

Convective Aggregation, Clouds, and Climate: Implications of Recent CRM Results

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Organized tropical convection has long been known to be important but traditional convective parameterizations in ESMs don't handle it well (or at all)

Growing consensus that radiative processes, and especially, their interaction with clouds, are essential to the physics of many atmospheric phenomenon

These two issues:

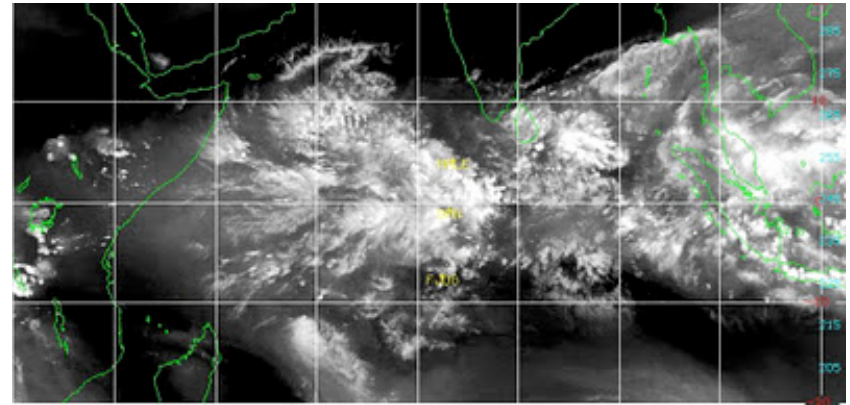
Organized convection

&

Cloud-radiation interactions

should be a focus of ESM development efforts

Why is organized tropical convection important?

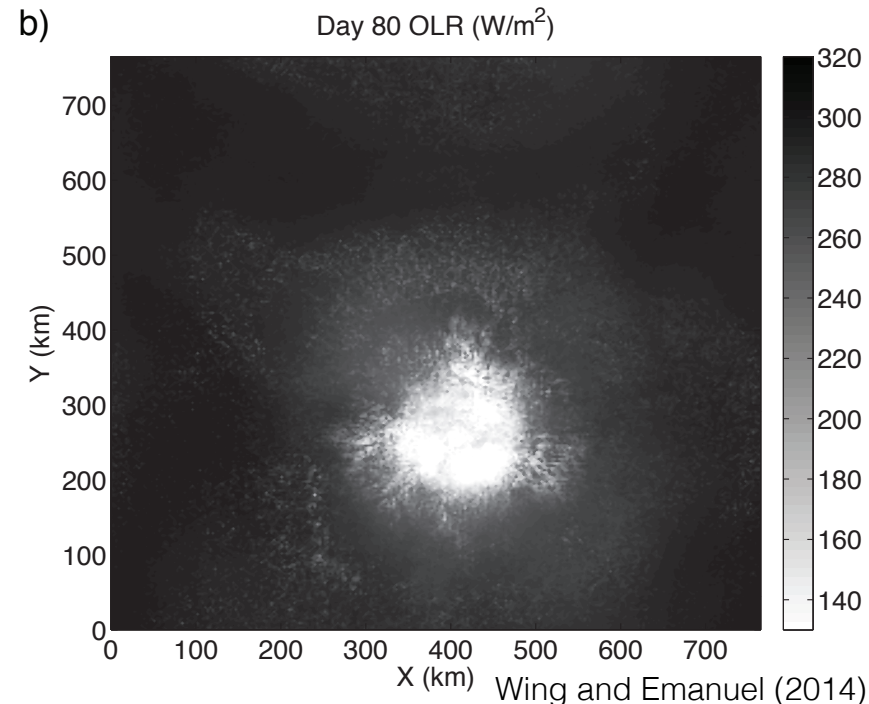
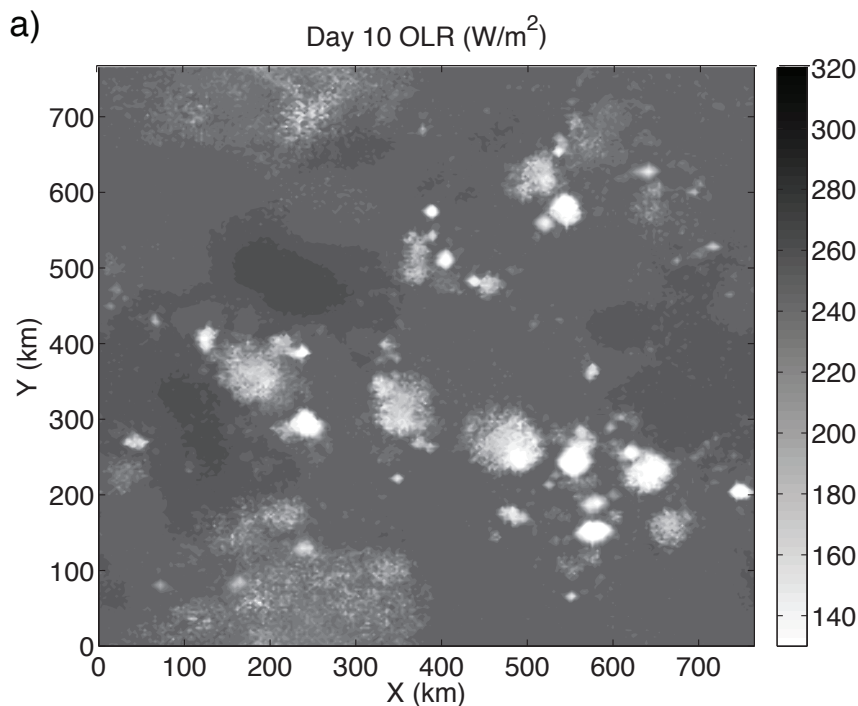


