Parametric sensitivity analysis of precipitation at global and local scales in CAM5

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Motivation

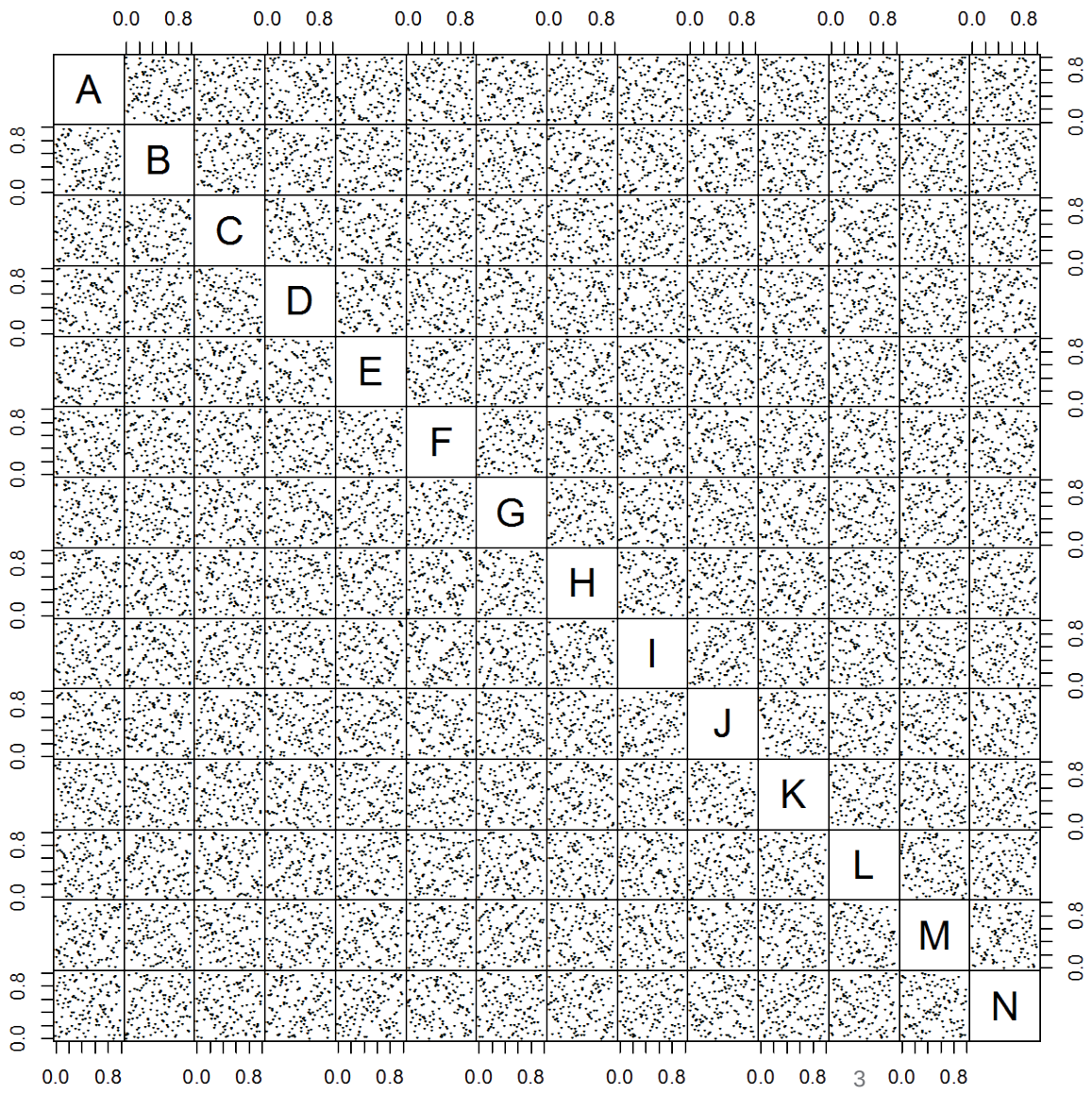
Science Questions:

1. Are there parameters that can dramatically influence the precipitation in CAM5?
2. If yes, how does the parametric sensitivity vary with scale/region/season?
3. Does the parametric sensitivity change with the sampling method or accompanying parameters?
4. What is the relative contribution from individual parameters versus their interactions?
5. What is overall relative importance/sensitivity of aerosol and cloud related parameters in affecting the precipitation characteristics?

Answering these questions could help:

1. better understand the CAM5 model behavior and physical processes associated with the parameter uncertainties and external forcings
2. guide model tuning
3. calibrate and optimize model performance

C-Ensemble (LHP) and A-Ensemble (QMC)



- LLNL: C-Ensemble
  - Latin Hypercube
  - 22 parameters
  - 1100 sample sets (forward simulations)
  - Each simulation: 5-yr
  - Each parameters is sampled 1100 times

- PNNL: A-Ensemble
  - Quasi Monte Carlo
  - 16 parameters
  - 256 sample sets
  - Each simulation: 5-yr
  - Each parameter is sampled 256 times.

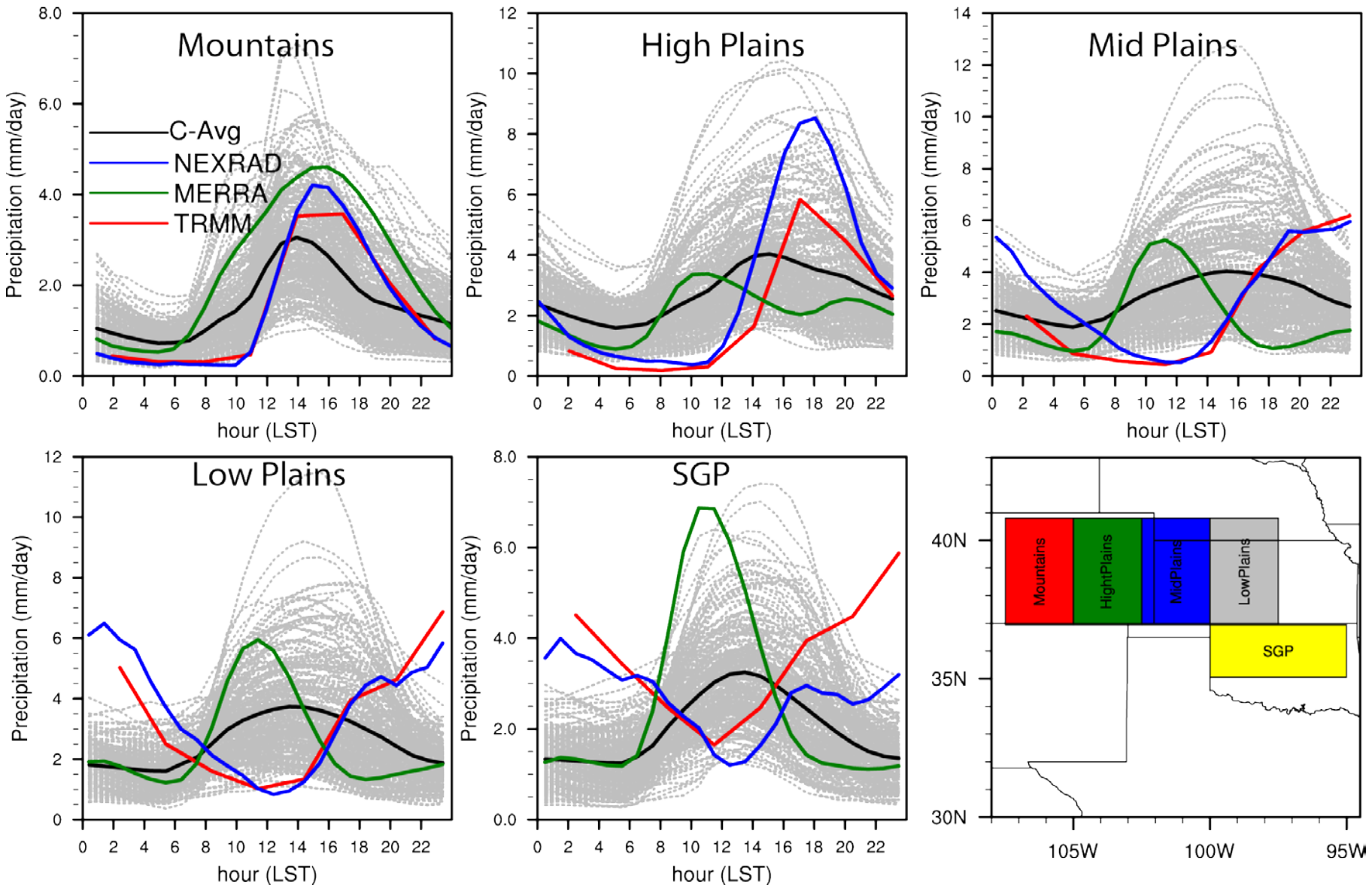
CESM/CAM5 Uncertain Parameters of Interest (C-Ensemble)

#	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

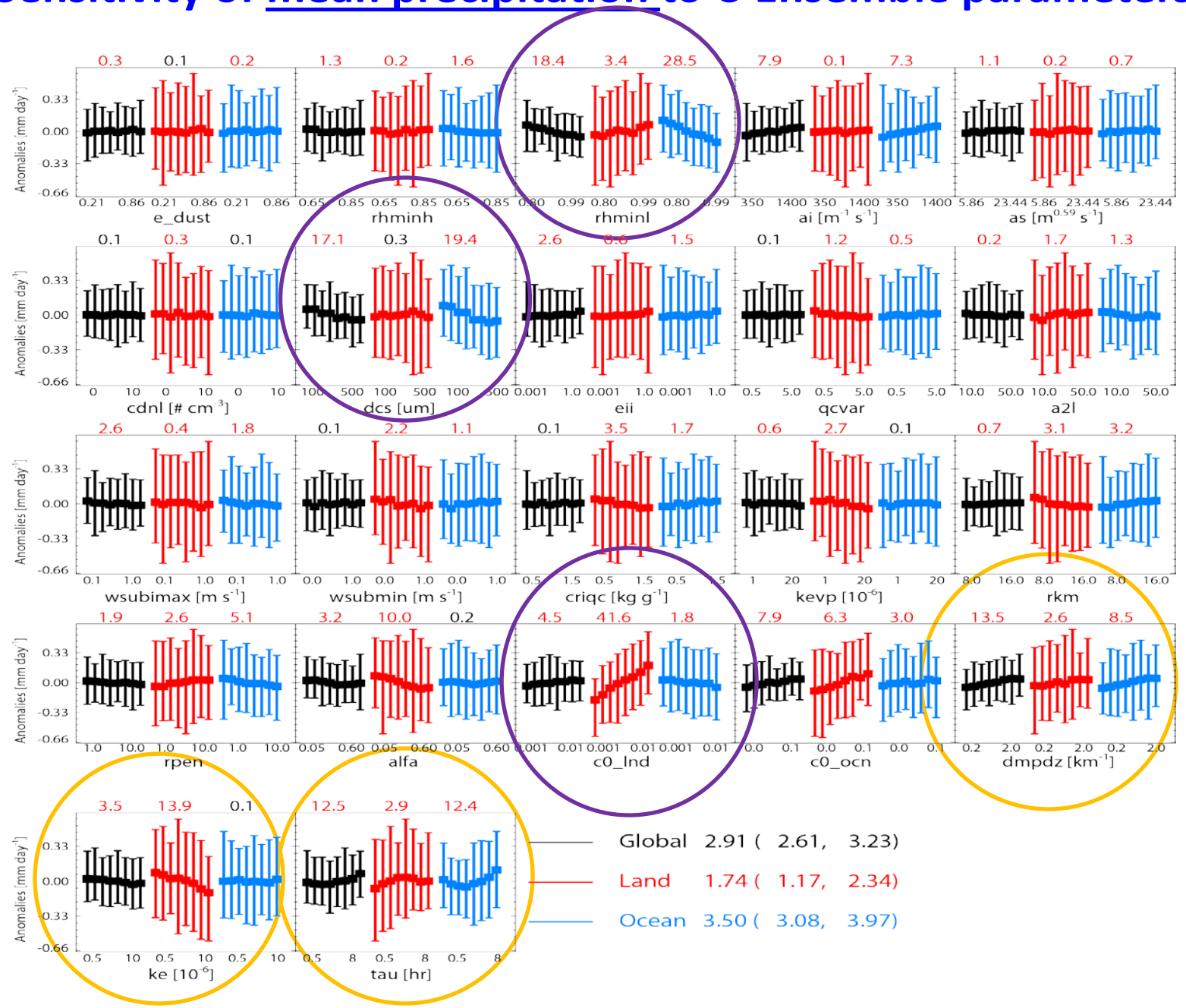
CESM/CAM5 Uncertain Parameters of Interest (A-Ensemble)

