Constraining Estimates of Aerosol Effects on Clouds

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Published estimates of aerosol indirect forcing

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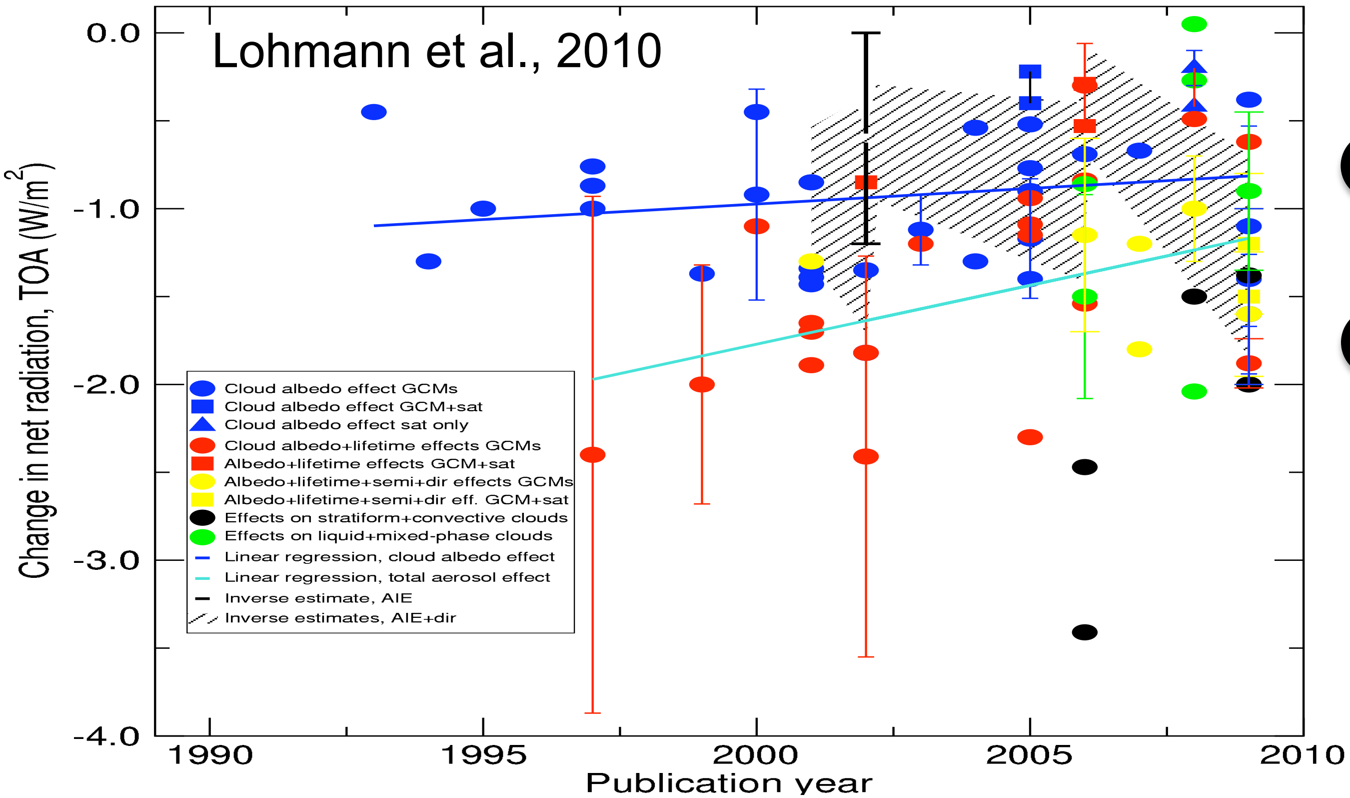
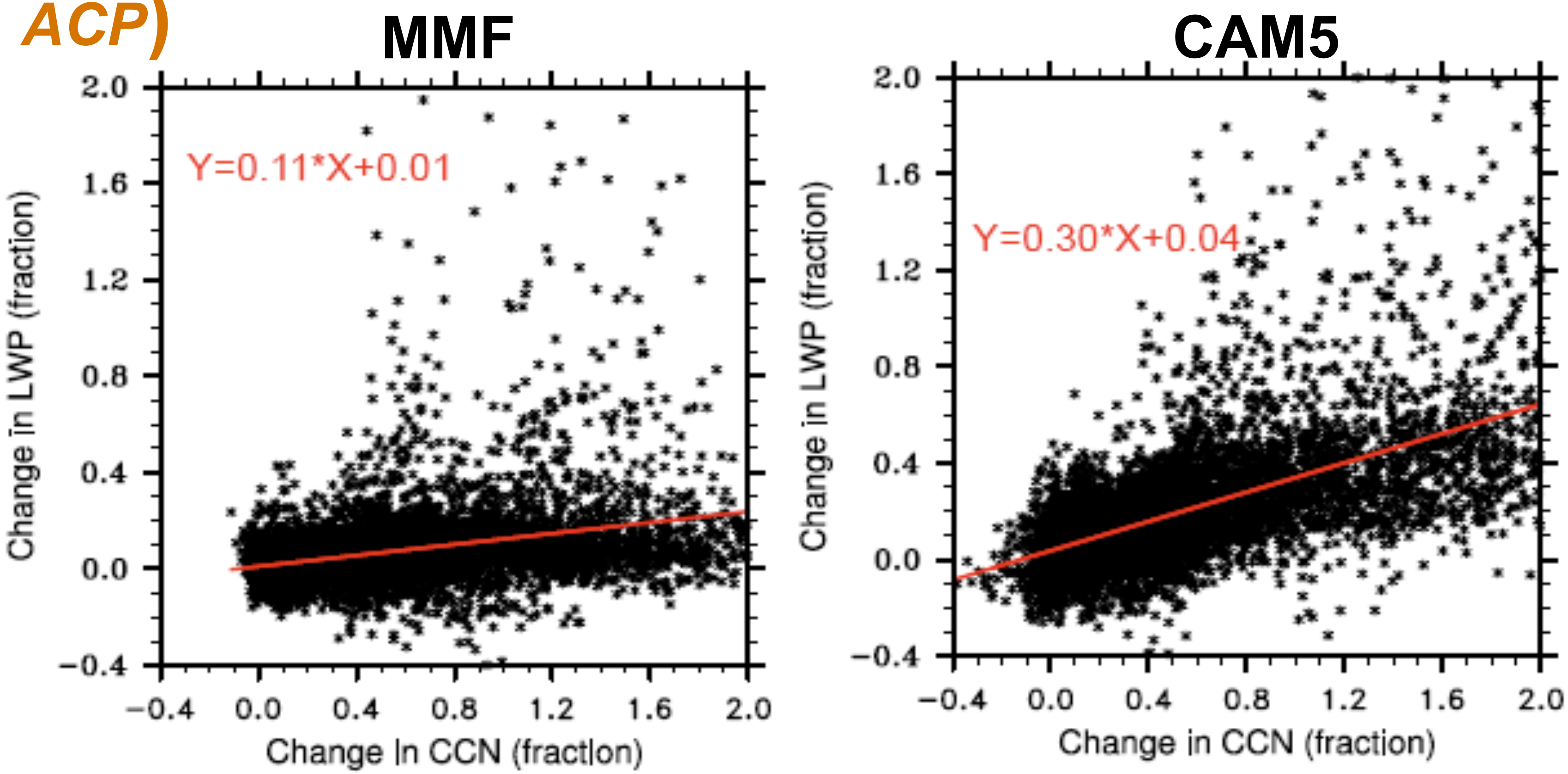


- MMF (-0.77 W m^{-2})
- CAM5 (-1.79 W m^{-2})

- Increases in liquid water path (LWP). 3.9% in the MMF vs. 15.6% in CAM5

Relative changes in CCN vs. relative changes in LWP: (PD-PI)/PI (Wang et al., 2011, *ACP*)

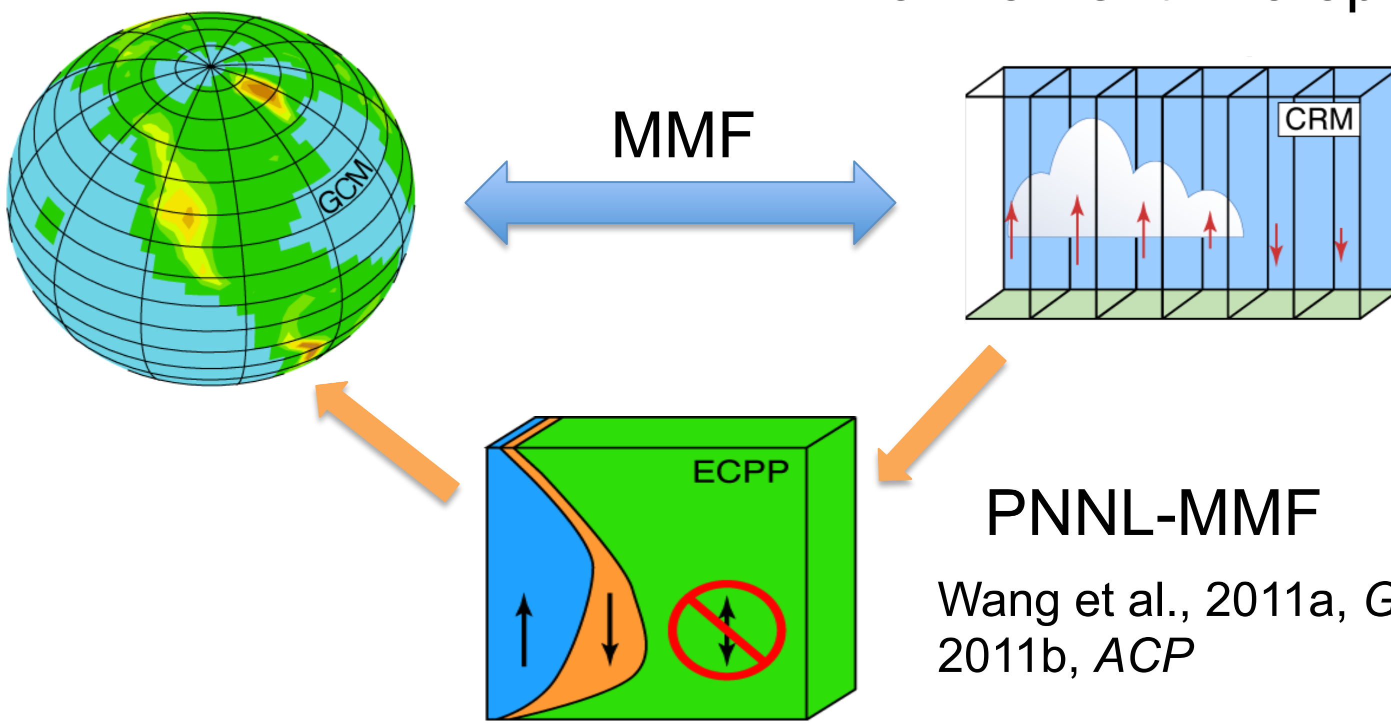


- The response in LWP to a given CCN perturbation in CAM5 is about 3 times that in the MMF.

