Precipitation Characteristics in the CAM and Their Dependence on Model Physics and Resolution

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Introduction and Motivation

To fully characterize a discontinuous variable like precipitation, one often needs not only the accumulative amount (A), but also its frequency (F, the percentage of time it precipitates), intensity (I, the precipitation rate averaged over the precipitating time) and duration (D, mean precipitating interval averaged over all precipitation events) (Dai, 2006; Trenberth & Zhang, 2018).

Current global climate models (GCMs) tend to overestimate precipitation F and D but underestimate I, even though precipitation A is realistic (Dai, 2006; Trenberth & Zhang, 2018). Models with finer grid sizes should produce lower F and higher I because of 1) physical improvements (Bacmeister et al., 2014) and 2) the reduced area-aggregation effect (Chen & Dai, 2018). Thus, the "drizzling" problem in coarse-resolution global models is likely to become less of an issue as the model resolution increases.

To address these issues, we performed and analyzed a series of carefully-designed simulations with varying resolutions using the CAM4 and CAM5. Our focus is on what causes the resolution dependence of the A, F, I and D in CAM and how the resolved and parameterized precipitation differs in these characteristics.

Data and Method

- Model experiments design

Experiment group	Simulation number	Components set	Grid configurations
A (CAM4)	A1	**F_2000** **Components:** CAM4, CLM4.0, DOCN, CICE **Description:** CAM4 physics forced by climatological SSTs and sea ice	0.23X0.31_gx1v6 (f02_g16)
	A2		0.47X0.63_gx1v6 (f05_g16)
	A3		0.9X1.25_gx1v6 (f09_g16)
	A4		1.9X2.5_gx1v6 (f19_g16)
B (CAM5)	B1	**F_2000_CAM5** **Components:** CAM5, CLM4.0, DCON, CICE **Description:** CAM5 physics forced by climatological SSTs and sea ice	0.47X0.63_gx1v6 (f05_g16)
	B2		0.9X1.25_gx1v6 (f09_g16)
	B3		1.9X2.5_gx1v6 (f19_g16)

- All simulations are designed to run for 5 years and hourly output of precipitation and a few other variables are archived.
- Examine characteristics of total, convective & non-convective precipitation.
- Directly calculate F, I, and D using output from each run.
- Apply spatial averaging (Chen & Dai 2018) to F, I, and D on the highest-resolution (e.g. 0.25°->1.0°), to quantify the area-aggregation effects.

- Observational datasets

Dataset	Resolution and coverage	Online documentation
TRMM 3B42	0.25° grid, 50° S-50° N, 180° W-180° E; 3-hourly precipitation rates, 1/1998-12/2014	https://pmm.nasa.gov/data-access/downloads/trmm
TRMM 3A25	0.5° grid, 37° S-37° N, 180° W-180° E; monthly rates for stratiform and convective precipitation, 1/1998-12/2014	https://pmm.nasa.gov/data-access/downloads/trmm
GPCP v2.2	2.5° grid, globe, monthly precipitation, 1/1998-12/2014	http://precip.gsfc.nasa.gov/

