Convective Self-Aggregation Enhances Cloud-Rain Conversion

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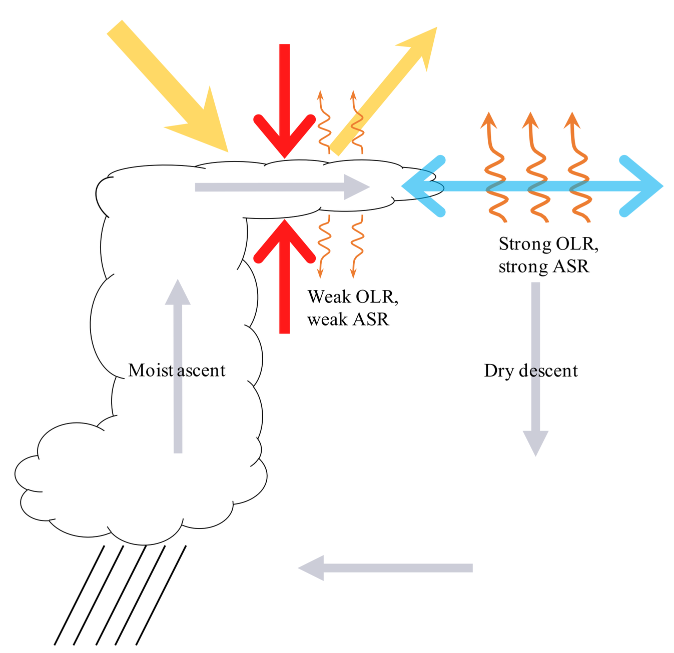
1. Motivation

- Convective self-aggregation is the spontaneous organization of moist convection into isolated clusters, typically under warm surface conditions.
- Self-aggregation is driven by various mechanisms, which may differ depending on the parameter regime or stage of self-aggregation, that spatially limit deep cumulus clouds to reside within the moist region(s).
- Aggregated convection has increased humidity variability, a drier mean state, and more outgoing longwave radiation than disaggregated convection. These properties, combined with a potential dependence on temperature, suggest that self-aggregation could influence climate sensitivity.



The iris feedback as a combination of cloud fraction and cloud optical depth changes, suggested in Li et al. (2019).

- Cloud-rain conversion directly influences the amount of cloud water detrained in the upper troposphere that forms high clouds, which could be the link between self-aggregation and climate sensitivity.

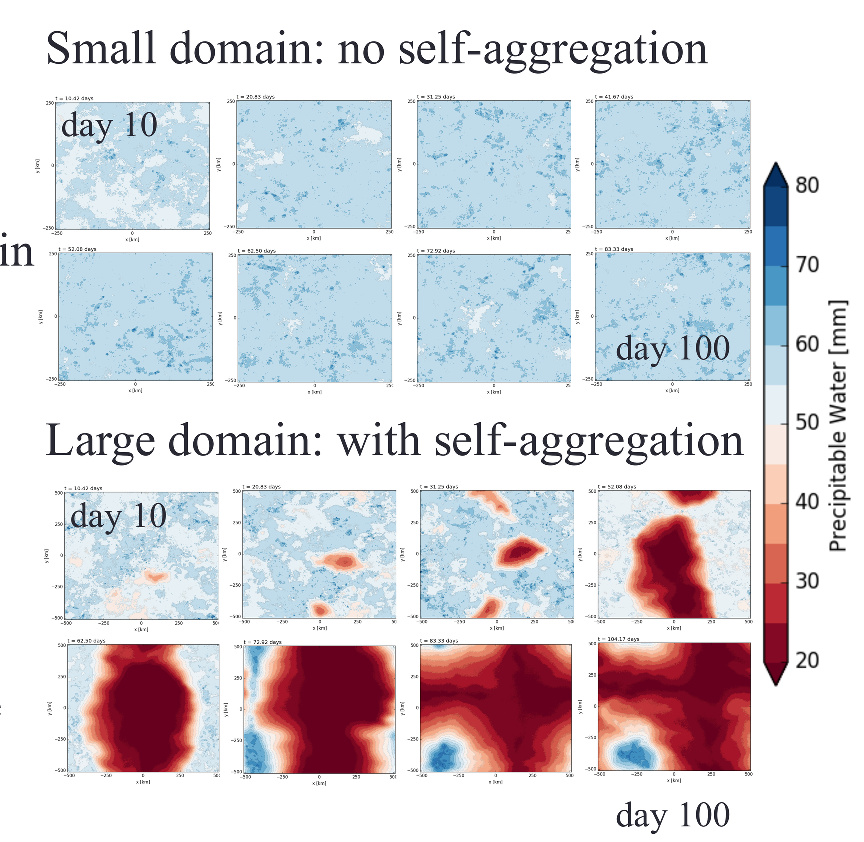
Questions:

1. Does cloud-rain conversion depend on temperature?
2. Does the answer to (1) change with self-aggregation?

2. Cloud-Resolving Simulations

The experiments herein are performed using the System for Atmospheric Modeling (SAM) version 6.10.3:

- 2km resolution and doubly periodic in x and y
- No rotation, no mean wind, and no external forcing
- Initialized using the same tropical sounding
- Perpetual sun and no diurnal cycle, forced below by uniform sea surface temperatures (SSTs)



- 2 sets of experiments of small (**512 x 512 km**) and large (**1024 x 1024 km**) domains are carried out with SSTs ranging from 297 K to 309 K.
- The smaller domain simulations do not self-aggregate while the large domain simulations do self-aggregate, which is likely to due the suppressed effectiveness of cold pools that communicate the moist and dry regions (Jeevanjee and Romps 2013)

References

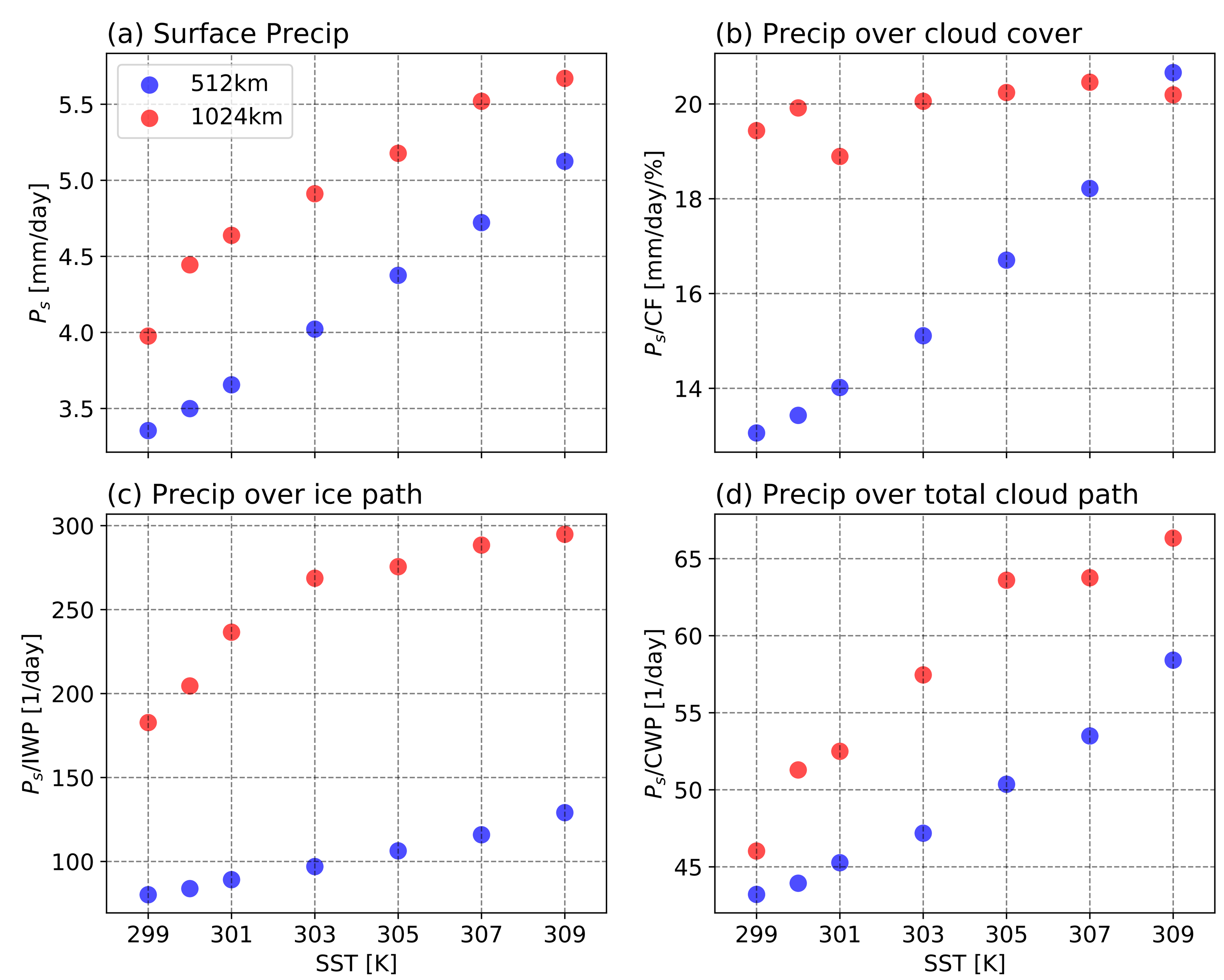
[1] Li, R.L., T. Storelvmo, A.V. Fedorov, and Y. Choi, 2019: A Positive Iris Feedback: Insights from Climate Simulations with Temperature-Sensitive Cloud–Rain Conversion. *J. Climate,* **32**, 5305–5324, doi:10.1175/JCLI-D-18-0845.1