The Multi-scale Modeling Framework (MMF) approach and the PNNL-MMF (an aerosol-MMF)

CAM5 with modal aerosols

Two-moment microphysics



PNNL-MMF

Wang et al., 2011a, *GMD*; 2011b, *ACP*

CRM cloud/precipitation statistics used for cloud processing of aerosols

Probability of Precipitation (POP) for warm clouds

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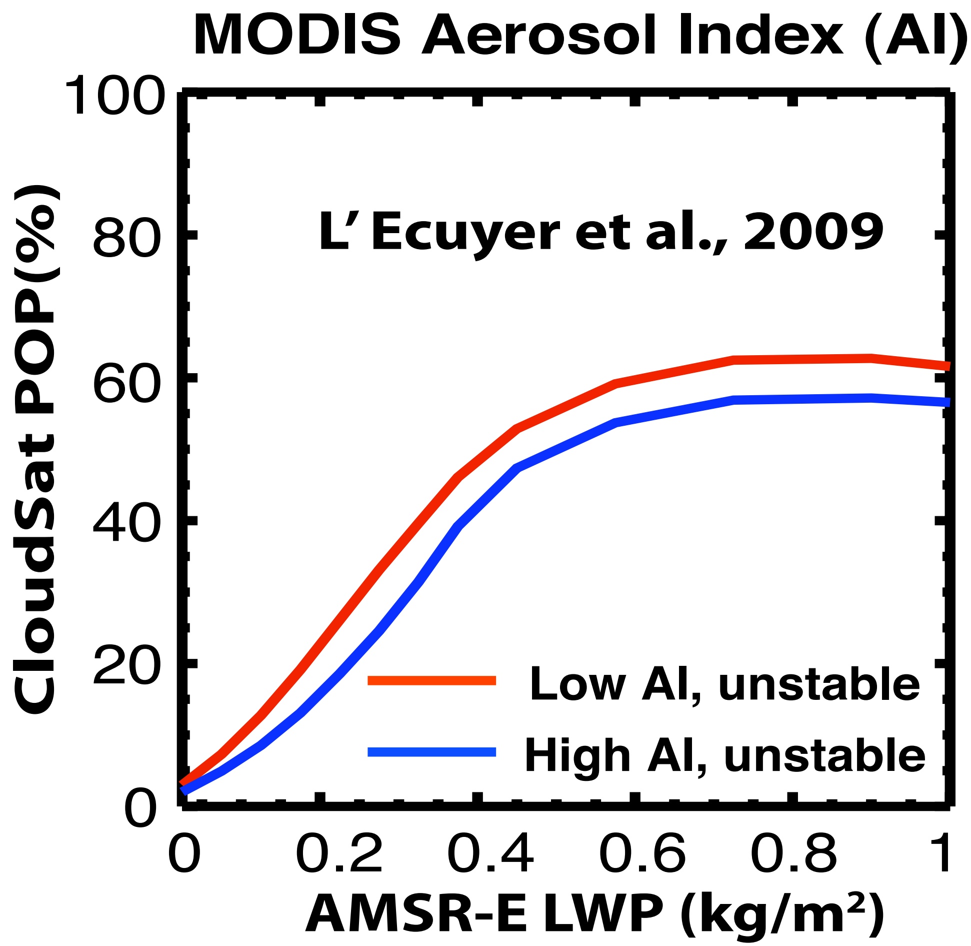
At a given LWP:

$POP = N_{rain}/N_c$

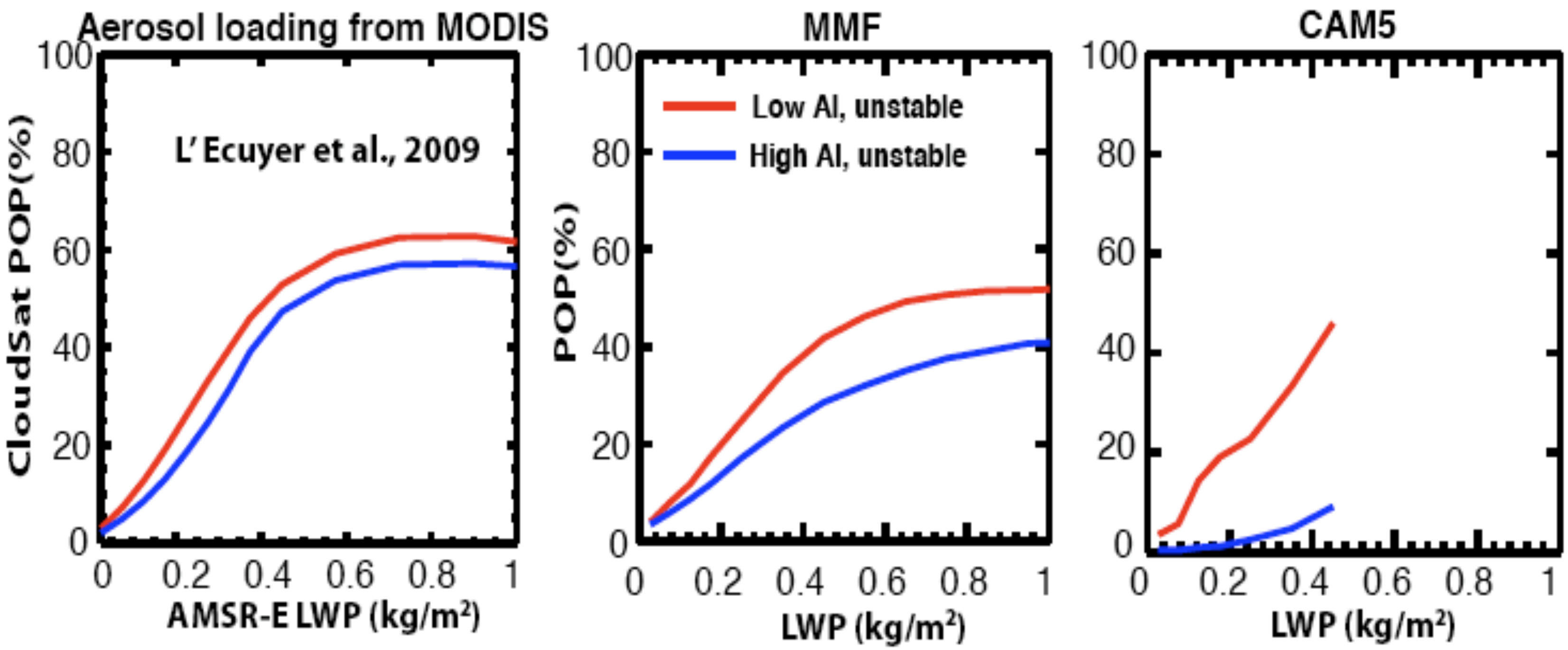
N_c: the number of cloud events.

N_{rain}: the number of precipitating events.