Precipitation Characteristics in CAM4 & CAM5

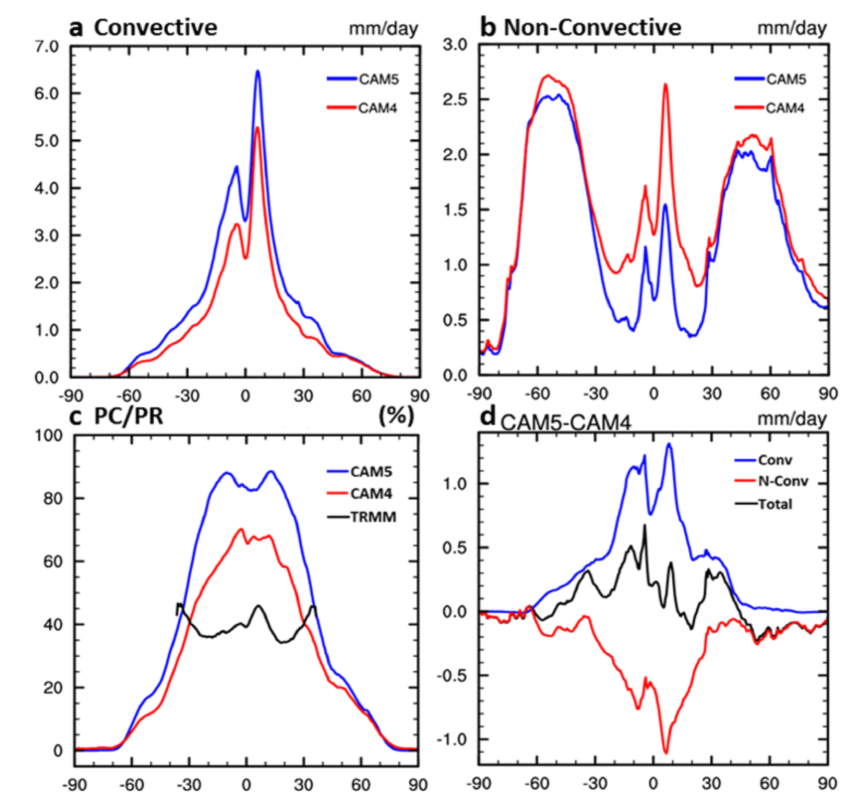


Figure 1. Zonal-mean annual (a) convective precipitation, (b) non-convective precipitation, (c) convective-to-total (PC/PR) precipitation ratio, and (d) the CAM-minus-CAM4 difference. Results are calculated based on outputs from CAM4 and CAM5 simulations on 0.47° lat×0.63° lon resolution.

- Precipitation A is comparable to GPCP, but CAM produces too much convective precipitation at low latitudes compared with TRMM 3A25.
- CAM considerably overestimates F and D while underestimates I.
- Substantial differences of the F , I and D are seen between CAM4 and CAM5.
- Different cloud microphysics schemes are likely responsible for most of the precipitation characteristics differences between CAM4 and CAM5.

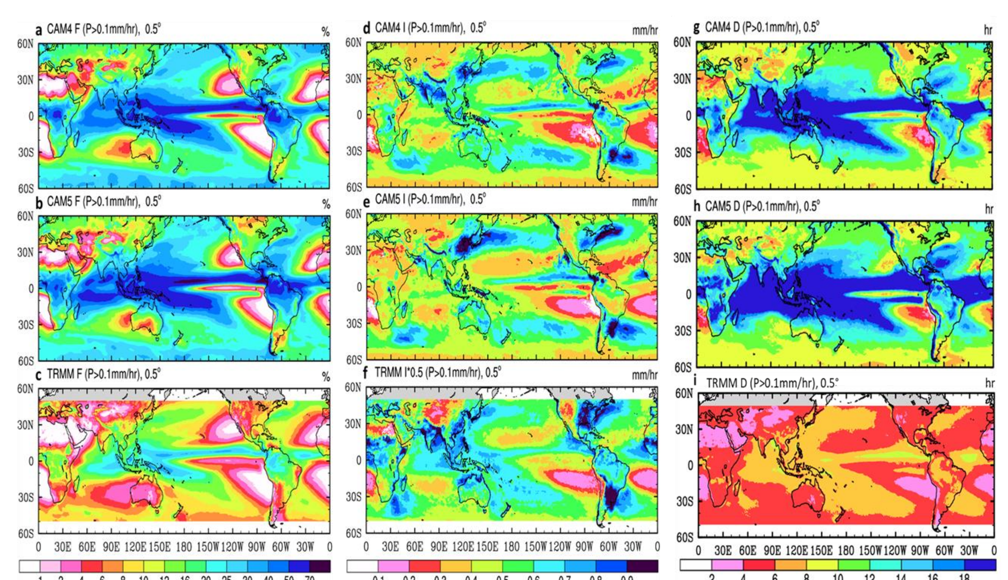


Figure 2. Mean precipitation (a-c) F (%), (d-f) I (mm/yr), and (g-i) D (hours) estimated using 3-hourly total precipitation from (a, d, g) CAM4 and (b, e, h) CAM5 (on 0.47° lat × 0.63° lon resolution), and (c, f, i) from TRMM 3B42 data from 1998-2014 (averaged onto a 0.5° grid).

