The impact of an interactive sea surface temperature on the aggregation of deep convective clouds

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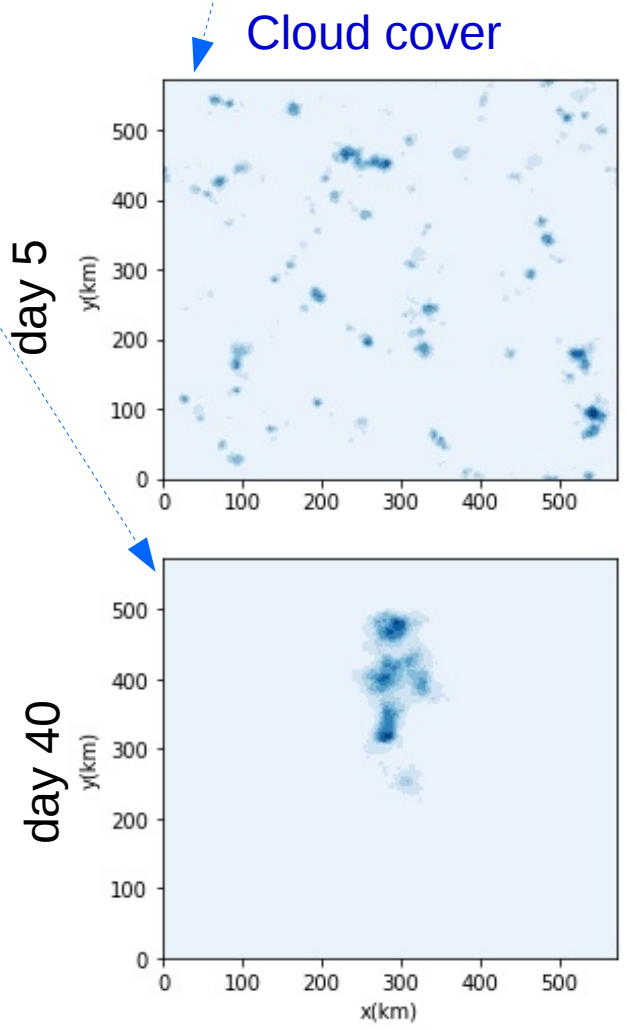
What is the aggregation of convective clouds?

The spontaneous organization of initially scattered convection into isolated convective clusters without any external forcing.