- Satellite observations: more aerosol → smaller POP

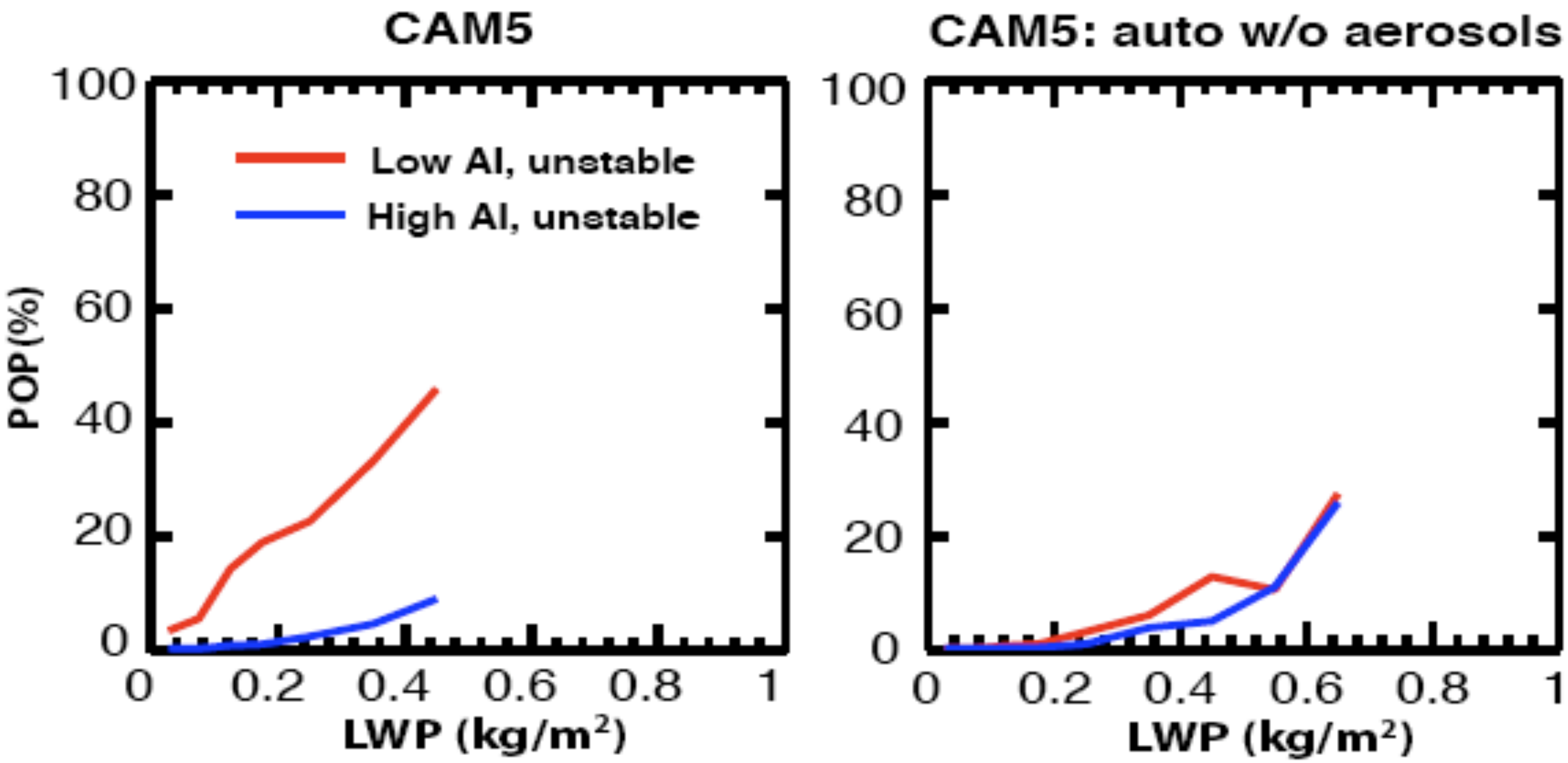


Probability of precipitation (POP) for warm clouds



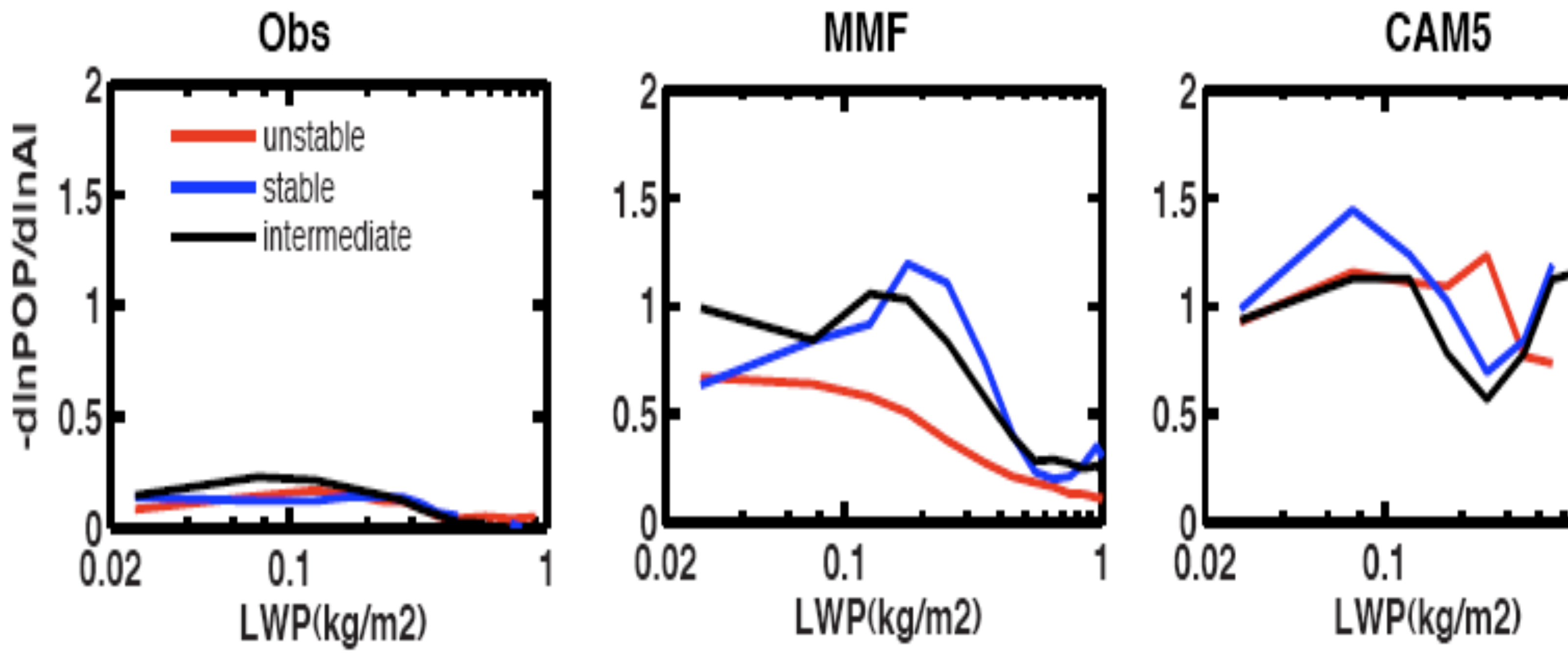
- The POP dependence on aerosol loading in MMF is weaker and agrees better with satellite observations

POP in CAM5: non-microphysical factors



- Non-microphysical effects (e.g., wet scavenging) play a minor role on the POP dependence on aerosol loading in CAM5.

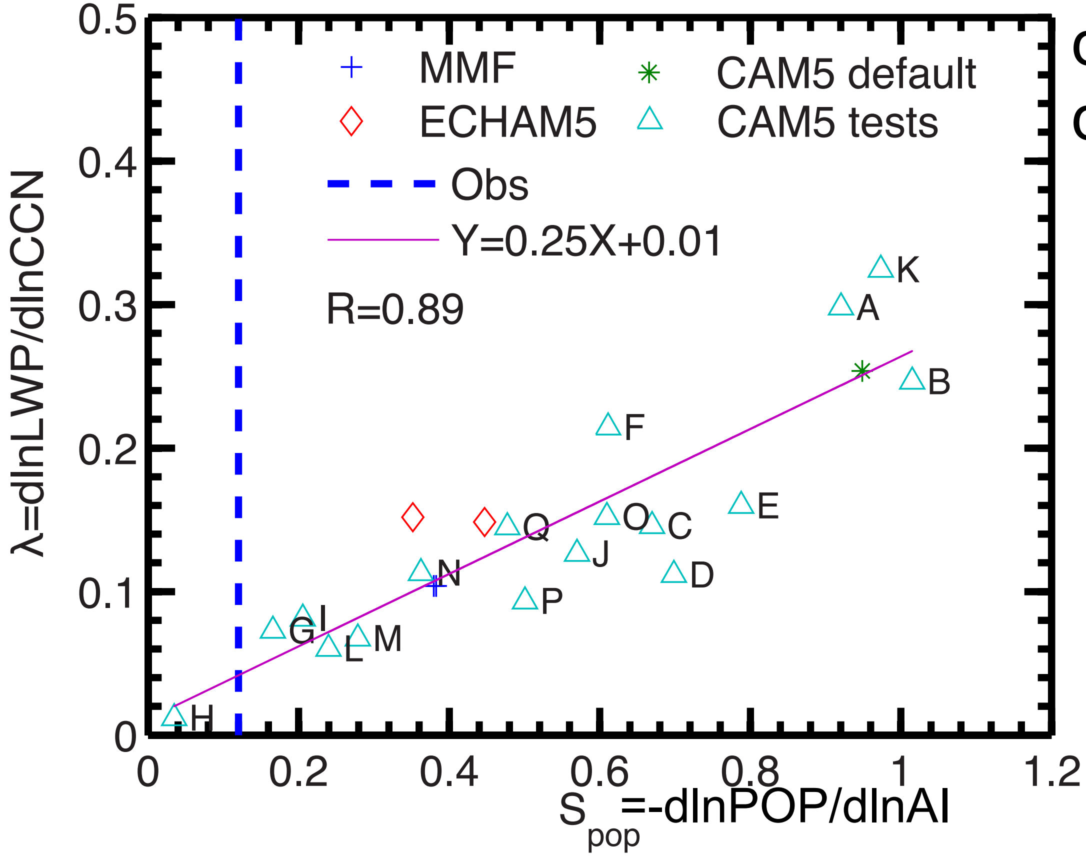
-dlnPOP/dlnAI: A quantitative measure



- LWP-weighted:

Obs: 0.12; MMF: 0.42; CAM5: 1.06

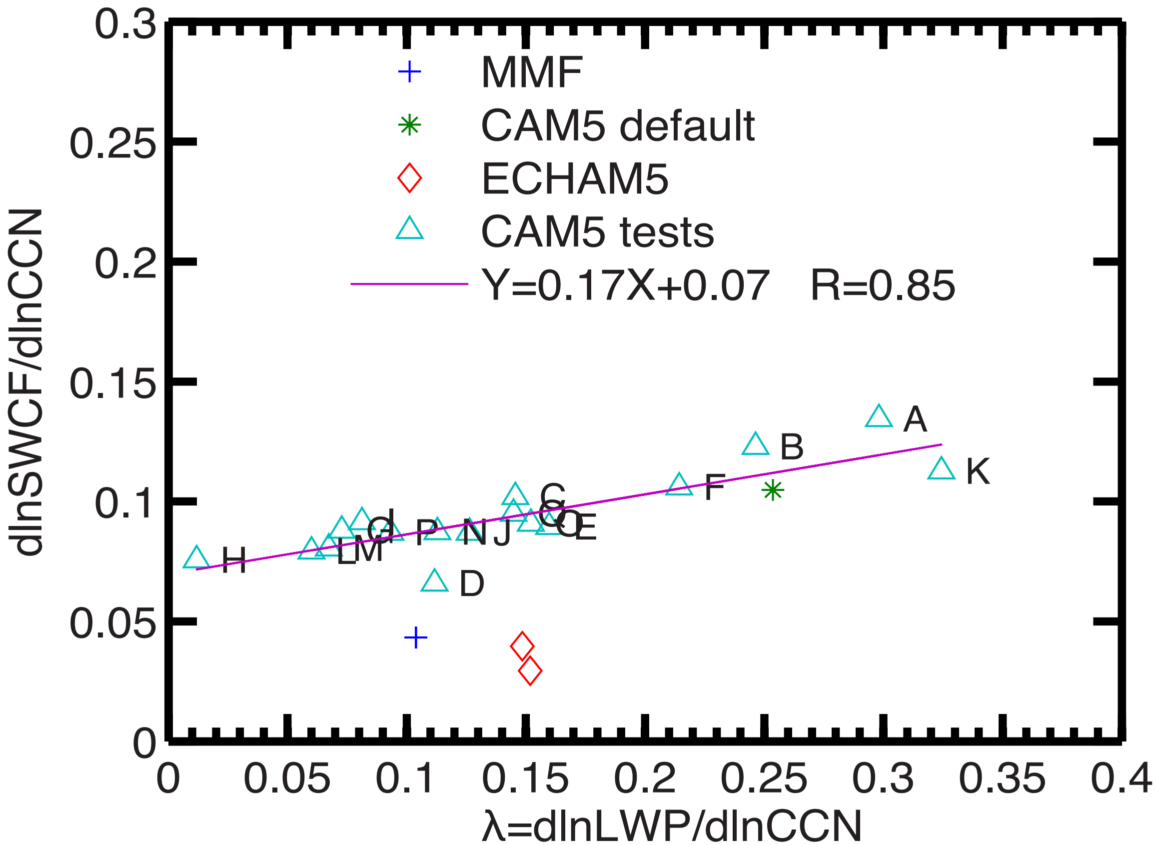
S_{pop}= - dlnPOP/dlnAI provides a good measure of the LWP response to CCN perturbations.



dlnLWP: (PD-PI)/PI
dlnCCN: (PD-PI)/PI

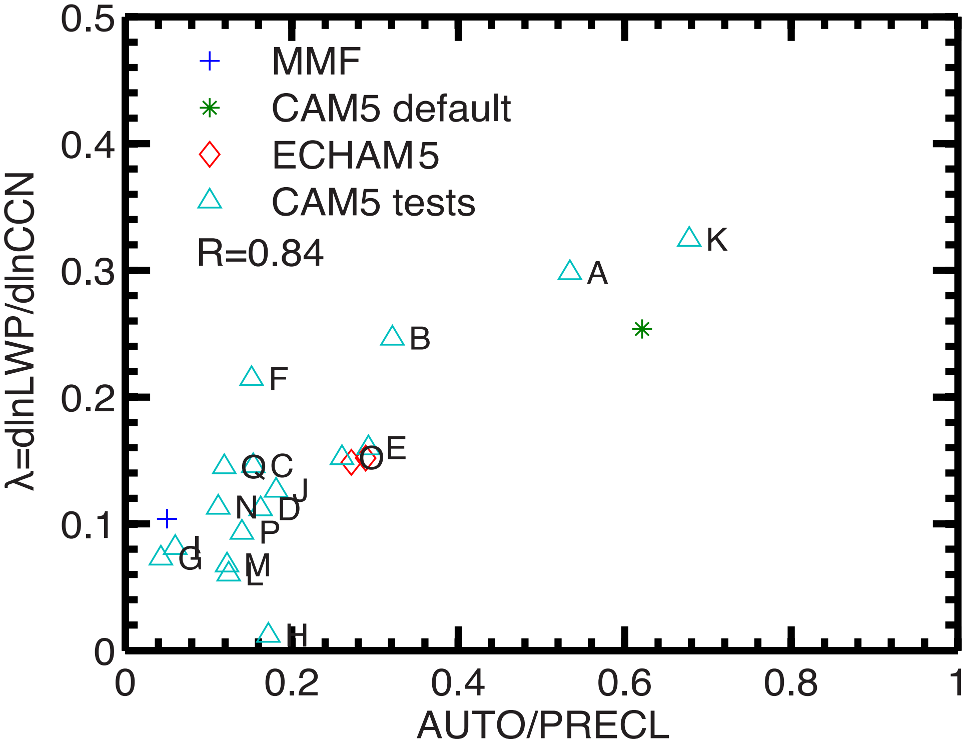
- CAM5 tests change treatment of autoconversion
- Intercept of regression with S_{pop}=0.12 suggests λ=0.04