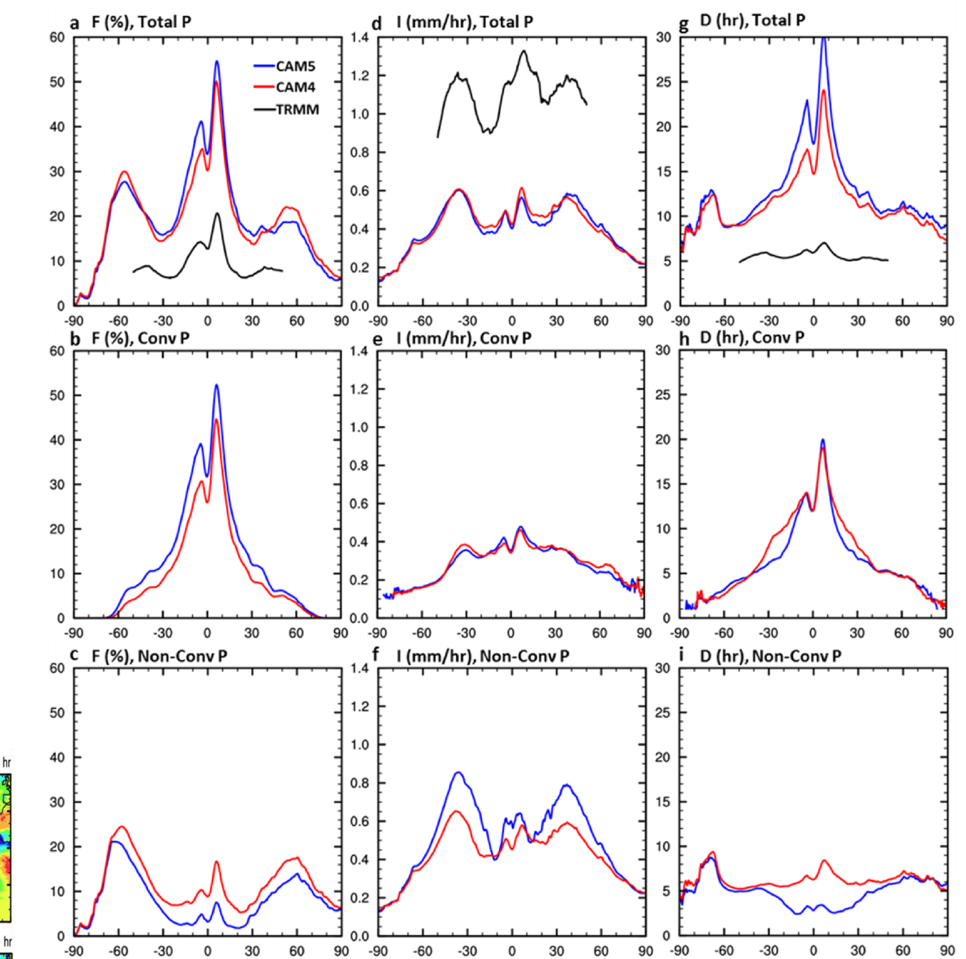


Figure 3. Zonal-mean (a-c) F, (d-f) I and (g-i) D of 3-hourly total precipitation, and of hourly convective and non-convective precipitation from simulations using CAM4 and CAM5 on 0.47° lat×0.63° lon resolution. The F, I, and D from TRMM 3B42 3-hourly precipitation averaged onto a 0.5° grid are shown as the black line in (a, d, g) for comparison.