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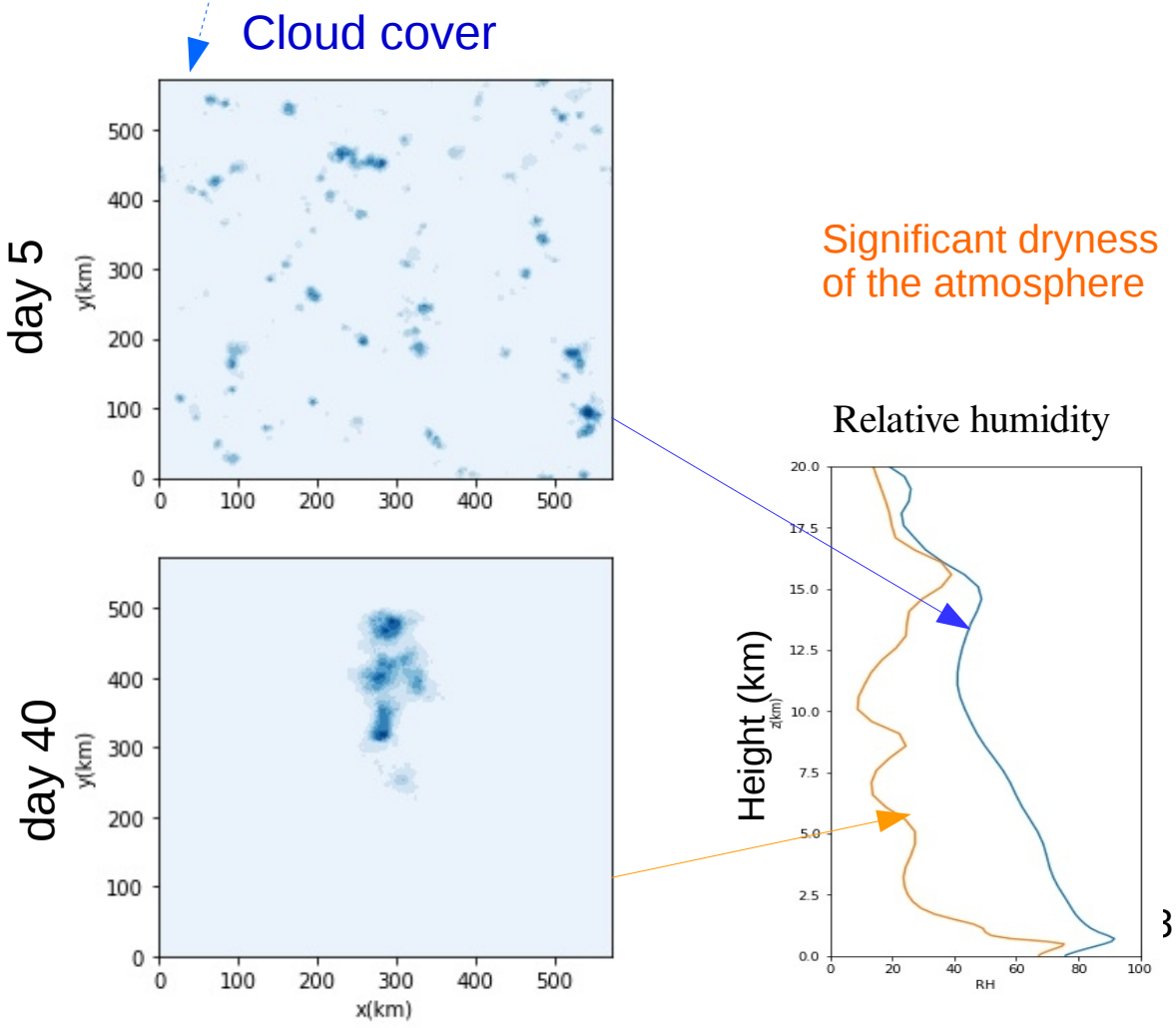

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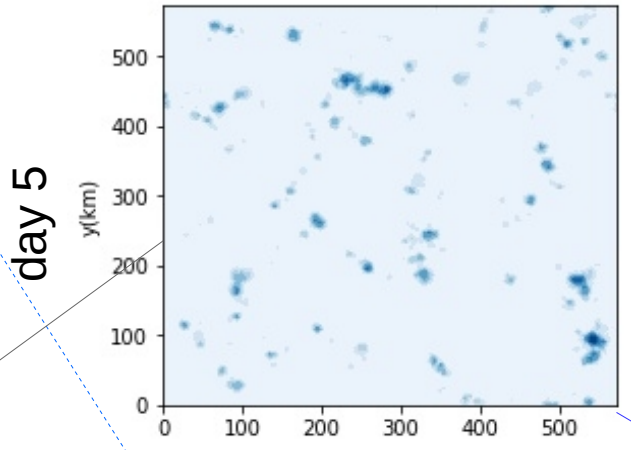
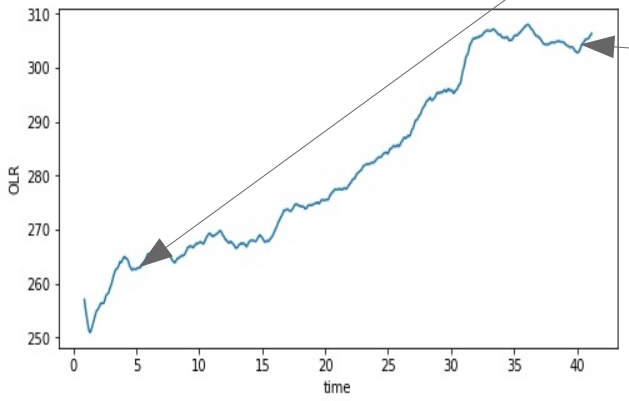
Cloud cover



