical Cyclones



Increased convective aggregation enhances tropical cyclones (increased number of seeds)

Summary

Synoptic-scale Radiation-Cloud-Circulation Interactions

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Increased Convective Aggregation

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Increased Extremes: Tropical Cyclones, Precipitation, Circulation

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Potential Climate Feedbacks: Drier Free Troposphere, Reduced High Clouds, Increased Low Clouds