Resolution Dependence

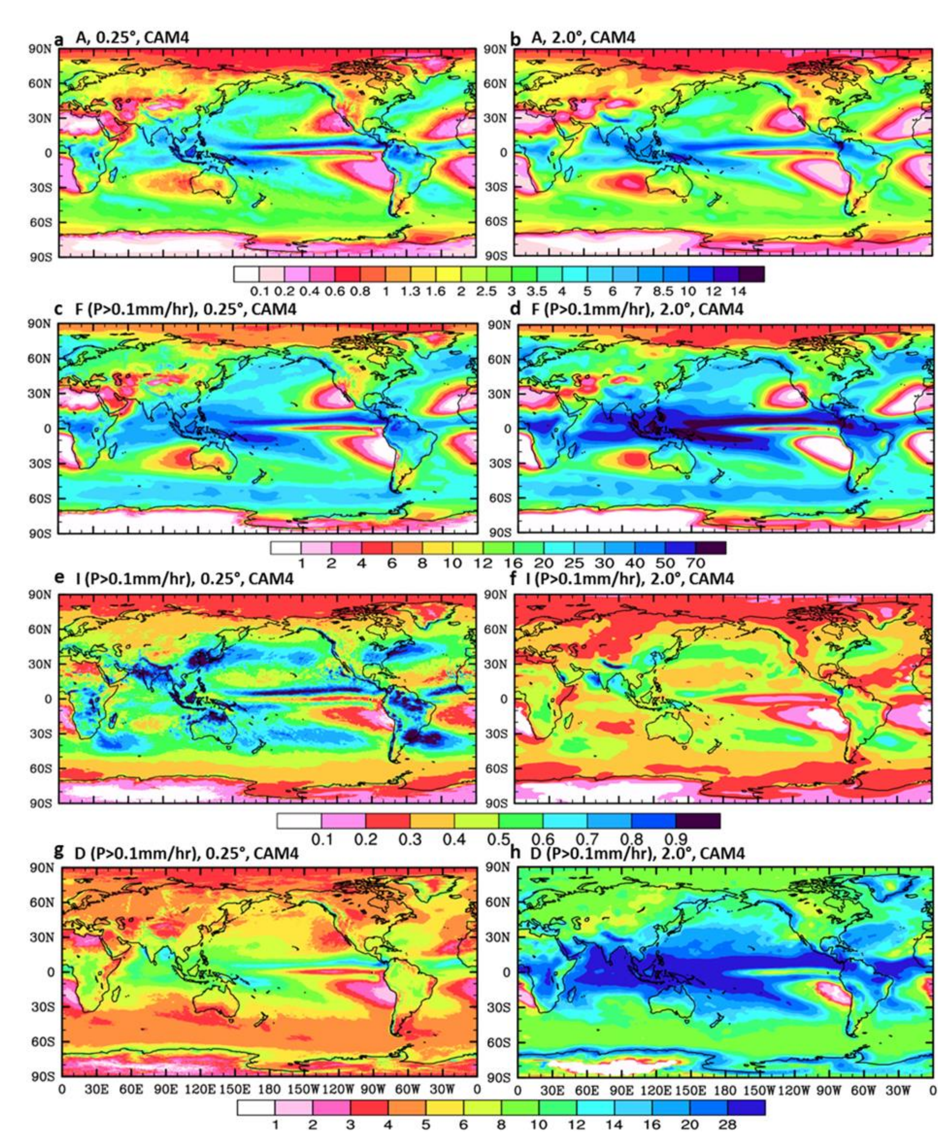


Figure 4. Mean annual total precipitation (a-b) amount (A), (c-d) F, (e-f) I and D estimated using CAM4 outputs on 0.23° lat×0.31° lon (0.25° , left) and 1.9° lat×2.5° lon (2.0° , right) grids.