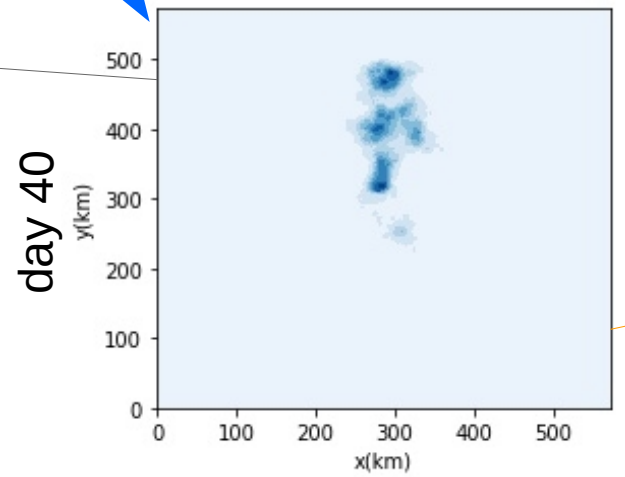
Significant dryness of the atmosphere

Enhanced outgoing longwave radiation

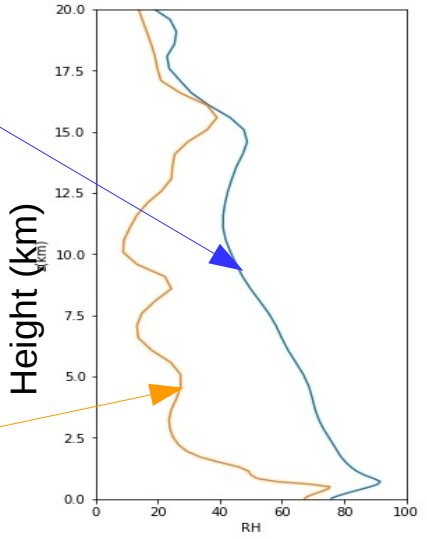
Outgoing long-wave radiation



time(day)



Relative humidity



Importance

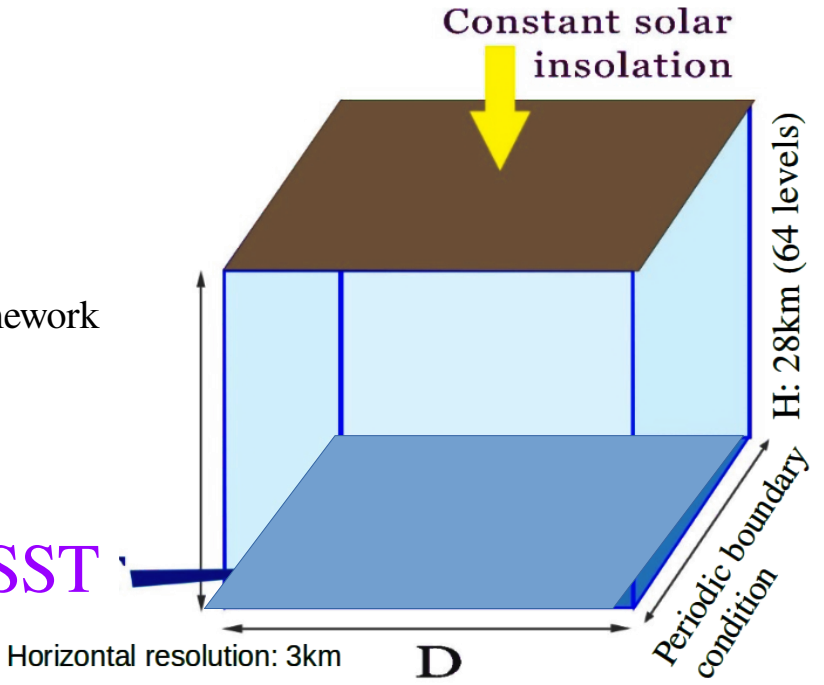
- The aggregation of convection has a significant impact on mean climate.
- Cloud clusters responsible for much of the rainfall and cloudiness over the tropics.
- The aggregation impacts precipitation pattern and hydrological cycle.
- The level of aggregation could possibly modulate climate sensitivity.