- Globally, 6.4% of tropical cloud clusters develop into tropical cyclones per year [Hennon et al., 2011]
- Cloud clusters responsible for much of the rainfall and cloudiness over the tropics
- Changes in the amount of organized convection with warming strongly influences precipitation patterns and could possibly modulate climate sensitivity

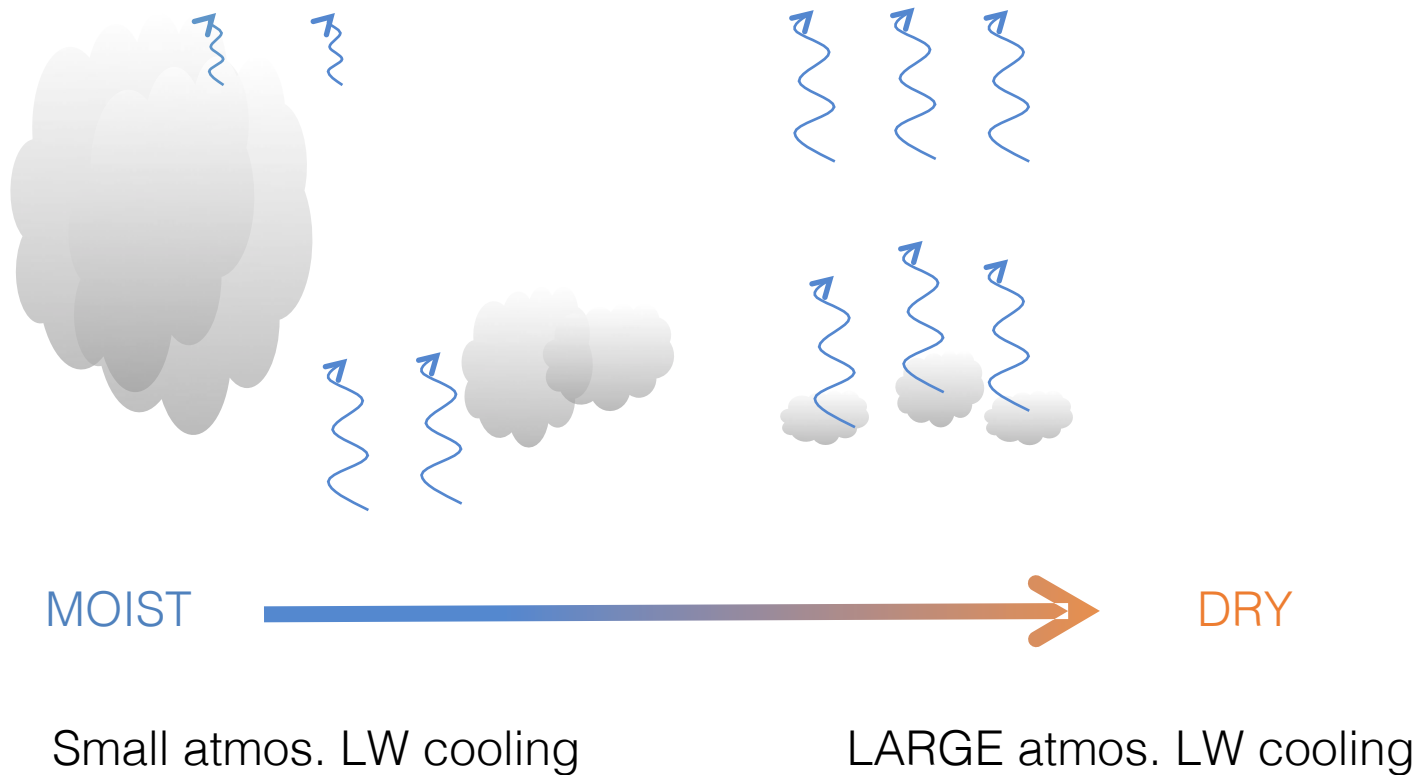
[Tan et al., 2015, Mauritsen and Stevens 2015]

What is convective self-aggregation?

Spontaneous clustering of convection in homogeneous environment driven by radiative and surface flux feedbacks