Expressing indirect forcing in terms of liquid water path sensitivity



- Intercept is first aerosol indirect effect
- Value at λ=0.04 provides estimate of indirect forcing given change in CCN

Liquid water response is closely related to role of autoconversion in precipitation

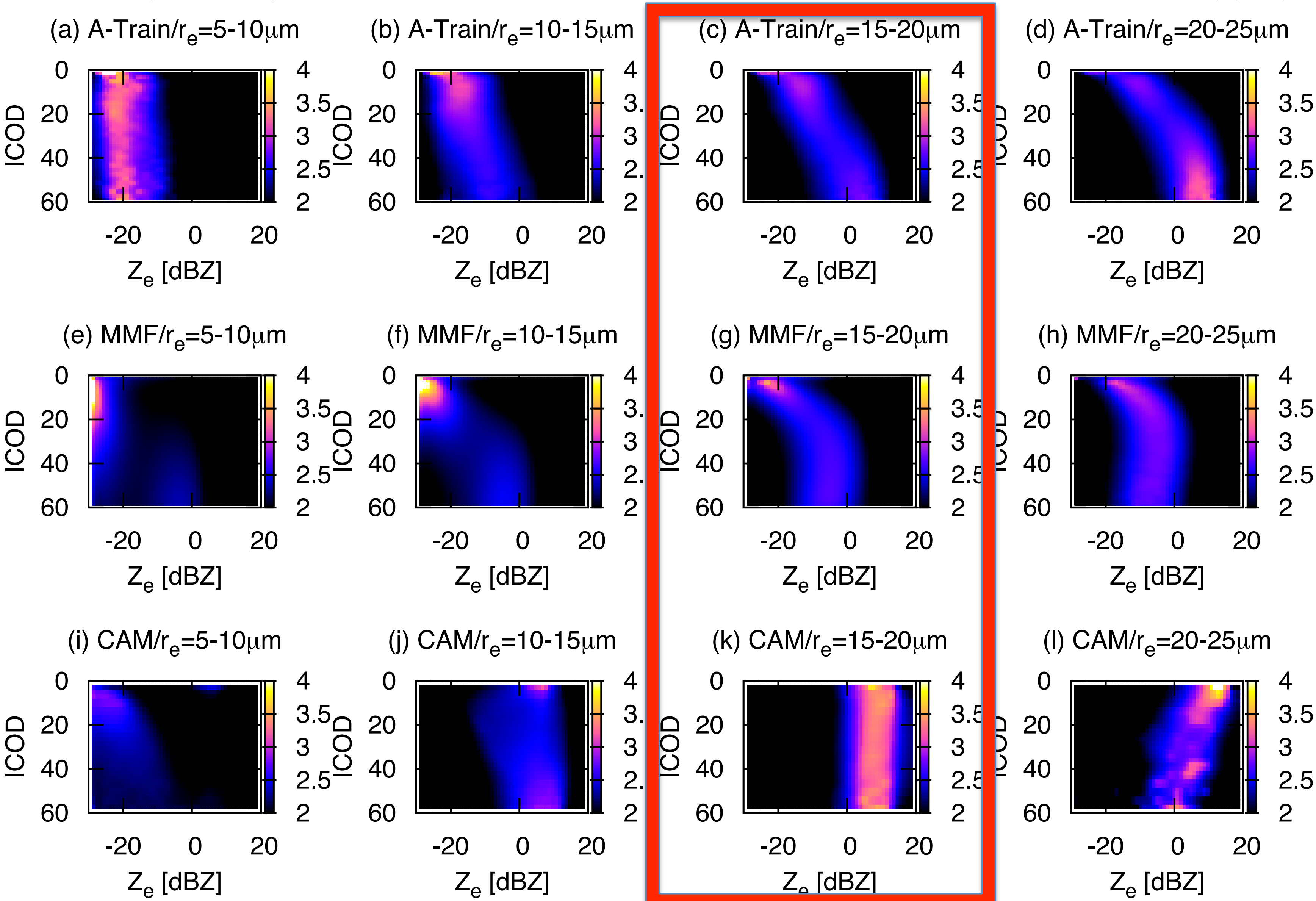


- Small role of autoconversion in MMF might be due to prognostic precipitation

Wang, M., S. Ghan, X. Liu, L'Ecuyer, K. Zhang, H. Morrison, M. Ovchinnikov, R. Easter, R. Marchand, D. Chand, Y. Qian, and J. E. Penner, Constraining cloud lifetime effects of aerosol using A-Train satellite observations, *GRL*, 2012.)

Contoured Frequency by Optical Depth Diagram

CAM5 optically thin clouds drizzle more



Suzuki et al., in preparation

Distinguishing Direct and Indirect Effects

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Estimating indirect effects I
Easy method: $I=\Delta C$
where $C=F-F_{clear}$ shortwave cloud radiative forcing

But if total aerosol forcing $T=\Delta F$ is direct $D + I$,
this implies $D=\Delta F_{clear}$
which we know is biased toward cooling because over a dark surface

- it overestimates cooling by scattering
- it underestimates warming by absorption

A More Representative Estimate

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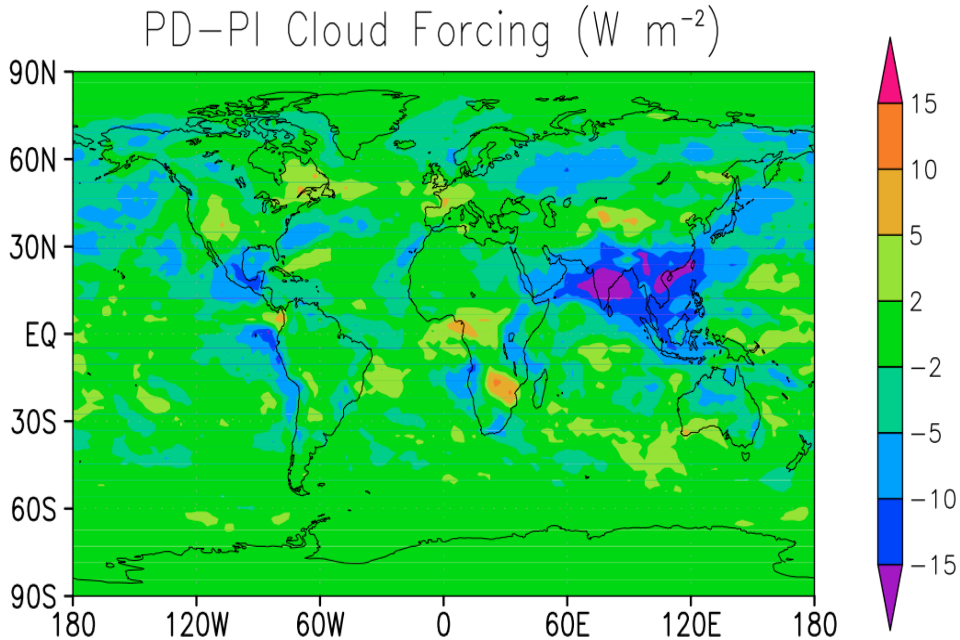
$D = \Delta(F - F_{clean})$ where F_{clean}=F diagnosed w/o aerosol
$I = \Delta(F_{clean} - F_{clear,clean}) = \Delta C_{clean}$ includes semi-direct effects

Total aerosol forcing $T = \Delta F = D + I + S$
where $S = \Delta F_{clear,clean}$ surface albedo forcing