Objective

How does an interactive Sea Surface Temperature (SST) feed back the progress of aggregation ?

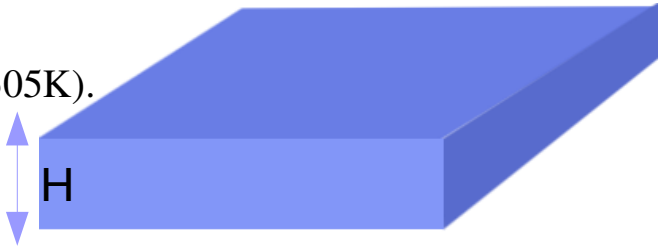
Simulation Set-up

3D cloud-resolving simulations using The system for atmospheric modeling[1] in radiative-convective equilibrium framework



A single layer slab ocean (one layer ocean) with depth H (5, 10, 50 m)

The surface mean temperature is kept constant by relaxing it to a constant SST (300 K , 305K). This method allows sea surface temperature (SST) to vary horizontally.



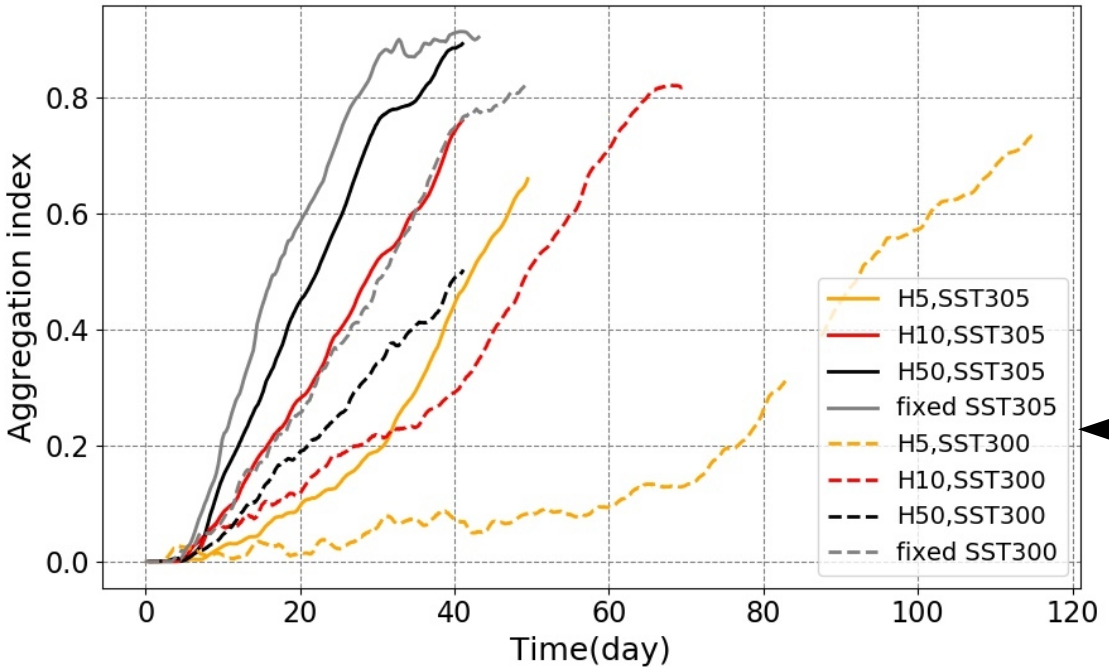
Aggregation index

Aggregation index is defined as fractional area with CRH<0.6. CRH is the column relative humidity defined as :

$$CRH = \frac{\int q_v \, \rho \, dz}{\int q_{v,sat} \, \rho \, dz}$$

1. Khairoutdinov, M. F., & Randall, D. A. (2003). Cloud resolving modeling of the ARM summer 1997 IOP: Model formulation, results, uncertainties, and sensitivities. J. Atmos. Sci.

