Parametric sensitivity analysis of precipitation at global and local scales in the Community Atmosphere Model CAM5

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1. Introduction

- In this study, we investigate the sensitivity of precipitation characteristics, including mean, extreme, and diurnal cycle, to dozens of uncertain parameters mainly related to cloud and aerosol processes in CAM5.
- Science Questions: Are there parameters that can dramatically influence the characteristics of precipitation in CAM5? If yes, does the influence on precipitation vary with scale/region/season? What is the relative contribution from individual parameters compared to their interactions? What is relative importance/sensitivity of aerosol and cloud related parameters in affecting the precipitation characteristics?
- The results of this study help to better understand the CAM5 model behavior associated with the parameter uncertainties and will guide the next step to reduce model uncertainty in precipitation via calibration of the most uncertain model parameters and/or developing new parameterizations.

2. Method

- **Latin hypercube and quasi-Monte Carlo sampling approaches** to effectively explore the high-dimensional parameter space.
- **C-Ensemble:** 1100 simulations perturbing 22 parameters related to cloud microphysics, macrophysics and convection.
- **A-Ensemble**: 256 simulations perturbing 16 parameters related to cloud microphysics and aerosols.
- **Generalized linear model (GLM**) is used for Sensitivity Analysis (SA).

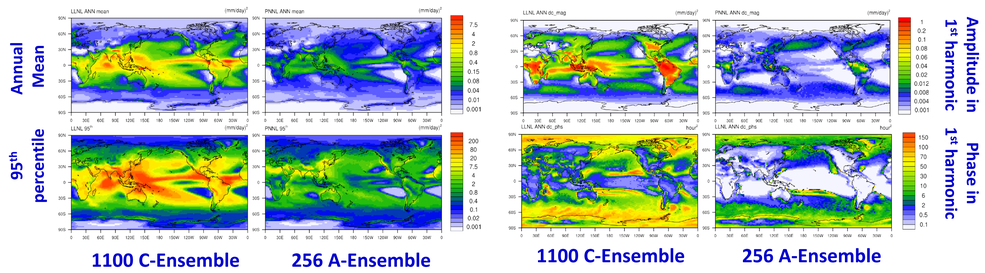
Table 1 CESM/CAM5 Uncertain Parameters of Interest (C-Ensemble)

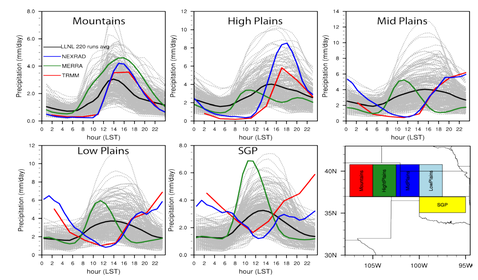
#	Parameter Name	Range			Description	Namelist Prefix	File Name (.F90)
		Low	Default	High			
1	rhminh	0.65	0.80	0.85	Threshold relative humidity for stratiform high clouds	cldfrc_	cloud_fraction
2	rhminl	0.80	0.8875	0.99	Threshold relative humidity for stratiform low clouds	cldfrc_	cloud_fraction
3	alfa	0.05	0.10	0.60	Maximum cloud downdraft mass flux fraction	zmconv_	zm_conv
4	c0_lnd	1.0e-3	0.0059	0.01	*Deep* convection precipitation efficiency over land	zmconv_	zm_conv
5	c0_ocn	1.0e-3	0.045	0.1	*Deep* convection precipitation efficiency over ocean	zmconv_	zm_conv
6	dmpdz	-2.0e-3	-1.0e-3	-0.2e-3	Parcel fractional mass entrainment rate	zmconv_	zm_conv
7	ke	0.5e-6	1.0e-6	10.0e-6	Evaporation efficiency of precipitation	zmconv_	zm_conv
8	tau	1800.0	3600.0	28800.0	Time scale for consumption rate deep CAPE	zmconv_	zm_conv
9	ai	350.0	700.0	1400.0	Fall speed parameter for cloud ice	no nml	cldwat2m_micro
10	as	5.86	11.72	23.44	Fall speed parameter for snow	no nml	cldwat2m_micro
11	cdnl	0.0	0.0	1.0e+7	Lower bound on droplet number	no nml	cldwat2m_micro
12	dcs	100e-6	400e-6	500e-6	Autoconversion size threshold for ice to snow	no nml	cldwat2m_micro
13	eii	0.001	0.1	1.0	Collection efficiency aggregation ice	no nml	cldwat2m_micro
14	qcvar	0.5	2.0	5.0	Inverse relative variance of sub-grid cloud water	no nml	cldwat2m_micro
15	a2l	10.0	30.0	50.0	Moist entrainment enhancement parameter	no nml	eddy_diff
16	criqc	0.5	0.7	1.5	Maximum updraft condensate	nml/add	uwshcu
17	kevp	1.0e-6	2.0e-6	20.0e-6	Evaporative efficiency	nml/add	uwshcu
18	rkm	8.0	14.0	16.0	Updraft lateral mixing efficiency	nml/add	uwshcu
19	rpen	1.0	5.0	10.0	Penetrative updraft entrainment efficiency	uwshcu_	uwshcu
20	e_dust	0.21	0.43	0.86	Dust emission tuning factor	aerosol_	aerosol_intr^
21	wsubimax	0.1	0.2	1.0	Maximum subgrid vertical velocity for ice nucl	x	microp_aero
22	Wsubmin	0.0	0.2	1.0	Minimum subgrid vertical velocity for liquid nucl	x	microp_aero