#	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		progsseasalt_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

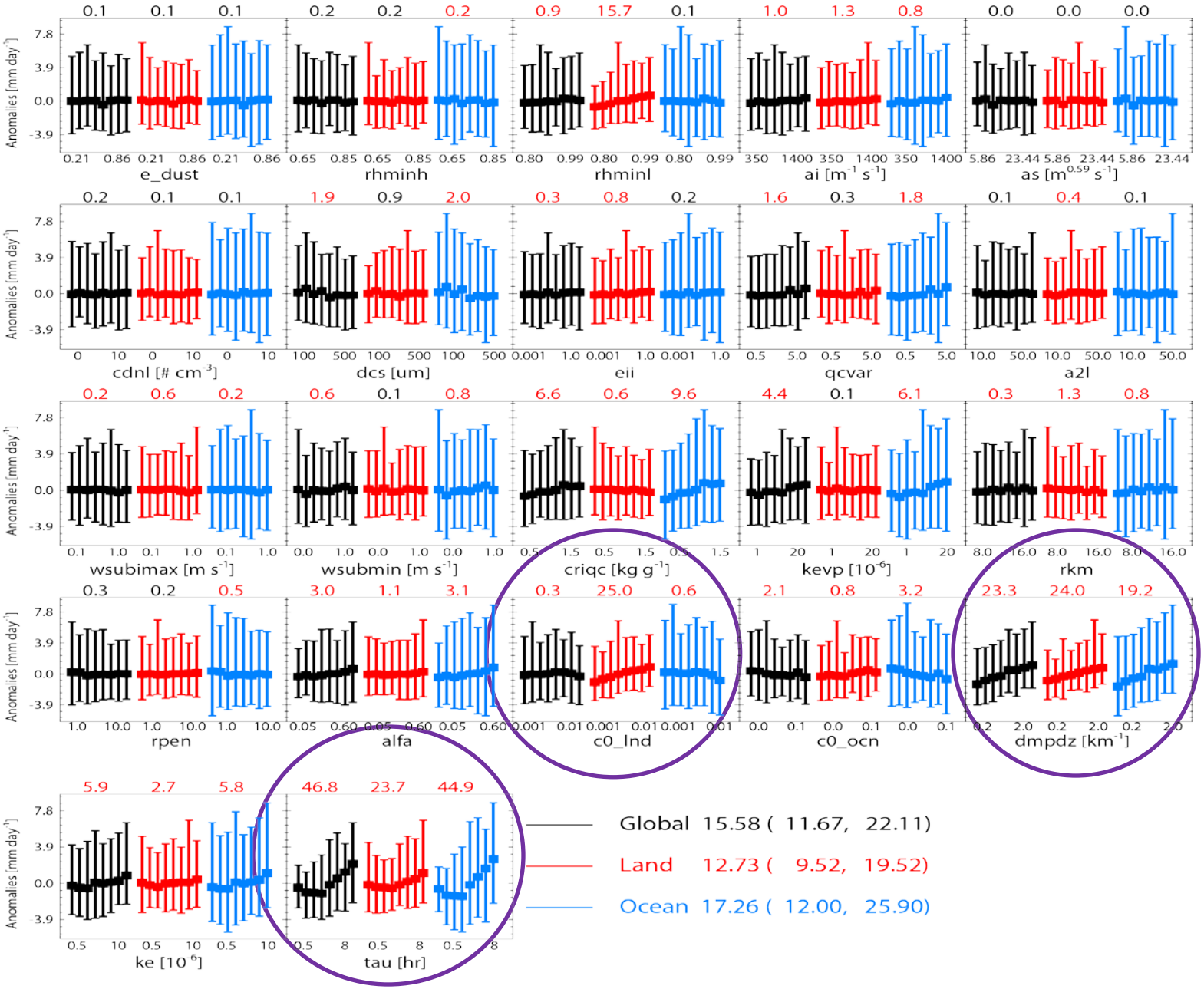
Diurnal cycle of precipitation at five CONUS regions from observation and a subset of C-Ensemble CAM5 simulations (gray dashed lines)



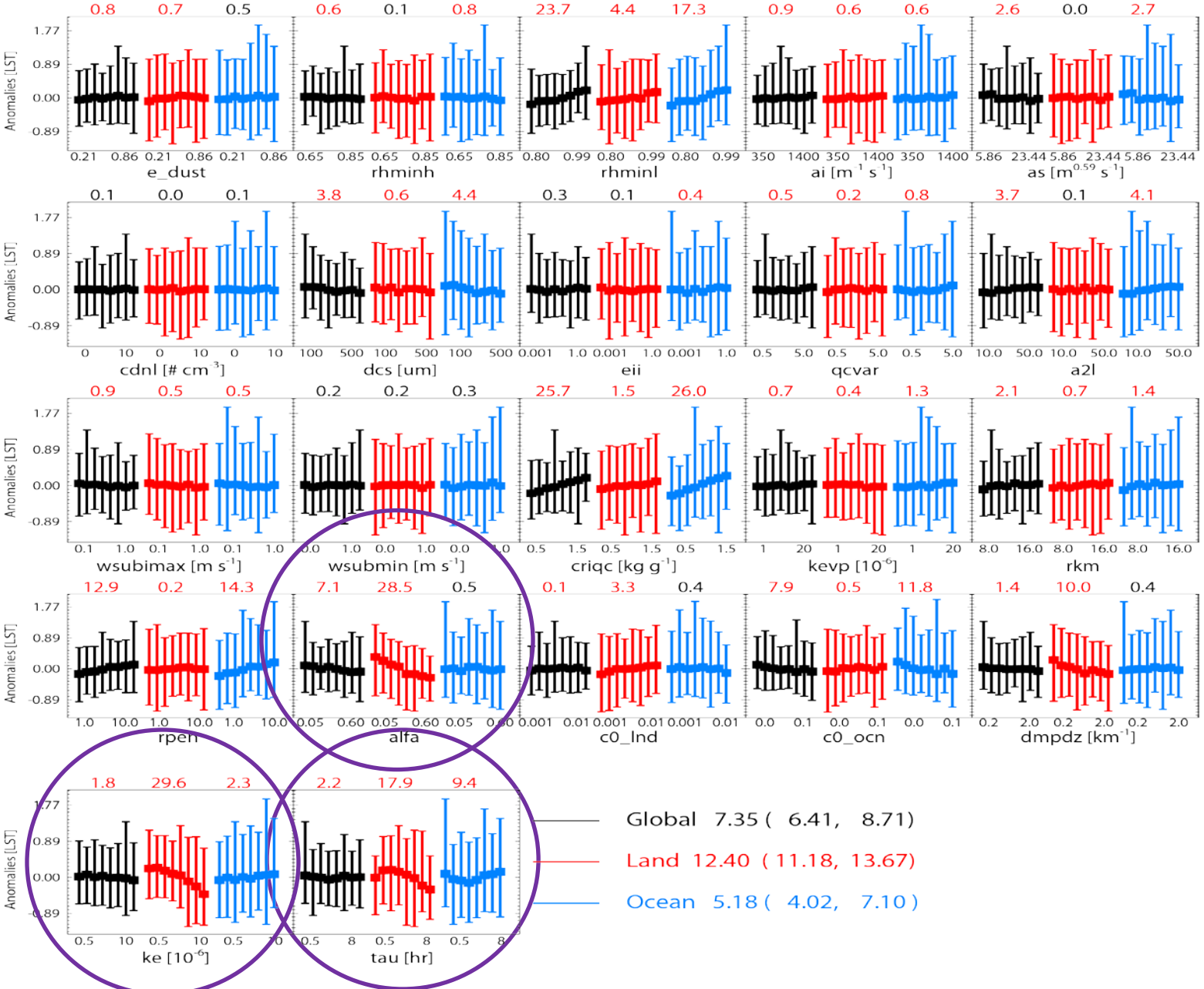
Sensitivity of mean precipitation to C-Ensemble parameters



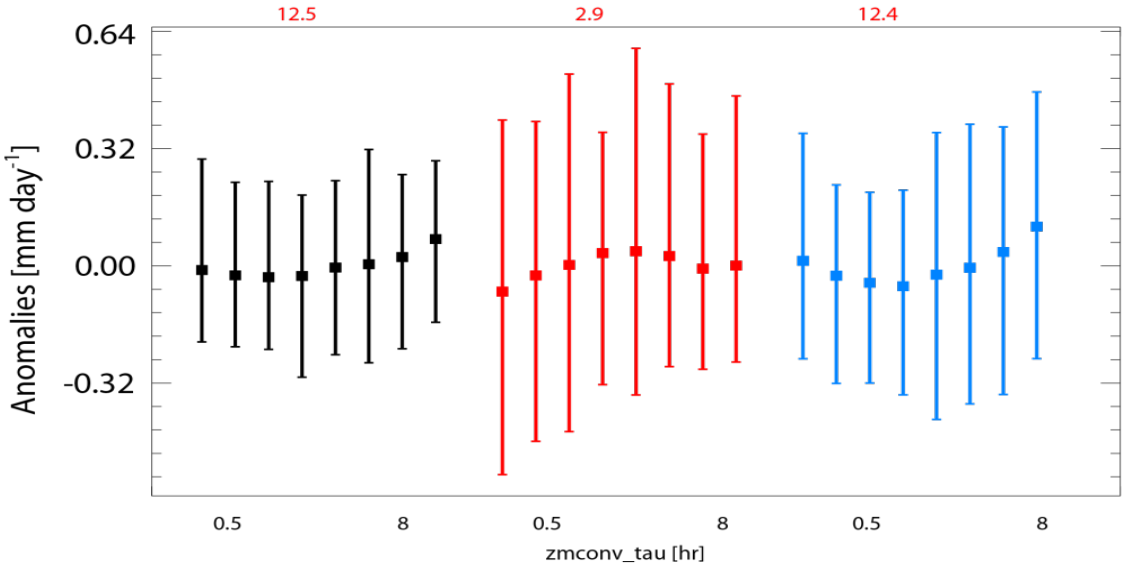
Sensitivity of 95th precipitation to C-Ensemble parameters



Sensitivity of phase of PDC to C-Ensemble parameters



CAPE consumption time scale (tau)