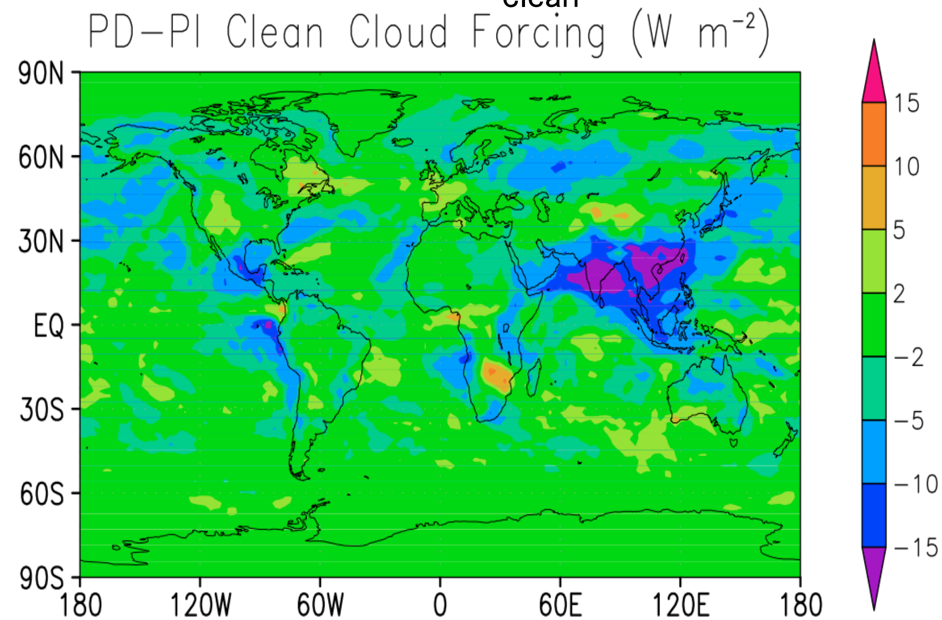
Ghan, ACPD, 2013

CAM5 Results

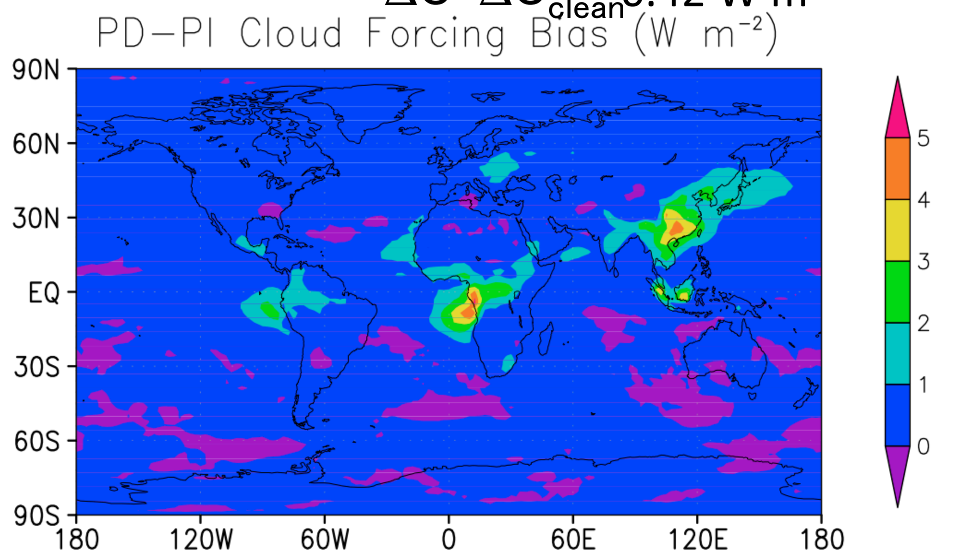
ΔC -1.50 W m^{-2}



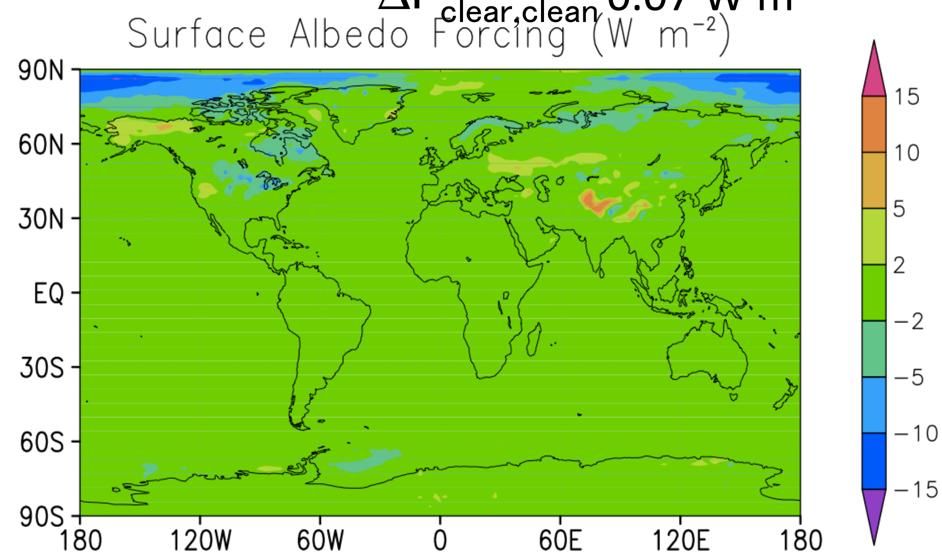
ΔC_{clean} -1.92 W m^{-2}



$\Delta C - \Delta C_{clean}$ 0.42 W m^{-2}



$\Delta F_{clear,clean}$ -0.07 W m^{-2}



Indirect Effects Diagnostic Requirements

- F_{clean} aerosol set to zero for diagnostic radiation
- $F_{clear,clean}$ aerosol & cloud set to zero for diagnostic radiation

Summary

- S_{pop} has been demonstrated to be a good measure of LWP response to CCN perturbation and provides a way to use observations to constrain cloud lifetime effects of aerosols in global climate models

- S_{pop} from A-Train observations is substantially smaller than that from global climate models, and suggests a LWP increase less than 5% from doubled CCN concentrations

- We are applying the S_{pop} metric to examine cloud lifetime effects of aerosols in other AeroCom models

- Aerosol effects on clouds are most consistently estimated using the diagnosed change in cloud forcing with aerosol absorption and scattering of solar radiation neglected

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Cloud Lifetime Effects of Aerosols First Results

Steven Ghan, Minghuai Wang: Pacific Northwest National Laboratory

David Neubauer, Ulrike Lohmann, Sylvaine Ferrachat: ETH

Toshihiko Takemura: Kyushu University

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Objectives and Approach

- Objectives:
  - Use S_{pop} metric to evaluate and constrain cloud lifetime effects of aerosols in other global aerosol-climate models, especially those used in CMIP5
  - Understand the spread of simulated cloud lifetime effects of aerosols in those models
- Approach:
  - Use satellite observations to evaluate simulated aerosol-cloud-precipitations
  - Examine microphysical process rates to understand the model spread of cloud lifetime effects of aerosols

Extending Penner et al. (2006) and Quaas et al. (2009)

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- Precipitation observations along with coincident aerosol and clouds observations from A-Train and ground/aircraft observations are used to evaluate model results

- λ=dLWP/dlnCCN is used to separate differences of aerosol loading from differences in cloud lifetime effects

- S_{pop} and microphysical rates provide new tools to understand the model spread of cloud lifetime effects and further to help to provide constraints

Experimental setup

- Model runs: prescribed-SST with winds and temperature nudged to ECMWF analysis 2006-2010
  - PD: present day aerosol (and precursor) emissions
  - PI: 1850 aerosol (and precursor) emissions
- Model output:
  - Monthly mean and 3-hourly instantaneous fields: F, F_{clean}, $F_{clear,clean}$, N_d, LWP, r_e, CCN, AOD, AI,, liquid cloud cover, column-integrated autoconversion and accretion rates, stratiform precipitation rate, T_{cld}, LTSS (all averaged over the entire grid cell)
  - 3-hourly Cloud Frequency by Altitude Diagram (CFAD) CFMIP COSP Diagnostic

Participation

Model	Investigators	Organization
CAM5	**Ghan, Wang, Zhang**	**PNNL**
ECHAM6	**Neubauer, Lohmann, Ferrachat**	**ETH**
SPRINTARS	**Takemura**	**Kyushu U.**
SPCAM	Wang, Ghan	PNNL
UKCA	Stier, Partirdge, Bellouin	Oxford U., U. Reading
IMPACT	Penner	U. Michigan
AM3	Ming, Yun	GFDL
GEOS5	Barahona, Nenes	GSFC
CAM4-Oslo/ NorESM	Kristjansson, Storelvmo, Kirkevåg, Iversen	U. Oslo
GISS ModelE	Bauer, Ban-Weiss	GISS, USC
CAM5-APM	Yu	SUNY-Albany

Forcing Decomposition by ECHAM6

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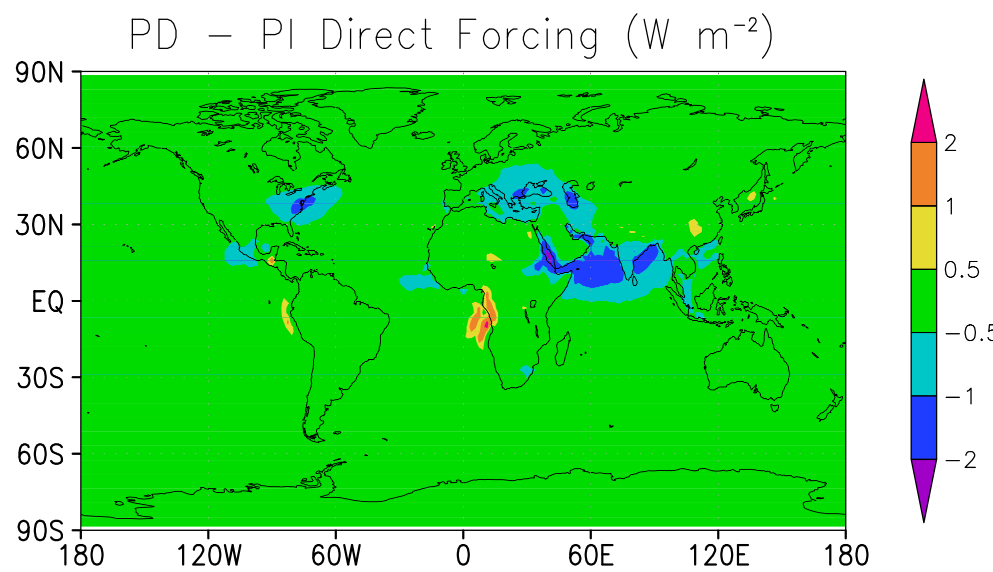