Table 2 CESM/CAM5 Uncertain Parameters of Interest (A-Ensemble)

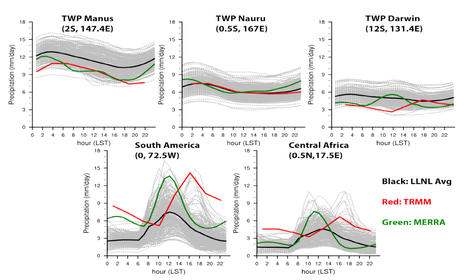
#	Parameter Name	Range			Description	Namelist Prefix	File Name (.F90)	
		Low	Default	High				
1	ai	350.0	700.0	1400.0	Fall speed parameter for cloud ice	cldwatmi_	cldwat2m_micro	M
2	as	5.86	11.72	23.44	Fall speed parameter for snow	cldwatmi_	cldwat2m_micro	M
3	cdnl	0.0	0.0	10.0e+6	Cloud droplet number limiter	cldwatmi_	cldwat2m_micro	LGE
4	dcs	100.0e-6	400.0e-6	500.0e-6	Autoconversion size threshold for ice to snow	cldwatmi_	cldwat2m_micro	M
5	wsubmin	0.0	0.2	1.0	Minimum sub-grid vertical velocity	micropa_	microp_aero	LGE
6	e_dust	0.21	0.35	0.86	Dust emission tuning factor		aerosol_intr	LGE
7	e_sst	0.5	1.0	2.0	Sea salt emission tuning factor		progseasalt_intr	LGE
8	e_soag	0.5	1.5	2.0	SOA (g) emission scaling factor		emission file	LGE
9	e_acnum	0.3	1.0	5.0	Number emission scaling factor for fossil fuel aerosol		emission file	LGE
10	sol_factic	0.2	0.4	0.8	Solubility factor for the removal of interstitial aerosols in convective clouds		mz_aerosols_intr	LGE
11	sol_facti	0.5	1	1	Solubility factor for cloud-borne aerosols in stratiform clouds		mz_aerosols_intr	LGE
12	ref_dust	0.001	0.005	0.01	Visible imag refractive index for dust		modal_aero_init_data	LGE
13	e_so2	0	1	2	emission tuning factor for SO2			
14	e_bc	0	1	3	emission tuning factor for BC			
15	e_pom	0	1	3	emission tuning factor for POM		modal_aero_init_data	LGE
16	e_so4f	0	0.025	0.05	emission tuning factor for sulfate		modal_aero_init_data	LGE

3. Inter-simulation Variance of Precipitation



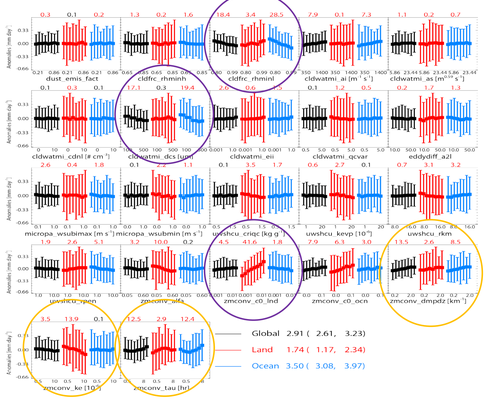


Diurnal cycle of precipitation over five CONUS regions

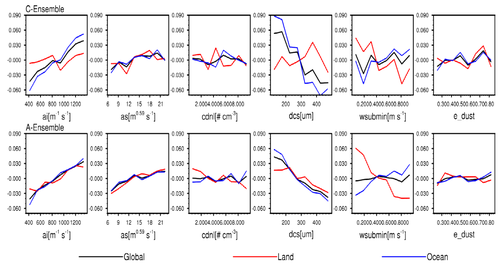


Diurnal cycle of precipitation over five sites

4. Precipitation Sensitivity



Anomalies of variation of global (black), land (red), and ocean (blue) averaged precipitation in response to the perturbations of parameters from the 1100 C-Ensemble. The numbers above each plot box represent the relative contribution (%) of each input parameter perturbation to the total variations. Red indicates the contribution with 95% statistical significance.