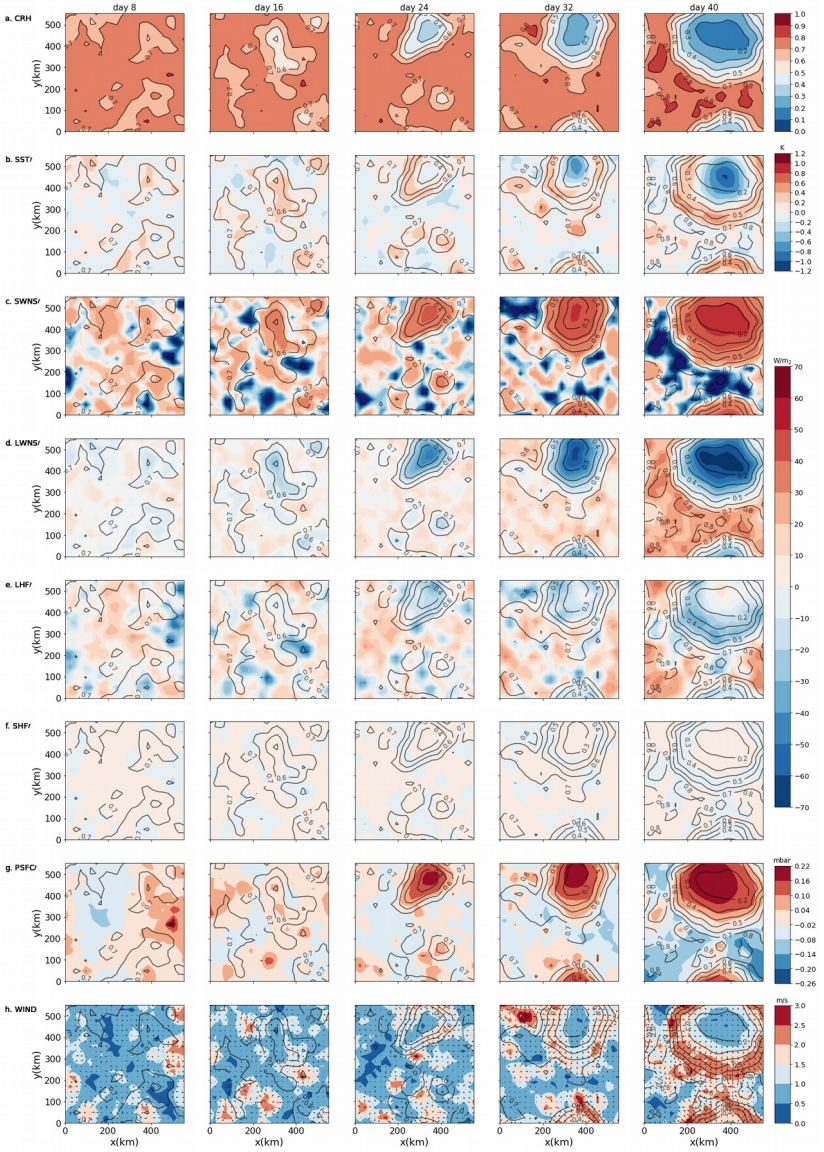
How do slab depth and mean SST impact the aggregation progress?



H indicates the slab depth
SST is the domain mean.

- The deeper the slab the faster the aggregation. → interactive SST delays the aggregation
- The higher the SST the faster the aggregation.