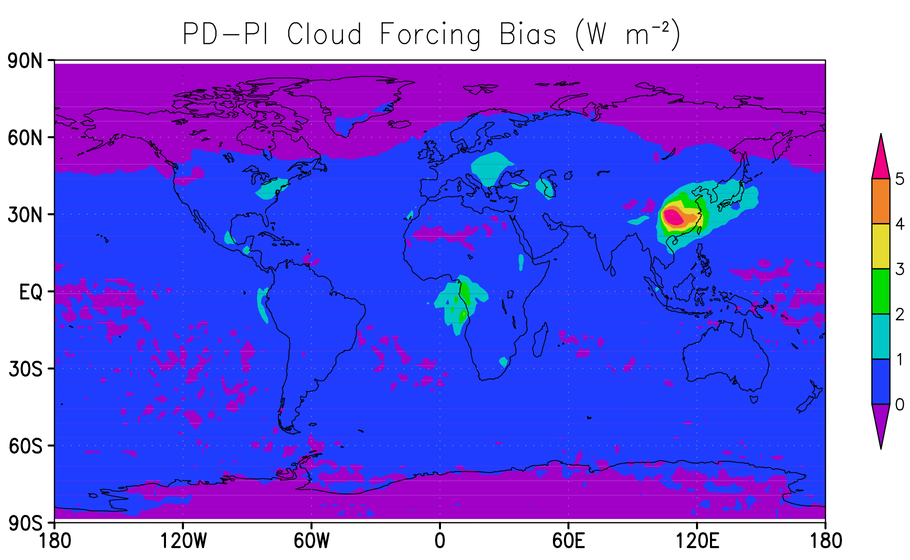

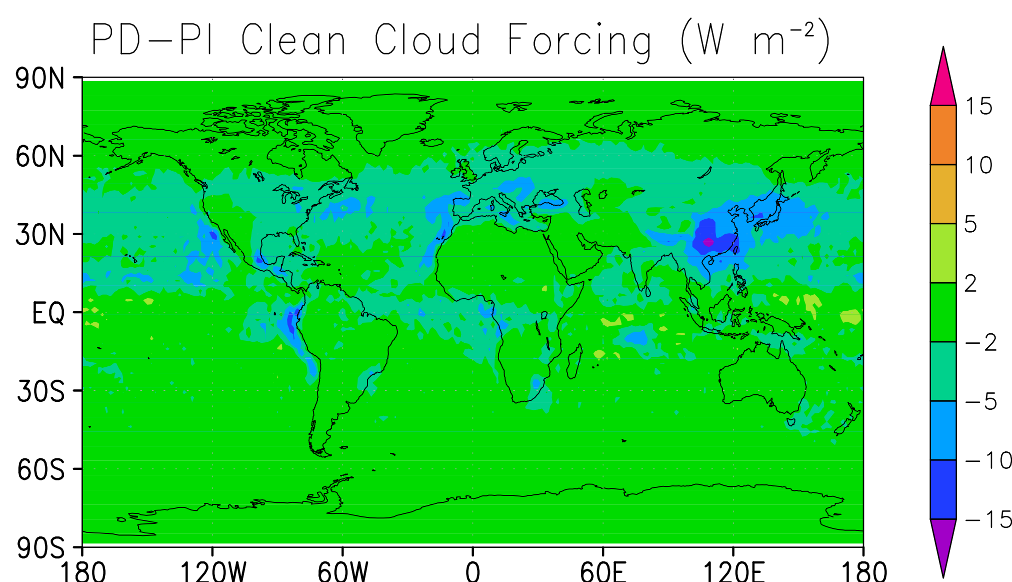

Solar Forcing Decomposition

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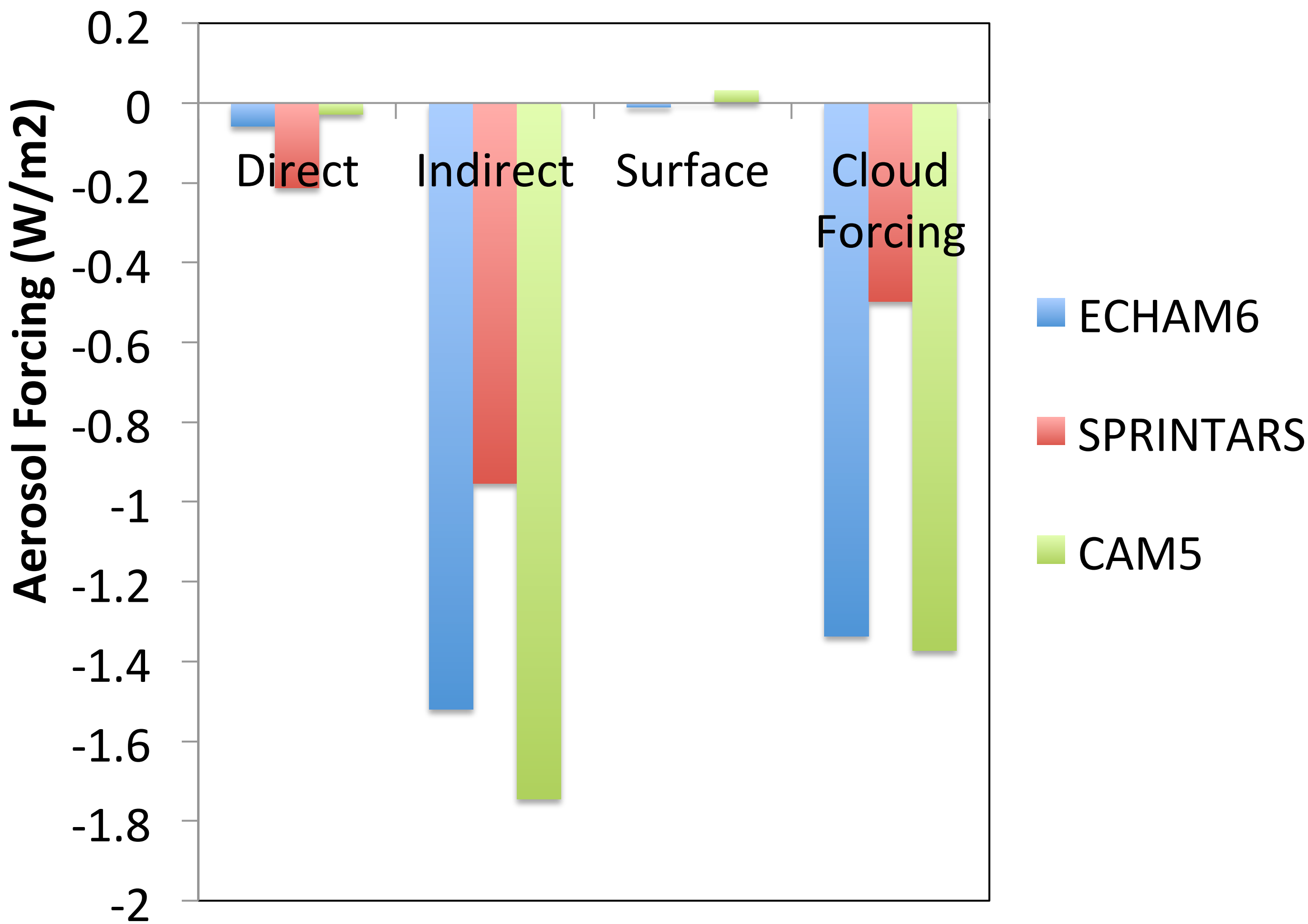

Global means (PD-PI) (PD is in parenthesis)

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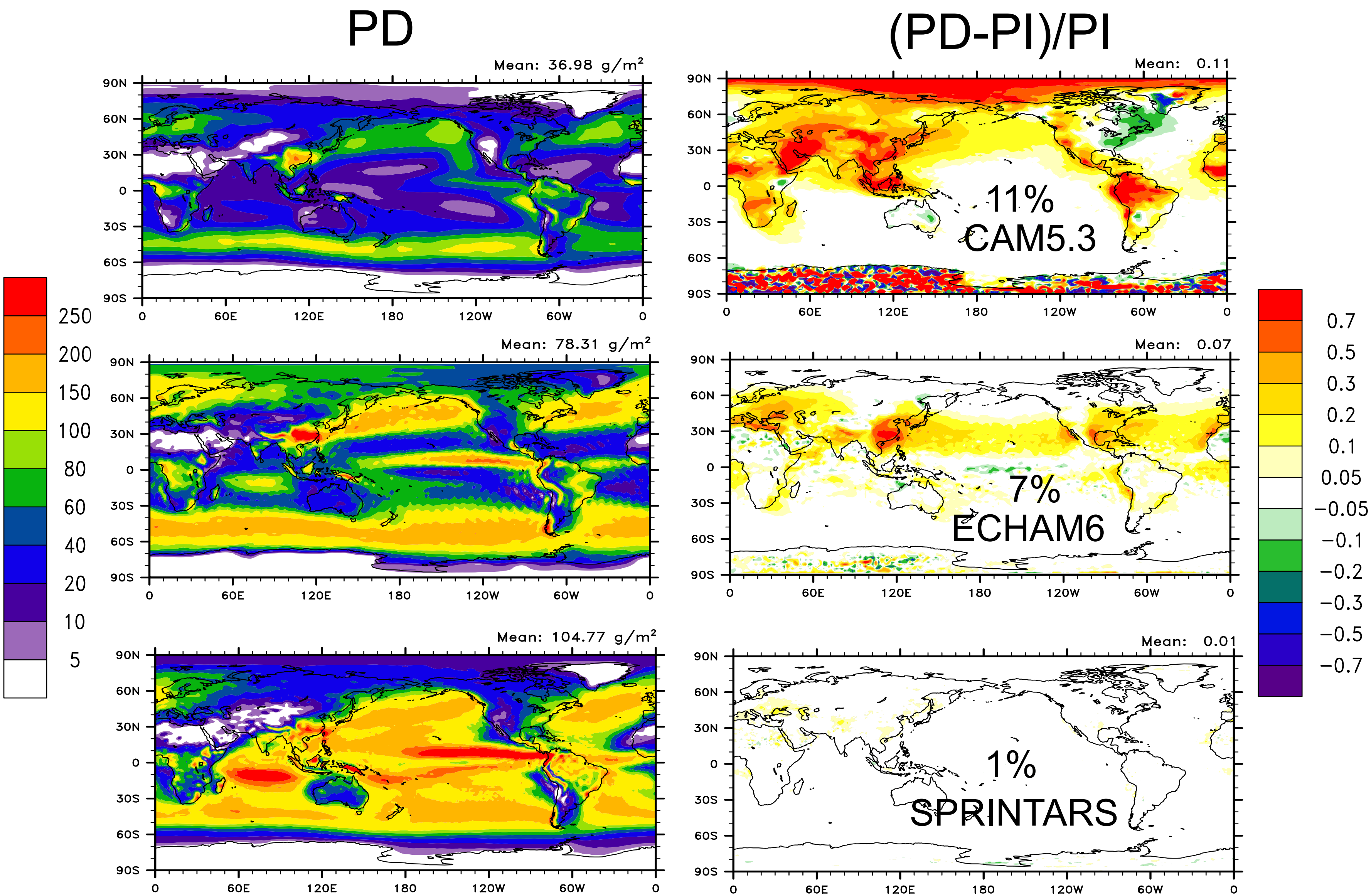
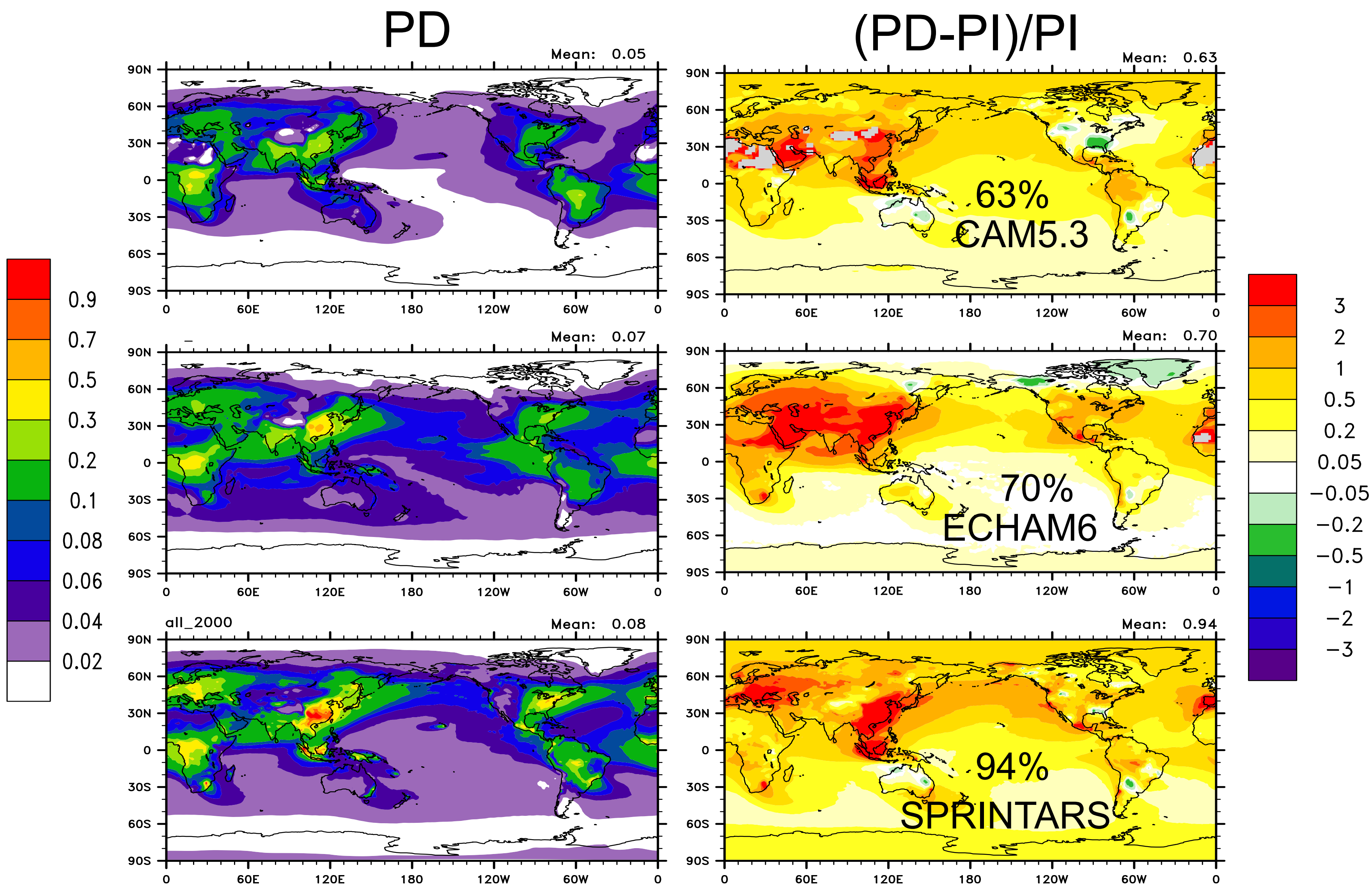
	CAM5.3-PNNL	ECHAM6-ETH	SPRINTARS
AOD	0.017 (0.125)	0.017 (0.123)	0.020 (0.089)
CDNUM (#1.0e10/m2)	0.35 (1.52)	0.42 (3.07)	0.29 (4.12)
LWP (g/m2)	4 (37)	5 (78)	1 (105)
SWCF (W/m2)	1.37 (53.1)	1.34 (46.1)	0.50 (47.8)
LWCF (W/m2)	0.14 (19.4)	0.88 (23.1)	0.067 (20.2)
SPRECIP (mm/day)	-0.009 (0.89)	0.000 (1.31)	-0.003 (1.29)