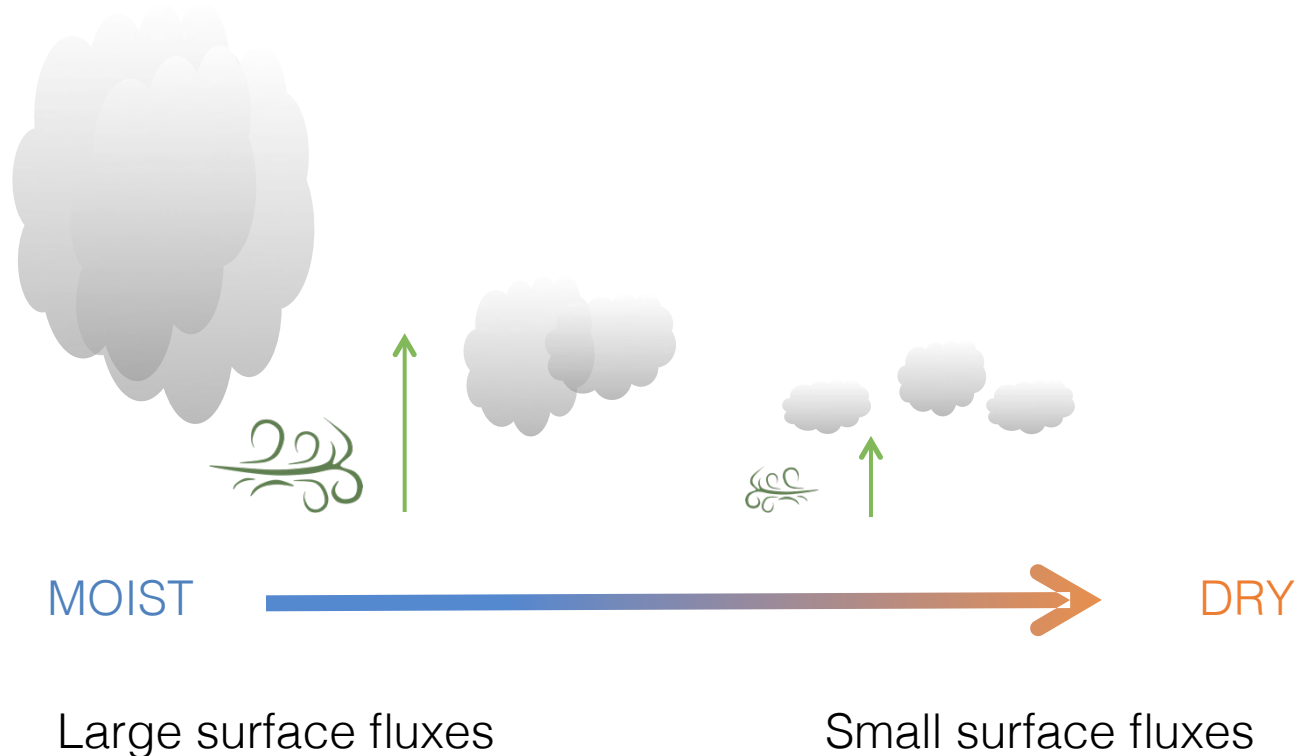


Positive Longwave Radiation Feedback



Implication: Importance of cloud-radiation interactions. Sign of feedback depends on subtleties of initial moisture, cloudiness profile and structure of the changes

Positive Surface Enthalpy Flux Feedback

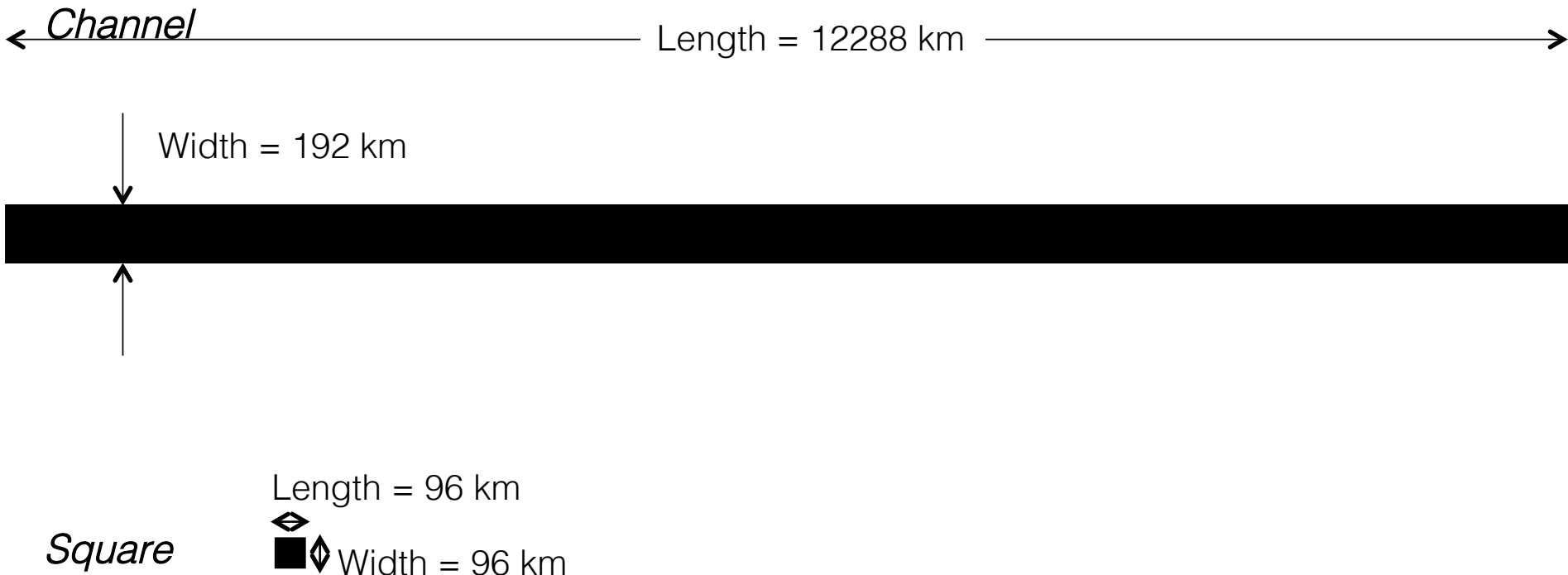


Implication: Need interaction between convection and surface fluxes, coupling between convection and boundary layer schemes. Sign of feedback depends on spatial co-variability of surface winds & column moisture, opposing influence of boundary layer enthalpy.

Why might self-aggregation be important?

