The effect of GCM time step on climatology in Superparameterized Community Atmospheric Model 3.0

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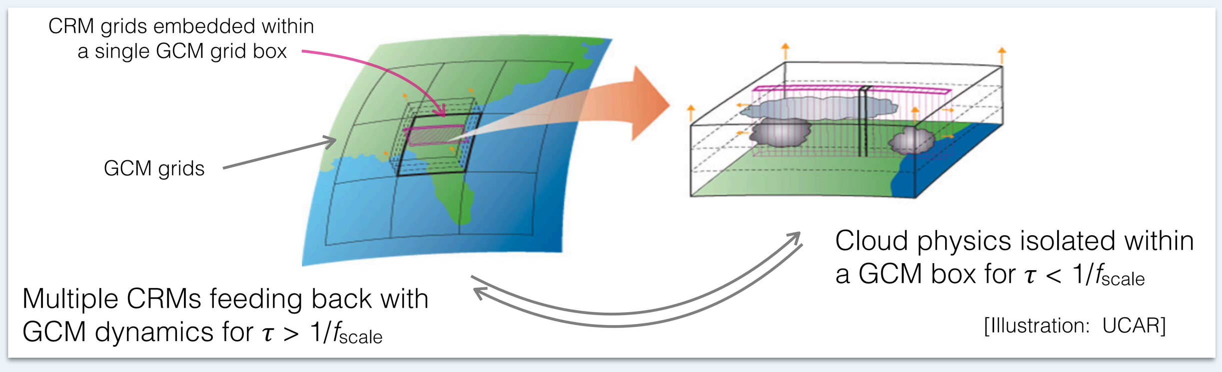
Motivations

What is Superparameterization (SP)?
Superparameterized GCM is a type of GCM that the conventional cloud parameterizations are replaced by cloud resolving models (CRMs) in order to reduce uncertainties from those statistical subgrid schemes.



How do GCM and CRM communicate in SP?
The current SP scaffold allows GCM and CRM to communicate only at each GCM time step. Sale coupling frequency between GCM and CRM increases with decreasing GCM time step.

Scale coupling frequency (f_{scale}) is an important parameter that controls GCM – CRM communication frequency, but its effect is hardly known
Better understanding on f_{scale} would tell us its potential as a tuning parameter and provide useful insight for future SP model development.

So, we explored the effect of f_{scale} in a SPGCM!
Our major findings include:

1. f_{scale} monotonically impacts climate. With a higher f_{scale},
   - Shortwave and longwave cloud forcing biases lessen.
   - Tropical rainfall extreme becomes more frequent.
2. Convective organization changes with f_{scale}, and it seems to be the main cause of the climate sensitivities.