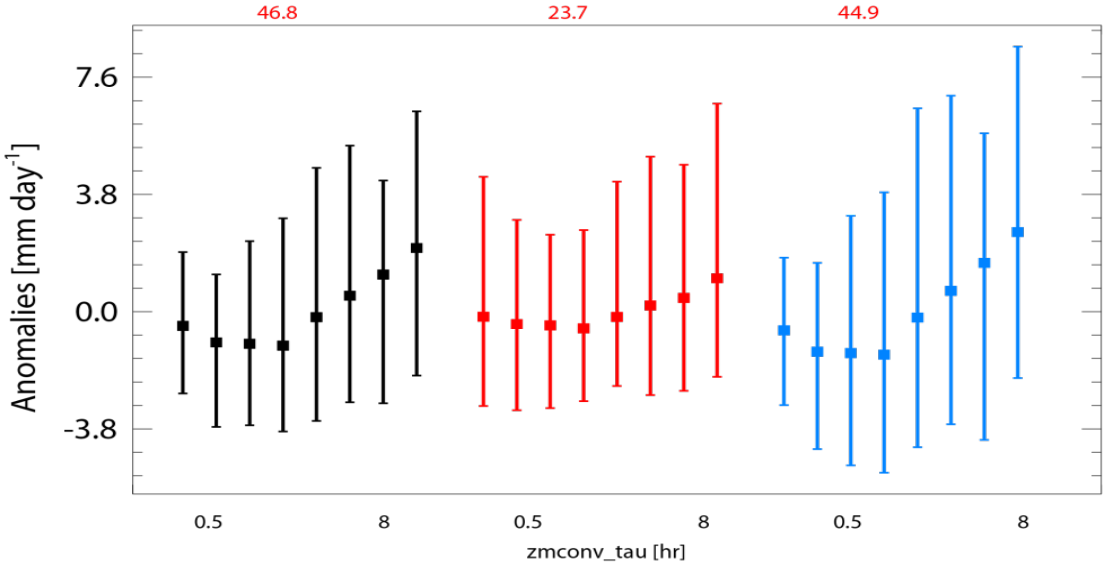


Mean Precip

Global 2.91

Land 1.74

Ocean 3.50



95th Precip

Global 15.58

Land 12.73

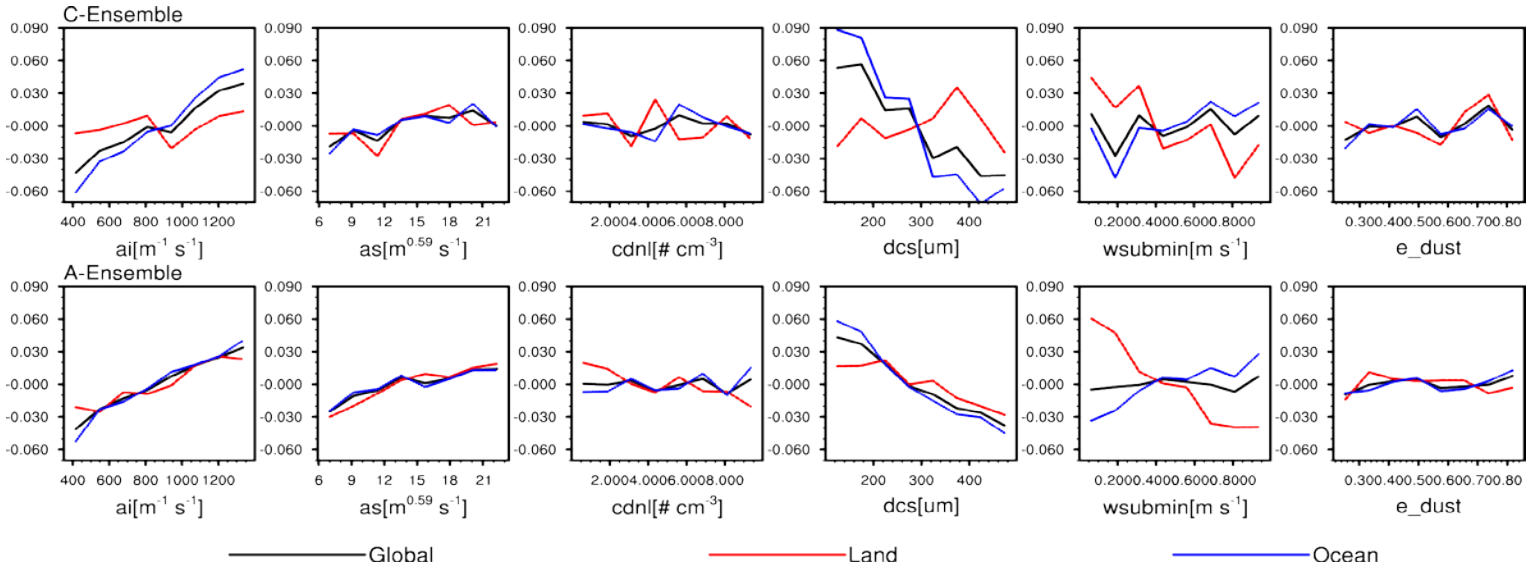
Ocean 17.26

Relative contribution (%) of each parameter to the total variance of global mean precipitation

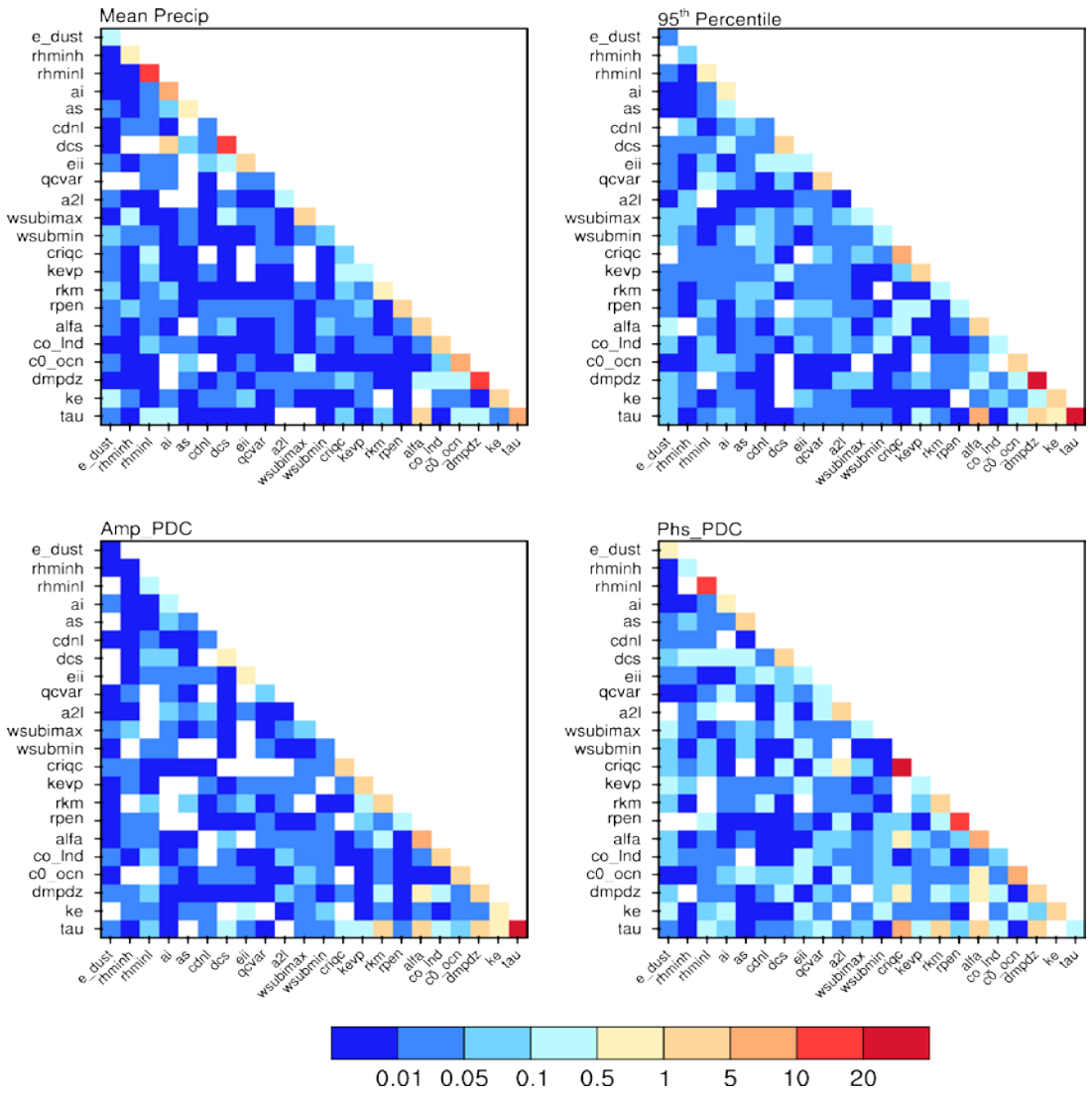
Six common parameters in C- and A-Ensemble

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

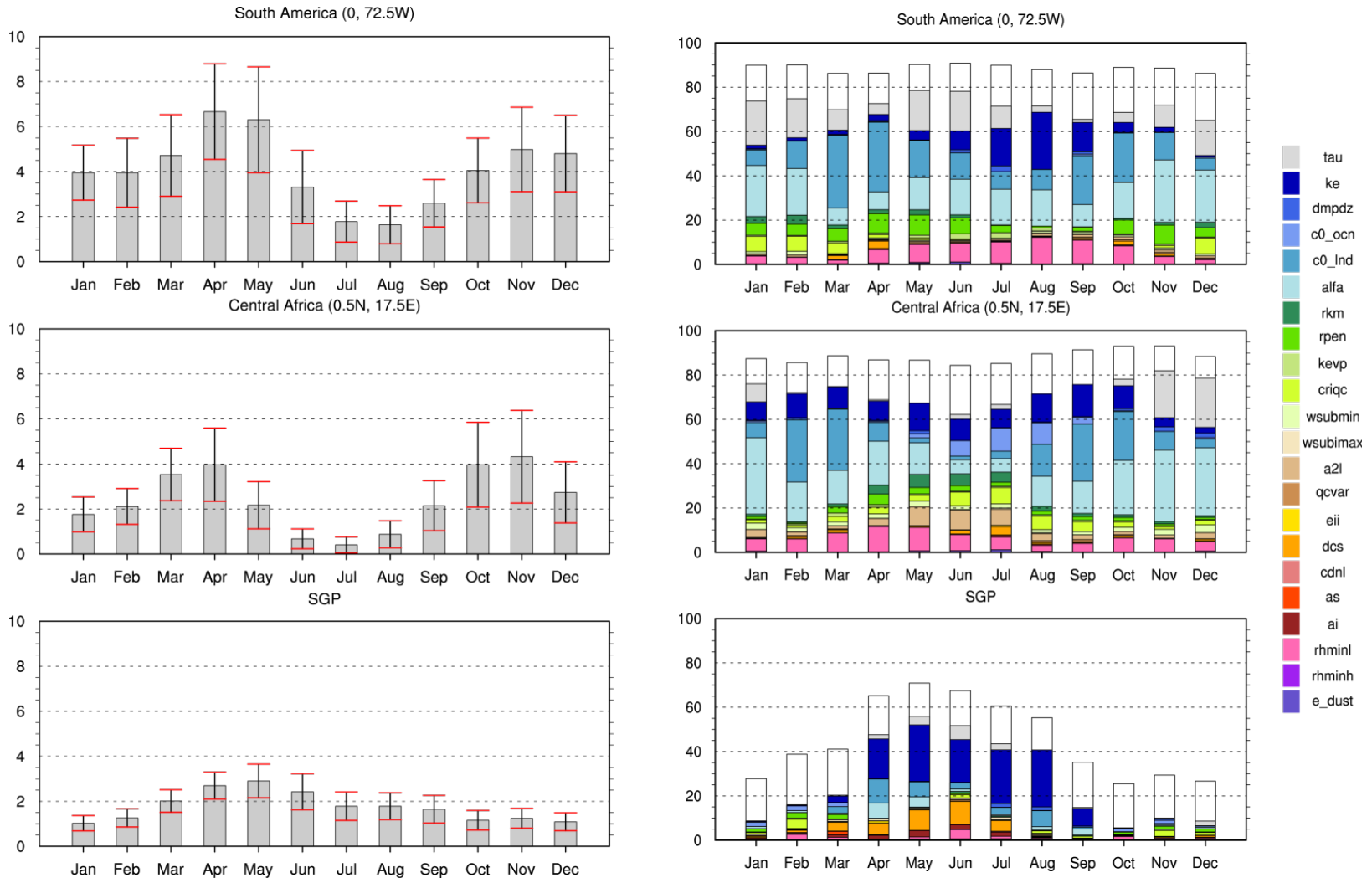
Responses of global mean precipitation to the six common parameters