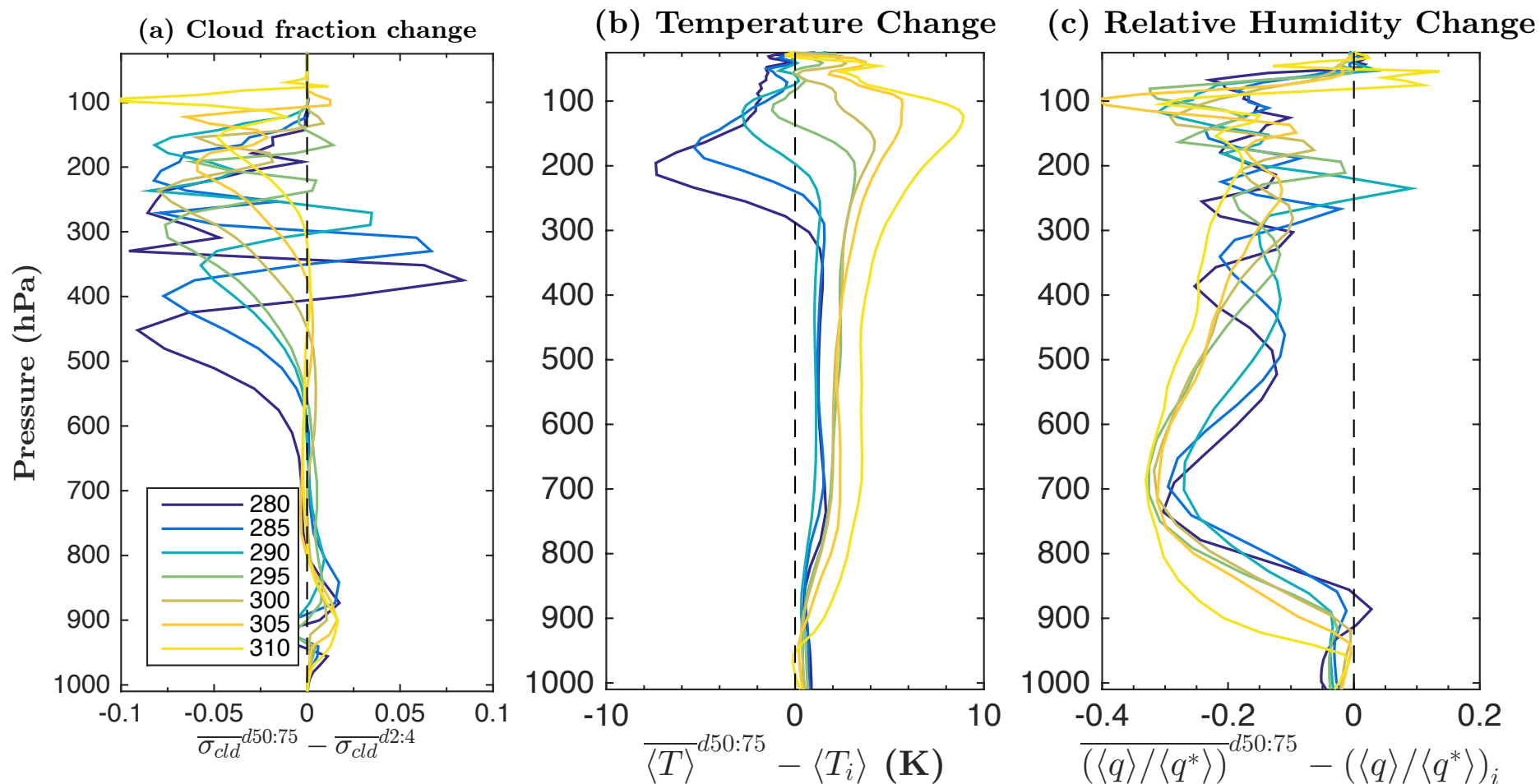
Approach: Radiative-convective equilibrium using a cloud resolving model (SAM; Khairoutdinov and Randall (2003))

Doubly periodic domain, no background wind, no rotation, fixed SST
Interactive radiation and surface fluxes



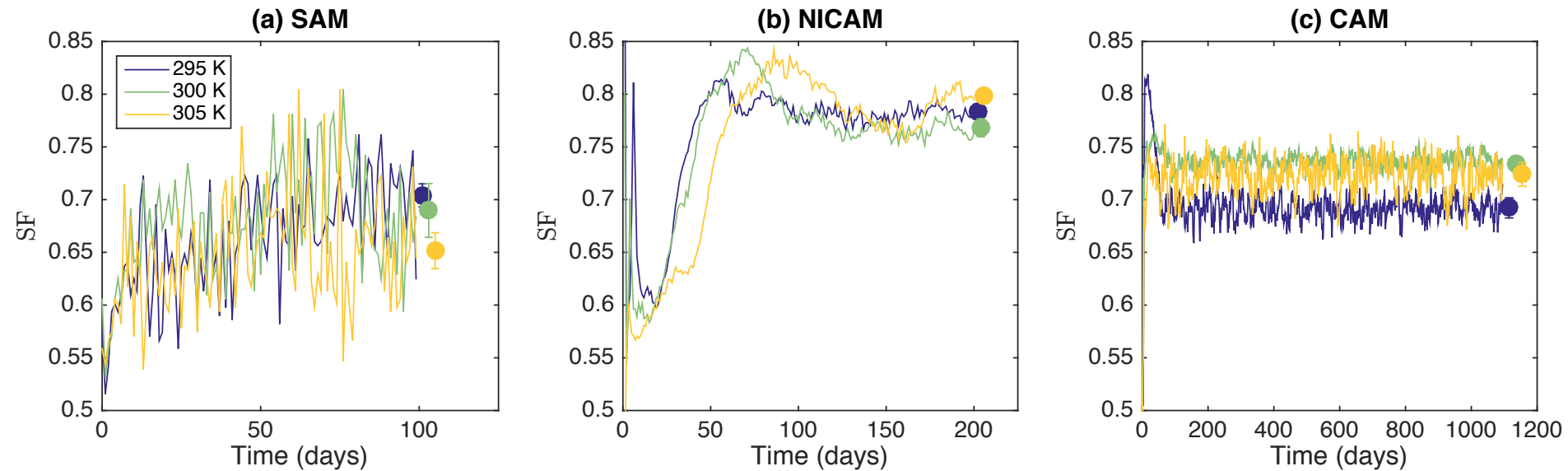
Why might self-aggregation be important?