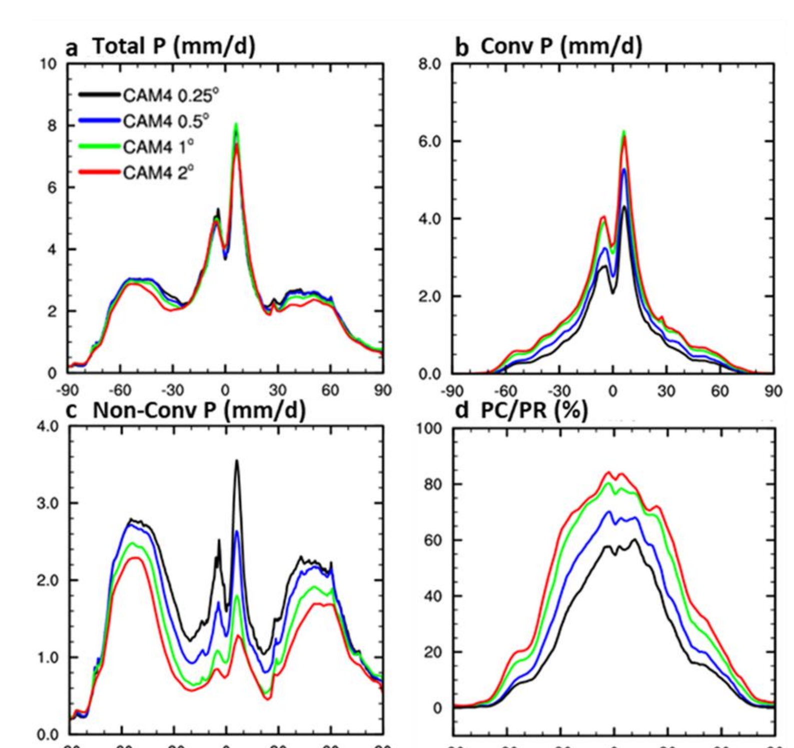
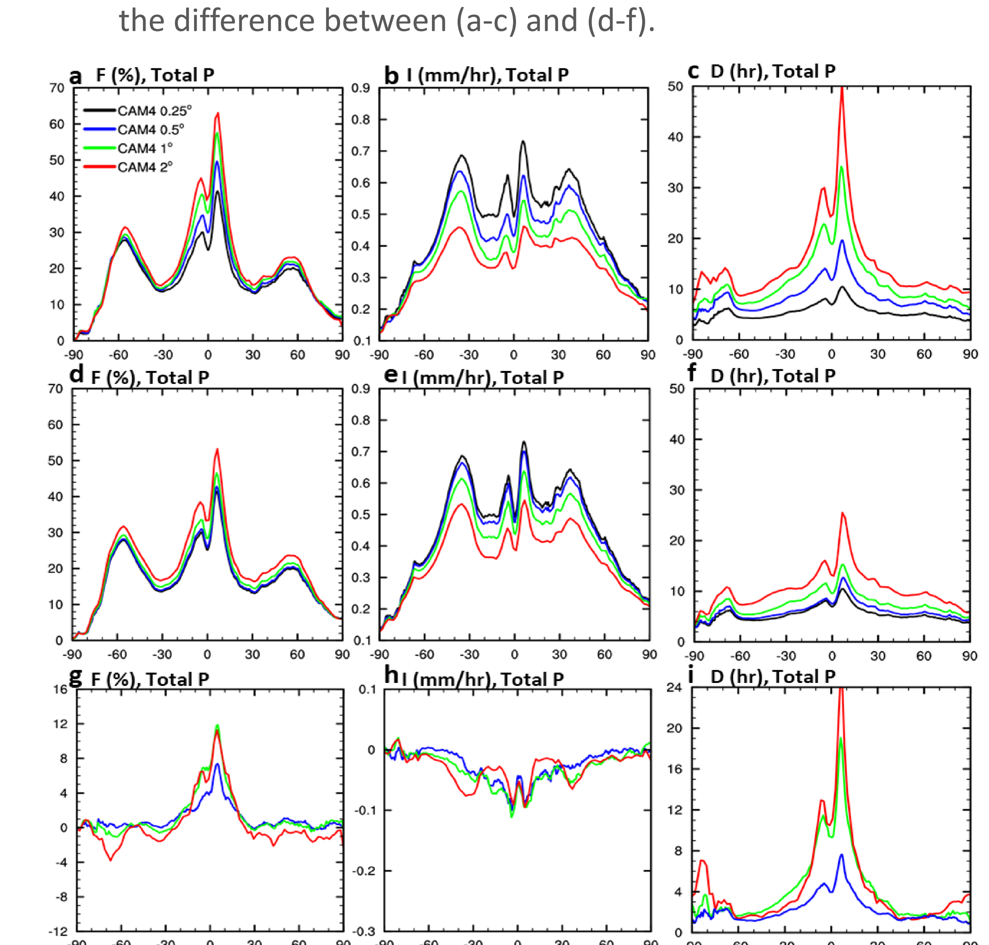