Relative contributions (%) of individual parameter and their interactions (C-Ensemble)



Seasonal Variability of Sensitivity

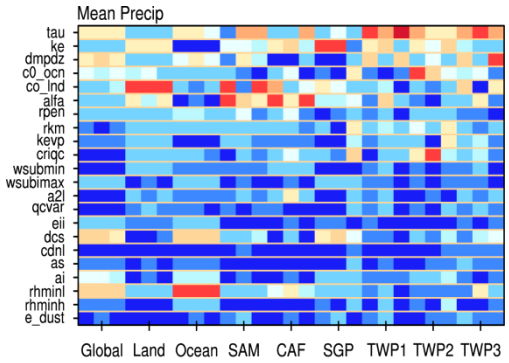


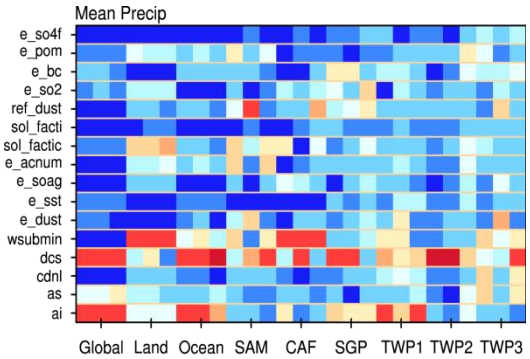
Sensitivity of each parameter at different region/scale/season

C-Ensemble

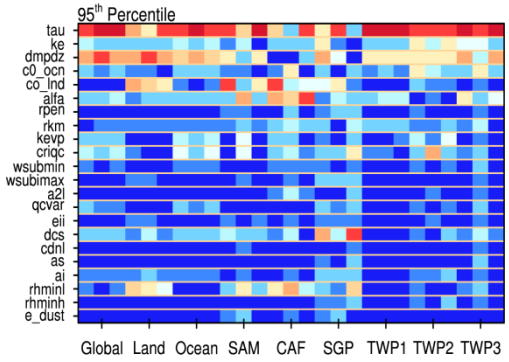
A-ensemble

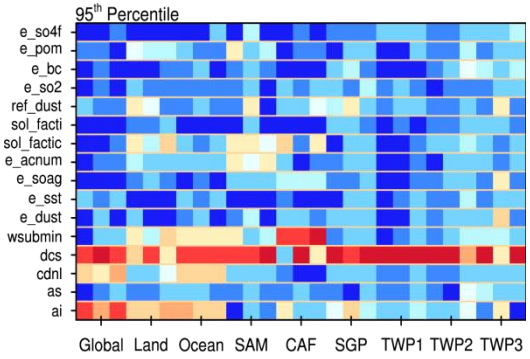
Mean precipitation



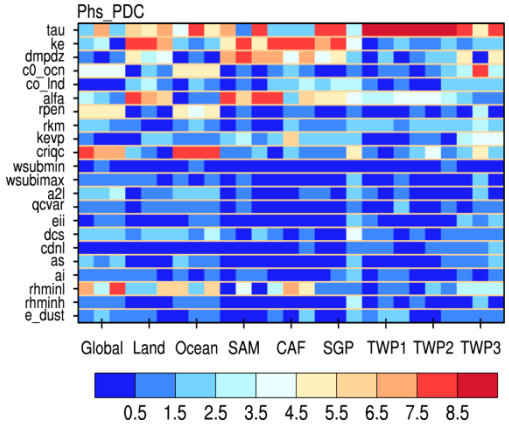


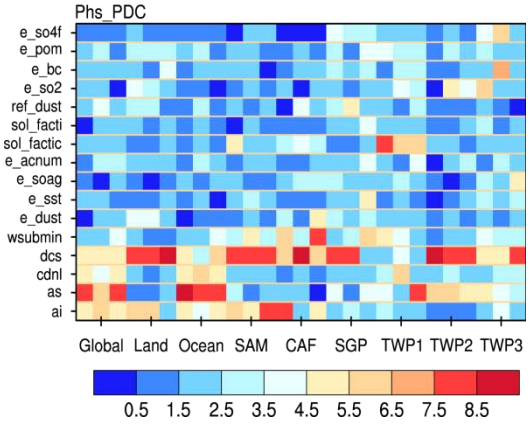
95th precipitation





Phase of PDC





Summary

- We investigated the sensitivity of precipitation characteristics to dozens of uncertain parameters mainly related to cloud and aerosol processes in the CAM5.
- Most sensitive parameters to

  Mean Precip: *c0_lnd, rhminl, dcs, tau, dmpdz,* and *ke*

  Extreme Precip: *tau (~50% total variance), c0_lnd, dmpdz*

  Phase of Diurnal Cycle: *ke, alfa* and *tau*

  *Precipitation not monotonically respond to *tau (*a turning point ~ 1.75 hours)
- The influence of individual parameters does not depend on the sampling approach applied or concomitant parameters selected.
- The total variance for precipitation is primarily contributed by the individual parameters (75-90% in total), and their interactions contribute to the rest of total variance explained.

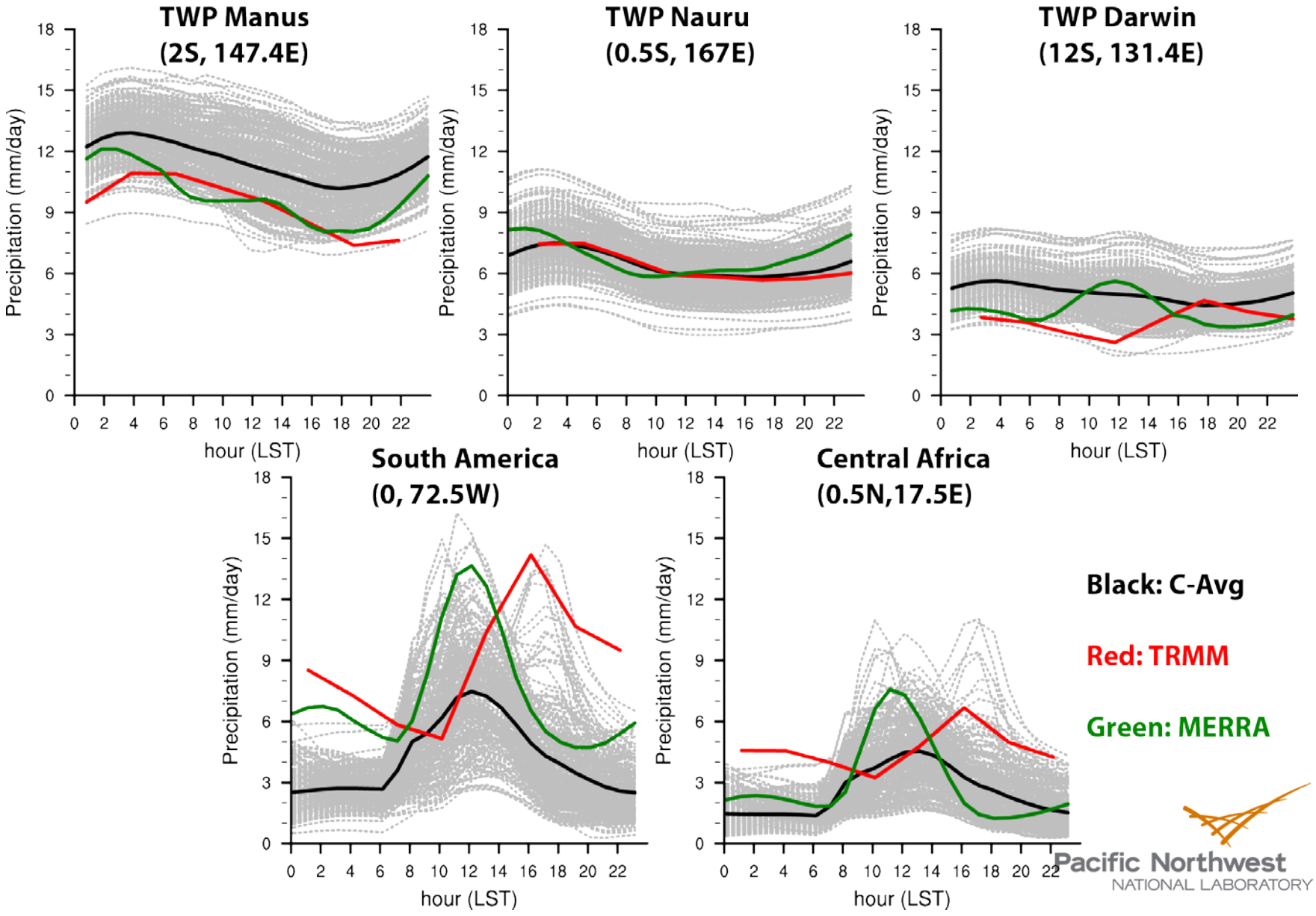
Uncertainty Quantification (UQ) Activities at PNNL
(Atmosphere)

- Quantifying parameter uncertainty and sensitivity:
  - Zhao et al., 2013 (CAM5, radiation flux and cloud forcing);
  - Qian et al., 2014 (CAM5, precipitation including extremes and diurnal cycle)
  - Guo, Wang, Qian et al., 2014 (CAM5 CLUBB)
  - Wan et al., 2014 (Long-term run vs. short-term ensembles)

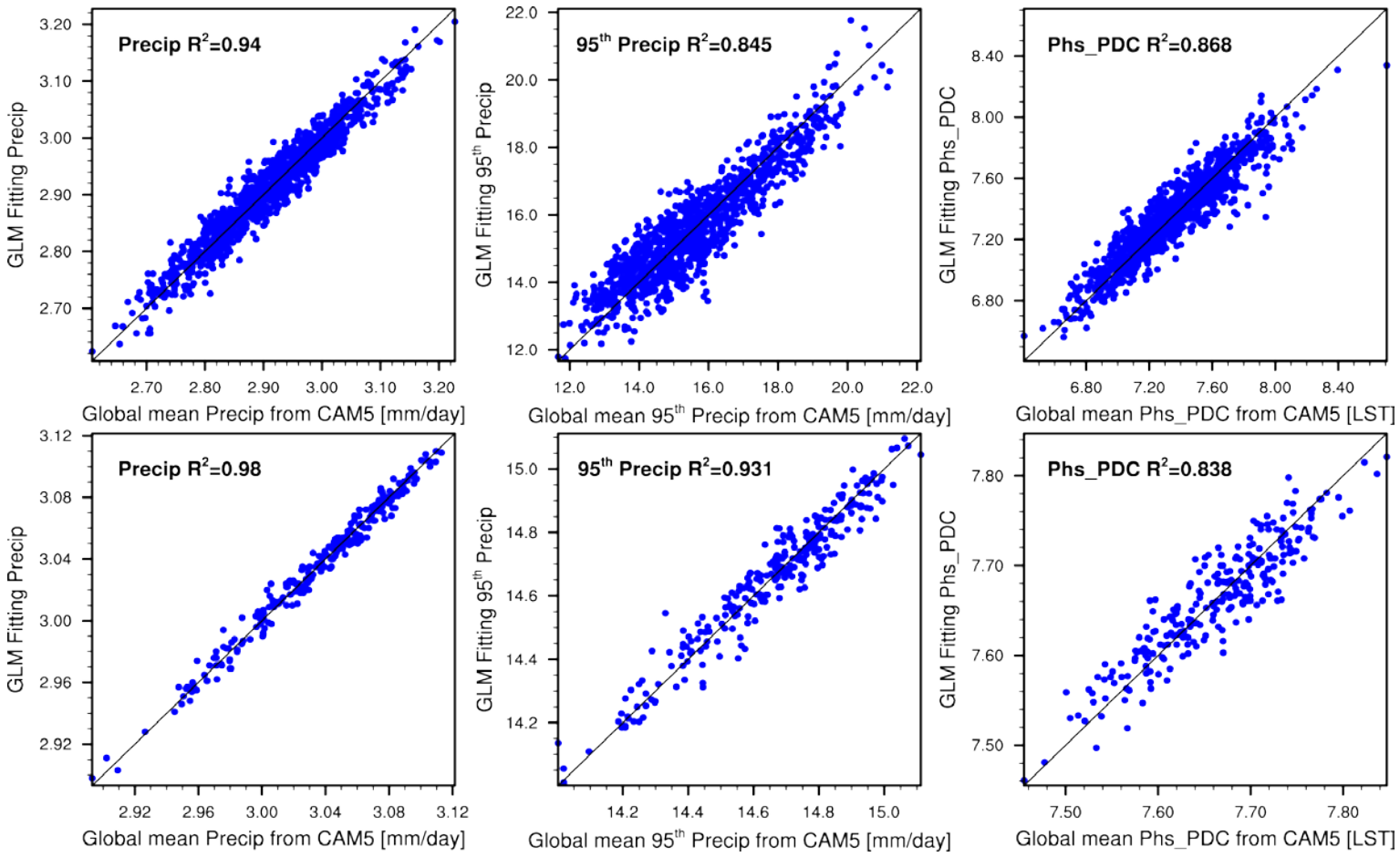
- Model Calibration and Optimization:
  - Yang, Qian et al., ACP, 2012; Yan, Qian et al., CR, 2013. (WRF, KF deep convection);
  - Yang, Qian et al., JGR, 2013 (CAM5, stratiform-convection precipitation partition)
  - Manish et al. (SOA), 2014