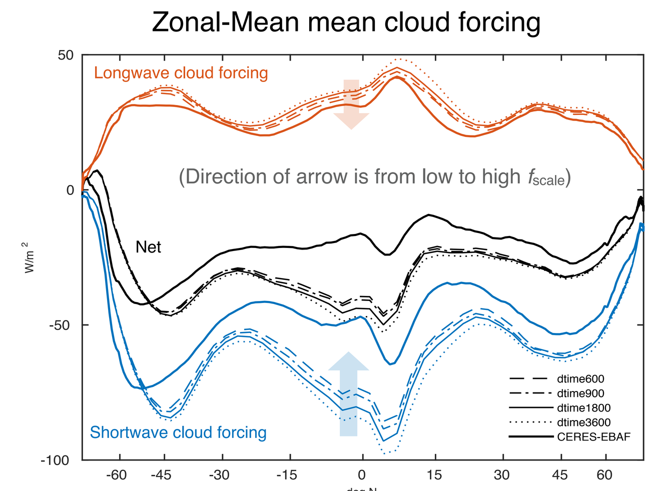
Methods

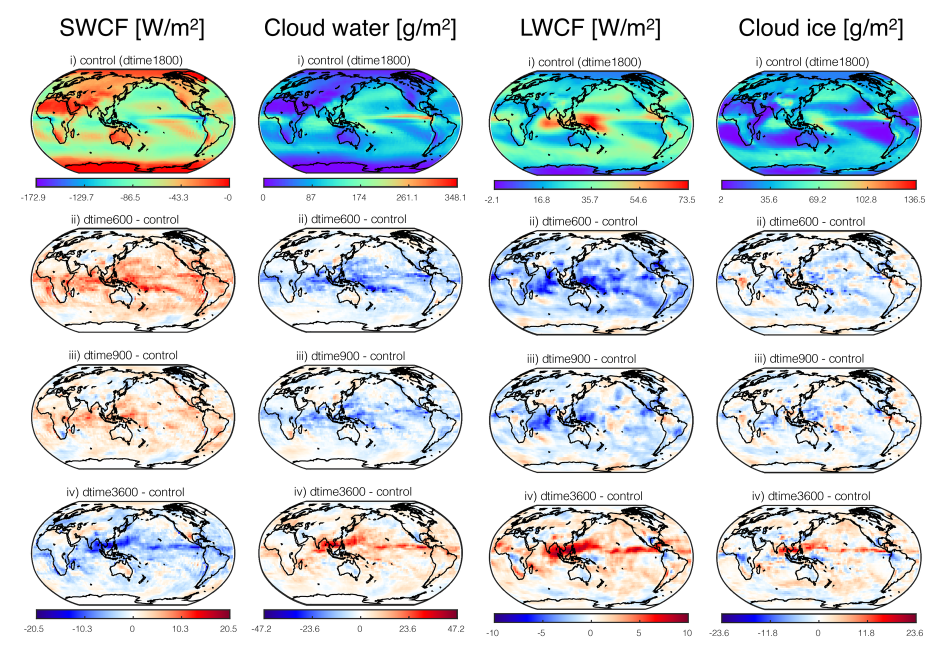
SPCAM Version: 3.0
CRM setup: 1x8 columns with 4km horizontal grid size
Control simulation: dtime (GCM timestep, ~ $1/f_{scale}$) = 1800 [s]
Experiment simulation: dtime = 600, 900, 3600 [s]
Simulation length: 10 years with 4 months of spin-up
Boundary conditions: prescribed monthly SST

1. f_{scale} monotonically impacts simulated climate

Shortwave and Longwave cloud forcing biases decreases

- Liquid clouds systematically become less dense and less bright as f_{scale} increases.
- High clouds reduce with f_{scale} but this response is weaker and more complex.

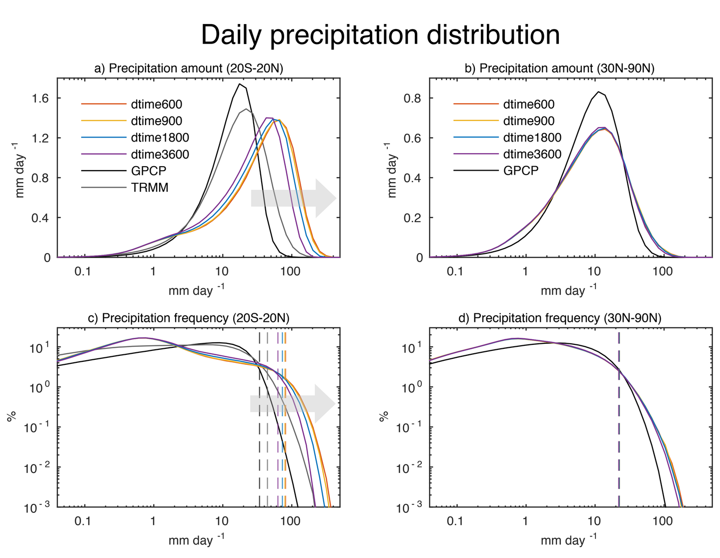




[Top] (i) Control simulation and (ii–iv) experiment simulation anomalies against control simulation.
[Left] Zonal mean annual mean cloud forcing in SPCAM3 (thin lines) and observation (thick lines).