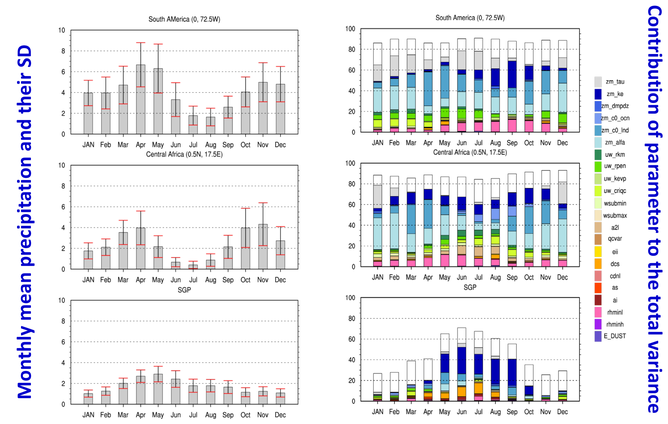


Responses of global precipitation to the six common parameters in LLNL (top) and PNNL (bottom) simulations

Parameters	Global		Land		Ocean	
	C-Ensemble	A-Ensemble	C-Ensemble	A-Ensemble	C-Ensemble	A-Ensemble
ai	29.3	37.1	7.2	14.6	25.3	31.4
as	4.0	9.3	10.2	10.6	2.3	5.1
cdnl	0.5	0.1	6.8	5.4	0.5	1.0
dcs	61.8	52.7	13.2	14.0	65.5	51.6
wsubmin	0.8	0.2	51.2	54.1	4.3	9.9
emis_dust	3.6	0.6	11.4	0.6	2.2	1.1

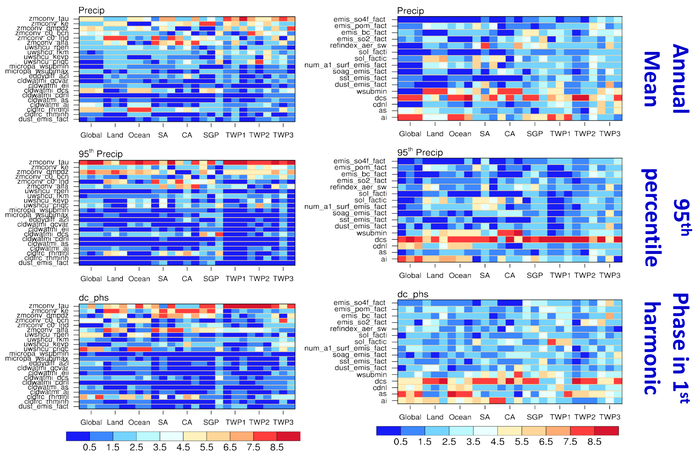
Relative contribution (%) of each parameter to total variance of global precipitation using 6 common parameters in GLM

5. Seasonal Variability of sensitivity



6. Summary

- Among the 22 parameters, the *c0_lnd, rhminl, dcs, tau, dmpdz,* and *ke* are the six most influential parameters to the mean precipitation at global scale.
- The extreme precipitation is sensitive to a fewer number of parameters. The *tau* is the dominant parameter changing the 95th precipitation. The mean and extreme precipitation does not respond monotonically to changes in the parameter *tau*, which has a turning point around 2 hours.
- Three parameters in the deep convection scheme, *ke, alfa* and *tau*, are the primary factors contributing to the total variance of the diurnal cycle of the precipitation over land. The influence of individual parameters does not depend on the sampling approach applied or concomitant parameters selected.
- Generally the variance explained by the GLM for all precipitation metrics are larger in global mean than at local scale.
- While the total variance shows a significant (small) seasonal variability in the mid-latitude (tropical) continental region, the contribution from individual parameters has remarkable seasonal variation in all regions.
- Overall the total variance for precipitation is primarily contributed by the individual parameters rather than their interactions.



Relative significance of each parameter to the variations of precipitation over multiple regions (ANN, JJA and DJF)

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