- Determining source-receptor relationship
  - Ma et al., ERL, 2013 (CAM5, black carbon)

Diurnal cycle of precipitation at five tropical regions from observation and a subset of C-Ensemble CAM5 simulations (gray dashed lines)



GLM-fitted global precipitation versus the CAM5 simulations



C-Ensemble

A-Ensemble

Mean

95th

Phase

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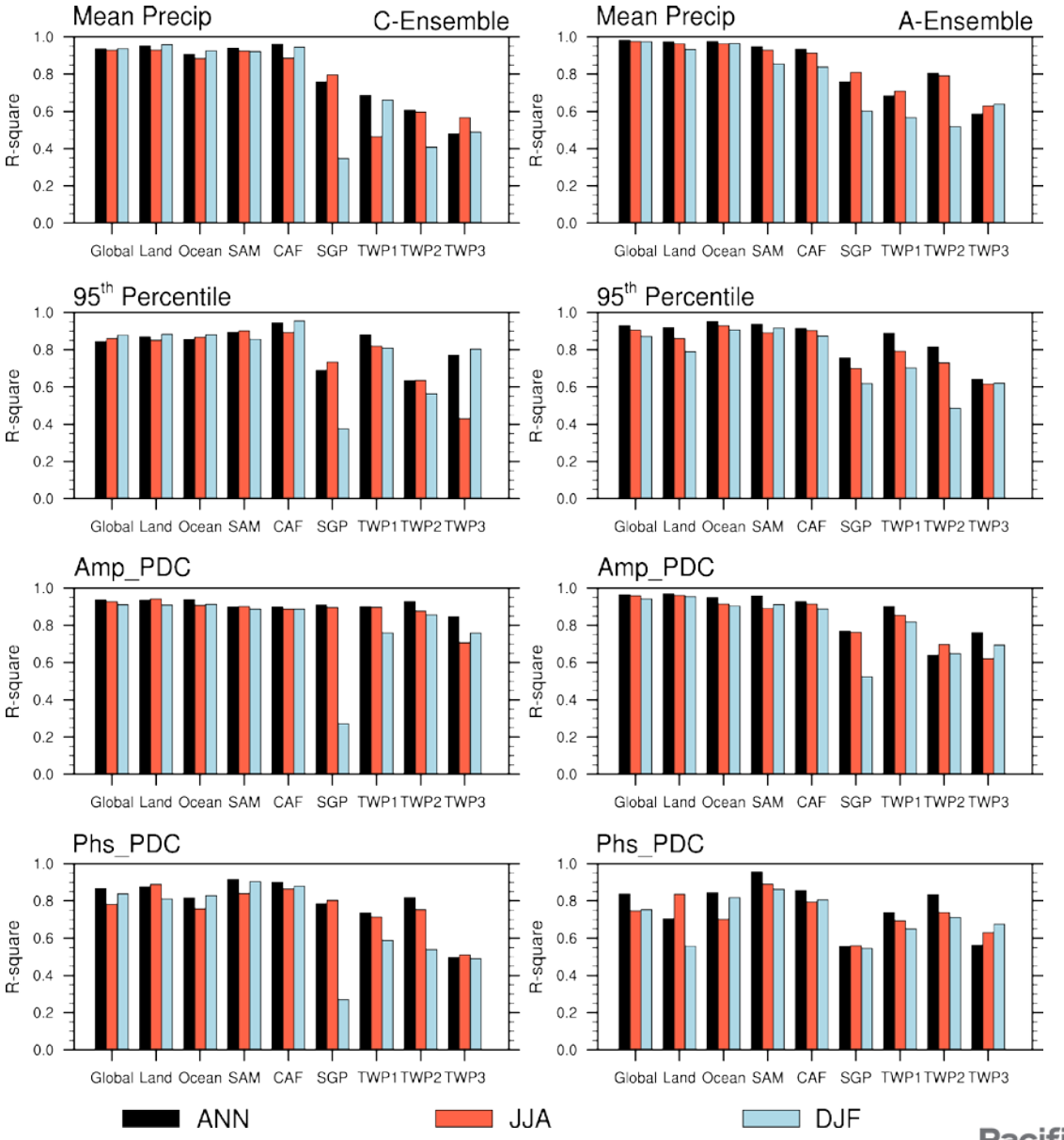
R-square



1100 C-Ensemble **256 A-ensemble**

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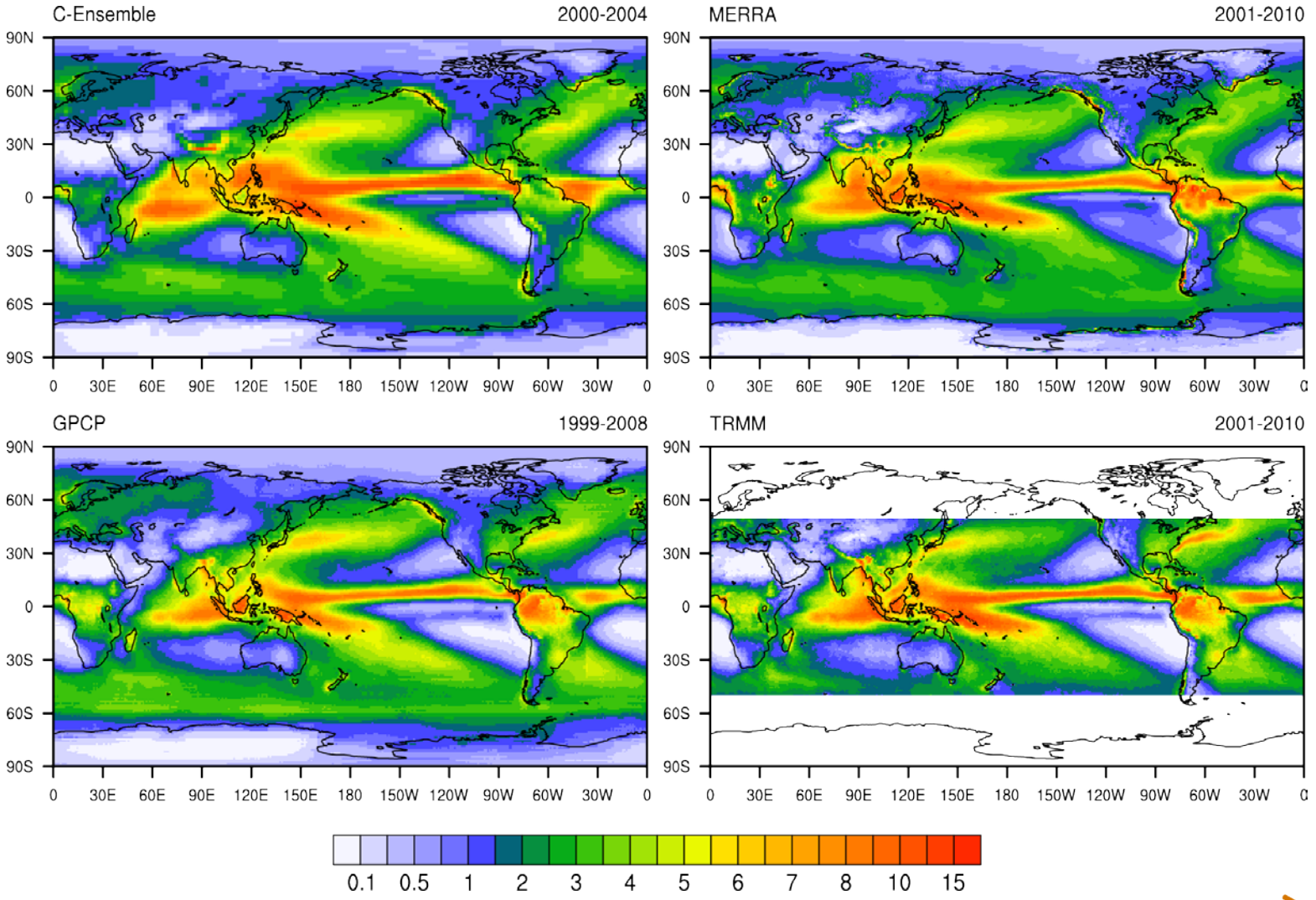
Annual mean Precipitation