Tropical rainfall extremes increase

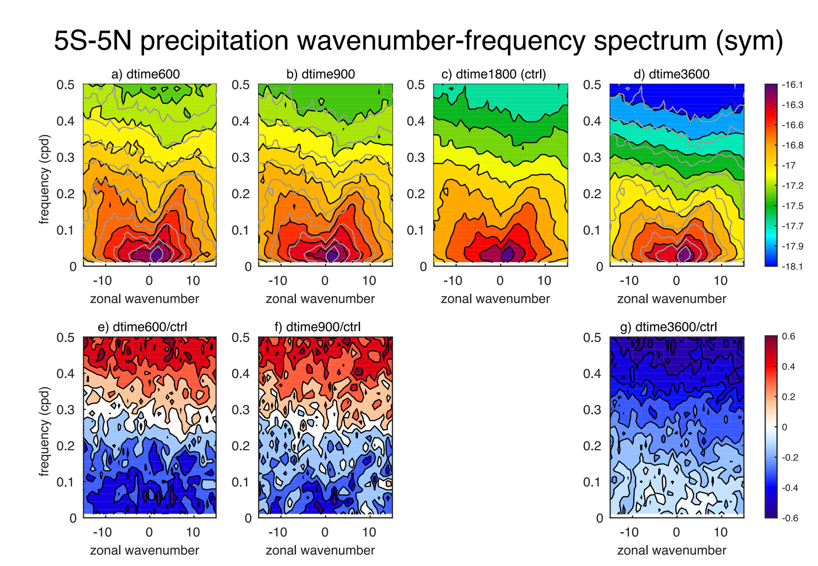
- Rain intensity tail amplifies as f_{scale} increases.
- Rain intensity tail response is mostly from the tropics.



(a, b) Amount and (c, d) frequency distributions of daily mean precipitation

Spectral power shifts to higher frequencies

- No single mode of equatorial wave variability dominates rain intensity change.
- Daily mean power is shifted to higher frequencies at all zonal wavelengths.

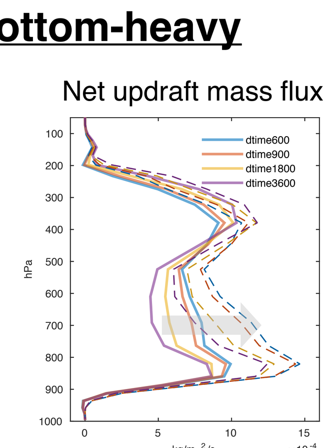


(a–d) Raw log power spectra and (e–g) the ratio of log power of experimental simulation to control simulation. Gray contour lines in a, b, and d are from control simulation

2. Convective organization changes seem to cause the f_{scale} sensitivity

Convection becomes bottom-heavy

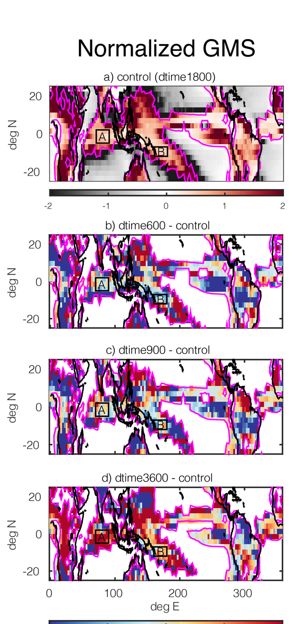
- f_{scale} appears to affect the net updraft mass flux profile of convection rather than simply boosting mass flux at all level, promoting more bottom-heavy convection with a high fscale.

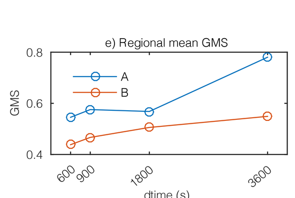


The profiles of the CRM updraft mass flux (solid lines) and their saturated moist components (dashed lines)

GMS decreases in active convection areas

- GMS (following Raymond et al. 2009, *JAMES*) decreases with f_{scale} in convective regions, as expect from more bottom heavy convection.
- Reduced GMS enhances net precipitation efficiency to a given diabetic forcing and may link to the rain distribution shift toward extreme and possibly to cloud water and ice.





(a) Control simulation, (b–d) experimental simulation anomalies against control simulation, and (e) horizontally averaged GMS in two subregion A and B. Magenta line shows the contour of GMS of 0.1.