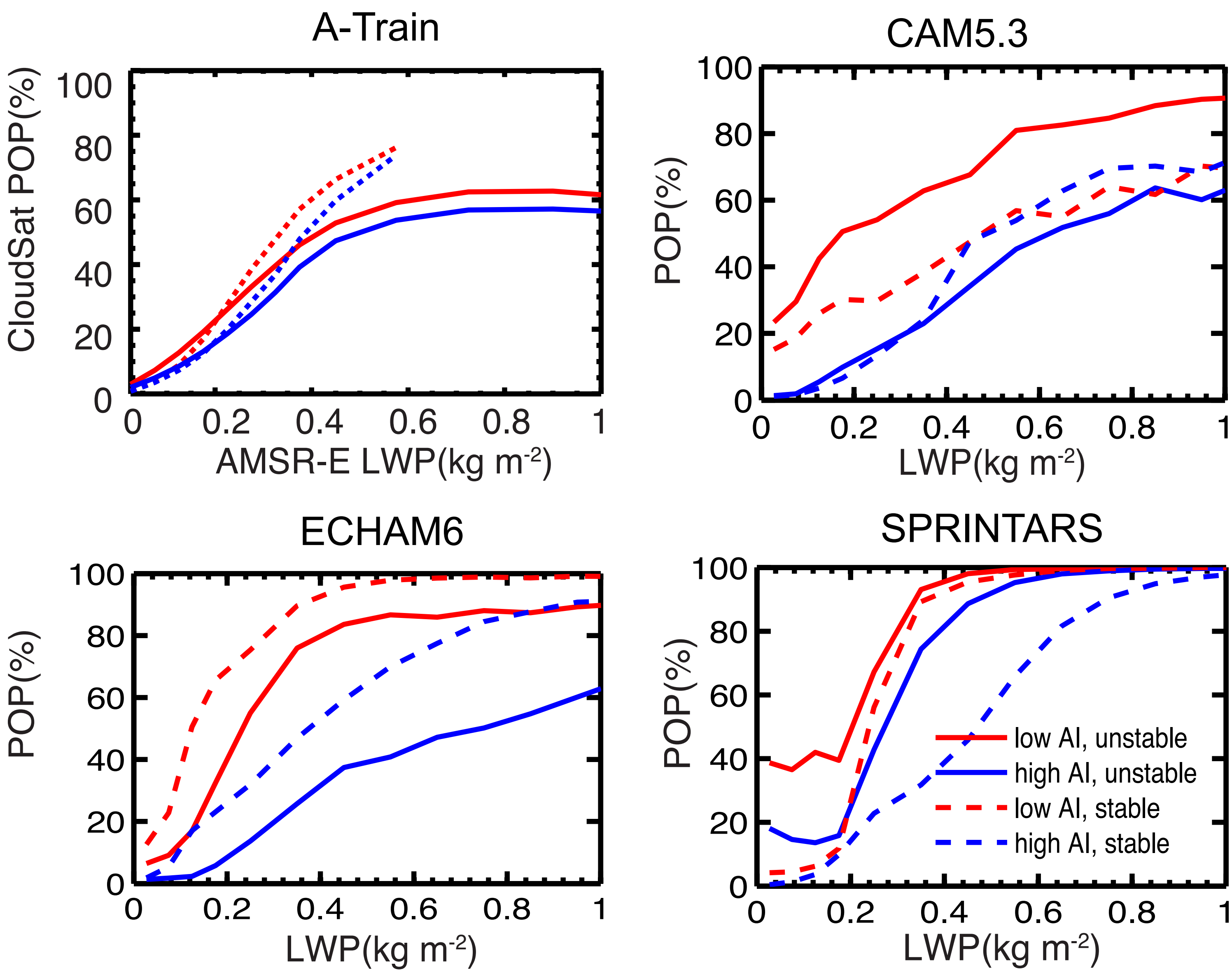
Anthropogenic aerosol effects on LWP



Change in AI from anthropogenic aerosols (AI=AODxANGSTRM)



POP for warm clouds over global oceans



S_{pop}=-dlnPOP/dlnAI (number: LWP-weighted S_{pop})

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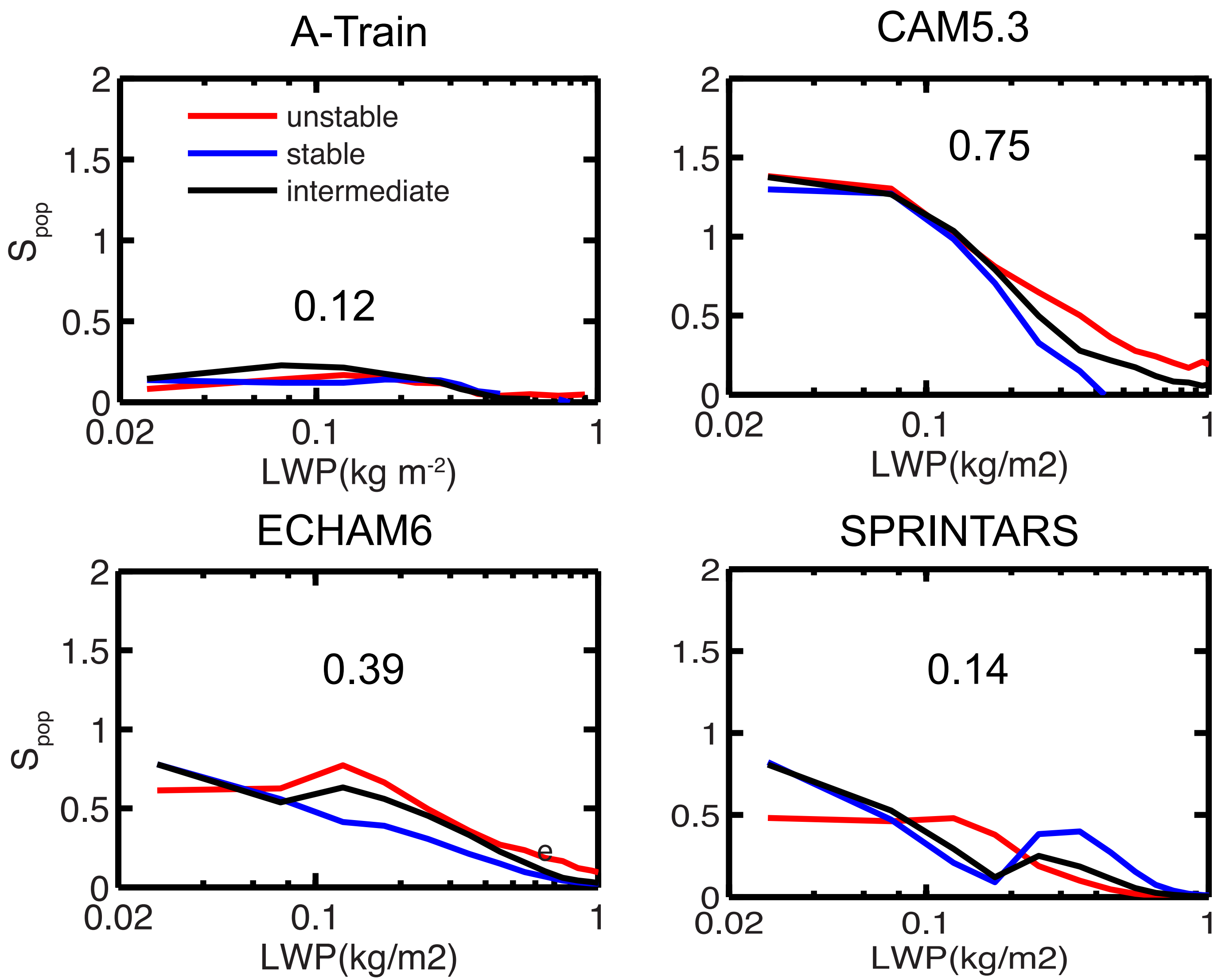

S_{pop} from LWP sampled before and after microphysics (NCAR CAM5.3)