[2] Jeevanjee, N., and Romps, D. M. (2013), Convective self-aggregation, cold pools, and domain size, *Geophys. Res. Lett.*, 40, 994– 998, doi:10.1002/grl.50204.

[3] Coppin, D., and Bony, S. (2015), Physical mechanisms controlling the initiation of convective self-aggregation in a General Circulation Model, *J. Adv. Model. Earth Syst.*, 7, 2060– 2078, doi:10.1002/2015MS000571.

3. More Precipitation per Cloud Water

The figure below shows the spatially and temporally-averaged (a) precipitation, (b) precipitation normalized by cloud fraction, (c) precipitation normalized by ice water path, and (d) precipitation normalized by total cloud water path (water + ice).



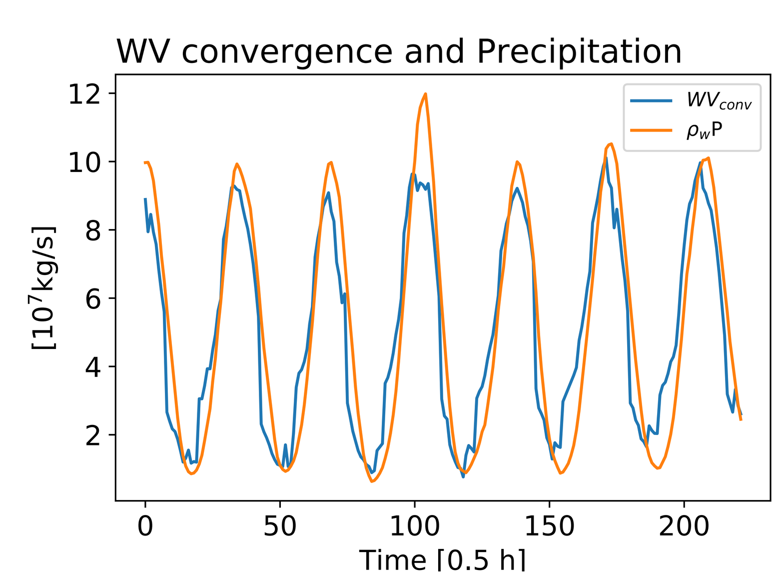
Main Points:

a) With higher SSTs, more precipitation is required to balance the increased latent heat flux at the surface, with and without self-aggregation.