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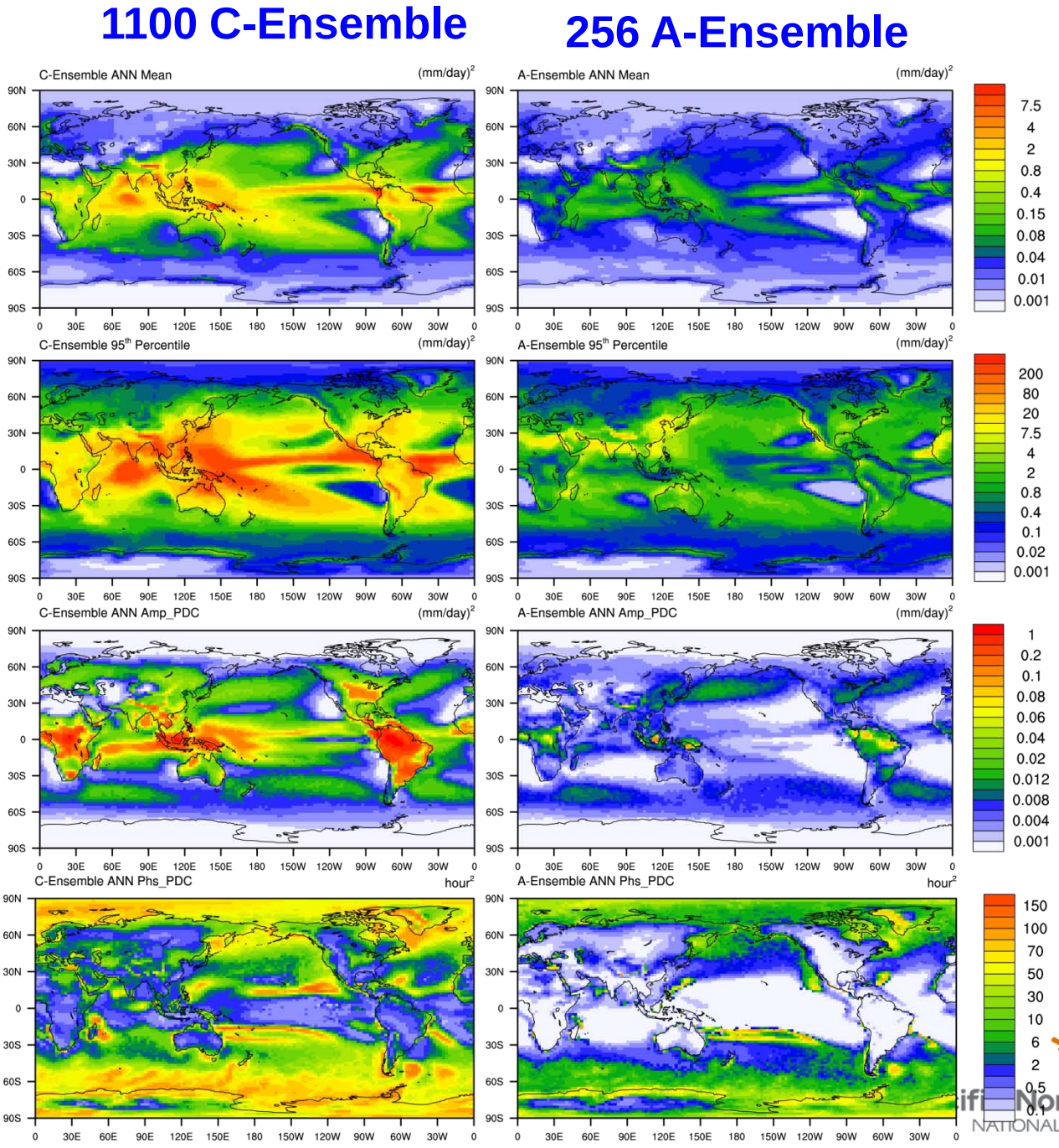
Variance



Mean Precip

95th percentile

Amplitude of DC

Phase of DC

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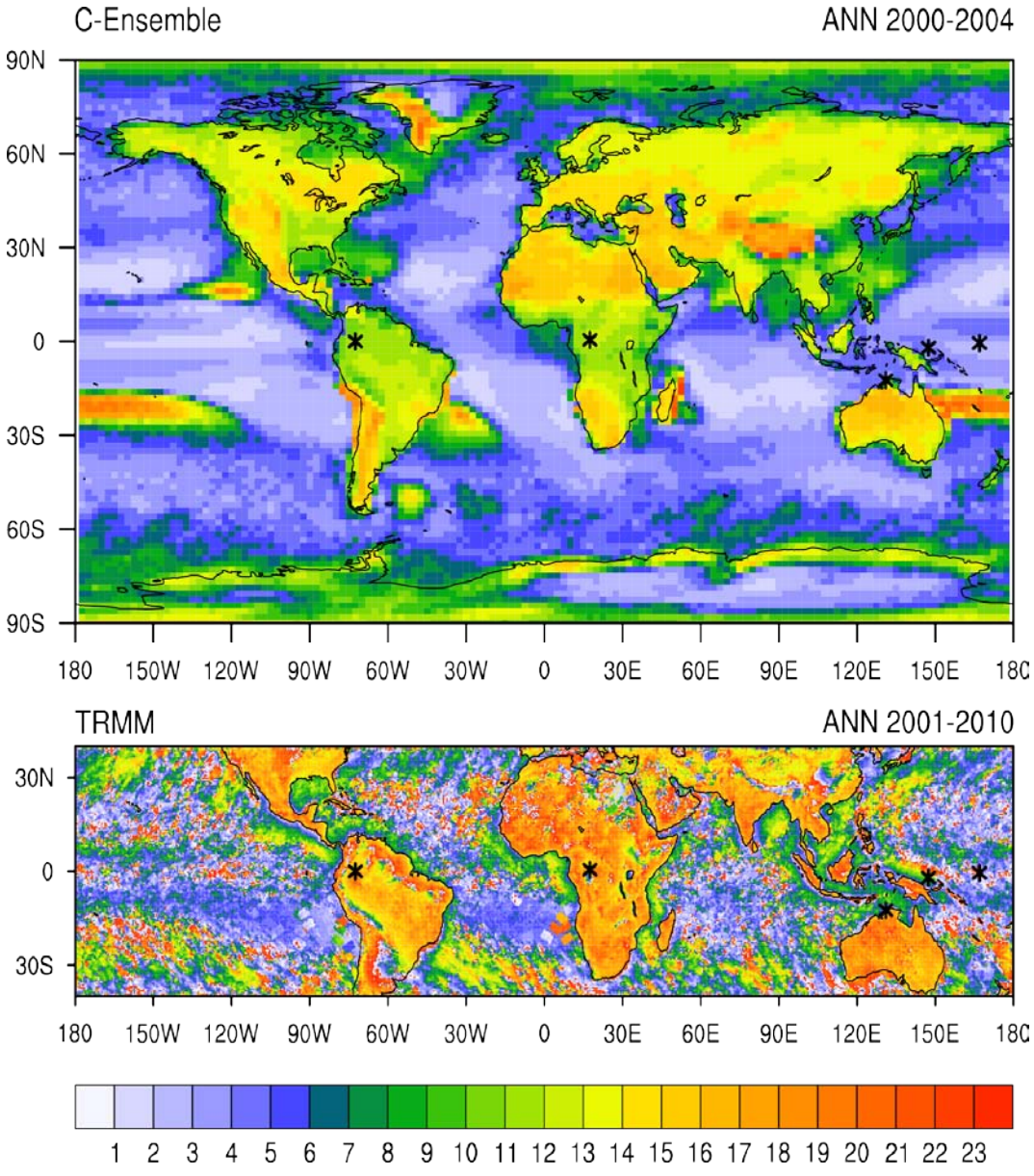
Phase of Diurnal Cycle of TRMM and 1100 C-Ensemble Average



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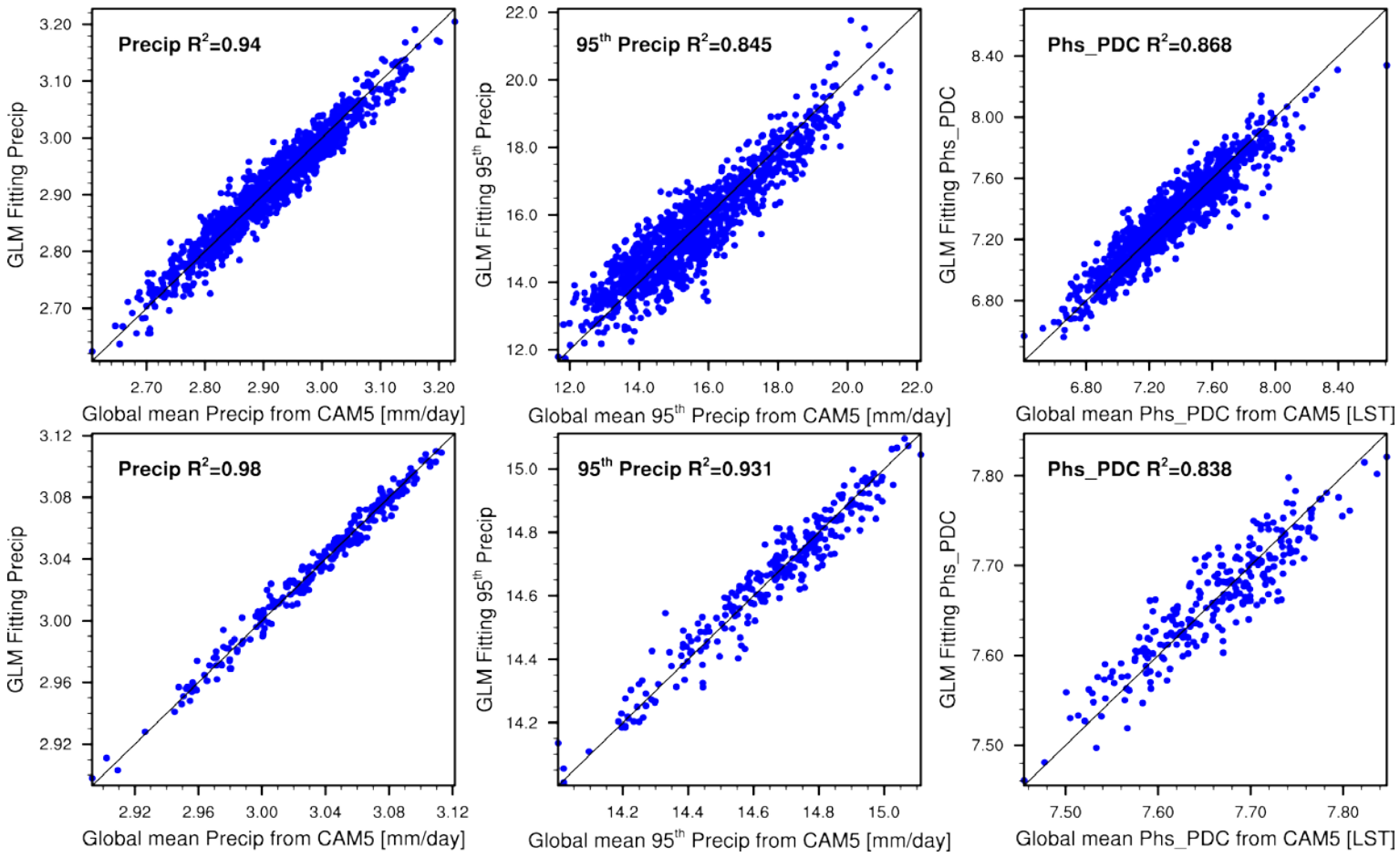
GLM-fitted global precipitation versus the CAM5 simulations