How does SST respond to the dryness resulted from the progress of aggregation?



- Aggregation proceeds by appearance and expansion of dry regions.

- At its early stage, dryness leads to a warm SST anomaly.

- With further dryness, surface latent heat flux (LHF) and long wave radiative cooling at surface (LWNS) increases.

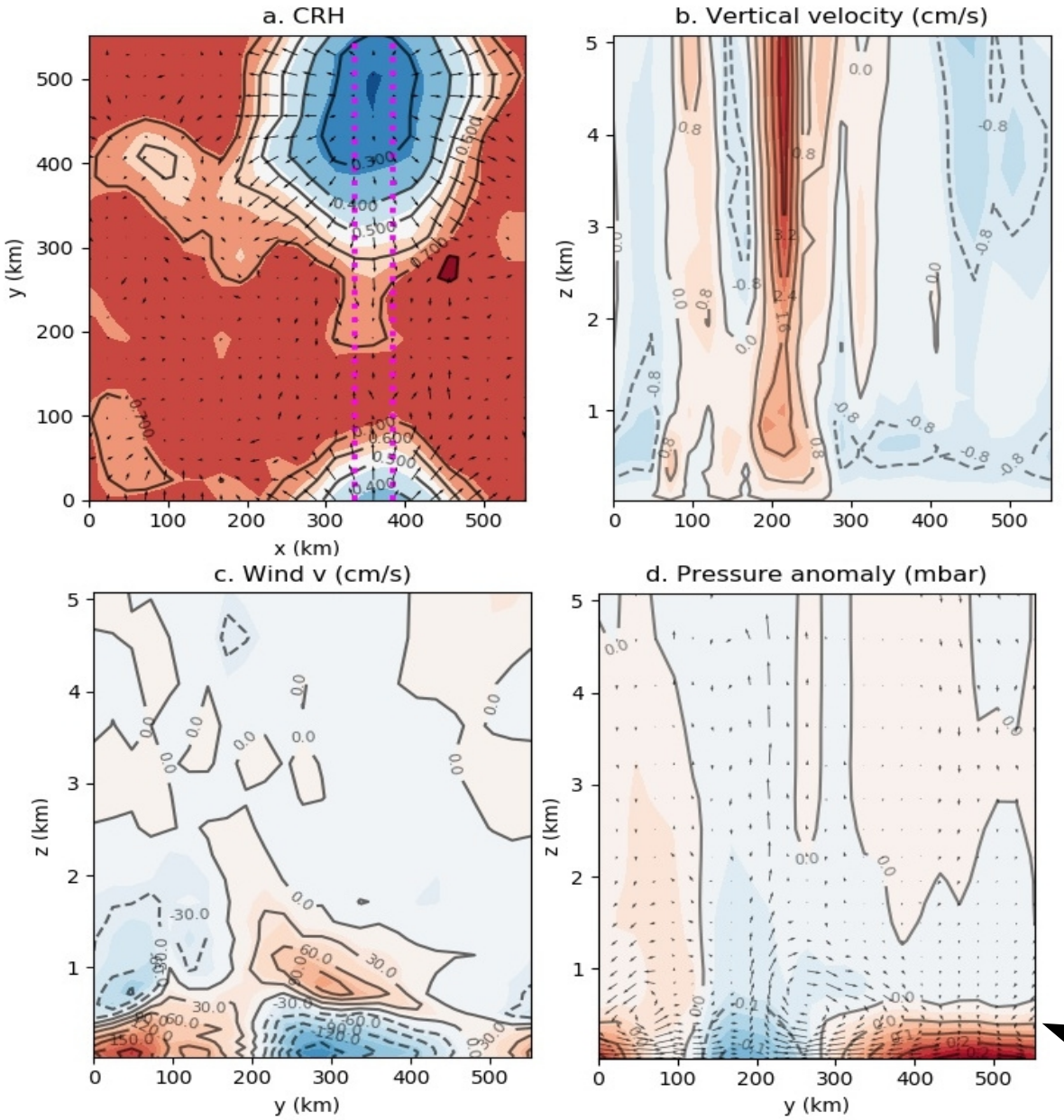
- With enhanced LHF and LWNS the center of dry region cools.