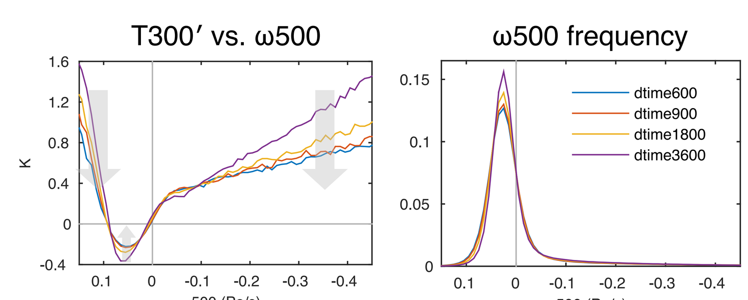
Convective organization hypothesis

It seems possible to explain a broad set of simulated climate responses to f_{scale} as the result of an overarching change in convective organization favoring more bottom-heavy convection, reduced gross moist stability, and ultimately enhanced precipitation efficiency at a high f_{scale}. In addition, the systematic responses of cloud water and ice—accordingly, SWCF and LWCF—could be viewed as stemming from changes in precipitation efficiency.

3. Weak-temperature-gradient conforms better with a high f_{scale}

Better WTG conformity with high f_{scale}

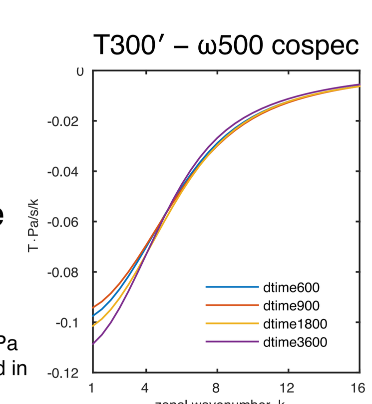
- Increasing f_{scale} reduces T300′ such that SPCAM3's behavior becomes more WTG-like.



[Left] Daily horizontal-mean anomalies of temperature from its horizontal field at 300 hPa (T300′) across vertical velocity at 500 hPa (ω500) in equatorial region (5°S–5°N). [Right] Relative frequency of vertical velocity at 500 hPa.

Large waves dominates T anomalies

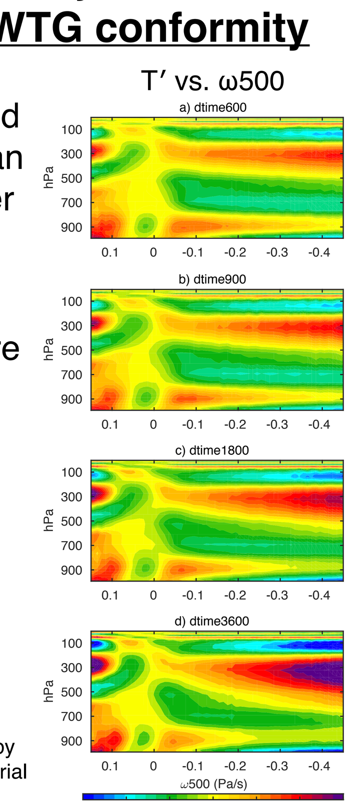
- Planetary-scale disturbances, i.e., small zonal wavenumbers, dominate the sensitivity to f_{scale} of the covariance between T′ and ω.



Cospectrum of daily T anomalies at 300 hPa and ω at 500 hPa from their horizontal field in equatorial region (5°S–5°N)

Frequent dynamical adjustment to T anomalies helps WTG conformity

- Local convection confined in an embedded CRM can build up to produce larger thermal anomalies.
- These local heat anomalies (e.g., T′>0) are then spread to adjacent GCM grid columns via dynamical adjustment.
- In SPGCMs, dynamical adjustment is limited by f_{scale}, indicating a high f_{scale} can reduce T′.



Vertically resolved profiles of temperature anomalies from its horizontal mean, binned by vertical velocity at 500 hPa (ω500) in equatorial region (5°S–5°N).

For further details, refer to:

Yu and Pritchard (2015), *JAMES*. (doi: 10.1002/2015MS000493)

Take-home Points

1. f_{scale} impacts simulated climate monotonically. With a high f_{scale},
   - Both shortwave and longwave cloud forcings decrease.
   - Tropical precipitation tail amplifies.
2. f_{scale} also impacts the organization of tropical convection. With a high f_{scale},
   - Convection becomes more bottom-heavy, and accordingly GMS decreases.
   - WTG conforms better due to dynamical adjustment to thermal anomalies.
3. f_{scale} can be a useful tuning parameter for SP models and provide some insights for future SP model development.

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