b) With higher SSTs, the cloud cover increases at a similar rate as precipitation, and the ratio of precipitation to cloud cover changes little.

c) With self-aggregation, the ratio of precipitation to ice water content in clouds is more than double that of the simulations without self-aggregation for all SSTs – supporting that **self-aggregation enhances the cloud-rain conversion in deep cumulus clouds**. The relative increase of this ratio is similar for small and large domain (60-65% from 299K to 309K).

d) The ratio of precipitation to total cloud water path increases with SSTs at a similar to (a), with and without self-aggregation.

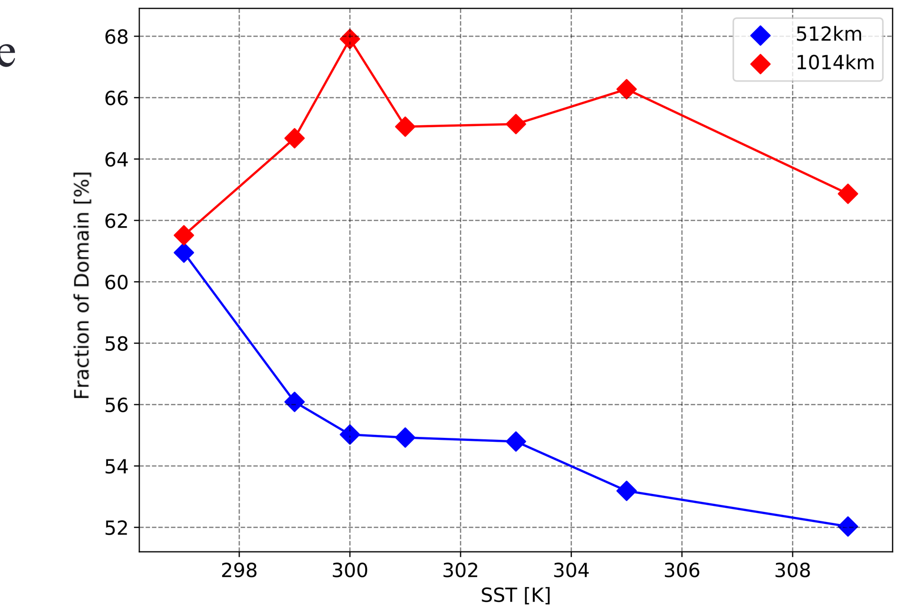


The water vapor convergence in convection balances the surface precipitation, giving a precipitation efficiency of close to 1.