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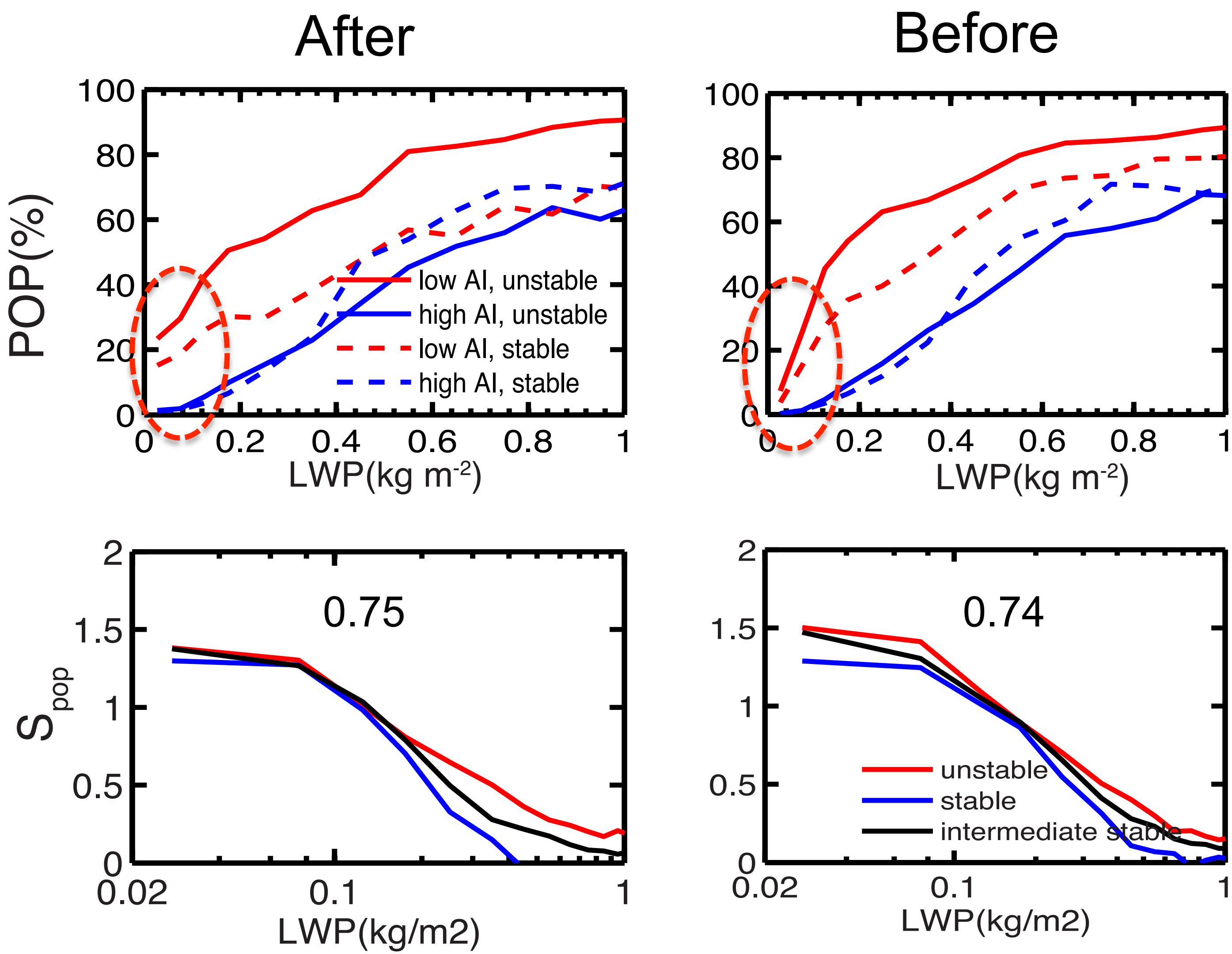
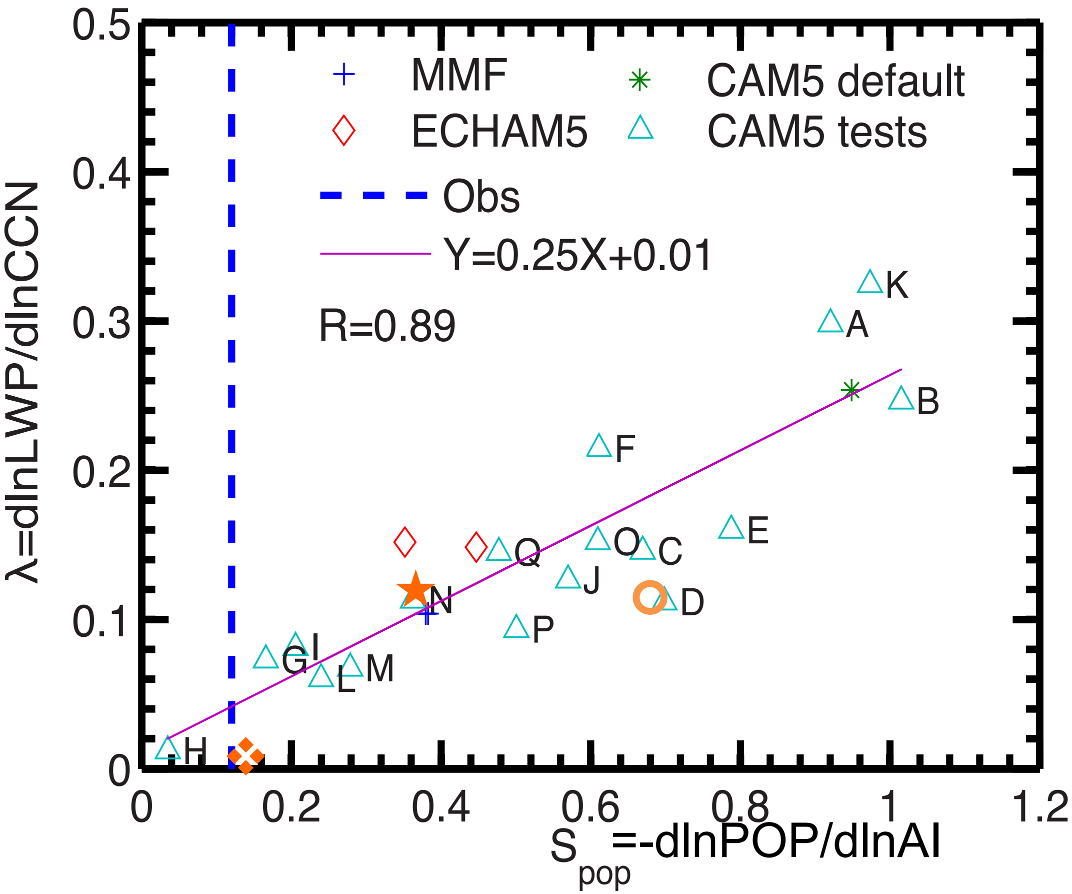


S_{pop} vs. λ with new model results



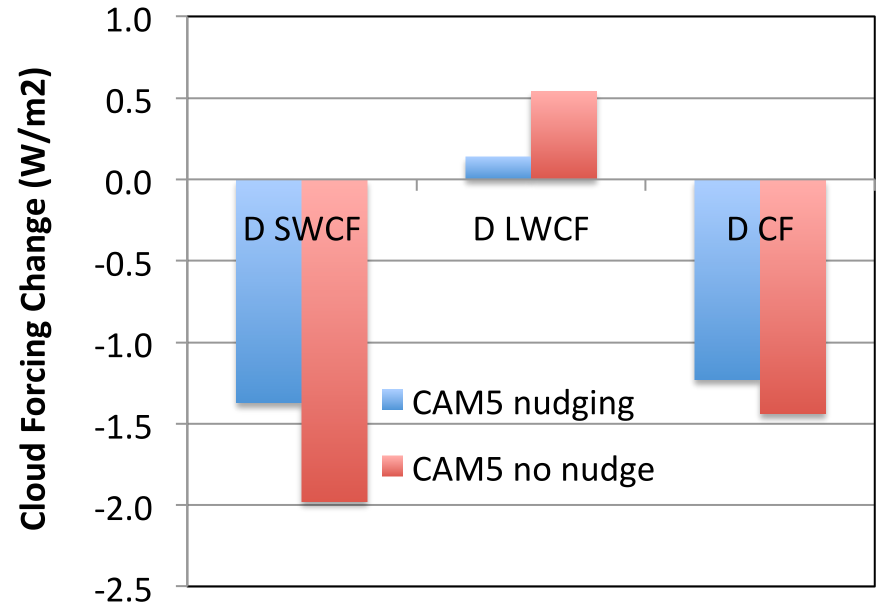
λ is defined as
Old results:
dln(LWP)dln(CCN)
New results:
dln(LWP)/dln(AI)

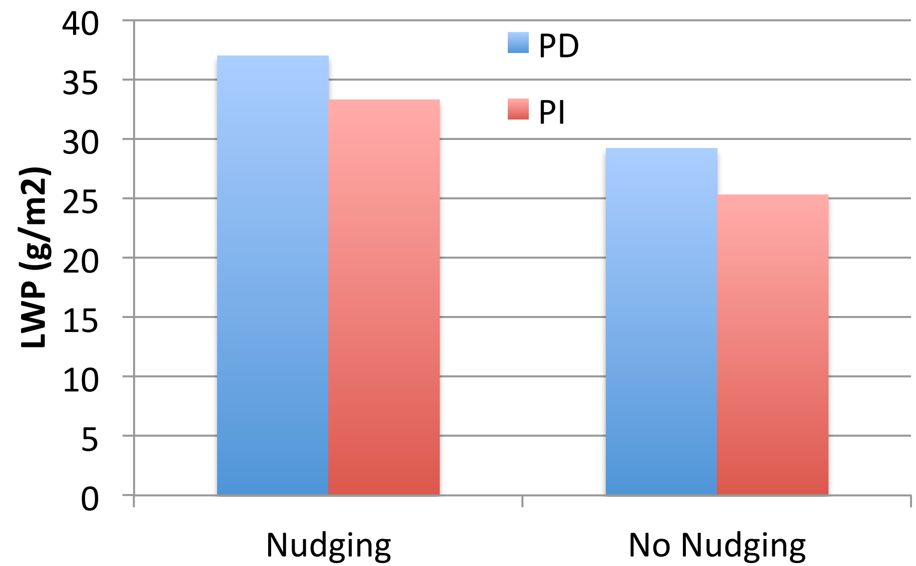
dln(LWP): (PD-PI)/PI
dln(CCN): (PD-PI)/PI
dln(AI): (PD-PI)/PI

ECHAM6 ★ SPRINTARS ❖ CAM5.3 ○

Nudging Impact on Forcing

- ECMWF convection differs from CAM5 treatmemt
- Nudging toward ECMWF temperature affects CAM5 convection and LWP&IWP
- LWP&IWP changes affect SWCF and LWCF response to aerosol





Summary

- Our preliminary results confirm that S_{pop} is a good measure of LWP response to aerosol perturbation.

- SPRINTARS simulates much smaller S_{pop} than NCAR CAM5.3 and ECHAM6, consistent with its much smaller LWP response to anthropogenic aerosols (1% in SPRINTARS vs. 7% in ECHAM6 and 11% in NCAR CAM5.3)

- Our preliminary analysis also reveal some potential issues and points further refinement in experiment design and data submission

Interested? Contact Steve Ghan (Steve.Ghan@pnnl.gov)

Issues

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- Filenames:
  - ”aerocom_<ModelName>_<ExperimentName>_<VariableName>_<VerticalCoordinateType>_<Period>_<Frequency>.nc”
  - details at https://wiki.met.no/aerocom/indirect
- Additional diagnostics: Monthly AI (aerosol index), CCN at multiple S (0.1% and 0.3%), geopotential height, air density
- CCN grid cell mean, whether cloud present or not. Surface or cloud base?
- LWP before or after microphysics?
- Nudge toward analysis or a model baseline?
- CFAD or CFOD?