Decrease in high clouds, warming, drying with aggregation



Why might self-aggregation be important?

It might depend on temperature



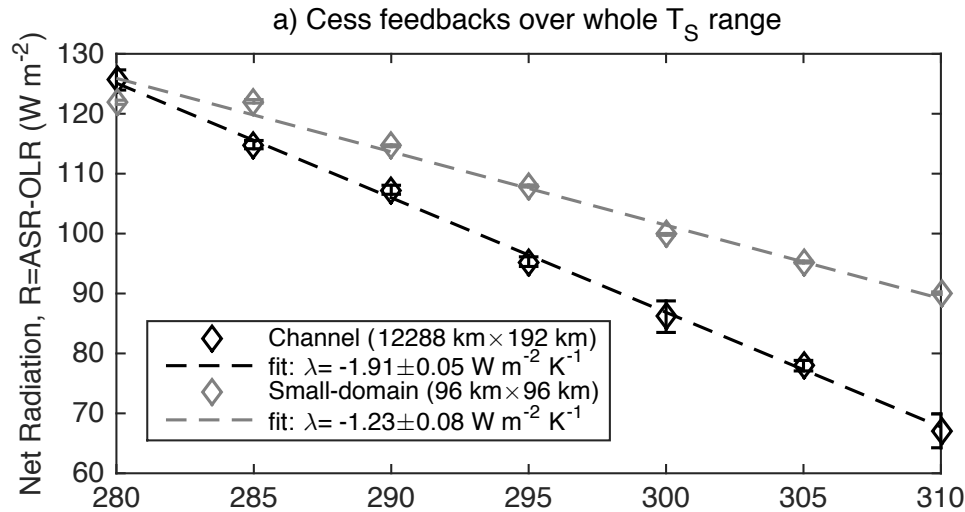
Models, metrics seem to disagree with each other

Why might self-aggregation be important?

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

→ Implications for climate sensitivity?

Aggregation modestly reduces climate sensitivity



- Net feedback over whole SST range more negative in channel than square
 - Implies lower climate sensitivity in channel
 - Contributions from both non-cloud and cloud feedbacks
- Kernel-corrected cloud feedbacks are positive
- Caveat: large variability across simulations

RCEMIP

Objectives

1. Clouds & climate sensitivity
2. Temperature dependence of aggregation
3. Robustness of RCE state

6 Simulations, 3 different SSTs, 2 domain configurations

20+ Models

CRMs, GCMs, GCRMs, SCMs, LES

Implications: Desirable to have flexible modeling systems, built-in idealized configurations

<http://myweb.fsu.edu/rcemip.html>

Wing et al., (2018), Geosci. Model Dev.

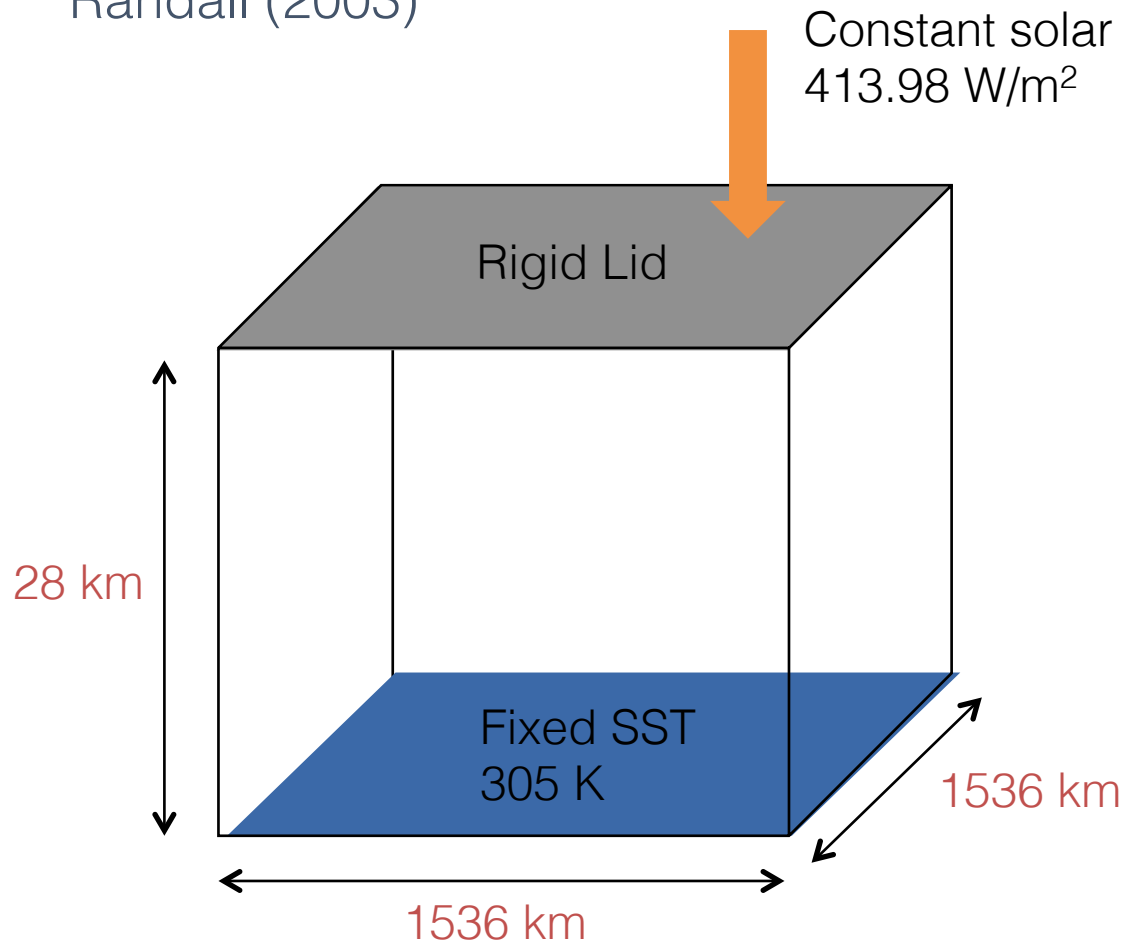
Importance of cloud-radiation interactions