Figure 5. Zonal-mean annual (a) total, (b) convective (Conv) and (c) non-convective (Non-Conv) precipitation amount, and (d) convective-to-total precipitation (PC/PR) ratio produced by CAM4 on four different spatial resolutions (0.23° lat×0.31° lon, 0.47° ×0.63° , 0.9° ×1.25° and 1.9° ×2.5°).

- Precipitation characteristics are sensitive to model resolution to different extent.
- Area-aggregation effect (Chen & Dai, 2018) can only explain part of the resolution dependence.
- Model adjustments increase the F and D for convective precipitation but decrease the F and I for non-convective precipitation, with the largest impacts on the F over the tropics.

Figure 6. Zonal-mean F, I and D of total precipitation estimated using (a-c) direct model output, (d-f) spatial averaging method (i.e., 0.25°->0.5°, 1.0° and 2.0°) and (g-i) the difference between (a-c) and (d-f).



Summary

- CAM4 and CAM5 systematically overestimate precipitation frequency and duration but underestimate intensity.
- CAM5 produces more convective but less non-convective precipitation than CAM4, and both produce too much convective precipitation.
- The "drizzling" bias in CAM may be reduced by reducing its convective precipitation and/or increasing its resolution.
- Resolution dependence in CAM is a combination of grid aggregation effects and physical adjustments.

References

Bacmeister, J. T., M. F. Wehner, R. B. Neale, A. Gettelman, C. Hannay, P. H. Lauritzen, J. M. Caron, & J. E. Truesdale (2014). Exploratory high-resolution climate simulations using the Community Atmosphere Model (CAM). *Journal of Climate*, 27 (9), 3073–3099.

Chen, D., & A. Dai (2018). Precipitation Characteristics in the Community Atmosphere Model and Their Dependence on Model Physics and Resolution. *Journal of Advances in Modeling Earth System*, submitted.

Chen, D., & A. Dai (2018). Dependence of estimated precipitation frequency and intensity on data resolution. *Climate Dynamics*, 50, 3625.

Dai, A. (2006). Precipitation characteristics in eighteen coupled climate models. *Journal of Climate*, 19, 4605–4630.

Morrison, H., G. Thompson, & V. Tatarskii (2009). Impact of cloud microphysics on the development of trailing stratiform precipitation in a simulated squall line: Comparison of one- and two-moment schemes. *Monthly Weather Review*, 137(3), 991-1007.

Trenberth, K. E., & Y. Zhang (2018). How often does it really rain? *Bulletin of the American Meteorological Society*, 99, 289–298.

Acknowledgements

We thank Dr. Brian E. J. Rose for his help in setting up the CESM1 simulations, and Dr. Robert Fovell for constructive discussions on cloud microphysics schemes. Dai acknowledges the funding support from the U.S. National Science Foundation (Grant #AGS–1353740 and #OISE-1743738), the U.S. Department of Energy's Office of Science (Award No. DE–SC0012602), and the U.S. National Oceanic and Atmospheric Administration (Award No. NA15OAR4310086).