4. Degree of Self-Aggregation

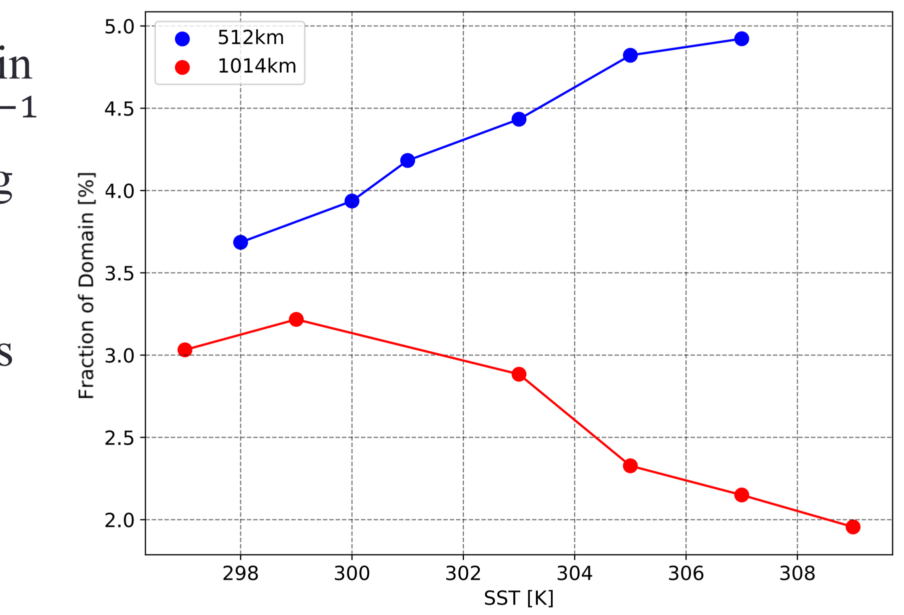
1. Subsidence Fraction: $w < 0$ where w is vertical velocity (Coppin and Bony 2015).

- It is unclear from this metric whether the degree of self-aggregation depends on temperature.



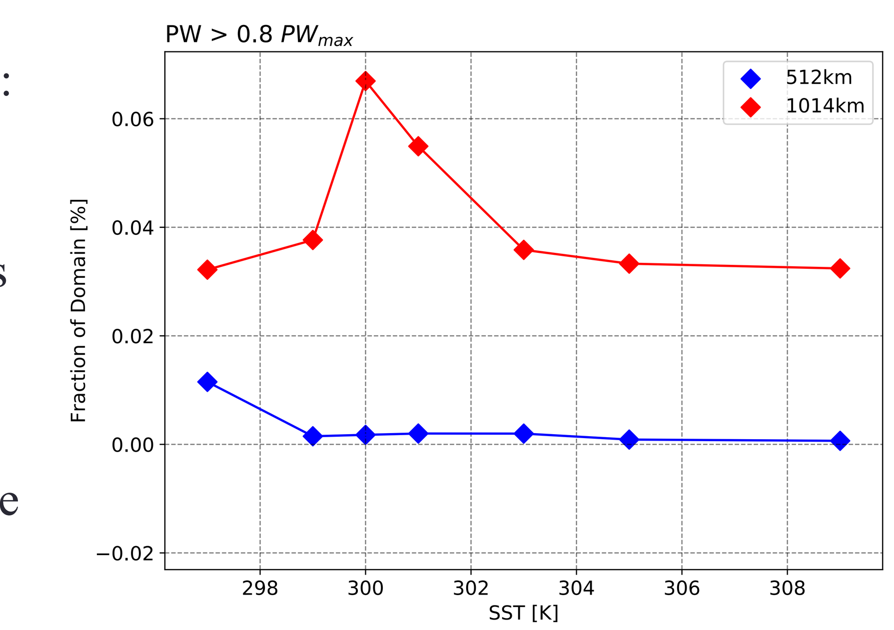
2. Convective Fraction: at any level in the column, $wq_c > 0.5{\times}10^{-3}ms^{-1}$ where q_c is the cloud water mixing ratio.

- For large domain simulations, the convective fraction decreases. This metric suggests that the degree of self-aggregation increases with temperature.



3. Precipitable water (PW) threshold: PW greater than 80% of the maximum PW in the domain.

- The 299K SST simulation depends on the time range used for averaging. For the large domain cases warmer than 300 K, this metric also suggests that the degree of self-aggregation increases with temperature.



5. Summary

1. Self-aggregation increases the cloud-rain conversion in deep cumulus clouds. However, we found little dependence of this conversion on temperature.
2. The degree of self-aggregation shows a weak dependence on temperature.

Snapshot of the 305K SST simulation at 123.5 days: 500mb vertical velocity in color and the 80% PW threshold in contour.