- Organization of convection
- Tropical cyclones
- MJO: Anomalies grow and are sustained by water vapor & cloud radiative feedbacks [Sobel et al (2014), Andersen and Kuang (2012), Arnold and Randall (2015)]
- Cloud-circulation coupling: Radiative changes of clouds and water vapor are key to the regional response of precipitation and circulation to global warming. [Voigt and Shaw 2015].

Are cloud-radiation interactions important for tropical cyclones?

Approach: Idealized numerical simulations of rotating radiative-convective equilibrium using a cloud resolving model

System for Atmospheric Modeling (SAM) of Khairoutdinov and Randall (2003)

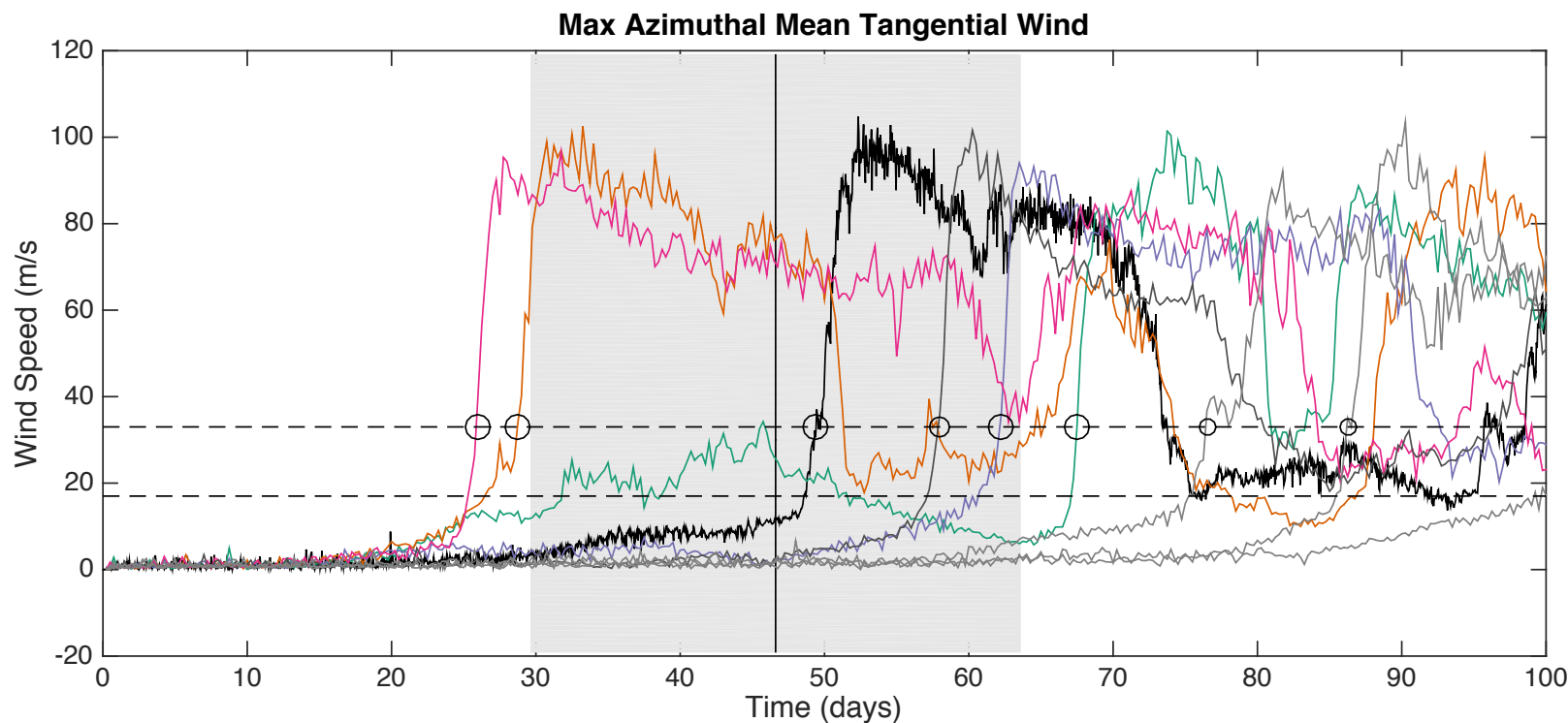


- Horizontal Resolution: 3km
- Vertical Resolution: 64 levels
- Periodic lateral boundaries
- f-plane at 20°N
 $f = 5 \times 10^{-5} \text{ s}^{-1}$
- Fully interactive RRTM radiation and surface fluxes.
- Initialize with random noise in boundary layer temperature field

Are cloud-radiation interactions important for tropical cyclones?