C-Ensemble

A-Ensemble

Mean

95th

Phase

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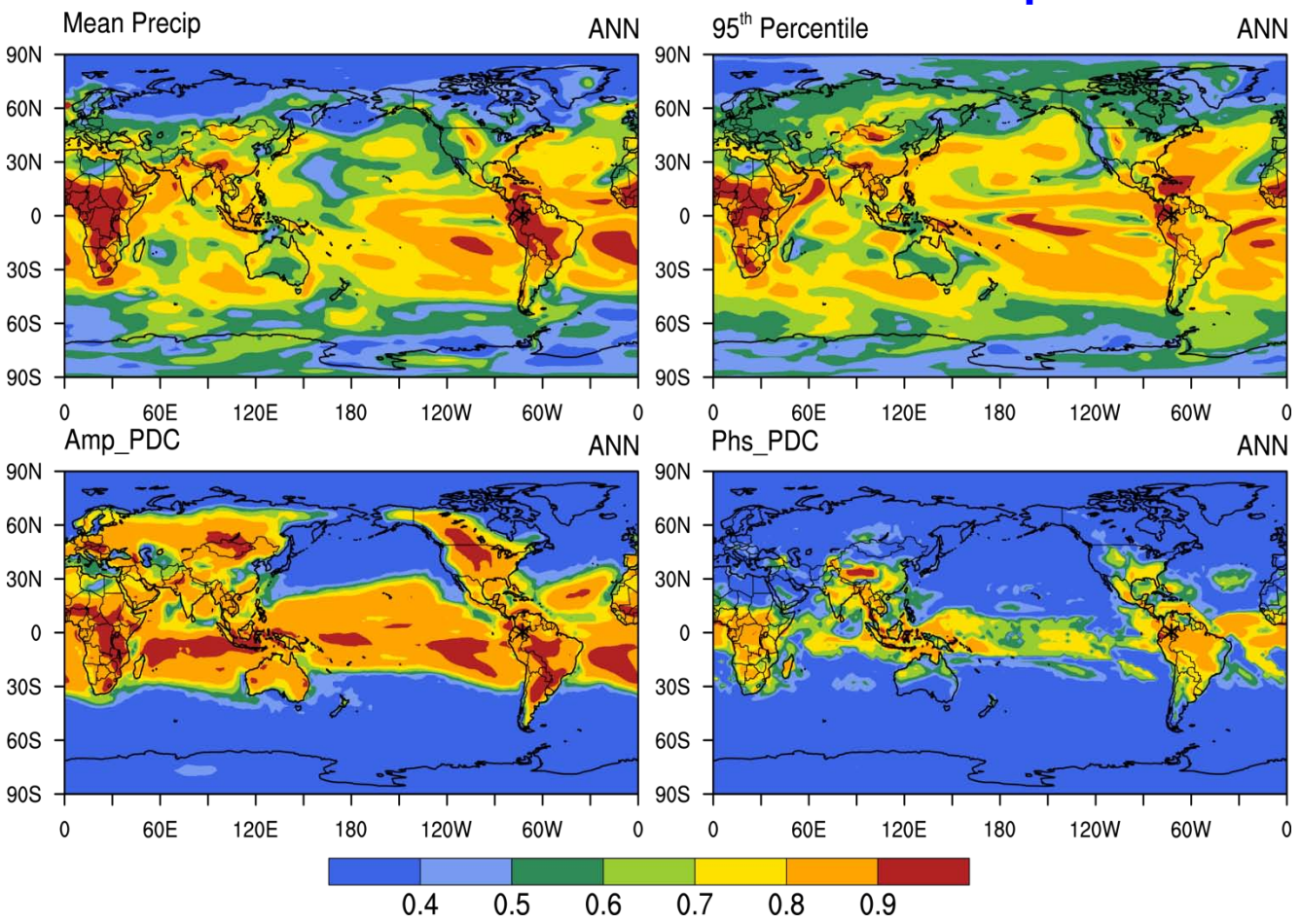
R-square in C-Ensemble
(fraction of variance explained/captured by GLM)

Mean Precip

95th Precip



Amplitude of PDC

Phase of PDC

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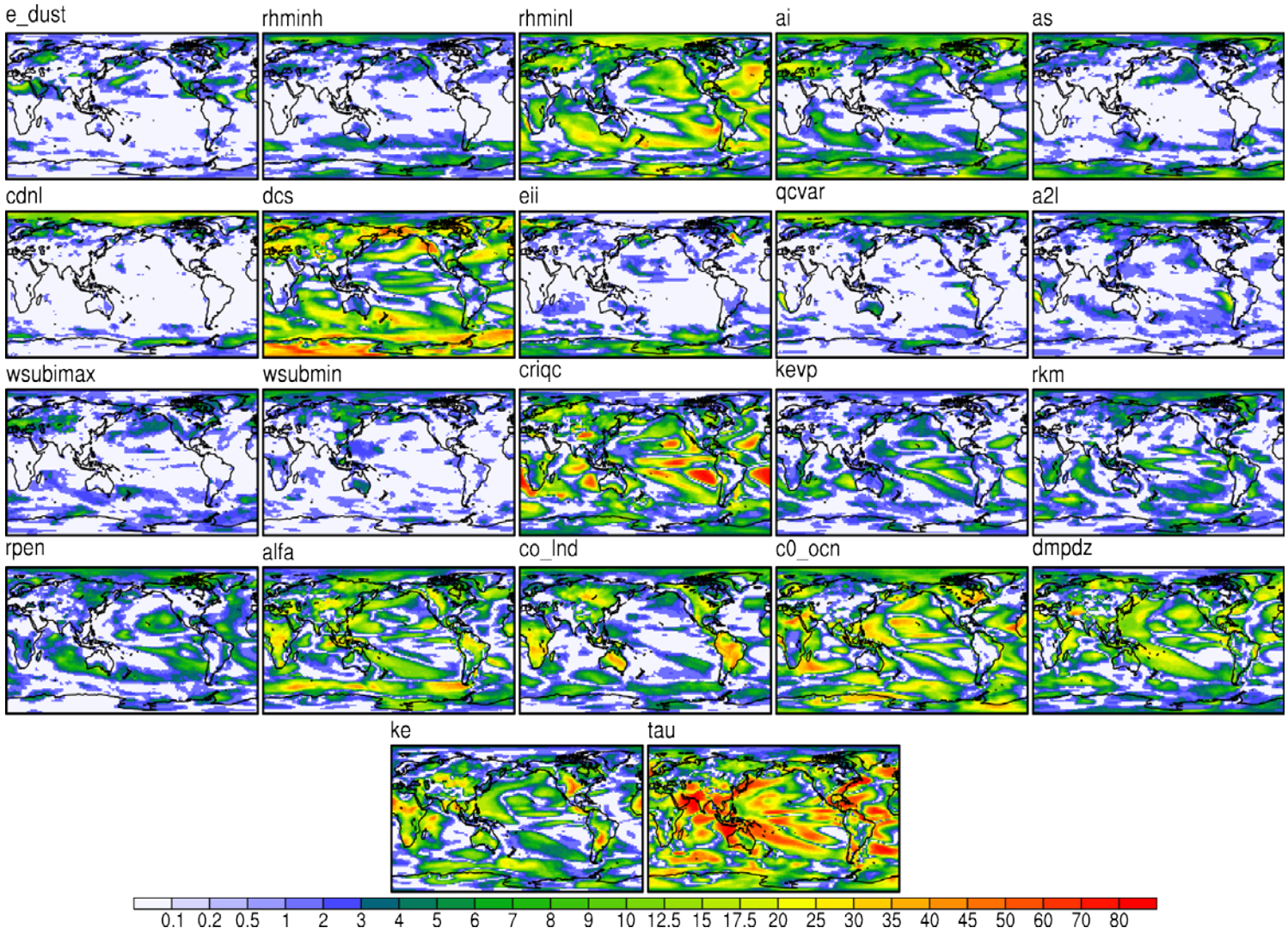

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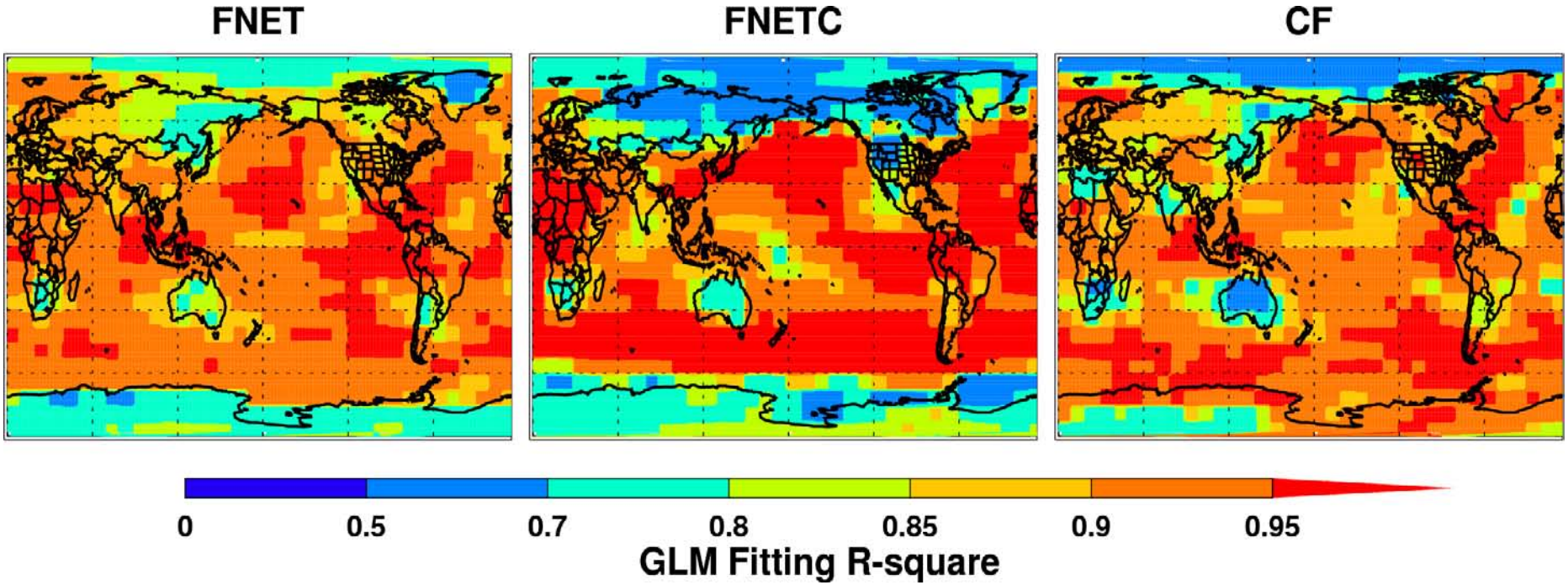
R-square of TOA radiation flux and cloud forcing (256 PNNL runs)



R-square: Fraction of variance explained/captured by GLM

FNET: Net radiation fluxes (SW+LW) at the top of Atmosphere (TOA)
FNETC: Clear-sky FNET
CF: Net (SW+LW) cloud forcing at TOA

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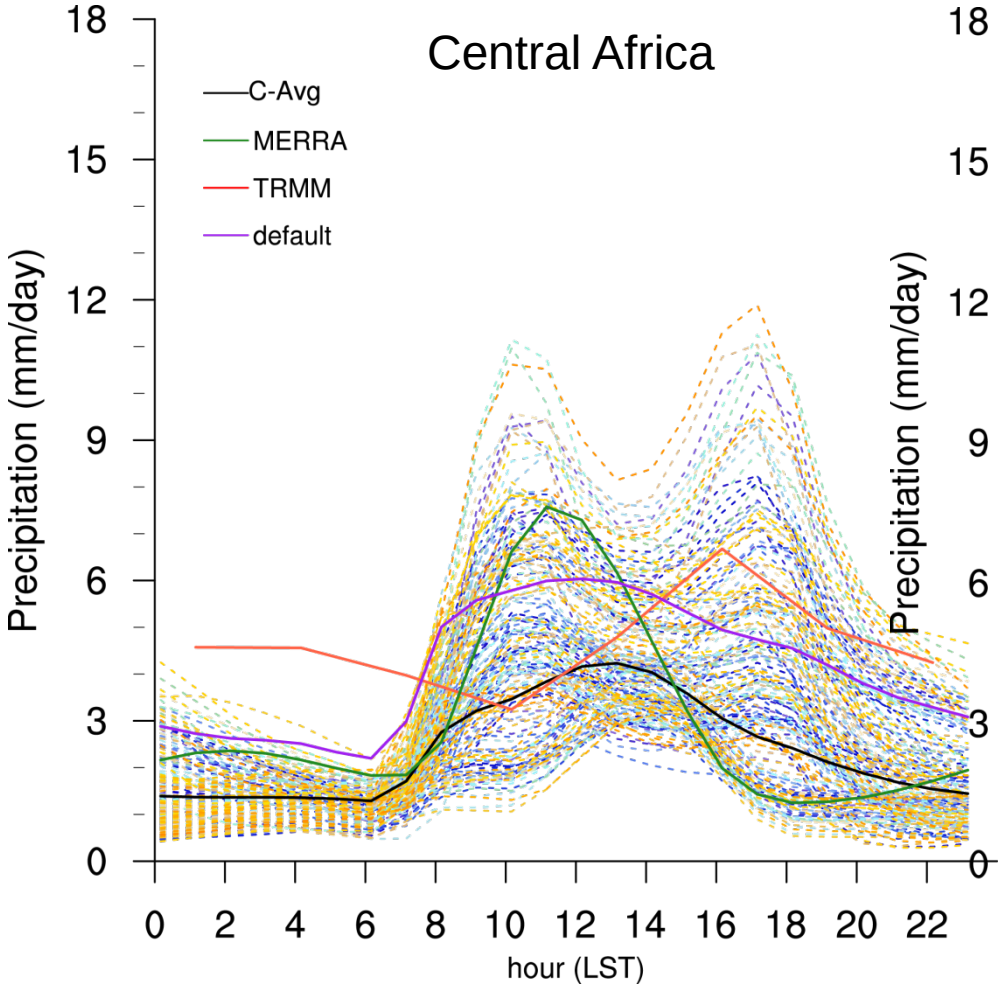