- A positive pressure anomaly forms in dry region that drives a divergent shallow circulation and transports moisture up-gradient.

- With cooling at the center, a ring of warm water forms and enhances the high pressure anomaly at the center of dry patch.

- The increased pressure thus enhanced up-gradient transport of moisture accelerates the aggregation.

High Pressure Anomaly and Shallow Circulation



The high pressure anomaly in dry regions drives a shallow circulation (boundary layer divergent flow) that transports moisture up-gradient.

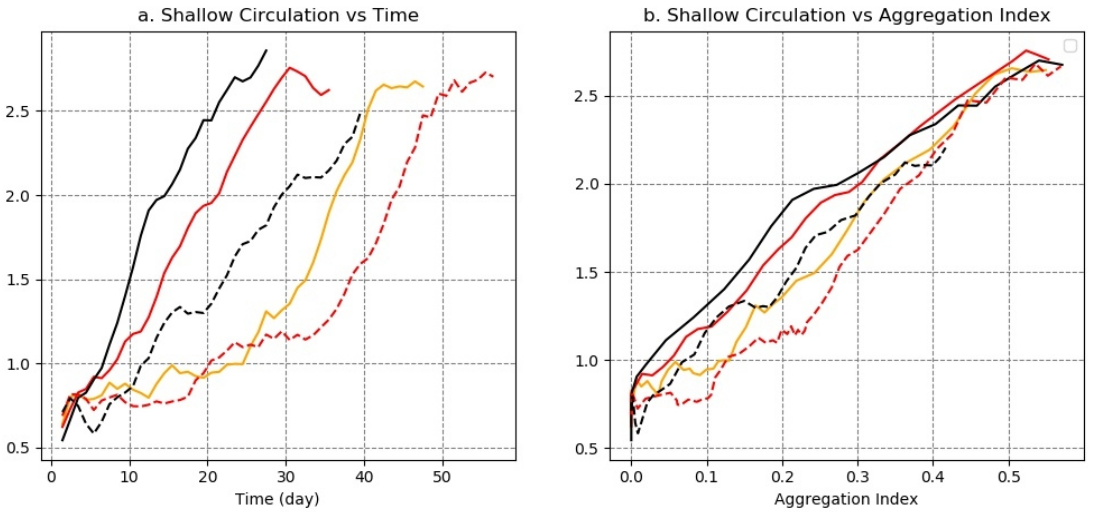
A high pressure anomaly is originated only from the boundary layer.

The higher pressure anomaly is the consequence of a negative moisture and positive radiative cooling anomaly in the boundary layer.

SST anomaly in dry region opposes shallow circulation when negative (early days) but favors shallow circulation when it turns negatives. Thus SST anomaly has a opposition acceleration impact.

Results for a simulation with H=5 and mean SST =305 at day 30.

Shallow circulation



- The shallow circulation (boundary layer convergence) correlates with aggregation speed.

Summary

- The aggregation is faster at higher SST. The interactive SST slows down the aggregation, the shallower the slab the slower the aggregation.
- The moist cluster (or cloudy area) stays over the cold region and does not migrate toward the warm patch.
- When the dry patches just form, the enhanced shortwave radiation warms the surface. While with further dryness, enhanced long wave radiation and latent heat flux at the surface results in a cooling of the surface the the center of the dry patch.
- The pressure anomaly in dry region is positive and drives a shallow circulation that transports moisture up-gradient. The SST anomaly in dry region has opposition-acceleration impact on shallow circulation.
- Stronger circulation at higher SST/deeper slab makes the aggregation faster. The strength of shallow circulation correlates with the aggregation speed.