Yes, they significantly accelerate spontaneous genesis

Yes, as important as surface flux feedbacks during initial spin-up

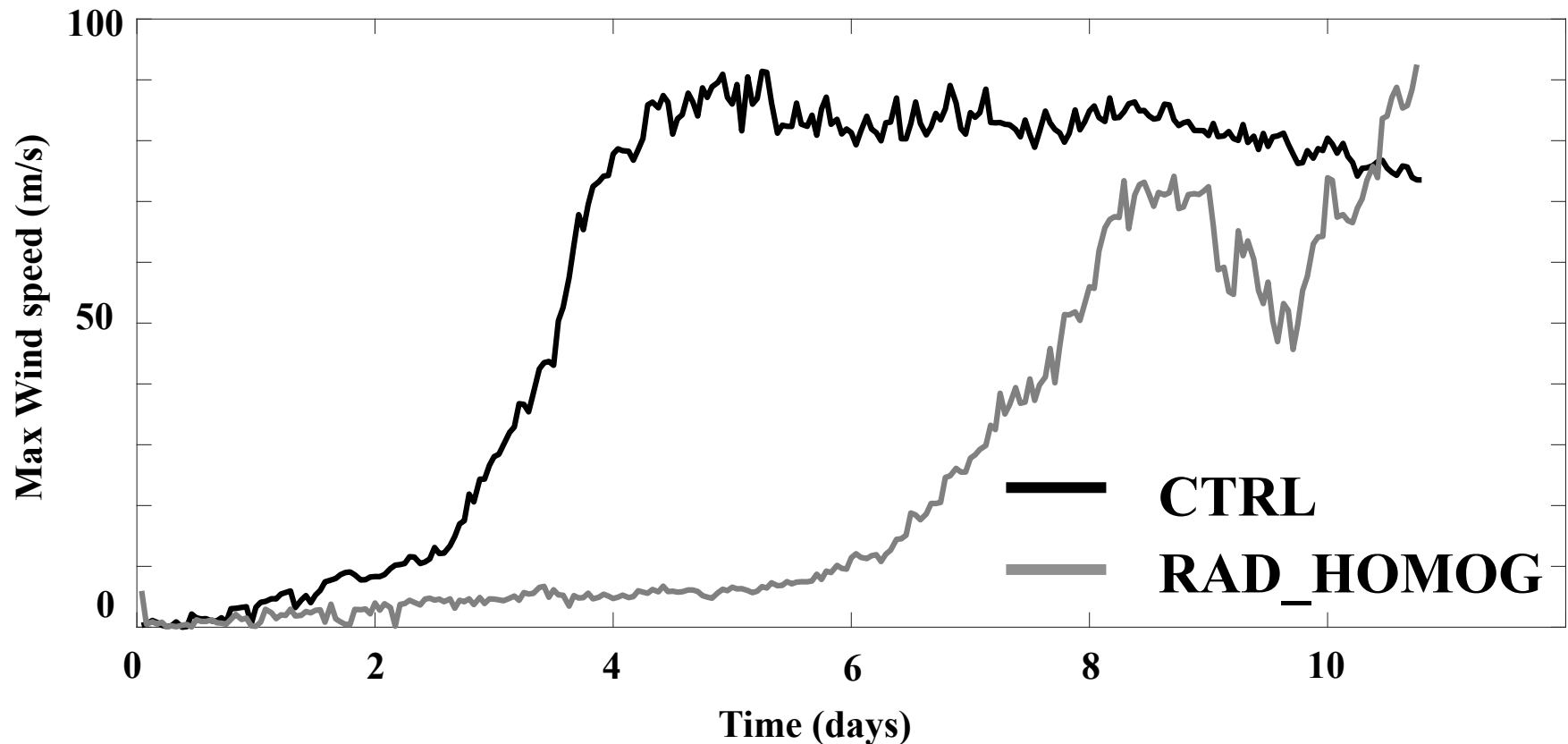


Ensemble generated by varying initial random thermal noise

Delay in genesis in simulation with no radiative feedbacks

Use moist static energy variance budget to diagnose feedbacks

Are cloud-radiation interactions important for tropical cyclones?
Yes, they accelerate genesis, even in storms that start from pre-existing

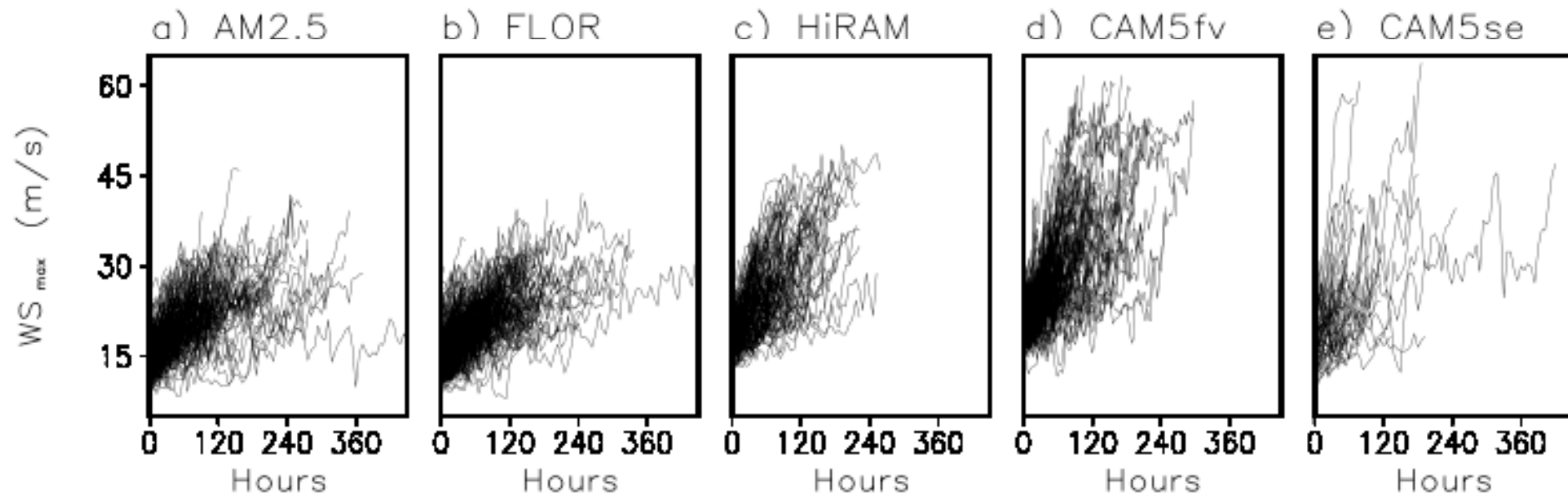


Also: Impact on TC structure and motion (Fovell et al. (2010), Bu et al. (2014), Fovell et al. (2016)), Diurnal cycle accelerates TC genesis and intensification (Hobgood (1986), Craig (1996), Melhauser and Zhang (2014), Ge et al. (2014), Tang and Zhang (2016))
Wing (2018)