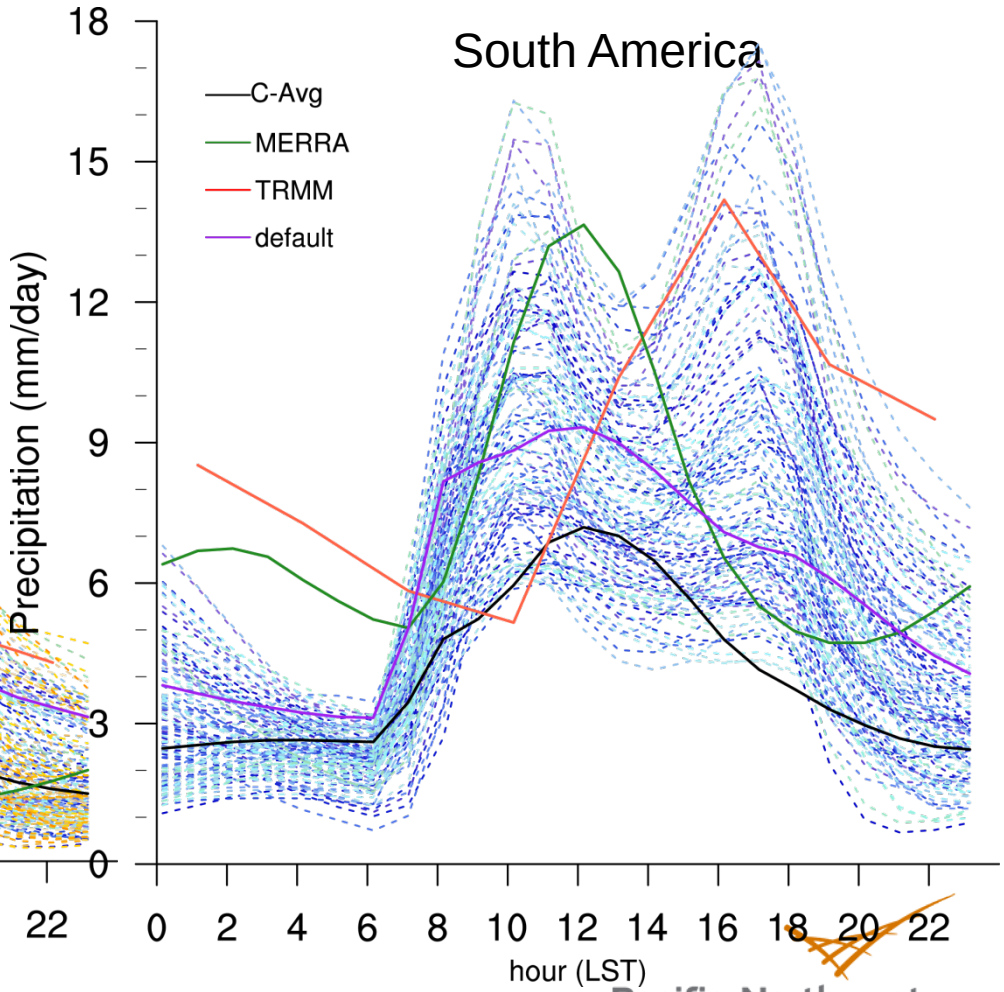

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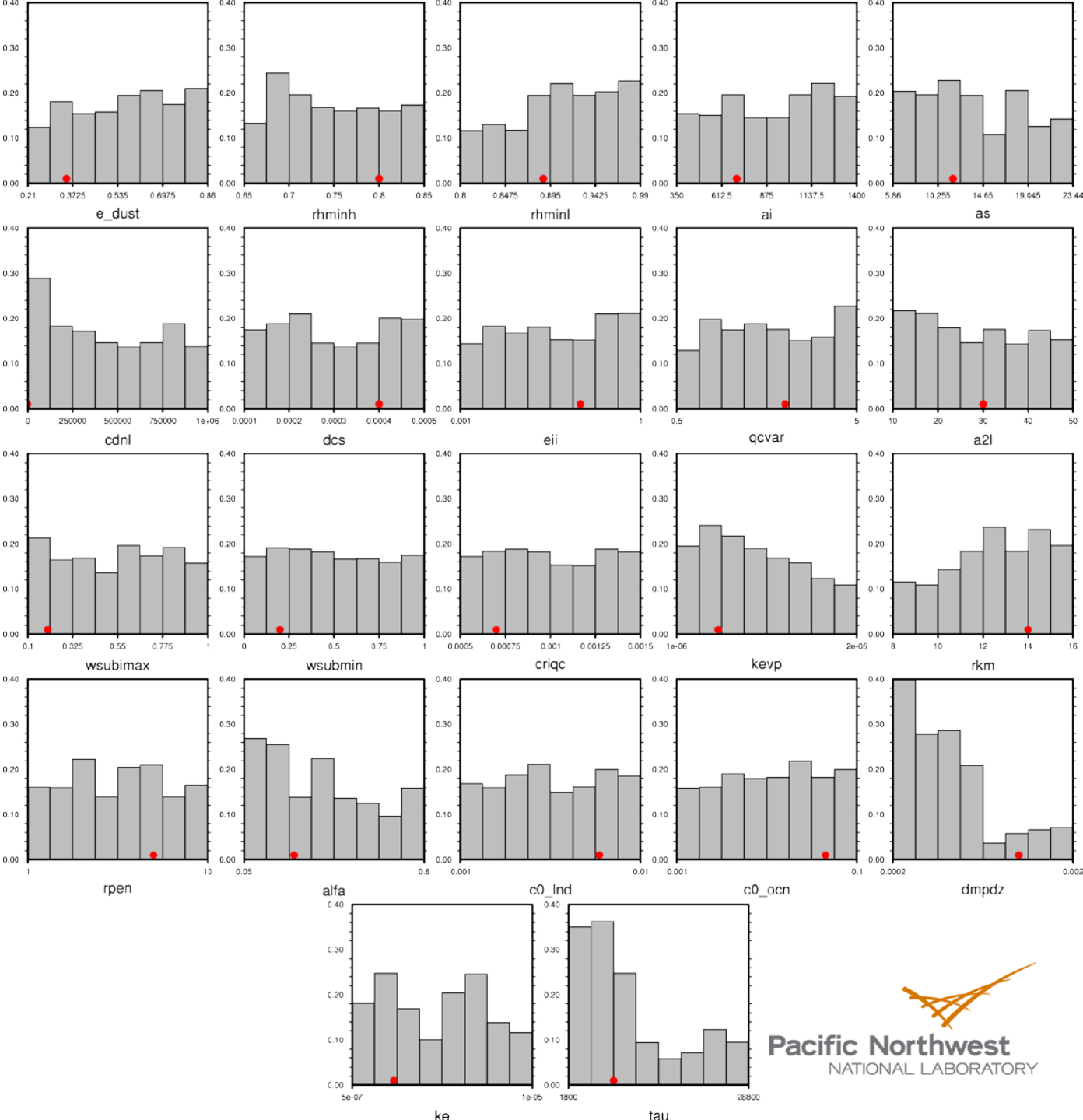
Frequency of two-peak simulations (193)
as functions of parameters
in **Central Africa**

Red dot indicates the default value



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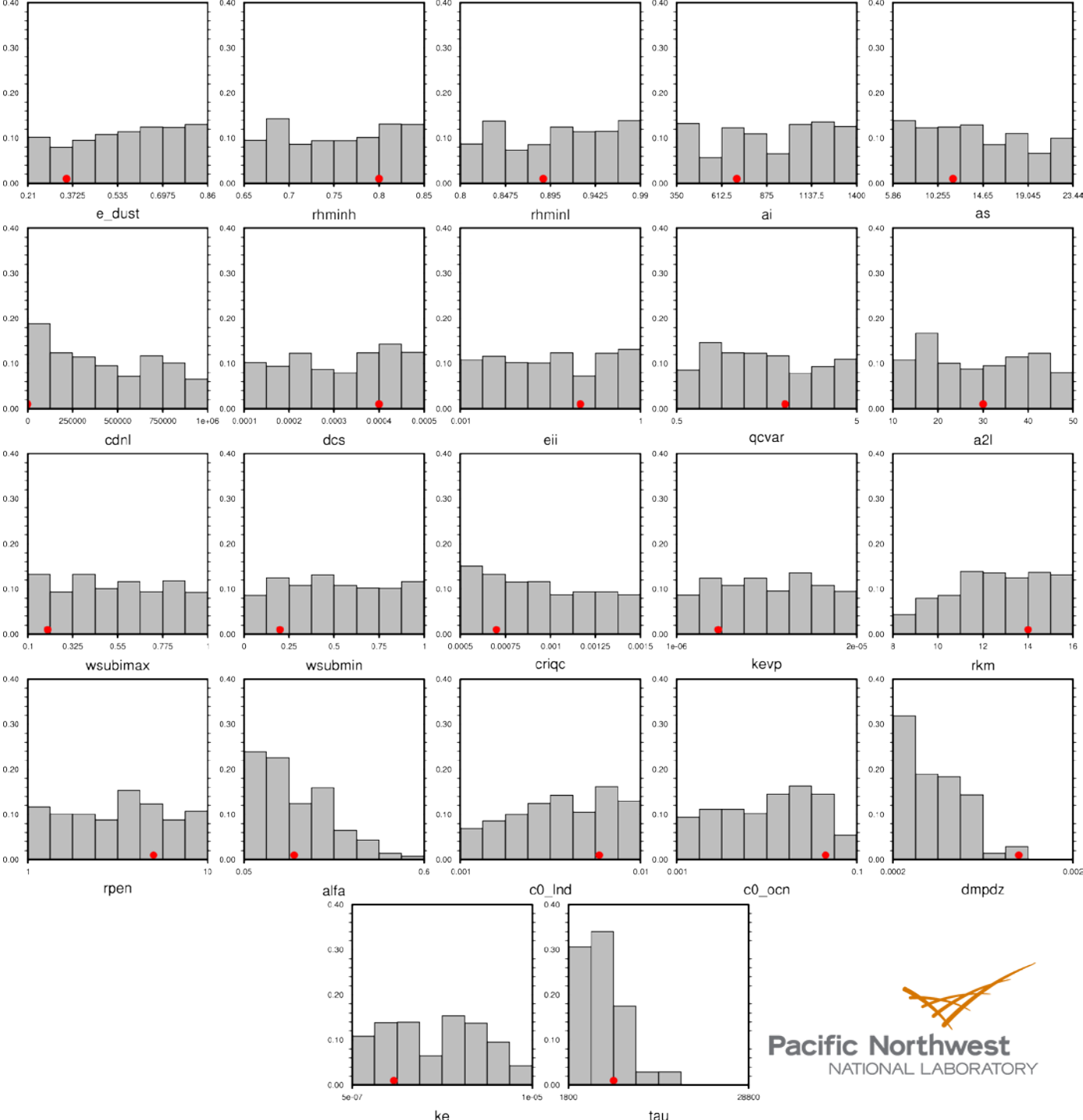
Frequency of two-peak simulations (121)
as functions of parameters
in **South America**

Red dot indicates the default value



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