Implications for climate model representation of TCs

Climate model simulation of TCs has improved, can represent TC climatology with some fidelity, but serious biases remain.

Implications: Need *process-oriented* diagnostics for model evaluation. There are many ongoing efforts in this area (NOAA MDTF), but models could be designed with these types of metrics in mind



Moist static energy variance budget can be used to diagnose feedbacks

Implications: Models should diagnose MSE budget *online*

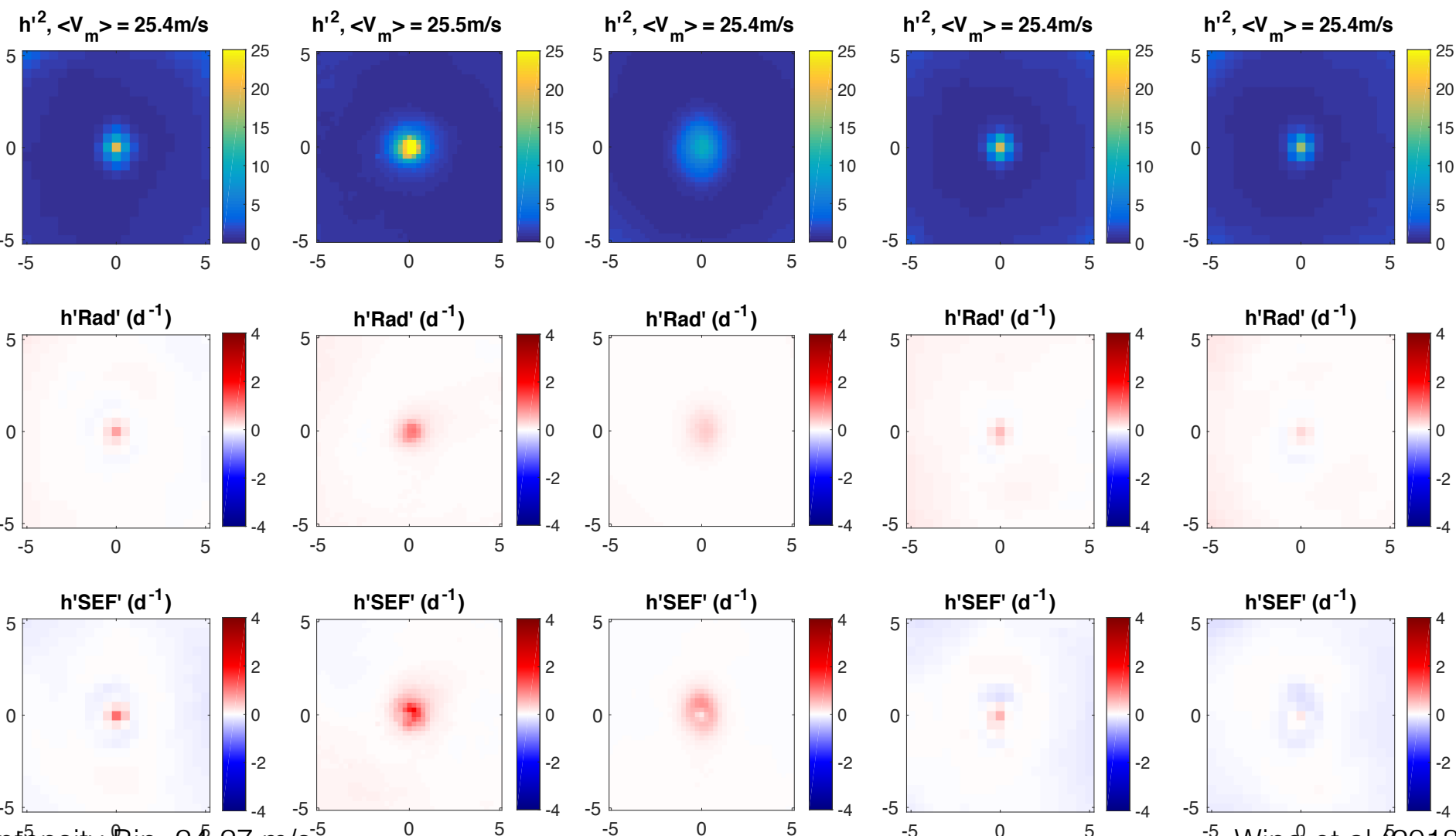
HiRAM

CAM-SE

CAM-FV

AM2.5

FLOR



Implications

1. Need our models, parameterization to be able to handle convective organization, enable multi-scale interactions
2. Need to allow for convective memory and exchange of subgrid-scale information across grid columns
3. Need to enable convection – surface flux feedbacks
4. Given the importance of cloud-radiation interactions for many phenomenon, should be a focus.
5. Built-in options for idealized version of models
6. Use process-oriented diagnostics for model evaluation
7. Diagnose budgets online!
8. Manage large amounts of data
9. Don't lose readability of model code
10. Will better handling of one process expose biases driven by another?